ABSTRACTS

Of

Oral and poster contributions to the international

CHR-Workshop – Expert Consultation

LOW FLOWS AND DROUGHTS

Würzburg, Germany, 25 and 26 September 2007

International Commission for the Hydrology of the Rhine Basin (CHR)

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Workshop – Expert consultation
Low flows and droughts

Würzburg – Germany

25 and 26 September 2007

Book of Abstracts

CONTENT

Abstracts of oral presentations:

Abstracts of poster presentations:

BACKGROUND

Drought is considered a major natural hazard affecting large areas and millions of people every year. It is a regularly recurring phenomenon with strong environmental and socio-economic impacts. The decade 1996-2005 was globally the warmest since systematic monitoring started in 1850. According to the latest information, global warming will continue and as a result the hydrological cycle is expected to intensify. The hydrological prospects for summer periods, however connected to uncertainties, indicate more frequent low flows and stream flow droughts in the Rhine basin. The recent occurrence of severe and prolonged drought conditions in various regions of Europe and throughout the world has again emphasized the need for in-depth research on the causes as well as the environmental and socio-economic impact of drought. Appropriate tools for drought alert, monitoring and assessment are urgently needed. Such information is essential to manage and implement adequate mitigation and adaptation strategies.

Objectives

- To exchange knowledge about historic low flow and drought periods.
- To discuss local and regional analysis methods of low flow and drought indices and related processes.
- To exchange knowledge about seasonal weather prediction and low flow forecasts.
- To exchange knowledge about the influence of climate variability and climate change on future low flow and drought periods.
- To discuss decision-making procedures, the role of stakeholders and the public.
- To detect research deficits.

The International Commission for the Hydrology of the Rhine Basin (CHR) invites scientists, decision makers and stakeholders in the field of low flow and drought management to discuss these issues during a two-day workshop.

WORKSHOP THEMES

The workshop is divided in three plenary working sessions:

Theme 1: **Observed low flow and drought periods**
Keywords: At site and regional indices, case studies, data quality

Theme 2: **Impact of climate change on low flow and drought**
Keywords: Recent developments in climate scenarios, effects on the hydrological cycle, effects on water user functions

Theme 3: **Management and adaptation strategies**
Keywords: Seasonal predictions and real-time forecasts (incl. water temperature) prediction at ungauged sites, risk and crisis management, the role of stakeholders and the public in decision-making procedures

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 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 Chair: Siegfried Demuth / Rapporteur: Peter Krahe	
14.30	Recent developments in climate scenarios in The Netherlands: Bart van den Hurk, Royal Dutch 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 – 18.15	Discussion of theme 2
19.30	Participants' dinner

Day 2 – 26 September 2007

Theme block 3 – Management and adaptation strategies
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

ORGANISERS

The invitation to the event is issued by the International Commission for the Hydrology of the Rhine Basin (CHR) in cooperation with UNESCO IHP Paris and the German IHP/HWRP Secretariat. For further information about CHR and about the workshop, please visit our website at www.chr-khr.org.

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ABSTRACTS

OF ORAL PRESENTATIONS

KEY ASPECTS OF LOW FLOW AND DROUGHT

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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.

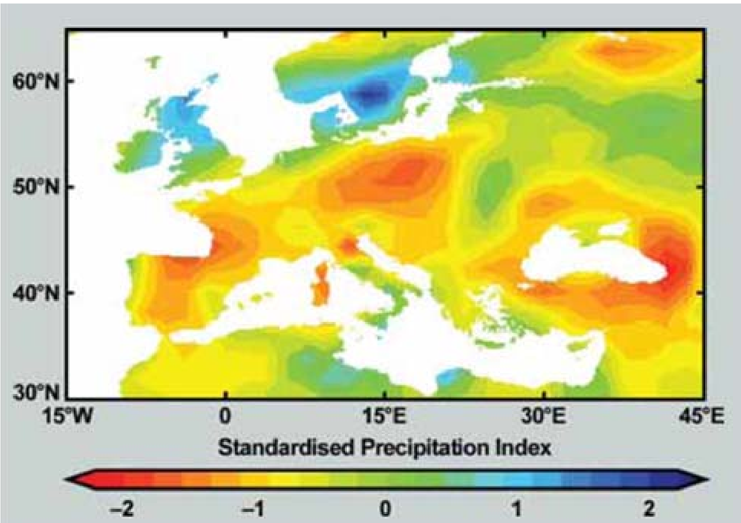

Figure 2: Extent and severity of the 2003 drought in Europe – a negative SPI implies dryer conditions than normal (from EurAqua, 2004).

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. Kundezewicz & 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.

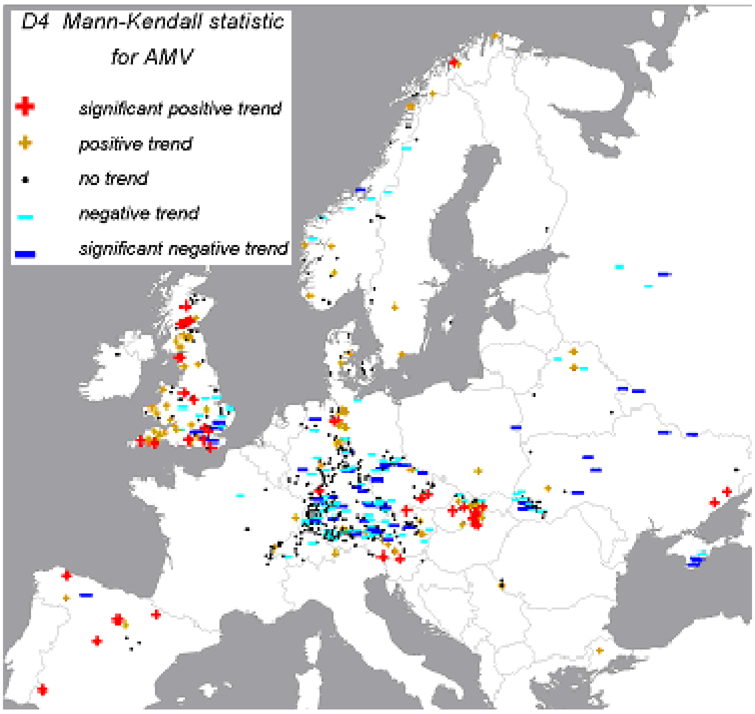

Figure 3: Spatial distribution of the Mann-Kendall test statistic for Annual Maximum Volumes (AMV) of drought deficits (from Hisdal *et al*., 2001)

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 <u>annual</u> 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 shifts 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 (20^{th} 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[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.

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

AT SITE AND REGIONAL INDICES OF LOW FLOW AND DROUGHT PERIODS

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Introduction

Low-flow and drought periods are very complex meteorological/hydrological events. When does such an event begin and when does it end? Even such simple questions are not yet adequately clarified. So, it is not astonishing that there are no universally valid definitions nor generally accepted indices for the characterisation of these events. The choice of the indices depends on the purpose of the intended study and also on the flow regime of the area under investigation. Of course, the experience and the traditions of the person in charge do play a role too.

In this paper, I want to limit myself to the hydrological drought, that is low flow in watercourses. Definitions and indices for meteorological and ecological (soil moisture) droughts may be found in Tallaksen & van Laanen (2004) or Ebner von Eschenbach (2003). I want to put the main focus on the indices established in the DVWK-Richtlinien (DVWK Rules, DVWK 1983, 1992), which are preferrentially used in Germany. Other indices, which are used e.g. in Austria and Switzerland, will also be introduced in this context. Finally, I will report on some applications of our indices.

Mean minimum flow

The German Association for Water, Wastewater and Waste (DWA formerly DVWK) issued recommendations for statistical low-flow analysis and defined the mean minimum-flow parameter NMxQ – the lowest arithmetic mean of x consecutive daily values of flow within the time period ZA during the reference period BZ [in m3/s] (DVWK 1983). BZ is the reference period, dependent on the low-flow regime of the water body under consideration. In a pluvial flow regime, the water year is counted from 1 April to 31 March. ZA is the time period under consideration, for instance the summer half-year, the water year, or the growth season.

The DVWK Rules recommend the values 1, 7, 10 und 30 as number of days x, although often also the values 5, 14, 15, 21, 60 and 90 are used, depending on the aim of the statistical analysis. 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, the 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

In the DVWK Rules we find following threshold-related indices:

MaxD: longest period of non-exceedance of a threshold Qs within the time period ZA during the reference period BZ [in days];

SumD: sum of all periods of non-exceedance of a threshold Qs within the time period ZA during the reference period BZ [in days];

MaxV: maximum deficit volume between the threshold Qs and the hydrograph Q(t) within the time period ZA during the reference period BZ [in mm or hm3];

SumV: sum of all deficit volumes between the threshold Qs and the hydrograph Q(t) within the time period ZA during the reference period BZ [in mm or hm3].

The Figure 1 shows an example of BZ=ZA=water year with three low-flow events at Qs = 30 m3/s.

MaxD and MaxV are determined from event No. 3. SumD and SumV are the sums of all three events.

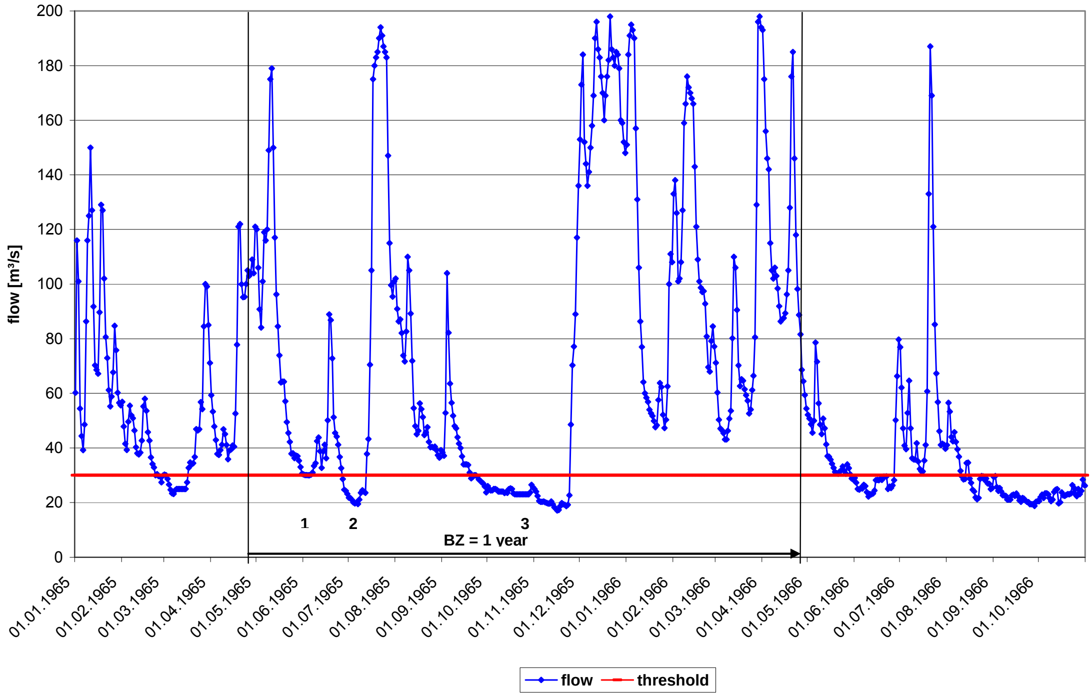

Fig. 1: On the definition of the low-flow parameters MaxD, MaxV, SumD, and SumV

Thresholds may be flow minima that are either ecologically substantiated or are derived from the requirements of water-resources management, reservoir operation, and navigation on the river. For regional comparisons the long-term mean low-water discharge MNQ is often used. The indices MaxD and SumD as well as there long-term means are applied for planning purposes in ecology, navigation, and generation of energy. The indices MaxV and SumV are especially significant for studies concerning water-resources management and low-flow enhancement.

Percentiles from the flow-duration curve and other indices

Often low-flow indices are derived from the flow-duration curve (FDC). The FDC is the empirical probability distribution of daily flows. For instance, the 95%- or 90%-percentile are applied (Fig. 2). Q95 is the flow, which is exceeded in 95% of the time.

For comparisons, the index can be divided by the size of the catchment area (q95) or the mean value.
Kan (BWG 2003) in Switzerland mostly uses the flow Q347, which is exceeded on 347 days of the year. In Austria, the Q95 is used (Laaha 2006).

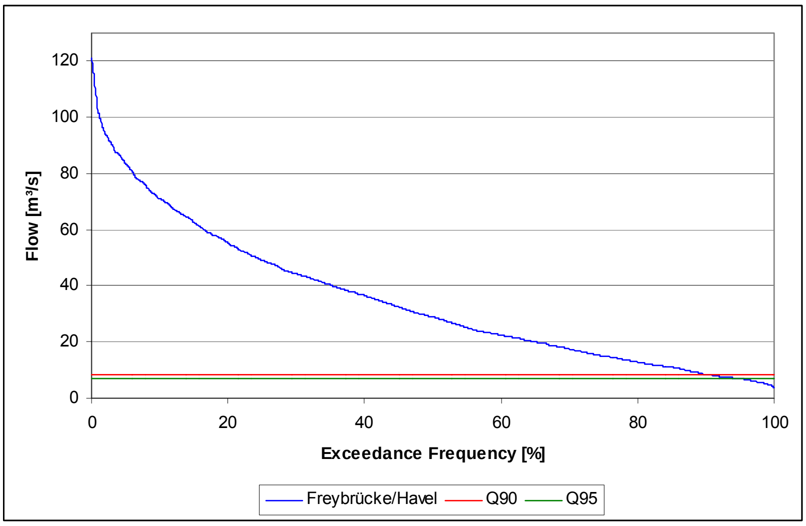

Fig. 2: Flow-duration curve for the River Havel at Berlin-Freybrücke

Further low-flow indices, which are also used in Germany, are:

- base flow and ratio of base flow to total flow (BFI)
- parameters of the recession curve, such as recession constants of linear or non-linear storage and recession rate.

The parameters can be determined either for whole years, half-years or vegetation periods, so that they can provide time series as well as over longer time periods.

Regionalisation

In principle, all low-flow indices can be regionalised, i. e. they can be calculated for locations from which no observed data are available. Regionalisation serves to represent the low-flow conditions for a larger area and to derive low-flow indices for the design in hydraulic engineering, for concessions for water uses or for environmental impact assessment. In Germany, experiences have been gathered especially concerning the regionalisation of MNQ, but also of MNMxQ and BFI.

The most important methods of regionalisation are

- Simple estimation methods;
- Multiple regression analysis;
- Index-method;
- Spatial interpolation;
- Calculation with water-balance models.

The DWA is preparing a working paper „Regionalisierung von Niedrigwasserkennwerten“, that combines methods and experiences from Germany and Austria.

Applications: Characterization of the year 2003 (Koehler, G. et al., 2006)
The summer 2003 brought over wide parts of Europe an extraordinarily long period of sometimes very high temperatures and little precipitation. Germany was also affected. In water-resources management, the most severe consequences were the decrease in streamflow and falling water levels in rivers, lakes and groundwater. This coincided with higher water demand.
It is an important task to evaluate such events regarding regional differences and in comparison with former events as well as the consequences for the population and the economy. For the analysis of the year 2003, the low-flow indices MNQ and NMxQ were also used. The NM7Q values of 2003 were compared with the low-flow probabilities (logPearson-3) out of a long-term series (e. g. 1961-2002):

River basin	Return period Tn min	Return period Tn max
Rhine	5-10 years	50 years
Danube	2-5 years	10-20 years
Weser	5-10 years	
Elbe	5-10 years	20 years
Oder	20-50 years	> 100 years

At 2/3 of the gauges, the event of 2003 had to be rated as one that is reached or non-exceeded once or more often every 10 years on average. Generally, the east of Germany was affected most severely, the south least.

Applications: Long-term behaviour of low-flow parameters at gauges of the anthropogenically influenced Elbe river basin (Finke & Krause, 2005)
The reason for the notably reduced low-flow values in the rivers Spree and Havel since the 1990s is often found in the decreasing mine drainage in the lignite mining industry of the Spree basin and the beginning rehabilitation of the water balance in this region. However, there are still other influencing factors that may have contributed to this flow reduction. The management schemes of reservoirs, water-transfer pumping stations, and wetlands have also changed in the years since 1990. Water demand and use losses had a declining tendency. Farming was abandoned on some areas, while the impervious surfaces of housing areas, roads, and industries spread; and last but not least, possible climate variations must be taken into account. All these factors ultimately influenced the runoff process and found their reflection in the measurement series. The quantitative separation of the effects of the individual influences on streamflow would require great investigative and data-processing efforts, although a methodology for doing this is available (Ebner von Eschenbach, 2003).

The Offices for Waterway New-Construction Berlin and Magdeburg are responsible for the planning of construction projects on Federal waterways in the Elbe basin. This requires - irrespective of the planned projects themselves - also the observation of ongoing developments in the river basin. Against this background, the two Offices for Waterway New-Construction commissioned the Federal Institute of Hydrology with a statistical study of the temporal variation of low-flow parameters from several gauges in the Havel river basin. The task was to compare the temporal development of low-

flow parameters in the Lower Havel with those in its tributaries and in the River Elbe. Additionally, a comparison should be made with trend analyses of hydro-meteorological parameters and of some parameters of water uses.
The following workflow was devised for the statistical analyses:

- Search for sufficiently long streamflow data series and thresholds, without the ambition for a uniform length of the series;
- Formation of series of low-flow data NMxQ, durations of non-exceedance MaxD, SumD, and cumulative deficit volumes MaxV, SumV;
- Jump analyses according to Bernier and Pettitt;
- In cases of significant jumps, separation of the series at the point of the jump;
- Determination of primary statistical parameters, especially mean values, medians, variation coefficient, skewness, MQ related mean;
- Homogeneity analyses by univariate statistical tests;
- Trend analyses, linear and with significance testing;
- Interpretation of the results with the help of information on climate trends and changes in water-resources management;
- Comparison of the results from the Lower-Havel Waterway with those from the tributaries and from the River Elbe.

The error probability was always selected at 5 %. The tests were used equally despite their differing resolutions. The question for the statistical significance of unambiguous results in several tests was not raised. It must be kept in mind here that changes in series can be identified only if a long time series with long rows before and after the jump is available. The fact that no jumps were found by statistical tests does not prove the absence of such jumps. Tests cannot identify weak or short-term changes (Radziejewski & Kundzewicz, 2004).

The results of the trend analyses of climatological variables may be summarized with view to the Elbe basin as follows:

- The precipitation series in the hydrological winter half-years (November to April) show a positive trend, while the summer half-years have a negative trend of nearly the same magnitude , which both compensate each other in the series of yearly values.
- The yearly series of potential evapotranspiration have a positive tendency at all stations.
- The computation of yearly series of the climatic water balances yielded slightly negative tendencies that are not significant.
- The station Potsdam has a negative climatic balance in the yearly average regarding water surfaces (Pkor – Ew).

The State Agency for the Environment of Brandenburg kindly provided the yearly data of mine drainage from the lignite mines in the basins of the rivers Spree and Schwarze Elster. Its temporal variation is shown in Figure 3, and it is obvious that there is no sharp turning point in the year 1990, when lignite mining in the middle Spree region declined in the wake of Germany's reunification. The reduction in mine drainage cannot be fixed to one single year.

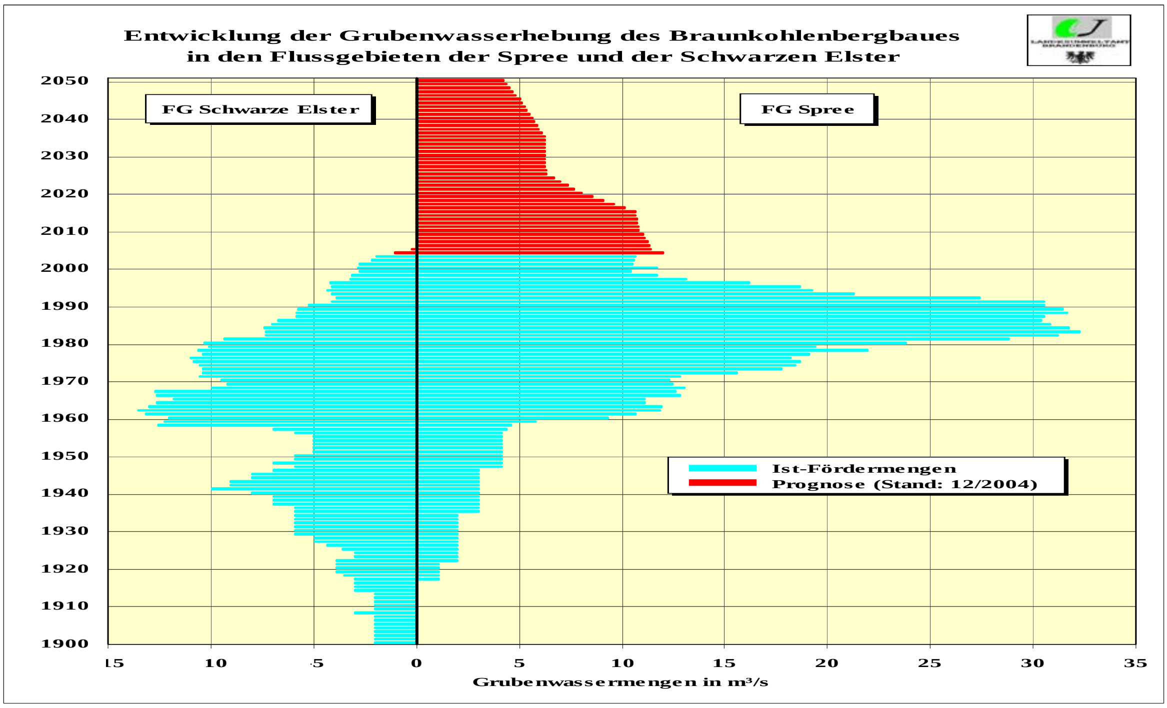

Fig. 3: Development of mine drainage [m3/s] in the river basins of the Spree and the Schwarze Elster (blue: actual pumping, red: prediction based on May 2001)

The jumps in the low-flow series of the River Havel occurred between 1967 and 1988, i.e. somewhat earlier than those in the lower Spree basin (1987-1990) but coinciding with those in the Upper-Havel and in the River Nuthe. The jumps in the Lower-Spree series occurred roughly at the time when the lignite mine-drainage scheme in the Middle Spree basin changed. There were no significant jumps in the series of the gauge Bautzen on the River Spree upstream of the mining district. The low-flow data series of the River Elbe have jumps between the years 1954 and 1964. These jumps may be explained by the effect of reservoir construction in the Czech Republic, since this interval is nearly identical with the period when the large reservoirs in the river basins of the Moldau and the Eger came into operation.

The gauges on the River Elbe between Dresden and Wittenberge have positive trends in the series of low-flow data. Every 10 years, the low-flow discharge at the gauge Dresden increased by approximately 3 m³/s (cf. Figure 4). This corresponds roughly to an increase by 1% of the mean streamflow. In the Lower Havel and most of its tributaries, the trends in the low-flow range are clearly significant and negative (cf. Figure 5). At the gauge Ketzin the decrease was about 6 m³/s per 10 years, corresponding to 8% against the mean flow at this gauge.

