DISTRIBUTION OF SNOW COVER AS INFLUENCED BY LANDSCAPE UNITS IN SOUTHWESTERN ONTARIO

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ABSTRACT

Initial results from a field investigation undertaken to assess the importance of variations in snow cover among different land cover units are reported.

Snow depth distribution patterns in the Upper Grand River watershed for the winter of 1985-86 are given for different land cover types, as well as for edges (e.g. fence lines). Representative snow densities are given for each cover type and edge effect. Temporal changes in the distribution patterns show that at the maximum accumulation open fields contain less snow than average and edges and ditches more than average. After sustained ablation almost all snow is in edges and ditches.

From a comparison of snow water equivalent (WE) estimates made using the detailed snow cover measurements, routine snow course surveys and meteorological observations, it was shown that estimates of mean basin WE need to account for not only the different land cover types, but for edge effects as well.

INTRODUCTION

Snow-course surveys have been conducted in the Upper Grand River watershed and elsewhere in southwestern Ontario for over 20 years. The mean values of the ten readings from each snow course at each measuring date are used to measure the variation from year to year of the mean snow accumulation at each site for that date. So far, little use has been made of the data to specify the pattern of snow distribution over the watershed surface.

In this paper, we present initial results from a field investigation undertaken to assess the importance of variations in snow cover among different land uses. Extensive measurements of snow cover distribution were made on a weekly basis in the vicinity of three snow course sites in the Upper Grand River watershed for the winter of 1985-86. Observed snow depth distribution patterns are given for different land cover types, as well as for edges (e.g. fence lines and ditches). Representative snow densities are given for each cover type and edge effect.

Temporal changes in the distribution patterns are examined as well. A comparison of snow water equivalent estimates made using the detailed snow cover measurements, routine snow course surveys and meteorological observations is presented, in order to assess the effectiveness of using the routine snow course data for operational predictions of areal snow cover patterns.

DATA COLLECTION ACTIVITIES

STUDY AREA

The Upper Grand River Valley is a 694 km^2 agricultural watershed located in southwestern Ontario about 75 km northwest of Toronto (Fig. 1). The watershed was chosen for study because background information is available from previous studies (e.g. Watt, 1979; MacLaren, 1984), and excellent data is available, in terms of meteorological, streamflow, snow courses, and topographic information.

