ANTECEDENT SOIL WATER FOR MANAGED LANDSCAPES IN CENTRAL ALBERTA

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ABSTRACT. *Land management practices are known to influence runoff through alteration of the antecedent soil water. For accurate estimation of runoff, direct measurement of antecedent soil water would be necessary. This study investigated antecedent soil water and the potential for summer storm runoff under different land management practices. The two-year study was conducted on five sites: three sites under forage (one on reclaimed mine lands), and two sites under pasture. Treatments included haying, mowing, fallow, and moderate and heavy livestock grazing. Soil water was measured with a neutron probe and was generally less than 50% of water holding capacity (dry conditions). During recharge periods, water increased to near field capacity, but soil water was close to wilting point for some measurement dates. Pasture sites were generally wetter than forage sites, with the difference being most pronounced on fallow treatments. The reclaimed site had generally lower total soil water than the unmined ones.*

Keywords. *Total soil water, Forage, Pasture, Reclamation, Water retention.*

Antecedent soil water conditions represent a balance among evaporation, transpiration, infiltration, and internal drainage. These processes are partly controlled by the water retention and transmission properties of the soil (Singh et al., 1998). As soil water increases, air filled porosity and infiltration rate generally decrease, resulting in increased flow across the soil surface as runoff (Sharma et al., 1983). Soils with dry antecedent soil water conditions have a higher infiltration capacity than do wet soils. It is generally accepted that less overland flow occurs on dry soils than wet ones, assuming similar soil texture, structure and organic matter content. Therefore, measurement of soil water provides a way of determining the potential for runoff.

Land management practices such as tillage, fallow, crop rotations, mowing, grazing and surface mining may influence antecedent soil water conditions in two ways: through their alteration of soil characteristics and their effect on hydrologic processes (Singh et al., 1998). For example, conservation tillage practices maintain substantial crop residue cover on the soil with the intent of increasing infiltration, reducing runoff and erosion, and conserving soil water compared to conventional tillage systems (Izaurralde et al., 1994). Furthermore, conventional tillage practices may promote decomposition of organic matter and reduce soil aggregation, which in turn affect antecedent soil water conditions.

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Fallowing is a system in which the land is not cropped and weeds are controlled with tillage or herbicides during the growing season. Soil moisture conservation under fallow systems is usually quite low, and excessive use of such management systems is associated with reduced organic matter levels, soil erosion and deterioration of soil tilth (Larney et al., 1994), which could reduce infiltration rates.

Mowing and haying practices involve frequent removal of vegetation and thus reduce surface residue cover. This increases the amount of bare ground and ultimately increases the rate of evaporation. Livestock grazing can profoundly affect antecedent soil water through its influence on infiltration as a result of increased surface bulk density due to animal trampling and on evapotranspiration through defoliation (Naeth and Chanasyk, 1995), but these changes do not respond linearly to increased grazing intensity (Chanasyk and Naeth, 1995; Mapfumo et al., 1999). Moreover, evaporation losses from soil subjected to heavy grazing may be high because of increased bare ground compared to that for ungrazed areas with large amounts of litter (Naeth et al., 1991).

Land disturbances due to surface mining and subsequent reclamation greatly influence infiltration, runoff and antecedent soil water. Newly-reclaimed surface-mined soils are characterized by low infiltration rates and high runoff due to soil compaction caused by heavy machinery used in replacement of subsoil and topsoil during reclamation operations (Schroeder, 1995). For example, Jorgensen and Gardner (1987) found that infiltration rates on newly reclaimed minesoils were lower than those of undisturbed soils.

The influence of land management practices on runoff is represented in the Soil Conservation Service (SCS) curve number technique through alteration of runoff curve numbers based on cover, hydrologic condition and soil group (Ponce, 1989). Runoff curve number varies with antecedent soil water. The concept of antecedent moisture condition (AMC) is used to represent variability in soil moisture, and includes three categories: AMC 1 (lowest runoff potential), AMC 2 (average runoff potential), and AMC 3 (highest runoff potential). The SCS have prepared a table that relates AMC to total five-day antecedent rainfall and seasons (dormant or growing). Unfortunately this table does not account for regional differences or scale effects (Ponce and Hawkins, 1996). Moreover, there is a lack of clear guidance on how to vary AMC to suit various design situations. Therefore, direct measurement of the antecedent soil water would be necessary, and its effect should be taken in a probability context to enable more accurate estimation of runoff.

The objectives of this study were to determine the impact of different land management practices (i.e., forage and pasture fields) on antecedent soil water and to determine the frequency of occurrence of differing levels of soil water. An additional objective was to compare soil water status in reclaimed and unmined soils.

Materials and Methods

Study Sites

This project was conducted at five field sites located near Keephills, Alberta (lat 53°30′N and long 114°27′W), approximately 80 km west of Edmonton, Canada. The region is dominated by rolling topography having slopes of 5 to 25%. Land use is predominantly cattle grazing and alfalfa hay production.

The climate is characterized by 432 to 508 mm of precipitation annually, 60% of which falls in the growing season from May through August (Lindsay et al., 1968). The mean annual temperature for the area is 3°C. To determine the amount of rainfall received at the four unmined sites, a standard rain gauge was installed adjacent to each site. These gauges were read every two weeks or as needed and cumulative rainfall determined using summed precipitation data from previous readings. Evaporation from the rain gauges was not a concern because readings were taken within 24 h after each major precipitation event.

