3.10 Specific Low-Flow MN10q

The occurrence of low-flow situations has a lasting effect on the intensified use of surface water and groundwater. Consequently, low-flow research has increasingly gained in importance. The term „low-flow“ has not been comprehensively defined yet; it is rather a collective term for various indices, which could be applied for the characterisation of flows. Low flows during periods with little or no precipitation are predominantly fed by groundwater (base flow component). Low-flow situations constitute a natural process within the seasonal runoff dynamics of streams, and the biocoenosis of this aquatic habitat is adapted to these situations. Floodplain forests, for example, are dependent on alternating high-flow and low-flow periods.

Our streams are increasingly used during low-flow periods, which may result in dangers for ecology and economy. More detailed knowledge about low flows is of particular importance when water is extracted for consumption or for the use in power stations, when polluted or heated water is discharged, when a continuously navigable channel is required for navigation, or when water is exported to other catchments. Indices, which can be directly deduced from the hydrograph, serve as basis for the planning and evaluation of further interventions into stream hydrology. At ungauged sites, these indices can be acquired through an estimation procedure taking physiographic and hydrometeorological parameters as catchment descriptors.

For each water management issue, particular low-flow indices are asked for. In case of water extraction or discharge, for example, magnitude and frequency of the occurrence of low-flows are of particular interest. The expected duration of low-flow periods needs to be determined to plan for additional water resources, to make provisions for temporal storage of polluted water, or for power plants to prepare for the use of a cooling tower instead of using non-recyclable stream water. For regulated streams, the management of dams and reservoirs requires an analysis of runoff deficits (DVWK 1992, 1983).

For a map to give a beneficial overview of the regional distribution of low-flows several requirements need to be met. Since the map can only represent mean conditions, the stability of the depicted index over time must be considered. To be able to compare different catchments it is necessary to standardise the index with the respective catchment area.

As low-flow index for the map presented, the MN10q (equivalent to the specific MAM10) is selected. The value is an index of the specific discharge during low-flow conditions. It is deduced from a hydrograph as the lowest arithmetic mean of ten consecutive days (Fig. 1). In comparison with the Q347, which is used in Switzerland, the MN10Q (the capital Q signifies the absolute discharge without standardisation by the catchment area) shows a similar temporal behaviour. In contrast to the MN10Q, the Q347 is calculated from a duration curve as quantile (Fig. 1, corresponding to the 95-percentile). Both indices are independent of given threshold values, which are required for the calculation of the maximum duration of a low-flow period or flow deficits. For practical water management issues, the MNxQ is also used for time intervals of x=7, 14, or 21 days.

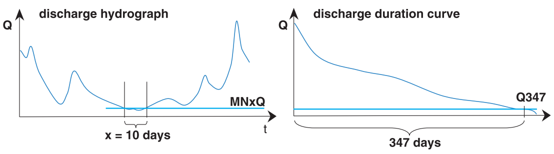

Fig. 1 **Example of the deduction of low-flow indices from a hydrograph (e.g. MN10Q) and from a duration curve (e.g. Q347).** (Threshold approaches, which can be based on either the hydrograph or the duration curve, are not shown)

Methodology

Calculations of low-flow indices for the catchments presented are based on daily flow data of the FRIEND European Water Archive (Flow Regimes from International Experimental and Network Data, Rees & Demuth 2000) and Federal and State data bases. For the determination of MN10Q, the 14-year time series from 1976 to 1989 is chosen to obtain an extensive data set with a good spatial coverage. Research in Baden-Württemberg and Switzerland has shown ten-year-time series to be adequate for an accurate and stable deduction of the MN10Q (and the Q347, respectively) (Schreiber & Demuth 1996, Aschwanden 1992). For the statistical analysis 330 non-nested catchments with catchment areas ranging between 22 km² and 675 km² are selected. For the sake of comparison, the values are computed as specific discharge during low-flow periods, MN10q in l/s·km², for the catchment areas that correspond with the catchment areas as found in the German Hydrologic Yearbooks.

Applying a multiple linear regression model, the specific low-flow parameters are transferred to the entire territory of the Federal Republic of Germany. For this purpose, information on various factors (such as physiographic and hydro-meteorological catchment descriptors) are deduced from other HAD (Hydrological Atlas of Germany) maps. The set of catchments is split into a calibration and a validation data set, respectively. The calibration data set consists of 200 catchments. The calibration yields the following regression model with a coefficient of determination R^2 of 65 %:

	Median of precipitation during the summer months [mm]	Map 2.6
	Lithology (proportion of consolidated sediment) [-]	Map 1.5
MN10q = f	Land cover (proportion of sealed surface) [-]	Map 1.4
	Land cover (proportion of arable land) [-]	Map 1.4
	Minimum drainage density [km/km²]	Map 1.2

Validating the results with the remaining 130 catchments yields a comparable R^2 of 61 %. The results are similar to studies for Baden-Württemberg (R^2= 56 %, Schreiber & Demuth 1996) and Europe (R^2= 65 % to 92 %, Gustard et al. 1989).

For the areal deduction of the MN10q the derived regression equation is transferred to the entire study area. This transfer requires that the catchment descriptors of the study area lie within the range of the catchment descriptors of the calibration data set.

The median size of the investigated catchments, 130 km², is defined as the reference value for the catchment area. Applying a grid-based approach, virtual catchments are created where each 1 km² grid cell is conceptualised as the central point of a circular catchment with an area of 130 km² (point-density method similar to the method used for Map 1.2). The catchment-based estimate for the MN10q value for each cell is calculated by estimating the MN10q within the defined circular catchment around the respective cell based on the regression equation. The resulting map shows the low-flow-index MN10q as a smoothed representation, which is independent of arbitrarily set catchment boundaries.