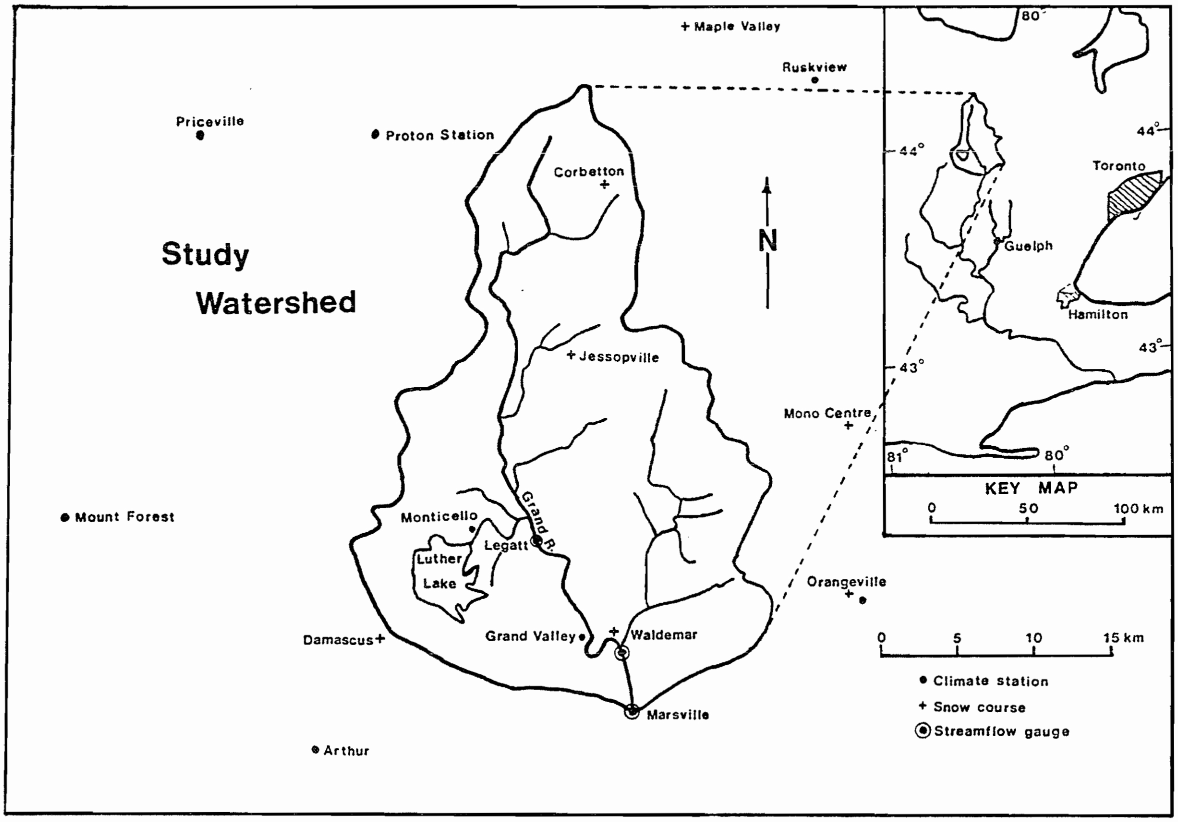

Fig. 1. The Upper Grand River Valley Watershed

Three snow course survey sites operated by the Grand River Conservation Authority (GRCA) were selected as foci for detailed sampling of snow depth and density in their vicinity. The chosen snow course sites near Corbetton, Jessopville and Waldemar, are situated reasonably close (less that 15 km) to observing climate stations (see Fig. 1), and are in regions that together represent the surface cover and topography of the watershed.

FIELD PROCEDURES

Several authors have shown that estimates of the true water equivalent of basin snowpack must account for the variations in snow cover found in the different land cover units (McKay, 1968; Adams, 1976; Goodison, 1977). Although the influence of 'edge effects' has been studied previously, (e.g. Kuzmin, 1960) little has been written about the inclusion of 'edge effects' in calculations of water-equivalent amounts. The field sampling program, described below, was specially designed to examine the magnitude of 'edge effects' within a study of snowpack variation with land cover.

The majority of the field work consisted of making numerous snow depth measurements (about 5,000) with a ruler along prescribed survey lines at intervals of 3 m (about 3 or 4 walking paces). The survey lines were chosen to sample different land cover units according to slope, aspect, wind exposure, and edge effects. Included in edge effects, were the transition areas between land cover types (e.g. open field to forest), as well as fence lines and roadway ditches. Each survey line was designed to cross or follow a GRCA snow courses at some point (Fig. 2). A list of the cover types and edge effects sampled at each site is given in Table 1. The field procedures were carried out once a week for the period January 15, 1986 to March 31, 1986, and were scheduled to coincide with the GRCA snow surveys on every second week.

