# 5.5 Mean Annual Groundwater Recharge

The groundwater recharge (GWN) is an important parameter of the water budget, because it provides a measure of the regeneration of our groundwater resources. It is of special interest for water resources management, since more than 63 % of the drinking water supply in Germany is from the groundwater (Map 7.2). According to DIN 4049 the groundwater recharge rate is obtained by substracting the rate of evapotranspiration (ETa) and fast runoff components from the corrected precipitation rate ($P_{corr}$). The long-term mean of this parameter is equivalent to the baseflow ($R_B$) from the aquifer. Groundwater recharge and baseflow are given in mm per unit time, $m^3$ per unit time, or liter per unit time.

Groundwater recharge is shown in Figure 1 as part of the water budget of the region. The total runoff (R) (Map 3.5) can be subdivided into direct runoff ($R_D$) and baseflow ($R_B$). The direct runoff is the sum of the surface runoff, interflow and part of the groundwater flow. The baseflow is the long-term, stable flow into a stream from the aquifer even during dry periods. It is often considered equivalent to low flow (Map 3.10). The baseflow is normally determined from the discharge hydrograph recorded by the stream gauge.

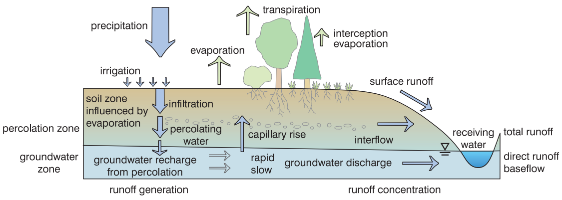


**Fig. 1** **Factors that influence groundwater recharge** (Map 3.5, Fig. 1)

Thus, the long-term, mean net flow into the aquifer (i.e., the groundwater recharge), without consideration of changes in storativity can be considered equivalent to the baseflow. The groundwater recharge is given in equations 1 to 3 as a function of the baseflow, total runoff, direct runoff, infiltrated precipitation, and evapotranspiration:

$$GWN = R_B \quad \text{in mm/a} \quad (1)$$
$$GWN = R - R_D \quad \text{in mm/a} \quad (2)$$
$$GWN = P_{corr} - ETa - R_D \quad \text{in mm/a} \quad (3)$$

## Methodology

A regression model designed for the scale of the Hydrological Atlas of Germany (HAD) and the given data (NEUMANN et al. 2003) was used to calculate the mean annual groundwater recharge. The output parameters of the model are the measured baseflow and the corresponding baseflow index BFI ($=R_B/R$), which is used as a measure of the ratio of baseflow to the total runoff. The determination of the baseflow index from the hydrograph is based on an empirical equation of KILLE (1970). This equation sets the reduced monthly mean low flow equal to the rate of groundwater recharge. This assumption is supported by physically based procedures such as the linear storage model DIFGA (SCHWARZE et al. 1999). Data available for all of Germany and parameters derived from them were used as independent variables. The model was calibrated using the long-term regional mean values of the daily runoff data from 106 catchment areas in Germany (Fig. 4). The catchment areas were selected to obtain an environmentally representative data base. Criteria were, for example, correspondence of the surface water and groundwater drainage areas, little or quantifiable anthropogenic influence, and a data set that is as complete as possible. The digital data used for modeling groundwater recharge were taken mainly from the HAD database.

The two-step procedure described in the following paragraphs and represented in Figure 3 was developed for the preparation of the map. This was done to obtain the best fit of the model results to the actual baseflow conditions in all regions. This is of particular importance for the 1 : 1 000 000 map scale, because the uncertainties in the data can have a direct influence on the quality of the groundwater recharge rates produced by the model.

In the first step of the regression analysis, the relationship between the baseflow index (BFI) and the factors that significantly influence the mean baseflow is formulated in a regression equation and applied to each grid cell:

| | | |
|---|---|---|
| BFI = f | ratio of $R_D$ to R | Map 5.1 |
| | slope gradient (percent area with > 5°) | DEM/Map 1.1 |
| | drainage density | Map 1.2 |
| | land cover (percent forest area) | Map 1.4 |
| | available field capacity | BÜK1000/Map 1.3 |
| | depth to groundwater table (percent area 0–100 cm) | BÜK1000 |

This equation was then used to analyse catchment areas with a total runoff of less than 200 mm/a separately from those with more than 200 mm/a total runoff. The groundwater recharge rates in the catchment areas with < 200 mm/a were calculated by multiplying the regional BFI with the total runoff (Map 3.5) calculated using the Bagluva procedure (GLUGLA et al. 2003). The groundwater recharge rates in the catchments with > 200 mm/a were determined using a second regression model that includes the total runoff ($R_{Bagluva}$) and the mean depth to the groundwater table as independent variables, in addition to the baseflow index determined in the first step:

| | | |
|---|---|---|
| BFI = f | $R_{BAGLUVA}$ | Map 3.5 |
| | depth to groundwater table | BÜK1000 |
| | regionalised BFI | Regression Equation 1 |

The results of the analyses are shown on the map of mean annual groundwater recharge. The mean annual groundwater recharge rates show a good agreement (variance explained 0.8) with the baseflow values derived from the stream gauge data (Fig. 4). The values for recharge < 300 mm/a show little scatter and represent more than 95 % of the area of Germany. The areas of the Schwarzwald (Black Forest) and the Alps with a high precipitation rate (> 300 mm/a) show more scatter.

