UPDATING SEASONAL SNOWMELT ESTIMATES USING SNOWCOURSE MEASUREMENTS

by

Hamed Assaf[1], Athanasios Loukas and Michael C. Quick[2]

ABSTRACT

In mountainous watersheds, like those of British Columbia and northern Pakistan, rivers are mainly fed by snowmelt from winter-accumulated snowpack and glaciers. For a safe and optimal operation of reservoirs fed by these watersheds, it is therefore important to obtain reliable estimates of the volume and time distribution of seasonal snowmelt.

An iterative procedure has been developed to utilize snowcourse measurements to update estimates of snowfall contribution to the watershed. Consequently snowpack volume available for melting is modified and seasonal forecasts are adjusted accordingly.

The updating scheme has been applied to the snowpack measured at Mount Fidelity in the Upper Columbia River Basin in British Columbia. The results showed great improvements in streamflow forecasts, particularly during the critical melting season.

INTRODUCTION

In mountainous regions, like the Canadian Rockies and northern Pakistan, the major portion of yearly precipitation is received in the form of snowfall during the winter season. The accumulated snowpack acts as a natural reservoir that will later release its water content throughout the spring and early summer seasons (Martinec, 1985; Ferner and Wigham, 1987). Efficient and safe operation of reservoirs fed by inflows from these regions is therefore largely dependent on obtaining reliable estimates of seasonal snowmelt.

In British Columbia, Canada, over 90% of energy demand (over 40,000 gigawatt-hours per year: one gigawatt-hour serves 100 residential customers) is supplied by hydroelectric generation from reservoirs fed mostly by spring and summer snowmelt. The system operations unit of British Columbia Hydro Corporation (BC Hydro), which owns and operates the majority of these hydroelectric plants, uses the University of British Columbia (UBC) Watershed Model to generate seasonal flow forecasts for the Columbia, Peace, and Campbell River portions of the system and these forecasts are based on historical weather patterns. The UBC Model is particularly suitable for application in such mountainous regions since the simulation of snowpack accumulation and depletion lies at the heart of its design.

The UBC Model applies a simplified energy based approach to simulate snowpack heat balance (Pipes and Quick, 1987). Daily meteorological data of precipitation and maximum and minimum temperatures are used to calculate estimates of percentage of cloud cover, snowpack albedo and wind velocity. These variables are then used to estimate net heat input to the snowpack. A positive heat input is converted into snowmelt, while a negative value which indicates an energy loss is added to the snowpack cold content.

The UBC Model has gone through a major upgrade in the last few years. Improvements in forecasts have been achieved for many basins in British Columbia and Pakistan. However, problems arise when limited hydro-meteorological data are available for model calibration. Under such circumstances, forecasts may be upgraded by

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[1] Hydrotechnical Engineer, Hydrotechnical Department, B.C. Hydro, 6911 Southpoint Drive, Podium A02, Burnaby, B.C., V3N 4X8 Canada

[2] Respectively, Post Doctoral Research Associate and Professor, Department of Civil Engineering, University of British Columbia, Vancouver, B.C., V6T 1Z4 Canada

incorporating available measurements of other hydrological variables. A procedure was developed to make use of available snowcourse measurements to update UBC Model estimates of snowfall and consequently improve the overall estimate of snowmelt volume. Since snowcourse measurements are taken during the early part of the hydrological year, the snowfall season, the procedure would provide operators of hydroelectric plants with early season estimates of contributing snowmelt. This procedure was applied to update flow forecasts at the Illecillewaet basin in British Columbia, Canada.

In the next sections, the general outline of the snowpack algorithm used by the UBC Model is presented, followed by a discussion on the role of updating and selection of procedure. The algorithm of the updating procedure is described and then the results of the application of the procedure to Illecillewaet River watershed are presented and discussed. Finally, the findings are discussed and conclusions are drawn.

THE UBC SNOWPACK ALGORITHM

In the UBC Watershed Model, the snowpack is represented as follows:

1. The average temperature, T_a is estimated equal to the mean of the measured maximum and minimum temperatures.

2. The snowfall, PP_s, is estimated from the total precipitation according to a threshold temperature, above which all the precipitation is in the form of rainfall.

