Development of spatially distributed hydrological WetSpa modules for snowmelt, soil erosion, and sediment transport

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Summary

Hydrological modelling is very important for prediction of runoff and soil erosion, and is a major tool for research hydrologists and water resources engineers for planning and management of water resources. Distributed hydrological models are based on our understanding of the physics of the hydrological processes which control catchment response and use physically based equations to describe these processes. A spatially distributed hydrologic model, WetSpa, has been developed at the Department of Hydrology and Hydraulic Engineering of VUB. The hydrologic processes considered in this model are precipitation, interception, depression, surface runoff, infiltration, evapotranspiration, percolation, interflow, groundwater flow, and water balance in the root zone and the saturated zone. The basic model inputs are a digital elevation model (DEM), land use and soil maps of the study area in GIS raster format, and hydrometeorological data. The model combines these data within GIS, and predicts flood hydrographs and the spatial distribution of hydrologic characteristics in the watershed. The purpose of this research is to develop and test new WetSpa modules for (a) snow accumulation and melt, and (b) soil erosion and sediment transport.

Snow is important in cold regions and in these areas snowmelt is of importance to many aspects of hydrology including water supply, erosion, and flood control. A snow module was provided in the original WetSpa model based on a conceptual temperature index or degree-day method, which three snowmelt parameters which should be calibrated. The new snowmelt module is developed based on an energy balance approach which is fully physically based, and hence, does not need any calibration. This approach only needs physical data that can be easily obtained, as air temperature and windspeed. Three study catchments with distinct basin characteristics are selected to investigate the applicability and adaptability of the module: The first one is the Hornad river basin (4262 km^2) up to Zdana station in Slovakia, for which the model was applied and calibrated with 8 years of daily data. The model (Nash-Sutcliffe) efficiency turns out to be 79%. The second is the Hornad river up to Margecany station (1133 km^2), a mountainous watershed situated in the upstream part of the Hornad river in Slovakia. The model was applied, calibrated, and verified with 10 years of daily data. The first 5 years were chosen for model calibration and the second 5 years for model validation. The model efficiency is good, i.e. 74% and 79%, respectively for the calibration and verification period. The third catchment is the Latyan dam watershed (435 km^2) in Iran. The model is applied and calibrated with 3 years of daily data. The results of the degree day method and the energy balance approach are compared for this catchment. The model efficiency is more than 80% for both models, but for the energy balance approach this is obtained without calibration of snowmelt parameters. Hence, this study shows that the new model for snow accumulation and melt has great potentiality to predict the impact of snow accumulation and melt on the hydrological behaviour of a river basin.

Also a physically based, spatially distributed model is developed to simulate erosion, sediment transport and deposition, within the framework of the hydrological WetSpa model. Soil detachment by raindrop impact is calculated based on relationships between soil detachment and the kinetic energy of rainfall. Soil particle detachment by overland flow is calculated based on actual and critical shear stresses. Water and sediment are routed over the land surface along topographically determined flow paths with travel times and flow rates determined by physical relationships. This module does not need any more data than for the WetSpa model, except sediment measurements for model calibration. This module can simulate not only the suspended sediment concentration, but also can give the variation in sediment loads with time. The model performance is tested by simulating erosion and suspended sediment concentration in the three catchments. For the Maarkebeek catchment (50 km^2) in Belgium, the model was applied, calibrated, and verified for two particular storm events with 15 minutes time step data. The model efficiency shows good overall results for the calibration event, i.e. 0.88% and 0.90% Nash-Sutcliffe efficiency respectively for suspended sediment concentration and sediment yield. For the Hornad watershed in Slovakia, the model is also applied, calibrated, and verified for two storm events but now with daily time steps. For this event an automated calibration and parameter sensitivity analysis using PEST is applied focusing on 2 parameters, i.e. detachability of the soil and overland flow erodibility. The second event is used for verification. The calibration results are good for both events, i.e. mean errors of 0.25 gl^{-1} and 7.30 kgs^{-1} respectively for suspended sediment concentration and sediment yield for the calibration event, and -0.05 gl^{-1} and -1.77 kgs^{-1} for the verification event. The module is also applied and tested, to mountainous catchment Latyan dam watershed in Iran, where there is large snowfall. The results show that the model can also be applied for simulating erosion and sediment in snow covered areas.

We conclude that the two new modules that were developed for the WetSpa model are important contributions that enable to apply and use the model for different purposes in different catchments with distinct characteristics and hydrological behaviour. Hence, other researchers may benefit from this work and continue to expand the possibilities of WetSpa.