The sites were selected based on slope position, gradient and aspect. The greatest distance between any two sites was approximately 12 km, that being the distance from the reclaimed site to the nearest unmined site. Three sites (1, 2, and 3) were alfalfa/grass hay fields, while two (4 and 5) were grazed pastures (table 1).

Site 1 was located on reclaimed coal-mined land at the Highvale Mine. This site had a southern aspect and a slope gradient of 13 to 16%. Sandy loam textured subsoil, formerly minespoil, was recontoured and overlain by approximately 27 cm of stockpiled loam topsoil after reclamation in 1992. Site 2 was unmined land and had been under alfalfa/grass hay management for five years prior to the study. The site had a southern aspect, a slope gradient of 15 to 22%, a light colored, silty clay loam textured Ap horizon approximately 17 cm thick and a particularly hard and dark silty clay textured subsurface horizon (17 to 30 cm). Site 3 was a five-year-old alfalfa stand with a southwest aspect and a slope gradient of 12 to 18%. Topsoil depth at this site was approximately 12 cm. Generally, this site had a fine textured profile, nearly uniform in clay content (table 1).

Two grazed pasture sites, Site 4 and Site 5, were developed on unmined lands in the same area. Site 4 was on a west-southwest aspect having a uniform slope gradient of 16 to 18% and topsoil depth of 4 cm, and had been under a pasture for 7 to 10 years as part of an early/late season heavy grazing rotation. The site had medium textured soils and did not appear to contain any impermeable horizons. Site 5 was a 10-year-old grazed pasture with a southern aspect and a slope gradient of 16 to 19%. It was unique in that it had horizons of varying silt and clay composition within the profile. Although topsoil was generally 9 cm in depth, an organic litter layer 3 cm deep occurred above mineral soil, particularly in depressional areas. There were no impermeable layers evident at the site (table 1).

Experimental Design and Treatments

This study was conducted between June 1995 and May 1997. Treatments were established by the end of June 1995. Experimental plots, each 3 × 3 m, were constructed at each site in a randomized complete block design using three treatments (hayed, mowed, and fallow) in triplicate at forage sites (Sites 1, 2 and 3) and two treatments (fallow and moderately grazed) in triplicate at pasture sites (Sites 4 and 5). Each plot was separated from the next by a 1.5 m wide buffer. A series of three randomized plots constituted a block. The three blocks were placed adjacent to each other across the width of the slope to minimize interflow contribution, to maintain constant slope gradient and to maintain as relatively uniform soil conditions as possible across the blocks.

Forage on hayed treatments was cut to 4 cm and removed from the plot area. Mowed treatments had frequent removal of forage (two to three times per week), and no litter was allowed to accumulate on mowed surfaces. Fallow treatments were established using rototilling equipment late in spring 1995 to break the forage cover. Fallow treatments were tilled in mid- to late spring thereafter and maintained vegetation-free during the growing season using a broad spectrum glyphosate herbicide followed by a late fall cultivation at the end of September.

Table 1. General site characteristics

	Site 1	Site 2	Site 3	Site 4	Site 5
Management	Alfalfa/grass	Alfalfa/grass	Alfalfa/grass	Pasture	Pasture
	Reclaimed	Unmined	Unmined	Unmined	Unmined
Topsoil depth (mm)	270	180	120	40	90
Slope (%)	16	22	18	18	19
Depth Interval			Soil Classification		
0-150 mm	Loam	Silty clay loam	Silty clay loam	Silt loam	Silt loam
150-300 mm	Clay loam	Silty clay	Clay	Silty clay loam	Clay
300-450 mm	Sandy loam	Silty clay	Clay	Clay	Clay

Site 4 was heavily grazed with approximately 45 yearling heifers on 8 ha, while Site 5 was moderately heavily grazed with about 120 cow-calf pairs/64 ha. Fallow plots were tilled late in the spring and maintained weed free thereafter as chemical-fallow treatments using a broad spectrum glyphosate herbicide. A final fall cultivation was performed near the end of September.

Statistical analysis was conducted using Friedman's chi-square test on the soil water frequency data to compare frequencies in different treatments. Two separate Friedman's tests were conducted, one for Sites 1-3 and another for Sites 4-5. The generalized linear model (GLM) procedure in SAS was used to obtain the sum of squares that were used in calculating the chi-square values.

Soil Water Measurement

An aluminum access tube was randomly installed to a depth of 1.2 m in each plot on 20 June 1995 to facilitate measurement of the antecedent soil water to a depth of 85 cm using CPN 503 neutron probes. Soil water measurements were taken approximately every 2 weeks in both 1995 and 1996, every 10 cm to a maximum depth of 85 cm, starting 15 cm below the soil surface. Surface (0-7.5 cm) water measurements were also taken at the time of depth measurements using the neutron probe with a surface shield installed around the source (Chanasyk and Naeth, 1988).

As part of fall sampling in 1995, a CPN 501 depth moisture/density probe, which measures soil water and bulk density simultaneously, was used to determine the bulk density and soil water. These soil water data were incorporated into the CPN 503 water data set. Surface bulk density (0-10 cm) was measured in spring and fall 1996 using a CPN MC1 surface moisture/density probe.