3. The heat balance to the snowpack is represented by the following equation:

$$H_t = H_s + H_l + H_c + H_a + H_r$$

where,

H_t is the sum of heat influxes;

H_s is net shortwave heat input consisting of incident solar radiation less portions intercepted by cloud cover and reflected by snowpack surface;

H_l is net longwave heat radiation from snowpack, clouds, overlying air mass and surrounding objects;

H_c is the convective (air turbulence) heat component;

H_a is the advective (condensation) heat component; and

H_r is the advective heat transfer by rainfall.

4. Calculation of snowmelt:

The cold content of the snowpack is updated on a daily basis by the net heat input H_t. Positive cold content is converted into equivalent snowmelt, or less if there is less snow available for melting, and then to set to zero. Negative cold content is reduced by a given decaying factor and no snowmelt is generated.

If not observable, critical variables essential for the snowmelt calculation are estimated using available meteorological weather data. Percentage of open sky is estimated as the daily temperature range expressed as a percentage of a given maximum temperature range. Daily temperature range is also used to estimate wind velocity. Albedo of new snowcover is given a maximum value that is reduced on a daily basis to reflect the aging of snowpack (UBC Watershed Model Manual, 1995).

ROLE OF UPDATING AND SELECTION OF PROCEDURE

A critical step in developing a river flow forecasting system is the calibration of the watershed model to best represent the hydro-meteorological conditions of a contributing watershed. The calibration process involves adjusting a selected set of model parameters to achieve the best correspondence between measured flows (reference data) and simulated flows generated using meteorological variables (input data). However, good calibration results do not necessarily guarantee good forecasts. Some of the future years may not be well represented by the data record used for calibration. Data from meteorological stations may not be always representative of average conditions in the basin, e.g. storm tracks may shift dramatically from one year to another. These factors can result in significant errors in flow forecasts.

One approach for improving flow forecasts is to provide a feedback of available independent measurements of other hydrometeorological data to the watershed model during the forecasting mode, a procedure usually referred to as updating. The authors have tested two possible updating methods, one using snowcourse measurements to update snowpack estimates and the second updates the snowmelt estimates. Snowcourses are measured in many watersheds across North America, and although they may not be representative of all parts of the watershed at all times, they are measured with a reasonably good accuracy. This makes them useful for checking against data from high elevation weather stations, which may run into many problems during periods of heavy snowfall. The two methods which will be tested can be summarized as,

1) Modify estimates of snowfalls, and consequently update overall estimation of accumulated snowfall volume.
2) Upgrade estimates of percentage of cloud cover and/or albedo of snowpack cover. Estimation of snowmelt is largely influenced by these two variables.

The second method can not be functional until the beginning of the snowmelt season, so it may not provide enough lead time for the reservoir operators to modify their estimates of seasonal snowmelt. On the other hand, the first approach can be applied much earlier in the year, during the snowfall accumulation season, allowing a much longer, and needed, lead time. The two methods can complement each other since they operate at different times of the year. The authors applied a combination of the two methods and the first method alone. Better results were obtained from applying the first method alone, in which the updating procedure has been restricted to modifying only snowfall estimates.

DESCRIPTION OF UPDATING ALGORITHM

Two stages can be recognized for the variation of the seasonal snowpaks, the accumulation phase and the depletion or snowmelt phase. In most mountainous watersheds melting starts late in the spring, usually in April or May and distinguishes the two phases. In this paper two updating procedures have been developed for the two phases of the snowpack.. The first procedure updates the snowpack estimates using snowcourse measurements for the accumulation period. Each time a new snowpack measurement is available, the error between the observed and simulated snowpack estimates is assessed. The error is then used to calculate a new value of the “Snowfall Representation Factor” of the meteorological station, to minimize the error in the snowpack estimation. This is the P0SREP parameter of the UBC Watershed Model. The UBC Watershed Model then re-runs automatically between the start of the hydrologic year or the previous and the current snowcourse measurement to update the snowpack estimate.

The above procedure continues until the maximum snowpack accumulation date, usually April 1 or May 1. Then, the second procedure for the snowmelt updating is invoked. In the snowmelt updating procedure once a snowpack measurement is available the snowpack error is calculated. An iterative procedure has been developed that adjusts the cloud cover and the albedo of the snowpack to match the observed snowpack Snow Water Equivalent (SWE). Once the snowpack SWE is matched, then, the U.B.C. Model uses the updated values of cloud cover and albedo for the forecast period until the next snowpack measurement.

