OPERATIONAL USE OF SNOW ACCUMULATION AND ABLATION MODEL IN THE UNITED STATES

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OPERATIONAL MODEL

The snow accumulation and abalation model described by Anderson (1973) is the snowmelt model currently used in the U.S. National Weather Service River Forecast System (NWSRFS) (Curtis and Smith 1976). The basic models in the NWSRFS are the snow model plus soil moisture accounting and channel system models. The NWSRFS is being implemented by the River Forecast Centers (RFC's) of the National Weather Service. The NWSRFS models have been calibrated for many basins in the U.S. Calibration is continuing with a goal of having the entire country calibrated within 10 years. The operational portion of NWSRFS is now being implemented by the RFC's.

The Hydrologic Research Laboratory (HRL) of the Office of Hydrology (O/H) has calibrated the NWSRFS models for river basins in most major snow areas of the United States in order to verify the general applicability of the models. These areas include:

1. Several basins in New Hampshire and Vermont
2. St. Johns River Basin in Maine and portions of Canada
3. Upper Ohio River Basin
4. Drainage to Lake Erie
5. Upper Midwest (northern Iowa and Minnesota)
6. Upper Colorado River Basin in Colorado
7. Sierra Nevada and northern Rocky Mountains
8. Chena River Basin in Alaska

Model performance in all of these areas has been generally quite satisfactory. The snow model has been able to provide reasonable estimates of accumulation and snowmelt in all of these basins.

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CALIBRATION OF THE SNOW MODEL

In general, the snow model parameters have been found to be related to climatic and physiographic characteristics and reasonable initial parameter values can be obtained from a knowledge of typical conditions over the watershed. The selection of initial parameters for the snowmelt model is only one step in the calibration process, but, as with any conceptual or physically based model, it is a very important one if the model is to be used conceptually rather than as a black box.

Since the publication of the model in 1973, additional experience has been gained in calibrating the model, especially in deriving initial parameter values. A loose-leaf user's manual is maintained for in-house use for the complete NWSRFS. Part IV.2.2.1 of the user's manual was recently completed and contains up-to-date guidance on obtaining initial parameter values for the snow accumulation and ablation model. For the benefit of those who may apply the model, this section has been reproduced as an appendix to this report. References to the soil moisture accounting model refer to the Sacramento model (Burnash et al. 1973), which is currently used in the NWSRFS. A description of the soil moisture accounting model and techniques for initial parameter estimation for that model are contained in another report from O/H (Peck 1976).

DEFICIENCIES OF MODEL

Although the snow model has given generally satisfactory results, certain deficiencies do exist. Most of these deficiencies were anticipated when the model was first developed.

In mountainous areas, errors occur during the accumulation season and subsequently result in runoff volume errors when there is insufficient precipitation data at the higher elevations. Also, there is a problem in classifying precipitation as to rain or snow based solely on maximum-minimum temperature data. This is mainly a problem in basins where both rain and snow frequently occur during the same event. These are both deficiencies in data and not in the structure of the model.

Air temperature is generally a good index to snowmelt. However, under certain conditions, listed below, the use of air temperature as the sole index to snowmelt has proven to be inadequate:

a. Under really clear skies with abnormally cold temperatures, the index does not indicate enough melt.

b. Under very warm temperatures with little or no wind, the index overpredicts. In this case, the turbulent exchange is much less than normal.

c. With high dew points and high winds, the model will underpredict. This condition results in much more latent heat (condensation) transfer and also more sensible heat transfer than normal.

The model has not been tested where extreme redistribution of snow occurs. The only other major problem has been in cases with frozen ground. This is due to a deficiency in the soil moisture accounting model and not in the snowmelt model. None of the known soil moisture models are able to handle this problem adequately. Application of the model to areas with frozen ground has resulted in poor simulations during the years when frozen ground was present. The severity of the problem has varied. In one basin (Rock River near Rock Rapids, Iowa), where infiltration rates are very low even without frozen ground, the effects of frozen ground were less severe than for two basins in Minnesota (Elk and Root), where infiltration rates are generally higher. In Alaska, where frozen soil conditions are similar from year to year, no effect of frozen ground on model results could be detected.

