SNOWPACK MODELLING
USING DAILY CLIMATOLOGICAL DATA

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ABSTRACT

In many regions of Canada snowfall and subsequent snowmelt are the major contributors of water supply used in the generation of hydro electric power, irrigation systems, reservoirs and numerous industries.

Information on the existing snowpack is therefore widely desired in order to plan the efficient use of the water supply and forecast water surpluses or deficiencies resulting from the snowpack melt or runoff.

This paper describes a method of building and depleting a synthetic daily snowpack at a given point, using a computer program which requires only daily climatological data.

The program produces daily snowpack values for five different melt models which are compared with measured values from snow courses and a monitored snowmelt study.

INTRODUCTION

Water runoff from snowmelt is a major contributor to the fresh water supply in many parts of Canada.

A great deal of time and expense are spent each year in obtaining measurements of the snow pack so that accurate estimates of the spring runoff may be made.

Normally, snowpack data are obtained from snow courses which are measured weekly, bi-monthly or monthly. The snow course data taken by the Atmospheric environment Service are published annually but may not be readily available immediately after the measurements are taken. Some data may be obtained from 'snowpillows' which are connected to remote processing units and transmit data on a daily or selected time basis. However, these installations are few in number and are mostly located in western Canada and the USA (Ferner and Wigham, 1985).

The melting of a snowpack is difficult to estimate due to the variability of exposure to sunlight and elevation differences. Meteorological conditions which create snowmelt are also highly variable and may change from site to site (Louie and Hogg, 1980).

This paper describes a method of building and depleting a daily snowpack at a given point, using a computer program which requires only daily climatological data as input. These data are available for the complete period of record for more than 2500 stations across Canada and may be obtained from the Atmospheric Environment Service, Environment Canada.

Data

Daily climatological data are stored in the AES digital archive by station, year, month and element. The element number designates the weather parameter observed. The elements used as input to the snowmelt program are:

Number	Element	Resolution
001	Maximum Temperature	0.1 C.
002	Minimum Temperature.	0.1 C
003	Mean Temperature	0.1 C.
010	Total Rain	0.1 mm
011	Total Snow	0.1 cm

In order to validate the output of the snowmelt program, data from snow courses and a measured melt plot were also used.

Method

The five snowmelt models selected, were developed and tested in various regions but were not explicitly designed for any one geographic locality of Canada. For this reason, the output from several models were examined at each of the selected sites. The five snowmelt models are shown in table #1.

The algorithms are based upon synthetic snowpacks which are accumulated according to the daily snowfall measurements and depleted according to the snowmelt as determined by each of the snowmelt models. The algorithms cease operating when the synthetic snowpack is reduced to zero.

Attempts to calibrate the models with snow course data have not proven very successful. The major problem being that the locations of the climatological station and the snow course differ. The snowmelt models calculate the snowpack at the point where the daily meteorological parameters are observed while the snow course data are the averages of five or ten measurements. These are normally samples from both forested and open terrain so it is unlikely to find a climatological station and snow course at a similar observing site.

Data from a controlled snowmelt plot were used to assess the snowmelt models for the winter of 1987-1988 at Dorset, Ontario. The daily melt was obtained by measuring and recording the actual runoff from a controlled snow plot (Goodison and Metcalfe, 1986). The measured melt was subtracted from the daily accumulated precipitation total of rain and snow as measured by a recording precipitation gauge. The result was used to calculate the actual daily snowpack water equivalent. This value was then compared with the snowpack estimated by models # 1,4, and 5 (Figure # 1).

The majority of days in the November to April period were accumulating the snowpack. With the accumulation values bearing a close relationships to the measured values, it is not surprising to find correlation coefficients ranging from 0.98 to 1.00 for all models. However, when only days with actual snow melt are considered, in either the model's dataset or the measured melt dataset, the correlation coefficient drops to a range of 0.76 to 0.90 as seen in the table below.

