

APPLICATION OF A SNOW ACCUMULATION-ABLATION MODEL
FOR AREAL DISTRIBUTION OF SHALLOW EPHEMERAL SNOWPACKS

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ABSTRACT

A new model for simulating the areal distribution of snow in shallow ephemeral snowpacks is presented for typical land use and edge (e.g. fences, ditches) blocks found in rural watersheds. Model inputs are readily available meteorological information and watershed land use characteristics. The calculated distributions provide an improved basis for streamflow modelling during conditions of partial snowcover which occur for many large flood events in Eastern Canada.

INTRODUCTION

In an earlier paper (Schroeter and Whiteley, 1987), we presented the initial development of an operational areal snow accumulation-ablation model (ASAAM) designed to simulate the spatial distribution of snow in shallow ephemeral snowpacks throughout the winter. The calculated distributions provide an improved basis for streamflow modelling during the conditions of partial snow cover which occur for many large flood events in eastern Canada.

In this paper, we report improvements to the snow erosion and redistribution components of the ASAAM, and give initial results of applying the model for simulating snow distribution patterns in the Upper Grand River valley of southwestern Ontario. The ablation sub-model processes (refreeze, sublimation, snowpack compaction, snowmelt, rain deposition and release of liquid water) were outlined in the previous paper, and hence, only a brief summation will be given here.

APPROACH TO SNOW ACCUMULATION MODELLING

The way in which a snow cover accumulates on a watershed has a major bearing upon the subsequent pattern of melting. An initial variation in snowpack depth and structure is created by the weather system which deposits the snow. Large local variability is caused by wind transport and by energy exchange processes (ablation and melt). These cause patterns of redistributed snow that differ considerably from those produced by the initial snowfall.

Even though snow accumulation involves a series of complex processes, snow accumulates in patterns that have considerable similarity from one year to the next. Therefore, our philosophy in the development of the ASAAM is to exploit this high degree of consistency in the accumulation process. In addition we wish to utilize as much existing information as possible.

EQUIVALENT ACCUMULATION BLOCKS

Several authors have shown that estimates of the true water equivalent of a basin snowpack must account for the variations in snow cover found in different land cover units (Adams, 1976; Goodison et al., 1981). Moreover, Schroeter and Whiteley (1986) showed decisively that the amount of snow accumulated in 'edges' (e.g. ditches or fence lines) can be large and must be included in calculations of water-equivalent amounts.

Therefore, to account for the spatial distribution of snow cover, the accumulation-ablation processes are modelled by considering a watershed comprising 'equivalent accumulation blocks' (EAB), each defined according to homogeneous land cover types (e.g. open fields, forests) and edges (e.g. roadway ditches, fence lines and forest-field edges). The 'blocks' in similar climate zones within the watershed are grouped together for calculation. Climate zones are the largest possible areas that show acceptable spatial uniformity in sequences of rainfall, snowfall, air temperature and wind speed. At present no account is taken of the orientation of an EAB with respect to the prevailing wind direction in a climate zone. The major assumption here is that all blocks of the same type within a climate zone will accumulate snow in a similar or 'equivalent' manner.

Cellular subdivision within blocks

To allow for the snow cover variability within the different block types, each block is divided into a number of 'cells', each representing a portion of the block area. Each cell is defined by a capacity height, H , which denotes the maximum depth of snow that can be stored in the cell during full drifting snow conditions. Therefore, the snow depth distribution the time of maximum accumulated snow cover can be used as a direct measure of the cellular capacity heights. For field and forest blocks, the snow depth at peak accumulation has been characterized by a Gaussian distribution (Goodison et al., 1981). Observed maximum snow depth profiles for edge blocks resemble common geometrical shapes (e.g. triangular, trapezoidal) (Schroeter and Whiteley, 1986).

For field and forest block calculations, the cells are arranged by capacity heights from lowest (cell 1) to highest (cell n) (see Fig. 8a). The cell capacity heights for edge blocks are arranged according to measured depths from profile surveys (see Fig. 8b). In the model, Cell 1 is always assigned the lowest capacity height for a block.

Snowpack representation in a cell

Snowpack stratification, caused by the snow deposition, erosion, redistribution, and ablation processes, is modelled by dividing each snowpack cell in an EAB into five layers as defined in Fig. 1. The first layer represents newly deposited snow, the second layer comprises snow that was deposited on the previous day, and the third layer contains snow

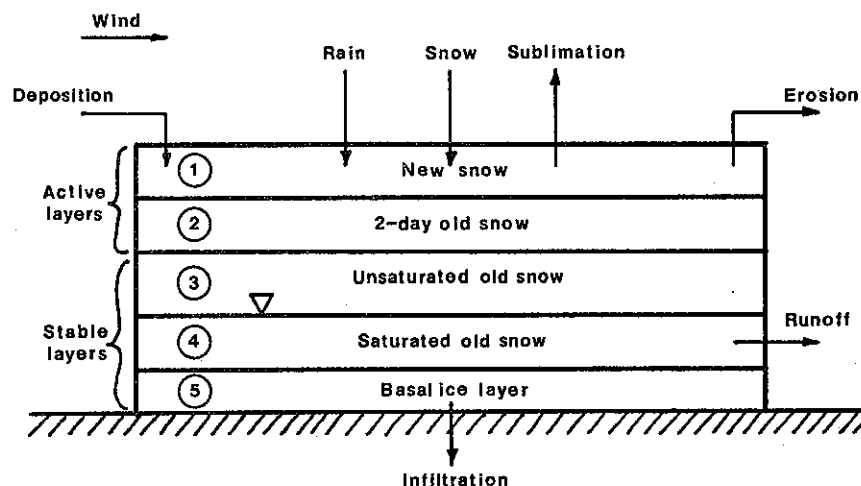


Fig. 1 Definition sketch for layered snowpack concept

that is older than two days. If meltwater released from the snowpack cannot infiltrate into the underlying ground, then a saturated basal layer (layer 4) will develop in the third layer and can form an ice layer at the very bottom of the snowpack upon refreezing (layer 5).

The top two layers are assumed to be 'active' layers, representing snow that can be eroded by the wind and hence is available for redistribution. Having been compacted and metamorphosed due to the ablation process, the bottom three layers make up the 'stable' part of the pack, or snow that is not transported by the wind.

There are two major components or sub-models in the ASAAM: 1. a snow deposition/redistribution model, to simulate the initial deposition, erosion and redistribution between snowfalls, and 2. an ablation model that accounts for snowpack density changes due to energy exchanges and meltwater releases from the pack.

OPERATIONAL CONSIDERATIONS: INPUTS, OUTPUTS AND UPDATES

Inputs

The ASAAM program is designed to run on a daily basis, and to accept readily available meteorological information only (e.g. daily maximum and minimum temperature, daily rain and snowfall, and mean daily wind speed).

