3.9 Mean Annual Discharge and Discharge Variability

In hydrology and water management, the term discharge refers to the volume of water which flows through a defined cross-section of a watercourse per unit of time. Depending on the size of the river or stream, the discharge is measured either in m³/s or l/s. If the discharge is applied to the related section of the catchment area, the resulting measurement is the discharge per unit area (l/s·km²) or depth of runoff (mm/a). The latter one can be directly compared with the precipitation and evaporation parameters in the water balance equation.

The discharge in surface waters has been changing continuously. This is true both of the geographical distribution and the time and duration of discharge events. The changes have been caused by the variety of ways in which water is used and hydraulic intervention in the natural watercourse systems; well-known examples are dams, river-regulation, surface-sealing and water transfer beyond the natural boundaries of the catchment area.

The regional distribution pattern of the mean annual discharge (MQ) offers valuable basic information on the availability of surface water for public, industrial, agricultural and private water consumption as well as for shipping. However, the mean volume of discharge varies considerably depending on the region as well as time and duration. During low-frequency, high-volume discharge events (floods), large volumes of water flow through the watercourses without being able to be used for water management purposes. Furthermore, major installations and housing estates which use large amounts of water also need information on whether the water volume they require can be guaranteed without any risk of long interruptions in supply. Because of these dependencies, measurements of flow variability, based on the quotients of main discharge values (MHQ/MNQ or HHQ/NNQ), are important indicators. Multi-year discharge measurements are required in order to calculate the main values for a gauging station (Table 1).

Table 1 Main discharge values for gauging stations (correspondingly discharge values per unit area NNq, Nq etc.)

NNQ	lowest discharge ever observed
NQ	lowest discharge value during equal intervals (e.g. month, half-year, year) in defined period
MNQ	mean of the lowest discharge values of equal intervals (e.g. month, half-year, year) in the single years during defined period
MQ	mean of daily discharge values of equal intervals (e.g. month, half-year, year) in the defined period
MHQ	mean of the highest discharge values of equal intervals (e.g. month, half-year, year) in the single years during defined period
HQ	highest discharge value during equal intervals (e.g. month, half-year, year) in defined period
HHQ	highest discharge ever observed

Methodology

The map is based on all the available main discharge values measured at the approximately 1 000 gauging stations for discharge rate and water level (Map 3.1). The water-level and discharge values are published regularly in the Deutsches Gewässerkundliches Jahrbuch (DGJ). In order to generate a long-term view of the mean annual discharge values represented in bands, the main discharge values for gauges along the watercourse have to be regionalised. The regionalisation algorithm used follows two simple rules. Firstly, the gauge related values were applied to the watercourse downstream and upstream of the gauge half-way to the next gauge. Using this as the basis, the regional values were revised in line with hydrological aspects. In this context, the total discharge values were used as the basis for the long-term characterisation particularly where watercourses join (confluence). In tidal areas it is almost impossible to determine the rate of discharge without any outside influences. In these cases, it is usually only the water level that is measured, which means that there were no base values to use for the long-term view in those areas.

Map Structures

In the map, the mean annual discharge values (MQ) of selected watercourses are presented in a long-term view with the bandwidths corresponding to defined units of measurement for the channel flow in the river reaches. This manner of presentation makes differences in channel flow very easy to see. The shading of the discharge bands indicates the regional variability of the discharge. For this map, the discharge variability is calculated as the quotient based on the mean highest and lowest discharge values (MHQ/MNQ). All relevant gauges are shown, too. The main discharge values of the 15 named gauges are listed in Table 2, which also shows the ratio of the extreme values based on the quotient of the highest and lowest discharges ever observed (HHQ/NNQ). This ratio is numerically higher – sometimes by more than one order of magnitude – than the ratio of mean highest and lowest discharge values presented in the map. The tidal areas along the North Sea coast are shown in their entirety. In some watercourses – particularly in the large rivers – the tide head is defined artificially by weirs and barrages and brought forward towards the sea.