Soil water measurements in 1995 were taken on 30 June, 12 and 26 July, 9 and 25 August, 14 and 28 September and 16 October; in 1996 on 22 April, 27 May, 10 and 24 June, 8 and 23 July, 15 and 27 August, and 21 October. Soil water data for individual tubes were averaged by treatment.

Volumetric soil water content at a given depth was determined using locally derived calibration curves. Total soil water to a given depth for a given access tube was determined by calculating the amount of water in a given depth interval by multiplying the volumetric water content by the thickness of the depth increment and then summing appropriately to the given depth. Two depths were considered: 7.5 and 30 cm. These two depths were chosen because near-surface soil water influences runoff potential the most. Total soil water to 30 cm is referred to as TSW30 hereafter.

Water Retention Properties

To determine soil water retention, three samples each for air-dried soil for depth intervals of 0 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 75, 75 to 90, and 90 to 105 cm were used. Water content was determined at 0.033 and 1.5 MPa pressures, corresponding to field capacity (FC) and wilting point (WP), respectively, using a pressure plate apparatus (Topp et al., 1983). The available water holding capacity (WHC) of the soil was then calculated as the difference between FC and WP. Gravimetric moisture content at these pressures was determined by oven-drying at 105°C for 24 h. Volumetric moisture content was calculated as the product of the gravimetric water content multiplied by the ratio of bulk density (determined from CPN 501 depth density readings for the depth increment considered) to water density.

Frequency of occurrence of a given soil water level was determined by site, by dividing its WHC for that site into four equal classes. For convenience, soil water between FC and WP was categorized into Classes I-IV. Class I was defined as the total soil water in the range WP < TSW < (WP + 0.25WHC). This class represented a relatively dry soil condition for plant growth. Class II was defined as the total soil water in the range (WP + 0.25WHC) < TSW < (FC – 0.50WHC), which represented a moist soil condition for plant growth. Class III was defined as the total soil water between (FC – 0.50WHC) < TSW < (FC – 0.25WHC), which represented a more moist condition for plant growth. Class IV was defined as the total soil water between (FC – 0.25WHC) < TSW < FC, which represented ideal soil water condition for plant growth.

Results

Characterizing Summer Precipitation

Summer precipitation in 1995 was similar to that in 1996 (table 2), but fall precipitation in 1995 was only 30% of that received in 1996. Total precipitation in 1995 was similar at Sites 2, 4 and 5, but Site 3 had approximately 50 mm lower accumulated precipitation over the measurement period (data not shown). The trend in precipitation in 1996 was similar at all sites, but total amounts received varied by approximately 50 mm (data not shown).

In 1995 and 1996, there were two dominant periods over which most of the site-averaged summer precipitation was received. In 1995, a large proportion of the summer rainfall occurred from 26 July to 9 August, accounting for 48% of the measured summer precipitation, while in 1996, 42% of the summer precipitation was received from 10 June to 23 June. Note that the summer measurement period in 1996 was longer than in 1995.

Soil Water Retention Properties

Soil water retention at FC and WP were similar at Sites 1, 3, 4 and 5 with FC at Site 2 being notably highest (table 3). Site 2 also had the highest WHC to all depth increments, while Site 5 had the lowest. At Site 1, less

Table 2. Precipitation in the study region (mm)

Year	Measurement Period	Summer*	Total Growing Season Rainfall†	Summer or Fall Rainfall as % of Total Season Rainfall
		Precipitation		
1995	26 July-9 Aug	101.5	212.0	48
1996	10-23 June	106.0	252.8	42
		Fall		
1995	1 Sept-31 Oct	25.0	212.0	12
1996	1 Sept-31 Oct	82.0	252.8	32

* Summer was taken as the months between 1 June and 31 August of the respective year.

† Growing season was the months from 1 May to 31 October in each respective year.

