Annex 1

FACT SHEET
Inventory of the
low water situation of the Rhine

Low water is part of the natural discharge pattern of rivers, but it may cause ecological and economic problems. While floods quickly drain off and may cause much damage within a short lapse of time, phases of low water develop over a longer period of time and seem to be less spectacular to begin with. Nevertheless, financial losses may be the result of long lasting events as they may lead to restrictions for navigation or less energy production. Water provision and agriculture may also be affected. The reduction of the size of habitats may detrimentally impact aquatic biocoenoses, in particular in situations when low flow occurs together with high water temperatures and low oxygen contents in the water bodies, as was the case in the extreme summer of 2003. Due to climate change, the development and extent of low water events might be altered.

For the Rhine bordering countries, the ICPR inventory provides a common understanding of low water situations and their transboundary effects. Existing knowledge concerning low water periods in the Rhine catchment has been compiled and hydrological monitoring data since the beginning of the previous century have been analysed.

Examination of hydrological conditions

The area examined is located between the gauge at Diepoldsau on the Alpine Rhine upstream of Lake Constance and the gauge at Lobith in the Netherlands (see Fig. 1) and the gauging stations in between show the increasing influence of larger Rhine tributaries. Apart from the gauges Fig. 1 indicates changes of the long-term annual lowest mean of discharge during 7 consecutive days (MNM7Q). The low water discharges from the Alpine and pre-Alpine area determined at the Basel gauge as 527 m^3/s still contribute with up to two thirds to the low water discharge of 850 m^3/s at the Mayence gauge. At the Lobith gauge in the Netherlands this share still amounts to about half of the local low water discharge of 1095 m^3/s. Thus, the base load of mean low water discharges is fed by the Alpine and pre-Alpine region. In these regions, discharges are high in summer and - due to snow retention - reduced during the winter half year. In addition, the great Alpine lakes have a buffer effect. On average, the great tributaries increase the characteristic low water values by 12 % (Neckar) up to 18 % (Main and Moselle). Pronounced low water situations on the Rhine often develop after decreasing discharge from the Alpine and pre-Alpine region from September/October on and during dry or very cold winters.

Apart from examining the development of low water discharges along the Rhine, the duration of low water periods expressed in consecutive days below certain threshold values was looked into. Different statistical analyses have been made with respect to the long-term annual time series in order to determine trends. With a view to establishing a comparability of characteristic low water values at different locations along the Rhine, the low water parameters were interpreted according to extreme values in order to derive threshold values for the reference period 1961 to 2010 with respect to their probability of occurrence. Thus, directly comparable classifications can be obtained along the Rhine despite differing discharges.