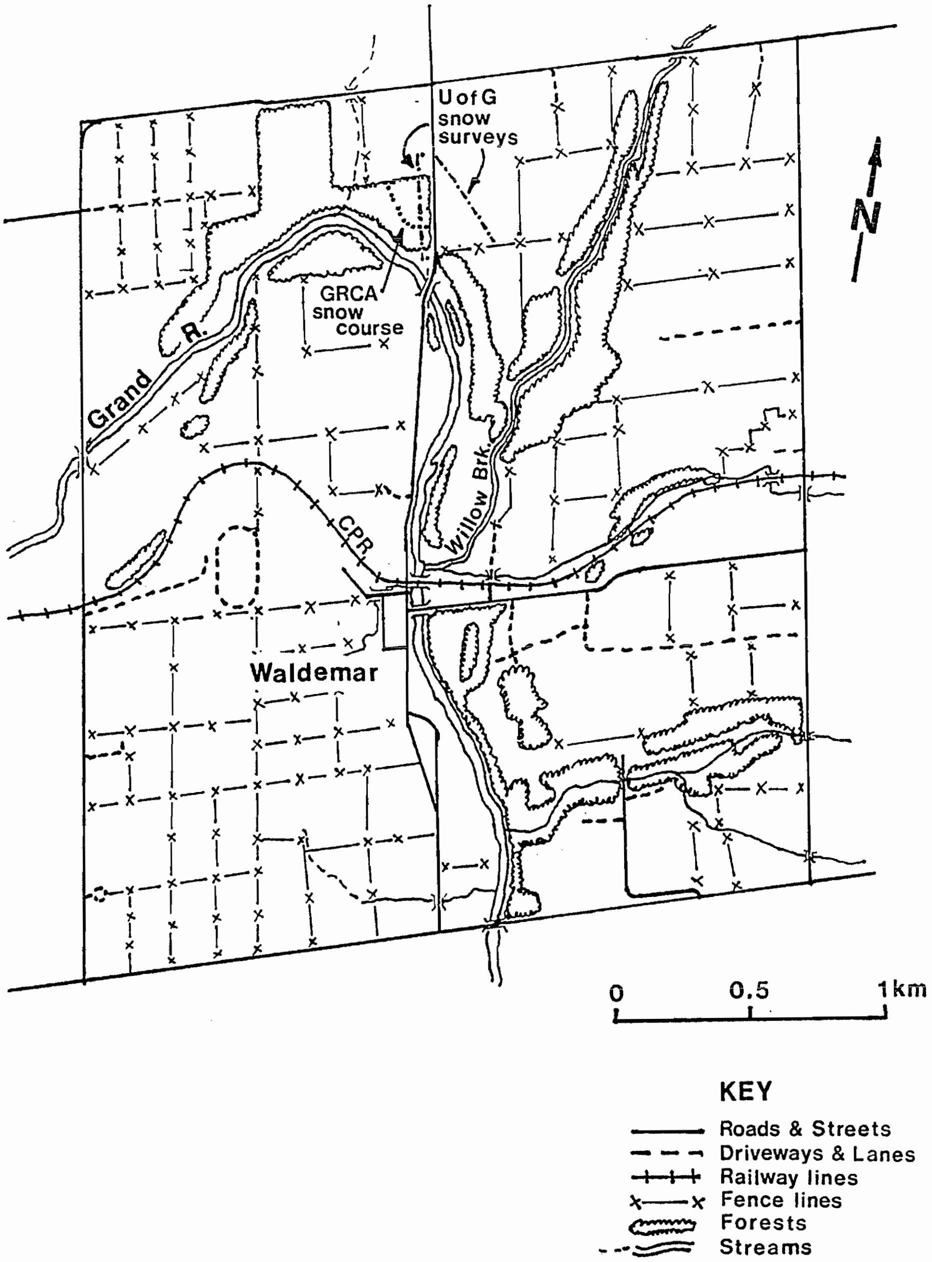

Fig. 2. Waldemar Study Area

Based on the experience of others (e.g. Dickinson and Whiteley, 1972; Stepphun and Dyck, 1974; Stepphun, 1976), we took considerably more snow depth measurements than snow mass measurements in order to maximize the efficiency of field sampling.

Table 1. Cover Types and Edge Effects Sampled

Sample Site	Cover Type and Edge Effects
Corbetton	-deciduous forest, sheltered natural grassland and partial wetland forest -roadway ditches and forest edge
Jessopville	-Hay & stubble fields, coniferous re-forested area -NW-SE road ditches, fence line and forest edge
Waldemar	-ploughed field, natural grassland, coniferous forest with varying stand heights. -North-South road ditches, East-West fence lines
Additional Sites	-wetland brush, unharvested corn fields -East-West road ditches, and North-South fence line

In addition to depth measurements, snow core samples were collected along the survey lines at intervals of 50 m, or about two cores per cover type, using a MSC (Meteorological Service of Canada) core sampler (70.5 mm diameter). Early in the sampling period, a basal ice layer developed in all unforested sites and this layer persisted and grew thicker through the rest of the winter. It was difficult to cut and retain the ice layer with the MSC sampler in grass sites and impossible in ploughed fields. Consequently, a larger diameter coring device (known as the Guelph sampler) was built with a 160 mm diameter core, which permitted the removal of the basal ice layers by chipping once the perimeter was cut by the sampler. All snow plus ice layer cores were placed in plastic bags and later weighed in the laboratory.

AERIAL OBSERVATIONS

On March 20, 1986, a two-hour mission was flown in a single-engine aircraft to observe and photograph the snow cover distribution on the study watershed following a period of substantial ablation. The GRCA, having been concerned about regulating the Conestogo Reservoir, agreed to sponsor the aerial mission. In total, 148 oblique angle photographs were taken of the watershed, including the areas surrounding the detailed ground sampling sites.

In the example photograph exhibited in Fig. 3, it can be seen that most of the open fields are mostly bare of snow cover, and the remaining snow is largely restricted to fence lines, in the forests, and along road ditches.

OBSERVED SNOW COVER PATTERNS

In this section, examples of the observed snow cover patterns are given for two dates: 1) February 21, 1986, a typical day during the full snow cover period, and 2) March 21, 1986, the day following the aerial observation mission. In addition, snow depth profiles are shown for typical 'edge effect' snow drifts at a fence line and in road ditches.