APPLICATION OF UPDATING ALGORITHM

The updating procedure was tested on seasonal forecasts of the Illecillewaet River, which is a tributary to the Upper Columbia River. Flowing northeasterly within the Rocky Mountain Trench, the Columbia River along with the Canoe River feeds into Mica Dam Reservoir (Kinbasket Lake). Meteorological data from the Revelstoke station at 440 m was used for calibration and forecasting. The updating procedure was run using snowcourse measurements from Mount Fidelity which is located at an elevation of 1870 m in the Illecillewaet River watershed.

Updating was performed for two calibration settings. Initially, three years (1970-1973) of data were used for calibration which simulates the situation when not much calibration data are available. The updating procedure was then applied to the forecasts of the following two years (1974-1976). For the second phase, the model was recalibrated using ten years (1970-1980) of data, and forecasts were updated for the following ten years (1980-1990). These runs were designed to resemble phases of calibration and forecasting in real life systems and to demonstrate the changing role of updating with regard to calibration. At the early stage of developing a runoff forecasting system data suitable for calibration is scarce. As more data becomes available the forecasting model is recalibrated to achieve a better representation of the watershed.

Figure 1 shows hydrographs of measured flows, un-updated forecasts and updated forecasts generated using the three year calibration for the period April to September, 1976. Without updating seasonal runoff had been underestimated by 34%. With feedback from snowcourse measurements, the volume error was reduced to only -5.9%. Figure 2 shows snowcourse measurements, estimated snowpack with no updating and the updated snowpack for the hydrological year, October 1975 to September 1976. This figure shows that the watershed model significantly underestimated the snowpack throughout the snow accumulation season (November to April). These negative errors triggered the updating procedure to increase snowfall contribution and hence more snowpack volume became available for melting in the months of May to August. These results, with similar ones obtained for the year 1975, show that feedback from snowcourse measurements is useful not only in estimating magnitude of volume errors but also in detecting these errors at a very early stage (February and March).