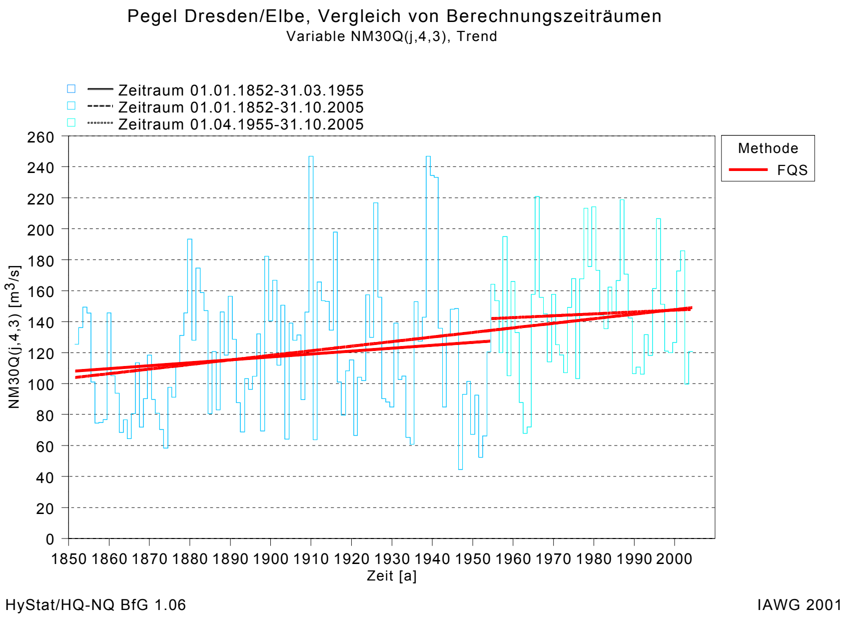

Fig. 4: Trend of the series NM30Q Dresden/Elbe, 1852-2005, comparison of the trend before and after the jump in 1954

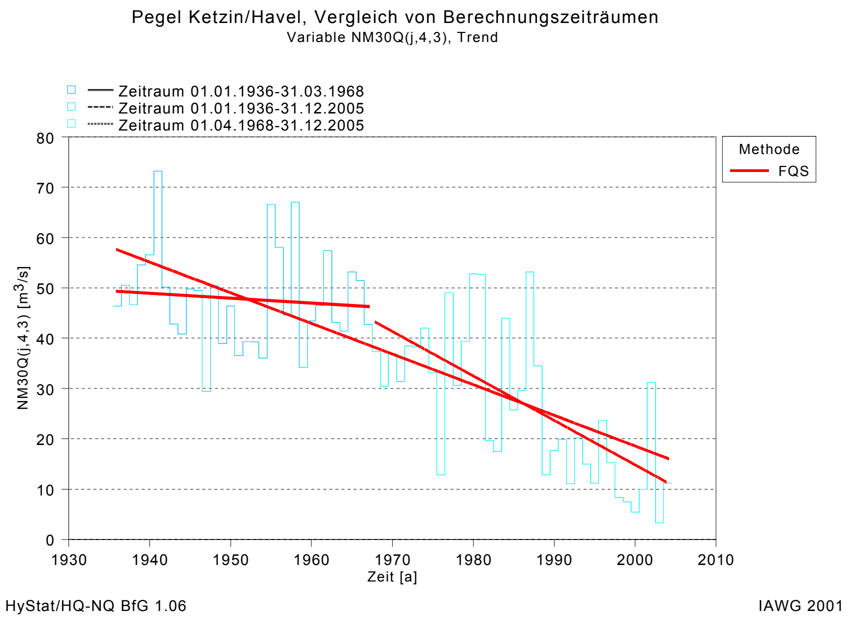

Fig. 5: Trend of the series NM30Q Ketzin/Havel, 1936-2005, comparison of the trend before and after the jump in 1967

The trends in the series of low-flow discharge of the gauges on the River Elbe are generally positive, those of the Havel river basin negative. Accordingly, the low-flow events in the Havel basin became more extreme, those in the Elbe less extreme. Of special interest is the development of the low-flow parameters after the jump: The gauge Ketzin/Havel (see Figure 5) is characterized by a distinct negative trend of low-flow discharges, which is here with 12% of the mean streamflow even stronger than that of the complete series. After the jump, low-flow discharges continue to decrease. In contrast, regarding the River Elbe in Dresden no statistically clear trend was found after the jump.

In the Lower Havel, a dramatic decrease in low-flow discharge was recorded. Here, the development of the low-flow regime is the result of a superposition of the following influences:

- Decreasing portion of the lowland part of the Elbe basin in the climatic water balance;
- Reduced lignite mining resulting in reduced streamflow in the River Spree despite compensation efforts in water-resources management;
- Reduced inflow from other catchments (Elde, Oder) due to changed management strategies;
- Reduced inflow from lowland areas to the River Havel due to changed management strategies of impoundments with the aim of increasing water retention in the lowland region and the resulting intensification of evaporation.

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LOW FLOW CONDITIONS IN THE RHINE BASIN – DEVELOPMENTS IN THE 20TH CENTURY

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This paper presents some results specifically regarding low-flow characteristics, which were achieved under a larger project, commissioned by the *Kommission für die Hydrologie des Rheins*/KHR. Its aim was to analyse changes in the flow-regime of the River Rhine and its tributaries in the 20th century (BELZ et al., 2007, *in print*) . Therefore, the long-term development of low-flow extreme situations in the Rhine river basin is here examined by means of the parameters NM7Q[2]. These abbreviations stand for the lowest arithmetic means of streamflow over 7 consecutive days, respectively within a time interval (year, half-year). These parameters are more reliably than the single-day minimum value NQ, because the latter is often distorted by singular events (short-term influences or measuring errors). Moreover, the averaging over seven days reduces distortions resulting from water-management operations: If daily minimum values are used, for instance the operation of hydropower stations can strongly influence this statistical value since the water throughput through the turbines on Saturdays and Sundays is significantly less than on the other days of the week. In this case, the single-day low-flow parameters would reflect a massive anthropogenic interference in the flow regime.

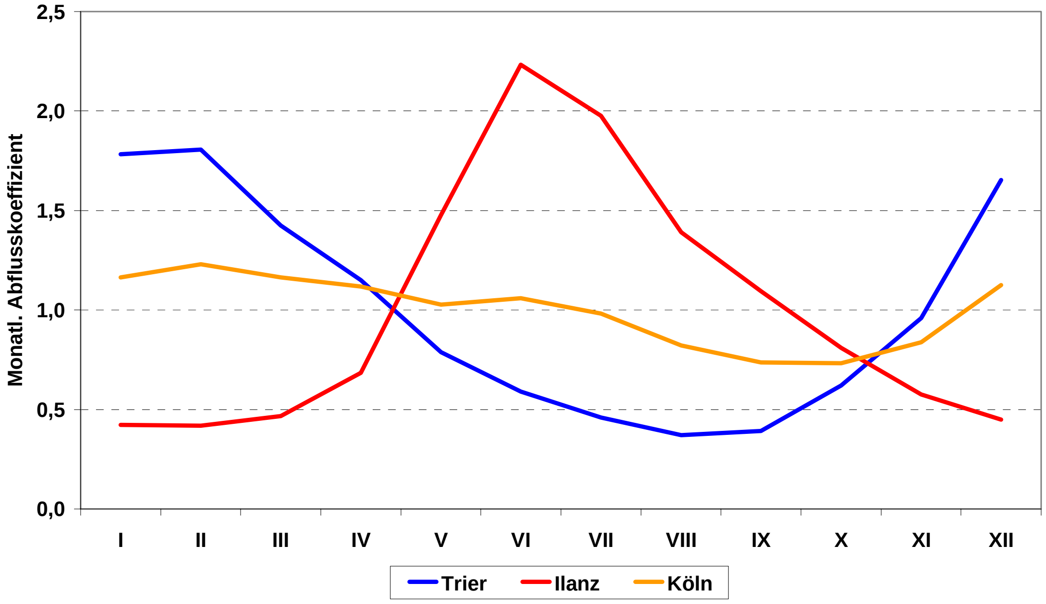

Figure 1: Characteristic types of flow regimes in the Rhine basin, reference period 1951-2000

[2] It should be noted here that the examination of low-flow conditions is oriented at the pertinent *DVWK* Rules (DVWK 1983, DVWK 1992) and uses accordingly the recommended time intervals of low-flow years. The low-flow year lasts from april to March, the summer season is here from April to September, the winter season from October to March.

The developments in low-flow extremes in the 20th century in the Rhine basin are better understood with the knowledge of the major types of the flow regime there. These are, as shown in the Figure 1:

- the nival (= snow-dominated) regime of mountainous areas, illustrated with the example of Ilanz (Vorderrhein), with a very wide range of amplitude, single-peak with a maximum in summer due to snowmelt and a minimum in winter when the water is retained in form of ice and snow;
- the pluvial (= rain dominated) oceanic regime, represented here by the example of Trier (River Mosel), with a wide range of amplitude, single-peak, with a maximum in the mild rainy winter months and a minimum in summer resulting from intensive evapotranspiration;
- a balanced pluvial mixed regime („complex regime 2nd order“) of the rain-snow type, shown by the example of Cologne (River Rhine), two-peaks, with the main maximum in late winter and a minimum in autumn.

Numerous other combinations of these regime types exist.

Accordingly, for each watercourse and region, the typical low-flow period may occur in different seasonal intervals of the year. A development towards distinct extremes over the course of the year can be observed when changes of climatic and other external conditions of runoff generation coincide with these low-flow-prone seasons.

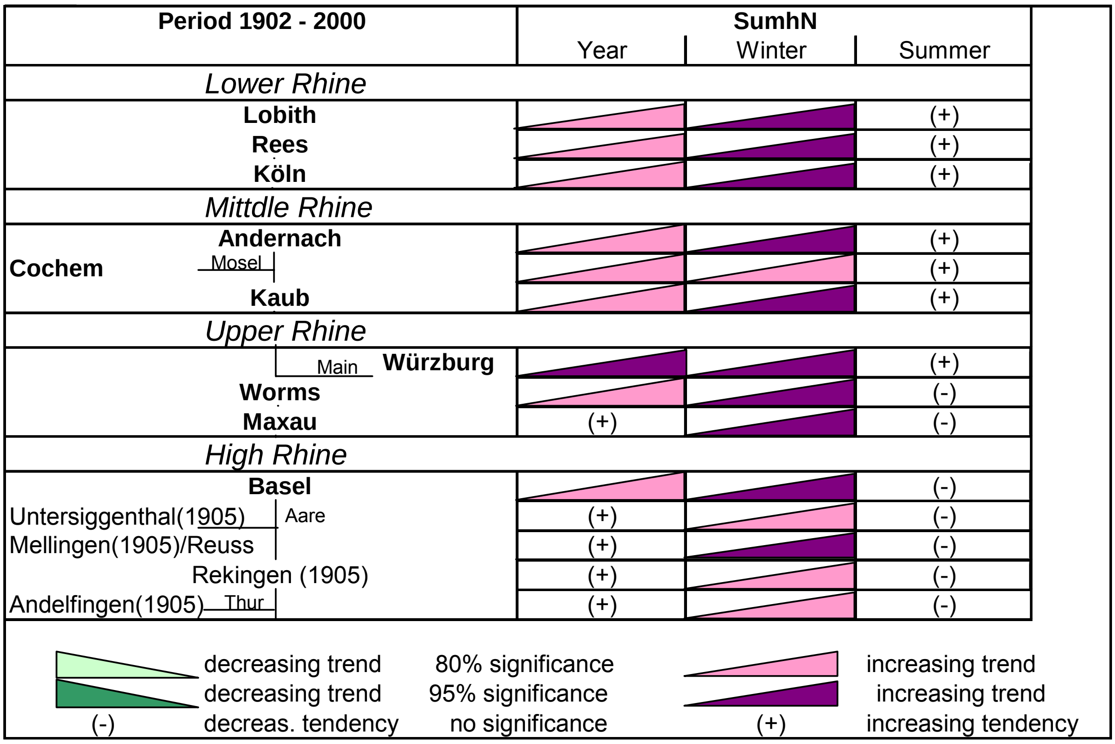

Figure 2: Trends and tendencies of half-year and yearly values of areal precipitation (SumhN) in sub-catchments of the Rhine basin in the series 1902 – 2000

Changes in the streamflow regime are primarily conditioned by climate dynamics: The areal mean of precipitation in the Rhine basin from the Alps to the German-Dutch border at Lobith shown in a review of the 20th century changes in the yearly values and even more pronounced in the half-year values. This process is controlled by modifications of the atmospheric circulation patterns that occur in varying frequencies in specific *Großwetterlagen* (*GWL*)[3]. Of particular relevance are here the humid *GWL* that occur more frequently in the non-alpine parts of the river basin where the terrain relief is less pronounced.

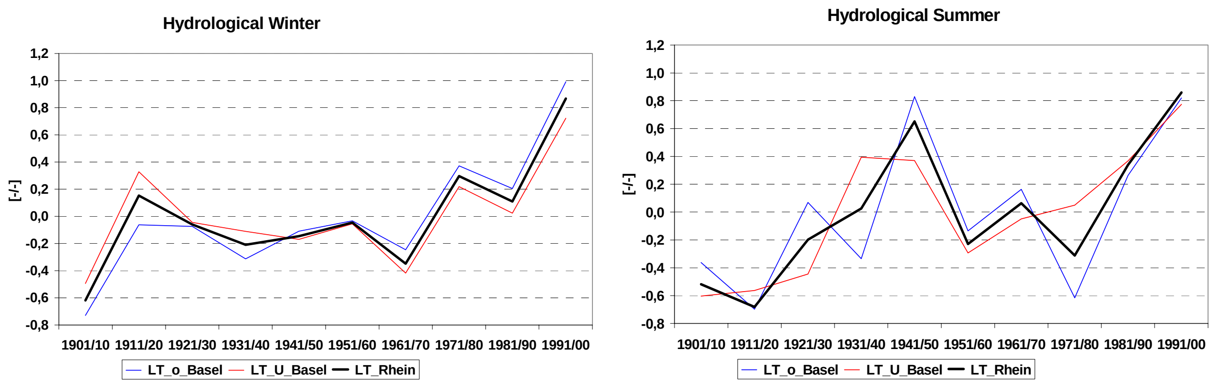

Figure 3: Standardized ten-year means of air temperature (LT) in the Rhine basin in the hydrological winter- (left) and summer half-years (right), period 1901 – 2000

Ultimately, the result is higher cumulative precipitation over the whole year, with a seasonal differentiation into significantly higher winter precipitation and generally hardly changed cumulative precipitation in summer. The latter decreases even widely in the southern Rhine basin, because there the more humid *GWL* do not show a significant increase in frequency.

An even stronger increase than precipitation did the air temperature show in the course of the 20th century. In this regard, the Rhine basin has experienced since the end of the 1970s a significant climatic change that is unprecedented in this intensity throughout the series of measurements that goes far beyond the 100-year period under consideration in this study.

Against this background, the underlying interactions of the changes in the flow dynamics in the southern Rhine basin can be described as follows: The rising temperatures in the 20th century caused also changes in the form of precipitation („more rainfall, less snow“). The increase of cumulative winter precipitation is associated with the fact that with the milder temperatures during this season a higher portion of winter precipitation more directly becomes runoff. The higher the portion of direct runoff in winter precipitation without storage in form of snow, the less water can be fed into the watercourses in the warmer season by snowmelt. On the whole, this increases the streamflow at the river gauges in winter and accordingly reduces flow in summer. In terms of the flow regimes one can say that in the course of the century pluvial elements have been gaining in importance, thus weakening the nival main component of the flow regime of the River Rhine. This development is additionally intensified by anthropogenic impacts in form of the management of (large) storage

[3] GWL means „weather type“ on the planetary scale. A GWL is defined by the mean spatial surface air pressure distribution of several (at least 3) successive days over an area at least of the size of Europe (BAUR, 1963).

reservoirs, which store water in summer and release it in winter, and thus produce similar seasonal redistribution and balancing. A study commissioned by the CHR-KHR found that in the course of the 20th century alone the construction of large reservoirs with capacities of at least 0.3 hm³ per unit created in the Rhine basin downstream to Basel (Switzerland) a total storage capacity of 1,900 million m³ and downstream to the German-Dutch border even 3,120 million m³ (WILDENHAHN & KLAHOLZ 1996).

Outside the alpine region, reservoir storage management is less uniformly controlled and thus loses in significance as influencing factor of large rivers. In the northern Rhine basin, the climatic changes, especially the increase in winter precipitation, are decisive driving forces in the dynamics of developments..

The fiercely disputed consequences of glacier melting are of marginal relevance in the Rhine basin in this context. This was substantiated in a study by the University of Zurich (FRAUENFELDER-KÄÄB 2005) on the alpine-dominated catchment of the gauge Ilanz (Vorderrhein), which has the highest degree of glaciers of all examined Rhine gauges. It found that the River Rhine received at Ilanz in the period 1850-2000 in the average of years less than 1% of its streamflow from additional glacier meltwater due to temperature increase.

Moreover, it should be kept in mind in this regard that glacier melting in noteworthy dimensions always occurs in the warm season that is – as shown above – on the Upper Rhine usually not the season of low-flow extremes.

The consequence of this development for gauging stations with long observation series between 95 and 100 years is illustrated in Figure 4. It shows predominantly positive tendencies, often also highly significant trends in the low-flow parameters. Accordingly, a development towards a mitigation of low-flow extremes prevailed in the 20th century in the Rhine basin. This applies above all to the large rivers, while the catchments of smaller tributaries show more differentiation.

Against the background of the above-mentioned interrelations, it becomes clear that this mitigation of extremes is most intensive there where the winter season is the actual low-flow season, this means in the southern Rhine basin that is characterized by a nival regime. Conversely, in the pluvial upland- and lowland-regions, where the low-flow period occurs usually in late summer or in autumn, this tendency to mitigation of extremes is lacking, because precipitation changed little in these months (Figure 2). Only other influences, as shown below with the example of the River Neckar that gains from water transfers, can explain exceptions from this constellation.

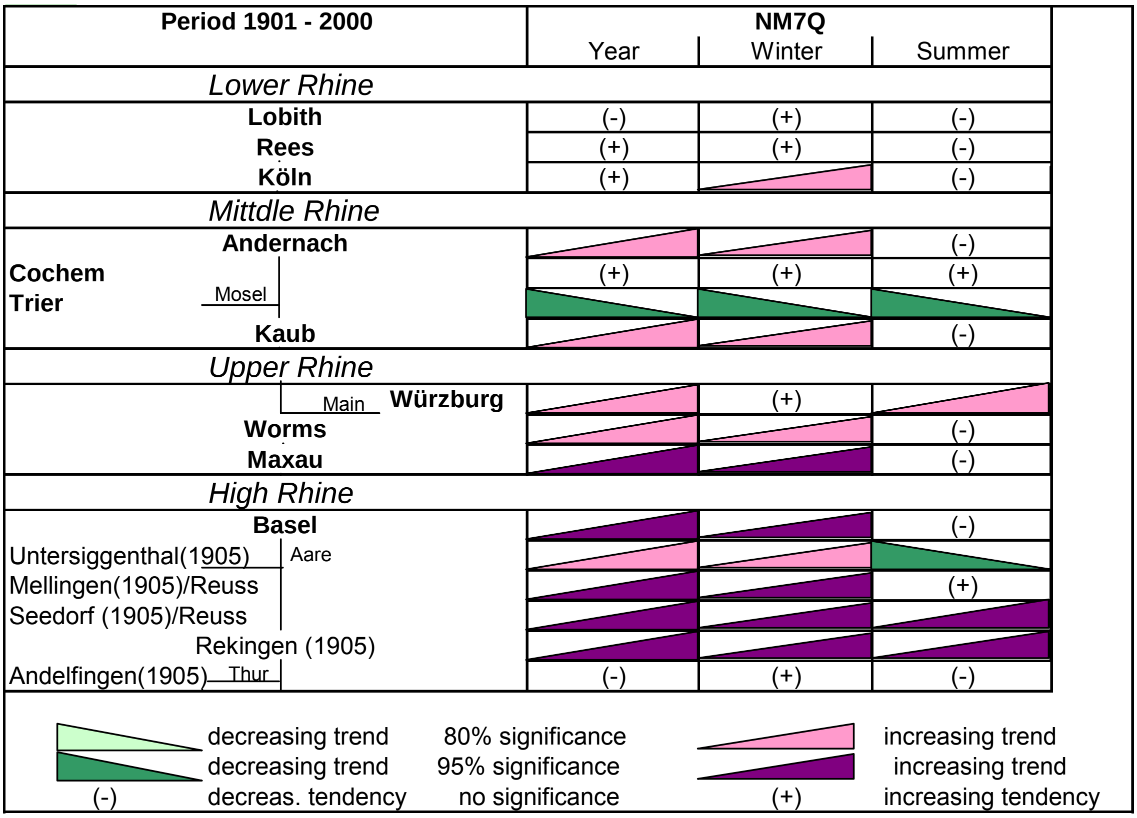

Figure 4: Trends and tendencies of half-year and yearly values of the low-flow parameter NM7Q at gauges with long observation series in the Rhine basin, period 1901 – 2000

In the case of the complex flow regimes that characterize in diverse individual types the different reaches of the River Rhine, the trend significance of the low-flow parameters increases with growing distance to the Alps, i.e. with increasing pluvial dominance. This is due to the fact that in view of the above-mentioned seasonal redistribution of the flow pattern, the quantitive significance of the summer flow peaks that originate in the High Rhine is decreasing. This applies both in absolute as well as in relative terms, because of the growing portion of inflows from the non-alpine catchment that is becoming larger and larger with growing distance from the Alps.

Flows that are small in quantity respond sensitively to interferences, both in positive and negative direction. For instance in the basin of the River Neckar, the addition of small amounts of water transferred from other river basins suffices to reverse the trend as it is shown here with the example of the gauge Lauffen/River Neckar: For the water supply of the urban-industrial agglomeration between Stuttgart und Heilbronn that was rapidly growing in the second half of the 20th century, a dense network of drinking-water transfer lines from other catchments (Lake Constance, River Danube, western Black Forest) was established. Its construction began as early as in 1917 and was continued in several steps, particularly intensive between the mid-1950s and the late 1970s.

The data series of low-flow parameters from the gauge Lauffen indicate anthropogenic influences on the flow behaviour of the River Neckar that are related to this drinking-water transfer (DWT). The transfer at the gauge Lauffen has been around 6 m³/s since the 1980s. A revising of the transferred volumes from the NM7Q year and half-year series gradually in analogy with the development stages of the water-transfer network removes not only the significance of all computed increasing trends, even the identified tendencies are mostly reversed, that means they assumed the sinking direction (Figure 5).

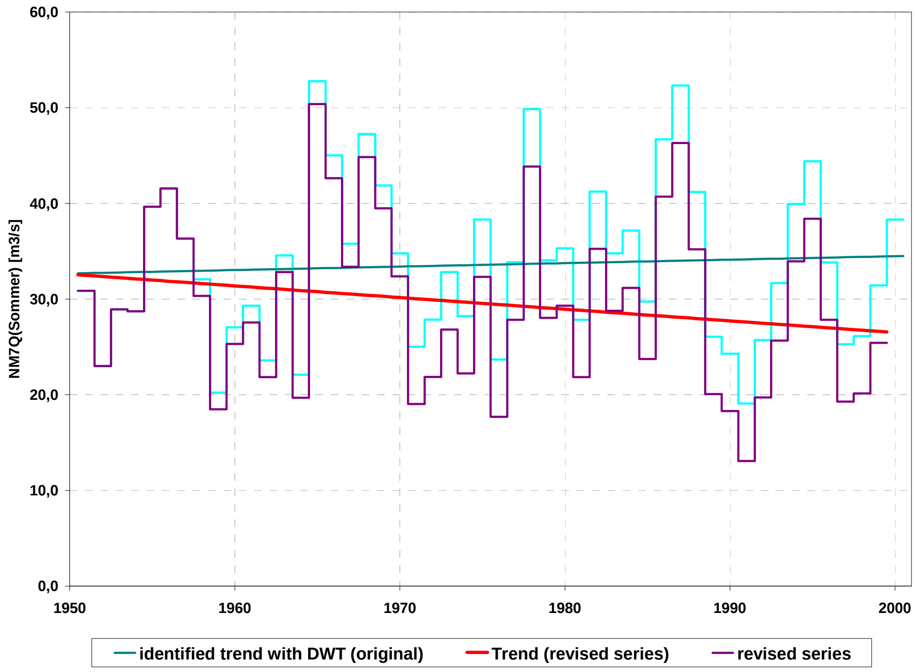

Figure 5: Trend and reversed trend in the summer half-year NM7Q series of the River Neckar at the gauge Lauffen against the background of DWT (drinking-water transfer), period 1951-2000

The sensitivity of low-flow situations with small water volumes against interferences is also suggested by results of jump-analyses of the low-flow parameter NM7Q[4]: The times of the occurrence of jumps are widely scattered and can rarely (and without chronological preference) be associated with statistical jumps (structural break-points) in the precipitation data series. Instead, it is not infrequent that such jumps can be ascribed to anthropogenic interferences like the construction of power stations (nuclear power station Cattenom: Gauge Trier/River Mosel), storage reservoirs (reservoir system „Kleine Kinzig“: Gauge Schenkenzell/River Kinzig) or controlled water transfer for low-flow enhancement (canal-water transfer: Gauge Haltern/River Lippe).