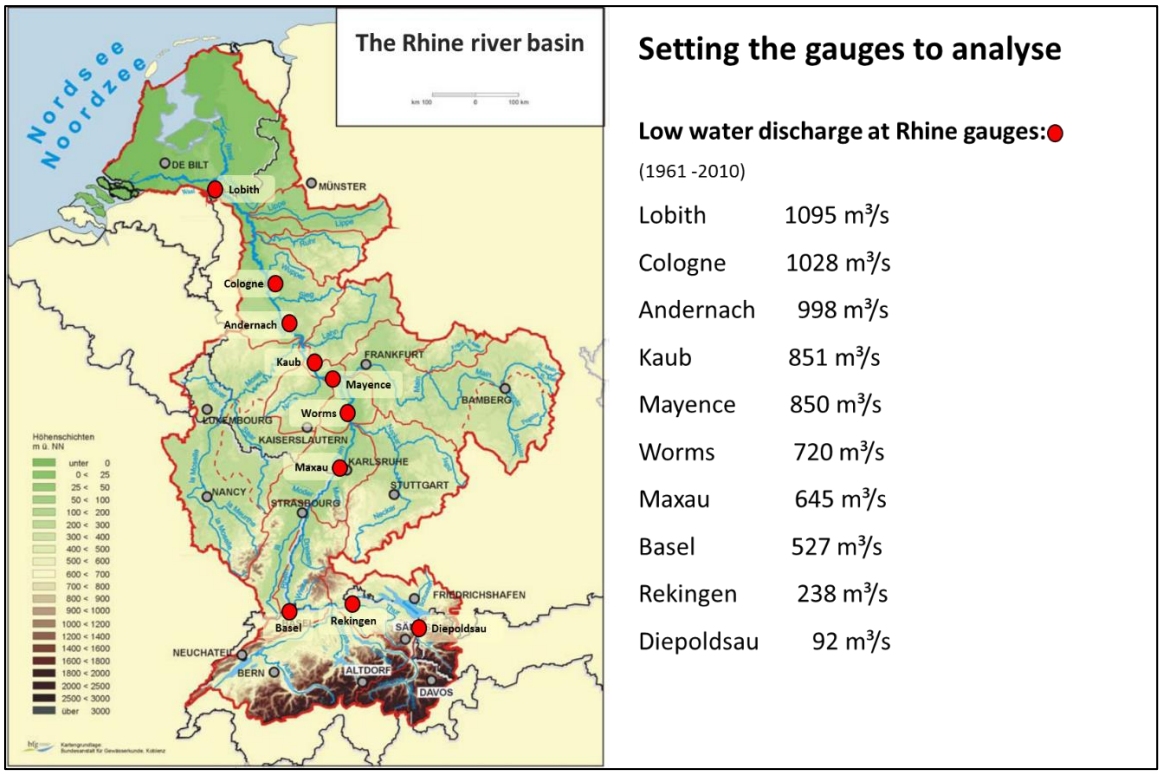

Figure 1: Location of examined gauges on the Rhine including the long-term annual lowest mean of discharge during 7 consecutive days (MNM7Q) (MNM7Q) (modified according to the German Federal Institute of Hydrology (BfG)).

The analysis of historical discharge series showed that, during the first half of the past century, low water on the Rhine was distinctly more pronounced occurring with lower discharges and lasting longer than in the past 50 years. For low flow discharges between Diepoldsau and Andernach a significantly increasing trend is to be stated for the period between 1901 and 2010. **Predominantly**, this trend is to be **attributed to the management of reservoirs in the Alpine region. The increasing trend for annual precipitation** stated for the Rhine catchment during the 20th century may also account for its share. Concerning low water discharge, no trends are to be detected for the period 1961 to 2010. The present perception of low water events is on the one hand being influenced by a long absence of important low water events and, on the other hand, by increased vulnerability of users.

Influences on low water

Along the Rhine, the low water discharge regime is influenced by abstraction, inflows and by the management of reservoirs. Considerable transfer of water takes place from the Inn catchment into the Rhine catchment (7,8 m³/s) and from the Danube catchment into the Main and Rhine catchment (up to 16 m³/s). Drainage from the Rhine area supply the Ticino area with some 2 m³/s and the Rhône area with about 3 m³/s. Direct water abstraction from the Rhine amounts to 1.5 m³/s on the Upper Rhine for groundwater infiltration and may reach peaks up to 5 m³/ over a short period of time for agricultural irrigation purposes. On the whole and due to the above-mentioned measures, the discharge balance of the Rhine increases.

The management of reservoirs in the Alpine and pre-Alpine area for energy production purposes has an even more important positive influence on low water discharge of the Rhine. In these regions, more than 1.8 billion m³ of reservoirs are used to store water in summer which is discharged during the predominant low water period of the Rhine in winter to serve energy production. Thus, the low water discharge of the Rhine in winter is being increased by up to **100 - 120 m³/s** (corresponding to **10 to 20 % of the long-term annual mean low water discharge MNM7Q).** On the whole, positive influences on the low flow regime of the Rhine are prevailing.

Effects of low water

Low water directly impacts water quality and ecology. Due to uses, navigation, energy production, industry, agriculture, tourism and leisure as well as the safety of infrastructure are concerned.

Along the main stream of the Rhine no severe, long standing negative effects on Rhine water quality have been stated due to low water events. This is above all a result of the considerable efforts of waste water treatment during the past decades. Ecological problems occur in particular during low water events in summer when combined with higher water temperatures and thus lower oxygen content (fish and mussel death 2003, among others along the Middle Rhine).

Inland navigation and the persons and businesses depending on it are impacted across borders by low flows. These are linked with negative economic impacts and supply shortfalls for sources of energy and raw materials. In the Netherlands low water leads to salinization of the surface waters for water supply when marine water penetrates. This may lead to stopping drinking water intake and to limiting water abstraction for agricultural purposes. Energy production is on the one hand impacted due to reduced production of hydro power plants and on the other hand by restricted abstraction of cooling water or restricted thermal discharge. This may also lead to restrictions for industry and trade. During low water, peat embankments might locally fall dry in the Netherlands, which leads to corresponding danger of dike breach.

Possible future effects due to climate change

The range of future developments of low water discharges caused by climate change indicated by current discharge projections for the Rhine for 2021-2050 shows decreases by 10 % up to increases by 10 % so that no distinct trend can be identified. For the far future (2071-2100), discharge projections for the hydrological summer half year coincide in showing distinct reductions of low water periods.

A pessimistic scenario for the period 2021-2050 shows that with increasing return periods low water discharges with a return period between two and fifty years will diminish by 7 to 14 %. Reduced flow will lead to distinctly prolonging the low flow duration.