Mean discharge values

The discharge in the rivers situated in the humid area of the Federal Republic of Germany increases as the catchment area and length of the water course increase. This increase can be clearly seen in the long-term view of the map. It is illustrated even better by hydrological longitudinal sections (Fig. 2). These longitudinal sections show the mean discharge (MQ), the mean lowest discharge (MNQ), the mean highest discharge (MHQ) and the mean highest discharge per unit area (MHq). The specific discharges usually decrease in the direction of the flow, corresponding with the decrease of the runoff generation with increasing catchment area and due to meteorological and catchment related characteristics. Occasionally, the discharge can jump if high-volume tributaries flow into the receiving waters. Such a situation is shown in Fig. 2 for the points at which the Aare and the Moselle flow into the Rhine. The Danube's mean discharge is more than doubled when the Inn flows into it. At the confluence the Danube's mean discharge is around 665 m³/s, the Inn's is roughly 765 m³/s.

The hydrological longitudinal section of the Rhine downstream from Lake Constance is a prime example of the flow in a watercourse (Fig. 2). The values given in the hydrological longitudinal section are based on the 1931–1990 time series and were taken from the Deutsches Gewässerkundliches Jahrbuch (DGJ). At Constance, the Rhine's catchment area is 10 922 km², the mean discharge is approximately 350 m³/s and the mean highest discharge per unit area exceeds 30 l/s·km². By the mouth of the Aare, the mean discharge has reached 451 m³/s. The Rhine's mean discharge (MQ) almost doubles due to the Aare joining it and reaches around 1000 m³/s. There are no significant rises in the mean discharge in the Upper Rhine Valley between the Aare and the Neckar. During this approximately 325 km-long stretch the discharge increases to around 1 220 m³/s and the mean highest discharge per unit area reaches 22.5 l/s·km²

Fig. 1 Flood and low flow situation at Ruhr

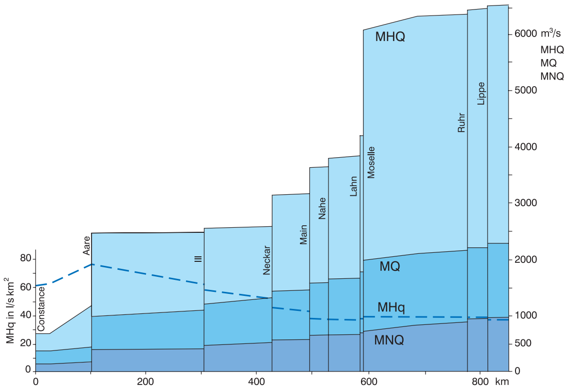

Fig. 2 Longitudinal section of the discharge along the Rhine downstream of Lake Constance up to the Dutch border (time series 1931-1990)

at the mouth of the Neckar. Again, the discharge only increases slightly between the mouths of the Neckar and the Main. With its mean discharge of approximately 160 m³/s, the Main raises the Rhine's mean discharge to around 1 550 m³/s.

Whereas the mean discharge grows at the mouth of the Moselle in relation to the size of the Moselle catchment area, the mean highest discharge increases disproportionately from around 4 250 m³/s to 6 000 m³/s. This value indicates the high flood-risk potential which the Moselle catchment area poses for the lower course of the Rhine. The Moselle's susceptibility to flooding is chiefly due to the pronounced relief and the low permeability of the bedrock in the upland section of its catchment area. Downstream from the mouth of the Moselle, the discharge only increases slightly. At Emmerich, near the German-Dutch border, the Rhine's catchment area takes in 159 784 km² and the mean discharge is approximately 2 300 m³/s, corresponding to a mean specific discharge of around 14 l/s·km².