Correlation Coefficients of Measured Daily Melt versus Model Daily Melt
Dorset, Ontario, November 1987 - April, 1988

	Nov - April (156 days)	Melt Days only
Model # 1	0.99	0.84
Model # 2	1.00	0.89
Model # 3	1.00	0.90
Model # 4	0.98	0.76
Model # 5	1.00	0.90

Figure #2 shows the comparison of snowmelt models # 2,3 and 5 with snow course data for the winter of 1984 - 1985 at Fort Vermillion, Alberta. The snow course measurements were taken three times each month from December to April, thus providing a fairly representative sampling of the snow pack water equivalent. The snow course measurements averaged 25 mm higher than any of the Models throughout the measuring period. The melt periods were consistent in both the snow course data and the Model data except for two occasion. On one, the snow course data was reduced by 25 mm while the synthetic snowpack data increased by 15 mm. The second event increased the snow course data by 20 mm while the snowpack data was reduced by 50 mm. The models reduced the snowpack to zero at approximately the same time as the snow course.

Figure #3 compares the data from Models # 1,4 and 5 and the snow course measurements for the winter 1984 - 1985 for Mount Carlton, N.B. The snow course data was measured three times per month from December to April. The data from the three models compared very well with the snow course measurements until January. At that point, the snow course indicated very little increase until late February while the Models increased 35 mm or more over the same period. As the melt season progresses, the snow course data sustain higher values than the Models,until the snowpack reduces to zero.

CONCLUSION

The process of calibrating or validating any of the five snowmelt models selected, will be extremely difficult if not impossible without a daily dataset of measured smowmelt values. Using such a dataset, of course, only calibrates the models for that one location, therefore to make the calibrations at least 'regional', datasets from several stations should be considered.

The program to build and deplete an annual snowpack may become a useful aid in determining snowpack water equivalent depth and melt rate. The comparison of the various Models to a measured snowmelt for the winter 1987-1988 did show that Models #3 and #5 have the highest correlation coefficient for a melt plot in Central Ontario. Whether the same results will be obtained on other datasets for another time period is only speculation at this time. Measured melt data must first be collected from additional sites and these high correlation coefficients confirmed before these models are considered creditable.

REFERENCES

Ferner, S.J. and J.M. Wigham, 1985: The Use Of Snow Pillow Data For Melt Rate Input To The SSARR Watershed Model. CDN. Soc. for Civil Eng., Annual Conf. 1985, pp 191 - 202.

Goodison, B.E., P.T.Y. Louie and J.R. Metcalfe, 1986: Investigations of Snowmelt Acidic Shock Potential in South Central Ontario, Canada. Modelling Snowmelt - Induced Processes, IAHS Publ. NO. 155, 1986, pp. 297 - 310.

Louie, P.Y.T. and W.D. Hogg, 1980. Extreme Value Estimates of Snowmelt Proc. Cdn. Hydrol. Symp.: 1980. pp 64-78. NRC Ottawa, Ontario.

TABLE # 1

Model 1 - developed for: Eastern Canada Forested Basin
SM1 = 0.0397 (Ta - 27.6) (inches/day)
Ta = mean daily air temperatures F
Ref: Pysklywec, D.W., K.S. Davar and D.I. Bray (1968): Snowmelt at an Index Plot, Water Resour. Res., 4(5), 937-946.
Model 2 - developed for: Western North America Mountain Basin
SM2 = (0.074 + 0.007 R) (Ta - 32) + 0.05(in./day)
R = daily rainfall in inches
Ta = mean daily air temperature F
Ref: United States Army Corps of Engineers (1956): Snow Hydrology, North Pacific Division, Portland, Oregon
Model 3 - developed for: Western Canada Mountain Basin
SM3 = 3.0 (Ta + TCA) (((Tx - TN)/8) + TN) (mm/day)
Ta = mean daily air temperatures C
Tx = maximum daily temperature C
TN = minimum daily temperature C
TCA = (TN/4.4) but MUST be in the range of 0 to 1.5
Ref: Quick, M.C. and A. Pipes (1975): The UBC Watershed Model, Proceedings of Symposium in Bratislava, Application of Mathematical Models in Hydrology and Water Resource Systems, IAHS Pub. No. 115
Model 4 - developed for: Southern Ontario
SM4 = 0.02 (Tx - 32) (inches/day)
Tx = maximum daily air temperature F
Ref: Bruce, J.P. and R.H. Clark (1966): Introduction to Hydrometeorology, p. 257, Pergamon Press, Toronto
Model 5 - Modification of Model 4
SM5 = 0.08 (Ta - 32) (inches/day)
Ta = mean daily air temperature F