FUTURE PLANS

The future direction for improvement in the operational snowmelt model for the NWSRFS is to:

1. Create an areal energy balance snow cover model. This would be done by using the point energy balance model (Anderson 1976) as the basis for the areal model. The equations used in the point model will be simplified and the number of layers that the snow cover is divided into will be reduced. This will greatly increase computational efficiency without seriously reducing accuracy. Algorithms will be added to account for the effect of vegetation, slope, and aspect on radiation so that the model can be applied to forested as well as open areas.

2. Modify the temperature index model so that energy exchange at the snow surface would still be computed using the current equations but the heat transfer and water movement within the snow cover would be more similar to the energy balance model. This would result in estimates of depth, density, and heat flow through the snow cover that are not computed in the current model.

Plans would allow the option of using either the modified temperature index model or the areal energy balance model as conditions and basic data warrant.

CONCLUSIONS

Both the temperature index and energy balance models should be of value for operational use. For heavily forested areas and for areas with little climatic variability during the melt season, the energy balance model does not seem to be needed. There would also be areas where economics would not warrant the additional data cost needed for the energy balance model. There will be a need to identify those areas based on climatic and economical considerations where we would want to apply an energy balance model. We would have to relate quality of data with potential benefits.

A big advantage of a reliable conceptual model is that we can make statements about intermediate state variables or can use the state variables to update the model. For example, snow course data could be used during the accumulation season to update computed water equivalent values and thus correct for errors resulting from insufficient precipitation data in mountainous areas.

Another advantage of a reliable model is the opportunity to use the results in conjunction with measurements obtained by remote sensing. Both the model simulation and the remote sensing data should contain qnformation. Snow course data may be good for updating the snow model during accumulation but not during snowmelt. Remote sensing may provide more information during snowmelt on such variables as areal extent of snow cover and albedo. The main point is that more information on basin snow accumulation and ablation can be obtained by using models and various measurements in concert than can be obtained by using either separately.

For northern research basin studies, the energy balance model allows us to test our understanding of what is taking place. The computed state of the snow cover can be checked against many observable quantities. This permits us to thoroughly evaluate the model and make changes to the proper components when necessary. However, it should be noted that such verification studies require very high quality data. As we improve our understanding of the snow accumulation and ablation process, we should be better able to create improved operational models and use these models more intelligently.

REFERENCES

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APPENDIX

DRAFT

IV.2.2.1 INITIAL PARAMETER VALUES FOR THE SNOW ACCUMULATION AND ABLATION MODEL

by Eric Anderson

Introduction

This section presents guidelines for determining initial parameter values for the snow accumulation and ablation model. The section is divided into two main parts. The first part discusses the relationship between each snow model parameter and various climatic and physiographic factors which affect snow accumulation and ablation. The second part discusses how water-equivalent data, obtained from a snow course or some other type of point measurement, can be used to get initial estimates of the snow model parameters for an area. It is assumed that the user is familiar with the NWSRFS snow model described in chapter II.2.

Guidelines for Determining Initial Values of Snow Model Parameters from Climatic and Physiographic Factors

Introduction

Information about appropriate initial values of many of the soil-moisture accounting model parameters can be obtained from an analysis of the daily discharge hydrograph. However, the hydrograph is not very helpful when one is trying to determine initial estimates of the values of the snow model parameters. The snow model parameters are mainly related to various climatic and physiographic factors which affect snow accumulation and ablation. Thus, the user needs information on typical meteorological and snow cover conditions, as well as the physiographic characteristics of the area. This subsection discusses what is known about the relationship between climatic and physiographic factors and the value of each of the snow model parameters. From this discussion and a knowledge of the area, the user should be able to determine reasonable initial values for the snow model parameters.

Major Parameters

As discussed in section II.2.7, these are the parameters which typically have the greatest effect on the simulation results. Since most of the effort during the calibration of the snow model will likely be devoted to determining the proper value of these parameters, it is important to start with reasonable values for each of these parameters.

Table 1 can also be used to get initial estimates of MFMAX and MFMIN at a point. However, even though the point itself might be classified as open, the surroundings should be taken into account. A snow course in a small forest clearing may act similar to a mixed forest, whereas a snow course in a larger opening should be approaching the conditions at a truly open site.

3. UADJ - The wind function which was found to give the best results at the NOAA-ARS Snow Research Station [Anderson (1976)] can be used to obtain an initial estimate of UADJ. This wind function can be expressed as:

$$f(u_1) = 0.002 \cdot u_1 \qquad (1)$$

where:

$f(u_1)$ = average wind function using measurements taken 1 m above the snow furface ($mm \cdot mb^{-1}$) and

u_1 = wind movement at a height of 1 m (km).

