3.5 Mean Annual Runoff Depth

The volume of water that flows through a certain channel cross-section per unit of time is referred to as *discharge*. It is usually measured in m^3/s or l/s. If the flow observed at a certain cross-section is applied to the surface of the related catchment area, the resulting entity is referred to as *discharge per unit area* in $l/s{\cdot}km^2$ or *runoff depth* in mm/unit of time.
Figure 1 shows the factors which determine the runoff in the area and thus the discharge in the receiving water (Map 3.9).

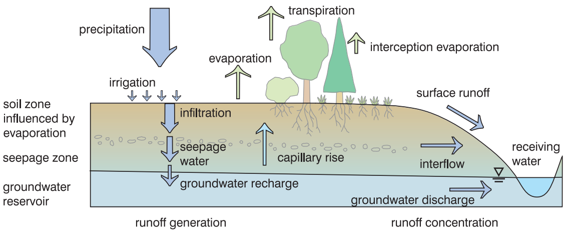


Fig. 1 **Runoff generation and runoff concentration**

Precipitation is intercepted by plant surfaces, flows into the receiving water in the form of surface runoff or infiltrates the subsoil immediately. Part of the infiltrated or intercepted water can re-enter the atmosphere by evaporating from the soil, transpiring from plants or evaporating from intercepting surfaces, the remainder seeps away.

The seepage water, which accumulates in less permeable layers, emerges again in the form of interflow on the surface or in receiving water depending on the surface gradient. Only the part of the seepage water which enters the groundwater reservoir (Map 4.5) contributes to the groundwater recharge (Map 5.5). The groundwater discharge ultimately feeds into the receiving water even in low-precipitation periods. The capillary rise from the groundwater reservoir can help improve the supply of water to vegetation in areas close to groundwater table.

To calculate the long-term average, the *total runoff depth* R below the evaporation-influenced range is defined as the difference between the hydrometeorological factors "corrected precipitation depth P_{corr} minus actual evapotranspiration depth ETa" for selected units of area. Sprinkling on agricultural irrigated areas is added to the precipitation at the relevant points. Changes in the water stocks in the reservoir are not taken into account.

$$R = P_{corr} - ETa \quad \text{(in mm/a)} \qquad (1)$$

With area units of 1 km^2, it can be assumed that the land-surface runoff, interflow and groundwater discharge are largely contained in the total runoff of the unit. The mean runoff depth at the measuring point in the receiving water results in the arithmetical mean of the values of the total runoff depth of all area units in the related catchment area.

The runoff process can be illustrated in terms of space and time (down to daily intervals) using rainfall-runoff models. After runoff concentration in the catchment area, the variably simulated total runoff depth, consisting of land-surface runoff, interflow and groundwater discharge, corresponds to the temporarily variable channel runoff of the receiving water as recorded at the measuring point. The volume of water which flows into or out of the individual area can only be roughly estimated because it is not possible to measure the groundwater discharge in the aquifers. This error becomes negligible as the catchment area grows in size.

There are currently over 4000 gauging stations in Germany which are used to measure the water level resp. the discharge (Map 3.1). The readings allow the overall effect of all influences on the discharge to be seen for the entire catchment area. A more refined representation of runoff depth R, as carried out in Map 3.5 for grid cells of 1 km^2 as an average annual total, on the other hand, provides more detailed information on the *total runoff generation.*

Viewed over several years, the total runoff indicates the volume of the potential water resources. Its usability is limited by many factors, such as yield, quality, ecological aspects and storage capacity. But the values are relevant for examining the water resources in small areas such as catchment areas of waterworks and reservoirs, for instance.

The total runoff depth is limited by the corrected precipitation. In areas of low precipitation and in regions with groundwater close to the land surface, the evapotanspiration can exceed the corrected precipitation which means that negative runoff values point to discharge areas.

Methodology

In order to calculate mean annual runoff depths by accounting the precipitation and evapotranspiration values, the latter two values must be precisely determined. For precipitation, which has largely been determined for specific regions based on measured values, the corrected values in Map 2.5 are used. The actual evapotranspiration is calculated using the BAGLUVA method presented in Map 2.13 and based on the modified Bagrov equation, with ratios derived at the site being applied to the overall area (GLUGLA et al. 2002).

Figure 2 shows the HAD Maps and informations used to produce Map 3.5. It also demonstrates the close connection between the key parameters and the fact that they are the primary factors that influence the evapotranspiration and runoff depths.

In order to verify the method, the values for mean annual runoff calculated using Equation (1) for catchment areas of different size, land use, soil properties and geomorphological and climatic conditions were compared with the runoff depths based on measurements at the gauging stations concerned (Fig. 3).

To calculate the runoff depth, two values which are of similar size in some areas are subtracted from one another where the individual errors could accumulate and thus result in a large relative error in the case of low runoff values. Figure 4 shows the dispersion of the calculated runoff depths in relation to the values based on measurements. The average differences are below 5 % but can be as much as 30 % in some areas, e. g. due to anthropogenic influences (discharge and inflow of water, intake, sprinkling) and problems in determining the catchment area to which the water belongs (JANKIEWICZ & GLUGLA 2002).

The land-surface runoff (direct runoff component) was not explicitly considered in this method since it is a phenomenon which occurs on a small scale. A large part of the surface runoff, which is most relevant in higher locations, seeps away again in the valley floors. The influence on the runoff characteristics of the vertical and lateral delay due to snowfall resp. snow thawing has yet to be clarified.