CALCULATED DAILY SNOW PACK - MODELS 1,4,5

DORSET MOE ONT. - DAILY SNOW PACK (1987 - 1988)

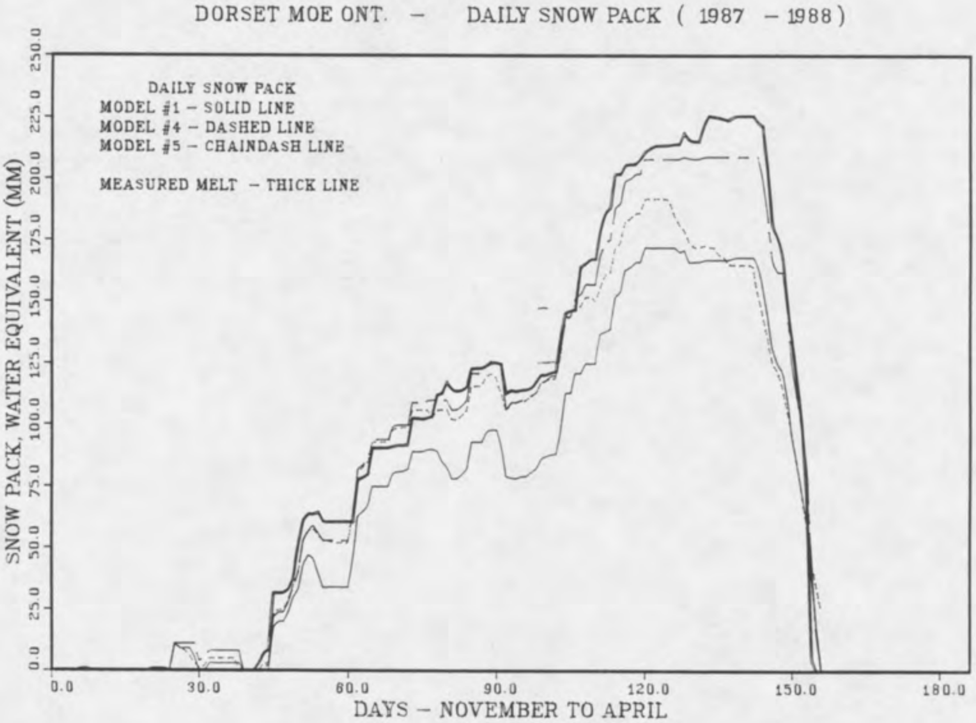

Figure 1

CALCULATED DAILY SNOW PACK - MODELS 2,3,5

FORT VERMILLION ALTA.– DAILY SNOW PACK (1984 – 1985)