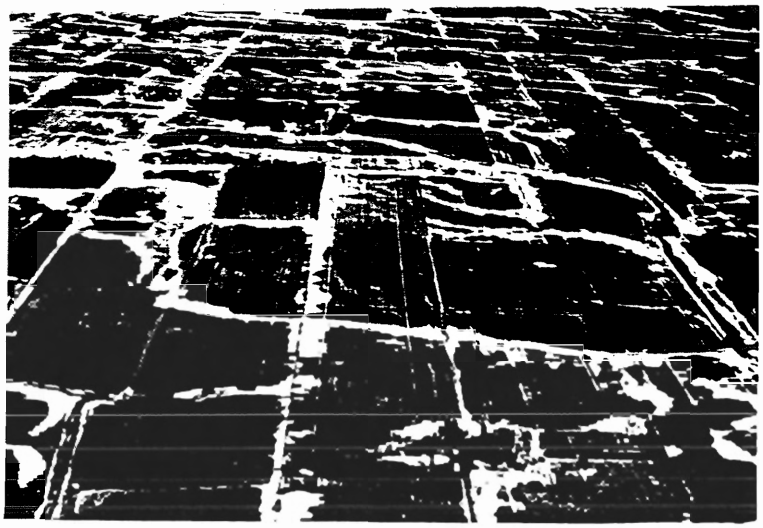

Fig. 3. Watershed snow cover patterns on March 20, 1986

The snow depth profiles along the main survey line at the Waldemar Site are displayed in Fig. 4. This survey line traversed three land cover types: ploughed field (distance 0 to 72 m), coniferous forest (82 to 300 m) and tall grass (300 to 350 m). The GRCA snow course crosses the survey line at distance 220 m, and remains in the forest. The tree heights are noted in Fig. 4 to indicate the influence of surface cover and edge effects on the snow cover pattern. The large spike in the profile just north of the forest was a snow drift on either side of a cedar-rail fence. The March 21 profile illustrates the importance of accounting for cover type in snow water equivalent estimates. Here, the ploughed and grassy fields are bare, but the forest still contains a substantial amount of snow.

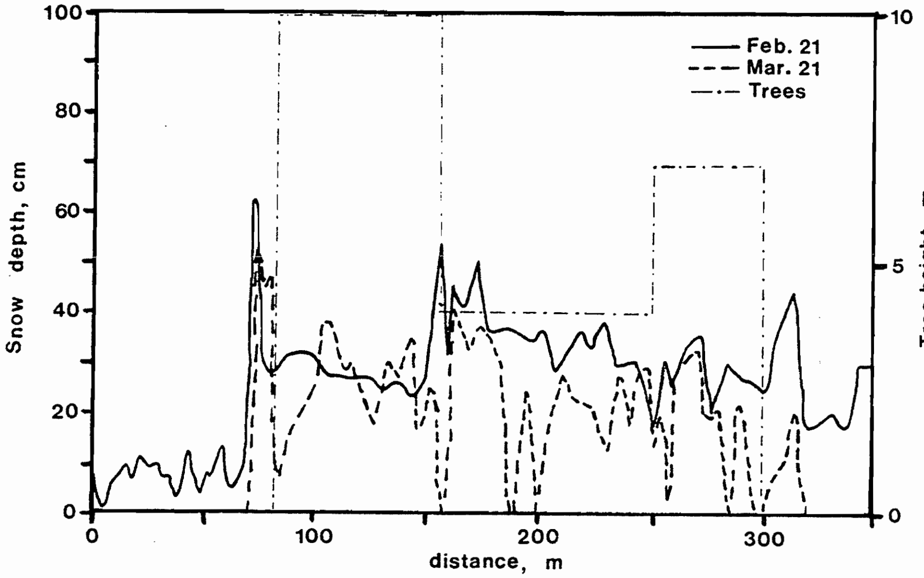

Fig. 4. Snow depth profile for main survey line at Waldemar (view east)

The elevation of the snow and ground surface are shown in Fig. 5 to illustrate typical drift profiles for road side ditches. The larger amount of snow in the east ditch is attributed to the elevation differences across the road. The east fence is on a slight ridge and accumulates snow from east and west winds; the west fence is below road level and receives little blown snow from east winds.

