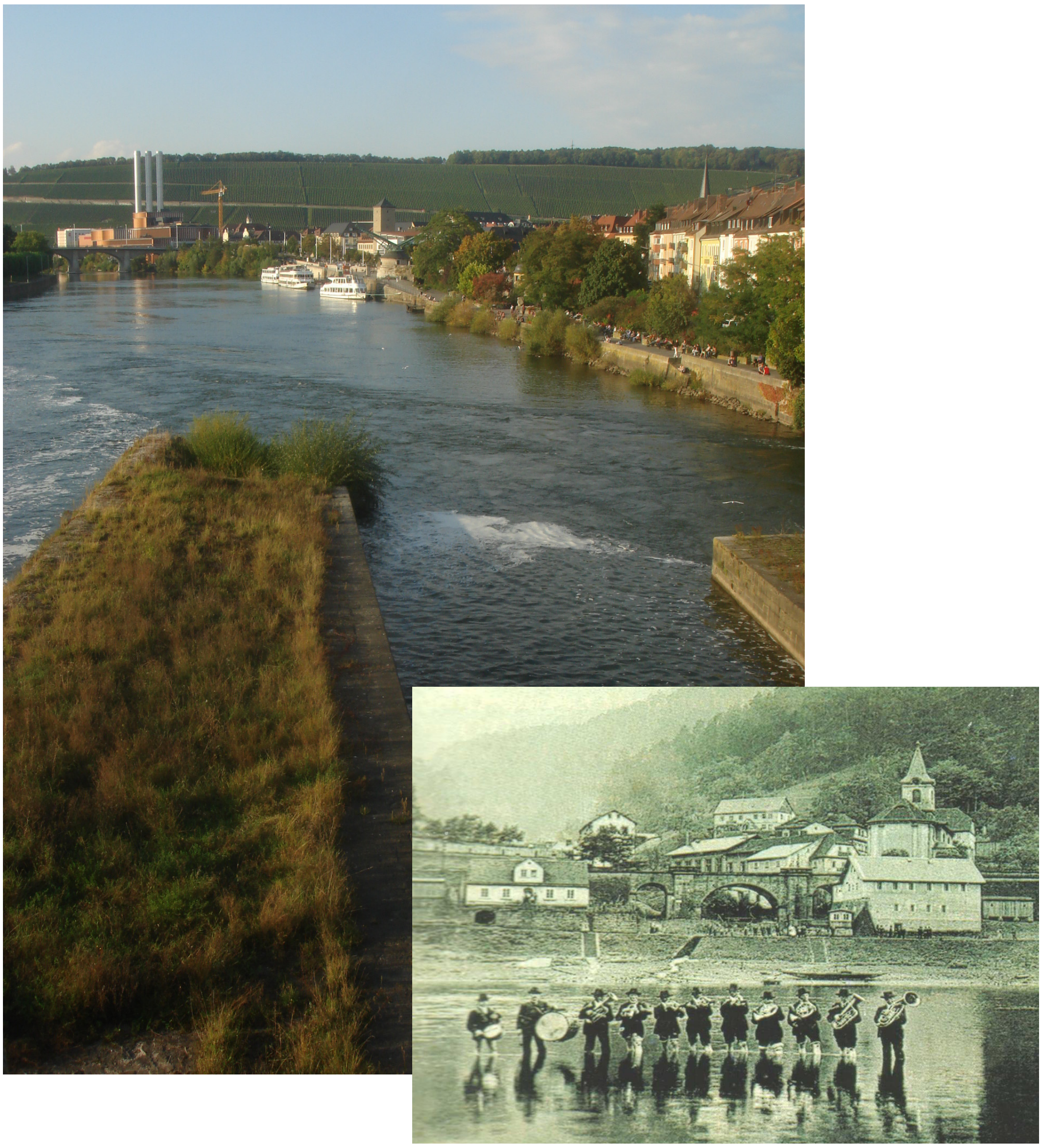
# Low flows and droughts

Würzburg (D), 25–26 September 2007

Workshop report



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The workshop «Low flows and droughts» was hosted by the Wasser- und Schifffahrtsdirektion Süd in Würzburg, Germany, from 25 to 26 September 2007.

The workshop was organized by the international Commission for the Hydrology of the Rhine Basin (CHR), together with the German National Committee IHP/HWRP, with support from UNESCO's International Hydrological Programme (IHP).

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The CHR is an organization in which the scientific institutes of the Rhine riparian states develop joint hydrological measures for sustainable development of the Rhine basin.

The CHR was founded in 1970 following advice by UNESCO to promote closer co-operation in international river basins. Since 1975, the work has continued within the framework of UNESCO's International Hydrological Programme (IHP) and of WMO's Operational Hydrological Programme (OHP). The member states of the CHR are: Switzerland, Austria, Germany, France, Luxembourg and the Netherlands.

CHR's mission and tasks:
- Expansion of the knowledge of the hydrology in the Rhine basin through:
  - joint research;
  - exchange of data, methods and information;
  - development of standardized procedures;
  - publications in the CHR series.
- Making a contribution to the solution of cross-border problems through the formulation, management and provision of:
  - information systems, e.g. GIS for hydrological practice;
  - models, e.g. models for water management and a Rhine Alarm model.

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Front cover: the river Main, a tributary of the Rhine river, near Würzburg (D), September 2007.
[Photo: Michael van der Valk | CrossVision] • Low flow of the river Elbe near Königstein, in 1904.