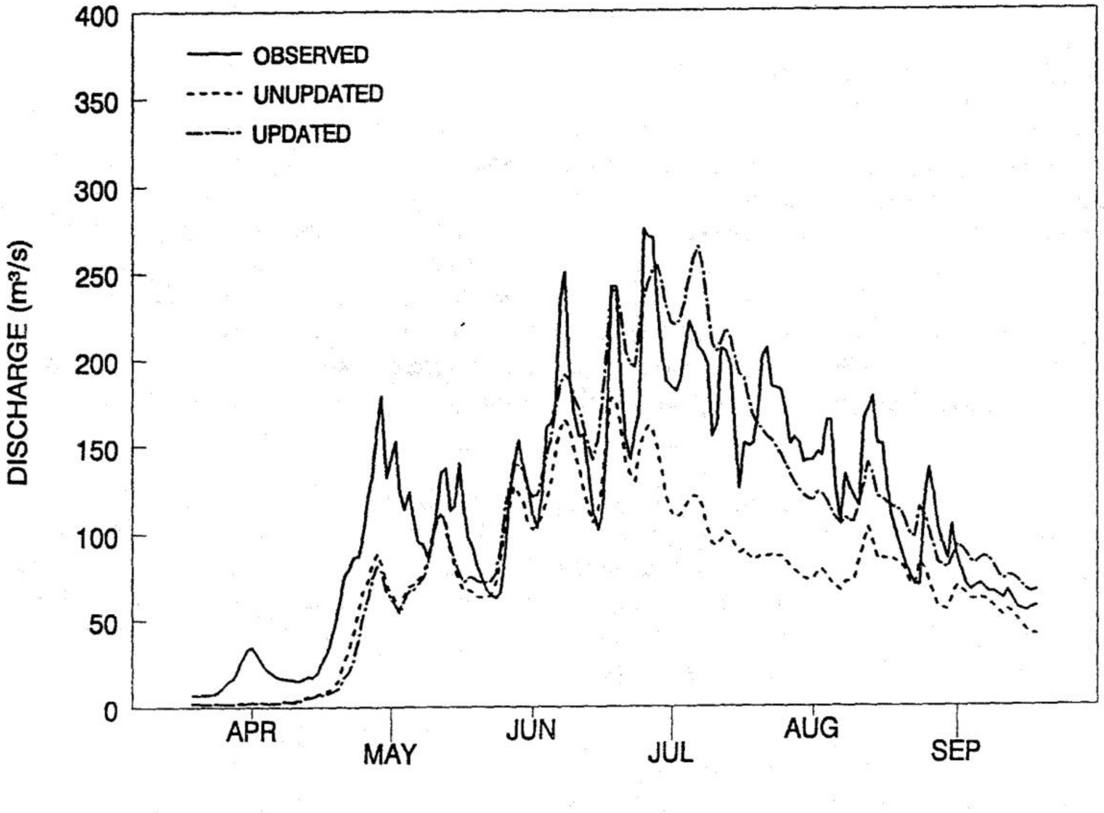

Figure 1. The observed, unupdated and updated seasonal flow for 1976.

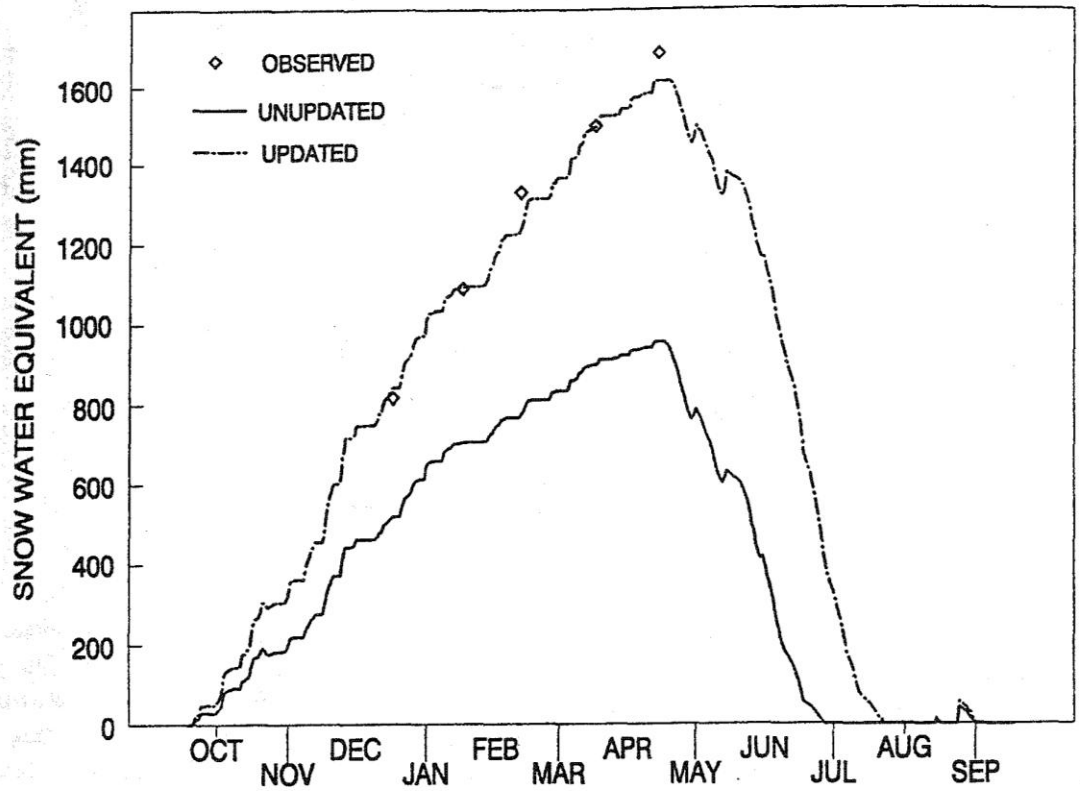

Figure 2. The observed, unupdated and updated snowpack for 1975-76.

