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Impact of Climate Change on the Regional Hydrology – Scenario-Based Modelling Studies in the German Rhine Catchment

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Abstract. The aim of the study is an impact analysis of global climate change on regional hydrology with special emphasis on discharge conditions and floods. The investigations are focussed on the major part of the German Rhine catchment with a drainage area of approx. 110,000 km^2. This area is subdivided into 23 subcatchments. In a first step, the hydrological model HBV-D serves to simulate runoff conditions under present climate for the individual subbasins. Simulated, large scale atmospheric fields, provided by two different Global Circulation Models (GCMs) and driven by the emission scenario IS95a ("business as usual") are then used as input to the method of expanded downscaling (EDS). EDS delivers local time series of scenario climate as input to HBV-D. In a final step, the investigations are focussed on the assessment of possible future runoff conditions under the impact of climate change. The study indicates a potential increase in precipitation, mean runoff and flood discharge for small return intervals. However, the uncertainty range that originates from the application of the whole model chain and two different GCMs is high. This leads to high cumulative uncertainties, which do not allow conclusions to be drawn on the development of future extreme floods.

Key words: climate change, regional hydrology, floods, uncertainty

1. Introduction

The issue of climate change and the future development of runoff and flood conditions is of high priority within water resources research and a number of related studies deal with regional impact analysis and related uncertainties (e.g., Bergström *et al.*, 2001; Menzel and Bürger, 2002; Prudhomme *et al.*, 2003). So far, few investigations on the possible impact of climate change have been carried out for the Rhine, although it is a major river in

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Central Europe and represents an international basin with water resources and flood problems shared by different countries (Figure 1).

Observations indicate an over-proportional increase of surface temperatures in Central Europe over the last 100 years in comparison to the global mean value of $+0.6 \pm 0.2$ K (IPCC, 2001; Müller-Westermeier and Kreis, 2002). Investigations on changes in large-scale precipitation characteristics prove that the development of annual precipitation totals in Germany shows a distinct behaviour, with an increasing trend in the western part and a clear reduction over large areas in Eastern and South-eastern Germany. This is a direct consequence of changes in the frequency and mean residence time of certain weather conditions. For example, the occurrence of relatively warm westerly patterns during winter, causing extended rainfall and snow melt and thus triggering the formation of floods, has significantly increased over extended parts of Western and Central Europe, especially within the last 30 years (Werner *et al.*, 2000). Moreover, the

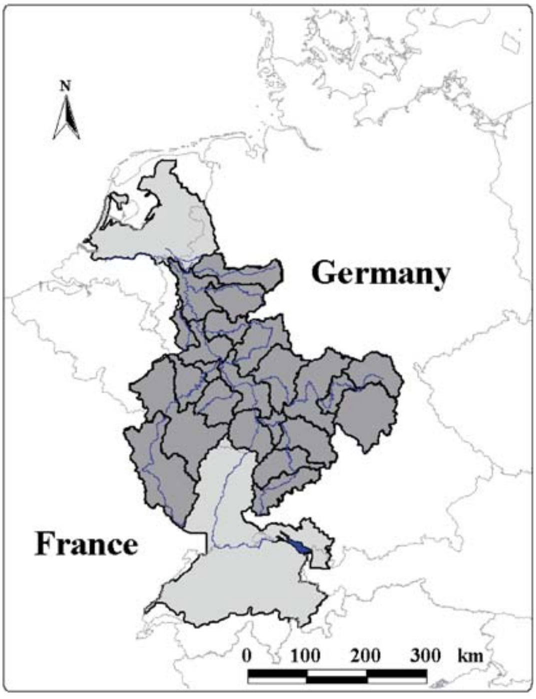

Figure 1. The catchment of the Rhine (shaded area) and its location within Central Europe. The dark grey surface marks the extension of the area investigated, enclosing the drainage basin between the Maxau and Emmerich gauges (approximately 110,000 km^2, representing the major part of the German Rhine catchment). The figure also illustrates the subdivision of the area under investigation into 23 subbasins, including the main river paths.

increase of precipitation totals in winter has often been accompanied by increased precipitation intensities in these areas (LFU, 1997; Osborn *et al.*, 2000). The drainage basin of the German Rhine catchment, extending over South-western and Western Germany (Figure 1), is located within the reach of these circulation patterns and has thus been affected by the changes described. Consequently, the analysis of measured discharge time series indicated a rise in flood incidents within the last 30 years, both for the Rhine itself (Bendix, 1997) and several of its tributaries (Caspary, 1996; KLIWA, 2000). However, if the analysis is extended over a longer time period, only weak trends towards increased discharge or even reductions in peak flow conditions can be detected (KLIWA, 2000).