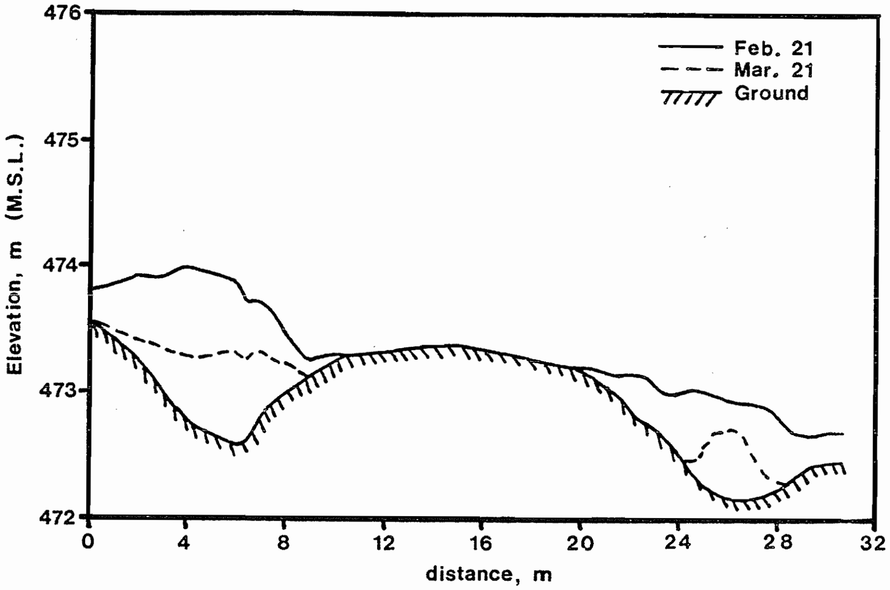

Fig. 5. Typical road ditch snow drift profiles (view south)

An example of a fence line snow drift profile is depicted in Fig. 6. This drift formed at a cedar-rail fence (at 22 m mark), with an east-west orientation, between a ploughed field on the north side and tall grass to the south. The influence of the fence on the drift profile appears to extend about 10 m on either side of the fence, where it becomes indistinguishable from the field snow.

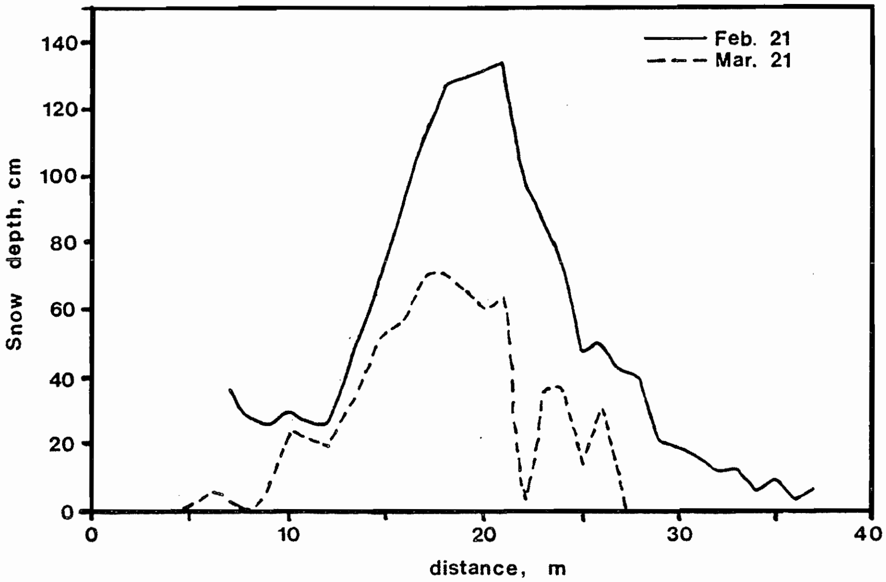

Fig. 6. Typical east-west fence line snow drift profiles (view west)

The snow cover statistics for the different land cover types and edges sampled at the Waldemar Site are summarized in Table 2. These snow cover statistics generally confirm well established relationships between the amount of snow accumulated in fields and forests; forests accumulate more snow than fields, and open fields exhibit the widest variations in depth and density, both in spatial as well as temporal terms. The snow depth variability, as expressed by the standard deviation, for the different land cover types are comparable to the results obtained by Stepphun and Dyck (1974).

The affect of using the larger coring device is evident upon examination of the density values for some of the field samples. Generally, the densities for the field samples are higher from February 21 onward because when the larger sampler was used the full basal ice layer was included in the sample. Note in particular the 605 kg/m^3 density value listed in Table 2 for the ploughed field for March 14. This sample had a depth of 4.5 cm, but contained a 15 mm ice layer, which could not have been retrieved using the smaller diameter core.

