SNOW COVER DYNAMICS ON ŠUMAVA'S EXPERIMENTAL CATCHMENT

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Introduction

Snowmelt in the mountains in central Europe is very important resource of water. Persistence of snow cover in these areas is longer the five months and snow water equivalent often represents half of total year precipitation.

Šumava's catchments highly participate on outflow from snowmelt in Otava river basin. Aim of this study is description of snow quantitative and qualitative characteristics in winter and spring periods 2006, 2007 and 2008.

Areas of study

Studied watersheds Modrava 1 and Modrava 2 are situated in the Šumava Mountains (Bohemian Forest) in the Southwest of the Czech Republic. Watersheds were delimitated in 1998 and continual measurement of snow cover and snow melt started in 2006.

Experimental watershed Modrava 1 is situated in the spring area of the Roklan Creek basin. The watershed spreads out over a drainage area of 0.10 km^2 in the non-interference zone of Šumava National Park; after the bark beetle calamity the natural development of the watershed was reserved. The elevation is between 1210-1275 m; the watershed exposure is northwards. The vegetation cover is formed by dead forest. The experimental watershed Modrava 2 is situated on the northern hillslope of Malá Mokrůvka mountain, its source is part of the Ptačí Creek basin. The watershed's drainage area is 0.17 km^2, the elevation is between 1180-1330 m. The vegetation cover is formed by a young forest that grew up after forest clearing work following the bark beetle invasion. Subsurface flow is dominant in both areas. Granite and paragneiss bedrock and soil types Dystric Cambisols and Cambic Podzols shape both catchments.

Both watersheds are equipped with permanent measuring and registering tools. Several characteristics are measured: runoff, rainfall, temperature, conductivity, snow height, snow density and chemistry of melt water and stream water. For runoff measuring a V-shape measuring weir was built near the creek spring. The rainfall is measured by a tipping-bucket rain gauge (not heated) located in free space next to the V-shape measuring weir in elevation 1 m above surface. Temperature is measured by a thermometer in elevation 2 m above surface, conductivity by a conductometer. Snow height is measured by snow stakes placed in snow transect; snow density is measured by snow sampling tube and chemistry and other characteristics are analysed in off-site laboratory.

For snowmelt analysis runoff data in snow free season or during the period of snowmelt are registered in two-minute time intervals and subsequently aggregated into a one-hour time step series. Precipitations and temperature are available in hourly data step and snow height, snow density and chemistry are available in weekly data step.

Data of snow height and snow density were measured during snow periods of years 2006 -2008. Chemistry of snow cover and melt water were collected during 2007-08 winter period.

Methods

Quantitative methodology

Snow characteristics on both watersheds are monitored from 2006. Measurements in spring period 2006 and 2007 were done irregularly. Detailed monitoring of snow cover dynamics started from November 2007. Snow height is measured by 12 snow stakes placed in snow transect of watershed Modrava 2 and by portable snow stake of 1.5 m length. Snow stakes in Modrava 2 are space out in approximately 60 m distance, from the closure profile to the top of Malá Mokrůvka mountain. At watershed Modrava 1, snow height is measured only by portable snow stake. Snow density is measured by snow sampling tube with diameter 8 cm and 150 cm of length; snow density is measured between and in position every snow stakes in watershed Modrava 2, or approximately after 60 m in watershed Modrava 1. Snow water equivalent (SWE) for both watersheds is calculated on the basis of obtained values.

Obtained values were used for two types of model: degree-day models and linear reservoir model.

Degree-day model

Degree-day models assume an empirical relationship between air temperatures and melt rates. This method uses one or more variables in an empirical expression to estimate snow cover energy exchange. Air temperature is the most commonly used index, but other variables, such as net radiation, wind speed, vapor pressure and solar radiation are also used (Sing, 2001).

The most basic formulation relates the amount of ice or snow melt, *M* (mm), during a period of *n* time intervals, Δt (d), to the sum of positive air temperatures of each time interval, T^+ (°C), during the same period, the factor of proportionality is the degree-day factor, *DDF*, expressed in mm d^{-1} $°C^{-1}$ (Hock, 2003).

$$\sum_{i=1}^{n} M = DDF \sum_{i=1}^{n} T^{+} \Delta t$$

Two approaches of degree-day model were used in this study:

1. Degree-day approach which uses average daily air temperature as only one variable. This model was set in day and hour time step. Part of this model is melt time delay, which is caused by refreezing of snow cover during the night and so this time delay express time needed to cumulate the heat for snow melt. Simulated outflow by this approach is presented in figure 1.

