Key aspects of low flow and drought

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Extended abstract

Introduction
Drought is one of the most severe natural hazards that can occur in almost every hydroclimatological region. It is a reoccurring and worldwide phenomenon, with spatial and temporal characteristics that vary significantly from one region to another. Drought should not be confused with aridity, 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.

This presentation addresses the definition and analyses of drought (incl. low flows) in different hydrological regimes, the significance of hydrological processes and catchment characteristics for drought development, spatial and temporal patterns of drought and potential impacts on drought behavior under climate change. The main focus is Europe, although examples will be given also from other regions in the world. Recent extreme events in Europe will be discussed, like the 2003, 2005 & 2006 events (Fig. 1). The record breaking event in 2003 was a strong reminder of Europe’s vulnerability to drought with serious impacts on society, environment and sectors like agriculture, forestry, river transport and energy production. The minimum economic costs of the 2003 drought has been estimated to be in the order of 12 billion €, and the heat wave that accompanied it contributed to the deaths of more than 30.000 people (EurAqua, 2004). The presentation concludes with information on international cooperation and recent research initiatives and needs, including drought management and policy issues.

Figure 1 River l’Eygues (France) during the drought in August 2003 (photo by H.A.J. van Lanen).
Low flow and drought

Drought is defined as a sustained and regionally extensive occurrence of below average natural water availability and may affect all components of the water cycle (Tallaksen & van Lanen, 2004). Hydrological drought includes drought in streamflow and groundwater (recharge, storage and discharge), and can be defined in terms of both low flow and deficit characteristics. A time series of low flow characteristics, e.g. the annual minimum series, is suitable to characterize the hydrological regime of a river, but provides only one feature of the event, i.e. the severity. To enable also the duration and time of occurrence to be defined, a threshold level needs to be introduced, which defines the start and end of the drought as a period when the streamflow or groundwater variable is below a certain value (i.e. in a deficit situation). In addition, spatial aspects such as the area covered by drought and the total deficit over that area, are important measures of the severity of an event. By analyzing spatially distributed data, these properties can be included in the definition of the event and for instance the probability of a specific area to be covered by a drought of a given severity calculated.

Droughts often cover wide areas and last for a long time periods (Fig. 2), and there is a need to better understand the spatial and temporal aspects of drought at the regional scale. This includes the extent of the event, the variability within the affected area, the dynamic of the drought and possible links to large scale climate drivers. In 2003 a high pressure system developed over Western Europe. This led to blocking of moist air masses from west and allowed warm, dry air masses from Northern Africa to move northwards. The result was large precipitation deficits that extended across most of Central and Southern Europe with drought conditions lasting from March to September.

![Figure 2](image_url)

**Figure 2** Extent and severity of the 2003 drought in Europe – a negative SPI implies dryer conditions than normal (from EurAqua, 2004).

Physically based, distributed hydrological models can be used as a tool to define the spatial behavior of drought for different variables, like infiltration, soil moisture and groundwater. In studies by Peters *et al.* (2006) and Tallaksen *et al.* (2006) the propagation of drought in the hydrological cycle has been analysed using gridded information, focusing on drought in interpolated time series of precipitation and simulated time series of groundwater recharge, hydraulic head and groundwater discharge. The results demonstrate the catchment control in modifying the drought signal from a series of short duration droughts in rainfall covering large parts of the catchment, through fewer and longer droughts in groundwater. Process-based studies are also important when assessing the potential impact due to global
change, i.e. climate change and anthropogenic influences like abstractions, land use and urbanization. The natural system can be simulated using physically based hydrological models and the impact on drought of past and future interventions in the catchment investigated. Such studies may help to analyse the impact of both re-active and pro-active measures to adapt to the negative effects of drought.

**Impacts of climate change**

Generally, two approaches can be used to assess the impact of climate change on hydrology; analysis of observed data for changes and trends and scenario calculations using physically-based models (e.g. Stahl & Hisdal, 2004). A summary of observed and projected impacts of climate change on hydrological droughts is presented by van Lanen et al. (2007). The detection of trends requires, however, care considering its statistical assumptions and quality of the data (e.g. Kundzewicz & Robson, 2004). Regional scale variability in the spatial and temporal behaviour of hydrological drought due to the high natural variability in climate as well as catchment properties, further complicates the picture. This is demonstrated by Hisdal et al. (2001) for streamflow drought in Europe. The study showed that although there were no significant changes for most stations in the period 1962-90, distinct regional differences were found. Trends towards more severe droughts in Spain, the western part of Eastern Europe and in large parts of the UK, whereas trends towards less severe droughts occurred in large parts of Central Europe (Fig. 3). The study further illustrates the high sensitivity in the resultant trends to the time window chosen by analysing periods of 30 consecutive years obtained from a 100 year dataset with daily streamflow. Trends towards both more or less severe hydrological droughts were found over the period 1901-2000 for this particular catchment with no clear development over the century.

**Figure 3** Spatial distribution of the Mann-Kendall test statistic for Annual Maximum Volumes (AMV) of drought deficits (from Hisdal et al., 2001).

The 4th Assessment Reports of the IPCC (IPCC, 2007)) provide a recent summary of observed changes in hydroclimatological variables. Records of global surface temperature
show that the eleven years from the period 1995–2006 rank among the 12 warmest years in the record of the last 150 years. Although not consistent for all regions, a long-term trend over the period 1900-2005 could be observed, showing a significant precipitation increase for Northern Europe and a decrease for the Mediterranean region. Zhang et al. (2007) confirm that anthropogenic forcing has contributed significantly to observed increases in precipitation in the Northern Hemisphere mid-latitudes and drying in the Northern Hemisphere subtropics. More intense droughts affecting an increasing number of people have been observed since the 1970s, globally and in Europe. Such droughts have been linked to higher temperatures and decreased precipitation, and it is likely that it has a human cause. This also holds for the frequency of heat waves.