The areal proportion of each land cover and edge type in the watershed are used to define the 'equivalent accumulation blocks'. This information can be obtained from topographical and land use maps or remote sensing imagery if available. The Landsat 5 Thematic Mapper (30 m resolution) could be used to find the total area for each of the various land cover blocks. For edge block areas (e.g. roadway ditches), the total length of the edge is required multiplied by some effective width. Schroeter and Whiteley (1986) have suggested effective widths for edge blocks; for roadway ditches, the effective width is the road easement; for open field fence lines the width is about 20 to 30 m and for forest-field edges, the width is about 40 to 50 m.

Outputs

Output from the ASAAM provides the initial snowpack conditions (depth and water equivalent) required as input to a hydrologic model (e.g. HYMO) from which streamflow predictions are made. For each accumulation block, the ASAAM program outputs the mean depth and total water content, percent bare area, and the simulated distribution of snow depths.

Updates

As an operational model, ASAAM is designed to be updated with observed snow depth and water equivalent measurements from routine snow course surveys. As such, the component algorithms are kept as simple as possible to facilitate model updates. Where possible the model parameters are expressed as functions of snow depth and density, which makes it easy to update the model when observed values of these two parameters are available.

Ten processes (refreeze, sublimation, compaction, rain deposition, snowmelt, basal layer development, release of liquid water, new snow deposition, erosion and redistribution) are considered in model. The flow chart for the computational steps is given in Fig. 2. For a given time step during the simulation, each individual process or sub-model is completed for all snowpack layers, cells and accumulation blocks in a climate zone before proceeding to the next stage in the flow chart. With the exception of the development of the snowpack basal layer, each process is considered by starting at the top layer and working downward through the pack.

The first seven processes are included in the ablation sub-model, and the remaining three processes are considered in the deposition and redistribution sub-model described later.

SIMULATION OF ABLATION PROCESSES

The ablation process calculations are carried out for each type of equivalent accumulation block (EAB) using a time step of one day. For each cell in an EAB, layer-by-layer computations allow for the downward transmission of water to the soil surface where infiltration or runoff occurs.

In the ablation sub-model (see Schroeter and Whiteley, 1987), a degree-day method is used to compute snowmelt and refreeze rates, a constant sublimation rate is assumed during below freezing periods, changes in pack density due to compaction are calculated using a growth curve, the liquid water holding capacity of the pack is used to compute the rate of meltwater released between layers, and constant infiltration and lateral runoff rates are used to determine the thickness of the basal layer. The major input parameters for ablation sub-model are listed in Table 1.

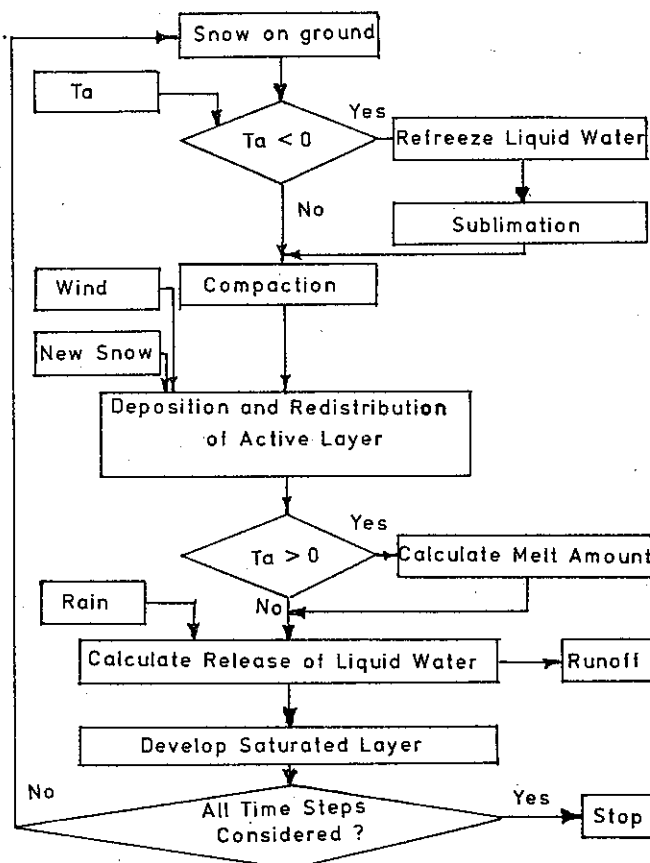


Fig. 2 Flowchart for computational steps in the ASAAM

MODELLING SNOW DEPOSITION AND REDISTRIBUTION

In the ASAAM it is assumed that the initial deposition of new snow can be treated separately from any erosion and spatial redistribution by wind. Although this is not true in reality, because blowing snow does occur during initial deposition, any error introduced by this assumption will be corrected during real-time simulation by updating the model with snow survey measurements.

The redistribution sub-model is based on the observation that snow tends to redistribute by erosion of open fields and deposition in edges (Schroeter and Whiteley, 1986). Snow in forests does not redistribute. Moreover, 'edges', such as a roadway ditch for example,

have a limiting capacity to accumulate snow. When this capacity is exceeded, any new snow deposited in the edge will be eroded during the next drifting event. Therefore, the redistribution sub-model is applied only to open fields and edges.

INITIAL DEPOSITION

On a day when new snow occurs it is deposited evenly in each accumulation block within a given climate zone. The snow layers in each cell of an EAB are rearranged to account for new snow deposits. Snow in layer 2 is added to snow currently stored in layer 3 as follows

$$\begin{aligned} \text{SDEP}(3,j,k)_f &= \text{SDEP}(3,j,k)_o + \text{SDEP}(2,j,k) \\ [1] \quad \text{SWC}(3,j,k)_f &= \text{SWC}(3,j,k)_o + \text{SWC}(2,j,k) \\ \text{LWC}(3,j,k)_f &= \text{LWC}(3,j,k)_o + \text{LWC}(2,j,k) \end{aligned}$$

where SDEP is the snow depth (mm) in layer i of cell j in block k , SWC is the solid (ice) water content (mm of liquid water), LWC is the liquid-water content (mm), and the subscripts o and f denote values of a certain quantity (e.g. SWC) before and after a specific calculation.