Thus, the initial estimate of UADJ would be 0.002 multiplied by the average wind movement in kilometers for 6 hours at a height of one meter above the snow surface during a rain-on-snow event. For example, if the average one meter wind speed during rain-on-snow events is estimated to be 6 $km \cdot hr^{-1}$, then the 6 hour wind movement is 36 km and the estimate of UADJ is 0.072 $mm \cdot mb^{-1}$. In most cases values of UADJ range between about 0.03 and 0.19 $mm \cdot mb^{-1}$, corresponding to one meter wind speeds of about 2.5 to 16 $km \cdot hr^{-1}$ (1.5 to 10 mph). The lower values of UADJ are commonly associated with heavily forested watersheds, while the higher values usually occur in generally open areas. However, there are many exceptions, thus it is best to base the initial estimate of UADJ on a knowledge of typical wind speeds during rain-on-snow events at the particular location being modeled.

4. SI and the areal depletion curve - The parameter SI and the areal depletion curve are related, therefore initial estimates of both can be made at the same time. If a lot of data on both the mean water-equivalent of the snow cover and its areal extent were available, SI and the areal depletion curve could be determined by plotting mean areal water-equivalent versus the areal extent of the snow cover for a number of years. Such an analysis would require a sufficient number of snow courses to represent snow cover conditions over the entire watershed. Photographs documenting the percent snow cover would also be helpful. Such data are rarely available in the United States.