**Programme**

**Day 1 – 25 September 2007**

09.00 Welcome by Prof. Dr. Manfred Spreafico, president of CHR

09.15 Keynote by Lena M. Tallaksen, Department of Geosciences, University of Oslo: Key aspects of low flow and droughts

Theme block 1 – **Observed low-flow and drought periods** (At site and regional indices, case studies, data quality)
Chair: Hans Moser / Rapporteur: Caroline Kan

10.00 At site and regional indices of low flow and drought periods: Walter Finke, Federal Institute of Hydrology, Koblenz

10.30 Low-flow conditions in the Rhine basin – Developments in the 20th century: Jörg U. Belz, Federal Institute of Hydrology, Koblenz

11.00 Tea/Coffee – Posters

11.30 The low-flow period of 2003 in Austria: Franz Nobilis, Technical University Vienna

12.00 Meteorological conditions leading to the hydrological droughts in Central Europe – Three case studies: 2003, 2005 and 2006: Bruno Rudolf, German Weather Service, Offenbach

12.30 Discussion of theme 1

13.15 Lunch

Theme block 2 – **Impact of climate change on low flow and drought** (Recent developments in climate scenarios, effects on the hydrological cycle, effects on water user functions)
Chair: Frans Claessen / Rapporteur: Peter Krahe

14.30 Recent developments in climate scenarios in The Netherlands: Bart van den Hurk, Royal Netherlands Meteorological Institute, De Bilt

15.00 Effects of climate change and climate variability on hydrology: Jaap Kwadijk, WL | Delft Hydraulics

15.30 2 min. oral poster presentations

16.00 Tea/Coffee - Posters

16.30 Effects of climate change and climate variability on water user functions: Joergen E. Olesen, University of Aarhus – Department of Agroecology and Environment

17.00 Effects of climate change and climate variability for the delta area of the River Rhine: Vincent Beijk, RWS RIZA Institute for Inland Water Management and Waste Water Treatment, Rotterdam

17.30 Discussion of theme 2

19.30 Participants' dinner

**Day 2 – 26 September 2007**

Theme block 3 – **Management and adaptation strategies** (Seasonal predictions and real-time forecasts – including water temperature – prediction at ungauged sites, risk and crisis management, the role of stakeholders and the public in decision-making procedures)
Chair: Henk Wolters / Rapporteur: Gabriela Müller

09.00 Developments in seasonal to decadal predictions: Daniela Jacob, Max-Planck-Institute for Meteorology, Hamburg

09.30 Low-flow estimation at ungauged sites: Günter Blöschl, Technical University Vienna

10.00 Operational low-flow forecasts: Silke Rademacher, Federal Institute of Hydrology, Koblenz

10.30 Tea/Coffee – Posters

11.00 Predicting low flows – so what?: Undala Alam, Cranfield University, Centre for Water Science

11.30 The seven rules for hydrologists wanting to make an impact on water management, Erik Mostert, Technical University Delft - Centre for Research on River Basin Administration, Analysis and Management

12.00 Discussion of theme 3

12.30 Summary and conclusions of the workshop

13.00 Closing of the workshop

13.15 Lunch

## Summary and recommendations for policy and research

**Droughts are sustained and regionally extensive occurrences of below-average natural water availability.** They affect all components of the water cycle: from deficits in soil moisture through reduced groundwater recharge and groundwater levels to low streamflows or dried-up rivers. Droughts are reoccurring and worldwide phenomena, with spatial and temporal characteristics that vary significantly from one region to another, and can have wide-ranging social, environmental and economic impacts.

On 25 and 26 September 2007, scientists gathered in Würzburg (D) to discuss low flows and droughts in the Rhine River Basin – their origin and occurrence, and the influence of climate variability and change. Ideas on decision-making and public participation were also brought forward. The aims were to find possible research gaps and recommendations for further research.

The most severe social consequences of droughts are found in arid or semi-arid regions where the availability of water is already low under normal conditions. Droughts should not be confused with aridity, however, which is a permanent feature of a dry climate; nor with water scarcity, which implies a long-term imbalance of available water resources and demands.

**Drought research and operational applications have been lagging behind the development in flood-related areas. There is both an urgent need to address emerging issues in drought research and management and to interact with the scientific and operational communities, as well as policy-makers and the larger public, to raise awareness about potential drought hazards.**

### Drought management

Before 2003, most research on European river basins focussed on flood forecasting rather than on drought management. Following the long dry period in Europe in 2003, most affected countries began to overview the consequences of droughts on a national level, the results of which were presented by Austria, Switzerland, Germany and the Netherlands.

A list of drought consequences was drawn up, including:

- very low water levels in surface water (rivers and lakes) and in groundwater
- reduced crop growth
- reduced surface water quality (locally, a.o. leading to algae bloom)
- reduced possibilities for power plants and other heat-generating factories to rid them of hot water
- reduced capacity for transport over water
- reduced possibilities for recreation on and near water.

Also, a joined report, «Flow regime of the river Rhine and its tributaries during the 20th century – analysis, changes, trends» (Das Abflussregime des Rheins und seiner Nebenflüsse im 20. Jahrhundert – Analysen, Veränderungen, Trends) is under preparation.

The following key questions were asked:
- How can we distinguish a (severe) drought from an average dry period?
- What are the characteristics of droughts?
- Are there effective ways to forecast droughts?

**One major problem is that, by nature, droughts develop slowly** – they are the result of what one would call an unusually long series of hydrological non-events. This slow development makes it difficult to use common hydrological forecasting tools, as these have mainly been developed for hydrological (precipitation) events and the routing of the subsequent flow of water. **Speakers noted a need for drought-related forecasting tools.**

Several speakers addressed the different ways currently used to describe (and subsequently compare) the Rhine River's hydrological behaviour. A multitude of parameters has been developed, each with a different meaning. Speakers looked at averages and extremes of water-levels and flows to characterize the hydrological regime, e.g. in terms of the number of consecutive days with a mean flow rate below a certain value, or, reversely, the lowest arithmetic mean of x consecutive daily values of flow within a certain time period during the reference period.

The best set of parameters depends both on the characteristics of the basin and on the spatial and temporal characteristics of the hydrological 'input', the precipitation. This means that for different drainage areas, the most characterizing parameters will probably be different. This is not a problem in and of itself; it does affect comparability, however, of the values of the parameters between different catchments or between different parts of the same catchment, as in the case in the Rhine River Basin. The solution here lies in either transposing the parameters (if possible) or in using more general yet meaningful parameters.