The wide temporal fluctuations in the density for the tall grasses illustrates another difficulty in obtaining sensible field snow density readings. In places, snow accumulates on thick mats of grass, suspending the bottom of the snow several cm above the ground surface. Ruler measurements taken to the ground surface overstate the actual thickness of the snow, but this is the only operationally-consistent way of measuring snow depth. The low snow density for tall grass sites for January 31 in Table 2 exemplify this. Since the overstated snow depth is used in both the determination of average snow depth and as the denominator in calculating snow density, the product of density times the average depth used to estimate WE is free of this error.

DETAILED WATER EQUIVALENT ESTIMATES

PROCEDURE

A 822 ha section of land surrounding the Waldemar sampling site (Fig. 2) was selected for a detailed estimate of mean snow water equivalent using the measured snow cover distribution data. The estimation procedure involved dividing the study section into homogeneous land use blocks according to the land cover types and edge effects represented in the area.

For a particular land use block, the volume of equivalent snow water was calculated using

$$V_i = (d_i \rho_i A_i)/100 \qquad [1]$$

where V_i is the volume of snow water for land use block i (ha-mm), d_i is the mean snow depth (cm), ρ_i denotes the mean snow density (kg/m^3), and A_i is the area of land use block (ha). The factor 100 combines the conversion of depths to mm from cm and division by the density of water (1000 kg/m^3).

The mean snow water equivalent (expressed in mm) for the entire study section was determined as

$$WE = (\Sigma \ V_i)/A_T \qquad [2]$$

where A_T is the total area of the section.

The land use blocks within the study section were delineated using 1:10 000 scale base maps available from the Ontario Ministry of Natural Resources. The various cover types and edges considered for the land use blocks were agricultural fields (ploughed, hay and stubble), forests (deciduous and coniferous), swamps, other lands (streams, land bordering streams, and developed sites), fence lines, forest edges, and roadside ditches.

Table 2. Summary of Snow Cover Statistics for Waldemar Site

Date	Ploughed Field				Coniferous Forest				Tall Grass				Ditches		Fence line	
	d	s	n	ρ	d	s	n	ρ	d	s	n	ρ	d*	ρ	d*	ρ
Jan. 15	7.6	3.9	81	221	27.4	7.8	71	186	23.6	11.5	14	245	23.4	330	44.6	251
Jan. 24	0.0			---	14.8	5.3	85	346	8.7	8.4	28	293	10.7	402	----	---
Jan. 31	5.3	3.7	157	179	21.8	5.5	100	253	16.1	6.7	29	131	22.0	448	30.6	243
Feb. 7	9.1	5.4	117	283	26.1	6.8	79	313	24.8	8.4	18	246	36.6	358	30.6	210
Feb. 14	14.6	6.5	103	258	35.7	8.1	76	214	32.1	10.1	23	214	39.0	296	52.8	253
Feb. 21	9.4	5.8	57	367	31.7	8.0	37	246	28.3	8.9	13	342	39.2	317	74.5	360
Feb. 28	7.7	5.0	34	467	32.5	9.3	61	241	----			---	34.8	312	----	---
Mar. 7	9.5	6.0	51	276	44.4	12.0	41	246	39.3	10.8	14	194	37.7	314	70.0	336
Mar. 14	1.4	2.6	91	605	31.8	11.0	54	323	21.8	12.0	18	191	23.3	478	56.8	363
Mar. 21	0.0			---	22.7	12.3	47	349	4.9	8.2	18	277	14.9	536	34.9	422
Mar. 31	0.0			---	0.0			---	0.0			---	0.0	---	0.0	---

Note: d = mean snow depth in cm
ρ = mean snow density in kg/m^3
s = standard deviation of snow depth in cm
n = number of snow depth samples
* denotes integrated value from profile measurements.

Several road ditch cross-sections were measured using a surveyor's level to define a typical ditch profile (Fig. 5). An easement width of 30.5 m and the total length of road in each study section were used to calculate the area of the road way ditch block.

For fence lines, the zone of influence was taken to extend 10 m on either side of the fence, whereas the influence zone for forest edges was assumed to be 20 m on either side of the edge. Fences or forest edges sheltered by nearby forests (with a separation distance of less than 20 m and parallel to the edge line) were considered to create no special snow deposition and were ignored. The total area of the edge blocks was computed as the length of fence or forest line times the width of zone of influence (20 m for fences, and 40 m for forest edges). Aerial photographs supplied by the GRCA were used to confirm the location of fence lines.

The representative values of mean snow depth and density given in Table 2 were used directly in the detailed estimates of WE for land use blocks. However, for the edge-effect blocks, a different technique had to be used to obtain an 'effective' mean snow depth for use in Eq. [1]. The road ditch and fence drift profiles (e.g. Figs. 5 and 6) were integrated to find the total cross-sectional area of snow in the profile. The effective mean snow depth was calculated by dividing this area by the width of the section. For the road ditch profiles, the profile width was taken as the roadway easement (e.g. 30.5 m) and for fence lines, the width of the zone of influence (e.g. 20 m) was taken as the profile width.