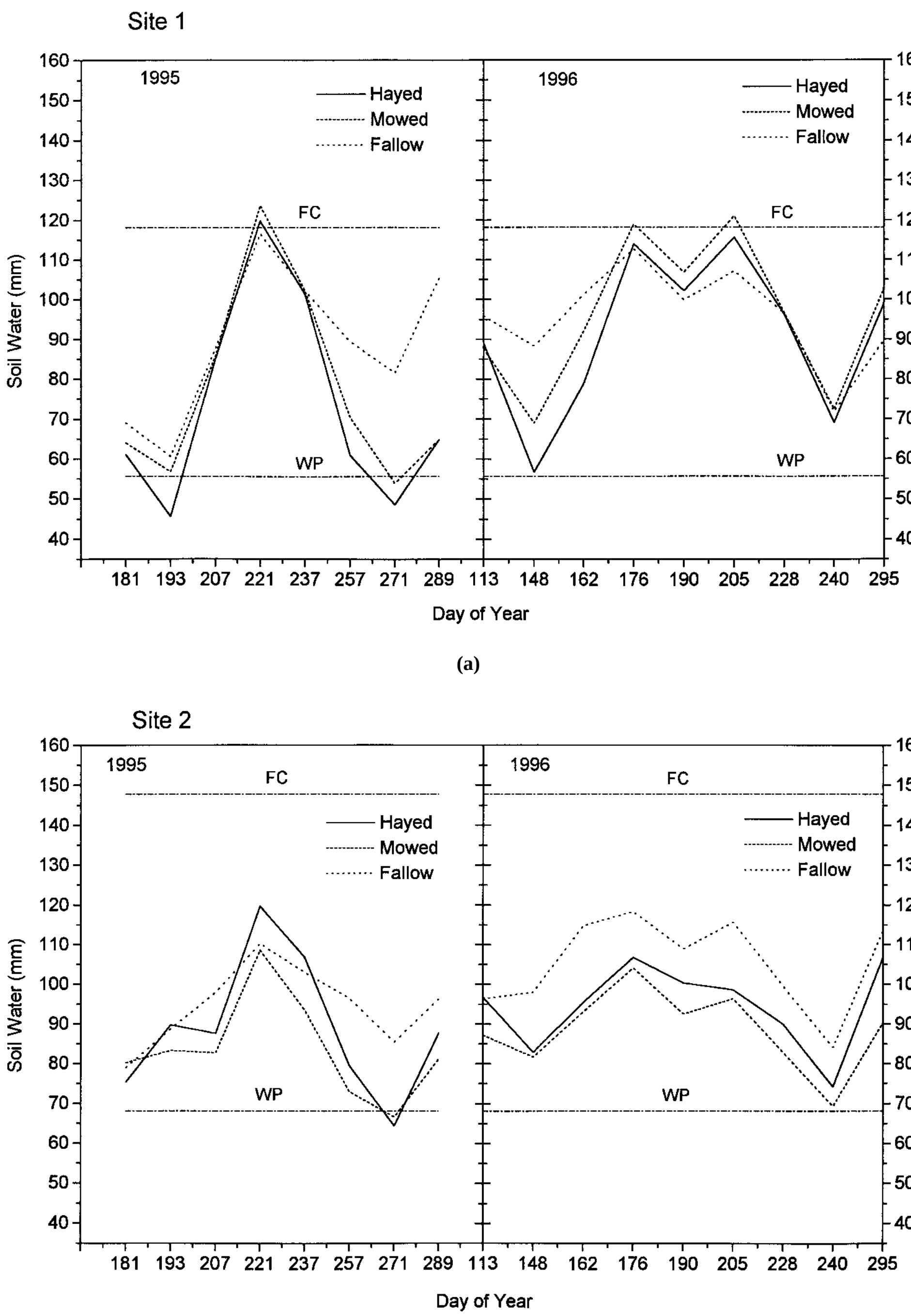
Table 3. Total soil water (mm) at field capacity (FC) and wilting point (WP), and water holding capacity (WHC)

	0-7.5 cm			0-30 cm		
Site	FC	WP	WHC	FC	WP	WHC
1	38	17	21	118	56	62
2	46	19	27	148	68	80
3	39	15	24	124	54	70
4	39	21	18	123	61	62
5	37	19	18	119	67	52

water was retained in the subsoil (> 30 cm) than the topsoil (0 to 30 cm): the loam and clay loam textured surface (0 to 30 cm) material at this site had higher soil water retention than did the sandy loam subsoil.

SEASONAL CHANGES IN TOTAL SOIL WATER

The TSW30 was generally at or near WP at all five sites at the start of the study. TSW30 at Sites 1 and 2 was generally highest in the fallow treatment, with little difference in TSW30 between the hayed and mowed treatments at any of Sites 1, 2 or 3 (fig. 1). TSW30 was higher in the fallow than the grazed treatment at both sites 4 and 5 (fig. 2).



(b)

Figure 1–Total soil water to 30 cm at (a) Site 1, (b) Site 2, and (c) Site 3. Note FC and WP represent field capacity and wilting point, respectively.

Fluctuations in TSW30 were greatest at Site 1, with FC and WP each being attained three times during the measurement period. TSW30 at Site 2 was generally in the lower 50% of WHC, reaching WP twice, while at Site 3 it tended to vary about mid available range, reaching FC once.

In general the snowfall season begins in October and ends in March. Soil water just prior to snowfall was generally higher in 1995 than 1996. Snowmelt recharge did not raise TSW30 to FC at any of the sites in either 1996 or 1997, although it is possible that the first spring measurement in both years was made after some evapotranspiration had already occurred, lowering soil water. The greatest recharge in soil water occurred between 26 July and 9 August 1995, with all sites except Site 2 reaching FC. Approximately 85 mm of rainfall occurred during this period (data not shown). Between 10 and 24 June 1996, 92 mm of rainfall fell (data not shown), but the increase in soil water as a result was much less dramatic than that in 1995.

Frequency of Soil Water Status

Soil water frequency at Sites 1, 2, and 3 varied by depth interval and treatment, though (for at least 50% of all measurements) soil water was generally low, falling into Classes I and II for surface soil water and TSW30 (table 4). Frequency for surface soil water of hayed and mowed treatments tended to vary slightly among sites. The fallow treatment generally had a slightly greater (but non-significant) frequency of surface soil water in Classes I and II compared to the hayed and mowed treatments.