The previous layer 1 becomes the current layer 2, and the newly deposited snow becomes the new layer 1, so that

$$[2] \quad \text{SDEP}(1,j,k) = \text{SNOW}; \quad \text{SWC}(1,j,k) = \text{NEWDEN} * \text{SNOW}$$

where SNOW and NEWDEN are the depth and relative density of the new snow, respectively. Observations have shown NEWDEN in the range from 0.02 to 0.15, with a typical value of 0.1 for most regions (Goodison et al., 1981). The liquid water content of new snow is assumed to be nil. As a result of snow transfers between layers, the 'dry' (ice content), relative-to-liquid water, density for layer i , $\text{RHO}(i,j,k)$, and the porosity, $\text{POR}(i,j,k)$ are recalculated using

$$[3] \quad \text{RHO}(i,j,k) = \text{SWC}(i,j,k) / \text{SDEP}(i,j,k)$$

$$[4] \quad \text{POR}(i,j,k) = 1 - \text{RHO}(i,j,k) / 0.92$$

The total snow depth, d in a cell is the sum of the individual layer depths (e.g. SDEP).

Once the new snow has been deposited in each cell of an EAB, the redistribution of snow between the various edge blocks is considered.

Special treatment of forest and roadway ditch blocks

Because snow erosion is not permitted in forest blocks, the within block variations are considered by distributing the new snow among each cell in proportion to their capacity heights.

Plowing of rural roadways usually takes place during or shortly after new snowfalls. Therefore, in order to model the mechanical movement of snow during plowing operations, the ditch block cells are arranged so that cell 1 signifies the roadway area, and cells 2 and 3 represent the portion of the ditch immediately adjacent to the road. Then, the total amount of snow placed in cell 1 using [2] is removed and placed evenly in cells 2 and 3.

REDISTRIBUTION OF ERODED SNOW

The redistribution of eroded snow is handled in two stages. First, cell-by-cell snow erosion and deposition calculations are carried out for each accumulation block in turn as outlined in Fig. 3. For each cell, the computed amount of eroded snow is deposited within the block in only those cells with capacity to store snow. In stage two (Fig. 4), any eroded snow that did not deposit in the block during stage 1, becomes available for

