■ 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.