Regions located in the transition zone between major climate zones, e.g. from the temperate to the dry climates, are particular susceptible to drought and thus to potential changes in climate (Stahl & Hisdal, 2004). A shift in climate may create a new transitional climate zone with unknown feedback mechanisms. In southern Europe a northward shift is observed, causing a decline in summer precipitation in Central and Eastern Europe. Climate models consistently predict an increase in summer temperature variability in these areas and it is suggested that this can mainly be attributed to strong land-atmosphere interactions (Seneviratne et al., 2006). This may potentially cause more droughts and heat waves in this and other mid-latitude regions. Regional climate models suggest that towards the end of the century about every second summer could be as warm or warmer (and as dry and dryer) than the summer of 2003 (Schär et al., 2004).

In 2050, IPCC expects that the annual average runoff will have increased by 10-40% at high latitudes, and decreased by 10-30% over some dry regions at mid-latitudes and semi-arid low latitudes, some of which are presently already water-stressed areas. In many water scarce regions in the Mediterranean, the effects of climate change is likely overruled by the effects of land use, in particular by abstraction for irrigation. Cruces et al. (2000) illustrate this for the Upper-Guadiana catchment (Spain), where more water-demanding agriculture has been implemented under semi-arid conditions and as a result, groundwater has been heavily overexploited since the 1960-70s. At high latitudes where an increase in annual flow is predicted, the corresponding impact on low flow and drought depends on the seasonal distribution of precipitation, the storage capacity of the catchment (ability to take advantage of higher winter precipitation), and changes in evapotranspiration and the length of the growing season.

The IPCC reports increased annual runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, indicating a regime shift for some rivers. This trend is projected to continue in response to increasing temperatures, initially increasing, but eventually reducing summer streamflow downstream regions supplying melt water from major mountain ranges. In cold regions the scenarios predict a decrease in frost days, earlier snowmelt and longer growing season. This is confirmed by observations which show that the beginning of the growing season in mid-latitudes has clearly advanced since 1989 (Chmielewski & Rötzer, 2002). Subsequently, this might lead to an increase in the frequency and severity of summer drought. A study in the Nordic countries (Hisdal et al., 2006) reports that increased temperatures have already caused both an earlier snowmelt and higher evaporation, which in some regions has lead to longer summer droughts.

International cooperation and research needs
Drought cannot be prevented, but its impacts can be reduced through adaptation and mitigation, i.e. knowledge, preparedness and good management practice. Droughts are caused by large, global scale climate drivers, and as apposed to floods, drought forecasting has to consider large scale mechanisms over long time periods. Our ability to improve seasonal
forecasting of drought depends on the potential to link large-scale climate drivers to the occurrence of drought and heat waves at the regional scale. For instance, a high winter NAO Index implies that storm tracks shift northwards, leaving southern Europe, where anticyclone persists, without rain. Such situations may lead to more streamflow droughts in southern Europe due to the reduction in winter rain that normally replenishes the aquifers (Stahl, 2001). Other limitations in our knowledge of drought that limit our ability to understand, model and predict their current and future occurrence, include the need to better understand the processes controlling drought at different temporal and spatial scales. It is noticeable that neither of the major recent drought events in Europe were predicted, and as a consequence the response to drought is typically crisis based management instead of proactive risk management. An early warning system for droughts is in this respect an important and also sustainable way to adapt to changing demands and changing climate.

The recently initiated EU-funded WATCH project (WATer and global CHange) aims to advance our knowledge and skills to predict the effect of global change on hydrological extremes (flood and drought). It analyses and describes the current global water cycle (20th century), especially causal chains in the physical system leading to observable changes in extremes. WATCH brings together hydrologists, water resources experts and climate modelers. It will contribute to a clarification of the overall vulnerability of global water resources in response to global change and assess the uncertainties in the chain of climate-hydrological-water resources model predictions using a combination of model ensembles and observations.

In 2004, Europe’s leading fresh water research organizations presented a discussion document entitled “Towards a European Drought Policy” (EurAqua, 2004). The document focuses on the need to promote discussions on drought as an important characteristics of the European environment and to emphasis the need of an integrated and coordinated effort on all levels from research to policy to advance our ability to mitigate the impacts of drought. It is stated that “despite the often vast scale of Europeans drought there is no coordinated European drought forecasting, monitoring and mitigation network, or commitment to drought research and best practice”. Since then some actions have been taken, including the establishment of a working group on Water scarcity and Drought organized by EU member states. In July 2007 the European Commission presented a communication to the European parliament and the council addressing the challenge of water scarcity and drought in the European Union (CEC, 2007). The topic is seen as an essential environmental issue and a precondition for sustainable economic growth, also important in the context of climate change. Hopefully, these conclusions will result in further initiatives and actions taken by the Commission on this important topic.

The European Drought Centre (EDC\textsuperscript{1}) is a virtual centre established in 2004 with the aim to encourage and coordinate drought related activities in Europe. Its long term objective is to promote collaboration and capacity building between scientists and the user community in order to mitigate the impacts of droughts on society, economy and the environment. Although the EDC primarily has a European dimension, it also links with international projects, organizations and experts outside Europe. The EDC offers easy access to updated and relevant information on drought activities, information on the current drought situation in Europe and archived information on historical droughts in Europe and outside. The European Drought Centre will interact with the scientific and operational communities as well as policy makers and society to raise the awareness of the drought hazard and may represent an important platform for future European drought initiatives.

\textsuperscript{1} www.geo.uio.no/edc
References


