CHR WORKSHOP- EXPERT DISCUSSION

ON CLIMATE CHANGE AND ITS IMPACT ON HYDROLOGY AND WATER MANAGEMENT IN THE RHINE BASIN

24th and 25th JUNE 2003
De Reehorst, EDE
The Netherlands

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PROGRAMME CHR Workshop – Expert Discussion on Climate Change and its Impact on Hydrology and Water Management in the Rhine basin

24th June 2003

Registration - with lunch- from 11.00 am.

13.00 : Welcome by Prof. Dr. Manfred Spreafico – President of the CHR
13.10 : Introduction and goals of the workshop by Dipl. Met. Peter Krahe

Theme block I - Observed variability in climatological and hydrological data

Chairman: Dr. Laurent Pfister
13.30 : European Climate Assessment project and possible role of the CHR (Albert Klein Tank)
14:00 : Extreme hydrological events monitoring using Earth Observation data (Stephen Clandillon)
14.30 : Coffee and tea break
15.00 : Changes in the extreme discharge of the Meuse river over the past century (Tu Min)
15.30 : Streamflow trends in Switzerland (Paolo Burlando)
16.00 : CHR-Project: Developments in the flow regime of the river Rhine (Jörg Uwe Belz)
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Chairman: Dr. Christoph Ritz
17.30 : Regional climate modelling for the Rhine basin (Bart van den Hurk)
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18.30 : Discussion

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25th June 2003

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08.30: Impact of tropical and extratropical climate modes on the North Atlantic/European climate (Mojib Latif)
09.00 : Climate change and runoff from processes to scenarios (Christoph Schär)
09.30 : Precipitation distribution and its variability in the Elbe and Rhine drainage basins under current and future climate conditions (Daniela Jacob and Katharina Bülow)
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10.30 : Precipitation frequency and intensity under global warming scenarios (Gerd Bürger)
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Theme block III – Discharge regimes and hydrological extremes – What do the models predict?

Chairman: ir. Hendrik Buiteveld
11.30 : Impact of climate change on floods and the runoff regime in Rhine basin (Erwin Zehe)
12.00 : Lunch
13.00 : Impacts of climate change on flooding in the river Meuse (Martijn Booij)
13.30 : Estimation of future flows of the river Rhine in the SWURVE project (Geert Lenderink)
14.00 : Climate change and runoff statistics: a process study for the Rhine basin using a coupled climate-runoff-model (Jan Kleinn)
14.30 : Coffee and tea break
15.00 : Final discussion, summary and conclusions of the workshop
16.00 : Closing of the workshop

THEME I

Observed variability in climatological and hydrological data

Chairman: Dr. Laurent Pfister

European Climate Assessment and possible role of the CHR

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Diagnosis of observed climate variability and change in e.g. rainfall is of vital importance for future water resources management. In particular, detailed information is needed on the supposed increase in the incidence of extremes accompanying the 'global warming' of the last decades. In this paper, an overview will be given of the present state of research on recent trends in observations of climate extremes for Europe and the world. The overview will be based on the results of the European Climate Assessment & Dataset project, which started in 1998 and continues until 2006. Within ECA&D climate extremes are defined on the basis of WMO-CCL and CLIVAR proposed indices derived from daily data at meteorological stations. The indices focus on phenomena that occur (on average) several times a year, rather than solely on the extreme events that cause the major impacts. This choice is motivated by the fact that the detection probability of a trend depends on the return period of an event and the length of the observational series. In order to be able to draw conclusions for changes in extremes using daily series with typical length only ~50 years, the optimal return period is 10-30 days rather than 10-30 years. Most of the indices refer to counts of days crossing a threshold. Standardisation in the calculation of each index enables comparisons between results for Europe and elsewhere (see IPCC-TAR, 2001). As the selected thresholds are often outside hazardous levels, the observed changes in hydrology-relevant indices must be regarded as indicative of changes in those rare events that do cause the major floods. The possibilities for co-operation with CHR-parties in order to study the Rhine basin in more detail will be illustrated with an example of variability and change in the index: 'highest 5-day precipitation amounts'.