Soil at Site 2 was generally dry with most soil water values in the lower range of available soil water (Classes I and II); whereas, at Sites 1 and 3 values were variable. At greater depth, there was generally a shift in frequency such that classes representing higher soil water had more observations for the fallow treatment than for the hayed and mowed treatments. At Sites 4 and 5, the grazed treatment generally had at least 50% of soil water conditions in Classes I and II (table 5).

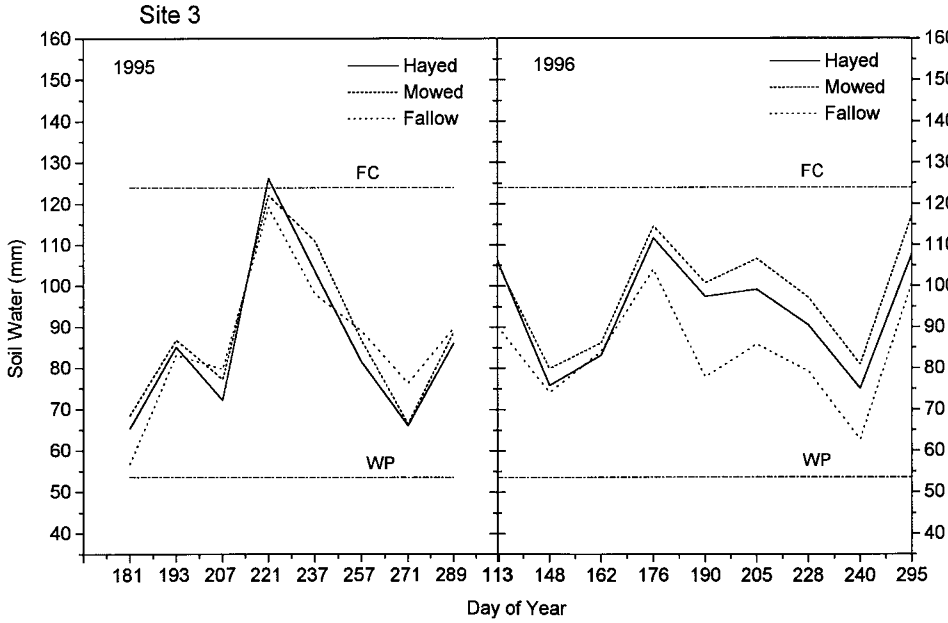
Both surface soil water and TSW30 frequencies were not significantly different among treatments across sites (table 6).

Plots of cumulative frequency of occurrence of soil water levels against soil water frequency classes varied from site to site and were fairly linear. Cumulative percentage frequency of occurrence for Class I was greatest in Site 2 (47-60%) and lowest for Site 3 (6-24%). For Site 2 between 70 and 78% of the total surface soil water occurred in Classes I and II, with few differences among treatments. However, for Site 3 Classes I and II constituted 36, 40 and 60% of total surface soil water in the mowed, hayed and fallow respectively.

Discussion

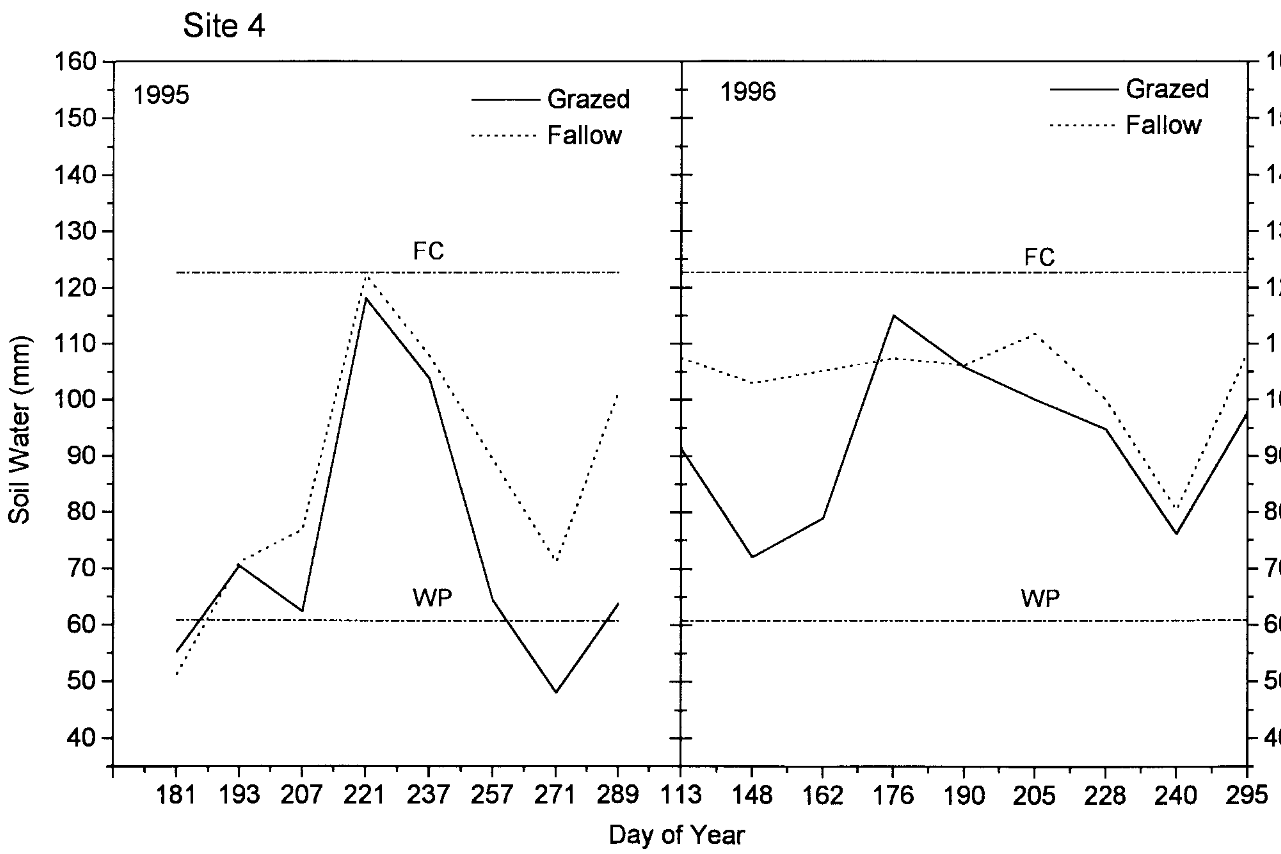
Elevated spring TSW30 on hayed and mowed treatments compared to fallow treatments at forage sites may be explained by entrapment of snow by vegetation. Early melting of snow may have occurred on all fallow plots due to a shallow snow cover and low albedo of the soil surface when it became exposed during melt. As small portions of the plot surface became visible, accelerated melting exposed more bare soil surfaces. Subsequent heating of the bare soils may have evaporated soil water which had accumulated during the winter and initial springmelt. This early loss of snow may have led to a reduction in infiltrated meltwater.