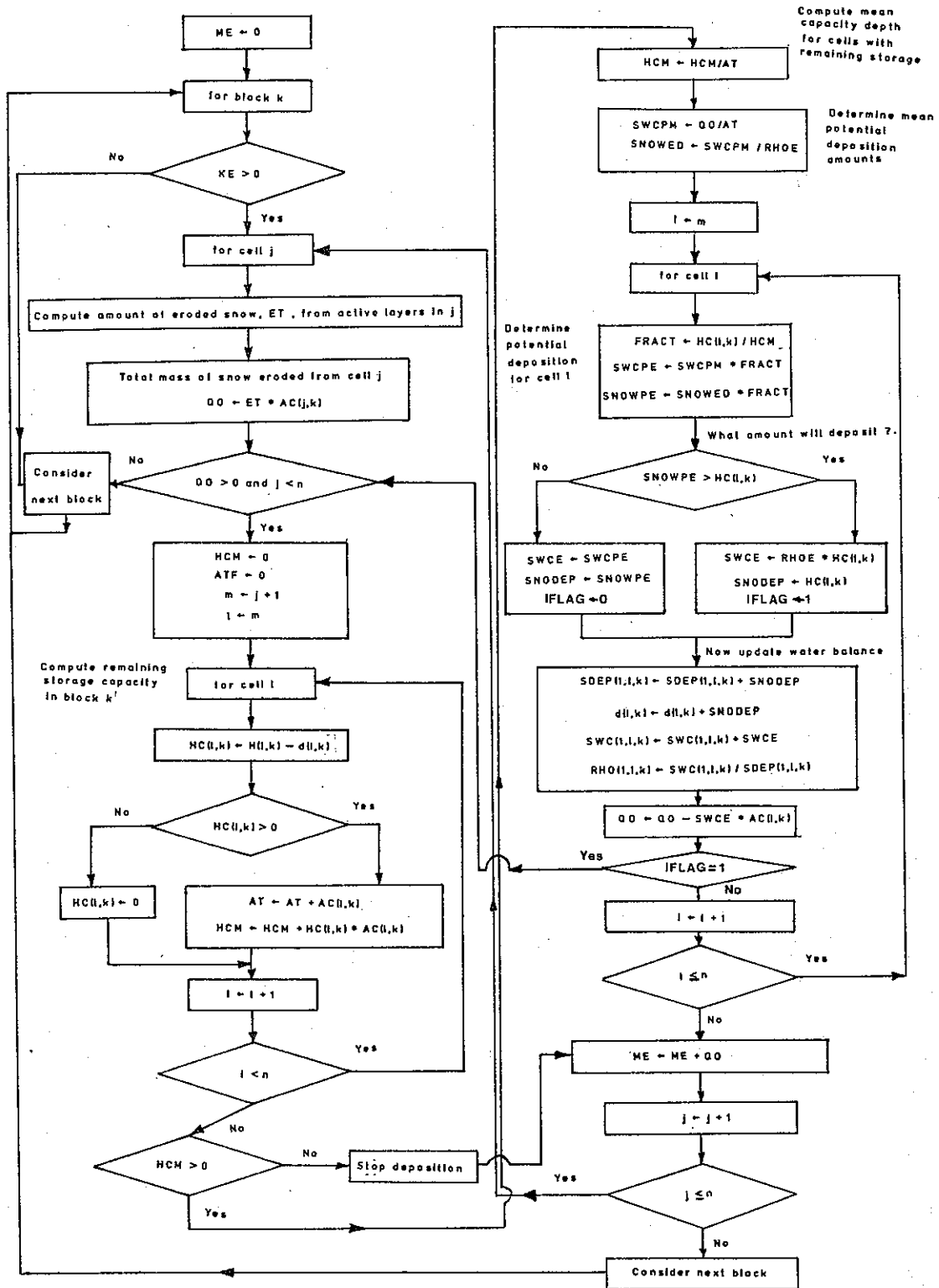


Fig. 3 Flowchart for snow erosion and deposition within blocks

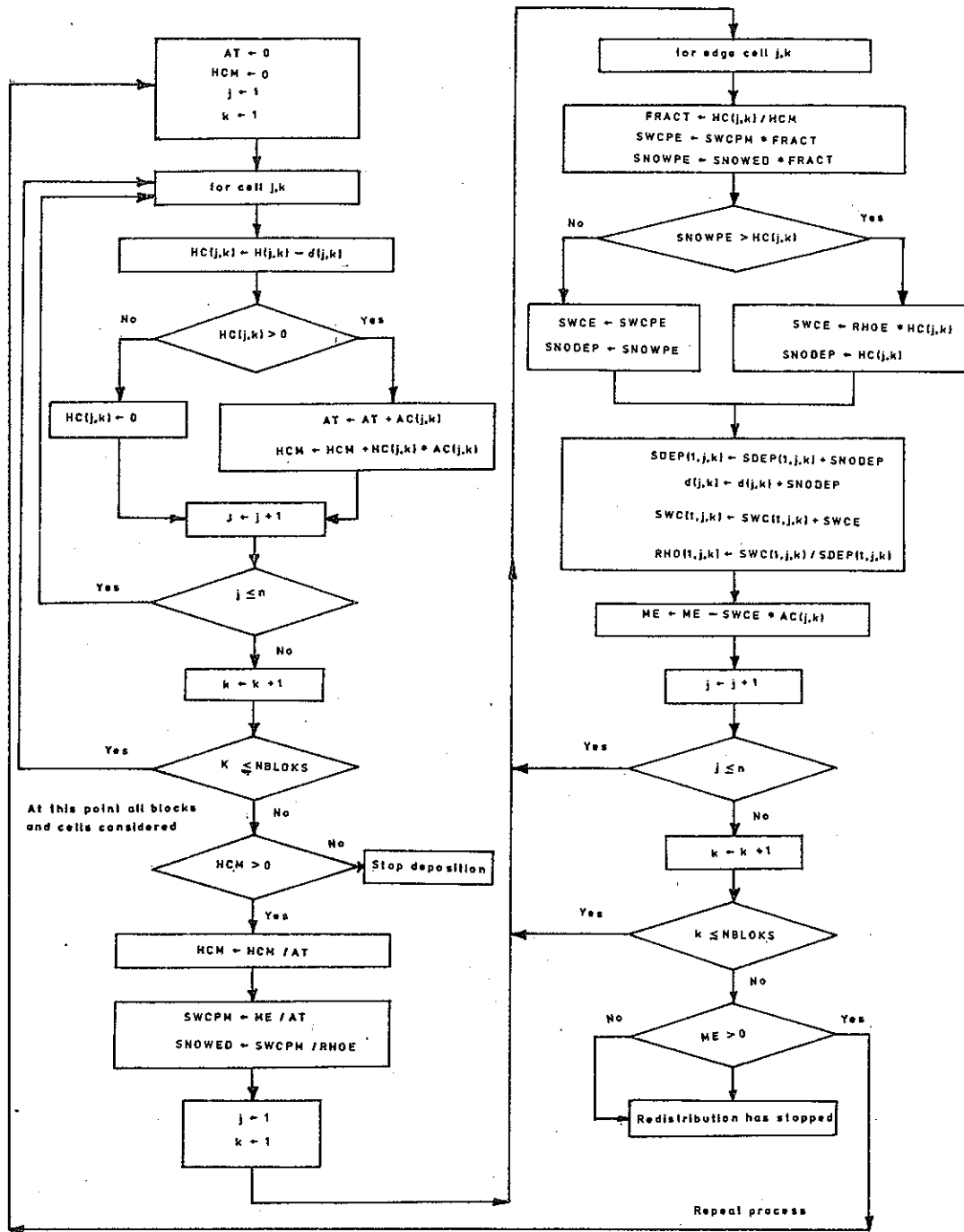


Fig. 4 Flowchart for deposition of eroded snow in edge blocks

deposition in edge blocks.

The average daily wind speed, WIND(t) for each time step t (measured in km/h, 10 m above the ground surface) from an open site within a climate zone is required input to the redistribution model. These wind speeds must be adjusted by some factor in order to correctly identify snow drifting events. Consequently, an 'effective' average daily wind speed, UEFF(t) (km/h) is used for snow erosion estimates.

$$[5] \quad UEFF(t) = WINDF * WIND(t)$$

where WINDF is an effective wind speed adjustment factor.

In some EAB's (e.g. tree fence lines), the actual wind speed is lower than in open field blocks. Therefore, the average daily wind speed, U (in km/h, measured 10 m above the ground surface) for a particular block is given by

$$[6] \quad U = WSRF * UEFF(t)$$

where WSRF is the wind speed reduction factor for block k.

Snow erosion and deposition within blocks

Snow transport by the wind is permitted only in the active layers of the snowpack (layers 1 and 2). The potential snow erosion rate, EP (mm/d) for cell j in block k is computed using an expression proposed by Schroeter (internal report, School of Engineering, University of Guelph, December 1986).

$$[7] \quad \begin{aligned} EP &= KE CD TS^b && \text{for } U > UC \\ EP &= 0 && \text{for } U \leq UC \end{aligned} \quad \text{with } TS = (U/UC)^2 - 1$$

where KE is a constant erosion rate (mm/d) for all cells in the block, UC denotes the critical wind velocity (also 10 m above the ground) required to initiate erosion, b is an erosion exponent (typically b=1.5), TS is the transport stage parameter and CD is a factor to account for the snow depth in an EAB cell. When the snow in a particular EAB (e.g. open cropped field) cell has reached a certain level, the erosion rate is at a maximum, and so a depth correction factor is introduced.

$$[8] \quad CD = 1 - \exp[-KD (d/H)^p]$$

where KD is a coefficient, d is the total depth of snow in the cell, H is the capacity depth for the cell, and p is an exponent. For a stubble field, H would be about equal to the stubble height, whereas for a roadway ditch, H would be equal to the ditch depth. We assume further that when d=H, CD should be approximately 1. So, if d=H and CD=0.99, then KD=4.6. At present, p is set equal to unity.

Kind (1981) indicates that UC increases with snowpack density, and from the limited information that he presents it is assumed that UC is a power law function of snowpack relative bulk density, or

$$[9] \quad UC(i) = KU [BRHO(i)]^m$$

where KU and m are coefficients, BRHO(i) is the bulk relative density for layer i calculated as

$$[10] \quad BRHO(i) = TWC(i) / SDEP(i,j,k)$$

where TWC(i) = SWC(i,j,k) + LWC(i,j,k), the total water content for layer i. From the sparse data given in Kind (1981), KU=134 km/h and m=0.85.

The actual amount of erosion for layer i becomes

$$\begin{aligned}
 [11] \quad E(i) &= EP(i) && \text{for } TWC(i) > EP(i) \\
 E(i) &= TWC(i) && \text{for } TWC(i) \leq EP(i)
 \end{aligned}$$

If $TWC(1) < EP(1)$, the top layer will be completely eroded during the current time step, and hence erosion of the second layer will take place. In this case, the potential amount of snow erosion for the second layer must be reduced to account for the time required to erode the top layer first. Therefore,

$$[12] \quad EP(2) = EP(2)_0 [1 - TWC(1)/EP(1)]$$

where $EP(2)_0$ is potential erosion calculated in [7] for layer 2. The water balance for layer i is then updated as follows

$$\begin{aligned}
 [13] \quad SWC(i,j,k)_f &= SWC(i,j,k)_0 - X E(i) && X = [SWC(i,j,k)/TWC(i)]_0 \\
 LWC(i,j,k)_f &= LWC(i,j,k)_0 - (1-X) E(i)
 \end{aligned}$$

where X is the solid fraction of total water content of the layer.