Acknowledgement:
ECA&D-participants from 37 countries in Europe and the Mediterranean
See also: http://www.knmi.nl/samenw/eca

Extreme hydrological events monitoring using Earth Observation data

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Flooding is one of the most devastating natural hazards on the Earth's surface. It causes damage each year to cities, roads and agricultural land and crops with a high human and economic cost. In Europe, floods are the most frequent type of natural disaster and involve 75% of all insurance claims due natural disasters. The indirect economic and social effects, less easily discernable, highlight the gravity of this type of natural hazard and the importance of taking steps to alleviate the effects and associated risks.

Space techniques such as geo-positioning, telecommunications, and especially earth observation can contribute to improve flood management. Space-derived information can be a valuable source of up-to-date geo-information for flood risk mapping (prevention), for flood forecasting (preparedness phase) and for the crisis and post-crisis phases dealing with flood extent mapping and damage assessment. This is particularly the case for Plain-Floods, the most frequently observed flood type to be observed depending on their duration and extent. EO missions (SPOT 1-5, Envisat, ERS, Radarsat, …) can play a key role in natural risk management. While this is true for optical data, it is theoretically even greater for the all-weather and space-borne SAR missions which allow the provision of timely geo-information over regions affected by natural disasters in spite of the weather.

Furthermore, the combination within a GIS of the EO based flood map extent with optical HR or VHR EO data (SPOT 5, Ikonos, …) is of great interest. These reference images describe the initial land use state, under normal hydrological conditions, and they can be used for vulnerability assessment during the prevention phase and provide flood impact information for flood damage assessment. Furthermore, the flood extent and land use information can enable a flood risk zonal mapping which are of interest to the Civil Protection Authorities (and their related services in charge of the flood prevention phase), water basin management bodies and the insurance sector.

Through client interviews and various types of feedback the main user demands are those of improved spatial resolution, in which EO improvements are being noted, enhanced temporal resolution, with more than one acquisition per day and improved data delivery schedules, with 12 hours acquisition to flood extent map delivery being the current standard. The Civil Protection Authorities and Watershed Authorities would prefer 3-6 hours delivery times.

Reference data bases and their implementation is an ongoing issue, because if the reference data bases are already in place the processing cycle simplifies with consequent time savings. Hence, one of the major domain where energy is being invested is in the setting up of agreements for the sourcing and implementation of reference databases for areas of high potential flood risk.

Changes in the extreme discharge of the Meuse river over the past century

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Recent floods in the Meuse river have increased the public concern about the risk of flooding and also raised the question as to whether the magnitude and frequency of floods have changed during the past century. This motivates the need to analyse the observed discharge and precipitation records in the Meuse basin.

Long daily records (>1911) of discharge at Borgharen/Monsin and precipitation in the upstream basin (about 21,000 km^2) have been tested by non-parametric and parametric methods for detection of non-homogeneity. The k-day (k=1, 3, 5, 7, 10, 15, 30) annual (November to October) and seasonal (November to April for winter and May to October for summer) peak discharges and antecedent precipitation depths for the winter peak were investigated. Spearman's rank correlation was applied to evaluate the absence of linear trend in the time series. Then, change-point analysis was performed by the Pettitt test and the SNHT test. Runoff coefficients were calculated for the different k days and also tested.

No significant trend was found for both the annual and seasonal k-day peak discharge over the past century. Significant change-points were found in the year 1983 for the annual and winter k-day peak discharges (k=1, 3). No significant change-point was detected for the summer k-day peak discharge. Antecedent k-day precipitation depths for the winter peak (k=3, 5, 7, 10) in the basin also showed a significant change-point in 1983. After 1983, these k-day peak discharges and precipitation depths have increased. Strong correlation coefficients were found for the antecedent 5-day to 15-day precipitation depths and the winter peak discharge. No significant change-point was detected for the runoff coefficients.

The results of the statistical analyses show that the increase of the annual and winter k-day (k=1, 3) peak discharges in the Meuse river after 1983 can be explained by an increase of the antecedent precipitation depth. This implies that the relative large frequency and magnitude of floods in the Meuse basin over the last two decades can largely be addressed to climatic variability.