The large decrease in TSW30 of all treatments at all sites following the August 1995 recharge was likely due to a period of high evapotranspiration as vegetation was growing rapidly, recovering from harvest which had

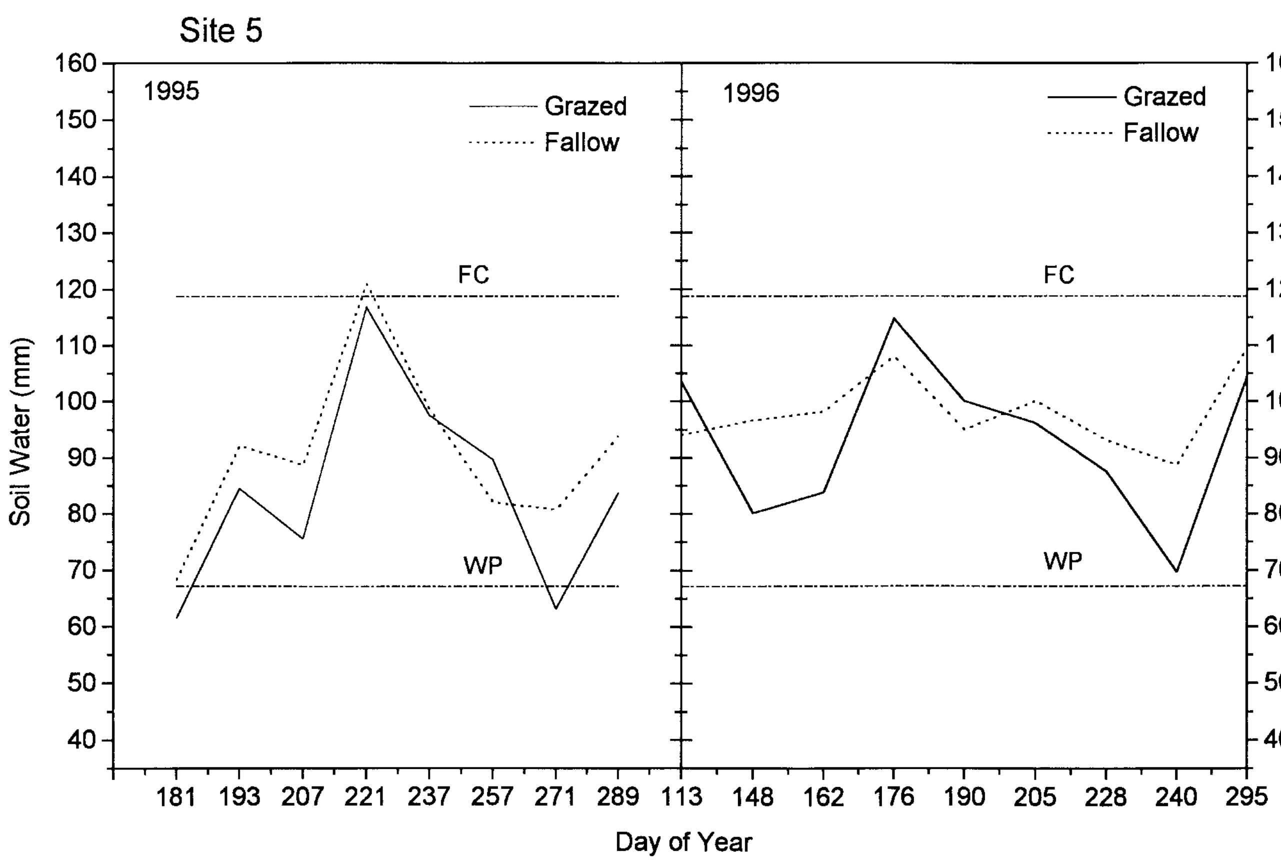


(c)

Figure 1(cont.)–Total soil water to 30 cm at (a) Site 1, (b) Site 2, and (c) Site 3. Note FC and WP represent field capacity and wilting point, respectively.



