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Incorporating hydraulic/hydromorphologic properties and their stage dependency into hydrologic compartmental models

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According to recent studies, the volumetric error of the predicted size of the spring flood in Sweden can be as large as 20%. A significant part of this error originates from simplifications in the spatial and hydrodynamic description of watercourse networks, as well as statistical problems to give proper weight to extreme flows. Possible ways to improve current hydrological modelling practises is by making models more adapted to varying flow conditions as well as by increasing the coupling between model parameters and physical catchment characteristics. This study formulates a methodology based in hydrodynamical/hydraulic theory to investigate how river network characteristics vary with flow stage and how to transfer this information to compartmental hydrologic models such as the HBV/HYPE models. This is particularly important during extreme flows when a significant portion of the water flows outside the normal stream channels. The aim is to combine knowledge about the hydrodynamics and hydro-morphology of watercourse networks to improve the predictions of peak flows. HYPE is a semi-distributed conceptual compartmental hydrological model which is currently being developed at the SMHI as a successor to the HBV model. The model (HYPE) is thought to be better adapted to varying flow conditions by using the dynamical response functions derived by the methodology described here.

The distribution of residence times within the watercourse network - and how these depend on flow stage is analysed. This information is then incorporated into the response functions of the HYPE model, i.e. the compartmental model receives a dynamic transformation function relating river discharge to storativity within the sub-catchment. This response function hence reflects the topologic and hydromorphologic characteristics of the watercourse network as well as flow stage. Seven subcatchments in Rönne River basin (1900 km2) are studied to show how this approach can improve the prediction of peak flows.

For the watercourse network analysis, two types of 1-D distributed network models are set up. One model contains a simplified hydraulic analysis of the watercourse network and how its properties vary with flow stage; the other network model is a numerical (stationary) routing routine. In the simplified hydraulic model, the effect of changed cross-sectional geometries is analysed. The focus is put on extreme flows with flooded cross-sections, where the hydromorphological properties of the network are changed considerably. By usage of the Manning equation, residence times are calculated for different flow stages. The second network model is used to numerically investigate the effects of the routing through each sub-catchment. Probability density functions of residence times are calculated for a range of flow stages to obtain subcatchment-specific information which incorporates the effects of flow stage and changed cross-sectional geometries. This information is thereafter used as response functions in the compartmental model which then will be more adapted to the effects of flooded cross-sections.

Both network models are based on continuity principles regarding mass, energy and momentum. In both models, stationary flow conditions within the watercourse network are assumed, an assumption that might not be valid during extreme flows. In the simplified hydraulic model, the flow is assumed to be uniform between computational nodes - hence allowing the usage of the Manning equation for calculations of travelling times. The statements mentioned above are considered as possible sources of errors, however, more effort will be put into minimizing these effects, for example by finding optimal resolutions in space and time.

The compartmental model and the network models are defined on a comparable form to facilitate the transfer of information between the models. Within the compartmental model, the streamflow component is separated from the remaining flows, since the network models only regard the attenuation in the stream channel. Parameters (derived from the simplified hydraulic routing model) and functional relationships (derived from the numerical routing model) are used together for parameter translation from the network models to the compartmental model. The derived compartmental model is then compared to an identical compartmental model but where the response function is independent of water level. The results show that the previous model version provides the best model behaviour during high flows, since it accounts for stage. The results call attention to the importance of accounting for the hydraulic-hydromorphological properties of watercourse networks to obtain correct response times, especially so in more complicated stream networks.