To begin the deposition of snow eroded calculations, the total mass of snow eroded from cell j, QD (in mm-km²) that is now available for deposition within the block, or redistribution to edge blocks, becomes

$$[14] \quad QD = ET * AC(j,k)$$

where ET is the total amount eroded from cell j, and AC(j,k) is the cell area.

The deposition procedure outlined in Fig. 3 involves depositing a portion of QD in each cell (from j+1 to n) with capacity to store snow, checking its capacity to determine how much snow will deposit, and then subtracting the amount deposited from the eroded snow total, QD. The procedure is designed to fill all cells within the block first, before any eroded snow becomes available for redistribution in edge blocks.

To determine how much of QD will deposit in a particular cell, each cell (from j+1 to n) is checked to see if it has capacity to store snow, that is if the present snow depth, d(j,k) is less than the capacity depth, H(j,k). From this the total area, AT and the mean capacity depth, HCM, of all remaining cells with capacity to store snow can be found to compute the average amount that will potentially deposit in each cell. The potential deposition amount for each individual cell is adjusted by the ratio of the cell capacity depth, HC(j,k) and the mean capacity depth, HCM. It is assumed that while being transported, eroded snow contains only ice crystals of uniform relative density, RHOE, therefore

$$[15] \quad SWCPM = QD/AT$$

where SWCPM is the average amount of eroded snow that will potentially deposit in each cell. The potential eroded snow deposit for a particular cell is computed using

$$[16a] \quad SWCPE = SWCPM * HC(j,k)/HCM$$

$$[16b] \quad SNOWPE = SWCPE/RHOE$$

where SWCPE is the mass of eroded snow that will potentially deposit in a given cell j, SNOWPE is the potential depth of the eroded snow deposit. Field observations indicate RHOE in the range from 0.1 to 0.15. The actual amount, SWCE and depth SNODEP of eroded snow deposited in the top layer becomes

$$\begin{aligned}
 [17a] \quad SWCE &= SWCPE && \text{for } SNOWPE \leq HC(j,k) \\
 SNODEP &= SNOWPE
 \end{aligned}$$

$$\text{SWCE} = \text{RHOE} * \text{HC}(j,k)$$
 [17b]
$$\text{SNODEP} = \text{HC}(j,k)$$
 for $\text{SNOWPE} > \text{HC}(j,k)$

where $\text{HC}(j,k) = [\text{H}(j,k) - \text{d}(j,k)]$. The relative dry density and porosity of the top layer are then updated using [3] and [4] to account for the addition of eroded snow. The total amount of eroded snow, QO is then reduced by the value of SWCE multiplied by the cell area, AC(j,k).

The procedure outlined by Eqs. [15-17] is repeated with new values for AT, HCM, and SWCPM, if SNOWPE exceeds HC(j,k) for any given cell. This is done to ensure that the current eroded snow total, QO is first used to fill all cells with remaining capacity, before any eroded snow leaves the block. If any QO remains, then it is added to ME (also in mm-km²), the running total for the amount of eroded snow to be deposited in edge blocks.

Deposition of eroded snow in edge blocks

The procedure for depositing eroded snow in edge blocks (see Fig. 4) is similar to the one used for depositing eroded snow within a given block. Eqs. [15-17] are applicable, except that ME replaces QO in [15], whereas AT represents the total area of all edge block cells with an average remaining storage capacity depth equal to HCM. The procedure outlined in Fig. 4 is repeated with a reduced value of AT, as more edge block cells become filled, until ME becomes zero, which signals that redistribution is complete.

Based on field observations, it is anticipated that ditches and open field fence lines will fill-up first, with forest-field edges and large depressions able to accommodate all available residual eroded snow.

As shown Fig. 2, the program then leaves the deposition-redistribution sub-model to continue with the ablation process.

MODEL APPLICATION

TEST DATA

A 822 ha area of the Upper Grand River Watershed in the vicinity of the GRCA (Grand River Conservation Authority) Waldemar snow course was selected for initial application of the ASAAM. Snow cover distribution measurements (see Schroeter and Whiteley, 1986) for different land cover and edge blocks are available for two winters (1985-86 and 1986-87). Additional forest block data were obtained from the GRCA snow course surveys.

Daily maximum and minimum temperature, rainfall and snowfall information was obtained from climate stations in the vicinity of the study area for the period December 1 to April 15. Average daily wind speed data were obtained from the Elora Research Station (maintained by the Department of Land Resources Science, University of Guelph), the nearest location to the study area for which wind speed data were available.

In order to demonstrate the robustness of the model, previously published values were employed wherever possible as first estimates for most parameters. A list of the parameter values is given in Table 1.

SIMULATION RESULTS AND DISCUSSION

The model was applied initially for the 1985-86 winter season. Results of simulating the mean snow depth and total water content for three blocks are summarized in Figs. 5, 6 & 7 to show the overall performance of major components in ASAAM.

The forest block results (Fig. 5) served as a test of the ablation sub-models, because snow erosion is not permitted in this block. The general agreement between the observed and simulated mean snow depths and water contents suggest that the ablation sub-models are

