Chapter D.2

Responses of Hydrological Processes to Environmental Change at Small Catchment Scales

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D.2.1 Introduction

Chapter D.2 deals with fundamental hydrological processes and their modelling at "small catchment scales". We specifically define such catchments as having areas from ~ 10^{-1} km^2 to 10^3 km^2, known as the hydrological micro- to meso-scale. Since the exchange processes between the land surface and the atmosphere (energy, water etc.) at small scales are already treated in Chapt. A.2, the primary focus in this chapter is on so-called "wet hydrology", i.e. soil moisture dynamics, runoff generation and resulting lateral flows of water and associated transports of sediments, chemicals and nutrients. The processes at and below the land surface in soils and aquifers represent an important part of the terrestrial phase of the hydrological cycle and associated biogeochemical cycles.

The dynamics of individual hydrological processes and their spatial differentiation is highly complex, leading to significant uncertainties. For example, the quantification of the different contributions to catchment-level runoff of landscape units, such as vegetated in contrast to non-vegetated (bare or sealed), sparsely vegetated or mixed, built-up areas; or dried out in contrast to moist areas (wetlands, shallow groundwater areas), is always problematic and often not sufficient in accuracy. The main reason is the enormous spatial and temporal variability of infiltration capacities dependent not only on soil and vegetation type, but also on current soil moisture. Accordingly, various simplifications are applied in modelling. These are often acceptable in large-scale modelling. They may cause problems, however, in smaller scale simulation studies and in special investigations of, for example, the effects of changing land use (see Sect. D.2.6.1).

With this in mind, the primary aim of this Chapt. D.2 is:

- to present an overview of fundamental hydrological processes and their spatial and temporal variability;
- to summarise recent improvements in our understanding of these processes;
- to provide specific information on the different component processes of runoff generation and lateral flows along various pathways, especially below the land surface;
- to provide a review of the utility of comprehensive field studies in small catchments;
- to review the movement towards high-resolution distributed hydrological modelling using GIS-based parameterisations; and,
- to highlight the rapid development and degree of application of "integrated" ecohydrological models which serve to describe the complex links and interaction between energy and water and associated biogeochemical fluxes at micro- and meso-scales.

Most parts of the chapter are descriptive by intention. Equations and modelling details are generally not presented due to space limitations. However, relevant references are given to available textbooks, review papers and selected papers.

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D.2.2 Terrestrial Hydrological Processes – Overview, Definitions, Classification

D.2.2.1 Fundamental Hydrological Processes

Fundamental hydrological processes occur roughly similar in character at all spatial scales. However, from a practical standpoint they are generally best studied at small scales, such as the plot, hillslope or small catchment (headwater) scale. An overview of these processes and their typical chronological sequence in the terrestrial phase of the hydrological cycle is given in Fig. D.1.

The left part of Fig. D.1 is focused essentially on "vertical processes" which basically define the water balance of a landscape unit. These specifically include the major processes of precipitation, evaporation, transpiration and runoff generation. An additional set of more specific component processes includes interception, snow cover dynamics, depression storage at the land surface, including initial wetting, infiltration, soil moisture dynamics

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in the unsaturated zone, including percolation and root water uptake, groundwater recharge and capillary rise, overland flow and subsurface stormflow generation. These are represented diagrammatically in Fig. D.2.

Most of these processes are treated extensively in available text books on hydrology (Maidment 1993; Dyck and Peschke 1995; Dingman 2001) and will not be discussed here. This chapter therefore concentrates on their relevance to global change. A fundamental element of this relevance is the remarkable temporal and spatial variability of these processes. Selected processes are discussed in detail in the sections below, including treatment of soil moisture dynamics (Sect. D.2.3), overland flow and erosion (Sect. D.2.4), subsurface stormflow (Sect. D.2.5), and ecohydrological processes (Sect. D.2.6).

D.2.2.2 Spatial Differentiation of Vertical Hydrological Processes

Fundamental vertical hydrological processes can best be studied and understood using elementary areal units (patches) characterised by similarities in a wide array of attributes. These may include similarity in terms of topographic characteristics (elevation, slope class), land use and land cover, soil type and texture, hydrogeology (especially depth of the groundwater table or impervious layers), proximity to river networks and catchment boundaries (water divides).