## The impacts of climate change?

As was noted by the keynote-speaker and other speakers, according to renowned and reputed institutions – including the World Meteorological Organization and the Intergovernmental Programme on Climate Change – we must expect more severe hydrological extremes because of an intensified hydrological cycle. This means more frequent and more severe floods, but also **more frequent and more severe droughts**.

Added to this, the regional **variability** of meteorological events **is expected to increase** at all time scales:
- daily: changes of extremes are stronger than changes of means;

– seasonal: the number of wet days changes and there is evidence for rapid transition of persistent anomalous episodes;
– annual: scenarios differ widely but none can be excluded.

As one climatologist remarked, climate change scenarios will continue to develop, such that the present state of the art will be different from that of tomorrow. **The trend of scientific development is towards greater uncertainty** more than changes in temperature rise per century.

Several speakers discussed that information on the ways in which climate will affect the Rhine River Basin (mainly in terms of temperature and precipitation) is not expected to improve soon. Scientific research on climate over the last few years has resulted in a better description of the uncertainty of the expected changes – and uncertainty has grown – but it has not improved knowledge about the kinds of changes to be expected: the expected changes in temperature and rainfall remained consistent over the last few years of research. For hydrologists and water managers, these consistent numbers of rise in temperature and the consequent changes in precipitation distribution are the point of departure.

When analyzing the consequences of climatic change on the discharge of the River Rhine, it becomes clear that climate change is 'just' an added effect to the different influences that cause alteration of hydrological behaviour of the River Rhine.

With population growth and development over the years, land-use has changed massively, leading to changes in hydrological behaviour. Changes in vegetation (e.g. for agriculture), or removal of vegetation cover (e.g. for roads and highways, urban growth) have altered evapotranspiration and runoff patterns throughout the catchment area of the Rhine River– especially downstream of Switzerland. Improvement of sewerage systems and a closer network of other means of artificial drainage in the last decades have resulted in quicker runoff than natural. The result of this mix of influences is that **it is hard to discriminate the hydrological changes that result from changes in average meteorological conditions from those that result from terrestrial (mainly land-use) changes**.

As historical climate change influence on Rhine River discharge is not exactly known, **it is difficult to use historical data for forecasts**.

All historical changes in the catchment have an effect on the 'signal' coming out of the changed area. These changed signals lead to changes in the 'wave length' of river discharge: the frequency and amplitude. For upstream catchments (headwaters), it might be easier to separate these changes from each other, as long as they have distinct known signatures. Upstream, the changes in discharge will be more distinct, mainly due to less averaging and mixing of different signals from tributaries (as is the case further downstream). In principal, this means that there may be better chances for short-term forecasting higher upstream (Alpine part) than downstream in the Rhine River Basin. In general, however, the relatively low spatial resolution of air circulation models will make it easier to forecast for a bigger area than for small areas, i.e. the forecast will have a higher certainty and significance for bigger areas than for small.

As noted by several speakers, the effects of, first, enhanced glacier melt, followed by reduced glacier melt, in summers will be noticeable mainly in the upper reaches of the Rhine in Switzerland. Downstream of Switzerland, the part of the discharge that was originally meltwater from glaciers is negligible.

Despite the ever greater uncertainty over the last years, the combination of stable trends in the climatological forecasts – more variability, wetter winters and dryer (end of) summers – and the relatively poor usability of historical data made several speakers to advise to **not base hydraulic and other structural design on historical observations only**, but to use the climate change scenarios in addition.

If western European air circulation patterns will change the way some climate change scenarios forecast, there will be major impacts on the management of low flows. Given the uncertainties in climate forecasting, it is questionable however, whether models with higher resolution (both temporal and spatial) will lead to better drought forecasts. This will only be the case when current hydrological models will significantly improve by using data with a higher resolution. This can happen where Global Circulation Models do not acknowledge local differences, such as the presence of major lakes, of importance to weather circulation.

What is clear is that temperatures will rise, and that this will lead to more energy in the hydrological cycle, leading to a higher occurrence of phenomena that are yet considered to be hydrological extremes: floods and droughts. **What is now extreme will become 'normal'.**

## Other difficulties in forecasting low flows and droughts

Discussion shed light on other forecasting difficulties (when, where, how intense how long ):

- 'Drought' is still not defined in quantitative terms, which makes is difficult to say when it starts
- It is difficult to distinguish between effects of climate change on hydrological drought and multi-decadal climate variability
- It is difficult to discriminate climate change from terrestrial human influences (e.g. land use change, water abstractions)
- Even 'climate change' is not clearly defined, as shown by discussions about changes in rainfall without changes in temperature.

**Despite these difficulties, scientists are almost certain that droughts are bound to happen, and more severely than in so far.**

**Scientists called for more studies on the effects of rainfall variability and change in variability.** While this might be valuable, as it is expected that this will lead to statistically improved forecasts, it remains however limited.

Speakers described that in most sectors, new technologies might provide the means to reduce water consumption. Wastewater can be reused for agricultural purposes. In addition, new schemes for water pricing and water rights might help to reduce the strains of water availability. When the European Commission becomes more aware of the possibility of droughts, the Water Framework Directive might become a suitable instrument for ensuring timely adaptation.

## How to best prepare for droughts?

This is a central question for water managers. Indeed, which measures can be taken to anticipate for droughts, and to prevent their potentially severe societal and natural consequences?

Certainly, **regional differences in the behaviour of droughts will have to be taken into account**. For example, low flows generally occur in the winter in the Southern part of the Rhine River Basin, when most precipitation is stored as snow. In the Northern part of the Rhine River Basin, low flows generally occur at the end of summer and during autumn. In subcatchments with dammed lakes, this might be completely different.

However, most importantly, all **preparatory steps involve communication between scientists, policy-makers and society/communities**.