(a)



(b)

Figure 2–Total soil water to 30 cm at (a) Site 4, and (b) Site 5.

Table 4. Soil water frequency, percentage of total and cumulative percentage for different land management practices at Sites 1, 2, and 3

		Hayed			Mowed			Fallow		
Class *	SW (mm)	Freq†	%	Cumul‡	Freq	%	Cumul	Freq	%	Cumul
Surface	(0-7.5 cm)	Site 1								
I	17-21	7	41.2	41.2	4	23.5	23.5	5	29.4	29.4
II	22-26	1	5.9	47.1	4	23.5	47.1	5	29.4	58.8
III	27-31	2	11.8	58.8	5	29.4	76.5	4	23.5	82.4
IV	32-38	7	41.2	100.0	4	23.5	100.0	3	17.6	100.0
TSW30										
I	55-70	7	38.9	38.9	5	27.8	27.8	2	11.1	11.1
II	71-85	2	11.1	50.0	2	11.1	38.9	2	11.1	22.2
III	86-102	5	27.8	77.8	5	27.8	66.7	9	50.0	72.2
IV	103-118	4	22.2	100.0	6	33.3	100.0	5	27.8	100.0
Surface	(0-7.5 cm)	Site 2								
I	19-24	8	47.1	47.1	9	52.9	52.9	10	58.8	58.8
II	25-31	4	23.5	70.6	4	23.5	76.5	2	11.8	70.6
III	32-37	3	17.6	88.2	2	11.8	88.2	1	5.9	76.5
IV	38-46	2	11.8	100.0	2	11.8	100.0	4	23.5	100.0
TSW30										
I	68-87	5	27.8	27.8	9	50.0	50.0	3	16.7	16.7
II	88-107	11	61.1	88.9	8	44.4	94.4	9	50.0	66.7
III	108-127	2	11.1	100.0	1	5.6	100.0	6	33.3	100.0
IV	128-148	0	0.0	100.0	0	0.0	100.0	0	0.0	100.0
Surface	(0-7.5 cm)	Site 3								
I	15-19	1	5.9	5.9	1	5.9	5.9	4	23.5	23.5
II	20-25	6	35.3	41.2	5	29.4	35.3	6	35.3	58.8
III	26-31	3	17.6	58.8	4	23.5	58.8	3	17.6	76.5
IV	32-39	7	41.2	100.0	7	41.2	100.0	4	23.5	100.0
TSW30										
I	53-70	2	11.1	11.1	2	11.1	11.1	2	11.1	11.1
II	71-87	7	38.9	50.0	4	22.2	33.3	9	50.0	61.1
III	88-105	5	27.8	77.8	5	27.8	61.1	6	33.3	94.4
IV	106-124	4	22.2	100.0	7	38.9	100.0	1	5.6	100.0

* Denotes soil water class divisions. FC = field capacity; WP = wilting point; SW = soil water; WHC = water holding capacity.
Class I WP ≤ SW < (WP + 0.25 WHC)
Class II (WP + 0.25 WHC) ≤ SW < (FC – 0.50 WHC)
Class III (FC – 0.50 WHC) ≤ SW < (FC – 0.25 WHC)
Class IV (FC – 0.25 WHC) ≤ SW < FC
† Freq = frequency of occurrence, a number.
‡ Cumul = cumulative percentage frequency of occurrence.

occurred three weeks prior to the peak TSW30. High TSW30 of the mowed treatments at both Sites 1 and 3 was most likely caused by reduced plant biomass and thus reduced transpiration; whereas, the low TSW30 for the hayed treatments on these sites was likely due to a high demand on soil water. Fallowing at both Sites 4 and 5 tended to equalize their respective soil water regimes, with high TSW30 at both sites.

Increases in soil water following haying operations at all forage sites and in both years were likely due to the removal of 75 to 85% aboveground biomass. Since August was past the prime growing season at these sites, plant growth at this time was slow and less water was evapotranspired. During the recharge period in August 1995, soil water increased sharply, coinciding with reduced evapotranspiration and regular additions of water through precipitation. As the first cut was removed near the beginning of August 1996, only a short growing period remained before winter. Because of little precipitation until the end of August, TSW30 decreased until the end of the month, at which time evapotranspiration decreased and precipitation increased, resulting in increased soil water.

Although TSW30 was low on all treatments, it was lowest for the vegetated treatments (hayed and mowed). It is likely that root uptake of water in the surface soil resulted in decreased water in the vegetated treatments. Since the fallow treatment was unvegetated, water likely moved deeper into the soil profile.

The decrease in soil water following the August 1995 peak was likely due to evapotranspiration, evaporation from bare soils and a lack of precipitation. As mowed and hayed treatments displayed this same increasing and decreasing pattern in August 1995, precipitation during this period was a controlling factor in soil water recharge as evapotranspiration was at a minimum following haying. Also, soil water was recharged significantly over the period from 12 July to 9 August 1995 and 27 May to 24 June 1996 as there was a large proportion of summer rainfall during these time periods, 51% in 1995 and 41% in 1996 over the specified time intervals.

