Part I
Response Mechanisms of Hydrological Processes in the Near-Surface Environment

To describe the flow and contaminant transport, induced by rainfall or snowmelt, through the landscape media, one is to consider several coupled processes occurring in the near-surface environment represented by soil and vadose zone in contact with a periodically forming movable water domain or with the atmosphere through the surface (Chow et al. 1988; Brutsaert 2005; Shaw et al. 2011). Thus, rain or snow-melting events intensify several mechanisms and processes, including: (a) the formation of a water body on the landscape; (b) the accumulation of pollutants of natural or anthropogenic origin in this layer after their release from the surface or from soil solution; (c) flow of polluted water over the surface; (d) the descending infiltration of a part of this water through the porous medium under the effect of capillary and gravity forces – a process, which controls the flow depth and, accordingly, the degree of water saturation with solutes, as well as the rate of water flow; (e) the development of paths of rapid pollution transport through macropores and fractures in the vadose zone and from depressions on the land surface toward water table, and, finally, (f) lateral contaminant transport through temporary or permanent phreatic horizons (sloping shallow aquifers).

The relevant hydrological analysis shall account for the differences between the space and time scales of the processes in the near-surface domains in contact with aquifer materials. Thus, the time scale for the conditions of runoff formation and solute migration is commonly of the order of hours, rarely a few days, while those of flow and solute transport in aquifers are of the order of months or years. The length of water flow paths in such systems is of the order of hundreds of meters or some kilometers. In terms of the time a water particle spends in it, the soil and vadose zone, with rare exceptions, occupy an intermediate position; however, unlike the systems involving surface and subsurface runoff, the vertical flow paths are much shorter in the sediments above the water table. For example, at such combination of time scales, a description of subsurface flow and solute transport can be based on the mean annual values of groundwater recharge and solute inputs, because the long pollutant residence time in the aquifer smoothes the effect on the solution of transport problem caused by daily and seasonal fluctuations in water flux and concentration functions on the upper aquifer boundary. From the viewpoint of stochastic analysis (Duffy and Gelhar 1985), for systems with large residence times (such as phreatic aquifers), small input correlation scale variations in continuous flow and solute inputs will produce little variation in the outflow characteristics. Under the same condition, the nearsurface domains are much more sensitive to small-scale changes in the flow and solute input characteristics. Therefore, to properly model the behavior of such system, in some practical situations it is important to use rainfall records with high temporal resolution.

The large differences in the time and space scales between the flow of water within the surface and subsurface domains allow a researcher to formalize the interaction between the domains through the transfer of boundary conditions from one domain into another, thus avoiding the solution of fully coupled equations of surface and subsurface flow (Furman 2008). In this part of the work, the relevant decoupling of the hydrological processes in the two domains is based on the raincontrolled infiltration interface approach allowing analytical solution of flow and solute transport problems with the assumption of prescribed infiltration rate or depth.

In this, first, part of the book, the behavior of the near-surface system under rainfall conditions will be analyzed based on an analytical framework at the column and hillslope scales. Mega-scale system's behavior is the subject of the second part of the book.

References

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