The objective of the present study is to apply climate change scenarios to simulate the long-term behaviour of runoff conditions in the German part of the Rhine catchment and to investigate possible future changes.

2. Procedure and Methods

2.1. THE HYDROLOGICAL MODEL

A preliminary task for modelling purposes was to subdivide the large-scale area investigated, the German Rhine catchment, into a total of 23 subbasins, with areas ranging from approx. 3,000 to 12,000 km^2 (Figure 1). This allows a better consideration of regional characteristics and the performance of the hydrological model is expected to increase (Krysanova *et al.*, 1999). The simulations were carried out using the hydrological model HBV-D (Krysanova *et al.*, 1999). The original HBV model was developed at the Swedish Meteorological and Hydrological Institute (Bergström and Forsman, 1973; Bergström, 1995). It can be classified as a conceptual, semi-distributed model, with subbasins as primary hydrological units. HBV-D represents one of several versions of the original HBV model and is a derivative of the "Nordic" HBV model (Saelthun, 1996). HBV-D allows to classify the primary units (subbasins) into an optional number of subunits. In analogy to the original HBV model the subunits are then subdivided into 10 elevation intervals, but each considering up to 15 different land cover types, including their proper parameterisation. In the original version of HBV, monthly estimates of potential evapotranspiration were used as input to the soil moisture routine (Bergström, 1995). Since evapotranspiration plays a key role in climate change impact studies, HBV-D includes a module to compute daily data of potential evapotranspiration according to the formula given by Blaney and Criddle (1950) and the modifications introduced by Doorenbos and Pruitt (1977). This method relates potential evapotranspiration to air temperature with a seasonally dependent coefficient. According to the original HBV model, actual evapotranspiration is calculated from the potential values based on a function of soil moisture deficit.

HBV-D was adjusted to the specific conditions of the individual subbasins, including topographical, soil and land cover characteristics. The HBV model family includes the option to explicitly incorporate major lakes in the modelling scheme through a storage discharge relationship (Bergström, 1995). However, since lakes and reservoirs are of minor importance in the area investigated, neither lake nor regulation effects were taken into account.

HBV-D requires daily precipitation and temperature data as input for a model run. They were provided by a total of approximately 600 climate and precipitation stations which are evenly distributed over the whole area investigated.

2.2. CALIBRATION AND VALIDATION OF THE HYDROLOGICAL MODEL

The calibration of HBV-D and the validation of model performance were based on daily discharge data determined at the gauges of the 23 individual tributaries and the main river sections. The reference time interval selected for model calibration and validation included at least 35 years starting from 1961, with calibration periods extending over 10–15 years. Since the relevant data were available on a daily resolution, the model application was also based on this time step. A model run was considered to be successful when certain measures of efficiency, such as the coefficient of determination, the square of the errors or the Nash–Sutcliffe criterion (Nash and Sutcliffe, 1970), were at an optimum. Visual inspection of the measured and simulated discharge curves also act as an indicator for model performance. The efficiency of the simulations was related in each case only to the whole calibration period, i.e., individual events were not considered for parameter optimisation.

In general, the model reproduces the discharge conditions fairly well in all investigated subbasins. Both individual flood periods and the long-term runoff behaviour are considered to be reflected well by the model. In Figure 2, the Nash–Sutcliffe parameter R^2, representing one of the objective criteria for model performance, is plotted for individual years over the period 1961–1998. The graph demonstrates the proper model performance for the three selected gauges, with values widely in the range between 0.6 and 0.9. Exceptionally low values of R^2 are mostly due to years with low flow conditions (e.g., year 1996 in the Main catchment) and small oscillations only around the mean discharge. An example related to problems with measured discharge data gives the distribution of R^2 values for the Rockenau gauge (Neckar basin) over the period 1961–1986 (Figure 2): the model performance is relatively poor within the time period 1961–1986. This is due to the fact that the discharge series at Rockenau is composed of

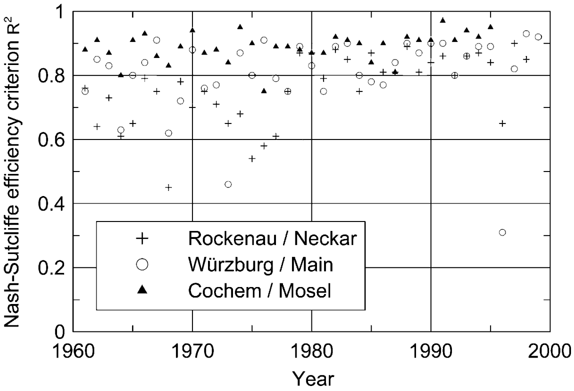

Figure 2. Compilation of the Nash–Sutcliffe efficiency values for the estimation of model performance at three different gauges. The graph shows the data for individual years over the period 1961–1998. Model calibration for the Main and Mosel catchments covers the years 1961–1970, while for the Neckar it is based on the period 1988–1998.