Streamflow trends in Switzerland

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Mean daily streamflow records from undisturbed watersheds in Switzerland were analysed for trends using a nonparametric test in three study periods (1931-2000, 1961-2000, 1971-2000). Identified trends in streamflow were related to observed changes in precipitation and temperature, and correlated with watershed attributes. Based on seasonal analyses of shifts in the daily streamflow distributions, evidences of changes of the natural streamflow regime in Switzerland since 1961 were found. The main changes consist of an increase in annual runoff due to increases in the winter and spring season runoff, an increase in winter maximum streamflow (at about 60-70% of the stations) and spring moderate and low flow. No coherent spatial structure in streamflow trends was observed. Changes in precipitation and temperature, exhibiting a general warming trend with a substantial increase in the number of days with minimum daily temperatures above 0°C which is concentrated in the winter and spring, can explain some of the observed increase in streamflow in those seasons. Correlation analyses revealed a strong relationship between streamflow trends and mean basin elevation, glacier and rock coverage (positive), and basin mean soil depth (negative). These relationships suggest that, as intuitively expected, mountain basins are among the most vulnerable environments from the point of view of streamflow change.

CHR Project: Developments in the Flow Regime of the River Rhine

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The present project is an attempt to identify possible changes in the flow regimes of the River Rhine and its tributaries during the 20th century, especially those of anthropogenic origin, and to quantify them if possible. The project is embedded in a broader context through the project "Der Rhein unter dem Einfluß des Menschen" (eng.: "River Rhine under the impact of man") that was implemented in the 1990s with its results published as *KHR-Bericht I-11*.

The study focuses on long time series of discharge data from the beginning of 1901 onwards. Additionally, the streamflow developments must be checked by means of climatic data series. The flow data originate from representative gauging stations all over the catchment. Basically, the approach is a classical hydrological one, based on statistical analyses of gauged primary values, closely linked with their interpretation by hydrological experts. The outcome of the project will be summarized in a *KHR*-report. This will be the first hydrological synopsis of the developments in streamflow throughout the whole Rhine basin during the 20th century. Moreover, it is expected that new information will be acquired about the course of natural and anthropogenically impacted hydrometeorological processes in the basin, what will be beneficial last but not least for improvements in river-basin modelling.

At present the project is in the stage of the so-called pre-studies, which should select the best-suited parameters and analytical methods for the subsequent in-depth investigations. Simultaneously, the needed long series of hydrological and meteorological data will be acquired and prepared. Positive side-effects of the project, which will remain valid even if the identification and quantification of streamflow changes might fail, are new substantiated arguments for the question which methods of classical statistics can be successfully employed in this matter and the establishment of a comprehensive data pool of long hydrological and climatological series.

THEME II

The creation and interpretation of climate scenarios

Chairman: Dr. Christoph Ritz

Regional Climate Modelling for the Rhine Basin

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Both statistical and dynamical downscaling methods are being used to construct climate scenarios affecting the discharge characteristics of the Rhine river. The scenarios based on statistical downscaling give rise to increased average precipitation in winter and only modest changes in summer. However, various regional climate modelling studies have shown significant summer drying and smaller changes to the average winter precipitation.

KNMI has geared up a regional climate model (RACMO) for scenario calculation and sensitivity analyses. In the context of the PRUDENCE project GCM output from the HadAM3 model for a control and SRES A2 climate are used for driving RACMO. First results of these RACMO calculations will be shown. The focus of the presentation will be on the sensitivity of the RACMO precipitation to various components in the modelling system, and on the verification of spatial and temporal variability of precipitation in the Rhine basin guided by ECA and CHR-observations. Final remarks will be made on future directions of coupled atmosphere-hydrology modelling.

Coupled catchment-based meteorologic and hydrologic data reconstruction - why, how and what for

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Data reconstruction or reanalaysis is of prime importance in the earth sciences. The objective of a coupled catchment-based reanalysis (CCR) is to create a long-term set of consistent hydro-meteorologic data for a given catchment. A CCR integrates point-based hydrologic and meteorologic observations with satellite observations and discharge records through a dynamic model. It does so by not only interpolating between observation points but also adjusting observations where needed, so that the entire system is physically consistent. One of the expectations is that a CCR will help answering questions about the variability of water in both the atmosphere and at the land surface, in particular as it concerns the hydrology of European catchments. To that end, a CCR will have to output all time-integrated quantities of water and energy budgets for a common grid. By definition a CCR will provide a good handle to analyse extreme events, such as floods and droughts.

