Addressing the challenges in hydrology with percolation theory

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It has been decades since groundwater hydrologists, attempting to predict flow, together with conservative, and reactive solute transport, became aware of the necessity of addressing the complications of structural disorder, connectivity, and scale. Although many techniques have been applied, and are mentioned in the workshop description, one technique that is absent is percolation theory, which addresses the scale and heterogeneity dependences of such properties by upscaling the connectivity. Percolation theory is applicable not only to systems in which flow or conduction is either allowed or disallowed, but also to those systems where local flow rates are distributed over a wide range of values, such as in pore networks with widely varying geometrical characteristics. In such a case, percolation theory applied to a network model of the pore space describes the upscaling of the dominant flow paths and the associated effects on transport, including scaling of the dispersivity, solute velocity, and moisture transport. Applications of these results are to a fully predictive treatment of the climatic, substrate, and time dependence of soil development, as well as the scaling of chemical weathering and other reactions in porous media. Further, the entire context of the discussion regarding scaledependent geostatistical properties (variograms), hydraulic conductivity, and dispersivity is changed. When, in the context of ecohydrology, interactions between plant roots and the soil are considered, treatments of the soil as a network using percolation concepts lend themselves to predictions much more naturally than do the standard differential equation treatments of solute and moisture transport. In particular, it becomes possible to predict vegetation growth rates as a function of transpiration and of time. Combined with the predicted scaling of vertical and horizontal moisture transport (transpiration), it becomes possible to predict net primary productivity and its dependence on transpiration. Additional problems that can be solved within this framework include the spatial-, substrate-, climatic-, and soil characteristic-dependences of tree growth rates, and the observed relationship of tree diameter to height. These results represent solutions to problems that have evaded other researchers using different methods, and show the advantage in matching across the land surface the network models of plants and soils.

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[2] A.G. Hunt and S. Manzoni, IOP Concise Physics: Networks on Networks, 160 (2015).

[3] A.G. Hunt et al. Eur, Eur. Phys. J. B **80**, 411 (2011).