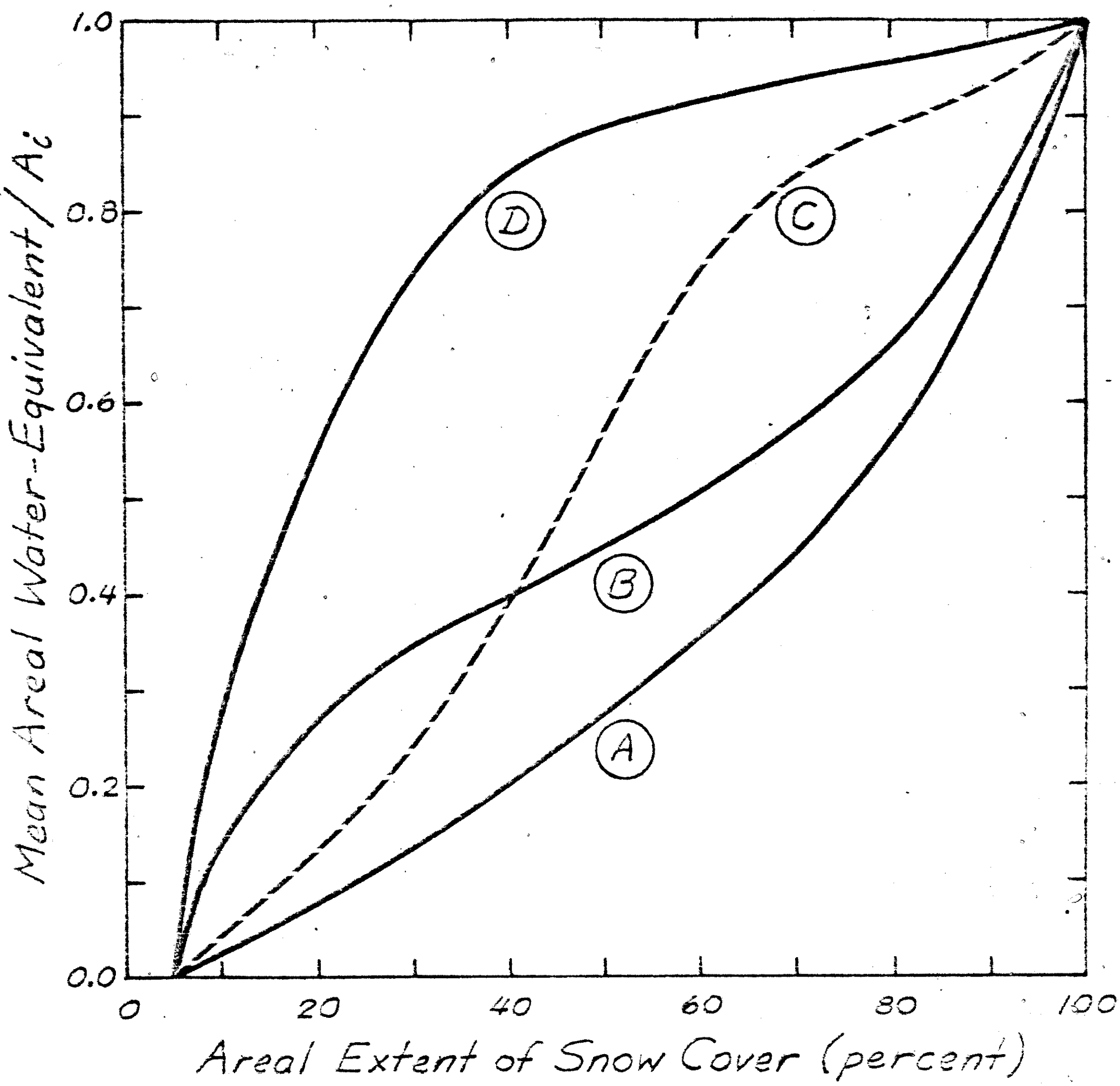

Figure 1. Characteristic shapes of snow cover areal depletion curves.

1. NMF and TIPM - These two parameters are partially interrelated. Thus, the value of each parameter is somewhat dependent on the value assigned to the other. The most logical way of selecting initial values seems to be to assign a value to TIPM first and then select an appropriate estimate for the maximum negative melt factor, NMF. If any adjustments are required during calibration, NMF should be adjusted while TIPM should remain fixed. The procedure used in the model to compute energy exchange during non-melt periods is somewhat empirical, plus it is a steady state approximation to a process where steady state conditions seldom occur. Thus, the parameters cannot be computed directly from experimentally measured heat transfer coefficients for snow.

Energy exchange during non-melt periods is assumed to be proportional to the temperature gradient defined by the snow surface temperature (approximated by the air temperature) and a temperature at some depth below the surface. The temperature of the snow at some depth below the surface is approximated by an antecedent temperature index, ATI. The parameter TIPM is used in the computation of ATI. A value of TIPM above 0.5 essentially gives weight only to air temperatures during the past few 6-hour periods in the computation of ATI. A value of TIPM below 0.2 gives weight to temperatures over the past 3 to 7 days. Thus, an ATI computed using a high value of TIPM would correspond to a snow temperature closer to the surface than an ATI based on a low value of TIPM. It seems logical to expect that heat transfer within a deep snow cover would be controlled by a temperature further below the surface than in the case of a shallow cover because of the increased depth and heat storage capacity. Thus, it would be expected that a smaller value of TIPM should be used for areas with typically deep snow covers than for areas which generally have a shallow snow cover. This has been confirmed by calibration results. It is recommended that a value of TIPM of 0.5 or greater be used in areas which typically have a relatively shallow snow cover like most of the upper Midwest portion of the United States. For areas which generally have a deep snow cover, a value of TIPM in the range of 0.1 to 0.2 would be appropriate. A value of TIPM between 0.2 and 0.5 would be reasonable in areas which usually have a moderate amount of snow like much of northern New England.

The steady state equation for heat transfer in a homogeneous snow cover can be expressed as:

Table 2. Computed negative melt factors for various values of snow density and Δz (values are in $mm \cdot {}^{\circ}C^{-1} \cdot 6\ hr^{-1}$)

density \ Δz	10 cm	20 cm	30 cm
0.3	.16	.08	.05
0.4	.27	.14	.09
0.5	.42	.21	.14

2. MBASE - A melt base temperature of 0°C has proven to be completely adequate in the vast majority of watersheds. An initial value of MBASE other than 0°C could be justified in the case of a heavily conifer-forested area. Since most climatological stations are located at relatively open sites, the measured daytime temperature is generally warmer than the temperature beneath a dense forest canopy. The use of a value for MBASE of 0.5 to 1°C is one way to compensate for this difference. Another way that is probably more realistic, is to adjust the temperature data to reflected conditions under the forest canopy. This can be accomplished by using an artificial elevation difference and lapse rates which increase temperatures slightly at night and reduce temperatures to a greater extent during the day with a net effect of lowering the temperature by about 0.5 to 1°C.