A CCR can be realized by linking a meso-scale climate model with a land-surface and a hydrologic routing model and using data-assimilation techniques to integrate observations with these models. One-directional linkages are possible (e.g. without feedback from land-surface to the climate model), but more realistic are schemes where the feed-back from the land-surface model to the climate model is included.

Examples of some existing CCR's are given, ongoing efforts are listed and plans for future work are discussed.

Impact of tropical and extratropical climate modes on the North Atlantic/European climate

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Several tropical and extratropical climate modes affect the North Atlantic/European climate. Among the two most important modes are the El Nino/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). Both modes have strong impacts on European climate. Anthropgenic climate change is likely to affect both the statisctics of ENSO and the NAO. The stabillity of the North Atlantic Thermohaline Circulation (THC) needs to be considered also in this context.

Climate Change and Runoff: From Processes to Scenarios

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The response of the continental and sub-continental-scale water cycle to global climate change involves a wide range of physical processes. For the construction of climate change scenarios, it is essential to isolate the relevant key processes and appropriately represent the underlying nonlinearities. In this presentation, some of the processes relating to cold-season precipitation and runoff in the Rhine catchment will be discussed and assessed.

The role of the Alps is highly essential for precipitation and runoff in the Rhine catchment. The key factors affecting orographic precipitation relate to the synoptic-scale flow impinging upon the Alps, the associated atmospheric moisture content (that is expected to increase in a warmer climate approximately with the Clausius-Clapeyron relationship), and cloud-microphysical processes (that might experience a shift from cold to warm microphysics). It will be demonstrated that current interannual variations of orographic precipitation are primarily controlled by the variability of the synoptic-scale flow, thus representing at first approximation an essentially linear sensitivity. In particular, changes in the past century appear to be driven to some extent by large-scale changes in synoptic-scale circulation (related to the North-Atlantic Oscillation and related circulation patterns). In relation to climate change, however, a scale analyses demonstrate that a pronounced warming might imply a shift in sensitivity towards the atmospheric moisture content and cloud microphysical processes. These considerations suggest that the frequency of heavy precipitation events is likely to increase during the colder seasons.

In terms of runoff formation, the expected (and observed) increase of the snow line is of key importance. It promotes a transition from snowmelt to precipitation-driven runoff regimes. It is demonstrated how a hypsometric terrain analysis can help to assess the relevance of this factor during the different seasons.

The nonlinearities discussed above need to be properly accounted for when constructing climate change scenarios. This appears particularly difficult in the framework of statistical downscaling methodologies, but it also represents a major challenge to global climate modeling and numerical downscaling studies.

Precipitation distribution and its variability in the Elbe and Rhine drainage basins under current and future climate conditions

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The regional climate model REMO was used to study the hydrological cycle within two drainage basins (Elbe, Rhine). To address the reliability of climate change studies, it is important to analyse a set of three regional simulations: for today's climate, control and future climate. The validation of the regional simulation for today's climate against observations shows the reliability of model results. With a double nesting dynamical downscaling procedure using the global climate model ECHAM4/OPYC3 on T42 horizontal resolution as lateral driving fields for REMO on 0.5° horizontal resolution and consequently the achieved results to drive the model on 0.16° resolution, detailed information about possible regional climate change for the future is produced.

To investigate the influence of climate change on the hydrological cycle, concentrations of greenhouse gases and sulfate aerosol are chosen according to IPCC (International Panel on Climate Change) scenario B2. Comparing the control period 1970-99 to the 3 decades between 2020-49, a clear increase of surface temperature, especially during the first half of the year can be found. This leads to a higher annual mean temperature. The contribution of high intensity precipitation events (higher 5 mm/day) to total precipitation sums is expected to increase during the first half of the 21st century. Correspondingly the contribution of low intensity events decreases.

Looking at the annual horizontal precipitation distribution different results are found. For example in most parts of the Elbe river basin mean annual precipitation is expected to increase, highest changes occur in the south-eastern parts of the basin with changes of more than 25%. This is most pronounced during the period of 2030-39. Annual precipitation sums in the north western parts of the basin will remain stable or might even decrease in some areas by up to 15%. In the north eastern part of the Danube drainage basin precipitation will increase and during the period 2030-39 the highest changes with 25 % are found.

