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REW approach, a new blueprint for distributed hydrological modeling at the catchment scale: development of closure Relations

Murugesu Sivapalan (1), Haksu Lee(1) and Erwin Zehe

(1) Centre for Water Research, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia (sivapala@cwr.uwa.edu.au / Fax: +61-8-6488-1015), (2) Institute of Geoecology, University of Potsdam, Germany

Reggiani *et al.* (1998, 1999) derived, from first principles and in a general manner, the balance equations for mass, momentum and energy at the Representative Elementary Watershed (REW) scale, and also developed an associated constitutive theory. It has been suggested that the REW approach, and the associated balance equations, can be the basis for the blueprint for the development of a new generation of distributed hydrological models with the REWs as building blocks. However, the balance equations of Reggiani *et al.* contain numerous terms representing mass exchange fluxes between different sub-regions of individual REWs, and between different REWs. Developing physically reasonable closure relations for these mass exchange flux terms is a crucial pre-requisite for the success of the approach. In this paper, we utilize several methodologies to establish these closure relationships, expressing mass exchange fluxes as functions of relevant state variables in a physically reasonable way, and effectively parameterizing the effects of sub-grid or sub-REW heterogeneity of catchment physiographic properties. Closure relations for infiltration, exfiltration and groundwater recharge were derived analytically, while numerical experiments with a detailed fine-scale, distributed model (CATFLOW) were used to obtain the closure relationship for seepage outflow. CATFLOW was also used to derive REW scale pressure-saturation and hydraulic conductivity-saturation relationships for the unsaturated zone. Closure relations for concentrated overland flow and saturated overland flow were derived using theoretical arguments and simpler process models. A relationship for the saturated area fraction as a function of saturated zone depth was derived for an assumed topography on the basis of TOPMODEL assumptions. These relationships were used to

complete the specification of all of the REW-scale governing equations (mass and momentum balance equations, closure and geometric relations) for a chosen catchment, which can form the basis of a numerical model of the catchment's response to climatic inputs. The resulting model is used to carry out sensitivity analyses with respect to various combinations of climate, soil, vegetation and topographies, to test the reasonableness of the derived closure relations in the context of a complete catchment response, including interacting processes. These sensitivity analyses demonstrated that the adopted closure relations produce realistic results, and can therefore be a good basis for more careful and rigorous search for appropriate closure relations in the future.