A tabular accounting technique was used to carry out the land-use-block estimates of WE. A sample of the detailed calculations is presented in Table 3. The WE estimates were made for several dates in order to include the time of maximum accumulation and the day after the aerial photo mission. The results of these computations are summarized in Table 4.

Table 3. Detailed Estimates of Mean Snow Water Equivalent
Waldemar Area, February 28, 1986

Land use	Area (ha)	Snow Parameters Depth (cm)	Density (kg/m^3)	WE (mm)	Volume (ha-mm)
1. Fields: Ploughed	228.7	7.7	467	36.0	8222
Crop Stubble	137.2	15.3	469	71.8	9844
Hay	91.5	25.7	361	92.8	8485
Total	457.3				26552
2. Forests: Coniferous	53.7	33.6	241	81.0	4348
3. Other Lands	119.5	29.0	262	76.0	9080
4. Edge lines:					
E-W: Fences	28.7	72.3	312	225.6	6474
Forest Edge	24.6	72.3	312	225.6	5558
N-S: Fences	37.6	72.3	349	252.3	9482
Forest Edge	46.4	72.3	349	252.3	11708
Total	137.3				33223
5. Roadway ditches					
East-West	28.2	34.4	410	141.0	3977
North-South	26.0	34.8	410	142.7	3710
Total	54.2				7687
Overall Total	822.0				80889
			Mean WE=	98.4	

Table 4. Snow Water Equivalent Estimates for Waldemar Area
(Percentage of total given in brackets)

Land Use	Area (ha)	Snow Water Volume, (ha-m) Feb. 28	Mar. 7	Mar. 14	Mar. 21
Fields	457.3 (55.6)	26.6 (32.8)	30.8 (34.1)	16.5 (25.7)	2.0 (6.0)
Forests	53.7 (6.5)	4.3 (5.4)	5.9 (6.5)	5.5 (8.6)	4.3 (12.9)
Other Lands	119.5 (14.5)	9.1 (11.2)	13.1 (14.5)	7.9 (12.3)	2.3 (6.8)
Fence-Forest edges	137.3 (16.7)	33.2 (41.1)	32.3 (35.8)	28.3 (44.0)	20.2 (61.2)
Roadway ditches	54.2 (6.6)	7.7 (9.5)	8.2 (9.1)	6.0 (9.4)	4.3 (13.1)
Totals	822.0	80.9	90.3	64.2	33.1
Mean WE (mm)		98.4	109.8	78.1	40.3

RESULTS AND DISCUSSION

The total volume of snow in each land-use block and the percentages of total snow in the study area held within each land-use block are listed in Table 4 for four dates at about the time of maximum snow accumulation and shortly thereafter. One can see that most of the snow (about 70% on March 7) is located in the open fields and at fence-forest edges. The fields never contain as much snow as their areal proportion would require for an even distribution. By contrast, ditches and fence-forest edges contain more snow than their areal fractions would require. Forests and other lands contain an amount of snow appropriate to the areal proportion. It is noteworthy that the maximum snow accumulation for fences and forest edges is reached before the entire area reaches its maximum. This suggests that these edge areas may have reached a limiting capacity to accumulate snow.

COMPARISON OF WATER EQUIVALENT ESTIMATES

OPERATIONAL ESTIMATES

In this section, we present a comparison between the land-use-block WE estimates and two operational procedures for estimating WE. The first operational procedure is to use the GRCA course located in the study section as the sole estimate of WE. Secondly, meteorological observations (Met data for short), of daily temperature and precipitation, are used together with a simple snow accumulation and ablation model. The Met data were obtained from the Atmospheric Environment Service for 15 stations surrounding the study sites, some of which are noted in Fig. 1.

The snow ablation model used here is similar to some of the models tested by MacLaren (1984). In this model, the snowpack is divided into three layers to account for different ages of snow, a degree-day method is used to compute the snowmelt and refreeze rates, changes in pack density due to compaction are calculated using a growth curve, and the liquid water holding capacity of the pack is used to compute the rate of meltwater released from the pack. The accumulation-ablation model was run with pre-selected parameter values to illustrate how meteorological observations are used to estimate basin snow water equivalent. To fully calibrate the model adjustments to the equilibrium snow density and melt factor would be required, as well as an allowance for sublimation during periods of below freezing temperatures.