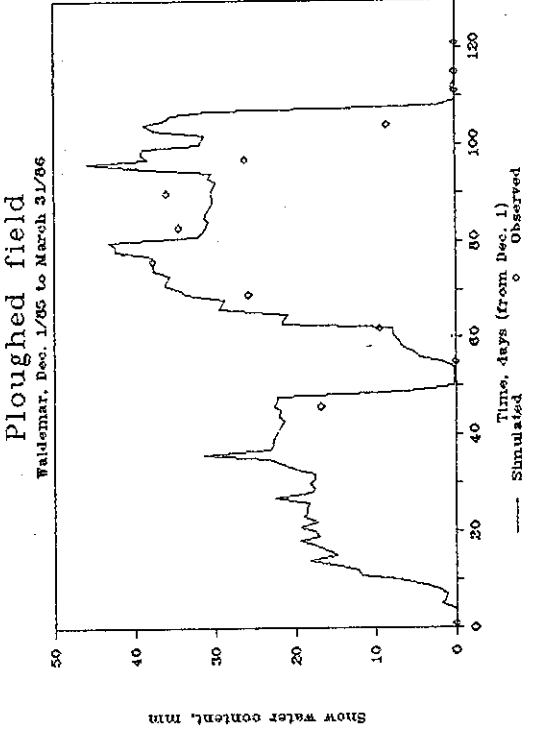
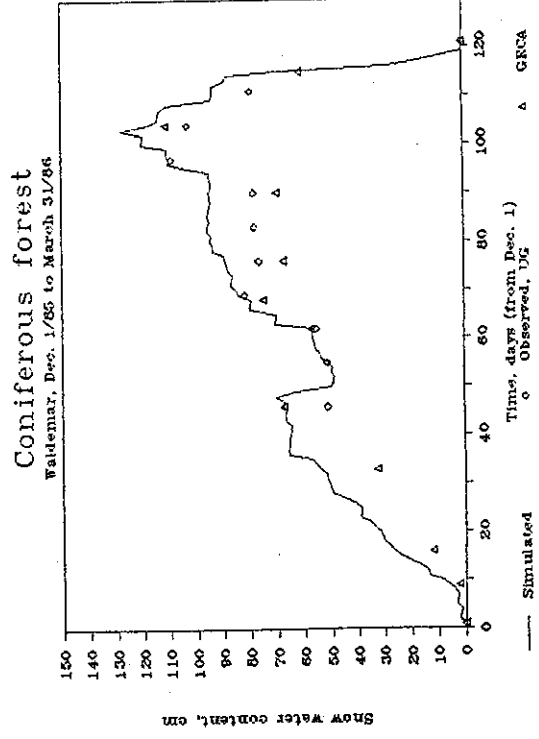
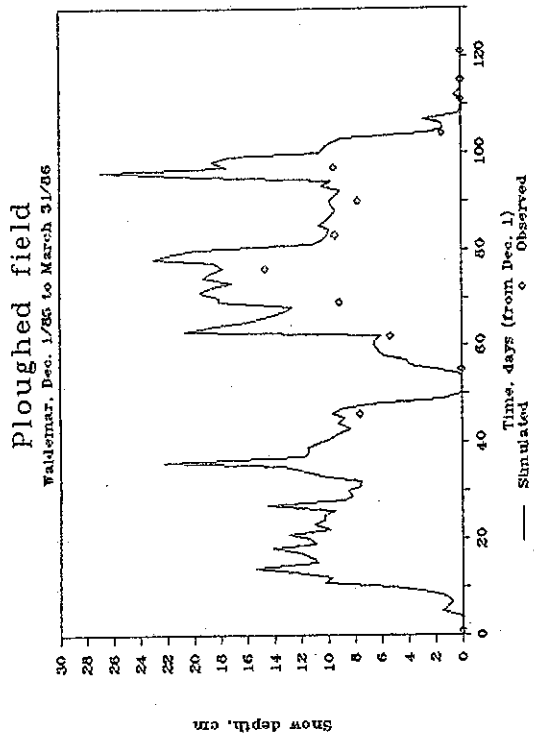
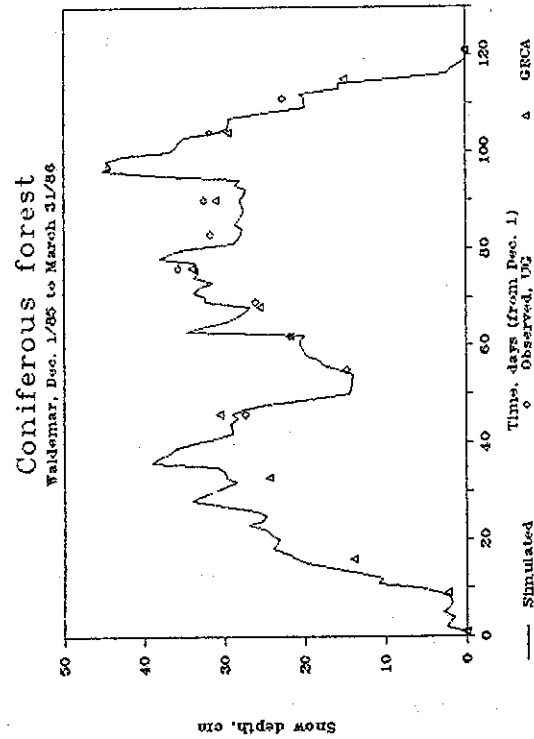
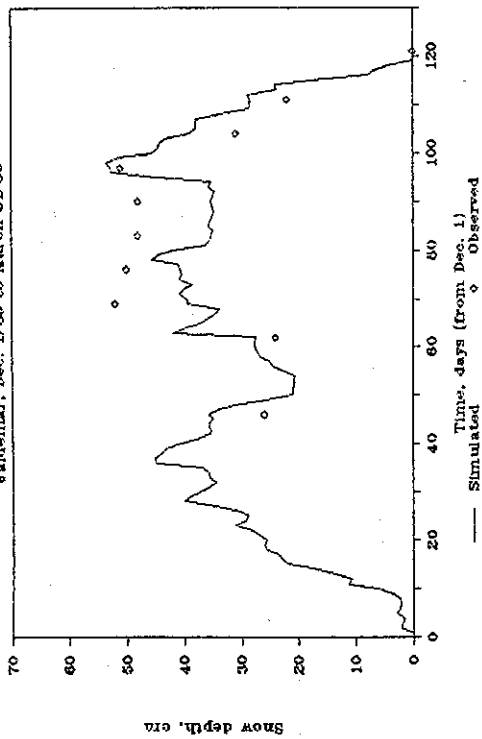


Fig. 5 Forest block model results for 1985-86

Fig. 6 Ploughed field block model results, 1985-86

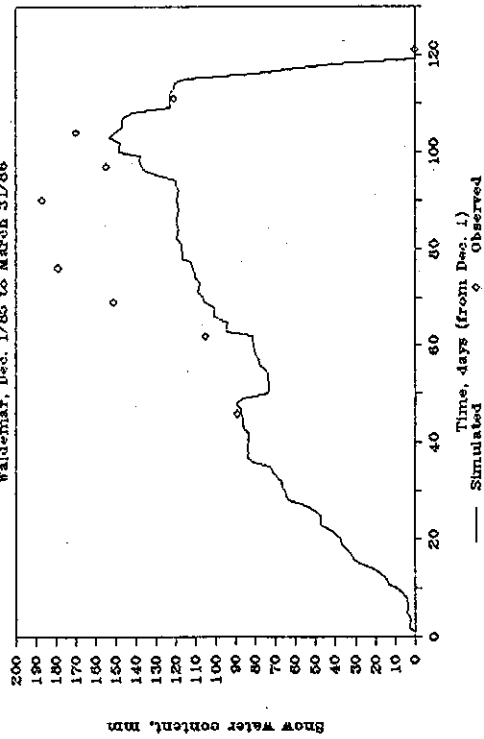
N-S roadway ditch, eastside

Waldemar, Dec. 1/85 to March 31/86



N-S roadway ditch, eastside

Waldemar, Dec. 1/85 to March 31/86



Coniferous Forest

Waldemar, Feb. 21, 1986 (Day 83)