Elementary areal units belonging to the same category or sharing similar hydrological behaviours are variably referred to as hydrotopes or Hydrological Response Units (HRUs) (Becker et al. 2002; Flügel 1995; Becker and Braun 1999). Natural landscapes and river basins are composed of a variety of hydrotopes, which may markedly differ from each other in essential hydrological characteristics. Accordingly, landscapes show a well known "mosaic structure", or landscape patchiness, with variably sized and shaped polygons when mapped. This is illustrated, for example, by the mixed use landscape in Fig. D.3. The mosaic structure represents an appropriate disaggregation scheme for hydrological studies, at least with regard to the vertical processes, to which runoff generation belongs.

Concerning the spatial differentiation of water balance components it should be emphasized that, for example, wet surfaces such as water surfaces (AW), wetlands and various shallow groundwater areas (AN; cf.

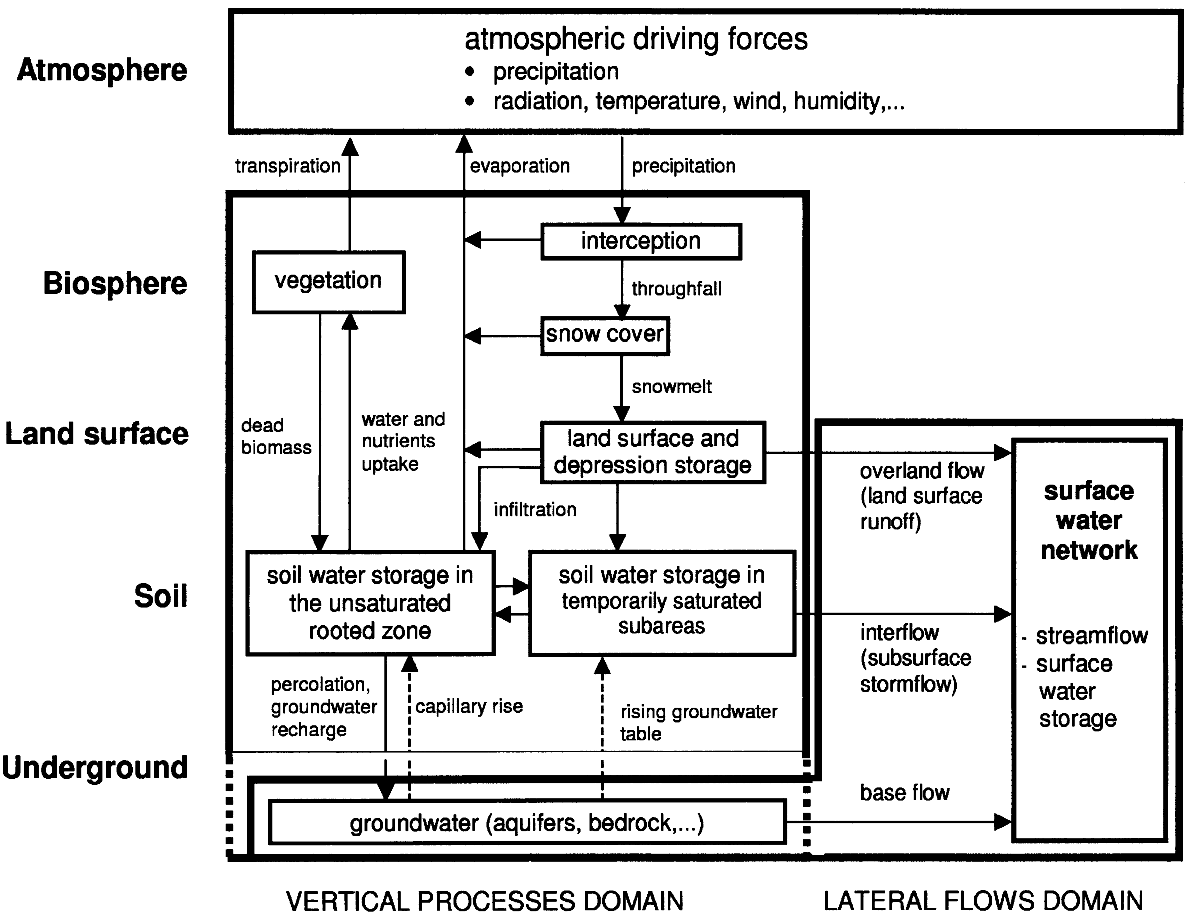

Fig. D.1. Schematic representation of the typical sequence of terrestrial hydrological processes with indication of vertical processes (fluxes in the *left block* marked by *up-* and *downward arrows*) and lateral flows (*lower right part, horizontal arrows*), after Becker et al. (2002)