The method used here is the same for the whole of Germany. In the Hydrological Atlas of the Federal Republic of Germany (1978), the runoff depth map was based on a regression method. The N-A-U-Atlas ("Precipitation-Runoff-Difference = Evapotranspiration") published for the GDR in 1958 was also based on annual runoff time series. This new version aims to be considerably more precise, as made clear by the more extreme variation in runoff formation from one grid field to the next – in line with the land cover and soil. However, due to the different methods used and the improved background data, the runoff depths calculated cannot be compared directly.

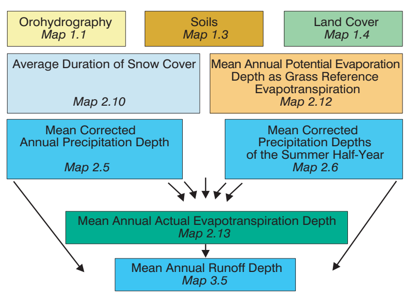
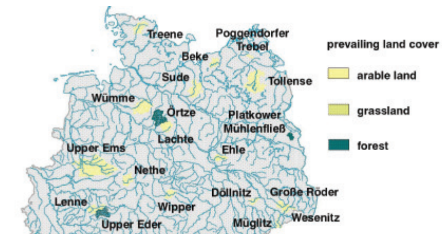


Fig. 2 **Use of HAD data to calculate the mean annual runoff depth**



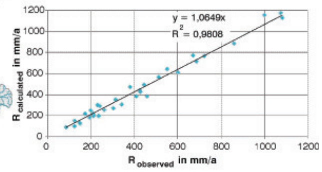


Fig. 3 **Selected catchment areas**

Fig. 4 **Observed and calculated discharges for different catchment areas**

Map Structures

Map 3.5 shows the mean annual runoff depth in grid cells representing 1 km^2 each for the period 1961–1990. The values are below 100 mm/a in north-east Germany and over 2000 mm/a in the higher regions of the Alps. The class amplitudes shown are 50 mm/a for the values below 200 mm/a, 100 mm/a for the values up to 1000 mm/a and 500 mm/a for the classes above 1000 mm/a.

Despite the actual evapotranspiration depth ETa (Map 2.13) varying significantly within a small area, the large-scale differences in the corrected precipitation depth P_{corr} (Map 2.5) determine the overall runoff depth. This is made particularly clear by the high values on the ridges of the upland regions and the Alps with its special status due to its snowpack and a partial absence of vegetation. Within the areas with lower runoff values in the low-precipitation north-east region of Germany, where, for instance, the groundwater recharge in the unconsolidated sediments of the glacial valleys is limited by the runoff depth and where the groundwater is often discharging through evapotranspiration when it is close to the land surface, there are urban "pockets" of high runoff values. Leeward of the upland regions (east of the Harz Mountains, Thüringer Becken), the climatic influence (low precipitation depths with high values of grass reference evapotranspiration) on the runoff generation becomes very evident.

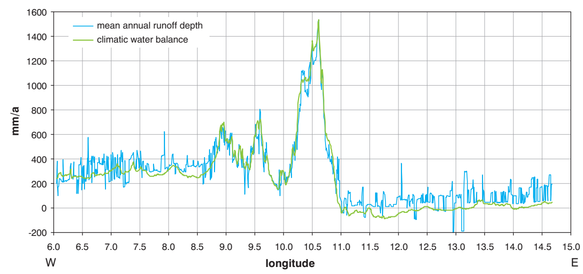


Fig. 5 **West/east section of mean annual values of runoff and climatic water balance for the reference period 1961–1990 at latitude 51° 50' north**

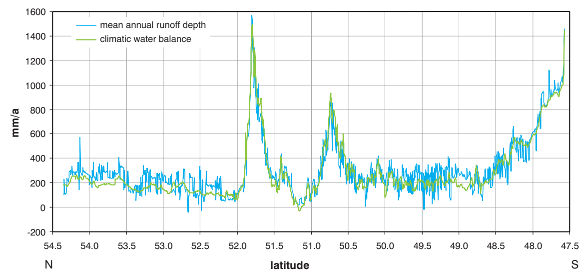


Fig. 6 **North/south section of mean annual values of runoff and climatic water balance for the reference period 1961–1990 at longitude 10° 10' east**

The resulting values for the territory of Germany are:

$$\mathbf{R\ (327\ mm/a)\ =\ P_{corr}\ (859\ mm/a)\ -\ ETa\ (532\ mm/a)}$$

R's maximum range of fluctuation extends from -258 mm/a in the discharge areas in north-east Germany to 3344 mm/a in the higher regions of the Alps.

As in Map 2.13, Figures 5 and 6 show west/east and north/south sections for grid cells indicating the runoff depth and climatic water balance (Map 2.14); the two lines cross at the summit of the Harz Mountains. The runoff depths reflect the climatic water balance CWB = corrected precipitation P_{corr} – grass reference evapotranspiration ET_0 especially in the north/south section, and hover around this value depending on the type of land cover and the soil properties. In the west/east section, the continental climatic influence leeward of the Harz Mountains affects the climatic water balance, which is sometimes negative. The runoff depths are also lowest here.