2. Degree-day approach, where are defined border conditions for snowmelt, like average temperatures for explicit previous period. DDF changes in dependencies on amount of previous temperatures. Last drain spline from snowmelt is replaced by function $y = x^{-\alpha}$. This model was set in day and hour time step. Simulated outflow by this approach is presented in figure 2.

Linear reservoir model

Black box model is based on knowledge of transformation function of watershed. Simulated snowmelt is predicted on the basis of temperature and outflow data in one hour previous time step.

Model can be written as matrix (Yu *et al.*, 1994):

$$Q = A \cdot \boldsymbol{\beta}$$

where Q is vector of simulated outflows from watershed, *A* is matrix of entry data (outflows and temperatures), **β** is vector that describes transformation function of watershed.

Qualitative methodology

Snow chemistry was monitored on Modrava 2 watershed since 1st December 2007. Snowcover and stream water were sampled once a week. Samples were taken in a single snowpit that was extended every week. The face of a snowpit was vertically cut and smoothed and before snow samples were collected, physical measurements (height and density) and descriptions (including snow-crystal size, type and hardness of all layers, position of ice layers and snow moisture) of the snowpack were made. Stream water was sampled right below the weir, same bottles were used.

Conductivity, total dissolved solids (TDS), pH, NH_4^+ and NO_3^- were determined in laboratory in Kostelec n.Č.L.. Conductivity and TDS were measured by a portable conductometer WTW Cond 330i, pH was measured by portable pH meter WTW pH 330i. Ammonium concentration was determined by absorption spectrophotometric method at λ = 630 nm, nitrate was determined by absorption spectrophotometric method at λ =410 nm (SPEKOL 11, Carl Zeiss Jena was used).

From each sample volume of 100 ml was conserved with 1 ml 65% Suprapur HNO_3 for further analyses.

In Institute of Geology (Academy of Sciences CR) Al, Ca^{2+}, Fe, K^+, Mg^{2+}, Mn, Na^+, P, $S0_4^-$ and Si were determined by AES-ICP method, in Kostelec nad Černymi Lesy Pb, Cu, Cd were determined by AAS-ETA method and Zn was determined by FAAS method.

Air masses, that brought the snowfall, were identified using HYSPLIT Trajectory Model (HYbrid Single-Particle Lagrangian Integrated Trajectory).

Results

Figure 1 and figure 2 represent results from 2 different approach of degree-day model. Changes of total dissolved solids (TDS) in snowpack and streamflow water during winter period 2007-08 are presented on figure 3.

Conclusion

Hydrological models applied on watersheds Modrava 1 and Modrava 2 for snowmelt period are able to simulate outflow discharge in daily and hourly time step. Standard degree-day model is not able to simulate snowmelt with high accordance for shorter time period. The best way is to use degree-day model extended by other characteristics which affect snowmelt.

Considering chemistry of snowpack layers melt water, rise in solute concentration has been observed in the topmost layer. It could be related with dry deposition. Drop in ionic concentrations has been observed in all layers that were metamorphosed and so were formed by big snow-grains. As chemical species migrated to the grain surfaces and because this winter was mild and temperatures had occasionally risen above zero, they were slowly leached to other layers and to the soils.

When the spring melting began, almost all the layers were metamorphosed and their chemistry became similar. Even when the snow was very pure, some effect on the chemistry of stream water has been observed, but it is still the object of further research.

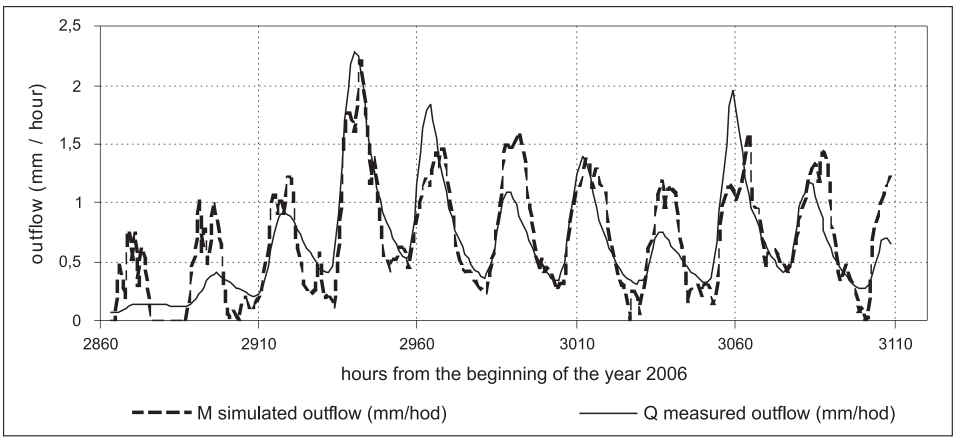

Figure 1. Aplication of degree-day model in hour time step at watershed Modrava 1, time delay 31 hours, D_f = 2,7