Despite the major problem of inherent uncertainties, making it difficult to find common language acceptable and understandable to all groups involved, steps can be taken in presenting research findings to bridge the gap between scientists, policy-makers and the general public, bearing in mind some of the following:

- Science and scientific data are only a part of the decision-making process – in the best-case scenario.
- One cannot assume that good data and good scientific results will automatically lead to good action.
- Decision-makers must be identified – as part of stakeholder analysis – and specifically in their own language.
- As actions aimed to improve the water system or to reduce water-related risks may increase political risks, it is advised to engage with policy-makers at an early stage.
- It is essential to manage the expectations of all – the public, decision-makers, and of course the scientists.

Communication is the way forward.

## Key aspects of low flow and droughts

### Keynote speech by Lena Tallaksen

Lena Tallaksen (University of Oslo, Norway) is co-author, with Henny van Lanen, of the standard textbook «Hydrological Drought: Processes and Estimation Methods for Streamflow and Groundwater». Drought is here defined as a sustained and regionally extensive occurrence of below average natural water availability and may affect all components of the water cycle. Explaining that different kinds of droughts can be distinguished, Tallaksen listed meteorological droughts, soil water droughts, groundwater droughts and surface water droughts. (See also Technical report 6 of the EC project ARIDE, Assessment of the Regional Impact of Droughts in Europe, 2000.)

The chief characteristic of a drought is a decrease of water availability in a particular period over a particular area, but different definitions would lead to different conclusions regarding the drought phenomenon. For instance, while rainfall statistics summarized over a calendar year may indicate no drought, the moisture supply in the growing season might. In addition, as drought affects so many sectors in society, there is a need for different definitions.

The European Drought Centre[1] is a virtual centre of European drought research and drought management organizations, which aims to promote collaboration and capacity-building between scientists and the user community. The long-term objective of the centre is to enhance European cooperation in order to mitigate the impacts of droughts on society, economy and the environment. Despite a primarily European dimension, the Centre will also link with other international projects, organizations and experts outside Europe.

While drought is a natural hazard that cannot be prevented, Tallaksen concluded that they are likely to become a larger threat to humankind as climate-change scenarios predict both more frequent and extreme floods and droughts. There is clearly an increasing pressure on water resources, which can be reduced through mitigation – knowledge, preparedness and good management practice. Some of the questions arising during the discussion concerned:

- the length of a dry period in order to be able to speak of a drought;
- the extent of the dry area in order to be able to speak of a drought;
- the question of the 'natural availability' of water: if 'natural availability' is accounted for in the definition, does this mean that improper water usage cannot lead to a drought? (Given the fact that the natural availability can remain unchanged.)

[1] http://www.geo.uio.no/edc.

## ■ 1 Observed low-flow and drought periods

*This block of the workshop on low flows and droughts concentrated on the different ways of characterizing hydrological droughts and low flows and offered some practical applications of these indices in form of different case studies.*

**Walter Finke** (BfG, Germany) spoke about at-site and regional indices of low-flow and drought periods. Low-flow and drought periods are very complex hydrometeorological events. Even simple questions like 'when does a drought event begin and when does it end' are not yet adequately clarified. As no universally valid definitions or generally accepted indices currently exist, the choice of indices depends on the purpose of the intended study and on the specific flow regime. Experience and traditions of the person in charge also play a role.

Finke spoke specifically about hydrological droughts: low flow in watercourses. In Germany, the so-called 'DVWK-Richtlinien' (DVWK Rules) are the indices that are preferentially used. The German Association for Water, Wastewater and Waste (DWA, formerly DVWK) issues recommendations for statistical low-flow analysis and defines the mean minimum-flow parameter NMxQ – the lowest arithmetic mean of x consecutive daily values of flow within a certain time period during the reference period (in $m^3/s$). NMxQ is used in low-flow statistics to characterize events and low-flow regimes for planning and design purposes. NMxQ is identical with the internationally used MA(n-day). Frequently, observed data are not used directly but as filtered data with moving average. Such derived indices are the long-term means MNMxQ and MNMxq, and the low-flow probability NMxQT with return periods of T years.

Threshold-related characteristics and percentiles from the flow-duration curve and other indices were also discussed. Finke then reviewed the most important methods of regionalization, notably:

- simple estimation methods;
- multiple regression analysis;
- index-method;
- spatial interpolation;
- and calculation with water-balance models.

Currently, DWA is preparing a working paper on regionalization of low-flow indices («Regionalisierung von Niedrigwasserkennwerten»).

Characterization of the dry year 2003 showed that at 2/3 of the gauges, the event of 2003 had to be rated as one that is not exceeded every 10 years on average. Generally speaking, eastern Germany was most severely affected, and southern Germany the least. Application of the indices to define the long-term behaviour of low-flow parameters at gauges of the Elbe river basin (anthropogenically influenced) showed that decreasing mine drainage in the lignite mining industry of the Spree basin and the beginning water-balance rehabilitation in this region both result in notably reduced low-flow values in the rivers Spree and Havel since the 1990s. Other factors possibly contributing to the flow reduction include changes in the management schemes of reservoirs, water-transfer pumping stations and wetlands. Although a methodology for quantitative separation of the effects of the individual influences on streamflow is available, doing so would require great investigative and data-processing efforts. Water demand and use losses, abandonment of farming, the widespread impervious surfaces of housing areas, roads and industries – not to mention possible climate variations – must be taken into account.

**Jörg U. Belz** (BfG, Germany) confirmed that the statistical low-flow analysis in Germany is mainly based on the recommendations of the DWA (formerly DVWK). To characterize events and low-flow regimes for planning and design purposes, the so-called NMxQ, the mean minimum flow over x consecutive days, is most often used. NMxQ is identical with the internationally used MAM(n-day), allowing to derive the low-flow probability NMxQT. In the context of EU Water Framework Directive only the single-day minimum value (NM1Q, NQ) is looked at, although it is often biased by singular events (short-term influences or measuring errors). The parameter NM7Q is more reliable and it reduces possible distortions resulting from water management operations during the week.