Changes occurred during the 20th century also in the dates of the occurrence of low-flow extremes in the Rhine basin. The seasonality-analysis according to BURN (1994) enables the determination of the most probable date (in the course of the year) of the extreme-event including the probability that the event will really occur on this day of the year.

[4] These analyses cannot be shown in detail here; an in-depth description is given in BELZ et al (2007, in print)

Because this analysis uses NM7Q values, it suffices to know the most probable week of the event. Table 1 lists the weeks of the calendar of one year (e.g. 1st calendar week (*KW*) = 1 January – 7 January). The shift of the time of the occurrence (in weeks) during the period 1926-2000 is also given.

The key conclusions that can be drawn from Table1 are: In the 20th century, the Rhine river basin, with the exceptions of the rivers Main and Mosel, experienced a distinctive shift to an earlier occurrence of low-flow extremes; least pronounced in the High Rhine and increasing downstream from the Upper Rhine from Basel onwards, increasing to a maximum of up to 9 weeks in the Middle Rhine, and reducing again to 3-4 weeks in the Lower Rhine. In the High Rhine at the gauge of Rekingen, a delay of one week was noted that may be associated with flow-retarding effects of the Lake Constance that is situated immediately upstream of this site.

Table 1: Rhine basin: Seasonality index according to BURN / most probable dates of occurrence of NM7Q [5] (KW = calendar weeks)

	Period 1901-1925		**Period 1926-1950**		**Period 1951-1975**		**Period 1976-2000**		**Shift [in weeks]**
	Occur-rence [KW]	P	Occur-rence [KW]	P	Occur-rence [KW]	P	Occur-rence [KW]	P	
Diepoldsau			6	0,89	4	0,89	2	0,85	4
Rekingen	6	0,77	4	0,86	3	0,65	5	0,78	-1
Untersiggenthal	51	0,73	52	0,76	51	0,73	50	0,69	1
Basel	2	0,73	2	0,80	52	0,65	1	0,71	1
Maxau	1	0,70	1	0,77	48	0,69	47	0,50	6
Rockenau					42	0,65	41	0,84	1
Worms	1	0,68	52	0,73	48	0,65	44	0,66	9
Würzburg	31	0,67	36	0,57	35	0,69	35	0,79	-4
Kaub	51	0,62	51	0,71	46	0,67	43	0,69	8
Cochem	33	0,83	35	0,83	36	0,79	35	0,85	-2
Andernach	47	0,66	51	0,51	45	0,58	42	0,75	5
Köln	46	0,65	50	0,49	45	0,58	42	0,75	4
Rees	45	0,55	50	0,49	45	0,53	42	0,75	3
Lobith	46	0,58	51	0,36	45	0,55	42	0,71	4

Regarding the stability resp. the probability of occurrence, the results in the indicated week are mostly improving over the course of the century.

[5] It should be noted here that this is not an analysis of flow mean values but the probable dates of the occurrence of extreme values of different stability of occurrence. This explains the shifts against the information given e.g. in the evaluation of the flow regimes that might be irritating at a first glance.

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THE LOW FLOW PERIOD OF 2004 IN AUSTRIA

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In 2003, large areas of Austria showed a significant precipitation deficit. Only about 80% of the mean annual long-term precipitation, and occasionally even less than 70%, was registered (Tab.1). The situation was intensified by high summer temperatures and associated increased evapotranspiration.
Nearly all observed watersheds and groundwater areas were affected by the drought. Some small streams were temporarely completly dry. In alpine areas with glaciers, this drought was observed between July and September but in the central and southern parts of Burgenland, as well as in the southern and south-eastern parts of Styria, it was apparent almost throughout the whole year 2003.
Discharge from glacier-influenced rivers was significantly increased by a record glacier melt. In alpine regions, the precipitation in September and mainly in October ameliorated the situation. However, in non-alpine areas this led to no improvement or only to a temporary improvement of the low flow situation in rivers. In groundwater regions only a slight interruption in the decrease of water levels was observed. In groundwater regions only a slight interruption in the sinking of water levels, which had come to a record minimum depth since February 2003, was registered. In some regions precipitation, discharges and groundwater levels were below the lowest observed seasonal and sometimes below the lowest-ever observed values.
Due to the severe damages caused to all agriculture, restrictions in hydro-power generation and inland navigation caused additional financial costs which were similar in the magnitude to those associated with the extreme floods of 2002.
The results of the precipitation and the low flow analyses can be summarized as follows:
The trend-analysis of meteorological dry spells shows a shortening of the periods rather than an increase. The duration of the dry spell in 2003 was striking but not unusual.
In the east and south of Austria, the low flow situation in 2003 was pronounced and can be classified as a “regional, hydrological drought” (Fig. 1 and Fig. 2).
A decreasing trend in the seasonal low flow can be recognized in the south of Austria in spring and in summer (Tab. 2).

River basin	Jan	Feb	Mrz	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dez	Year
Rhine	104	73	44	51	87	40	78	47	61	253	74	62	75
Danube before Inn	110	73	38	78	106	79	81	62	85	259	47	75	86
Inn before Salzach	97	55	38	80	104	92	92	63	69	269	66	71	88
Salzach	105	52	45	79	118	81	97	62	107	209	67	69	89
Inn beyond Salzach	166	52	47	41	83	47	98	48	69	190	22	66	74
Danube between Inn and Traun	144	47	33	45	69	80	112	46	42	203	28	66	75
Traun	129	44	58	55	98	53	105	55	109	176	46	73	82
Enns	99	35	63	71	108	69	99	57	118	176	58	69	83
Danube – betw. Traun and Kamp	174	29	69	43	102	68	97	49	113	156	36	66	80
Danube – betw. Kamp and Leitha	169	11	50	47	102	63	92	48	102	141	58	101	79
March	151	6	34	49	111	49	94	57	83	176	60	117	79
Leitha	102	25	40	45	120	73	91	75	98	131	82	119	85
Rabnitz und Raab	121	12	21	62	82	61	99	65	76	137	58	102	76
Mur	93	25	20	62	83	70	76	80	76	167	109	99	80
Drava	76	22	6	65	98	71	104	126	48	162	148	85	89
Overall	119	36	38	59	97	67	95	66	81	186	71	82	82

Table 1: Monthly and annual precipitation in 2003 as a % of the 1961-1990 mean value

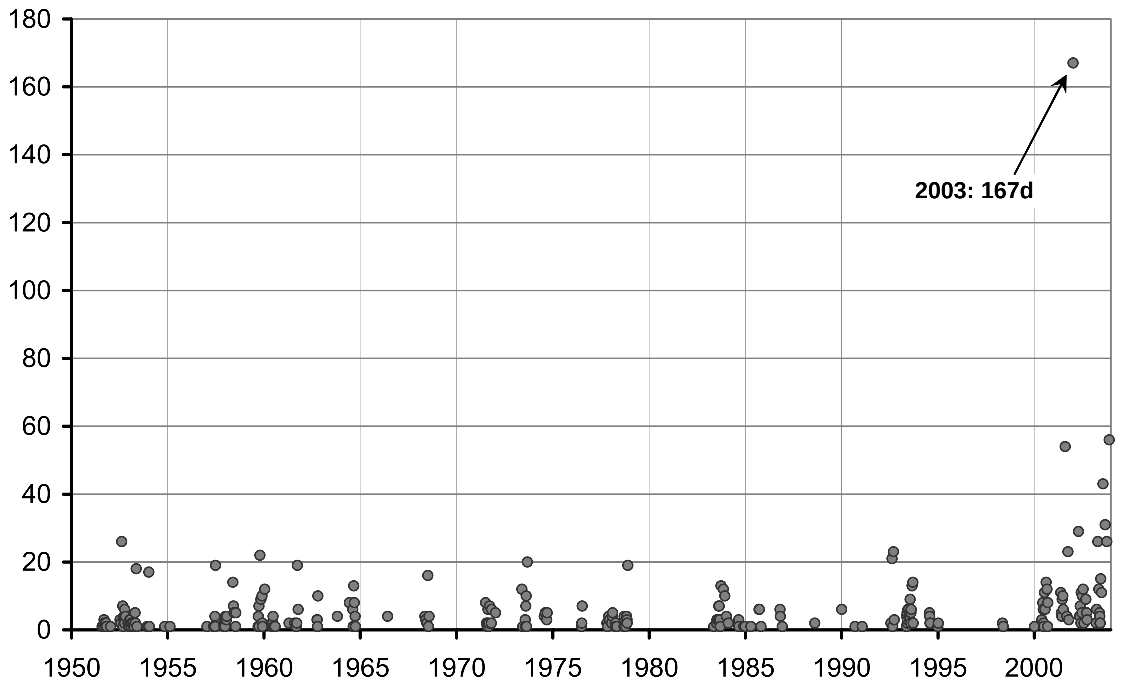

Fig. 1: Duration of transgression periods (threshold value: MQ7d) in days at Dobersdorf/Lafnitz

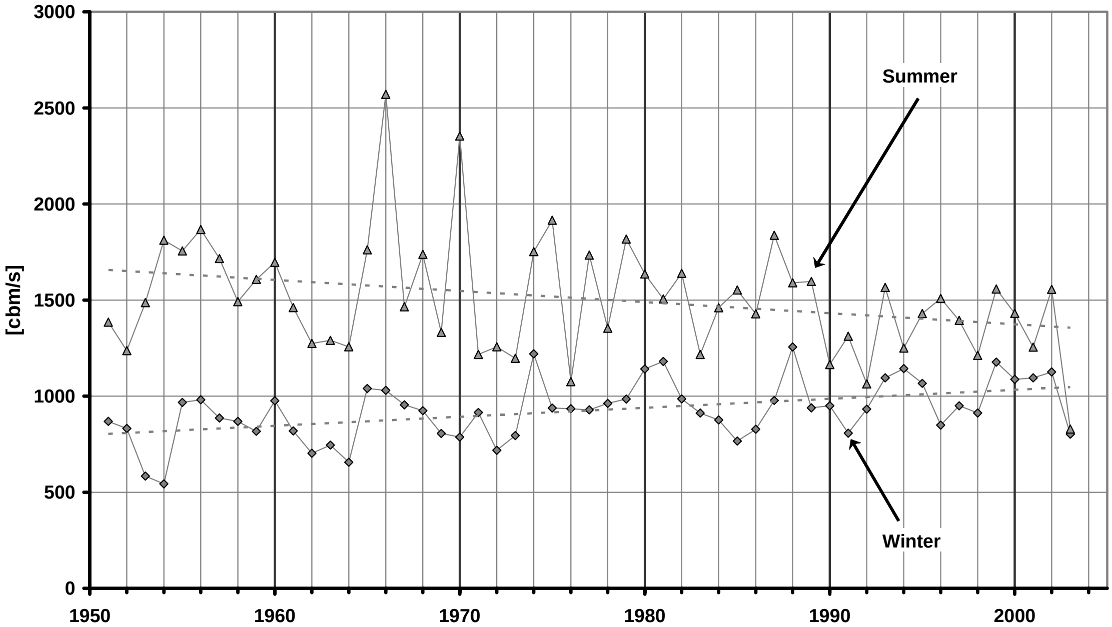

Fig. 2: Graph of the seasonal annual minimum mean 7 day discharge (MQ7d) at Vienna/Danube

Gauge	River	country	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dez
Rattersdorf	Güns	Bgl			-	--		--	--	-				
Dobersdorf	Lafnitz	Bgl			---			--	---	-			-	
Heiligenbrunn	Strem	Bgl	++									+++		
Brückl	Görtschitz	Car	+				-	---	-					
Federaun	Gail	Car				---	---	---	---	--	-			
Krottendorf	Lavant	Car		-	--	--	---	---						
Zell	Glan	Car		--	---	---	---	---	---	---	--			
Gumisch	Gurk	Car			--	---	--	---	--	--				
Zwettl	Kamp	LA						--	-					
Angern	March	LA							--	--				
Singerin	Schwarza	LA	+++	++	++						+++	+++	++	+
Dtsch.-Brod	Leitha	LA											--	-
Opponitz	Ybbs	LA		++	+			-	---	---				
Lilienfeld	Traisen	LA	+	+	+		-		-	-				
Obertraun	Traun	UA	+++	+++	++		+++		--		+++		++	+++
Pergern	Steyr	UA							---	---		+		
Haging	Antiesen	UA				--	---	---	---	---	---	--		
Salzburg	Salzach	Sbg	++	++			+	---	---		+			+
Feldbach	Raab	Styria		-	---	-			-			+		
Bruck	Mur	Styria		++				---	-			+++	+++	+++
Leibnitz	Sulm	Styria			---		--	---				+		
Voitsberg	Kainach	Styria			---	--	---	---	-					
Fluttendorf	Gnasbach	Styria												
Liezen	Enns	Styria							--		++	++		
Innsbruck	Inn	Tyrol	+++	+++	+++	+++	+++					+++	+++	++
Steeg	Lech	Tyrol	+++	+++	+++		+++					+	+++	+++
Vent	Rofenache	Tyrol	+++	+++	+++	+	+++	+++	+++	+++			+++	+++
Kennelbach	Bregenzerache	Vbg			+	---		-	-					
Hainburg	Danube		++	+				-	---	---			+	
Vienna	Danube		++	+				--	---	---			+	+

Table 2: Trend analysis (linear trend) of MQ7d at different gauges; The significance level denoted as follows: 5% (---,+++), 10% (--,++) and 20% (-,+)

METEOROLOGICAL CONDITIONS LEADING TO THE HYDROLOGICAL DROUGHTS IN CENTRAL EUROPE – THREE CASE STUDIES: 2003, 2005 AND 2006

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Introduction

In the past, the meteorological conditions causing low water flow have not been a major subject of the Hydrometeorology Department of the German Weather Service (DWD). Some studies on the evaporation losses from channels, lakes or water reservoirs have been carried out by DWD on demand of the Federal Institute for Hydrology (BfG).

Due to the climate change discussion the extreme meteorological events became a focus, but with special emphasis on river floods. So far, quite a number of studies about the origin of major national and transnational floods were carried out at the DWD: Odra 1997 (Fuchs and Rapp 1998), Wisla 2001 (Fuchs and Rudolf 2002), Elbe 2002 (Rudolf and Rapp 2003), Bavaria 2005 (Rudolf et al. 2006) and Elbe 2006 (Rudolf and Matthäus 2007). The extreme dry conditions of the summer 2003 became a matter of interest because of the high agricultural losses and of the high number of deaths during the heat wave. The spatial distribution of precipitation in Europe was analysed at DWD (Rudolf 2004a/b).

A study about the 2003 low flow conditions was published by Bundesanstalt für Gewässerkunde (BfG, 2006). DWD contributed a number of relevant meteorological data, statistics and maps used in this report. The low water event of July 2006 has been jointly investigated by BfG and DWD (BfG, 2007). The climate discussion and the enormous economic losses from the impact of low water on the capacity of transportation induced the DWD to put more emphasis to the related meteorological conditions and climatologic assessment. However, this is in its early stages.

1. Meteorological background: Variables of interest

1.1 Precipitation

Without doubt, precipitation (resp. the lack of precipitation) is the most important meteorological criterion for low water flow. It is the only supply quantity to the mean surface water budget.

Furthermore, the lack of precipitation has an indirect impact on the increase of heat: As long as precipitation is keeping the surface layer wet, the major part of the insolation, the incoming radiation, is consumed by evaporation or transpiration. If the surface is dry or mostly dry, evaporation and its cooling effect is zero or much reduced.

Another important aspect is that dense precipitation gauge networks are generally operated by the national meteorological services and/or other institutions. Measured data of high reliability are available to analyse the spatial/temporal distribution of precipitation.

1.2 Evaporation

Evaporation is an important parameter as well, at least as long as the surface is wet. One has to distinguish “potential evaporation” which describes the evaporation from a large water surface and can be calculated easily, the “real” evaporation which depends on many parameters as soil moisture, surface structure, vegetation type (evapotranspiration) and others. Frequently used (in particular for agrometeorology) is the “grass reference evaporation”, valid for a horizontal flat unique grass covered surface.

The real evaporation is only measured at very sparse points. All other standardised evaporation measures are calculated from other meteorological observations using empirical formulas. Measured meteorological variables being used to estimate the evaporation quantities are air temperature, dew point (relative humidity) solar radiation, cloud cover, sunshine duration, and wind speed.

1.3 The so called “Climatic Water Balance”

The climatic water balance (KWB in German) is defined as the residuum from precipitation and potential (or grass reference) evaporation. The KWB is a simple but quite useful budget quantity. As long as the KWB is positive, more water than needed is supplied, the surplus is available to fill the storages. A negative KWB indicates consumption of the available soil moisture by evaporation.

1.4 Agrometeorological Drought Indices

Drought indices can be derived from various observations or forecast model results. One large-scale method works with precipitation data only, due to the lack of more available information, others are based on precipitation and air temperature or more (WMO, 2006).

1.5 Categorized general weather situation (“Wetterlage” and Grosswetterlage”)

The general daily weather in Central Europe can be described by a set of characters indicating the location of the leading air pressure system in one or two levels (a mid atmospheric level and at the surface), the air flow direction (indicating origin of advected air masses), the air layer stability by the categories cyclonal (with vertical air lifting and convection) and anti-cyclonal (with sinking and, by this, drying of air masses) and finally the humidity condition (dry or wet). The conventional classification after Hess and Brezowsky (1977) is performed visually using the daily weather charts; time series from 1901 to present are compiled. An objective method has been developed by P. Bissolli and E. Dittmann (2002/2003). The classification runs automatically based on the numerical output from the data assimilation of numerical weather prediction models.

Some general weather situations are known to carry a higher risk of regionally heavy rainfall than other situations. An unusual frequency of certain weather situations might be connected to special seasonal impacts as drought (see section 2.3, Fig. 4).

2. Case-studies 2003, 2005, 2005

The individual case studies summarized in the following paragraphs have not been prepared following a given scheme or an existing experience. The goal was to individually describe an extreme event and to analyse its origin and development complemented by a climatologic subsumption. Through the analysis activities, experience with the subject was gained and some interesting data evaluation and visualisation methods were developed.

2.1 The extreme hot and dry summer 2003

The year 2002 was very humid over Central Europe and brought many severe floods (Danube, Elbe, Rhone). Extreme precipitation depths have been recorded. In the following year 2003 Europe was affected by extremely high air temperatures. The resulting drought was amplified by under-normal precipitation. However, the conditions have not been similar in all parts of Europe. While 2002 was characterised by atmospheric zonal stream flow and frequent trough situations, a blocking high pressure area covered Europe in summer 2003. Figure 1 shows the high seasonal anomaly of air temperature (up to 5K) over Central Europe. The heat is the major cause of the 2003 European drought.

For complementation, the spatial and temporal structures of precipitation anomaly have been evaluated based on gridded monthly precipitation analyses of the GPCC. The results represent areal mean precipitation. Therefore, a sufficient number of stations is required. One should be aware, that the data used have been received via GTS (from SYNOP and CLIMAT reports) and were processed near-realtime after some quality-control. This small study is based on 18 observation years only and does not consider homogeneity aspects.

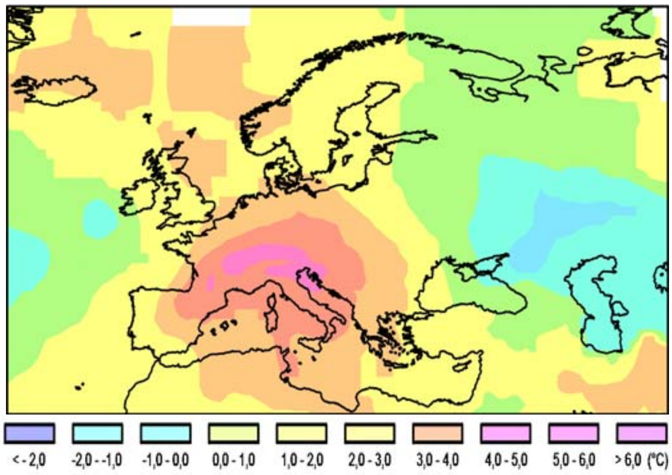

Figure 1: Seasonal anomaly of air temperature (K, June - August 2003)

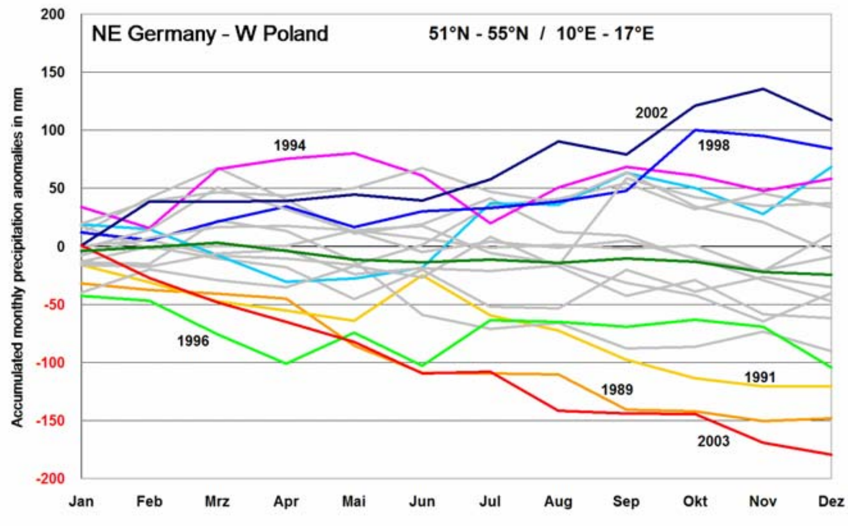

Figure 2: Annual accumulation of monthly precipitation anomalies (mm) for the individual years from 1986 to 2003 related to the period 1961-1990 for the region East Germany.

Table 1 summarizes the annual precipitation anomaly results. Within the considered period 1986-2003, the years 2002 and 2003 are the most extreme years for the regions Germany/Poland and South France (2002 very wet, 2003 very dry). On European scale, however, the behaviour is considerably different, especially for the annual evolution in the single years, caused by the large-scale circulation patterns. Over all, the period 1986-2003 has been drier than the normal period 1961-1990, apart from northern Sweden and northwest Russia.

Period / Year	1961-1990	1986-2003	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986
Germany (E)	628	604	449	737	666	581	588	713	567	524	624	687	697	538	508	593	480	619	662	639
France (S)	1029	931	714	1189	879	1082	1041	820	802	1066	1006	1042	976	1012	829	834	658	935	996	884
Ireland (NW)	1344	1085	930	1230	931	1248	1327	1199	935	925	1040	1121	1050	1156	964	1218	1044	1105	956	1147
Norway (SW)	1183	1005	972	756	944	956	1016	1079	1090	735	1043	978	954	1111	991	1222	1231	1054	941	1012
Sweden (N)	532	541	383	394	578	653	524	672	433	488	579	421	659	612	580	546	593	543	572	516
Russia (NW)	601	662	780	534	678	684	532	786	756	520	648	690	641	580	661	763	666	674	718	608
Greece (N)	644	561	661	792	535	373	644	604	516	640	595	604	451	421	562	494	407	549	667	573

Table 1: Mean annual precipitation for the periods 1961-1990 and 1986-2003 and annual precipitation for the individual years from 1986 to 2003. Wet years are coloured in blue and dry years in yellow.

