4.5 Mean Annual Rate of Percolation from the Soil

The mean annual rate of percolation from the soil is defined as the amount of water that leaves the soil after consideration of capillary rise (Map explanations 5.5, Fig. 1). It is expressed in mm/a.

Movement of water in the unsaturated zone is affected by infiltration of precipitation and irrigation water, evaporation, absorption of water by plant roots, and ascent of water from the groundwater table by capillary action. The percolating water leaves the soil as interflow, discharging into surface water bodies, or via the groundwater table, recharging the groundwater. In contrast to the mean annual runoff (Map 3.5), the mean rate of percolation from the soil does not include surface runoff. In contrast to groundwater recharge (Map 5.5), it includes interflow.

In addition to its significance for quantifying the amount of water available for the water supply, percolating water affects soil formation and the migration and leaching of plant nutrients and contaminants. Knowledge of the rate of percolation is of particular importance for protecting groundwater quality.

Methodology

The rate of percolation from the soil is determined primarily by the soil water balance, for which mainly pedological methods are used. Empirical equations and nomograms have been used up to now to calculate long-term mean values for the rates of evapotranspiration and percolation (Renger & Strebel 1980, Renger & Wessolek 1990). These methods are based on extensive field measurements of the annual rate of percolation and simulations using the GWNEU hydrologic budget model (Renger et al. 1977, Renger & Strebel 1982, Wessolek 1989). In the development of these empirical methods, only input data (pedological and meteorological parameters) that can be determined easily or are available in a database were used. In this way the regression equations can be used widely in practice. Map 4.5 is based on a new method comparable to those listed above.

Renger & Strebel (1980) derived the first multiple regression equations for calculating soil-influenced components of the hydrological budget. After further studies, they developed improved equations with which the annual rate of percolation from the soil in northern Germany could be calculated for a specific land use, e. g., coniferous forest, arable land, and grassland, with a standard deviation of 20–30 mm/a. Because these equations could not be applied for the whole of Germany, i. e., the spectrum of site conditions on which the equations were based was not sufficient, further development of the regression method was necessary that included

- further climatic regions with larger differences in precipitation and evapotranspiration,
- slopes (with consideration of surface runoff on arable land),
- soils near the groundwater table (with better consideration of capillary rise).

The regression equations to calculate the rate of percolation from the soil were modified for two further reasons:

- A new calculation of the potential evapotranspiration depth (FAO grass reference evapotranspiration) of Germany is available (Map 2.12), replacing the previously used Haude formula for evapotranspiration.
- The new countrywide correction of the precipitation depths (Map 2.5) makes it necessary to adjust the regression equations.

Fig. 1 Surface runoff from arable land in Germany

Thus, model calculations using the GWNEU water budget model were repeated using a larger number of site variations of soil and climatic parameter values, using the resulting mean annual rate of percolation to derive improved regression equations. The spectrum of site variations included four soils with different water storage capacities, six types of groundwater amplitudes, sixteen climate stations whose climate parameter values can be viewed as representative for the climatic regions of Germany, and four land use types (arable land (with the typical succession of grain and root crops), grassland, coniferous forest, and deciduous forest). The results of all the scenarios were analysed using multiple regression methods. New regression equations were derived, from which reliable estimates of the rate of percolation from the soil can be calculated. In contrast to the equations used previously, the nonlinear dependence of the rate of percolation on plant-available soil water and the climatic conditions at the respective site is distinctly better reproduced.

Before the rate of percolation from the soil was calculated, the proportion of precipitation accounted for by the surface runoff was estimated empirically and subtracted from the mean corrected precipitation depth. The empirical curve number method (USDA-SCS 1972) was used for this purpose. This is an often tested method that takes land use, soil, precipitation, and slope into consideration. As published by DVWK (1984), the method requires that the soil be classified as one of four "hydrological soil types", reflecting a semi-quantitative assessment of the infiltration capacity. With the additional consideration of the slope and the long-term frequency of rain events defined as heavy rain, the mean annual surface runoff was then calculated for arable land (Fig. 1). For grassland and forest, it was considered that surface runoff plays only a minor role, owing to the year-round vegetation cover and a nearly complete infiltration of precipitation in permanent pore systems with macropores and in the humus layer.