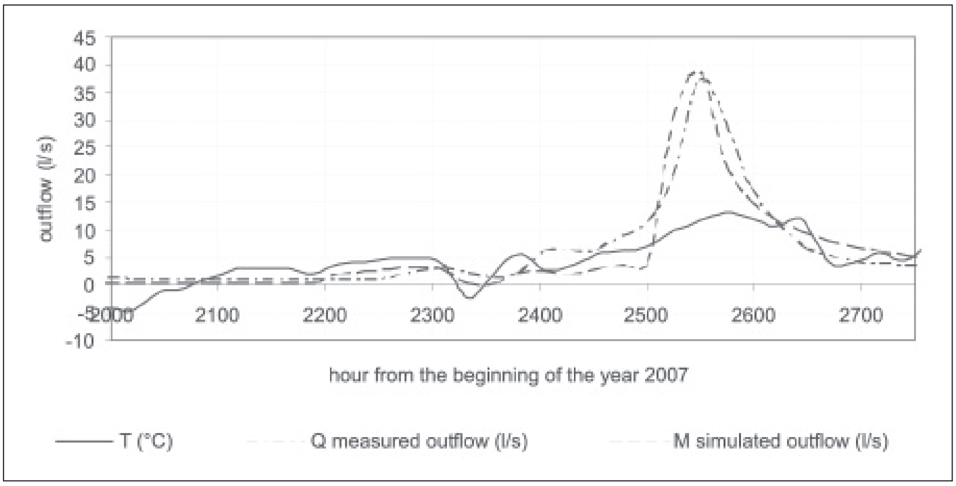

Figure 2. Degree-hour model with border conditions (day time step). Watershed Modrava 2

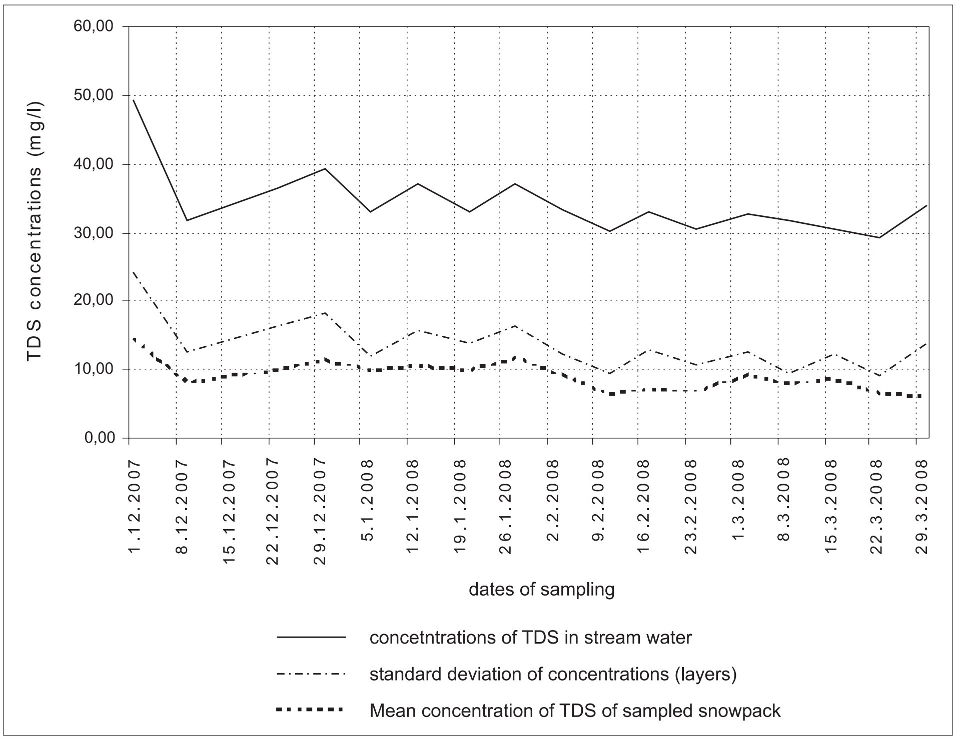

Figure 3. Concentration of TDS in snowpack and stream water on watershed Modrava 2

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