Table 2 Selected main discharge values for some gauging stations and discharge variability (rounded values)

river basin (gauging station)	**area** (km²)	**period** (years)	**MQ** (m³/s)	**HHQ** (m³/s)	**NNQ** (m³/s)	**ratio HHQ/NNQ**	**MHQ** (m³/s)	**MNQ** (m³/s)	**ratio MHQ/MNQ**
Mulde (Golzern)	5 442	87	61	1 740	1	1243	497	13	38
Moselle (Cochem)	27 088	65	315	4 170	10	417	2060	60	34
Neckar (Rockenau)	12 710	46	135	2690	18	146	1200	36	33
Ruhr (Hattingen)	4 118	54	71	1950	2	1189	524	18	29
Main (Kleinheubach)	21 505	38	158	1800	11	164	790	48	16
Inn (Eschelbach)	13 354	66	368	2900	82	35	1460	127	11
Weser (Intschede)	37 720	57	324	3500	59	59	1250	125	10
Unstrut (Laucha)	6 218	53	31	363	5	79	105	11	10
Saale (Calbe-Grizehne)	23 719	66	115	680	12	59	379	44	9
Elbe (Neu-Darchau)	131 950	72	712	3840	128	30	1870	274	7
Havel (Rathenow)	19 288	44	92	295	3	98	165	25	7
Rhine (Rheinfelden)	34 550	66	1030	4270	267	16	2760	453	6
Rhine (Rees)	159 300	65	2280	12200	590	21	6620	1040	6
Danube (Hofkirchen)	47 496	96	636	4470	165	27	1870	302	6
Odra (Hohensaaten-Finow)	109 564	54	521	3480	111	31	1220	259	5

Discharge variability

The discharge of Germany's major rivers usually remains quite balanced. In the upper courses of the smaller tributaries, however, the flow variability is higher, as shown by the increase in blue and red areas on the map. The variability is particularly high in the source regions of the uplands, e.g. the Rheinisches Schiefergebirge (Rhenish Slate Mountains), the Schwarzwald (Black Forest) and the eastern part of the Erzgebirge Mountains. This corresponds to the general tendency for the discharge variability to drop as the catchment area increases because the larger the catchment area, the more local conditions are compensated. This trend can also be seen in the ratio of the extreme values (HHQ/NNQ) in Table 2. The major river systems of the Rhine, Elbe, Danube and Odra have low discharge variabilities whilst the smaller-scale catchment areas of the upland ranges (e.g. Ruhr or Mulde) have very high discharge variabilities.

The map and the main values in Table 2 show further specific regional features in Germany's hydrological structure. Although the Eschelbach (Inn), Kleinheubach (Main), Cochem (Moselle) and Rathenow (Havel) gauging stations each cover areas of over 10 000 km² and thus have relatively large catchment areas, their discharge variabilities differ considerably. The Inn's variability is quite low with the influence of the Alpine foothills and their huge glaciofluvial gravel surfaces compensating for the flow with rich groundwater reservoirs. The Havel, with a catchment area which developed in loose glacial and glaciofluvial sediment, reacts similarly. The role of the Alpine foothills' large groundwater aquifer is also reflected in the Danube's variability pattern. Its upper course and northern inflows have an upland character with relatively high variability whereas the southern inflows from the Alpine foothills increasingly balance out the flow.

The rivers in the upland ranges (Main and Moselle) have significantly higher discharge variabilities than the lowland rivers which are mainly controlled by groundwater input. Beneath the catchment areas in the upland ranges there is bedrock of differing solidity and often with low storage capacity. Of the larger catchment areas in the uplands, the Moselle has a particularly high discharge variability because the Rhenish Slate Mountains mainly stands on impermeable slate which is not very conducive to groundwater recharge. The pattern is similar for most waters in the hercynian and crystalline mountain complexes, as can be seen in the examples of the Ruhr and Mulde for smaller-scale catchment areas. It was in those very areas with their high flow variability that dams had to be built to intervene in the natural water balance in order to reduce the flood risk downstream and to increase the water levels when the water is low (Map 7.4 "Flood Protection").