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Snowmelt modelling aspects in urban areas

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Abstract

Urban winter hydrology is generally poorly understood, despite the large number of cities which have annual seasonal snow cover and there are only few studies about urban snow and snowmelt rates in the cities. Two specific factors affecting the snow melting rate in urban areas are the degree of urbanization and the urban snow distribution. The net radiation balance of urbanised catchments differs from their rural counterparts. The choice of a snowmelt model for a particular application depends on data availability and snow characteristics. A review of attributes of common snowmelt models is presented for evaluation and selection of the best suited model for simulating snowmelt in a specific area. In snowmelt computations, the challenge is to identify a suitable model for the heterogeneous urban conditions from the existing model categories as TIM, EBM, or their combination as a hybrid method. For rural environments, empirical methods (TIM) have been demonstrated to reproduce a large part of the snowpack variations at both open and forested areas. For heterogeneous urban environments, it is necessary to apply an EBM in order to take into account all the characteristics of urban snow. Snow properties such as density and albedo vary both between urban and rural areas as well as between different urban locations belonging to the same urban agglomeration.

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Keywords: urban snowmelt; energy balance; snow water equivalent; flood

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1. Introduction

Urban snow characteristics differ from those of rural environments. While there is a fair number of studies of snowmelt modelling for rural areas, there are limited efforts focusing on urban winter hydrology. Basic approaches used to model snowmelt are: the energy balance model (EBM) that requires detailed description of each term of the mass or energy balance equation in order to simulate the energy fluxes within the snowpack, the Temperature index model - TIM (empirical approach) in which air temperature is used to index the energy fluxes, and the combination of these two model approaches as a hybrid method.

For open areas the accuracy of EBM is well-established [1]. EBM is more complex to be implemented and usually needs more input data sets than TIM. For operational forecasting, it is more realistic to apply TIM due to the difficulty to predict several meteorological variables used by EBM for several forthcoming days [2]. The snowmelt estimations for a heterogeneous urban environment cannot be adequately determined by using TIM because those models assume a homogeneous snowpack and a heterogeneous snow coverage.

Several snowmelt calculation schemes have been developed for catchment hydrology calculations. Examples of EBM approaches are ESCIMO [3]; SNTHERM [4, 5] and SnowMelt-R [2]. TIM approach includes SRM [5, 9], MIKE SHE [10], WINTER, ETI and COMBI [11-13]. Examples of the third, hybrid kind of approach are Snow -17[1], SWAT [6, 7] and HEC 1 [8].

Even though urban hydrology principles assume that the processes and factors governing both urban and rural snow hydrology are the same, the urban snowmelt models must incorporate the characteristics of urban snow that differentiate it from the snow outside the urban areas. Few urban snowmelt models use these characteristics. Within the EBM category, examples of these are HSPF [14], USM [15], GUHM [16], and SDM [17-19]. Urban conditions are also taken into account also TIM and hybrid model approaches. Within the TIM category, we mention MU (MOUSE RDII) [20]. EPA SWMM [21] is a hybrid model type. This study has identified several literature reviews on snowmelt modelling for rural areas [5, 22], but only one considering urban conditions [23].

The snow characteristics, its distribution and the snowmelt conditions in urban environments are related to land use and to the snow handling practices. Urban snow distribution depends on the initial snow distribution and location, the land use (houses, apartments, streets, etc.), the type of snow cover (snow piles, snow on road shoulders, snow on sidewalk edges, snow in open areas, etc.) and the land use after snow redistribution [18, 23-25]. Snow is removed from streets, front yards and parking lots and piled up near snow-free surfaces. Large amounts of snow are transported away from downtown to special city snow dumps. To what extent snow is transported, depends on the cities' design and as well on the funds allocated for snow handling. Several studies [26, 27] have shown that the snow density and albedo vary both between city and countryside as well as a function of the land use. Also, urban elements such as vehicle traffic and buildings can influence the energy balance of the snowpack into the city.

The objective of the present study is to review and compare different snowmelt models based on different snowpack characteristics in and outside the cities.

2. Snowmelt modelling aspects

In snowmelt computations, the empirical models (TIM) are commonly used to simulate a large part of the snowpack variations in open and forested areas. The TIM and hybrid methods needs the least number of types of data inputs. EBM require many input data in order to describe the physical processes of each component of the energy balance, but EBM are considered more accurate than TIM [1, 11].

Walter et al., 2005 [2] estimate the energy budget components using the maximum and the minimum daily air temperature, as most of the TIM are running. The results showed a good agreement between observed and predicted snow water equivalent values so the use of mechanistic snowmelt modeling approaches in hydrological models could be encouraged.

Empirical models (TIM) simulate a large part of the snowpack variations in open and forested areas. Even EBM usually need more input data sets, energy based Snowmelt runoff modeling has been developed mainly for surrounding areas of cities in cold regions, where snowfall constitutes a significant quantity of the annual precipitation [2, 3 and 11]. Few studies focus on the urban regions in cooler or Alpine climates with significant snowfall and snowmelt [19,