2.2 The severe drought in south-western Europe in 2005

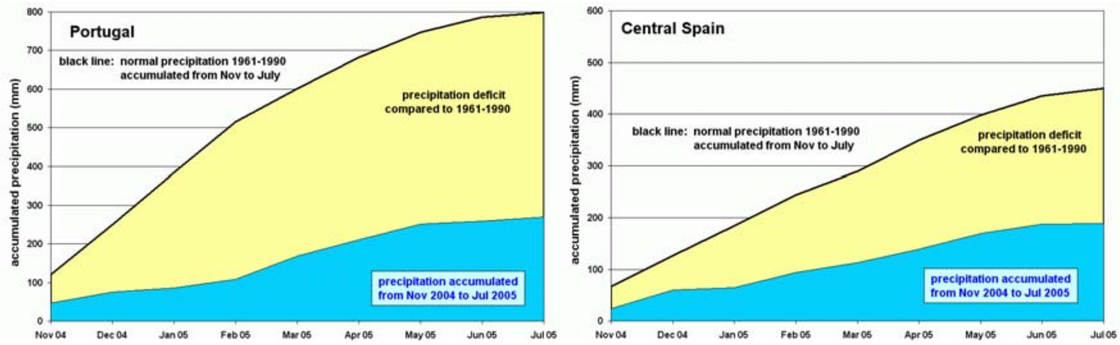

Figure 3: Annual accumulation of monthly precipitation (mm) for November 2004 to July 2005 and for November to July means of the normal period 1961-1990. The yellow area indicates the precipitation deficit of 2005 vs. the normal mean. Central Europe was not much affected by drought in this year.

2.3 The two dry months June and July 2006 in Germany

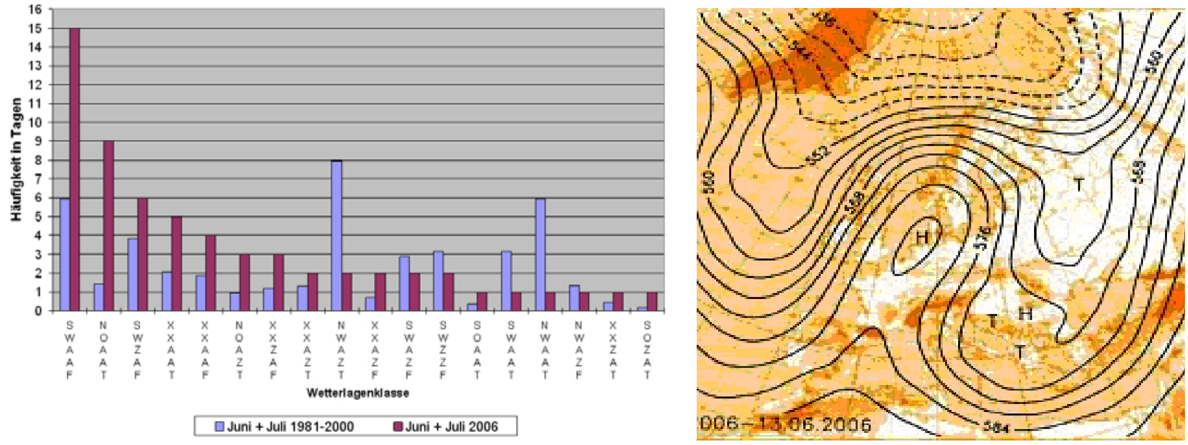

Figure 4: Left: Frequency distribution of the "Wetterlagen" (objectively classified after Dittmann and Bissolli 2003) for the two months June and July during the 20 years 1981-2000 (blue) versus 2006 (red). The classes dominating in 2006 are mostly characterized by anticyclonic, i.e. stable and drying conditions. Right: One typical example of this class.

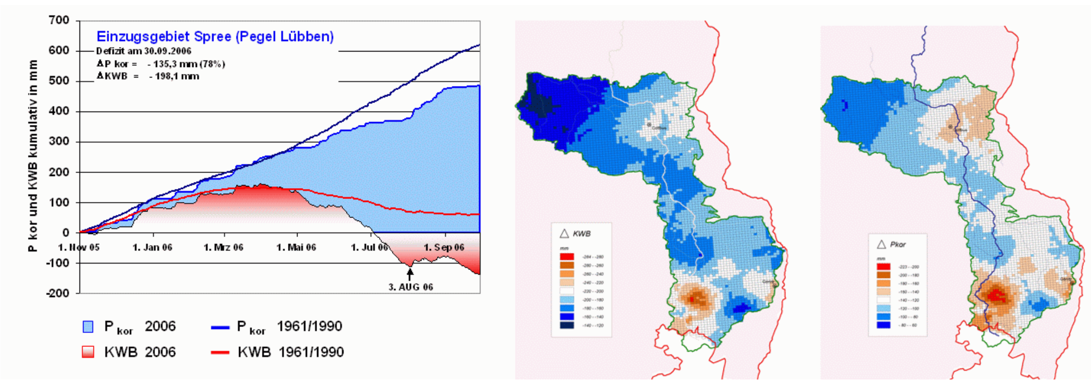

Figure 5: Left: Development of area-mean climatic water balance KWB (red) and precipitation P (blue) for the Spree catchment in East-Germany during the year 2006 (shaded) versus the normal mean period 1961-1990 (solid line). Centre: Regional distribution of KWB, right of P, both at 3. August 2006. The KWB became negative from the beginning of July; the minimum was reached by end of September.

3. Climate change

Just a few figures based on observed data of the DWD for Germany, and data being collected by the Global Precipitation Climatology Centre (operated by the DWD) for Europe:

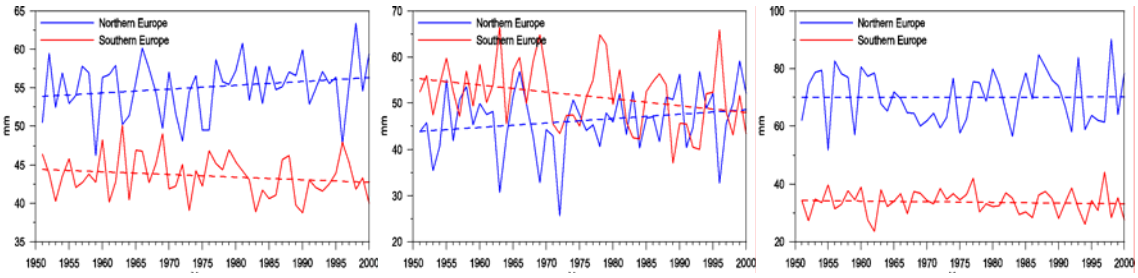

Figure 6: 50-year trends of monthly mean precipitation for northern and for southern Europe for the year (left), the winter (Dec - Feb, centre) and the summer (Jun - Aug., right):
The total precipitation is increasing in the north, but decreasing in the south of Europe.

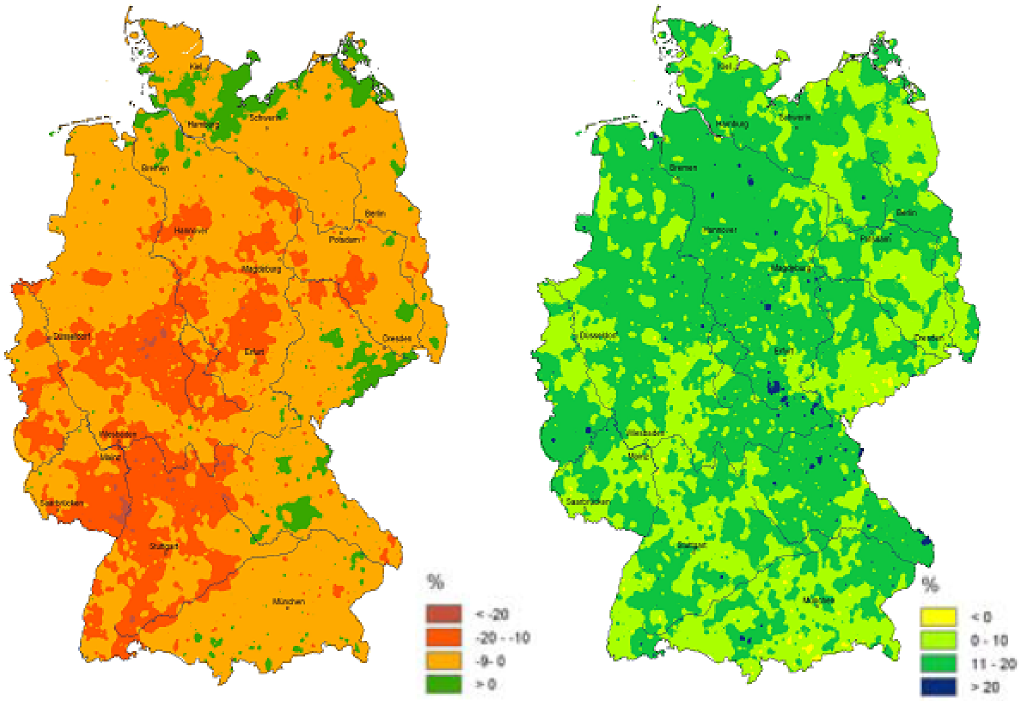

Figure 7: Relative change in monthly precipitation 1977-2006 vs. 1951-1980 for Germany: Summers are becoming drier (up to -15%), but winters are becoming wetter (up to 20%)

4. Conclusions

Agriculture can be affected by precipitation deficits even after the occurrence of one or two hot and dry summer months since only a thin soil layer is of importance. This is different in hydrology, in particular for larger rivers: the water is supplied from large catchments, and a connection to ground water is also given. The ground water has a slow development, it needs up to several years to fill or consume the ground water stores. Studies about low water flow conditions require the analysis of meteorological data from a longer period.

Generally, several aspects need more consideration:

- How can the uncertainty of climate model results adequately be quantified with respect to the hydrological demand?
- Are the observed trends in precipitation and hydrological variables significant?
- The variability of precipitation is very high. Statistical analysis requires large data collectives and long time-series. A lot of German historical climate data being important for hydrology are still stored in paper archives, and not yet digitized.
- How can/should the observed data be evaluated with respect to drought and low water?
- Are the categorized “Wetterlagen” a useful indicator for floods or droughts?
- Do the observed variations in the hydrological regime result from a systematic climate change (from the rising air temperature) or might they be caused by long-term atmospheric oscillations (e.g. the North Atlantic Oscillation NAO)?

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RECENT DEVELOPMENTS IN CLIMATE SCENARIOS IN THE NETHERLANDS

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1. Construction of the KNMI'06 scenarios

Climate change scenarios are a widely-used means to deal with the inherent uncertainty of future climate at the national or regional scale. In most cases these regional scenarios are constructed from projections from a limited set of Global Climate Models (GCMs), driven by a few greenhouse gas emission scenarios, and statistically or dynamically downscaled to increase the information content at the regional scale. The use of a small ensemble of GCMs introduces the risk of undersampling the range of features that are important for the climate in the region of interest. A large number of GCM projections has been made available by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) during the preparation of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). However, the (political and socio-economical) relevance of scenarios covering the full range of global temperature rise (+1.1 to +6.4°C in 2100, according to the Summary for Policy Makers (SPM)) is not uniform across this range. Limitation in available adaptation resources, political will and persistence of existing policy generally exclude a serious consideration of very extreme scenarios with a relatively low probability. Thus, a selection of a relevant range of global temperature rise is needed.

In addition, regional downscaling of the global projections is required to assess the impact of global climate change on local climate variables, including the likelihood of extreme events. To derive the regional information corresponding to the conditions defined by the scenarios, a general approach is to select a representative set of GCM simulations that fulfils the selected scenario conditions and use these to drive one or more Regional Climate Models (RCMs) (Giorgi, 2005). To date computer power and data storage constraints limit the available RCM resources. Additional details on local conditions may be obtained from local observed time series, capturing specific characteristics such as distance to the sea or topographic elevation.

To avoid information loss due to undersampling the GCM uncertainty and limited RCM resources, the climate change scenarios for the Netherlands are constructed differently from this general approach. A combination of GCM projections, RCM results and local observations is used, but a sophisticated set of scaling procedures is followed to derive the local scenario values. The independent scaling variables are chosen in order to explain a major portion of climate variability in the region of interest, and derived from the available AR4 GCM projections. Apart from the global mean temperature rise (ΔTg) the (uncertain) response of the regional atmospheric circulation to global temperature change appeared to be an important external indicator.

Scenarios are developed for two values of ΔTg in 2050 relative to 1990 (being +1 and +2 °C), which optimizes a sufficiently wide range, consistence with previous scenarios and socio-economic relevance. Up to 2050, differences in GCM projections of ΔTg are mainly associated with uncertainty about the climate sensitivity, and less with variations between greenhouse gas (GHG) emission scenarios.

The regional response to global warming is strongly dependent on changes in the regional atmospheric circulation. In West Central Europe, variations in the frequency distribution of the seasonal mean atmospheric circulation patterns explain a major part of the variability of the seasonal mean temperature.

The response of the regional circulation to global warming varies widely across five GCMs, selected for their ability to generate a realistic atmospheric circulation in the present-day climate. MIROCHi forms an example of the GCMs that show only a marginal change of the circulation statistics in both summer and winter, whereas GFDL2.1 represents a regime with a strong increase in the seasonal mean Western Geostrophic wind (GW) in winter and a decrease in summer. The combination of two global mean temperature changes and the two distinct circulation regimes yields four climate change scenarios.

Further downscaling is needed to calculate the local climate variables of interest that cannot directly be derived from the GCM projections, in particular those related to temperature and precipitation. The local effects on precipitation and temperature induced by gradients in land-sea, topography, clouds, snow, soil moisture and vegetation are not represented well in GCMs. Also extreme events are generally not reproduced in the course resolution GCM grid size. Nesting a high resolution RCM in the GCM fields allows resolving these processes in greater detail. In an ensemble of 10 selected RCM runs the desired scenario range (ΔTg of +1 and +2°C in 2050, small or large change of ΔGW) was not well covered. In particular, projections with a small change in circulation over Western Europe were not at all present in the collection of simulations due to the limited number of driving GCMs. To extrapolate the results from the available RCM integrations to the global temperature and circulation conditions covered by the scenarios, a two-variable scaling equation was designed to translate a selected set of ΔTg and ΔGW values into a set of local temperature and precipitation changes.

Apart from precipitation and temperature, also Sea Level Rise (SLR) and wind speed scenarios were constructed. More details about the scenario construction can be found at www.knmi.nl/climatescenarios. A complete table of KNMI'06 scenario values is given below.

The most pronounced features of these scenarios are:

- In winter the mean precipitation is increased in all scenarios, but the number of wet days hardly changes;
- In summer the circulation change has a significant impact on the precipitation regime: with a circulation change the number of wet days reduces, and this causes a strong reduction of the mean summertime precipitation;
- Extreme precipitation (intensity of events occurring on average once every 10 years) is increased both in summer and winter. A small circulation

change makes the likelihood of very intense precipitation events larger. However, extreme the 10-day sum exceeded once every 10 years shows the largest change in the scenarios with a larger circulation change, owing to the systematic rainfall increase in these scenarios;

- Also for temperature the mean change is different from the annually coldest (in winter) or warmest (in summer) day. The tails in the distribution tend to show a larger change than the mean, giving a smaller distribution in winter and a wider distribution in summer;
- For wind the changes are hardly significant compared to the typical interannual variability of daily mean wind speed;
- Sea level is continued to increase; projections for 2100 span a range between 35 and 85 cm.

Table 1: The KNMI'06 scenarios for 2050.

G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

*Legend for the KNMI'06 climate scenarios. * 'G' is derived from 'Gematigd' = Dutch for 'Moderate'*

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter [3]	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer [3]	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

2. Tailoring general climate scenarios for specific applications

The KNMI'06 scenarios are rather unspecific for many applications. In water management, safety policy, energy, traffic, agriculture and many more applications a specific need of tailored information is present, ranging from specific time series for climate variables, assessment of likelihoods of a given scenario, consistent high resolution fields of a set of variables etcetera. KNMI is involved in many projects involving the generation of tailored climate change scenarios. The projects have in common that an intensive iterative dialogue between climate scientists and stakeholders is needed to converge the possible deliverables with the requested information. A number of examples of these tailor-made climate scenarios is discussed below.

2.1 Groundwater tables in the Netherlands

A detailed hydrological model is operated in the Netherlands to monitor and predict groundwater tables at a high spatial resolution. The required computer resources hamper extensive simulations, and to define a climatological reference often use is made of a so-called 'standard year'. The changes in the seasonal groundwater levels owing to the change in the climate forcing have been assessed using the KNMI'06 scenarios. For this, observed time series of precipitation, temperature and potential evaporation have been modified in order to match any of the climate change scenarios, and fed into the hydrological model. The results were fairly sensitive to the details of the time series transformation and bias corrections, but in general an increase in the maximum spring groundwater level and a reduction by the end of the growing season were simulated for the W+ scenario.

2.2 Mean discharge from the Rhine

Rainfall-runoff models are used to project the discharge of the Rhine at Lobith. Climate change projections are applied by modifying the observed rainfall and temperature (giving rise to a modification of evaporation) governing the KNMI'06 scenarios. This procedure is also followed to assess the design discharge, based on the likelihood of discharge exceeding the 1/1250 to 1/4000 yrs return values. These rare events are calculated by generating long synthetic time series of precipitation and temperature in the Rhine catchment area by a technique called nearest neighbour resampling.

As a first analysis the impact of the new KNMI'06 scenarios on the *mean* discharge has been compared to the discharge projections based on an earlier generation of climate change scenarios. In these earlier scenarios circulation change was not a driving variable, and a reduction of summer precipitation (and increase of summer evaporation) was not foreseen in the earlier general low, middle and high scenarios. The new KNMI'06 scenarios show a strong reduction of the summertime discharge according to the W+ scenario, giving rise to new considerations of summertime water management. In winter the mean discharge does not deviate a lot from the old scenarios, and first impressions on the likelihood of extreme events do not give rise to large changes either.

3. Recent and future droughts

Western Europe has experienced a sequence of extreme spring and summer conditions in the last couple of years. 2003 was a summer with breaking temperature records in a large area of central Europe. A reliable estimate of the return period of this drought could not be made using the observed record. In 2006 a rapid alternation of an extremely hot and dry July and a very wet and cool August took place. 2007 is a year remembered by an extremely warm and dry April and considerable contrasts in the hydroclimate in summer, with floodings in the UK and extreme drought in South and South-eastern Europe owing to a persistent orientation of the jet stream. Is climate change happening already?

An analysis of the reasons of the anomalous temperatures in the last few seasons revealed that a combination of persistent anomalies in the atmospheric circulation, a global warming due to the enhanced greenhouse gas concentrations, and a couple of unresolved local mechanisms (leading to abundant sunshine, low snow cover in spring, and rapid soil drying) are needed to explain the observations. The likelihood of the sequence of anomalous temperatures in the Netherlands and surrounding area starting early 2006 is extremely low.

An analysis of the cumulative precipitation deficit of the 2003 growing season revealed that for the Netherlands the event could be expected to happen once every 10 years. Using the KNMI'06 scenarios the mean cumulative precipitation deficit was recomputed using a transformation of the observed time series of precipitation and potential evaporation according to each of the scenarios. Also the return period of the 2003 drought was calculated, and following the W+ scenario one could expect a summer like 2003 to occur once every two years in 2050.

However, the summer of 2006 provides a good illustration of the limited scope of climate scenarios as prediction tool. The July month in that year showed a repetition of the 2003 drought (although the circulation patterns leading to the 2006 drought were different from the 2003 case), and one could argue that the G+ or W+ scenarios could serve as an indication for our future summers. However, the wetness during August of 2006 (associated with an anomalous high SST in the North Sea) invokes a resemblance to the G and W scenarios much more, where circulation change is low and high SSTs in the Atlantic sector give rise to an increased amount of rainfall in our region. This sequence of rare and erratic events makes clear that climate is a highly variable phenomenon, and that simple interpretations of either climate change scenario should be handled with care.

EFFECTS OF CLIMATE CHANGE AND CLIMATE VARIABILITY ON HYDROLOGY

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Scenario's of effects of climate change on the River Rhine exist since the late eighties of the 20th century. Since then they have evolved from estimates for changes in seasonal discharges based on expert judgment to consistent scenario's including socio-economical developments and management styles. In this presentation we provide an overview how these scenario's for discharges in the Rhine were generated and how the results have varied in time. We will show that the scenario's remain surprisingly consistent in terms of the trends expected, summer discharges will probably increase, while winter discharges will probably decrease. However over time the scenario's have varied substantially in the magnitude of the change. We will discuss the results in view of their applicability in water resources management from the Dutch perspective. With respect to the applicability in water management practice the scientific progress is not such that the climate projections can be used in a straight forward manner in water management practice. On the one hand this is due to the uncertainties in the magnitude of the changes, on the other hand it is due to the little experience existing in the water management world on using future scenario's instead of using observed hydrological time series only to design water management strategies. Given the relatively little progress so far in reducing the uncertainties in magnitude of the changes we assume that in the near future these uncertainties will remain. As design in water management is a continuous process practical guidelines are welcomed by the water management world how to deal with these uncertainties. Based on the results and experience from recent projects we will attempt to provide some best practices that could be used to deal with climate scenario's in water resources practice. Opposite to the standard approaches, the method of finding the best practices does not use climate scenarios as the starting point but the robustness of the existing water management system.

EFFECTS OF CLIMATE CHANGE AND CLIMATE VARIABILITY ON WATER USER FUNCTIONS

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Introduction

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 (Krinner et al., 1999). The hydrological characteristics of Europe are very diverse, as well as its approaches to water use and management. Of the total withdrawals of 30 European countries (EU plus additional countries) 32% is for agriculture, 31% for cooling water in power stations and for hydropower, 24% for the domestic sector, and 13% for manufacturing (Flörke and Alcamo, 2005).

The principal source of abstracted freshwater in the EU Member States is surface water (about 75% of the total water abstracted) with a large part of the remainder from ground water and only minor contributions from desalinisation of sea water and from re-use of treated effluents (Krinner et al., 1999). Groundwater reserves are increasingly being exploited in preference to surface water sources. In many parts of Europe this has led to over-abstraction and lowering of the groundwater table resulting in the degradation of spring fed rivers, destruction of wetlands and, in coastal areas, in intrusion of saline water into aquifers (Nixon et al., 2003).

Freshwater abstraction is stable or declining in Northern Europe and growing slowly in Southern Europe (Flörke and Alcamo, 2005). There are many pressures on water quality and availability including those arising from agriculture, industry, urban areas, households and tourism (Lallana et al., 2001). Recent floods and droughts have put additional stresses on water supplies and infrastructure (Estrela et al., 2001). The projected climate changes are likely to further increase stresses on water supplies in Europe (Alcamo et al., 2007).

Uses of water

Agriculture

Agriculture is one of the biggest driving forces and pressures on water resources. Europe is one of the world's largest and most productive suppliers of food and fibre (in 2004: 21% of global meat production and 20% of global cereal production). About 80% of this production occurred in EU25. In terms of water use agriculture accounts for approximately 30% of total water abstractions (Krinner et al., 1999). However, in Southern European countries (Greece, Italy, Portugal and Greece) this percentage rises to 62% of total uses.

The most important agricultural water demand is for irrigation. This is particularly the case in the Mediterranean countries, where agricultural demands varies from 83% of total demand in Greece to 52% in Portugal. This is in marked contrast to North European countries, where on average less than 10% of the resources are used for irrigation. The volume of irrigation water applied depends on climate, crop type, soil type and irrigation method. The proportion of irrigated land therefore also varies greatly throughout Europe. The total irrigated surface in EU-15 is about 11.3 million ha and the average water use for irrigation is about 6,500 m^3/ha/year (Krinner et al., 1999). The extent of irrigation has been greatly influenced by the Common Agricultural Policy of the EU. During the last decade the EU Common Agricultural Policy has been reformed to reduce overproduction, reduce environmental impacts and improve rural development. This is likely to also reduce the pressure for irrigation in agriculture (Marsh, 2005).

Urban uses
Water use by households and small businesses shows large differences between countries in Europe. Thus several North European countries have decreased their consumption, whereas there have been increases in countries like Austria, France and Italy (Krinner et al., 1999). Future public water supply is expected to increase further in France, Greece, Netherlands and UK. Changes in lifestyle, water pricing policies and public awareness have great effects on consumption patterns.

Tourism
Mass tourism has become very important in national economies, in particular in Southern Europe. Tourism is often associated with limited availability of water resources, in particular in peak holiday periods. Consumption of water by tourists is generally to times higher than for local consumers. Also tourists often require large amounts of water for recreation such as for swimming pools, water parks and golf courses.