Other indices recommended by the DWA concentrate on the duration of a low-flow event or its corresponding deficit volume. Their calculation being dependent on the choice of a threshold value, these indices are used for applied studies concerning water resource management and ecology.

Other low-flow indices can be derived from the flow duration curve, e.g. the 95-percentile Q95. This index is very much used in Switzerland and in Austria. Further low-flow indices base on recession analysis or on base-flow separation techniques.

In principle, all low-flow indices can be regionalized. DWA will soon publish a working paper on regionalization of low-flow indices («Regionalisierung von Niedrigwasserkennwerten»). An example of Q95 regionalization was presented by Blöschl in block 3 of the workshop.

The extraordinarily dry conditions in the year 2003 over wide parts of Europe lead various countries to realize their vulnerability to both floods and drought events. This was the case in Austria for example, where the financial costs of the 2003 drought – the damages caused to agriculture and restrictions in hydropower generation and inland navigation – were similar to those of the 2002 extreme floods. In several countries in the CHR region the event was studied in detail.

In Germany, a study about the 2003 low-flow conditions was published by the Bundesanstalt für Gewässerkunde (BfG). The German Weather Service (DWD) contributed the analyses of the spatial distribution of precipitation. The summer of 2003 was characterized by stable anticyclonic conditions over Central Europe. The below-normal precipitation caused an accumulating precipitation deficit. The accompanying extraordinary heat accentuated the drought. The BfG compared the 2003 NM7Q values of 159 gauges throughout Germany with the low-flow probabilities out of the long-term series 1961–2002. About 66% of the gauges showed a return period of less than 10 years, 30% a return period between 10 and

50 years and for 7 gauges a return period of more than 50 years was calculated. The east of Germany, especially the Oder, was most severely affected.

**Franz Nobilis** (Technical University Vienna, Austria) discussed the study about the 2003 low-flow period in Austria, which reports significant precipitation deficits over large areas of the country. Only about 80% of the mean precipitation in the period 1961–90 was registered; in the east and southeast of Austria this was even less so. The low-flow situation was described by comparing the discharges as observed in 2003 with the mean flow (MQ) and the mean annual minimum flow (MNQ) in the different 'Bundesländer' (federal states of Austria). The results differ, due to differences in the local meteorological situation, past hydrological history and river basin characteristics. The biggest problems occurred in Burgenland and in south and southeast Styria. In alpine regions the drought was less pronounced. In river basins with a high influence of glaciers the discharge was increased by a record glacier melt. In general glaciers and high groundwater levels reduced the drought effects. In glacierized areas a precipitation deficit was registered, but no real problems occurred. At Lake Neusiedl (Neusiedlersee) the lowest water level was measured since the start of the lake regulation in 1965.

A comparison between the results of the German and the Austrian studies (and the studies of other countries) of the same drought event is made difficult by two facts:

- the use of different indices to characterize the low-flow situation;
- the use of different comparison periods.

A standardization of methods would improve the possibility of an overview on a transnational event such as the 2003 drought, but the specific circumstances (e.g. available data) in different countries would then be taken less into account.

An important part of low-flow analysis consists of detecting potential trends. This was also one of the aims of a project commissioned by the CHR. The long-term development of low-flow situations in the Rhine river basin was examined by means of the NM7Q (annual mean lowest runoff during 7 consecutive days). Most of the gauges with long observation series (1901–2000) show significant increasing trends in yearly and winter NM7Q and a decreasing tendency in summer NM7Q. The trend analysis of different gauges throughout Austria shows the same result. Therefore, summers tend to become dryer, and winters tend to be less dry on average, just as the average years.

This development corresponds with the change of mean precipitation for northern Europe during the last 50 years: significantly higher winter and generally hardly changed summer precipitation with a decreasing tendency in the southern Rhine basin. However, other factors are influencing the long-term behaviour of low flows. Due to higher temperatures a larger portion of winter precipitation falls as rain instead of snow. This leads to a seasonal shift of the flow regime in the southern Rhine basin. Pluvial elements are gaining importance at the expense of nival elements. This development is intensified by the management of the large reservoirs in the Alps. With the aim of energy production water is stored during summer and released in winter. Outside the alpine region the reservoirs serve multiple management objectives and are thus of less importance for the seasonal redistribution of discharge. Additional glacier melt due to higher temperatures is increasing discharge in summer in highly glaciated parts of the basin. In average years however, the additional water coming from glaciers is of little importance, also for the low flows. The European Water Framework Directive may become important when low flows harm the ecosystems.

In applied studies on smaller catchments the different influence factors on the long-term behaviour of low flows can be looked at in more detail. Thus a study in the Spree and Havel rivers (the Elbe river basin) showed that the reduced low flows since the 1990s are not only due to decreasing mine drainage. By statistically analysing different low-flow indices and comparing the results with information on hydrometeorological parameters and parameters of water use it could be revealed that the development is due to a superposition of multiple influences, besides the change in the mine drainage, such as changes in the climatic water balance and changes in the water resources management play a role.

Still, the quantitative separation of the effects of the different influences on low flow remains complicated. The detection of trends is a problem in and of itself. High natural variability makes it difficult to identify changes. Statistically sound analyses need large data collectives and long time-series of good quality.

As **Bruno Rudolf** (DWD, Germany) explained, understanding the meteorological conditions that cause drought is essential to improve seasonal forecasting and assess the impact of climate change on low flow. The main meteorological factor for low-water flow is the lack of precipitation. In 2003 this was caused by a high-pressure system that persisted above Poland and Ukraine for over 3 months, which is quite unusual. By drawing the accumulated precipitation in a year against the normal accumulated precipitation (e.g. 1961–90), the actual precipitation deficit can be shown. The climatic water balance (precipitation minus potential evaporation) reveals if there is a surplus of water to fill the storages or if the available soil moisture is consumed by evaporation. Agriculture can be affected by short-term deficits while low-flow situations especially in larger rivers need more time to develop. Depending on the hydrogeological situation it can even take several years to fill or consume groundwater stores. For instance, the Elbe flood did not effectively recharge the groundwater.