measurements at two different gauges. In 1986, a new gauge was constructed somewhat downstream of the old gauge. Both gauges measured discharge over two consecutive years in parallel, but there are pronounced differences between the two time series. Since the new gauge delivers more reliable data, a period after the installation of the new gauge (1988–1998) was chosen for the calibration at Rockenau. Consequently, the model performance is relatively poor for the time interval before 1986.

2.3. DOWNSCALING OF OBSERVED ATMOSPHERIC FIELDS

For the objective of the present study, a thorough assessment of climate change scenarios with regard to their impact on regional hydrology is required. However, data from Global Circulation Models (GCMs) cannot be processed directly using the hydrological model. The spatial resolution of GCMs is far too coarse and does not capture smaller scale climate effects (Cubasch, 2001). In order to bridge this scale gap a tool is required which considers both large-scale impacts on local climate and their modification by small-scale characteristics as recorded by local observations. For this purpose the method of downscaling has become popular in hydrological applications. For this study, we applied the technique of expanded downscaling (EDS) described by Bürger (1996) and Bürger (2002). An expanded regression method was used to link the characteristics of large-scale pressure fields to local weather variables like daily precipitation and temperature. One advantage of EDS in comparison to other regression methods is that EDS is capable of modelling extreme precipitation.

An intermediate step which serves for the calibration of EDS is the downscaling of observed, daily atmospheric fields that were delivered by the National Centre of Environmental Prediction (NCEP; http://www.ncep.noaa.gov). Subsequently, EDS was applied to generate local time series of meteorological parameters using observed, large-scale pressure fields P at the 500 hPa geopotential height, 850 hPa temperature T and 700 hPa specific humidity q. The reference period 1961–1995 was identical to the period used for the application of HBV-D with measured climate data. In order to improve EDS performance, the simulated daily local weather was then compared with measured meteorological variables. Furthermore, the generated data were passed to the hydrological model HBV-D in order to simulate runoff from the downscaled fields. These simulations were compared with measured discharge and were used for a further adjustment of the calibration parameters of EDS.

2.4. DOWNSCALING OF SIMULATED ATMOSPHERIC FIELDS

After its calibration, EDS was applied to simulated daily atmospheric fields, delivered by two different GCMs. In this study, GCM output from the ECHAM4/OPYC3 model of the Max Planck Institute for Meteorology (Roeckner *et al.*, 1999) and from the HadCM3 model of the Hadley Centre for Climate Prediction and Research (Gordon *et al.*, 2000) was used. Both models are driven by emission scenarios determined by the Intergovernmental Panel on Climate Change (IPCC; http://www.ipcc.ch). The basic forcing for our study is emission scenario IS95a (IPCC, 1995), usually termed the "business as usual" scenario, with a 1% per year compound rise in radiative forcing. The GCM model runs were both driven by IS95a for the period 1990–2100. For the preceding time intervals, historic measurements of atmospheric greenhouse gases were used. Data from a simulation run for the period 1860–2100 were available from ECHAM4/OPYC3 while HadCM3 delivered data for the period 1961–2100. In addition, data from a so-called control run with ECHAM4/OPYC3 were used. In this case, the GCM was driven by a constant greenhouse gas concentration, roughly representing the status of the year 1990. With these unmodified boundary conditions the model was run over 300 years. The generated data set is considered to represent the whole range of possible natural variability and therefore serves to mark off effects of a changing climate derived by the scenario runs from assumed natural conditions.

After the generation of local climate data from the GCM output and EDS, the hydrological model HBV-D was again applied to the reference period 1961–1995. The mean runoff conditions and statistical properties of simulated discharge time series using local climate measurements and downscaled GCM information could then be compared. Finally, HBV-D was applied to simulate discharge over the whole scenario period.

The described linkage of a chain of models (GCMs, downscaling method and the hydrological model) and the related work items are illustrated in Figure 3. Further details are given in the following section.