It is important to note that the poor performance of the watershed model in the results presented above is mainly due to inadequate calibration. Under such circumstances, the updating procedure proved to be very useful in improving seasonal forecasts, even before the beginning of the melting season. However, as more data become available calibration can be reassessed. As was mentioned before, the model was recalibrated for the years (1970-1980) and then forecasts were generated for the years (1980-1990). Table 1 shows the volume errors in these forecasts with and without updating. The results are inconsistent: five years show that updating had minimal effect on forecasts, while the other five years show that errors increased as a result of updating. Insignificant changes in forecasts due to updating indicate that snowcourse measurements were very close to the estimated snowpacks, triggering only minimal changes in the snowfall estimates. For the years where the updating procedure performed poorly, it appears that snowcourse measurements were not representative of the average snowfall conditions in the basin. Certainly more analysis is needed to identify the causes of these problems. The clear indication from these results is that a good calibration is superior to an updating procedure unless the data for updating are very reliable.

Table 1

Runofff volume errors (%) for the 10 year calibration

Year	Un-updated	Updated
1981	5.6	6.4
1982	18.1	17.9
1983	10.0	10.0
1984	1.9	1.9
1985	8.3	29.0
1986	6.3	17.8
1987	7.5	5.4
1988	9.6	27.0
1989	17.0	23.5
1990	1.8	38.0

To evaluate the differences between the two calibration settings under the same hydro-meteorological conditions, the year 1987 was rerun using the three year calibration. The results for the two runs are shown in Table 2. The three year calibration resulted in underestimation of runoff volume by 17.6%, reduced down to 7.9% by updating. These results parallel those for the years 1975 and 1976. The ten year calibration improved upon volume estimation, but overcorrected it by 7.5%. The increase in runoff volume for the ten year calibration was achieved by increasing precipitation contribution to the watershed. As was discussed earlier, these changes were adopted first by the updating procedure to correct for negative errors in snowpack estimation. This shows that results from updating can be helpful in determining direction for the next phase of calibration.

Table 2

Runofff volume errors (%) for year 1987

Calibration Setting	Un-updated	Updated
Three years	-17.6	-7.9
Ten years	7.5	5.4

The success of the updating procedure is dependent on the validity of its underlying assumption that runoff volume errors are proportional to errors in snowpack estimation. This assumption was tested by plotting runoff volume error vs. discrepancy between maximum snowcourse measurement and corresponding estimated snowpack for twenty years (1970-1990) using the ten year calibration (see Figure 3). The peak of the snowpack marks the transition from snowfall accumulation season to snowmelt season, so it is a good representation of the total snowpack volume available for melting. The plot shows a general correlation between the two errors. Therefore, errors in snowpack estimation are generally useful and give early indication of errors in seasonal forecasts. However, Figure 3 also show significant deviations from the correlation line, which may be attributed to situations where snowcourse measurements are not representative of average snowpack conditions in the basin.