To analyse hydrological drought events meteorological data from a much longer period can be necessary. Various useful datasets exist at the DWD[2] and other national weather services. As drought is a transboundary problem, data may be required from different countries and are not always easily obtainable.

As the amount of precipitation can be linked to different ‘Grosswetterlagen’, the DWD is trying to interrelate them to drought situations. It is not yet clear if the categorized ‘Wetterlagen’ are a useful indicator for droughts. To enhance the

[2] See for instance the Global Precipitation Data Centre, http://gpcc.dwd.de.

predictability of drought events in Europe also further evaluation of seasonal forecasts is required.

During the following discussion at the end of the session on ‘observed low-flow and drought periods’, it was asked whether Austria had problems with algae bloom, like in the Netherlands. This was not a known problem.

The EU seems to question when one can speak of a ‘prolonged drought’. Apparently there is no ‘drought directive’ similar to the recent flood directive. International communication is key.

## ■ 2 Impact of climate change on low flow and drought

*The presentations and discussions within this block aimed to share and exchange knowledge about the influence of climate variability and climate change on future low-flow and drought periods.*

In his talk **Bart van den Hurk** (KNMI, the Netherlands) presented recent developments in defining climate change scenarios for The Netherlands and for the Rhine and Meuse river basins. Climate change scenarios are widely used to deal with the inherent uncertainty of future climate at national and regional scales. In most cases, regional scenarios are constructed from projections from a limited set of Global Climate Models (GCMs), driven by several greenhouse gas emission scenarios, and statistically or dynamically downscaled to increase the information content at the regional scale.

A large number of GCM projections has been made available by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). The use of a small ensemble of GCMs introduces a risk for the preparation of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Thus, a selection of a relevant range of global temperature rise and corresponding regional response is needed for adaptation strategies that are relevant to practice. To avoid information loss due to undersampling, the GCM uncertainty and limited regional climate model (RCM) resources, the climate change scenarios for the Netherlands follow a specific path of construction. This can be outlined as a combination of GCM projections, RCM results and local observations by using a sophisticated set of scaling procedures to derive the local scenario values.

Independent scaling variables are chosen in order to explain a major portion of climate variability in the region of interest, derived from the available AR4 GCM projections. Apart from the global mean temperature rise ($\Delta Tg$), the (uncertain) response of the regional atmospheric circulation to global temperature change appeared to be an important external indicator. Scenarios are therefore developed for two values of $\Delta Tg$ in 2050 relative to 1990 (being +1°C and +2°C), which optimizes a sufficiently wide range, consistent with previous scenarios and socio-economic relevance. Up to 2050, differences in GCM projections of $\Delta Tg$ are mainly associated with uncertainty about climate sensitivity, and less so with variations between greenhouse gas emission scenarios. The combination of two global mean temperature changes and the two distinct circulation regimes yields four climate change scenarios.

The global climate change scenarios were downscaled in an ensemble of 10 selected Regional Climate Model (RCM) runs. In order to cover a larger scenario range the results from the available RCM integrations were extrapolated to the global temperature and circulation conditions by a two-variable scaling equation. In addition to regional precipitation and temperature scenarios, also sea-level rise and wind-speed scenarios were constructed.

A description of the new scenarios and their development can be found in the English brochure 'Climate in the 21st century: four scenarios for the Netherlands' and in the scientific background document 'KNMI Climate Change Scenarios 2006 for the Netherlands'. Both can be downloaded from www.knmi.nl/climatescenarios.

The KNMI'06 scenarios are rather unspecific for many applications. More tailored information is needed in water management, safety policy, energy, traffic, agriculture and many more applications, ranging from specific time series for climate variables, assessment of likelihoods of a given scenario, to consistent high-resolution fields of a set of variables. KNMI is involved in many projects involving the generation of tailored climate change scenarios. The projects have in common the premise that intensive iterative dialogue between climate scientists and stakeholders is needed to converge the possible deliverables with the requested information. The requirements for groundwater issues in the Netherlands and the mean discharge of the Rhine river were discussed as examples of such tailor-made climate scenarios.

The effects of climate change and climate variability on hydrology and the implications for water management in the future were addressed by **Jaap Kwadijk** from WL|Delft Hydraulics, preceded by an overview of 20 years of research in the field climate variability, climate change, hydrological modelling and decision support in water resource management was presented.

Scenarios of climate change effects on the Rhine river exist since the late 1980s and have since evolved from estimates for changes in seasonal discharges based on expert judgment to consistent scenarios including socio-economical developments and management practices. These results were transformed to discharge scenarios in the Rhine river by applying increasingly sophisticated hydrological models. Kwadijk states that during the last years the scenarios remained surprisingly consistent in terms of the trends expected: summer discharges will probably decrease, while winter discharges will probably increase. However, over time the scenarios have varied substantially in the magnitude of the change.

The applicability of the scenarios in water resources management were discussed from the Dutch perspective. It was noted that the scientific progress in scenario building is not such that the climate projections can be used in a straightforward manner in water management practice. This is due on the one hand to uncertainties in the magnitude of the changes, and on the other hand to a lack of experience on the part of water managers in taking future simulations as a basis for the design of management strategies rather than observed hydrological time series.

Recent progress in reducing the uncertainties in the magnitude of changes is relatively low and it can be assumed that these uncertainties will remain in the near future, as design in water management is a continuous process. Practical guidelines are welcomed by the water management world on how to deal with these uncertainties. Based on the results and experience of recent projects 'best practices' have to be provided to be used as examples of how to deal with climate scenarios in operational water resources management. However, and contrary to present approaches, the method of finding the best practices should not use climate scenarios as a starting point but the robustness of the existing water management system; an approach exploring the limits of the current strategies in view of the different and changing climate scenarios has to searched for.