Precipitation frequency and intensity under global warming scenarios

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We present results from various simulations of two GCMs (ECHAM4/OPYC3, HadCM3) as downscaled to daily precipitation of several sites in Germany. We analyze the significance of the induced changes, focusing on statistics such as sum, frequency and intensity of daily precipitation.

To derive the daily scenarios, we use the 'expanded downscaling' (EDS) model that has been applied in several previous studies on the impact of climatic change on hydrology. In short, EDS relates global and local daily covariances by optimizing a modified regression principle under constraints. The model is calibrated and validated using daily NCEP analyses.

Our main conclusions are:

A) Atmospheric moisture is a crucial predictor
   – for the simulation of extreme local events from analyses
   – for the derivation of precipitation scenarios from GCMs.

B) Precipitation sum is a bad indicator of climatic change.

C) Frequency and intensity show signals of opposite sign.

The statistics of extreme events is most clearly unveiled using the cumulative distribution functions of all relevant scenarios. It turns out that despite considerable model error and immense natural fluctuation (as simulated by a downscaled, long-year control simulation) of daily precipitation, a significant increase in heavy precipitation is projected, especially for the summer season.

THEME III

Discharge regimes and hydrological extremes - What do the models predict?

Chairman: ir. Hendrik Buiteveld

Impact of climate change on floods and the runoff regime in Rhine basin

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The overall goal of this model study is to quantify the hydrological impact of a double CO_2 scenario for the entire German part of the Rhine basin, based on the corresponding simulation results of the GCM ECHAM 4. Currently, GCM-models may simulate realistic fields of meteorological state variables, especially air pressure, but they may not simulate precipitation data suitable for distributed hydrological modelling purposes, due to their coarse spatial resolution and poor representation of precipitation relevant processes on that scale. To overstep this hurdle we statistically generated rainfall and temperature fields conditioned to the simulated pressure data in two steps. First we optimised a set of fuzzy rules for classification of pressure fields into circulation patterns, to explain the basin scale space-time variability of observed rainfall and temperature. For the optimisation we used rainfall data from selected stations in the Rhine basin to define the objective function as well as observed NMC pressure data. Given the optimised fuzzy rules for CP classification the simulated pressure fields from the double CO_2 scenario were classified into a daily sequence of CPs, that served as input for a stochastical generation of rainfall and temperature fields. Rainfall was linked to the individual CPs using conditional probabilities, that are a function of season and location. Temperature was modelled using an autoregressive approach, conditioned on atmospheric circulation and local point or areal precipitation.

These generated rainfall and temperature fields served as input data for a simulation of the hydrological cycle in the Rhine basin for a period of 30 years using the HBV-model. The model was calibrated to the actual climate using observed rainfall and temperature data from 949 stations as well as discharge data from 100 gauges in the Rhine basin. By comparing the simulated hydrological cycle based on the CO_2 scenario to the corresponding observations of the last 30 year, the possible impact of a climate change could be quantified. Due to a clear rise of the average daily temperature in the winter season, the amount of snow coverage in the Rhine basin was clearly reduced. Furthermore, the occurrence of CPs with a high precipitation probability was reduced in the scenario, shifting the precipitation regime to more arid conditions These changes in the temperature and precipitation regime did clearly affect the average discharge regime as well as the amount and magnitude of flood events in the Rhine basin.

Impacts of climate change on flooding in the river Meuse

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The impact of climate change on flooding in the river Meuse is assessed on a daily basis using spatially and temporally changed climate patterns and three constructed hydrological models. This is achieved by selecting a hydrological modelling framework and implementing appropriate model components (processes, spatial and temporal scales, formulations) into the selected framework (HBV). Additionally, two river basin models of differing complexities are set up to evaluate the sensitivity of the model results to model complexity and to allow for a verification of the model appropriateness procedure. Generations of a stochastic precipitation model under current and changed climate conditions have been used to assess the climate change impacts.