For the evaluation of the model quality the grid based MN10q values are compared to the observed (gauged) data for the 300 catchments. For 52.1 % of the catchments, the deviations of the estimated MN10q from the observed values do not exceed 1 l/s·km². For 3.6 % of the catchments, the MN10q is underestimated by less than half, for 12.4 % it is over-estimated by more than twice the observed value. The deviations of the predicted MN10q (estimated by the regression model) from the observed values are sorted and aggregated for each large river basin, as shown in Figure 2. The standard deviation of the residual is 1.83 l/s·km².

Map Structures

Map 3.10 shows the MN10q as a raster representation with a resolution of 1 km². The spatial distribution of the MN10q brings out several factors that impact low-flows. These factors are also reflected by the catchment descriptors in the regression equation: Precipitation depth (median of precipitation during the summer half-year) is responsible for the large-scale pattern.

At higher altitude and hence higher precipitation all through the year (such as in the Alps, Maps 2.2 to 2.6) the MN10q may exceed 12 l/s·km². High values (> 6 l/s·km²) can also be found in the Pre-Alps and in the more elevated regions of the lower mountain ranges.

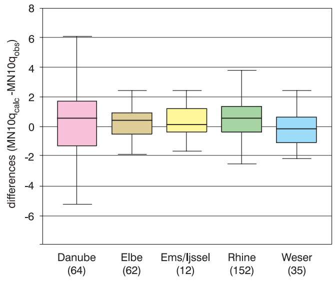

Fig. 2 **Box plots of the residuals**
(estimated MN10q minus observed MN10q), sorted and aggregated by large river basins (in brackets: number of test catchments)

For some regions (e.g. Eifel and Hunsrück), the MN10qs are lower than it would be expected based on altitude alone. This is due to the influence of the lithology (proportion of consolidated sediments). In the Pfälzer Wald (Palatinate Forest), the Eastern Rheinisches Schiefergebirge (Rhenish Slate Mts.), the Erzgebirge (Ore Mts.) and the transitional area between the Donau-Iller-Lech-Platten and the Schwäbische Alb (Swabian Alp), the alternating lithology is reflected by the varying MN10q. Consolidated sediments are characterised by lower MN10qs than unconsolidated rocks (e.g. Pre-Alps). However, they are more porous and yield a higher MN10q than igneous or metamorphic rock formations (Map 1.5).

Soil is a central component of runoff generation. The proportion of precipitation, which infiltrates and percolates through the soil to recharge groundwater, is predominantly responsible for low-flows. As a result, the characteristics related to storage capacity of the soil and to permeability of the soil and the land cover have a major impact on the generation of runoff and the partitioning of runoff into fast and slow components. The land cover is indexed by the proportion of sealed surface and by the proportion of arable land. Through intensive agricultural use the MN10q is decreased (e.g. Eastern Harz and the Börden).

A significant amount of uncertainty exists with regard to the parameter, which signifies the proportion of sealed surface (settlements). According to the understanding of the runoff-generating processes sealed surfaces should contribute to the generation of fast runoff components, which would result in a decrease of low-flows. Nevertheless, it was with the opposite effect that the regression analysis adopted the parameter into the model. This observation could be explained with the influence of wastewater discharge. In the map presented the effects of this parameter are not obvious.

High drainage densities are the result of high base-flow proportions (Map 1.2). They also promote fast drainage of the area. In the regression model minimum drainage density has a negative effect on the MN10q in the coastal regions and along the big rivers. In these regions, however, even the lowest drainage densities are still relatively high, compared to the mean of 0.77 km/km² for the whole study area.

As expected, the areas with the lowest MN10q can be found in regions characterised by low precipitation depths and rock formations with low storage capacity (such as in the Northeast and in several regions in Central Germany). Specifically the Northern and Eastern Pre-Harz, the Thüringer Becken and the Mittelfränkische Platten exhibit MN10qs between 1 and 2 l/s·km². In the lee of the Harz (Map 2.14) MN10qs of approximately 1 l/s·km² are estimated.

Practical Information

A variety of low-flow indices are used in scientific literature. Most of them, however, are disadvantageous since they are rather time-inconsistent, require threshold values or lack international comparability. Based on these findings, the Base Flow Index (BFI) has proven relatively adequate. The BFI parameterises the proportion of base flow compared to total flow and is used in Map 5.5 for the calculation of mean annual groundwater recharge. It is often used in low-flow-regression models for the characterisation of the underlying bedrock. In this data set, however, it contributed only marginally towards the improvement of the model.

Plotting the spatial distribution of residuals does not reveal clustering of catchments with uniform deviations of the estimated from the observed MN10q. Rather, areas with unevenly high deviation can occur anywhere, both during summer and winter. Therefore, it can be assumed that these uncertainties result from the boundary conditions of the method and cannot be accounted for by potentially missing catchment descriptors. The high number of grids for which the calculated value deviates from the observed one by 1 l/s·km² or less illustrates the general suitability of this method for relative and absolute statements at large scales. Due to specific regional conditions in the catchment greater deviations may occur when observing on a smaller scale.

In conclusion, the deduced regression model and the visualisation method have proven useful for gaining an overview of the low-flow conditions in Germany. The grid-based visualisation allows for the aggregation of values to determine specific discharges for catchments with an area ranging between 50 km² and 600 km² predominantly.

Several studies indicate an intensification of low flows due to climatic change, especially during the summer months (Kleeberg 1999). Over the course of a year, an increase of runoff during low-flow periods in winter time is likely connected with an increase of low-flow periods in frequency and duration during the summer. The effects of this change may be buffered in areas with extended porous aquifers (Hisdal et al. 2001).