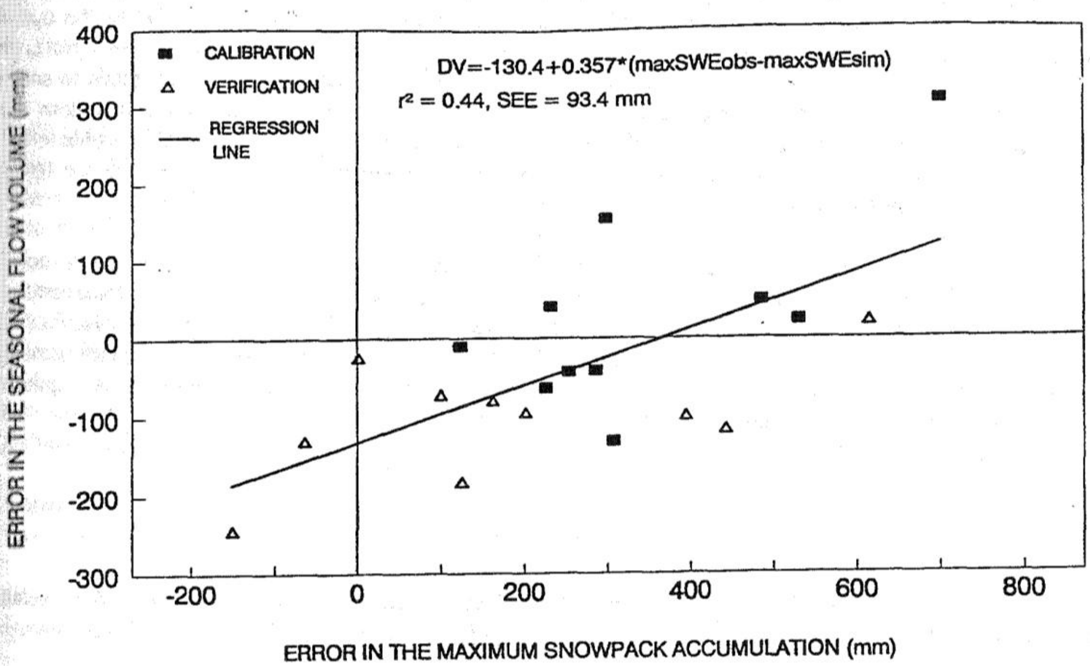

Figure 3. The relationship between the seasonal runoff volume error and the the discrepancy between maximum snowcourse measurement and snowpack simulation.

SUMMARY AND CONCLUSIONS

Efficient and safe operation of reservoirs in mountainous regions requires reliable estimates of seasonal runoff, which are mainly made up of spring and early summer snowmelt. The UBC Watershed Model is a well established tool for estimating seasonal runoff using meteorological data from AES stations. Precipitation data are used to estimate snowfall input and temperature data is used through an energy budget routine to calculate snowmelt distribution. Errors in snowfall estimates can result in significant errors in snowmelt volumes. The authors suggest the use of snowcourse measurement to detect and reduce these errors. Snowcourse measurements are ideal for this task since they are taken early in the snowfall season, so that they can provide an early indication of volume errors. Snowcourses are measured at high elevations so they provide valuable information of snowfall conditions in the active upper regions of the basin. This information may not be available otherwise since most weather stations are located in the lower regions of the basin.

The snowcourse updating procedure was tested under two settings of calibration of the UBC Watershed Model: a three year calibration followed by a ten year calibration. These runs were designed to resemble the real life situation where data is scarce at first stage of developing a flow forecasting system. As more data becomes available the calibration is reassessed to achieve a better representation of the basin. For the three year calibration, the results show that updating yields significant improvements in seasonal forecasts. This indicates the value of snowcourse measurements in situations where meteorological data is limited. The corrections to snowfall estimates were done early during the snowfall season, so a good estimate of snowpack volume was available well ahead of the snowmelt season.

The recalibration of the watershed using ten years brought about significant improvements in seasonal forecasts, similar to those experienced earlier by applying updating. However, inconsistent results were obtained when the updating procedure was applied to the next ten years. Updating yielded no significant changes for half of these years, since snowcourse measurements were close to estimated snowpack and therefore minimal changes were made to snowfall estimates. For the other years, updating resulted in larger volume errors. This may be attributed to situations where snowcourse measurements are not representative of average snowpack conditions in the basin. This problem will be addressed in future research. One possible approach to minimize this problem is to incorporate into the updating procedure snowcourse measurements from other sites.

The suggested updating procedure is based on the assumption that errors in seasonal forecasts are proportional to those in snowpack estimates. The validity of this assumption can be tested by plotting runoff volume errors vs. discrepancy between maximum snowcourse measurement and corresponding estimated snowpack. The plot for twenty years of run showed a general correlation between these two errors, indicating that the updating procedure showed, in general, be useful in reducing runoff volume errors, but this trend can be misleading in some years, so that updating a well calibrated watershed should be used with caution.

REFERENCES

Ferner, S.J. and J.M. Wigham, 1987. " The Use of Snow-Pillow Data for Melt Rate Input to the Streamflow Synthesis and Reservoir Regulation Watershed Model." Canadian Journal of Civil Engineering, Vol. 14, pp. 118-126.

Martinec, J., 1985. " Snowmelt Runoff Models for Operational Forecasts." Nordic Hydrology, Vol. 16, pp. 126-136.

Pipes, A. and M.C. Quick, 1987. " Modelling Large Scale Effects of Snow Cover". Large Scale Effects of Seasonal Snow Cover (Proceedings of the Vancouver Symposium), IAHS Publ. No. 166, pp. 151-160.

U.B.C. Watershed Model Manual, 1995. Mountain Hydrology Group, Department of Civil Engineering, University of British Columbia.