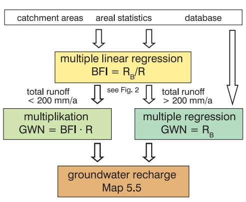


**Fig. 3** **Determination of the rate of groundwater recharge via a multiple linear regression calculation in a two-path procedure**

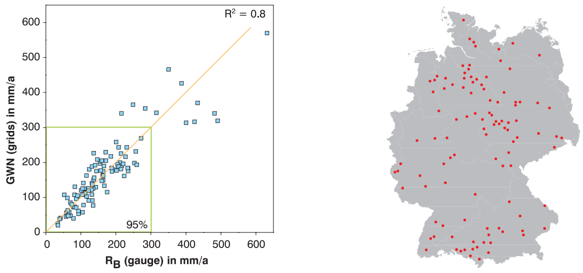


**Fig. 4** **Comparison of the calculated groundwater recharge (mean value for each catchment area) with the baseflow determined from the stream gauge records. The catchment areas represented within the green box cover 95 % of Germany. Right: Locations of the 106 selected catchment areas.**

## Map Structures

Map 5.5 shows the mean annual groundwater recharge with a spatial resolution of 1 km² for the period 1961–1990. The values range from less than 25 mm/a in northeastern Germany to more than 500 mm at high elevations in the Alps. The class intervals are 25 mm for recharge values <100 mm/a and 50 mm/a for values from 100 mm/a to 300 mm/a.

Map 5.5 and Map 3.5 show similar distributions, but the contrasts within regions are greater on Map 5.5. On this map, the areas of high precipitation (e.g., Black Forest, Harz Mts., and Rheinisches Schiefergebirge (the Rhenish Slate Mts.)) and those with little precipitation (e.g., the Thüringer Becken (Thuringian Basin) and the Main-Franken (Main/Franconia) region) show prominently, like on Map 2.5, which shows the corrected precipitation depths. In contrast to the influence of hydrometeorological parameters, all the other parameters, such as slope gradient, depth to the groundwater table, type of soil, land cover, drainage density, and hydrogeology, have only local effects. This is best seen in northwestern Germany, where the locations of rivers, marshes, and bogs show little correlation with the climate. A further example of this is the greater Berlin region, where the groundwater recharge rates are significantly higher than in the surrounding area due to differences in evaporation rates.

The following mean water balance is obtained for Germany as a whole:

$$GWN = P_{corr} - ETa - R_D \quad \text{in mm/a}$$
$$135 = 859 - 532 - 192 \quad \text{mm/a}$$

The baseflow index (Fig. 2) obtained in first step of the regression calculation describes the site-specific and recharge-relevant runoff. The BFI provides a long-term model parameter that is independent of the short-term variability of the climate and reflects the large influence of hydrogeology (Map 5.1), land cover (Map 1.4), and relief (Map 1.1) on runoff. This can be clearly seen, for example, in the high proportion of direct runoff in the Rhenish Slate Mts. and the drained areas of the lowlands of northern Germany (~0.2) and in the high proportion of baseflow (~0.8) in the areas of unconsolidated rock in the North German Lowlands, the Molasse region of southern Germany, and the Rhine graben region.


**Fig. 2** **Results of the first step of the regression: base flow index (BFI) as a measure for the proportion of groundwater recharge (base flow) in the total runoff. This parameter is independent of climate**

## Practical Information

The groundwater recharge varies considerably, not only from area to area, but also with time. The variation with time caused by the climate is reflected in changes of the depth to the groundwater table and is closely related to the variation in the amount of precipitation (see explanatory notes to Map 2.2). Similarly, changes in land cover and other anthropogenic situations can affect the rate of groundwater recharge. Thus, a 30-year mean recharge rate provides only an approximation of the actual water balance (Map 2.9).

The theme of Map 5.5 is related to those of Maps 3.5 and 4.5. Map 3.5 deals with the total runoff without consideration of the individual flow components. Maps 4.5 and 5.5 deal with different fast flow components of the total runoff. Because only surface runoff is of importance for the percolation rate of Map 4.5, in contrast to the groundwater recharge rate for which all the fast flow components reduce recharge, these three water balance parameters have the following hierarchy:

total runoff > percolation rate > groundwater recharge.

A detailed comparison of the model results is given by JANKIEWICZ et al. (2003).