Industry
Water is essential for power plant cooling in many European countries, and it is by far the largest industrial user of water in Europe. However, this is mostly regarded as a "non-consumptive" use as water is generally returned to the source (most of a river or lake) unchanged apart from an increase in temperature and contamination by biocides. Technological improvements are projected to cause the industrial uses of water to decline.

Droughts and climatic variability

Drought results from a combination of meteorological, physical and human factors (Estrela et al., 2001). The primary cause of any drought is a deficiency in rainfall or in availability elting of snow and ice from mountain reservoirs. In particular droughts are cause by timing, distribution and intensity of this deficiency in relation to existing storage, demand and water use. Temperature and evapotranspiration may aggravate the severity and duration of the drought. Human factors include the demand for water in relation to domestic and agricultural usages, and modifications in land use directly influence the storage conditions and hydrological responses of a catchment and thus its responses to drought.

It is apparent that climate variability and change already affects features and functions of Europe's production systems (e.g. agriculture, forestry, fisheries), key economic sectors (e.g. tourism, energy) and its natural environment. Some of these effects are beneficial, but most are expected to be negative (EEA, 2004).

The sensitivity of Europe to climate change has a distinct north-south gradient, with many studies indicating that Southern Europe will be more severely affected than Northern Europe (EEA, 2004). The already hot and semi-arid climate of Southern Europe is expected to become yet warmer and drier, and this will threaten its waterways and agricultural production. But northern countries are also sensitive to climate change. The Netherlands, for example, is among the countries most susceptible to large fluctuations in river discharge and climate-related sea level rise.

A recent example of the consequences of extreme high temperatures in combination with droughts is the European heat wave of 2003 (Alcamo et al., 2007). A severe heat wave over large parts of Europe in 2003 extended from June to mid-August, raising summer temperatures by 3 to 5 °C (Beniston and Diaz, 2004). This heat wave was determined to be extremely unlikely under current climate (Schär et al., 2004). However, it is consistent with a combined increase in mean temperature and temperature variability (Schär et al., 2004; Meehl and Tebaldi, 2004). As such the 2003 heat wave resembles simulations by regional climate models of summer temperatures in the latter part of the 21st century under the IPCC A2 emissions scenario (Beniston, 2004).

The heat wave in 2003 was accompanied by annual precipitation deficits up to 300 mm, and this drought contributed to the estimated reduction of 30% over Europe in gross primary production of terrestrial ecosystems (Ciais et al., 2005). This reduced agricultural production and increased production costs, giving an estimated damage of more than 13 billion euros (Fink et al., 2004). The hot and dry conditions led to many very large wildfires, in particular in Portugal (390,000 ha) (Fink et al., 2004). Many major rivers (e.g. Po, Rhine, Loire and Danube) were at record low levels, resulting in disruption of inland navigation, irrigation and power plant cooling (Beniston and Diaz, 2004). The extreme glacier melt in the Alps prevented even lower river flows of the Danube and Rhine (Fink et al., 2006).

Projected climate changes

The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of heat waves and droughts. Schär et al. (2004) concluded that the future European summer climate would experience a pronounced increase in year-to-year variability and thus a higher incidence of heat waves and droughts. The regions most affected could be the southern Iberian Peninsula, the Alps, the eastern Adriatic seaboard, and southern Greece. Although only the eastern Mediterranean currently has a regularly recurring dry period, the rest of the Mediterranean and even much of E. Europe may also experience such periods by the late 21st century. According to Good et al. (2006), the longest yearly dry spell would increase by as much as 50%, especially over France and Central Europe.

It is likely that climate change will have a range of impacts on water resources in different parts of Europe. Projections based on various scenarios and GCM's show that annual runoff increases in Atlantic- and Northern Europe and decreases in Central, Mediterranean and Eastern Europe (Alcamo et al.., 2007). Studies show an increase in winter flows and decrease in summer flows in the Alps, the Rhine, Slovakian rivers, the Volga and Central and Eastern Europe. Lowest annual flows shift from winter to summer in Central and Eastern Europe (Lehner et al., 2006). The volume of summer low flow may decrease by up to 50% in Central Europe (Eckhardt and Ulbrich, 2003), and by up to 80% around the Mediterranean (Santos et al., 2002).

Climate change impacts

Changes in the water cycle are likely to increase the risk of floods and droughts (Lehner et al., 2006). The river basin area affected by severe water stress increases under some scenarios due to both climate change and increasing water withdrawals and will lead to increasing competition for available water resources (Alcamo et al., 2003; Schröter et al., 2005). The regions most prone to an increase in water stress are the Mediterranean (Portugal, Spain) and some parts of Central and Eastern Europe, where the highest increase in irrigation water demand is projected (Döll, 2002). Irrigation requirements are likely to become substantial in countries where it now hardly exists. The irrigation demands may be influenced by changes in the amount and distribution of agricultural land as affected in the future by the EU Common Agricultural Policy (CAP). Irrigation requirements will be strongly influenced by effects of climate changes on the timing of the growing season for specific crops, e.g. maize, which in some cases may maintain irrigation requirements at current levels (Minguez et al., 2007).

Warmer temperatures may also result higher risk of algal blooms and increased growth of toxic cyanobacteria in lakes (Eisenreich, 2005). Although an overall drier climate may decrease the external loading of nutrients to inland waters, the concentration of nutrients may increase because of the lower volume of inland waters. Higher temperatures will reduce dissolved oxygen saturation levels and increase the risk of oxygen depletion (Sand-Jensen and Pedersen, 2005).

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 (Hanson et al., 2006). Furthermore, the availability of cooling water may be reduced at some locations of Europe because of climate-related decreases or seasonal shifts in river runoff.

Adaptation to climate change

To adapt to increasing water stress the most common strategies remain supply-side measures such as impounding rivers to form in-stream reservoirs (Santos et al., 2002). However new reservoir construction is being increasingly constrained in Europe by environmental regulations and high investment costs (Schröter et al., 2005). Other supply-side approaches such as wastewater reuse and desalination are being more widely considered but their popularity is dampened by health concerns in using wastewater, and high energy costs of desalination. 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 (Lallana et al., 2001). Strategies should be incorporated at watershed levels into plans for integrated water management (Cosgrove et al., 2004) while national strategies should consider the governance structures.

To compensate for increased climate-related risks of salinisation in aquatic ecosystems, species loss, eutrophication and lowering of the water table in Southern Europe, a lessening of the overall human burden on water resources is needed. This could re-locating intensive farming to less environmentally-sensitive areas, improved recycling of water within catchments, and increased efficiency of water allocation among different users.

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EFFECTS OF CLIMATE CHANGE AND CLIMATE VARIABILITY FOR THE DELTA AREA OF THE RIVER RHINE

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Introduction

In the Netherlands the effect of climate change on the river Rhine is usually discussed in terms of high discharge and the consequent probability of floods. Of course a major flood in a low-lying country like the Netherlands will most likely have catastrophic consequences. Therefore, it is important to stay focussed on the issue of safety against flooding.
However, an opposite effect of climate change on the river Rhine has become more and more evident in the last few years, that is a decrease in summer rainfall and the subsequent decrease of discharge. Consequently, this 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. This paper describes the process, effects and possible measures of the increased salt intrusion in the delta area of the River Rhine due to climate change.

Description of the Rhine delta

The Rhine delta consists of a number of distributaries and tributaries discharging into the North Sea (fig.1). As a response to the big floods in 1953 some of these tributaries were closed off from the North Sea and subsequently turned into fresh water lakes e.g. Haringvliet and Volkerak, or became completely saline due to a decreased inflow of fresh water e.g. Grevelingenmeer. Consequently, only one natural transition zone from fresh to salt water remained in the Rhine delta. This tributary, the Nieuwe Waterweg, is the main sea access to the port of Rotterdam. Due to its economic importance this branch is not permanently closed off from the sea. Instead a storm surge barrier was built, which is only closed during extreme storm events with significant setup at the North Sea.

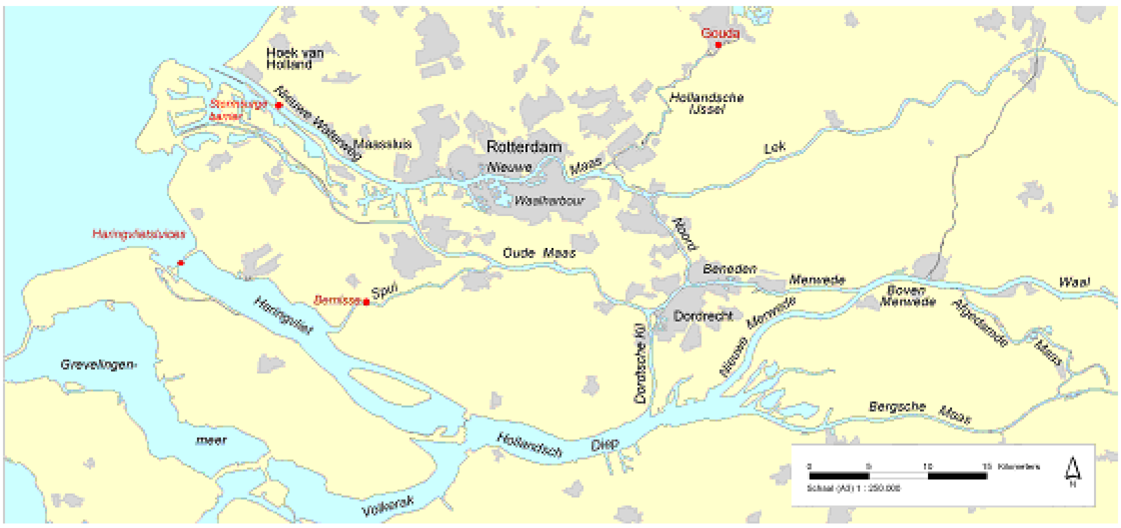

Figure 1: Overview of delta area of the Rhine River. Both the Lek and the Waal are branches of the Rhine. The Nieuwe Waterweg is the only open access to the North Sea.

The Rhine delta area consists mainly of polders, which lie below sea level and consist of large urban areas e.g. Rotterdam, as well as agricultural areas. The rivers Rhine and Meuse are predominantly used for drinking water and for irrigation purposes for which fresh water is extracted from a large number of locations. Water is only extracted from the Rhine when the chloride concentration does not exceed a certain standard. These standards lie between 150 mg/l and 600 mg/l depending on whether the water will be used for drinking water or for regional water management, which includes irrigation.

Salt intrusion in the Rhine Delta

Due to its open connection with the North Sea, a salt-water front moves up and down the Nieuwe Waterweg during each tidal cycle. This phenomenon is called salt intrusion. The maximum extend of the external salt intrusion in the Rhine system is mainly determined by the sea level, the discharge of the Rhine and the geometry of the river. In combination these parameters determine the total tidal discharge and therefore the maximum and minimum length of the salt intrusion. During average conditions i.e. a Rhine discharge of 2200 m^3/s and a tidal difference at Hoek van Holland of approximately 1.7 meter, the salt front will approximately move over a distance of 16 kilometres between Maassluis and the Waal harbour in Rotterdam (fig.1). In order to manage the extent of salt intrusion the Haringvliet sluices are used as a regulator to keep the minimum discharge through the Nieuwe Waterweg at 1500 m^3/s (Jacobs, 2004).

If the difference between high tide and low tide increases e.g. at springtide the difference between the maximum and minimum length of the salt intrusion will subsequently increase. During periods of low flow (discharge < 1000 m^3/s) this phenomenon will move upstream as far as the Hollandsche IJssel (fig.1). A combination of low flow and a short-term sea level rise due to storm setup will cause this pattern to move further eastward. During extreme events this process can even cause salt intrusion in the Haringvliet Lake and Hollandsch Diep through the Spui and Dordtsche Kil (fig. 1). This so-called “backwards” salt intrusion occurred in November 2005 during a period of strong westerly winds and a low Rhine discharge (Van Spijk, 2006).

Salt intrusion in the Rhine delta area also occurs through brackish seepage through groundwater flow, which emerges in the low-lying polders. This phenomenon results in the salinisation of the regional water system inside the polders. Because the regional water system is used for agricultural purposes, fresh water from the Rhine is used to flush the regional system and dissipate the more brackish water. However, during times of increased salt intrusion the possibility exists that water of sufficient quality will not be available. For instance, in the dry summer of 2003 the chloride concentration near the mouth of the Hollandsche IJssel raised up to 400 to 500 mg/l as a result of low Rhine discharge in combination with setup of sea level due to summer storms (Jacobs, 2004). In comparison, under average conditions the chloride concentration of the Rhine is 80 to 100 mg/l. In such situations a choice must be made between keeping the water level in the polders at a standard level, with the risk of salt damage to crops or allow the water level to drop with the risk of drought damage to crops and possible damage to the peat dykes surrounding the regional water system.

Effects of climate change

In 2006 the Royal Dutch Meteorological Institute (KNMI) presented four scenarios for climate change in the Netherlands until 2050, the so-called G, G+, W and W+ scenarios. The main characteristics for each scenario are presented in table 1. It is important to realise that each scenario has an equal probability. Although each scenario is unique, a few common characteristics can be revealed. Firstly, the intensity of individual summer rainstorms will increase, although the number of rainy days in summer will decrease. Secondly, in winter both average rainfall and intensity of rainfall will increase. Further, as a result of the rise in average temperature, the evaporation will exceed the average precipitation in summer. Lastly, the mean sea level will continue to rise. Note that the relative sea level rise will be higher due to land subsidence. In the 20th century the land subsidence varied from 0 to 4 millimetres per year, depending on the location.

	G scenario	**G+ scenario**	**W scenario**	**W+ scenario**
Worldwide rise in temperature	+1°C	+1°C	+2°C	+2°C
Change in large scale air circulation pattern	No	Yes	No	Yes
Winter				
Mean temperature	+0,9°C	+1,1°C	+1,8°C	+2.3°C
Mean precipitation	+4%	+7%	+7%	+14%
Summer				
Mean temperature	+0,9°C	+1,4°C	+1,7°C	+2,8°C
Mean precipitation	+3%	-10%	+6%	-19%
Sea level rise	15-25 cm	15-25 cm	20-35 cm	20-35 cm

Table 1: Selected characteristics of the KNMI climate scenarios for the Netherlands in 2050 compared to 1990

These climate scenarios are currently used in an impact study on salt intrusion along the Rhine river system. Understanding the effects of climate change on salt intrusion will contribute to defining the best strategy for sustainable water management in the delta area of the River Rhine. In general the effects of climate change will alter the characteristic discharge pattern (fig.2). In winter and early spring the average discharge will increase while in summer and autumn a decrease will occur. A reduction in the average discharge in combination with the expected relative sea level rise will cause a significant increase in salt intrusion. This will have a subsequent effect on the available amount of fresh water for drinking water supply and regional water management.

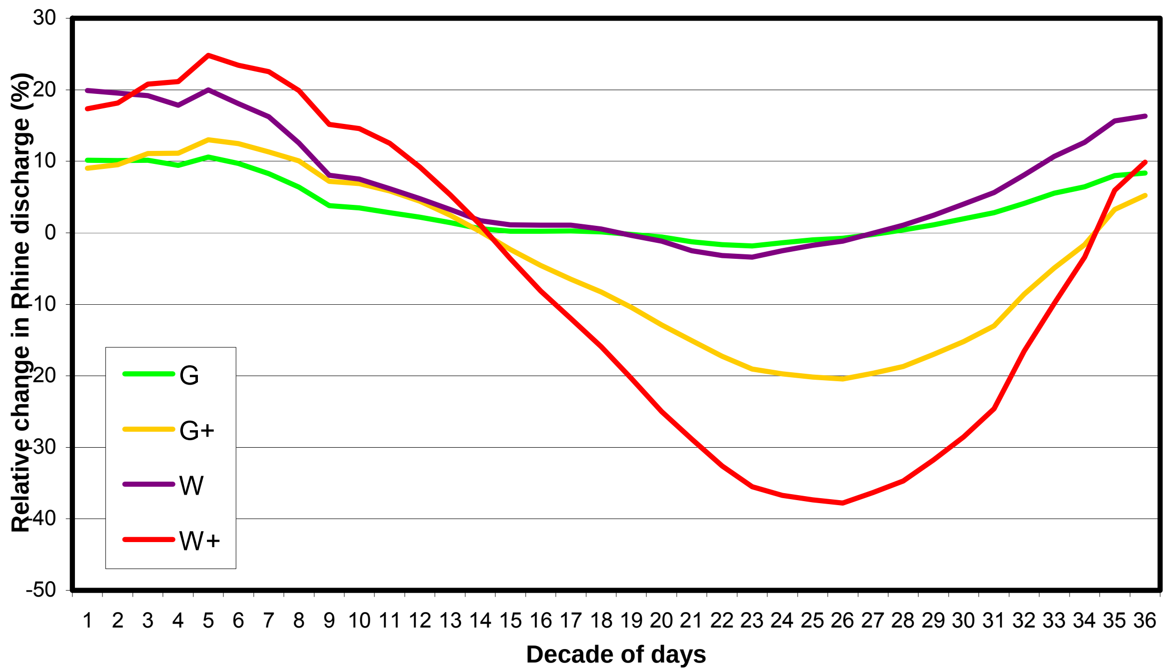

Figure 2: Relative change in Rhine discharge in the Netherlands in 2050 based on the four climate scenarios compared to the mean discharge of 1990

The impact study focuses mainly on the effects of climate change on the yearly average chloride concentration and on the duration of exceedance of certain critical chloride concentrations at locations where water is extracted. The study uses a simple 1-dimensional hydrodynamic model in combination with five sets of boundary conditions, each representing a year with various degrees of salt intrusion. Table 2 presents an overview of these so-called characteristic "salt" years together with the return period based on current climate conditions. For instance, a salt year with a return period of 1:11 will have salinity conditions similar to 2003. Note that the return period will decrease due to future climate changes (see for example Beersma *et al*, 2005).

	Characteristic year	**Return period**
Extreme saline	1976	1:32
Saline	2003	1:11
Brackish	1996	1:3.3
Moderately brackish	1994	1:1.6
Fresh	2002	1:1.2

Table 2: Characteristic salt years with corresponding return period based on current climate conditions

For each of the characteristic years a hydraulic calculation was made based on the current climate conditions as well as on the four future climate scenarios. The calculated duration of critical chloride concentration exceedance for the locations Gouda and Bernisse are shown in table 3 and 4. Gouda and Bernisse are important extraction points for regional water management. At Gouda the extraction of fresh water is interrupted when the chloride concentration exceeds 250 mg/l for more than 48 hours whereas at Bernisse the extraction will stop when the concentration exceeds 150 mg/l for more than 7 hours.

Characteristic salinity	Current	Scenario G	Scenario G+	Scenario W	Scenario W+
Extreme saline	72	85	138	89	161
Saline	46	54	102	60	146
Brackish	0	0	43	0	73
Moderately brackish	0	0	0	0	34
Fresh	0	0	0	0	0

Table 3: Total yearly duration in days of exceedance of 250 mg/l longer than 48 hours at Gouda

Characteristic salinity	Current	Scenario G	Scenario G+	Scenario W	Scenario W+
Extreme saline	102	122	142	128	151
Saline	57	69	95	54	118
Brackish	4	4	9	5	25
Moderately brackish	2	2	2	3	4
Fresh	1	2	3	2	2

Table 4: Total yearly duration in days of exceedance of 150 mg/l longer than 7 hours at Bernisse

The results show a distinct difference between the G/W scenarios and the G+/W+ scenarios for both locations. The strong reduction in mean annual precipitation in the G+/W+ scenario (table 1) will cause a distinctive increase in average chloride concentration and subsequent increase in duration of exceedance of a critical chloride concentration. For example during a “saline year” like 2003 under the W+ scenario, the total yearly duration in which the critical concentration is exceeded will almost double in 2050 at Gouda. Therefore, it is clear that a G+ or W+ scenario will impair future fresh water supply in the delta area of the river Rhine.
The rise in sea level accounts for an increase in total yearly duration of exceedance in all scenarios. However, the slight increase in mean annual precipitation included in the G and W scenarios could have a diminishing effect. Therefore, the total increase in yearly duration of exceedance is less dramatic in comparison with the G+ and W+ scenarios. Nevertheless, it is obvious that climate change will have an effect on the future availability of fresh water of acceptable quality in the delta area of the Rhine.

Possible measures

The current problems concerning salt intrusion together with the expected climate change raise the question whether measurements 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 Watermanagement commissioned a study in which a great number of possible solutions were examined (Van der Linden and Bosman, 2006). In this study the solutions were classified into four different frameworks:

- Prevention of (increased) salination through technical solutions
- Compensation of (increased) salination by technical and/or financial measures
- Spatial planning
- Alternative fresh water supply

Although 25 possible measurements were examined, only 5 of these measurements proved to be more or less feasible. Within the framework of prevention the most favourable solutions are lengthening and shallowing of the Nieuwe Waterweg. However, this solution does have some negative effects on the shipping industry. A favourable solution within the framework of compensation is the use of desalination units for drinking water supply. Spatial planning could be very effective in minimizing salt intrusion. However, due to the substantial social impact of these measurements the feasibility is (still) very low. A favourable solution within the framework of alternative fresh water supply could be water supply at the level of individual agricultural businesses. A possible measurement at a larger scale is relocation of the extraction points for drinking water and irrigation water.

In the above study the economic feasibility was not considered, but an earlier study showed that the costs of most possible solutions regarding salt intrusion are much higher than the profits (Blokhuis and Lodewijks, 2005). This indicates that the acceptance of increased salt intrusion in the future is just yet the best solution from an economic point of view. However, the social feasibility and consequences of this alternative are still unclear and subject to discussion.

Conclusion

Future climate change will most likely enhance the intrusion of salt water into the delta area of the river Rhine. Consequently, this will impair the amount of fresh water, which is used for drinking water and regional water management in the western part of the Netherlands. An impact study, for instance showed that the yearly amount of days that chloride concentration near a fresh water extraction point at Gouda exceeds a critical value would double in 2050.

However, other studies show that an adequate measure to reduce salt intrusion is not readily available. Therefore, the search for effective methods to avoid salt intrusion will continue. In particular because future climate change will most likely enhance this phenomenon in the delta area of the rivers Rhine and Meuse.

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DEVELOPMENTS IN SEASONAL TO DECADAL PREDICTIONS

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The maximum range for classical weather forecasts lies between 5 to 10 days depending on the current state of the atmosphere. This is due to the nonlinear nature of the atmosphere. Forecasts beyond this range are very likely to be uncertain.
There are three reasons why this is the case:

- uncertainty in the measurements that are used as initial conditions for the forecast,
- uncertainty in the numerical models used for the forecast and
- uncertainty in external parameters (Palmer & Hagedorn 2006).

The importance of these uncertainties changes with the forecast-range. In short-term forecasts the initial conditions are of particular importance, whereas in climate change projections the external parameters, i.e. the SRES emission scenarios, are of prime importance. Of course model uncertainty plays a role in all ranges. It has recently been shown that after 5-6 year green house gas (GHG) forcing plays the key role in the evolution of the global 2 m temperature (Troccoli & Palmer 2007). But also in seasonal forecasts the effect of an increasing GHG forcing can be seen (Doblas-Reyes et al 2006). In the case of seasonal to decadal (s2d) predictions all three kinds of uncertainties have a significant impact on the quality of the forecast.
The main tool to reduce these uncertainties is ensemble prediction. Operational ensemble forecasts are carried since 1986 (Murphy & Palmer). In these early attempts rather simple techniques were used to create ensembles by adding random noise to the initial conditions or taking ensemble members from consecutive analyses (Hoffmann & Kalnay, 1983). Since then, many sophisticated methods like singular-vector perturbations, breed vectors and ensemble data assimilation were developed to represent initial condition uncertainty in the models as it turned out that it is essential to get the “right amount” and direction of the uncertainty.
Model uncertainty is also represented in different ways. Since there are many models from different institutes world-wide one idea is to create a so-called multi-model ensemble by integrating the different models from the same initial conditions. One example for a multi-model system is the DEMETER (Development of a European Multi-Model Ensemble System for Seasonal to Inter-annual Prediction) system (Palmer & Hagedorn, 2006).