In future, summer low flow events on the Rhine could become increasingly important especially regarding their ecological impact. During low flow, water temperatures could rise more in summer. Examples are the low flow events in 2003 and 2006. According to ICPR investigations, water temperatures of the Rhine may rise by up to 1.5 °C in the near future and 3 °C in the far future. In particular during low flow this means an increasing number of days with Rhine water temperatures above 25 °C (ecologically critical threshold value).

Surveillance of low flows

Based on an in-depth analysis of historical discharge series, **threshold values for classifying the low water situation in five levels from "normal" to "extremely rare low flow"** have been derived for the Rhine in coordination with the International Commissions for the Protection of the Moselle and the Saar (ICPMS). The suitability of this classification resulting in a differentiated ranking of low water events has been validated by applying it to historical discharge series (see Fig. 2).

Due to the aforementioned results of the study the ICPR has decided to begin to monitor low water.

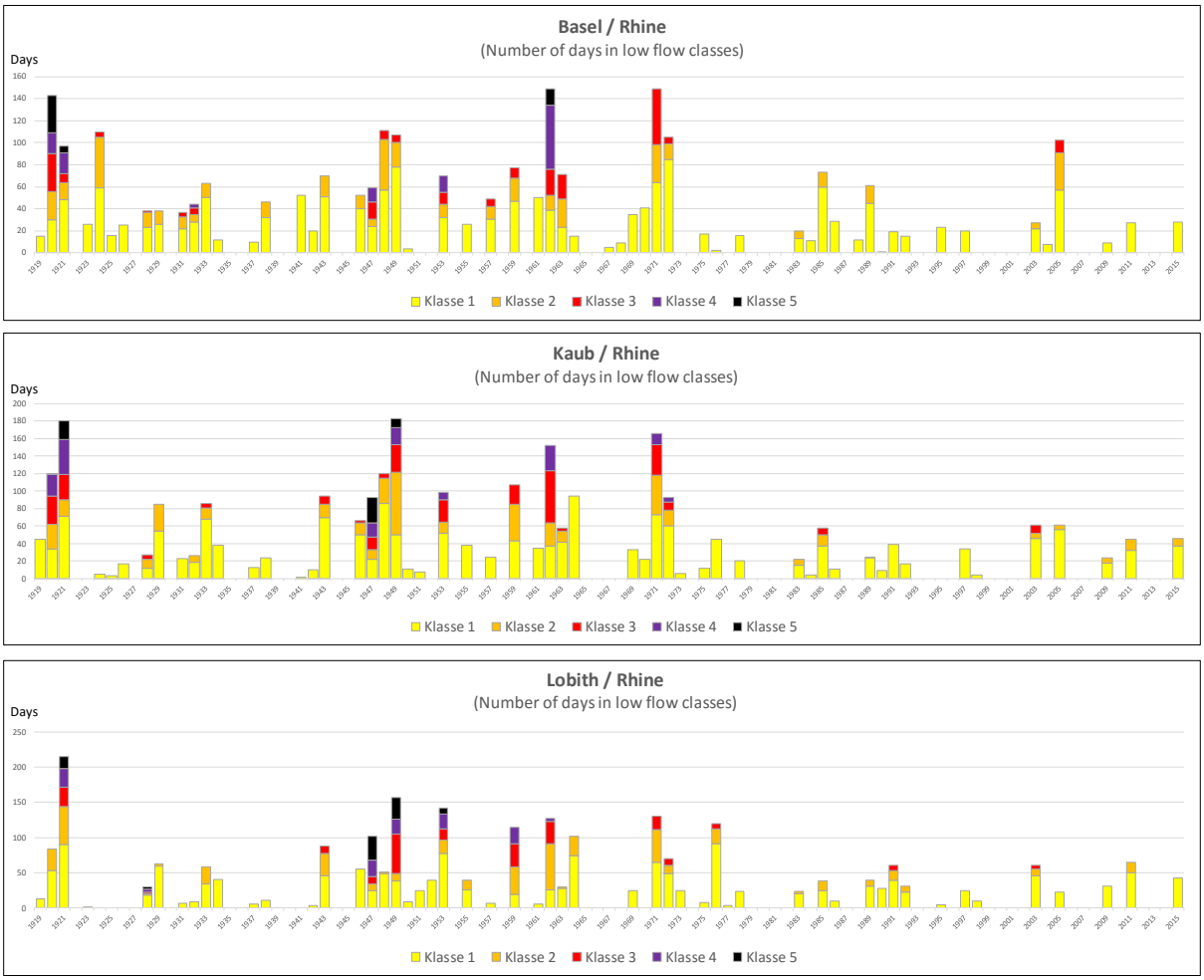

Figure 2: Annual low water days ranging from "normal low flow" (class 1) to "extremely rare low flow" (class 5) at the Rhine gauging stations Basel, Kaub and Lobith for the period 1919 to 2015.