From the point of view of a decision-maker the following questions were raised:

- Must I change my strategy?
- Is there a risk that policy targets will not be achieved?
- What is the risk of too few or too many measures?
- Should another decision be made?
- Would I take another decision if the climate changed?
- For how long will the strategy be efficient after the time horizon (robustness)?
- How easy is it to change in time to an alternative strategy (flexibility/no regret).

It was concluded that scenarios that provide the stakeholder a perspective to do something are most interesting. Starting point: the current water management is well designed to deal with the historical variation in weather/climate. Assessment of vulnerability of the management system has received remarkably little attention so far.

Reliable water supply and the protection of aquatic resources through adequate water management are essential to support all aspects of human life and dependent aquatic and terrestrial ecosystems. The hydrological characteristics of Europe are very diverse, as well as its approaches to water use and management.

**Joergen E. Olesen** from University of Aarhus tackled the perspective of the EU Member States as well as aspects of water uses for agriculture, urban areas, tourism and industry. The regions most prone to an increase in water stress are the Mediterranean areas. Besides water stress warmer temperatures may result in higher risk of environmental pressures, e.g. algal blooms and increased growth of toxic cyanobacteria in lakes, despite an overall drier climate that may decrease the external loading of nutrients to inland waters. Furthermore, climate change could have a negative impact on the efficiency of thermal power production plants because water withdrawn for power plant cooling is expected to be somewhat warmer on the average. The availability of cooling water may be reduced in some locations of Europe because of climate-related decreases or seasonal shifts in river runoff.

To adapt to increasing water stress the most common strategies remain supply-side measures such as impounding rivers to form in-stream reservoirs. However new reservoir construction is being increasingly constrained in Europe by environmental regulations and high investment costs. Other supply-side approaches such as wastewater reuse and desalinization are being more widely considered but their popularity is dampened by health concerns in using wastewater, and the high-energy costs of desalinization. Some demand-side strategies are also feasible such as household, industrial and agricultural water conservation, reducing leaky municipal and irrigation water systems, and water pricing. Strategies should be implemented at watershed levels into plans for integrated water management while national strategies should consider the governance structures.

The potential risk in the decreasing river discharge of the Rhine and Meuse rivers due to climate change may causes an increased intrusion of salt water from the North Sea into the delta area of the Rhine. Although this effect is not life threatening, the economic and social consequences can be substantial. **Vincent Beijk** (RIZA, the Netherlands) described the processes, effects and possible measures of the increased salt intrusion in the delta area of the Rhine river. Impact studies of the four climate change scenarios for the broader Netherlands on the yearly average chloride concentration and on the duration of exceedance of critical chloride concentrations were presented. The results show a distinct difference between the KNMI G/W scenarios and the G+/W+ scenarios for the Netherlands in the duration of exceedance of a critical chloride concentration. For example, under the W+ scenario during a 'saline year' (like 2003), the total yearly duration in which the critical concentration is exceeded will almost double in 2050 as compared to today. It is obvious that climate change will have an effect on the future availability of freshwater of acceptable quality in the delta area of the Rhine. The current problems concerning salt intrusion, together with the expected climate change, raise the question of whether measures should be taken to avoid an increase of chloride concentration in the Rhine delta area in the future. In 2006 the Ministry of Transport, Public Works and Water Management commissioned a study in which a great number of possible solutions were examined. The solutions were classified into four different frameworks:

- Prevention of (increased) salinization through technical solutions;
- Compensation of (increased) salinization by technical and/or financial measures;
- Spatial planning;
- Alternative freshwater supply.

However, other studies show that an adequate measure to reduce salt intrusion is not readily available. The search for effective methods will continue because salt intrusion will become more likely in the delta area of the Rhine and Meuse rivers due to climate change.

Within the general discussion of the session the participants felt the need to address the uncertainty of the future predictions by defining a corridor of the changes of temperature and precipitation. Furthermore, time scales that account for when certain changes will happen will have to be taken into account. This plays an important role for the Netherlands as spatial planning is a key issue in adaptation strategies and therefore there is a requirement for planning longer ahead.

It was stated that adaptation strategies must be further elaborated and that mitigation measures be moved forward as much as possible. Adaptation strategies have to take into account specific regions, the specific cultural background of decision-making and the feasibility of measures. Furthermore, during the development of adaptation strategies and hydrological scenarios, 'non-climate' pressures – such as land use changes, water uses, population development and other socio-economic factors – also have to be taken into account.

## ■ 3 Management and adaptation

*The third block concentrated on seasonal predictions and real-time forecasts (including water temperature), prediction at ungauged sites, risk and crisis management, the role of stakeholders and the public in decision-making procedures*

**Daniela Jacob** (Max Planck Institute for Meteorology, Germany) presented developments in seasonal-to-decadal (s2d) predictions, focusing especially on model uncertainties. However, between s2d predictions and weather forecasting, a gap exists in the forecast. Here further research is needed to understand the driving forces, the interactions, boundary conditions and memories, in global but also in regional scales. Uncertainty and predictability were main issues in the presentation. Many uncertainties make prediction so difficult, i.e. initial condition uncertainty, model uncertainty and the uncertainties of external parameters. The importance of the various kinds of uncertainties changes with the forecast range. In the case of s2d predictions, all kinds of uncertainties have significant impact on the forecast quality.

The primary tool used to reduce uncertainties is ensemble prediction. Many methods were developed to represent initial-condition uncertainty. Model uncertainty can be represented by the creation of a so-called multi-model ensemble by integrating the different models from the same initial conditions. One example is the DEMETER system. (DEMETER is the acronym of the EU-funded project entitled «Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction».) Another approach is a multi-parameterization ensemble, for which different parameterization schemes are implemented into one model and for every ensemble member different parameterizations are used. Furthermore, multi-parameter ensembles can be used, where one model is integrated with different parameters. A different view on the problem is the use of a stochastic parameterization scheme, where the subgrid scale is described by non-linear stochastic processes.