3. PXTEMP - Various studies have shown that the temperature at which precipitation is equally likely to be rain or snow typically is in the range of 0 to 2°C. Thus, a good default value for PXTEMP is 1°C. In some cases the fixed diurnal variation in temperature used in the MAT procedure causes the MAT values to be in error during periods of changing weather. Precipitation is often associated with such periods. In most areas these errors in MAT values cause random errors in the form of precipitation and cannot be corrected by adjusting PXTEMP. However, in some areas PXTEMP can be altered to compensate for errors in MAT values caused by using a fixed diurnal temperature pattern. For example, in the sub-alpine and alpine regions of Colorado, precipitation almost always occurs as snow even when the maximum temperature is as high as 4 to 7°C.

the snow model at a point (see section IV.4.3). Point water-equivalent measurements are available at selected climatological data stations and at snow courses (see sections III and III). A snow course is usually thought of as a point even though it actually consists of a number of points. This sub-section discusses recommended steps to follow when calibrating the snow model at a point. Also discussed is how and when to use parameter values from a point as initial estimates for the surrounding area.

Steps in the Calibration of the Snow Model at a Point

The three main steps in the calibration of the snow model at a point are data processing, selection of initial parameter values, and parameter optimization.

1. Data Processing - Three time series are required to calibrate the snow model at a point, MAP, MAT, and observed daily water-equivalent. In some cases precipitation and temperature time series are determined for the specific point. However, in most cases MAP and MAT time series for the surrounding area are adequate. The difference in precipitation between the point and the area can be accounted for by means of the precipitation adjustment factor, PXADJ. The difference in temperature is corrected by means of the elevation difference and the specified lapse rates. Recommendations on computing MAP and MAT are given in sections IV.1.2.1 and IV.1.2.2, respectively.

   Observed daily water-equivalent data are transferred from tape to the NWSRFS calibration disk files by means of Program DOBPP for climatological data (section III.4.2) and Program SCDPP for snow course data (section III). Water-equivalent data from some climatological data stations are of questionable quality, thus these data should be carefully examined before being used.

2. Selection of initial parameter values - A previous sub-section in this chapter (page IV.2.2.1-1) contains guidelines for selecting initial parameter values for the snow model. The final parameter values at nearby snow courses, which have previously been calibrated, should also be of help. Differences in physiographic conditions should be considered when using parameter values from other snow courses.

to determine which parameters to adjust or the magnitude of the adjustment. If daily observations of water-equivalent are available, it is somewhat easier to determine which parameters should be adjusted. In the case of snow courses, which usually have only one or two readings per month, the parameter adjustment process should be concentrated almost completely on the major snow model parameters. The most important parameters during the melt season are the melt factors, especially MFMAX. The elevation of the MAT time series, TAELEV, can also be important though it is not often thought of as a parameter. Adjustments in TAELEV attempt to correct for errors in the computation of MAT and for local factors affecting temperature at the snow course site. The average wind function during rain-on-snow periods, UADJ, is difficult to determine for a snow course site unless there are a lot of rain-on-snow events. The parameter SI and the areal depletion curve are of minor importance at a snow course site unless there is a considerable variation in snow cover or melt rates between the sampling points. If some points are bare of snow well before others, this should be evident in the simulation results during the latter portion of the melt season.

As mentioned previously, adequate point parameter values for the snow model can be determined for most areas solely by trial-and-error calibration. The automatic optimization method (see chapter II.8) used in Program SNOW needs good starting values to be successful. Also, only parameters which have a significant effect on the criterion value should be included. By the time the user is ready to properly use the automatic optimization procedure on the snow model at a point, the parameter values are generally already close to optimum. In some cases there is still uncertainty about the value of 2 or 3 parameters. In these cases it may save the user some time to use the automatic optimization option in Program SNOW rather than make further trial-and-error runs.

There is one other feature of Program SNOW which may be useful during calibration. This is the update feature. When the update option is turned on, the computed water-equivalent is reset to the observed value whenever the difference between the two values exceeds a specified tolerance. Experience has shown that the tolerance should not be too small, so as to avoid an excessive number of updates. A tolerance of 25 to 50 mm is reasonable. The update feature is especially useful at points where the year-to-year variation in SCF is significant. Updating at such points assures that the computed water-equivalent is reasonably close to the observed value prior to each melt season. The use of the update feature in conjunction with the automatic optimization option is not recommended. The number of updates changes as the parameter values change. This can cause the criterion to increase even though the change in the value of a parameter is in the right direction, thus preventing the parameters from attaining optimum values.

similar climatic and physiographic characteristics throughout, the value of further calibrations is minimal.

Reference

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