Soil water was higher in unmined soils under both hayed and mowed land management than when soils were fallowed or reclaimed. These results agree with the finding that mining disturbances adversely affect hydrologic parameters such as soil water and infiltration (Jorgensen and Gardner, 1988), but two factors must be considered: the reclaimed site in this study was not replicated and the reclaimed site had a very coarse subsoil (lower water retention) compared to the four unmined sites.

Table 5. Soil water frequency, percentage of total and cumulative percentage for different land management practices at Sites 4 and 5

		Grazed			Fallow		
Class*	SW (mm)	Freq†	%	Cumul‡	Freq	%	Cumul
Surface	(0-7.5 cm)	Site 4					
I	21-24	6	35.3	35.3	7	41.2	41.2
II	25-29	1	5.9	41.2	2	11.8	52.9
III	30-33	4	23.5	64.7	0	0.0	52.9
IV	34-39	6	35.3	100.0	8	47.1	100.0
TSW30							
I	60-75	7	38.9	38.9	3	16.7	16.7
II	76-90	2	11.1	50.0	3	16.7	33.3
III	91-106	7	38.9	88.9	5	27.8	61.1
IV	107-122	2	11.1	100.0	7	38.9	100.0
Surface	(0-7.5 cm)	Site 5					
I	19-22	3	17.6	17.6	4	23.5	23.5
II	23-26	8	47.1	64.7	5	29.4	52.9
III	27-31	2	11.8	76.5	4	23.5	76.5
IV	32-37	4	23.5	100.0	4	23.5	100.0
TSW30							
I	67-79	4	22.2	22.2	1	5.6	5.6
II	80-92	6	33.3	55.6	4	22.2	27.8
III	93-104	4	22.2	77.8	10	55.6	83.3
IV	105-119	4	22.2	100.0	3	16.7	100.0

* Denotes soil water class divisions. FC = field capacity; WP = wilting point; SW = soil water; WHC = water holding capacity.
Class I WP ≤ SW < (WP + 0.25 WHC)
Class II (WP + 0.25 WHC) ≤ SW < (FC – 0.50 WHC)
Class III (FC – 0.50 WHC) ≤ SW < (FC – 0.25 WHC)
Class IV (FC – 0.25 WHC) ≤ SW < FC
† Freq = frequency of occurrence, a number.
‡ Cumul = cumulative percentage frequency of occurrence.

Table 6. Summary of the Friedman's test to compare soil water frequencies within each class among different management treatments

Soil Depth	Class	Friedman's χ^2 for Comparing Hayed, Mowed and Fallow Treatments (Sites 1-3)	Friedman's χ^2 for Comparing Grazed and Fallow Treatments (Sites 4-5)
Surface	I	2.167ns	2.00ns
	II	0.167ns	0.00ns
	III	0.167ns	0.00ns
	IV	0.67ns	0.50ns
TSW30	I	2.00ns	2.00ns
	II	2.00ns	0.00ns
	III	4.67ns	0.00ns
	IV	2.00ns	0.00ns

Note: ns = non-significant difference among treatments.

Soil water frequency classes throughout the growing season for both years indicated that soil water was mostly between FC and WP, and never close to saturation. In a concurrent study on the same plots (Burk et al., 1999) using rainfall simulation, infiltration rates were high (rates at 5 min ranging from 83 to 98 mm h^{-1}) and runoff was low (generally < 50% of incident precipitation) on all treatments. These results were obtained even under a high rainfall intensity (48 to 55 mm in 30 min; greater than a 100-year return period) and relatively high antecedent soil water conditions (degree of saturation from 46 to 68%). Initial abstractions, expressed as a depth of water, ranged from 3 to 15 mm. Interestingly, Site 2, which had generally the lowest soil water relative to FC, also generally had the highest mean runoff coefficients in the rainfall simulation study. The authors attributed these findings at Site 2 to a high soil bulk density at this site, which may have resulted in poor root penetration and an overall reduction in vegetative growth. Sites 1, 2, and 3 had comparable 5 min and 30 min infiltration rates and 30 min accumulated infiltration, indicating that the infiltration parameters of the reclaimed soil were similar to those of the undisturbed soils. These results contradict those of Jorgensen and Gardner (1987) who found that infiltration rates of newly reclaimed minesoils were lower than those of undisturbed soils.

The frequency distribution of soil water depends on the number of measurements made and on the timing of those measurements. In this study soil water was measured eight times in 1995 and nine times in 1996, with measurements taken approximately every two weeks, adjusting only slightly if rain was falling on a measurement date. No attempt was made to stratify the sampling by measuring immediately after a rainfall. It is felt that the data collected are indeed representative of the soil water regime at the study sites.

Conclusions

Soil water across all treatments was generally most frequently measured in classes representing dry conditions (and hence a low runoff potential). Under fallow, the frequency distribution of soil water to greater depths shifted to higher classes (higher soil water), particularly at pasture sites, but even under this management regime which would maximize soil water, it was still rarely in the highest soil water class. In the prediction of summer storm runoff and in designing structures for runoff collection, antecedent soil water in a probability context, should be considered.

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