3. Results

3.1. THE DEVELOPMENT OF TEMPERATURE AND PRECIPITATION UNDER SCENARIO CONDITIONS

After EDS was calibrated on the basis of observed circulation patterns (see Section 2.3. and Menzel and Bürger, 2002), downscaling of climate change scenarios as described in Section 2.4. was applied to all available climate and precipitation stations of the 23 subbasins. It is important to be aware of the fact that the climate scenarios are completely independent from the climate measurements in terms of their temporal attachment. That is, the scenarios can only be compared among themselves or with measurements by means of the long-term statistical behaviour of the individual time series. It is therefore not possible to compare the simulated climate parameters with the respective measurements for individual years.

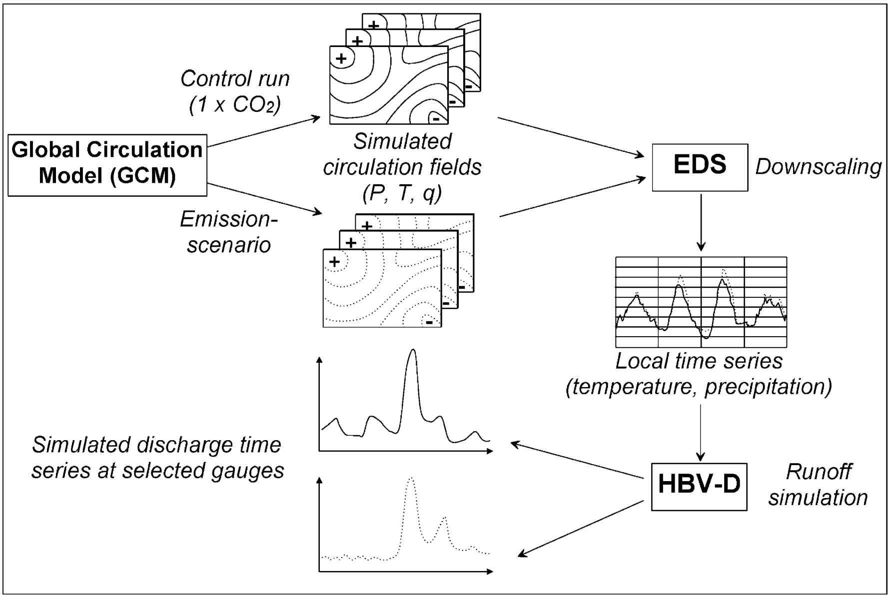

Figure 3. Overview of the model chain that translates simulated circulation fields into local climate time series for input to hydrological modelling. *P*, *T* and *q* refers to air pressure, air temperature and specific humidity, respectively.

Figures 4 and 5 show the temporal behaviour of areal temperature and areal precipitation as constructed from measured and simulated data at the individual climate and precipitation stations of the Neckar catchment (approx. 12,700 km^2). Figure 4 proves the good performance of both the two GCMs and EDS in reproducing temperature conditions over the reference period 1961–1995. Mean deviations between simulated and measured data lie in the range of -0.2–$+0.5$ °C for all investigated subbasins and both GCMs. The graph also demonstrates that the simulated areal temperature significantly increases within the next 100 years, with a stronger growth projected by the ECHAM4/OPYC3 model. Both future estimations are out of range of the assumed natural variability (given by the simulations of the ECHAM4 control run, the shaded area in Figure 4) at an already early stage.

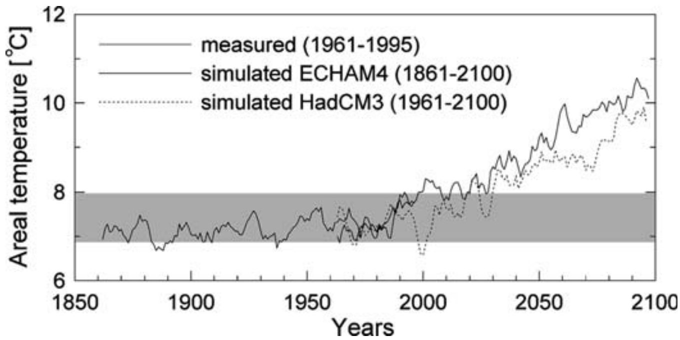

Figure 4. The temporal behaviour of areal temperature in the Neckar catchment, constructed using measured and simulated station data. The curves represent running averages over five consecutive years. The shaded area is the assumed natural variability as computed using downscaled data from the ECHAM4/OPYC3 control run.