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. A good example for this technique is the ensemble prediction system of the Meteorological Service of Canada (Houtekamer et al., 1996).

A third method is the multi-parameter ensemble, where one model is integrated with different parameters in the same parameterization scheme. The Met office QUMP system (Murphy et al., 2004) is an example for such an ensemble prediction system.
A different view on the problem of model uncertainty is the use of a stochastic parameterization scheme. Here the sub-grid scale is described by non-linear stochastic processes. In this way structural errors that come through the conventional formulation of the sub-grid scale are taken into account. Buizza et al. (1999) used a simple stochastic parameterization scheme and showed that probabilistic skill scores improved compared to a non-stochastic ensemble prediction system.
The combination of a cellular automaton (Palmer, 2001) with stochastic backscatter (e.g. Leith, 1990) was recently used by Shutts (2005) in a so-called hybrid stochastic-dynamic parameterization scheme. First results show that this scheme reduces systematic errors especially in the mid-latitudes (Jung et al, 2005).
The scientific basis for s2d predictions lies mainly in the long-term variations of the ocean and the land surface. The difficulty is to exploit these memories of the climate system. Some ideas to utilize the memories will be discussed as well as methodologies to assess the prediction skill within hindcast experiments.

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LOW FLOW ESTIMATION AT UNGAUGED SITES

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This paper compares and assesses various methods for estimating Q95 low flows at sites without runoff data. Q95 is the discharge exceeded on 95% of all days of the measurement period. Stream flow data from 325 Austrian catchments, ranging in area from 7 to 963 km^2, are used for the comparison. The first comparison suggests that 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 (Laaha and Blöschl, 2006b). The second comparison suggests that a regional regression approach based on a catchment grouping of eight seasonality regions outperforms regressions based on other catchment groupings including the residual pattern approach, weighted cluster analysis and regression trees, and explains 70% of the spatial variance of q95 specific low flow discharges (Laaha and Blöschl, 2006a). A third analysis exploits the information from short stream flow records for estimating Q95. One year of continuous stream flow data outperforms the best regionalisation method but one spot gauging does not outperform the best regionalisation method (Laaha and Blöschl, 2005). The analyses suggest that process understanding can indeed assist in regionalising low flow characteristics more accurately than existing standard methods. Finally we present a national low flow estimation procedure for Austria (Laaha and Blöschl, 2007). To maximise the accuracy of the estimates we combined relevant sources of information including long streamflow records, short streamflow records, and catchment characteristics, according to data availability. Rather than deriving a single low flow estimate for each catchment we estimated lower and upper confidence limits to allow local information to be incorporated in a practical application of the procedure. The components of the procedure consist of temporal (climate) adjustments for short record lengths; grouping catchments into eight seasonality based regions; regional regressions of low flows with catchment characteristics; spatial adjustments for exploiting local streamflow data; and uncertainty assessment. The results are maps of lower and upper confidence limits of low flow discharges for 21 000 sub-catchments in Austria.

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OPERATIONAL LOW FLOW FORECASTS

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The Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde – BfG) in Koblenz, Germany is developing the waterlevel forecasting system WAVOS on behalf of different federal states and Federal institutions. WAVOS can be used for low flow forecasts as well as flood forecasts. BfG itself is responsible for operational forecasting for low flows in the River Rhine and Danube. Their responsibility includes issuing forecasts for navigational users, currently at a lead time of two days. The objective is to extend this lead time at the River Rhine to four days in the near future.

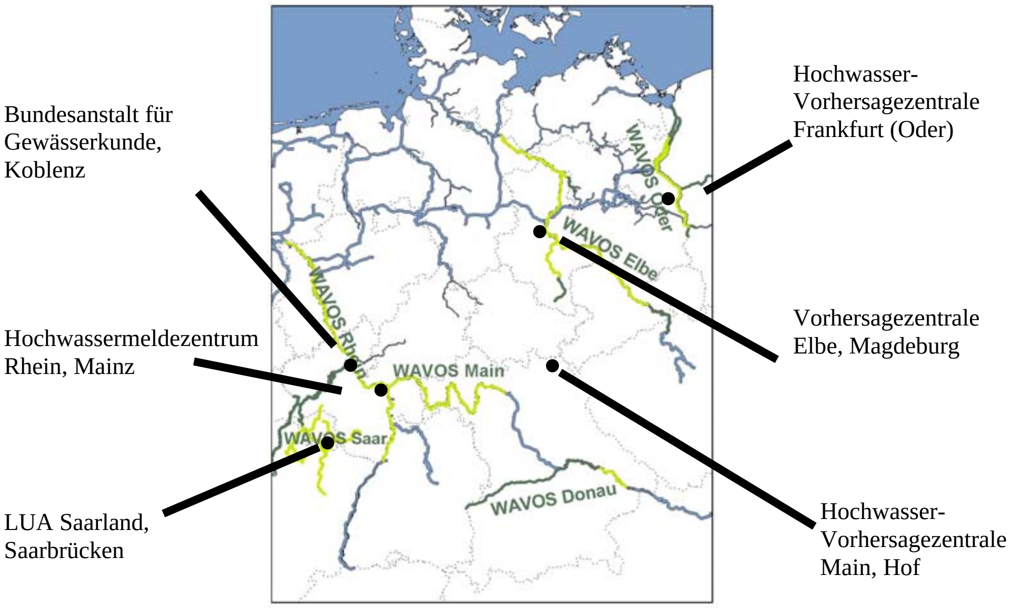

Fig 1: Application of the Water Level Forecasting System WAVOS

For extending the lead-time of reliable forecasts, it is necessary to make use of precipitation measurements and forecasts. Based on these, discharge is simulated by precipitation-runoff modelling. As part of a cooperation between the Institute for Inland Water Management and Waste Water Treatment (RIZA) of the Dutch ministry of public and BfG, an HBV precipitation-runoff model for the river Rhine basin downstream of Basel has been built up. This model, or if necessary an enhanced version, is meant to be used in the operational forecasting systems of both institutions. More details on the precipitation-runoff model can be found in Eberle et al. (2001), for the application at RIZA see Sprokkereef (2002).

To assist in the forecasting process with the precipitation-runoff model, both organisations are currently using a real time flood forecasting system for the Rhine basin. This system, referred to FEWS-NL in the Netherland and FEWS-DE in Germany has been constructed using the DELFT-FEWS flood forecasting shell as an operational platform (Werner et al., 2004). At the BfG the discharge forecasts for the Rhine and its tributaries are complemented with the WAVOS Rhein system to establish water levels at the forecasting points of interest.

It is clear that as the lead time increases, the uncertainty in the forecast levels and discharges will also increase with one of the main sources of this being the uncertainty in the forecast rainfall and temperature. The uncertainty of the meteorological forecasts is in part expressed through the use of ensemble weather predictions. Currently, two such ensemble weather prediction systems are available – the ECMWF-EPS ensemble, and the COSMO-LEPS ensemble. The first of these has been used within FEWS-NL for several years, whilst the COSMO-LEPS ensemble has only recently become operational. Despite the use of these ensemble forecast, the performance of these ensemble forecasts has to date not been assessed in detail, and reliability of these forecasts is unclear. Therefore BfG and RIZA started a CHR project to investigate the skill of the ensemble forecasts in the Rhine basin, which results are presented here.

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PREDICTING LOW FLOWS – SO WHAT?

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Why predict low flows?

- **Assumptions:**
  - **Need to know amount of water available**
  - **To ensure sustainability of source (control extraction)**
- **If system has low flows, it impacts:**
  - **Water availability and management (short and long term)**
  - **Users: economic, social, political, environmental**
- **Therefore, if can foretell water availability (scarcity) then can prepare for shortfall**

Good data ? good action

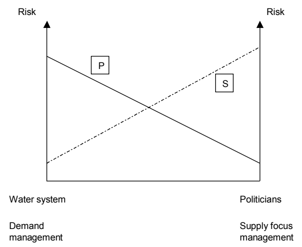
- **Suggest scientists assume:**
  - **If policy makers know, they will act**
  - **Good quality data leads to good quality action**
  - **Therefore, need good quality data on low flows**
- **Scientists spend a lot of time improving the quality of data collected on low flows, and improving the accuracy of predictions**
- **BUT. Despite good data and more accurate predictions, policy related decisions lag behind.**

Why?

- **What happens to the data?**
  - **Goes from the technical collection point**
  - **Passed onto technical personnel in national ministry**
  - **If low flows suggest need to alter water use, the government has to agree to change**
- **Who makes decisions, sets national strategies?**
  - **Politicians**
  - **Decision-making is politics *informed* by technical data, and a risk assessment**
  - **But risk to who – system or politician?**

Risk to who?

Water management strategies and associated risk



Good data ? ?

- **An example: Hurricane Katrina**
  - **Technical information points to an unusually strong hurricane, need urgent action**
  - **Top level political inaction, plus larger context, creates a disaster**
  - **Heavy cost: lives, financial, environmental etc**
- **Who are scientists talking to?**
  - **Focus on data quality AND communicating the message**
  - **Need to understand the politicians' framework**
    - **Timeline (votes), action needed**
    - **Speak in their 'language'**

Conclusion

- **Cannot assume that good data leads to good action**
- **If want action, speak to decision-makers in their language**
- **Necessary action that reduces risk to the water system, may be risky in political terms**

THE SEVEN RULES FOR HYDROLOGISTS WANTING TO MAKE AN IMPACT ON WATER MANEGEMENT

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Introduction

Science and policy often seem to be two different universes. Their inhabitants speak different languages, have different concerns, follow different rules and face different reward systems. Science aims to produce universally valid knowledge, based on mastery of scientific skills and knowledge of the scientific literature. Its major reward is recognition by the peers. Policy, on the other hand, is about practical action to address specific issues. This requires social and political skills. The major rewards in policy are political power and influence.

Yet, science and policy cannot be separated completely. To function as an independent "social field" with its own rules, science needs the tacit support and finances from the policy world. Sometimes, policy influences science directly through its funding policy. Conversely, science may also influence policy in different ways. Many scientists actually would like to contribute to the policy process.

This paper is about the use of research in the policy process, starting with agenda and goal setting, through strategy development and decision-making, up to implementation and evaluation. It addresses the question how researchers involved in fundamental or applied research can promote the use of their research. It focuses specifically on hydrological issues and hydrological research, but many points have a more general relevance.

This paper is structured according to the seven "rules" for researchers who want to make an impact on policy. These rules are based partly on the literature in the field of science and technology studies and research use and partly on personal involvement, sometimes of a peripheral nature, in a number of research projects, notably the SQR project (Sustainable and environmental Quality in transboundary River basins, 1995-1999) and the ongoing Niederrhein case study of the Newater project (www.newater.info) and the ACER project (Adaptation to Climate Extremes in transboundary River basins, www.adaptation.nl). This paper does not intend to provide a complete overview of the literature or prove the seven rules. Its aim is to stimulate reflection on the role of hydrologists and researchers more generally in the policy process. This may lead to experimentation with new approaches and to the acquisition of new experiences, thus starting an experiential learning cycle.

1. Reflect on the nature and possible roles of research

Scientists who would like their research to contribute to the policy process should first and foremost reflect on the nature of their research and the possible roles this could play in the policy process. Complete libraries have been written on this subject. This paper distils three conclusions from this body of literature.

First, scientific expertise is but one of the types of expertise used in the policy process. Scientific experts have relatively abstract but widely applicable knowledge and skills. The directly affected stakeholders, however, have more detailed knowledge about the current local situation (local or “lay” expertise”). Professional politicians and project managers have the necessary know-how to get things done (“policy expertise”). In theory, these types of expertise can complement each other. In practice, however, the different groups often do not recognize the other group’s expertise as relevant or valid.
Secondly, expertise is always subjective. This may be obvious for lay expertise and policy expertise, but it is also true for the different forms of scientific expertise. For example, when studying drought issues, hydrologists will study different aspects than agronomists or ecologists and economist, analyse them in different ways and come up with different types of solutions. This has little to do with the competence or integrity of the researchers concerned, but much more with the subjective choices that are implicit in any research, such as the choice of alternatives and effects to study and the way in which the results are presented. These choices are influenced or even determined by the researcher’s disciplinary background (or “bias”), personal values and interests and sympathies and antipathies, and by funding agencies clients through for instance the Terms of Reference for the research.
Thirdly, scientific expertise can nonetheless play a constructive role in the policy process. Lay person may have better knowledge about the current local situation, but abstract conceptualisation and modelling - in other words: scientific expertise - are needed for issues with a larger geographical or time scale, such as climate change and for designing radically new solutions. Moreover, while policy expertise may be needed to get things done, scientific expertise (combined and enriched with lay expertise) is needed to prevent unpleasant surprises, or at least reduce the chance of this.

2. Analyse the stakeholders and issues at stake

For contributing to the policy process it is necessary to know the stakeholders who are involved in this process and the issues that are at stake. This requires so-called stakeholder analysis. Stakeholders can be defined as all individuals, groups and organisations that can influence a problem or its solution (the “influential stakeholders”) or are affected by it (the “affected stakeholders”). Both categories overlap. In the case of drought, for instance, major water users such as farmers and electricity producers are both influential and affected stakeholders. Influential stakeholders need to be involved in the policy process to get anything done, whereas the affected stakeholders can be involved for ethical or democratic reasons.
Important questions concerning the stakeholders are, first, what their goals, objectives and perceptions are, and secondly, what resources they have. The stakeholders’ goals, objectives and perceptions determine what they see as an issue and as potential solutions for this issue. The resources of the stakeholders include their legal competencies, political influence, financial means, expertise and information. This determines the contribution they can make to the solution of an issue and influences the weight they carry in the policy process.
Different kinds of information and techniques can be used for a stakeholder analysis. These include previous experience with the stakeholders, discussion with colleagues or in so-called focus groups, interviews and literature study of policy statements, etc. Anyone can do a “quick and dirty” stakeholder analysis, and this can yield important

information, but for complex and potentially controversial projects a more elaborate form of stakeholders may be called for, involving experienced people.

3. Choose whom and what to serve

The third rule is perhaps the most controversial one: choose which stakeholders and which interests to serve. This rule is based on the recognition that it is impossible not to choose. As argued before, researchers inevitable make many subjective choices in their research, and these are influenced by their own values and sympathies and those of their funding agencies.

Even researchers involved in fundamental research choose, however implicitly. They may want to serve only science and not take sides on policy issues. Sooner or later, however, their research may be used in more applied research that directly affects policy. Fundamental research does not always benefit everybody equally. It benefits especially those stakeholders that have the necessary skills and knowledge to apply it to their own situation, for their own purposes, or have the necessary funds to hire others to do this.

4. Decide on your strategy

After having decided whom and what to serve, it is time to decide on the best strategy for this. A first issue is how you would like your research to be used. Much research aims at instrumental use. For instance, research studies the effects of different management alternatives and the stakeholders involved in the policy process use this information for deciding between the different alternatives.

However, much research is not used instrumentally, for instance because it does not fit in the current policy. Research may then still help the stakeholders to think about the issues in different ways (“conceptual use”). This may result in fundamental innovation in the longer run. Different researchers have argued that conceptual use is in fact more common than instrumental use.

A third form of research use is strategic use. Strategic use occurs when research is used to rationalize or legitimize preferred solutions or to oppose other solutions. Research may also be steered towards conclusions that favour specific solutions, e.g. by excluding specific alternatives or effects from consideration, by imposing specific assumptions to be used in the research (“use the high scenario”, “use the low scenario”) or by suggesting specific reformulations of the conclusions or the summary of the research. Other stakeholders - if they have sufficient expertise or funds – may then conduct or order research that considers different alternatives and effects, uses different assumptions and formulations, and consequently arrives at different conclusions. This may result a “report war”.

Any strategy for research use needs to be based on a clear view on how the policy process works and who the stakeholders. Researchers may relate to the stakeholders in three fundamentally different ways. First, they may opt for advocacy research and support a specific client or promote a specific cause (e.g. nature protection or the shipping industry). This calls for close cooperation with the stakeholder or –holders concerned. Much policy-relevant research supporting the implementation of official government policy van be seen as advocacy research as well.

Secondly, researchers may choose to facilitate learning and decision-making by the whole network of stakeholders. They may try to cater for the information needs of all

stakeholders and help them to clarify the issues and structure their discussions. Like any type of facilitation, this is not a completely neutral activity. The researcher first has to decide whether he wants to work with and for a specific group of stakeholders. Moreover, he inevitably influences the process by suggesting to invite additional stakeholders, consider specific issues or alternatives, etc. There are no objectively right solutions to these questions, and the solutions that researchers come up with will inevitably be influenced by their or their clients' values, interests and views.
Thirdly, researchers may work in isolation from the other stakeholders. This strategy is compatible with conceptual research use and gives researchers complete freedom to develop innovative concepts and approaches that may run counter to current policy and public opinion. To have maximum effect, the results should be communicated to as many influential stakeholders as possible. (See also rule 6.)

5. Design the process to implement your strategy
Strategies have to be put into practice. Activities need to be prepared and a time schedule has to be made. If cooperation with one or more stakeholders is foreseen, it is important to get into contact from an early phase onwards. However, it often happens that researchers first set up and specify the research, based on their own perception of the issues at stake and following the requirements of their own discipline and of funding agencies. The other stakeholders are invited to participate in the research only after this has been done. These may be interested in other aspects of the issue at stake, in a slightly different area, different measures, different effects, etc. Taking their concerns into account at this stage may result in delays, but not taking them into account may reduce support for the research and result in stakeholders opting not to cooperate.
For both cooperative and non-cooperative research, it is important to maintain as much flexibility as possible to be able to respond adequately to changing circumstances of surprising first results. Major changes require the consent of the stakeholders involved in order to reduce the risk of loosing support for and commitment to the research.

6. Communicate!
Communication is central to research utilization. Communication in general can be defined as social interaction through messages. One view on communication is the transfer of information from a sender to a receiver. This involves encoding of the information into a message, e.g. text and figures in a report, the transmission of the message, and decoding of the message by the receiver. In the field of science communication, this view is called the public understanding of science model, deficiency model or scientific literacy model. This model suggests that stakeholders require knowledge of particular scientific concepts and facts, which are portrayed as fixed and certain. The aim of science communication in this model is primarily pedagogic: the public has to be educated. Yet, despite many efforts in this tradition, there is little evidence of any increase in public understanding of science.
In response to the poor performance of the first model of science communication, a second one has been developed, titled the contextual or interactive model. Its starting point is not science, but the needs and interests of the audiences and the context in which they have to or can use the science. Moreover, it acknowledges the subjective or "constructed" character of science and pays as much attention to the

production as to the consumption of knowledge. Communication in this view is not one-way transfer of knowledge from researchers to the other stakeholders, but a continuous interaction between the two groups, in which both groups influence each other.
Communication by researchers working in isolation necessarily has to rely on the first model, but within more collaborative research strategies two-way communication should be central. Yet, even in collaborative strategies many instances of one-way communication occur. Researchers can interact directly with only a limited number of people. To reach more people, they have to rely on books and reports, the mass media, word of mouth dissemination and intermediaries such as communication officers of research institutes and journalists. In all forms of communication the different target audiences should be central in order to maximize understanding and communicative effectiveness. Messages should be tailored to background knowledge and interests of target audiences and jargon should be avoided.

7. Reflect on your own interests and skills

Last but not least, researchers should consider their interests and skills. While some people like and are good at solving specific, given problems, e.g. solve mathematical equations, others prefer to analyse complex and ambiguous problems and interact with the different stakeholders to support them to address their own problems. The former would be good candidates for more fundamental research, which requires especially very good analytical skills and stamina to work independently. The latter are better in more co-operative research. This requires analytical skills as well, but in addition good social skills, flexibility and the ability to cope with change and uncertainty.
It may be obvious that people without the proper skills for a specific type of research will not perform well, but people without an interest in this type of work will not perform well either. That being said, skills and interests are not given once and for all, but can be developed to some extent.

Discussion

As stated in the introduction, the aim of this paper was to stimulate reflection on the role of researchers in the policy process and to promote experimentation with new approaches and learning. To this end, seven rules have been formulated, addressed to researchers. Yet, there is much more to do. First of all, the role of the other stakeholders, such as government bodies/ clients and other potential users, has not been discussed at any length. For these stakeholders, rules could be proposed as well. These can be based on respect for the specific contributions that research can make to policy making and a critical attitude towards the assumptions used, alternatives included or excluded and the other implicit choices made.
Secondly, the seven rules pay little attention to institutional factors. Individual researchers are faced with many constraints. These include the reward structure in science, which generally rewards publications in journals with a high impact factor, that is, mono-disciplinary journals reporting about fundamental research and addressing the peers only. Science often frowns upon popularization. Another constraint is the (research) policy of funding agencies. Increasingly, research has to be “policy relevant”, that is, address officially recognized issues and alternatives, even though research that challenges current policy is equally policy relevant and

may result in more fundamental innovation in the long run (see under rule 4). These constraints may work in opposite directions, and their relevance depends on the type of organization that the researcher is working for (e.g. academia or government research institute) and especially the organization's policy concerning funding and promotion.

Not only individual researchers, but also other stakeholders face constraints, which are related to how policy making functions. For instance, an individual policy maker may want to avoid a “report war”, but he or she may be forced to react when someone else starts such a war. To be effective, both researchers and other policy makers should know the constraints that they are under and the freedom that is still left to them, and use this freedom maximally and wisely. In addition, the different constraints can be evaluated at higher levels, e.g. by editorial boards of journals, the management of research institutes, research policy making. These stakeholders need to develop a clear view on the effects of their policy, if they do not yet have one, and then decide whether that is what they really want.

There is ample room for more research, including comparative case study research. In addition, all research projects that aim to contribute to the policy process can be treated as research on research use. They all employ assumptions as to what promotes research use and this use may or may not occur. This provides opportunities for learning, if the researchers pay attention to the other stakeholders and whether, how and why they use the research, and if they reflect on the assumptions that they used. In addition, learning on research use can be promoted by an exchange of experiences in different projects, both between researchers and between researchers and other stakeholders.

ABSTRACTS

OF POSTER PRESENTATIONS

THE PREDICTION OF SOIL MOISTURE USING PROBABILISTIC MONTHLY WEATHER FORECASTS

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Despite technological advances in breeding and agricultural practice, crop yield remains subject to considerable inter-annual variability related to short-term (seasonal) climate fluctuations. Of utmost importance in this context are variations in soil water availability. Extreme conditions such as the heat wave observed in Europe during the summer of 2003 can lead to anomalous soil moisture depletion and induce considerable losses in crop production. The prediction of soil water levels using monthly forecasts could provide valuable means for risk assessment and mitigation.

We present first results of a prediction system for soil moisture forecasts with a lead time of up to one month. The system uses dynamical, probabilistic forecasts of daily temperature, precipitation and global radiation from the European Centre for Medium-Range Weather Forecasts. The forecasts drive a bucket model of the water balance in the root zone.

The prediction system is tested for several sites in Switzerland using monthly hindcasts covering the time period 1994–2005. Simple downscaling of raw model data is performed based on an anomaly correction. Resulting soil moisture forecasts are skilful in predicting levels of critical soil moisture. The system allows for the probabilistic estimation of reaching a critical level of soil moisture within the three weeks following the forecast release. Examples for the years 2001 and 2003 are shown in Figure 1 (Wynau, Switzerland): In 2001, the summer was wet, soil moisture never reached critical values and the probability of running dry was very low throughout the year. By contrast, the summer of 2003 was extremely dry, soil moisture levels were frequently below the critical threshold and the probability of running dry was high during an unusually long period. In the future, such probabilistic estimations shall serve as a valuable tool for the farmers' decision-making process.