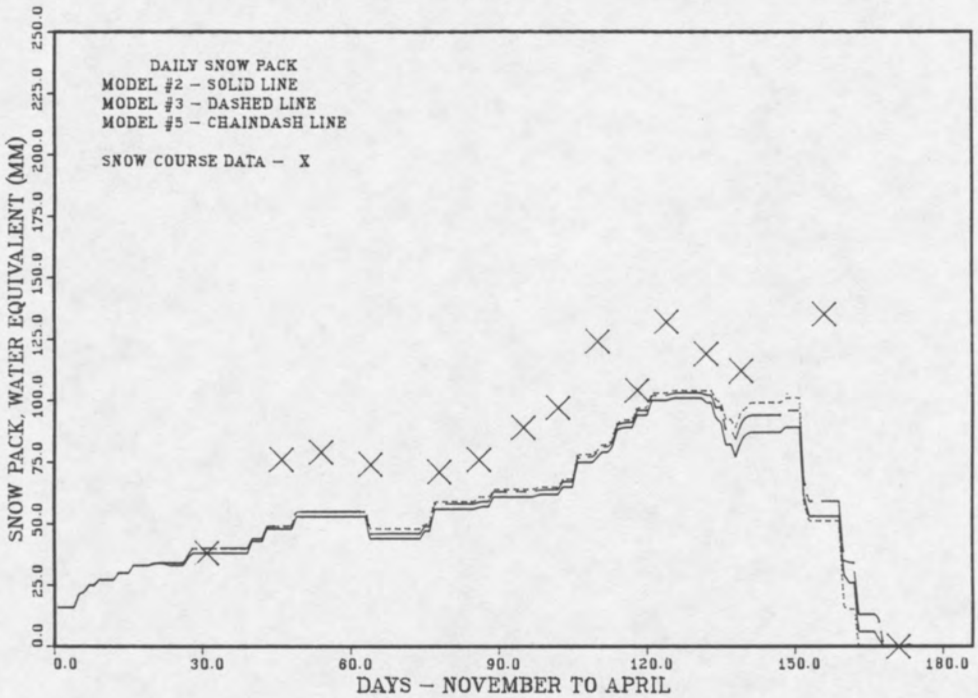

Figure 2

CALCULATED DAILY SNOW PACK - MODELS 1,4,5

MOUNT CARLTON N.B.– DAILY SNOW PACK (1984 – 1985)

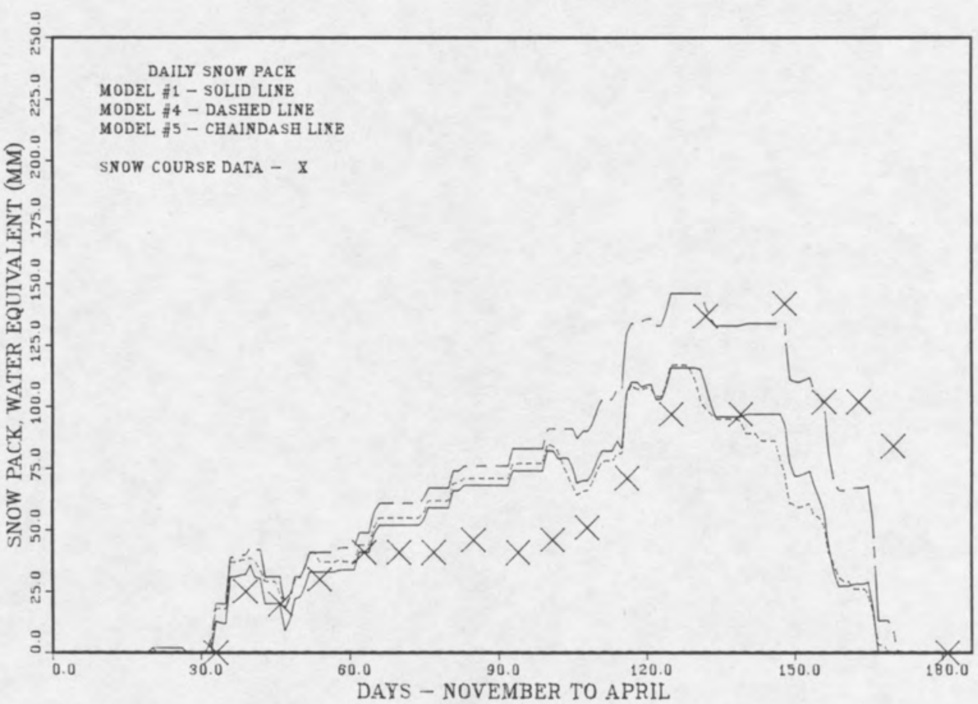

Figure 3