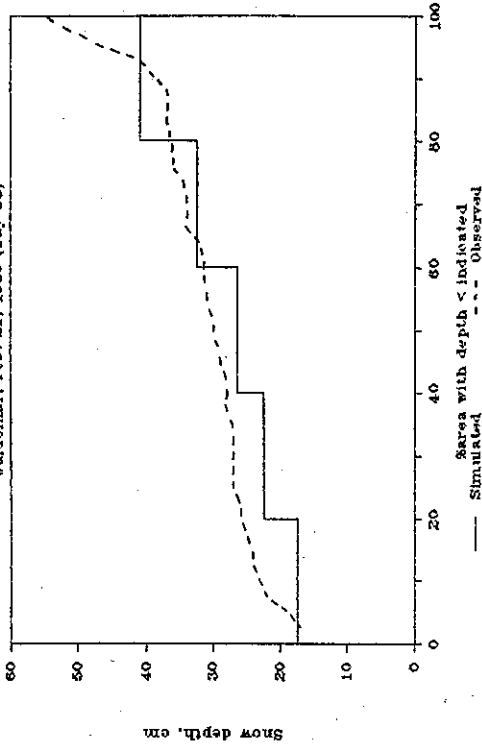


Fig. 8a Snow depth distribution in forest block
N-S Roadway Ditch, eastside

Waldemar, March 7, 1986 (Day 97)

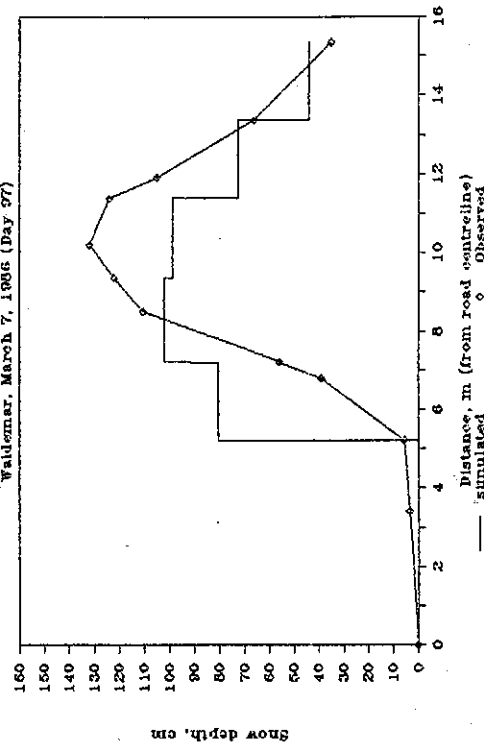


Fig. 7 Roadway ditch block model results, 1985-86

Fig. 8b Snow depth profile in ditch block

reasonably good models of the process. Furthermore, the predicted snow depth distribution for Feb. 21, 1986 (Fig. 8a) agrees closely with the observed pattern. In addition, Fig. 5 indicates that the rain and snowfall inputs were estimated correctly from climate stations in the area.

Table 1. Input parameters used in ASAAM.

| Parameter description | Symbol | Units | Block Type | | | | |
|-------------------------------|--------|-------|----------------|---------------|-------------------|-----------------|------------|
| | | | Ploughed Field | Natural Grass | Coniferous Forest | Roadway Ditches | Fence Line |
| Melt factor | KM | mm/d | 8.0 | 8.0 | 5.5 | 8.0 | 8.0 |
| Refreeze factor | KF | mm/d | 8.0 | 8.0 | 5.5 | 8.0 | 8.0 |
| Base Temperature | TBAS | °C | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sublimation rate | SUBLIM | mm/d | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| Bare ground infiltration rate | FG | mm/d | 25 | 25 | 22.5 | 30 | 27 |
| Ice layer infiltration rate | FICE | mm/d | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Lateral drainage rate | FLAT | mm/d | 20000 | 20000 | 20000 | 20000 | 20000 |
| Maximum depression storage, | DMAX | mm | 200 | 60 | 0 | 75 | 20 |
| Constant erosion rate | KE | mm/d | 25 | 25 | 0 | 25 | 25 |
| Maximum relative dry density | MRHD | | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Compaction rate constants: | A | 1/°C | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| | B | 1/d | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Wind speed reduction factor | WSRF | | 1.0 | 0.7 | 0 | 0.9 | 0.7 |
| Number of cells | | | 5 | 5 | 5 | 6 | 6 |

General: New snow rel. density NEWDEN = 0.085; Eroded snow rel. density RHDE = 0.12; Irreducible water fraction SWI = 0.07

Because the deposition of eroded snow from other blocks is not permitted in open field blocks, the ploughed field results provided a good test of the erosion sub-model. Setting, WINDF=1.5 (the effective wind speed adjustment factor) produced the surprisingly good results shown in Fig. 6, both in terms of mean snow depth and water content.

The roadway ditch (Fig. 7), being an edge block, allowed for testing of the redistribution model. Again, the model output compares favourably with the observations. Note in particular, the simulated snow depth profile for March 7, 1986 given in Fig. 8b. Some discrepancies between measured and modelled amounts are attributed to the field measurements. Snow cores were taken in the ditch centre, where in the late season the pack is wetter, and may yield and overestimate of water content. Furthermore, soft ground at the base of the pack may give an overestimate of snow depth.

ASAAM was applied next for the 1986-87 winter. Input parameters (Table 1.) were set equal to those for the 1985-86 winter, in order to test the robustness of the model. The 1986-87 season was characterized by a five week period of sustained ablation (due to bright sunny skies) with no new snow, which is surprising for southern Ontario. In addition, a late season snowfall provided an opportunity to test the erosion and redistribution sub-models for an isolated snow accumulation period, since more than 90 % of the snow cover had disappeared by then. The effective wind speed factor, WINDF was set to unity.

The predicted mean water contents for the forest block (Fig. 9) are in agreement with the measured values, which again suggests that our precipitation input estimates were reasonably correct. However, the simulated mean snow depths are generally lower than observed, which may infer that snowpack compaction rates were set too high in the model. By setting B=7, the rate of compaction is slowed, yielding higher snow depths that compare favourably with the field observations. A comparison of simulated and observed snow depth distribution for April 1, 1987 is given in Fig. 11.