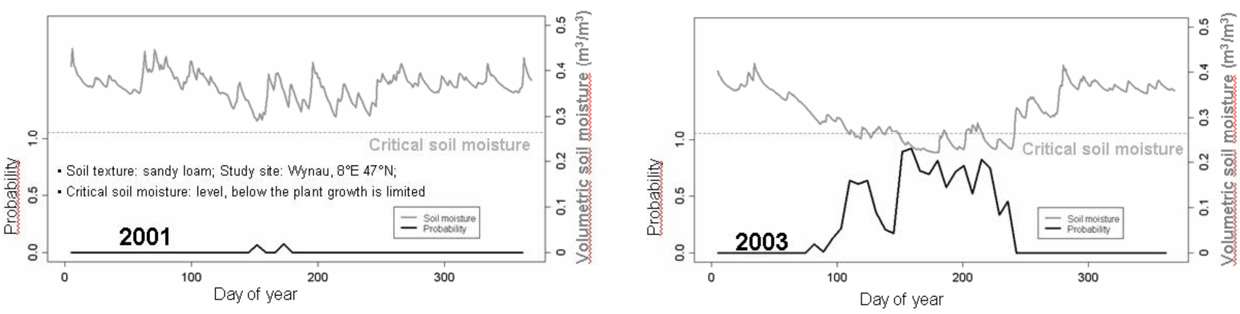

Fig. 1: Probability (black) of reaching critical soil moisture within 21 days following the forecast release and observed soil moisture (grey) for 2001 (left) and 2003 (right). A wet summer was experienced in 2001, whereas 2003 was extremely dry.

EXTREME VALUE STATISTICS FOR METEOROLOGICAL DROUGHT AT DIFFERENT SPATIONAL AND TEMPORAL SCALES IN THE MEUSE BASIN

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Drought is an important natural phenomenon influencing many aspects of environment and society. In Europe, expected climate changes may lead to drier summer and consequently more severe droughts. The aim of this study is to quantify meteorological droughts and assign return periods to these droughts. Moreover, the relation between meteorological and hydrological droughts is explored. This has been done for the river Meuse basin in Western Europe at different spatial and temporal scales to enable comparison between different data sources (e.g. stations and climate models). Meteorological drought has been defined as annual minimum precipitation amounts for certain return periods using the Weibull extreme value type 3 distribution. Statistical tests showed that the majority of annual minimum k-day point and spatially averaged precipitation values are Weibull distributed and therefore this distribution can be used.

Results show that the spatial variability in annual minimum k-day point precipitation is large and can be attributed to the sampling problem, the effect of orography and the distance to the sea. Annual minimum precipitation values decrease more pronounced with increasing return periods for small temporal scales compared to large temporal scales caused by the temporal averaging effect for larger temporal scales. Annual minimum precipitation values increase with spatial scale being most pronounced for small temporal scales. This amplification is not found to be related to seasonal effects or the spatial variability of annual minimum precipitation for a specific year. The uncertainty in annual minimum point precipitation varies between 68% for a duration of 30 days and a return period of 100 years and 8% for a duration of 120 days and a return period of 10 years. For spatially averaged values (150 km scale), these figures are respectively 50% and 7%. The uncertainty makes that annual minimum point precipitation values can correspond to a range of return periods differing in some cases almost an order of magnitude. There exist reasonable relations between the annual discharge deficit (hydrological drought) and annual minimum spatially averaged precipitation for different temporal scales (meteorological drought) which become more significant for larger temporal scales. The central date of occurrence of spatially averaged annual minimum precipitation does not show any pattern in time, while the annual discharge deficit is limited to the period August-October, obviously caused by the annual cycle of evapotranspiration.

The relations between annual minimum precipitation values and spatial scale can be used to compare observed point values with modelled grid values using data from GCMs and preferably RCMs for current climate conditions. Subsequently, assessment of climate change impacts on meteorological drought using GCM and RCM results for current and changed climate conditions can be done. Most RCMs agree on a general increase in winter precipitation and a general decrease in summer precipitation for Europe. It is therefore expected that meteorological droughts will become more severe in the Meuse basin and will be more concentrated in the summer half-year.

DAILY DISCHARGE FORECASTING WITH OPERATIONAL WATERBALANCE MODELS

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The water balance model LARSIM simulates all relevant aspects of the terrestrial water cycle, including interception, snow accumulation and melt, evapotranspiration, soil water, runoff generation, runoff concentration, and river routing. In addition, retention ponds, reservoirs, and lakes as well as water withdrawal and water addition can be accounted for. The meteorological forcing variables (i.e. precipitation, air temperature etc.) are internally interpolated from point measurements to any grid point within the model. The parametrisation of the model is commonly based on readily available data, such as digital elevation maps, digital maps of land cover and soil classification, digital river networks and geometries along with additional information about retention ponds, lakes, and reservoirs. The model can be run in various temporal and spatial resolutions (Bremicker 2000). For real time discharge forecasting LARSIM has been amended by a variety of automated, process-oriented optimisation techniques. In brief: hydrology is always simulated for at least two days before the start of forecast, using measured data for model forcing. These simulation results are internally compared with measured discharges. In the case of discrepancies, the model is automatically optimised to better match the measurements as described in detail by Luce et al. (2006). This optimisation has proven to increase the quality of discharge forecasts (Luce et al. 2006).

The complete area of the federal state of Baden-Württemberg is covered by LARSIM models with a spatial resolution of 1 x 1 km^2. For operational real time forecasting these models are run in a time step of one hour. Daily, automated forecasts with LARSIM are issued since 2003 (Bremicker et al. 2004). The operational model results serve for early flood warning and flood forecasting (Bremicker et al. 2006). During periods of low flow, forecasts are issued for up to seven days ahead. Beside the discharge forecast based on meteorological forecasts there is always a so called no-rain-scenario, for which it is assumed that there is no precipitation during the time of forecast. In the case of low flow, this scenario represents the minimum discharge and water level to be expected during the seven days to come. Low flow forecasts are of special interest for water authorities and water users if the withdrawal or input of water is restricted for discharge or water level falling below a threshold. Low flow forecasts may also help to optimise the operation of reservoirs which are used to sustain river flow.

Moreover, routine LARSIM forecasts also provide spatially distributed data of different components of the water balance. These data include information about the present soil water content simulated by the model. In the case of drought, this information may be helpful to gain a spatial overview of the drought’s severity.

LARSIM has been extended by a river water temperature module. The integrated water balance and water temperature model allows to simulate and forecast river water temperatures throughout the complete river network with a deterministic approach, accounting for heat exchange processes along the flow path as well as local sources such as thermal discharges. In addition, it is also possible to calculate river water temperatures with regression models for specific points in the river network (Haag and Luce 2008).

This integrated model has been routinely applied for automated daily water temperature and discharge forecasts in the River Neckar basin since summer 2004. The model accounts for thermal discharges from seven sites with power plants and the water losses due to cooling tower evaporation from three of these sites. Forecasts routinely cover seven days ahead (Haag et al. 2005). Water temperature forecasts for River Neckar are of particular interest, because the use of cooling water at the seven sites with power plants is restricted to a maximum mixing temperature of 28°C. The daily forecasts of water temperature and discharge contain valuable information for the water authorities as well as the operating company of the power plants. During summer periods the combined forecasts warn them well in advance of critical water temperatures or discharges, leaving enough time for appropriate counter measures. In particular, during the summer low flow seasons of 2004 and 2006 the operational model has proven to be of considerable ecological and economical benefit.

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CLIMATIC AND ANTHROPOGENIC EFFECTS ON LOW FLOW OF THE MIDDLE ELBE

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Introduction

The River Elbe is characterized by considerable variations in water flow. Low flow is a frequent phenomenon limiting the options for transportation on the Elbe. However, the mean low flow level could be increased markedly since the 1950s. Due to the building of dams and a cascade of water barriers in the Czech Republic, the upper part of the Elbe is now navigable up to Ústí nad Labem all year round. Low flows were also increased in the subsequent river section up to Magdeburg. However, severe low flow periods are still occurring on a regular basis. In order to assess the strategic potential for the usage of the river Elbe as transportation route, we analyzed recent trends in low water occurrence and possible links to climatic and anthropogenic changes.

Material and Methods

Long-term time series of yearly (median and low) water flows are analyzed at several gages of the Elbe and the Saale for their internal segmentation. Criteria of segmentation are level changes, changes in variability, periods of trend formation and points of trend collapse in the yearly minimum low flow. The different segments are discussed in respect to possible anthropogenic and climatic sources. Finally, an outlook is presented regarding future low flow frequencies in the middle section between Dresden and Magdeburg. The outlook is based on the extrapolation of recent climatic and anthropogenic trends. The time series of two gages are exemplarily discussed: Dresden and Calbe. Dresden reflects the upper basin part conditions. Calbe is the final gage of the river Saale - the largest tributary to the Elbe between Dresden and Magdeburg.

Results and Discussion

Both, the yearly median and low flows of the Elbe, follow a 7-year-rhythm as depicted in **figure 1** by the moving average line. Beside this, the low flows for Dresden as for other gages of the Elbe can be subdivided in four time segments. In phase I (1901-1938), the low flow variability is free of trend. The climate variables temperature and precipitation are similarly stable during that time **(Fig. 2)**. Phase II (1939-1954) is characterized by drastic low flow variations exceeding the long-term oscillation band. Anomalies in temperature and precipitation are consistent with this behavior. During phase III (1955-1969) the low flows continuously increase. They parallel the capacity enlargement of Czech dams during this period. In phase IV (1970-2003), these dams reached maximum capacity. Consequently, the mean low flow is 33,6 m^3/s higher in phase IV than in phase I ($p \leq 0,01$, Kruskal-Wallis-Test).

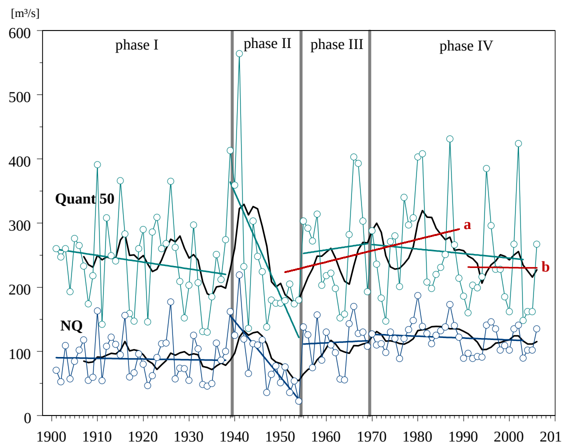


Fig. 1: Flows at the gage Dresden (Elbe) from 1901-2006, NQ: low flows, Quant50: median flows, black line: moving average (7 years), trends of segmentation: phase I: 1901-1938 / II: 1939-1954 / III: 1955-1969 / IV:1970-2006, additional phases a: 1951-1989, b: 1990-2003

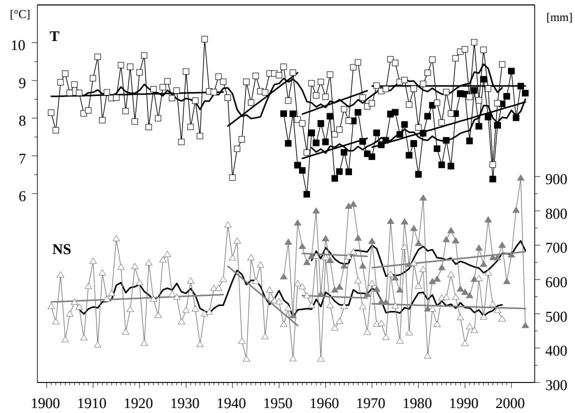
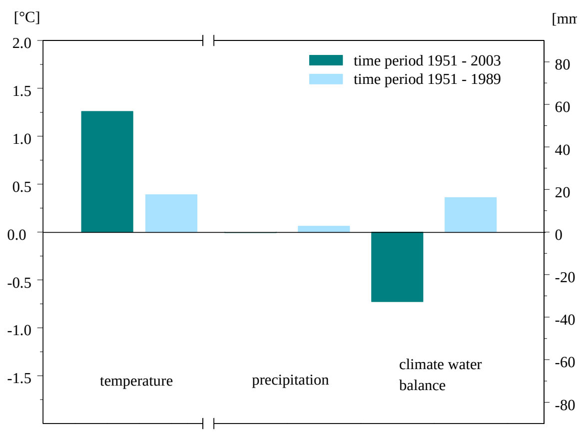


Fig. 2: Yearly variables of temperature (T), and precipitation (NS) in the Czech Republic for the time periods 1901-2003 (3 climate stations, blank symbols) and 1951-2003 (44 climate stations, filled out symbols)

A long-term increase trend in the yearly median flow lasts from the beginning of the phase III to the middle of phase IV. The trend collapses after 1989 **(Fig. 1)**. An increase in precipitation and in the climatic water balance found for weather stations in the upper Czech basin part probably generated this upward trend **(Fig. 3)**. Since the early 1990s, the trends reverse. The trend reversal is accompanied by an increase of temperature and radiation in the Czech basin part. The first probably links to global warming; the latter could be associated with decreased industrial SO_2-emissions (regional re-dimming) in the region. Although quite stable before 1990 in phase IV, the yearly low flow values recently show a decreasing tendency as well.



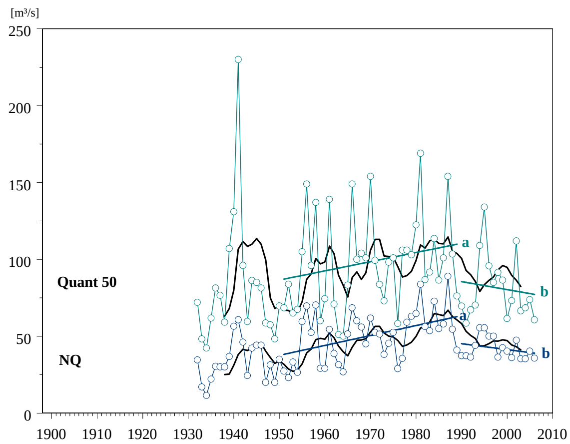


Fig. 3: Mean trends in temperature, precipitation and climate water balance in the Czech Republic for the different time periods: 1951-2003 and 1951-1989

Fig. 4: Median (Quant 50) and low (NQ) flows at the gage Calbe (Saale) from 1931-2006, trend lines: 1931-1989 and 1990-2006

Similar trends for the yearly median flows as found for the Elbe gage Dresden are also present at the Saale gage Calbe **(Fig. 4)**. Nevertheless, anthropogenic effects play a much more relevant role during both trend phases than for the Dresden gage. Both median and low flows are increased by large amounts of pumping water from brown coal mining fields in the region and drinking water imports from other basins. In addition, the low water discharge is increased by a regional dam regulation regime aimed to keep the impact of saline waters from salt mining below critical thresholds. With the rapid decrease of all regional mining activities after 1989 the increase trend collapses and the mean level of yearly values for median and low water decreases to a remarkably lower level. As a consequence, the river Saale contributes less water to the Elbe section between Dresden and Barby during low water periods. If recent climate trends in the upper part of the basin continue, the frequency and duration of low water in the Elbe between Dresden and Magdeburg is likely to increase. The effect is further strengthened, if the current water management of low flows remains at the current level in the Saale river basin.

RECENT VARIATIONS IN TERRESTRIAL WATER STORAGE: COMPARISON OF *GRACE* AGAINST BASIN-SCALE WATERBALANCE DIAGNOSTICS

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Although terrestrial water storage (TWS) plays an important role in the hydrological cycle, there are insufficient in-situ observations of its various components (soil moisture, snow and ice cover, surface and groundwater) available to assess the seasonal cycle of TWS over continental and sub-continental scales.

In recent publications, a basin-scale dataset (BSWB) of monthly variations in TWS was diagnosed for the ERA-40 time period (1958–2002) using an atmospheric-terrestrial water-balance approach (Seneviratne et al. 2004, Hirschi et al. 2006a; data available at http://www.iac.ethz.ch/data/water_balance/). Using a similar approach, the feasibility of using ECMWF operational forecast analyses – available for the recent time period in near real time – instead of reanalysis data for deriving these diagnostic estimates was tested (Hirschi et al. 2006b). For ten domains with recent streamflow measurements, the derived basin-scale diagnoses are compared against TWS retrieved from the Gravity Recovery and Climate Experiment (GRACE; data obtained from the University of Colorado GRACE data analysis web-site at http://geoid.colorado.edu/grace/grace.php).

In general, the atmospheric-terrestrial water-balance estimates and the analyzed standard resolution GRACE products agree on the phase of the TWS variations (Figure 1), and the amplitudes are similar for several of the considered domains. The water-balance estimates tend to show more geographical detail than the GRACE data when neighbouring domains are considered. Finally, the comparison highlights remaining uncertainties in the estimation of large-scale TWS, in particular between the GRACE products themselves.

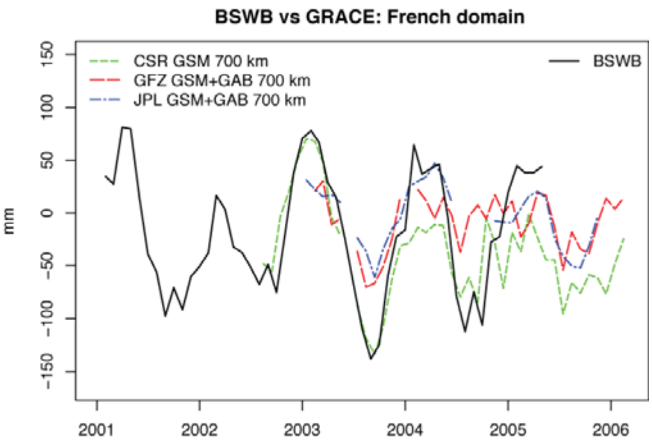

Figure 1: Diagnostic basin-scale water-balance TWS (BSWB) compared against TWS derived from GRACE (products from three data centers) for the French domain.

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PRIORITISING WATER USE DURING WATER SHORTAGE IN THE DUTCH CATCHMENT AREA OF THE MEUSE

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The Meuse takes its rise in France and flows then through Belgium. In Maastricht it reaches the Netherlands and it flows further to the North Sea. The length of the river is almost 900 km, of which 250 passes through the Netherlands. Between Maastricht and Maasbracht it forms the border between the Netherlands and Flanders and is called the Border Meuse. There are no barrages here, no navigation, many bends are present and the bottom consists of gravel. All this is unique for this region and that’s why nature values are here cherished. In 1995 the Netherlands and Flanders have signed a Meuse Discharge Treaty. The starting points are the equal sharing of water in dry periods and a common responsibility for the Border Meuse. Most problems with water shortages occur upstream of Roermond, being the mouth of the Roer. In the catchment area of this river in Germany there is a couple of barrages with water reservoirs which enlarge considerably the discharge of the Meuse.

The vulnerability for droughts of the Meuse is different to this of the Rhine. On one hand the Meuse is more vulnerable, on the other hand less. Unlike the Rhine, the Meuse is a typical rain river, with no reservoirs in the form of glaciers and rather poor groundwater storage. It makes it very vulnerable to lack of precipitation. The discharge pattern is very changeable: the largest discharges are approximately 150 times bigger than the smallest ones. The main discharge in Maastricht is 230 m^3/s; during dry summers discharges of 15 to 20 m^3/s can here occur.

On the other hand the Meuse has almost along its whole length barrages. They ensure a necessary depth for the navigation. But they also cause differences in water levels and to overcome them locks are applied. In the process of locking through the volume of water that fills a lock chamber goes downstream and can’t be used again in the same lock. A significant discharge is necessary for this. So in the Meuse the problem of water shortage is not insufficient depth, but low discharge (this is another difference to the Rhine).

The navigation is the biggest user of water, but not the only one. The Meuse fulfils different functions, both for nature, as for the economy. The most important are: industry, agriculture, horticulture, nature, drinking water, water for hydroelectric plants and cooling . The demand for water of these users often -especially in late summer/early autumn - exceeds the availability. On average approximately 3 months a year there is a shortage of water. One of the measures to deal with this problem is prioritising different categories of water users. Recently the authorities managing water in the Dutch catchment area of the Meuse (Ministry of Transport and Water Management, provinces and water boards) developed a prioritising system of water supply during water shortages. This system is based on a national one.

In the table there is a list of functions together with the priority that they have for water supply in dry periods. The system consists of four priorities. At the moment that there is not enough water, the water supply for functions with the lowest priority (4th) has to be reduced. These users have to take measures in order to be able to function with less water, or they have to stop the activity. If there is still not enough water, the functions of the 3rd priority would be shortened, and so on. The functions of the 1st priority should always be supplied with water.

Priority 1	**Priority 2**	**Priority 3**	**Priority 4**
Safety and preventing irreversible damage	*Public utilities*	*Small scale high profit use*	*Other functions*
1. stability of dykes by maintaining water level 2. protecting marshlands by maintaining water level in buffer areas	1. drinking water 2. cooling electricity	• horticulture • process water for industry • flushing urban surface water	1. aquatic nature and water quality • minimum flow in brooks with high ecological value • fighting botulism and green algae due to significant risks • minimum flow in fish paths (during fish migration) 2. other functions • navigation (inclusive recreation) • agriculture • nature (as far as no irreversible damage) • cooling water for industry
goes before -→	goes before -→	goes before -→	

Measures to cope with water shortage

The authorities managing water do their best to fulfil as long as possible the demand for water of all users. Therefore, before shortening the use, they take additional measures. First of all, whenever they foresee that a dry period is coming, they increase water reserves, for example by rising the damming level of barrages. They create buffers: water reserves that can be used during water shortage.

The Ministry of Transport and Water Management is responsible for the passage of ships. By water scarcity it decreases the demand of water for the navigation by economising the use of water during locking through. Water is pumped back from the lower section of a lock to the higher one, so that a semi close circuit is created. However, this measure is very expensive and causes emission of CO_2. Another possibility is the installation of reservoirs where a part of water from a lock chamber is stored instead of being discharged at the lower section of the canal, or by siphoning lockage (water is exchanged between two parallel chambers). Also these measures are rather expensive: it costs much to install the necessary equipment and locking through takes more time which is inconvenient for ships. Finally the frequency of locking through can be changed: instead of doing it for each ship that arrives, one can wait until the chamber is full. This is very inconvenient for ships, so this measure means actually *shortening* the use.

The users of water take different measures to decrease the demand for water too. Drinking water companies, industry and horticulture also apply buffers. By horticulture the rainwater that falls on the roofs of greenhouses, can be stored and used in dry periods. Agriculture can create a buffer as well, in the ground. For many decades farmers in the Netherlands tried to keep their land dry: rainwater was quickly brought away by middle of drainage and ditches. The reason for this is that the damage of crops caused by too much water is here in general higher than by water scarcity. When it got a bit dry, they often used irrigation. They were dependent on water supply. Nowadays one tries to store water in the ground by limiting the quick artificial runoff.

A very durable measure is to decrease permanently the use of water, f.i. by changing technologies, by using rainwater for toilets, by applying equipment to make it possible to use less water for showers or toilets, or just by being economical with water. Another possibility is to apply alternative solutions, f.i. to use cooling towers instead of cooling with water. The last option is to stop the activity. This is the case with hydroelectric plants: if there is not enough water they just stop to produce electricity.

Considering the possibilities above, the following measures have to be taken before shortening/cutting the use of water:

- restricted way of locking through (if possible with full locks),
- maximal utilization of pumps by locks, siphoning lockage (water is exchanged between two parallel locks) and applying water reservoirs to store temporary water from lock chambers,
- active fighting botulism,
- closing fish passages if no fish migration,
- utilization of cooling towers by thermal electricity plants,
- extra utilization of groundwater by drinking water companies,
- stopping sprinkling grasslands with surface water.

Other measures that should be taken by severe scarcity of water are:

- maximal utilization of water reservoirs by drinking water companies,
- maximal purchase of electricity elsewhere,
- no use of drinking water for sprinkling.

DAILY LOW FLOW FORECASTING OF THE RHINE BASIN: COMPARISON OF PROBABILISTIC STRATEGIES

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Flow forecasting is a central objective of operational hydrology. In low-flow conditions, the persistence of initial conditions allows to use much longer forecasting lead-times (weeks or months) than for flood forecasting. However, uncertainty on future rainfall is still high, which requires a probabilistic framework. In this study, a continuous lumped hydrological model is run with a stochastic rainfall model to produce ensembles of low-flow forecasts at the daily time-step with a 90 days lead-time on 7 gauging stations on the Rhine basin (with catchment size ranging from 13,230 to 160,800 km^2). Statistical scores are used to assess the quality of the probabilistic forecasts. Results indicate that a 30 days lead-time can be achieved on the downstream part of the basin. However, attempts to constrain the rainfall model with climatic indices showed disappointing results.