The average and extreme discharge behaviour at the basin outlet is well reproduced by the three models in the calibration and validation, the results become somewhat better with increasing model complexity. The model results with synthetic precipitation under current climate conditions show a small overestimation of average discharge behaviour and a considerable underestimation of extreme discharge behaviour. The underestimation of extreme discharges is caused by the small-scale character of the observed precipitation input at the sub-basin scale. The general trend with climate change is a small decrease of the average discharge and a small increase of discharge variability and extreme discharges. The variability in extreme discharges for climate change conditions increases with respect to the simulations for current climate conditions. This variability results both from the stochasticity of the precipitation process and the differences between the climate models. The total uncertainty in river flooding with climate change (over 40 %) is much larger than the change with respect to current climate conditions (less than 10 %). However, climate changes are systematic changes rather than random changes and thus the large uncertainty range will be shifted to another level.

Estimation of future flows of the River Rhine in the SWURVE project

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Output of the Hadley Center regional climate model has been used with the hydrological model RhineFlow in order to obtain estimates of the discharge of the River Rhine in present and future climate. These estimates are made as part of the European project SWURVE. Previously in SWURVE, estimates of the future Rhine discharge have been made by forcing RhineFlow with present day climate data modified with the change between present and future climate in the Hadley Center runs. Presently, it is attempted to force RhineFlow directly with the Hadley Center HadRM3 model output. The HadRM3 data consists of 3 times 30 years of the present day climate (1960-1989) and 3 times 30 years of future climate (2070-2099, with the SRES A2 emission scenario).

The presentation will emphasize the potential gains and the problems associated with the direct forcing approach. It turns out that, using the HadRM3 output without any bias correction, the mean and the extremes of the discharge of the Rhine at Lobith (the Netherlands) in the present climate are poorly reproduced. Bias corrections to precipitation, temperature and potential evaporation have been made in order to improve these statistics. In particular, the estimate of the potential evaporation turned out to be a critical issue.

Climate Change and Runoff Statistics: A Process Study for the Rhine Basin using a Coupled Climate - Runoff Model

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The consequences of extreme runoff and water levels are within the most important weather-induced natural hazards. The question about the impact of global climate change on the runoff regime, especially on the frequency of floods, is of utmost importance.

In winter-time, two possible climate effects could influence the runoff statistics of large Central European rivers: the shift from snowfall to rain as a consequence of higher temperatures and the increase of heavy precipitation events due to an intensification of the hydrological cycle. The combined effect on the runoff statistics is examined in this study for the river Rhine. To this end, sensitivity experiments with a model chain including a regional climate model and a distributed runoff model are presented. The experiments are based on an idealized surrogate climate-change scenario which stipulates a uniform increase in temperature by 2 Kelvin and an increase in atmospheric specific humidity by 15% (resulting from unchanged relative humidity) in the forcing fields for the regional climate model.

The regional climate model CHRM is based on the mesoscale weather prediction model HRM of the GermanWeather Service (DWD) and has been adapted for climate simulations. The model is being used in a nested mode with horizontal resolutions of 56 km and 14 km. The boundary conditions are taken from the original ECMWF reanalysis and from a modified version representing the surrogate scenario. The distributed runoff model (WaSiM) is used at a horizontal resolution of 1 km for the whole Rhine basin down to Cologne. The coupling of the models is provided by downscaling the climate model fields (precipitation, temperature, radiation, humidity, and wind) to the resolution of the distributed runoff model. The simulations cover the period September 1987 to January 1994 with a special emphasis on the five winter seasons 1989/90 until 1993/94, each from November until January.

A detailed validation of the control simulation shows a good correspondence of the precipitation fields from the regional climate model with measured fields regarding the distribution of precipitation at the scale of the Rhine basin. Systematic errors are visible at the scale of single subcatchments, in the altitudinal distribution and in the frequency distribution of precipitation. These errors only marginally affect the runoff simulations, which show good correspondence with runoff observations.

The simulation of a warmer climate results in an increase in winter-time precipitation of about 10% throughout Central Europe. The increase in precipitation is mainly due to an intensification of precipitation events. The frequency of rain days within the Rhine basin changes very little while the frequency of days with more than 20 mm precipitation increases by about 25%. With an increase in temperature, the snow line raises, more precipitation reaches the surface as rain, and less water is stored on the surface as snow. As a result of the changes in precipitation, winter-time discharge increases throughout the Rhine basin.

Whereas the increase of winterly discharge leads to a shift in the yearly runoff regime in the Alpine catchments, it leads to an increase of the yearly cycle downstream.

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