RESULTS AND DISCUSSION

The results of the comparison for WE estimates are given in Table 5. The forest block component from the land use block estimates is shown for the purpose of discussion. One would expect that the GRCA course values would at least be similar to the forest block amounts, because both estimates utilized measurements made at the same forest plot. As the table shows the agreement between the two estimates is extremely good, despite the difference in measurement technique. The GRCA value is the average of ten WE measurements, and forest block value is derived from the average of 35 or more depth readings and only a few density measurements. Moreover, the forest block, which was measured every seven days, provides a good indication of the snow course values for dates when no snow course surveys were made (e.g. March 7 & 21).

Table 5. Comparison of WE Estimates

Date	Land Use Blocks	Forest Block	GRCA Course	Meteorological Observations
February 28, 1986	98.4	80.9	69.9	124.4
March 7,	109.8	109.2	----	141.8
March 14,	78.1	102.6	110.5	152.5
March 21,	40.3	79.1	----	146.9
March 31,	0.0	0.0	0.0	0.0

Note: amounts are given in mm.

For the maximum WE estimate (March 7), the agreement is excellent between the forest block alone (and by interpolation the snow course amount) and the value for the combined land use blocks. By March 14, with the onset of the snowmelt period, the snow course estimate is 43% higher than the land use block estimate. A snow course value estimated for March 21 from the forest block is 96% higher than the detailed land use figure.

Because of the lack of calibration, the Met data estimates of WE made via an ablation model, are consistently above the land use block or the snow course estimates. However, a comparison of simulated and observed snow depths, as presented in Fig. 7, reveals that the ablation model gave results that are in general agreement with the forest block. With the previously mentioned adjustment in the model parameters, the Met data estimate of WE could be made to agree with the forest block.

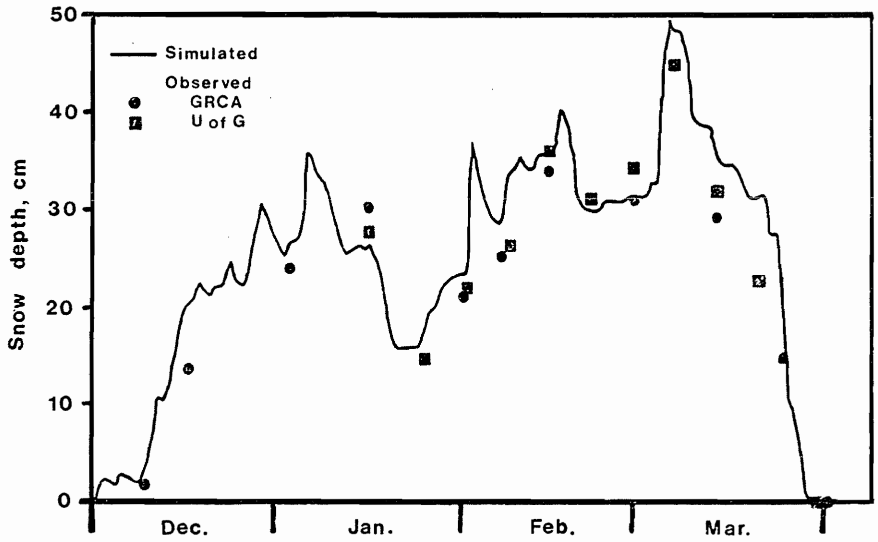

Fig. 7. Comparison of observed and simulated snow depths

These results indicate that if an accurate WE estimate is to be obtained as a watershed average estimating procedures need to account for different snow amounts on varying land cover types. This view has been presented by several authors (e.g. Adams, 1976; Goodison, 1977). However, as has been shown here, land cover is not the only consideration for an accurate WE estimate, especially when significant ablation has occurred. The results for March 21 show that edges (e.g. ditches and fence lines) are particularly important for late season estimates of basin WE.

How then can WE estimates be made more effective from an operational standpoint? One solution would be to use both snow courses and meteorological observations in conjunction with some type of snow accumulation-ablation model for each land use block. The snow course measurements, on the dates they are made, could be used to update or re-calibrate the snow accumulation model.

CONCLUSION

Snow course measurements in forested sites can give good watershed WE estimates during accumulation. Once a major ablation event has taken place, the WE estimates from these courses will be badly biased. Therefore, an estimate of mean basin WE needs to account for land cover types, and edges (e.g. fence line and ditches).

Meteorological observations can be used to estimate WE by using a simple accumulation-ablation model, however, the model needs to account for different cover types and edge effects as well.

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