The new method of the Technical University of Berlin (TUB) and BGR (Wessolek et al. 2003) consists of eight regression equations. In order to calculate the mean annual rate of percolation for arable land, grassland, coniferous forest, and deciduous forest and alternatively for sites with a shallow groundwater table (under consideration of capillary rise) or for sites with a deep groundwater table (i. e., no capillary rise), six kinds of input variables have to be known:

mean annual corrected precipitation depth	Map 2.5
mean corrected precipitation depth during the summer half-year	Map 2.6
mean annual potential evaporation depth as grass reference evapotranspiration	Map 2.12
available field capacity in the effective root zone	Map 4.3
calculated mean annual surface runoff R_0	Fig. 1
mean amount of capillary rise	

The base map for Map 4.5 – as for Maps 4.1 to 4.4 – was a land-use version of the 1 : 1 000 000 Soil Map of Germany (BÜK 1000; Hartwich et al. 1995). The legend of the land-use version of the soil map shows representative soil profiles for each of the land cover arable land, grassland, and forest. The land cover data were obtained from the "CORINE Land Cover" (Map 1.4) and aggregated into the three land-use classes of this map. In order to be able to calculate the percolation rate with the TUB_BGR method, the percentage of arable land, grassland, coniferous forest and deciduous forest in each of the classes of the CORINE land cover map had to be estimated (e. g. the unit "complex cultivation patterns" is parameterised as 40 % arable land, 35 % grassland, 25 % deciduous forest and 0 % coniferous forest, respectively).

Map Structures

In contrast to Maps 4.1 to 4.4, a grid calculation was chosen for Map 4.5, because at the 1 : 2 000 000 scale the range of precipitation values within the individual polygons of the land-use soil map was too large. Areas with an annual rate of percolation of up to 200 mm were subdivided into 50 mm intervals; areas with high precipitation rates at high elevations were divided into 500 mm intervals. Intertidal flats, the built up areas of large cities, areas of large open mineral extraction sites, dump sites, and rocky areas without vegetation or with permanent snow cover were not evaluated.

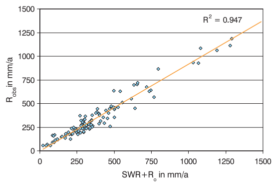

Fig. 2 **Comparison of the measured runoff rates (R_{obs}) with the mean rate of percolation from the soil (SWR) plus surface runoff (R_0) in selected catchment areas** (for the locations of the test catchment areas see Explanatory Notes for Map 5.5, Fig. 4)

In Germany, the areal distribution of the long-term mean rate of percolation from the soil is primarily a function of precipitation depth and only secondarily influenced by land cover and soil properties. The regional pattern, therefore, resembles that of precipitation depths in the Maps 2.2 to 2.6. The highest percolation rates are found in the Alps and high elevations of the Harz Mts., the Rheinisches Schiefergebirge (Rhenish Slate Mts.), the Black Forest, the Bayerischer Wald (Bavarian Forest), the Thüringer Wald (Thuringian Forest), and the Erzgebirge (Ore Mts.).

Very low values of less than 50 mm/a are found in the Magdeburg Börde and Thuringian basin regions. These areas correlate with those with annual precipitation depths of less than 550 mm. In regions with annual precipitation depths of more than about 800 mm, soil properties and depth to the groundwater table have little influence on the rate of percolation and differences are due essentially only to land use. The influence of soil properties and depth to the water table on the rate of percolation increases in importance with decreasing precipitation depth. This is observed particularly clearly in northeastern Germany. The typical soils of river valleys contribute little to the percolation rate or even capillary rise predominates: The groundwater table is so high that the vegetation has an optimal water supply via capillary rise and the potential evapotranspiration is nearly reached, which can be higher than the local precipitation depth.

For Germany as a whole, a mean annual rate of percolation from the soil of 316 mm/a was calculated and a mean surface runoff of 7 mm/a.

Practical Information

To verify the TUB_BGR method, the mean rate of percolation plus surface runoff in 106 catchment areas (Map 5.5, Fig. 4) of different sizes, land cover, soil properties, and geomorphological and climatic conditions was compared with the runoff measured by gauging stations. The differences between the measured and calculated runoff values average less than 10 % and are due in part to anthropogenic influences (e. g., tapping of groundwater for drinking water and irrigation). Regression analysis shows a good correlation between the measured and calculated values (Fig. 2), with the calculated values averaging about 8 % higher than the measured values. The calculated values of Map 3.5 are also higher than the measured ones by about the same amount. A detailed comparison of the results and methods used for Maps 3.5, 4.5, and 5.5 is given by Jankiewicz et al. (2003). The overestimation of the mean rate of percolation from the soil by the TUB_BGR method should be investigated in future research.

Map 4.5 is based only on the hydrological parameter values of one of the soils of the soil associations shown on the 1 : 1 000 000 soil map (BÜK 1000). The quality of this data base is discussed in the explanations of Map 1.3. The values on which the calculations for Map 4.5 are based can in some cases deviate from the mean values for the plant-available soil water of all soils weighted according to size of the area.

The mean rate of percolation from the soil for Germany as a whole must take into consideration the influence of irrigation. A regional differentiation was not made for this map because well managed irrigation will increase the mean rate of percolation by only about 20 mm/a.

The new TUB_BGR method is based on the assumption that separate regression equations for different land use can be applied for the whole of Germany. It was found, however, that further differentiation according to climate yielded a larger correlation coefficient. In addition, climate zones should be taken into consideration in the calculation of the effective root zone, as well as improved consideration of capillary rise in areas of near-surface groundwater.