The ploughed field block simulations (Fig. 10) are not at all satisfactory, because the erosion amounts were greatly overestimated, which yielded an early time of snow cover disappearance. Nevertheless, the late season accumulation period was modelled with surprising accuracy. A review of the wind records revealed that the prevailing wind direction

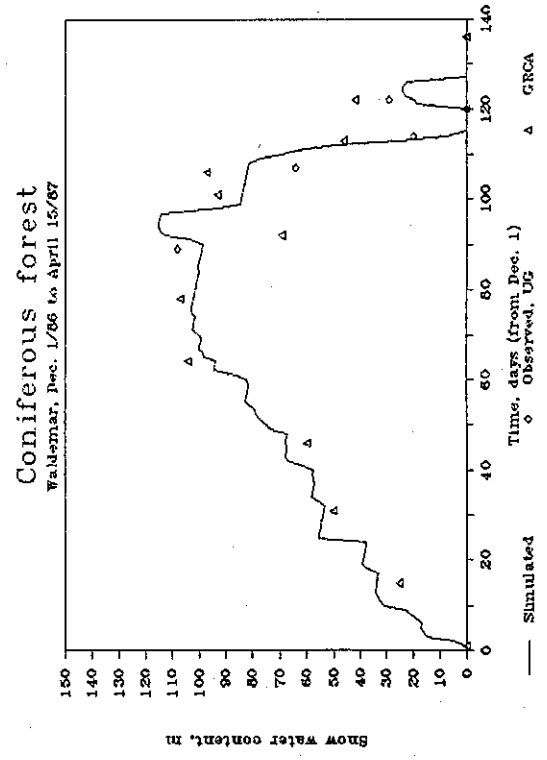
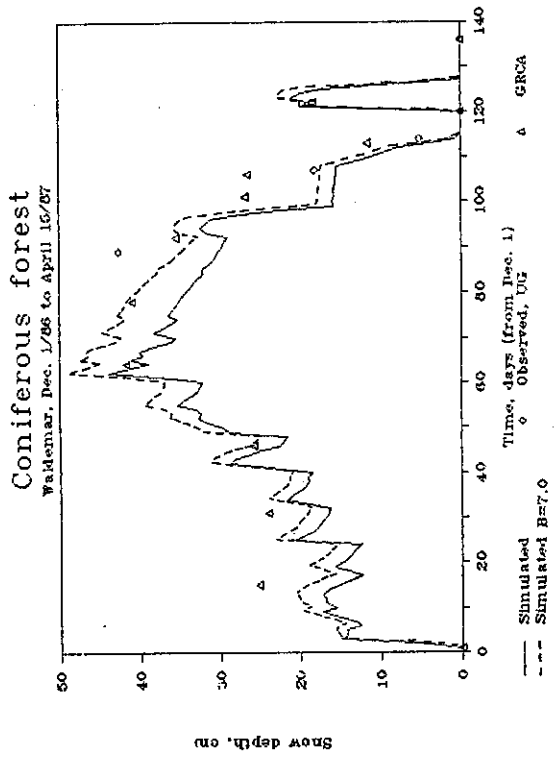


Fig. 9 Forest block model results for 1986-87

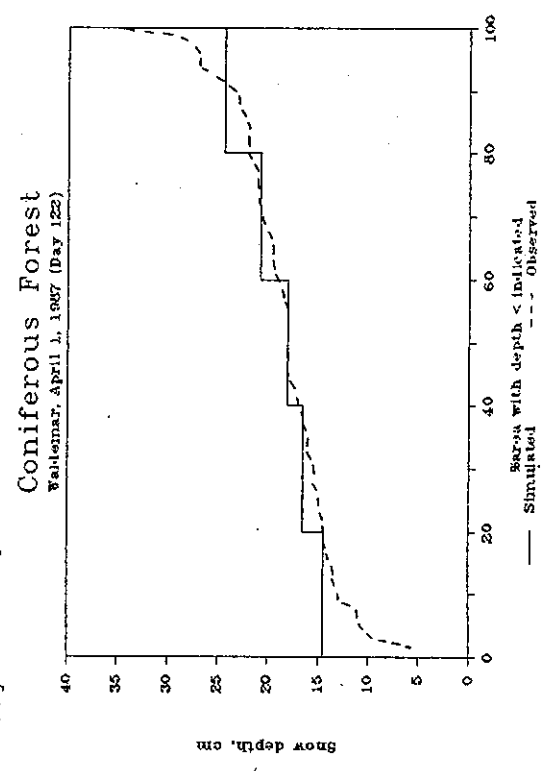
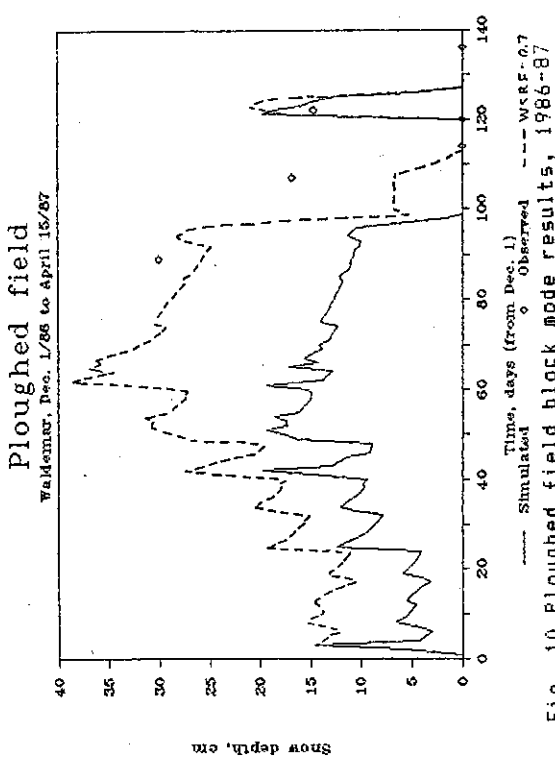


Fig. 11 Snow depth distribution in forest block

for this late season storm was more characteristic of the 1985-86 winter (from the northwest). Moreover, our field observations suggest that this particular ploughed field is sheltered somewhat from the east. Consequently, by setting WSRF=0.7 to account for some of the sheltering effect, more snow deposits in the block, and hence the simulated depths more closely agree with the observed values.

The next improvement to the ASAAM program will be to account for block orientation and prevailing wind direction.

CONCLUSIONS

ASAAM, the areal snow accumulation-ablation model, a relatively simple model with few parameters, shows good prospects for providing accurate operational estimates of the spatial distribution of snow cover. Input requirements for this model are limited; they include daily meteorological information (maximum and minimum temperature, rainfall and snowfall, and mean wind speed), the areal portion of land cover units (e.g. forests, open fields) and edges (e.g. ditches, fence lines) within a watershed, twelve ablation and seven erosion/deposition parameters. Encouraging results have been obtained from initial application of the ASAAM for two winters in the Upper Grand River Valley of southwestern Ontario.

ACKNOWLEDGMENTS

Financial assistance for this research was provided by the Natural Sciences and Engineering Research Council of Canada. The authors are grateful to the Grand River Conservation Authority, Cambridge, Ontario for supplying snow course data and climate information.

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