LOW FLOW FORECASTING MODEL FOR THE RIVER MUR AND COMPARISON OF THE LOW FLOW PERIODS 1992, 1993 AND 2003, 2004

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Low flow forecasting model

Three watersheds cover nearly 100 % of Styria region in Austria.. For the Mur and Enns Rivers (respectively around 10000 km² and 4000 km² in Styria) an automatic flood forecasting system has been setup during the three last years, whereas a similar system is planed for the Raab catchment (around 3000 km² in Styria) from the Austrian-Hungarian “Raab Comission”. The current systems are based on rainfall runoff modelling at the sub-catchment scale meaning that the hydrological status will be simulated for approximately the entire region in future.

The idea is to use this structure to forecast also low-flows. Especially the rainfall-runoff model NAM) and its ability to reproduce low flow dynamic will be tested first for the Mur watershed. The main modifications compared to the flood forecasting system will be 1) Extension of the calibration period including the extreme low flow periods of 1992-1993 and 2003-2004, 2) calibration using daily discharge values, 3) focus the calibration on recession limbs and low flow periods and 4) extent the lead time using the ECMWF meteorological model.

The NAM rainfall-runoff model is a conceptual lumped model build on a linear reservoir approach with 4 reservoirs (Fig 1, left side). A lower groundwater reservoir, i.e. a fifth reservoir is used in the Mur and Enns flood forecasting systems. This allows a better reproduction of long recession limbs and a good simulation of the overall water balance over the calibration period (Fig 1, right side). Although the parameters are lumped, rainfall, air temperature as well as snow fall and snow melt are distributed using an altitudinal gradient and altitudinal zones.

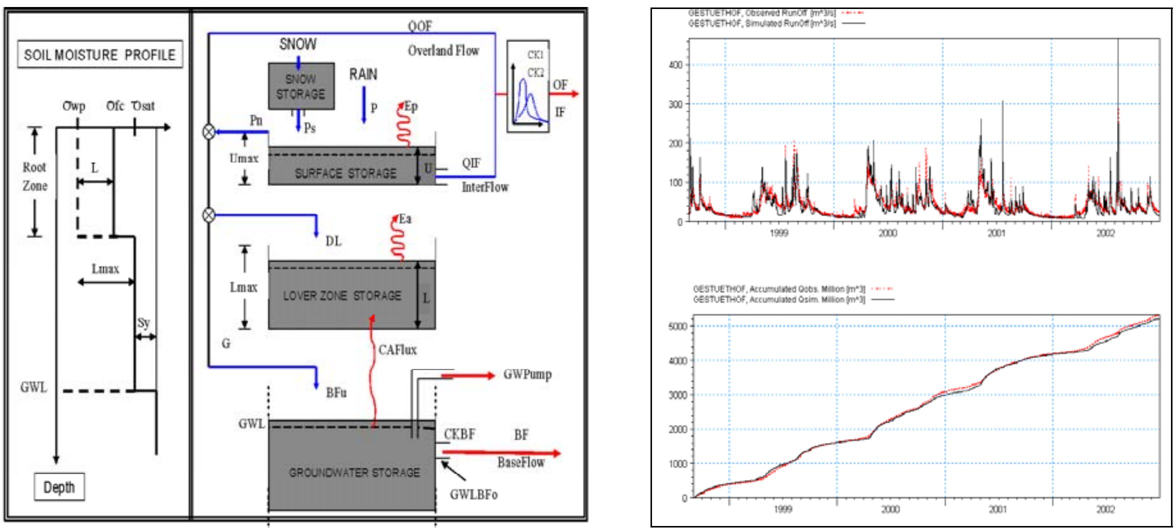

Fig 1:

The low flow forecasting system will focus much more on simulation results at the sub-catchment scale as the flood forecasting system. For the latter an automatic data assimilation procedure is implemented at the Mur gauging stations and error correction is distributed over the forecasted 2 days using an exponential decay. Because forecasts are further initiated automatically each hour it can be said that simulations errors made at the sub-catchment scale are of relative minor importance. The situation is quite different for the low flow forecasting since the forecast period will be largely augmented and the simulations should run only once a day. This means that data assimilation can only play a minor role on the simulation quality at the Mur gauging stations.

It is known that hydro-meteorological data vary significantly in mountainous area. A special challenge in this respect will concern the regionalisation of potential evapotranspiration values that is decisive for the low flow simulation. A difficulty of similar amplitude will be the correct simulation of the snow pack dynamic that influence dramatically the low flow pattern. Because water retained in the snow reservoir can’t participate to the catchment water cycle the simulation of snow related processes directly influences the recharge and outflow of the groundwater reservoirs.

It can therefore be postulated that the Mur low flow forecasting system as it is conceived will be much more challenging from the hydrological point of view as the actual Mur flood forecasting system. On the other hand, the latter system is technically more demanding including for example automatic simulations and results transfer from Austria to Slovenia or the maintenance and update of three independent simulation engines (two in Austria, one in Slovenia). At least, a better comprehension and simulation of hydrological processes at the sub-catchment scale will enable to produce enhanced flood forecasts in the Mur watershed. This low flow forecasting system will therefore permit to increase the overall water management quality for the Mur River and its tributaries.

Comparison between low flow periods 1992 and 1993 with 2003 and 2004

In 1992 and 1993 as well as in 2003 and 2004 two extreme low flow periods occurred in Styria. In different graphs some comparisons are shown between these two periods and long term minimum, maximum and mean values for five flow gauges and rainfall stations in the whole Styria (Fig. 2):

- Hydrographs based on daily runoff
- Monthly runoff
- Monthly precipitation

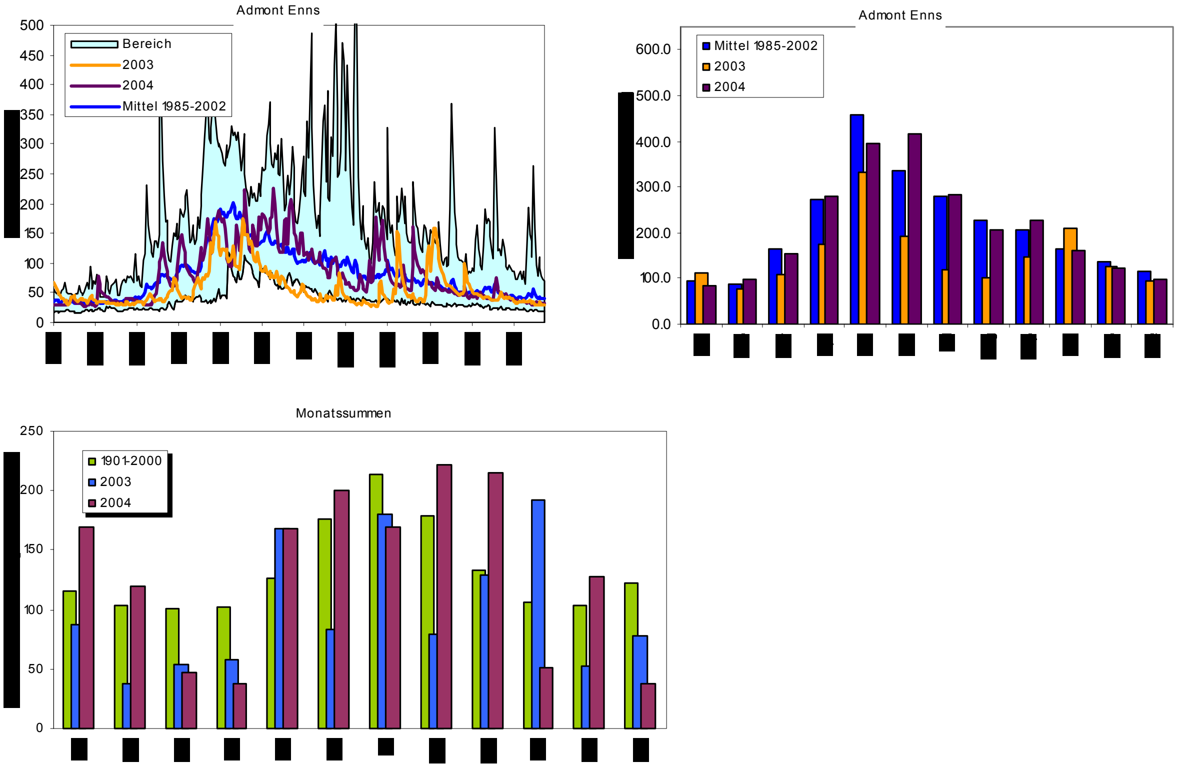

Fig. 2

SEASONAL STATISTICAL FORECAST OF LOW FLOW AND DROUGHT IN THE RIVER RHINE BASIN

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Introduction

Providing cooling water for power plants is an important function of the Rhine River. This function is threatened in dry and hot summer periods, when conflicts arise between enforcing environment-protecting standards and economical risk. Early warning for high water temperatures and low flows would give stakeholders time to anticipate crisis situations. This research investigated the feasibility of early warning on a seasonal timescale using statistically based forecast methods with large scale oceanic and atmospheric patterns as predictors.

Recent studies (e.g. Johansson *et al.* (1998), Colman and Davey (1999), Wedgbrow *et al.* (2002), Wilby *et al.*, (2004)) addressed possibilities for drought forecasting in Europe with statistically-based models that use winter large scale oceanic and atmospheric patterns as predictors. The rationale behind this predictor choice is that the slow timescale of variation in the large-scale oceanic and atmospheric circulation systems would make these good predictors for seasonal forecasts.

The purpose of this research is to assess the skill of winter large-scale atmospheric and oceanic patterns in forecasting Rhine summer cooling water problems. The range of possible applications of such seasonal forecasts is of course wider than for this cooling water issue alone. Also the shipping, agricultural and the recreational sector could benefit from seasonal low flow and heat wave forecasts.

Material and methods

As response parameters, summer water temperatures and discharges at Lobith, at the German-Dutch border, were used. High water temperature (and to a lesser extend low flow) at Lobith is a strong indicator for cooling water problems along all inland waterways in the Netherlands. The predictors are winter sea surface temperatures (SST), 500 hPa geopotential heights and several indices that describe important modes of variability in these fields (e.g. North Atlantic Oscillation (NAO)).

The analysis was performed in four stages. First, trends in the time series of wintertime predictors and summertime responses were removed. Second, the single and multiple correlations between the responses and predictors were calculated and the stability of the found correlations was evaluated. Skilful predictors were identified. Third, model predictor selection, calibration and testing were performed in a ‘pseudo-operational’ context. Last, the deterministic model predictions were translated to probabilistic forecasts for stakeholders using the bi-variate probability density estimates of historical forecast and measurements and Bayes’ rule.

Results

Significant, but moderate, correlations between winter large scale oceanic and atmospheric patterns and summer hydrometeorology in the Rhine Basin were found. Multiple linear regression models using the North Atlantic Oscillation Index were derived and tested in a pseudo-operational context. Model performance in terms of correlation coefficients ranged from 0.23 (July water temperatures) to 0.54 (August water temperatures).

Correlations for lag times up to five years were found to be significant and to improve results of multiple correlations and the regression forecast models. This suggests that the summer Rhine water temperatures and discharges are subjected to multiyear variability next to year-to-year variability. The correlations show instable behaviour. For the field data this instability is manifested as changes in the correlation patterns over time for example from dominant correlation centres over the Pacific Ocean to dominant correlation centres over the Atlantic Ocean.

Discussion and conclusion

The main limitations of this research concern the predictor selection and the use of a linear regression model. Only indicators of moisture and heat supply from the oceans to the continent were used as predictors. Information about the water storage on the continent like winter soil moisture and snow accumulation may increase forecast skill. A linear regression model was used although the results indicate non-linearity in the predictor-response relationships.

Yet, because models perform better than the climatic trend, the forecast can be informative to stakeholders. Translation of the deterministic model output to a probabilistic forecast is important to communicate uncertainties to these stakeholders and can for example be done with the Bayesian method used in this research. Stakeholders would benefit most from an operational forecast system on seasonal to daily timescales, combining various forecast techniques. An option is to set up operational drought forecasting similar to the existing flood forecasting system of the Rhine River (FEWS, Werner *et al.*, (2005)).

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IMPACT OF CLIMATE CHANGE ON LOW FLOWS IN THE RIVER MEUSE

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In this study observed precipitation, temperature, and discharge records from the Meuse basin for the period 1911-2003 are analysed. The primary aim is to establish which meteorological conditions generate (critical) low-flows of the Meuse. This is achieved by examining the relationships between observed seasonal precipitation and temperature anomalies, and low-flow indices. Secondly, the possible impact of climate change on the (joint) occurrence of these low-flow generating meteorological conditions is addressed. This is based on the outcomes of recently reported RCM climate simulations for Europe given a scenario with increased atmospheric greenhouse-gas concentrations. The observed record (1911-2003) hints at the importance of multi-seasonal droughts in the generation of critical low-flows of the river Meuse. The RCM simulations point to a future with wetter winters and drier summers in Northwest Europe. No increase in the likelihood of multi-seasonal droughts is simulated. However, the RCM scenario runs produce multi-seasonal precipitation and temperature anomalies that are out of the range of the observed record for the period 1911-2003. The impact of climate change on low-flows has also been simulated with a hydrological model. This simulation indicates that climate change will lead to a decrease in the average discharge of the Meuse during the low-flow season. However, the model has difficulties to simulate critical low-flow conditions of the Meuse.

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WATER QUALITY OF THE RHINE RIVER DURING SUMMER DROUGHTS

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Introduction

It is generally recognized that climate change will affect the discharge regime of the Rhine River. The anticipated increase in extreme river discharges (floods and droughts) poses serious problems to water management, both with regard to water quantity and water quality. Water quality effects of extreme river discharges are not sufficiently recognized, however. The purpose of this study was to investigate the impact of low flows on the water quality of the Rhine. Time series of river flow and water quality were analyzed for station Lobith for the droughts of 1976 and 2003, and their reference periods (1975-1977 and 2002-2004, respectively). Due to the short time span between the reference periods and each drought year, it can be assumed that other changes in the catchment which would influence water quality (e.g. changes in land use, emission reduction) are negligible. A summary of the river flow characteristics during the study periods is presented in Table 1. The droughts started in May (1976) or June (2003) and extended far into autumn (October-November). Three groups of water quality parameters were investigated: general variables (water temperature, dissolved oxygen, chlorophyll-a), chloride and nutrients. All data were retrieved from the water quality monitoring programme of the Netherlands (www.waterbase.nl).

Table 1: River discharge at Lobith during the drought years 1976 and 2003 and their reference periods

Year	**Q-min (m^3/s)**	**Q-max (m^3/s)**	**Q-avg (m^3/s)**	**n< 1000 m^3/s**	**n < 900 m^3/s**	**n < 800 m^3/s**
1975	972	5341	2170	3	0	0
1976	782	3459	1333	76	28	3
1977	1056	6279	2208	0	0	0
2002	1385	7958	2974	0	0	0
2003	788	9372	1821	48	16	5
2004	1164	6632	1890	0	0	0

n = number of days with Q < indicated value

Results

Water temperature

A comparison between the water temperature during the summer months (JJA) for the years of drought and their reference years is made in Table 2. The water temperatures during the (hot) summers of 1976 and 2003 are clearly higher than those in the reference years (on average by 1.4-1.8 °C in 1976 and 1.4-1.6 °C in 2003). It should also be noted that the water temperature of the Rhine has increased significantly during the past three decades. Comparing the periods 1975-1977 to 2002-2004, it can be concluded that the average water temperature at Lobith during the summer has increased by 1.7 °C, possibly reflecting an increasing use of the river water for cooling purposes. This increase in water temperature is of major importance as it affects the river capacity to deal with the impacts of climate change. Thus, in the summer of 2003 water temperatures often exceeded the ecological threshold of 25 °C, whilst in the summer of 1976 this was seldom the case (Table 2). Moreover, the maximum water temperature in 2003 (27.5 °C) was much higher than that in 1976 (25.2 °C). Obviously, the capacity of the river system to cope with the effects of increasing air temperatures has decreased significantly over the past three decades.

Table 2: Water temperature at Lobith during the summer of 1976 and 2003, and their reference periods

Summer (JJA)	n	n > 25 °C	T-min (°C)	T-max (°C)	T-avg (°C)
1975	92	0	14.9	23.8	20.1
1976	92	4	16.3	25.2	21.5
1977	92	0	16.4	22.8	19.7
2002	92	0	18.7	24.3	21.7
2003	92	18	18.9	27.5	23.1
2004	91	1	18.3	25.9	21.5

n > 25 °C = number of measurements with T > 25 ˚C

Dissolved oxygen

A comparison of dissolved oxygen in the Rhine during the summer months (JJA) of 1976 and 2003 and their reference periods is made in Table 3. One would expect a negative impact of droughts on dissolved oxygen, due to the low river discharge (less dilution capacity) and high water temperatures (increasing the degradation of organic matter). However, such a negative impact could not be established, which is probably related to an increase in primary production (Table 4), which introduces additional oxygen into the water.

Table 3: Dissolved oxygen concentration at Lobith during the summer of 1976 and 2003, and their reference periods

Summer (JJA)	n	O_2-min (mg/l)	O_2-max (mg/l)	O_2-avg (mg/l)
1975	13	4.5	7.5	5.83
1976	14	4.2	7.4	5.55
1977	13	4.2	7.8	5.85
2002	6	7.8	9.0	8.43
2003	6	7.1	9.7	8.63
2004	6	7.6	9.1	8.38

Figure 1 shows the relation between water temperature and dissolved oxygen for the Rhine. A linear relation is found, reflecting the temperature dependency of dissolved oxygen solubility. Positive deviations of data points can be seen at higher water temperatures, which probably reflect the impact of primary production (algae growth). We can use this regression line to estimate the impact of increasing water temperatures on the dissolved oxygen concentration. Using the maximum water temperature observed during the summer drought of 2003 (27.5 °C), the corresponding dissolved oxygen concentration is calculated to be 7.6 mg/l. For an extreme water temperature of 30 °C, the dissolved oxygen concentration is estimated to be 7.1 mg/l, which is still far above the ecological threshold of 5 mg/l. Therefore, it can be concluded that increasing water temperatures are unlikely to become a serious threat to the dissolved oxygen concentration of the Rhine in the future (under the current emissions of BOD).

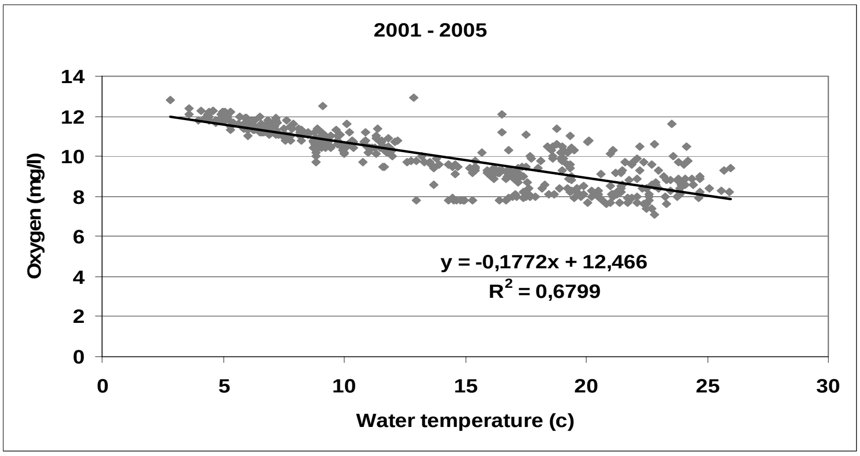

Figure 1: Influence of water temperature on dissolved oxygen concentration at Lobith (data 2001-2005).

Chlorophyll-a

The concentration of chlorophyll-a (reflecting the amount of algae in the river water) is generally high during the spring and the summer and low in autumn and winter. It should be noted that the current concentration of algae in the river water is much lower than that three decades ago, due to a major reduction of the nutrient load of the Rhine which started in the seventies and proceeded through the years. The chlorophyll-a concentration during the study period is shown in Table 4, showing higher concentrations during the summers of 1976 and 2003 compared to the reference years. On the other hand, effects of summer droughts could not be demonstrated for nitrate or phosphate, neither in 1976, nor in 2003 (not shown). Therefore, it can be concluded that water temperature is the primary driver of the algae blooms observed during the summer droughts of 1976 and 2003. However, the extent of the algae bloom does depend on the nutrient status of the river (cf. the chlorophyll-a levels in 1976 and 2003).

Table 4: Chlorophyll-a concentration at Lobith during the summer of 1976 and 2003, and their reference periods

Summer (JJA)	n	Chl. A-min (µg/l)	Chl. a-max (µg/l)	Chl. a-avg (µg/l)
1975	9	13	54	31
1976	13	26	151	88
1977	12	18	98	54
2002	6	2	30	15
2003	6	3	40	26
2004	6	5	18	11

Chloride and other salts

The impact of droughts on water quality is obvious for chloride and sulfate (Table 5), but also for minor elements such as fluoride and bromide (not shown). This is not surprising since these elements are largely non-reactive in river water. For non-reactive substances, the concentration depends on human input, background concentration and the river discharge, according to:

$$C = \frac{a}{Q} + b$$

in which C = the concentration (mg/l); Q = discharge (m^3/s); a = human input (g/s) and b = background concentration (mg/l). An example of the relation between river discharge and the concentration of chloride is given in Figure 2 (similar graphs are obtained for sulfate, fluoride and bromide). High concentrations are observed during low river discharges (i.e. droughts), due to the limited dilution of the load discharged by point sources. During the 2003-drought, the maximum chloride concentration recorded in the river water was 184 mg/l, which is close to the threshold value of 200 mg/l for drinking water production. If droughts are to occur more often and more serious in the future, chloride may (again) pose a threat to drinking water production in the Rhine River.

Table 5: Concentration of chloride (Cl) and sulfate (SO_4) during the summer droughts of 1976 and 2003 and their reference periods

Summer (JJAS)	n	Cl-avg (mg/l)	Cl-max (mg/l)	n	SO_4-avg (mg/l)	SO_4-max (mg/l)
1975	17	142	168	15	57	74
1976	18	233	315	18	92	108
1977	18	161	222	18	65	80
2002	119	89	123	8	56	66
2003	122	125	184*	8	72	85
2004	121	92	117	9	61	74

* value recorded on 2 October 2003

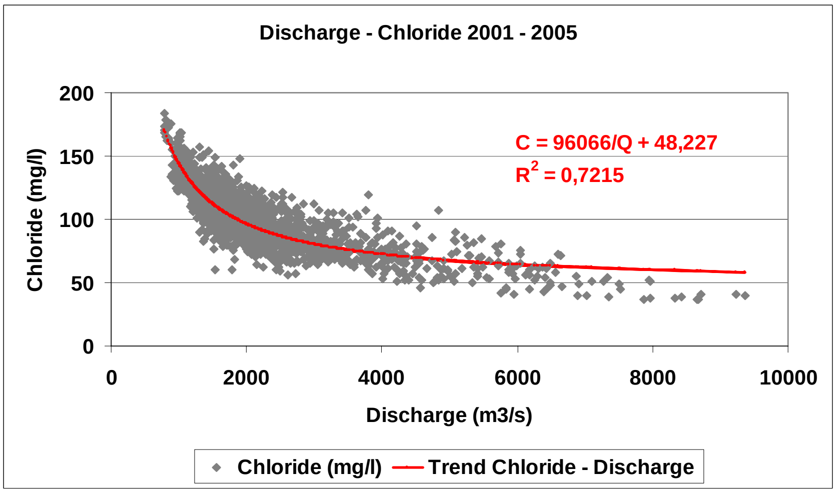

Figure 2: Influence of river discharge on the chloride concentration at Lobith (data 2001-2005).

Conclusion

The water quality of the Rhine River is negatively influenced by (summer) droughts, with respect to water temperature, eutrophication, chloride and other salts. The decline in water quality during summer droughts is both related to the high water temperatures and to low river discharges (limited dilution of the chemical load from point sources). Current practices in water management should recognize the fact that water quality is most vulnerable during summer droughts. For instance, permits for waste water emission should be based on realistic worst case conditions of the receiving water (low river flows, high water temperatures), so as to ensure effective protection of the aquatic ecosystem and the functions assigned to the river (e.g. drinking water production).

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