The scientific basis for s2d predictions lies mainly in the long-term variations of the ocean and the land surface, and Jacob provided an overview on actual projects on s2d prediction.

The discussion brought up a number of issues and questions, including:

- that essential research is still missing;
- what is now more necessary: improving predictions or going to the people?;
- how to communicate the uncertainties (including better communication to the users);
- should solutions be kept for use at the right moment to become implemented?
- choosing flexible responses with no regret;
- that there is a high potential for prevention of damages from low flows and droughts;
- that 100% predictability does not exist.

In his presentation, **Günter Blöschl** (Technical University Vienna, Austria) compared and assessed various methods for estimating Q95 low flows for ungauged catchments or sites. With examples from Austria he explained where different combinations of influencing factors on low flows could be detected (such as climate, catchment characteristics, anthropogenic effects). Single processes as well as combinations can influence low flow. Highlights of main results were summarized as follows (from the abstract):

- »… the use of low-flow seasonality indices to group catchments into regions improves the predictive performance of a regression model between low flows and catchment characteristics over a global model, provided separate regressions are used in each region«;
- »… a regional regression approach based on a catchment grouping of 8 seasonality regions (in Austria) outperforms regressions based on other groupings, […], and explains 70% of the spatial variance of q95 specific low-flow discharges«;
- to exploit the information from short stream flow records, »[one] year of continuous stream flow data outperforms the best regionalization method, but one spot gauging does not outperform the best regionalization method«.

Blöschl stated that process understanding could assist in regionalization low-flow characteristics more accurately than existing standard methods. Finally he presented a low-flow estimation procedure for Austria, where for maximizing the accuracy of estimates relevant sources of information were combined. The components of the procedure consist of:

- temporal adjustments for short record length;
- grouping catchments into seasonality based regions;
- regional regressions of low flow with catchment characteristics;

- spatial adjustments for exploiting local stream flow data and uncertainty assessment,

resulting in maps of lower and upper confidence limits of low-flow discharges.

Some aspects in the discussion included the need for expert information and the use of suitable methods.

**Silke Rademacher** (Federal Institute of Hydrology, Germany) presented the results of forecasts for the Rhine river using the water-level forecasting system WAVOS coupled with the flood forecasting system DELFT-FEWS. The system can be used also for low-flow forecasts as well as for flood forecasts. Discharge is simulated by a precipitation-runoff model and is coupled with water level forecast. The current lead-time is two days, but there is a need to extend it to four days for the Rhine river. With increasing lead-time, the uncertainty of forecasts increases, primarily due to the uncertainty of rainfall and temperature forecasts. To overcome the uncertainties of meteorological inputs, ensemble predictions are used. Currently two systems are available, the ECMWF-EPS ensemble and, most recently, the COSMO-LEPS ensemble. A typical BfG and RIZA project investigated the skill of the ensemble forecasts in the Rhine basin. One main problem for the second ensemble solution was the short length of available data series. Here the future will bring more experiences.

The last two presentations, by **Undala Alam** (Cranfield University, United Kingdom) and **Erik Mostert** (Delft University of Technology, the Netherlands), brought up a completely different but nonetheless very important aspect of research: How to transfer scientific knowledge and acknowledgments into understanding and spur for politicians and other stakeholders – how to communicate the scientific results?

Alam clearly stated the problem of agendas: those of scientists and those of politicians. If scientists want to have their results introduced into the practice, they have to provide stakeholders with information and bring them into making decisions. Therefore, scientists must not only keep the hydrological facts in mind, but must strategize to involve the stakeholders:

- One cannot assume that good data will lead to good action.
- Scientists should learn to speak decision-making language and understand their points of view; use effective ways of communication bearing in mind that a necessary action to reduce the risk for the water system may increase the risk for the politicians.
- Scientists should learn to manage expectations – their own, those of decision-makers and also those of the public.

Mostert offered 7 rules for hydrologists wanting to make an impact on water management:

- Reflect on the nature and possible roles of technical expertises.
- Analyse stakeholders and issues at stake.

- Choose whom and what to serve – but always keep in mind the scientific standards!
- Decide on strategy (kind of expertise; advocacy or facilitation; cooperation, confrontation or isolation; role of media and public opinion).
- Design the process to implement the strategy, from the start of the research.
- Communication: simple but correct messages, no jargon, consider background knowledge and interests of target audience.
- Reflect on your own interests and skills.

## Abbreviations

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| AR4 | Fourth Assessment Report (of IPCC) |
| ATV | Abwassertechnischen Vereinigung e.V. |
| BfG | Bundesanstalt für Gewässerkunde (Federal Institute of Hydrology) |
| BOKU | Universität für Bodemkultur (University of Natural Resources and Applied Life Sciences, Vienna) |
| CHR | international Commission for the Hydrology of the Rhine basin |
| DVWK | Deutscher Verband für Wasserwirtschaft und Kulturbau e.V. |
| DWA | Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA): union of ATV and DVWK since 1 January 2000 |
| DWD | Deutscher Wetterdienst (German Weather Service) |
| EC | European Commission |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| ETH | Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology, Zürich) |
| EU | European Union |
| GCM | Global Circulation Model |
| GHG | Greenhouse gas |
| IPPC | Intergovernmental Panel on Climate Change |
| KNMI | Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute) |
| MAM | Mean annual minimum flow |
| MQ | Mean flow |
| NMxQ | mean minimum flow over x consecutive days |
| NM7Q | annual mean lowest runoff during 7 consecutive days |
| RCM | Regional Climate Model |
| RIZA | Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling (Institute for Inland Water Management and Waste Water Treatment), formerly part of RWS, now partly Waterdienst and partly Deltares |
| RWS | Rijkswaterstaat (Directorate-General for Public Works and Water Management) |
| TU | Technical University |

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