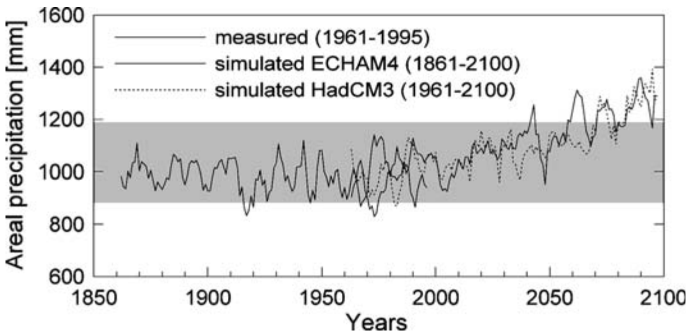

Figure 5. The temporal behaviour of areal precipitation in the Neckar catchment, constructed using measured and simulated station data. The curves represent running averages over five consecutive years. The shaded area is the assumed natural variability as computed using downscaled data from the ECHAM4/OPYC3 control run.

Since precipitation is subject to a far higher natural variability than temperature, its projected change is less significant (Figure 5). The uncertainty of the climate change scenarios, given by the agreement with measured data over the reference period 1961–1995, varies over the range of +4 – +20% (all investigated subbasins), i.e., both GCMs show a tendency to overestimate precipitation. However, both scenarios deliver a positive signal, i.e., the simulated precipitation increases within the next 100 years. While HadCM3 projects a steep rise of precipitation totals during summer (months of June, July and August), the simulations based on downscaled information from ECHAM4/OPYC3 show an increase in precipitation over the whole year (Menzel and Schwandt, 2004).

These findings can be generalised to the catchment as a whole, i.e., the scenarios simulate both clear temperature increases (between +1.6 and +2.6 °C for the period 2061–2095, depending on both the considered GCM and the related subbasin) and precipitation rises (between +18 and +45% for the period 2061–2095) for the over-all German Rhine basin. In general, the downscaled information from the ECHAM4/OPYC3 model delivers more pronounced scenarios (both stronger temperature and precipitation increases) in comparison to HadCM3. Also the seasonal timing of precipitation increase differs between the two GCMs over the area investigated (Menzel and Schwandt, 2004). Finally, it has to be pointed out again that the simulated changes have to be rated under the prevailing condition of model uncertainty.

3.2. CLIMATE CHANGE SCENARIOS AND MEAN ANNUAL DISCHARGES

The integration of the projected climate change information into the modelling of regional hydrological conditions leads to obvious changes. In a first analysis, mean annual discharges over the periods 1961–1995 and 2061–2095 were computed from daily simulated discharge series. Figure 6 gives a selection of results from the three subbasins Main, Mosel and Neckar. Compared to the mean annual discharge derived from daily measurements 1961–1995, the performance of the HBV-D model driven by measured climate data (the black bars in Figure 6) has proved to be good in all investigated catchments. Deviations in relation to measurements do not exceed ±10%.

Discharge simulations based on downscaled climate information for the reference period 1961–1995 overestimate the measured data in nearly all cases. This is especially true for the control run which is assumed to reflect the impact of natural variability on discharge conditions. This can be explained as a deficit in the model chain GCM–EDS (-HBV-D) which appears to reflect local conditions inaccurately, with an overestimation of precipitation (see Section 3.1) and thus discharge conditions. On the other

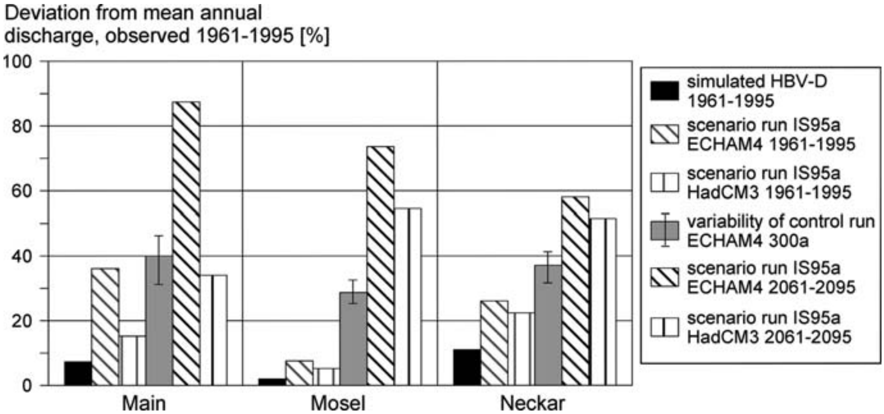

Figure 6. Deviations (in %) between mean annual discharge determined by measurements and simulations using HBV-D with measured (black bars) and downscaled climate input, respectively. The database is composed of time series of daily measured and simulated discharge. The reference periods are the years 1961–1995 and 2061–2095. The data represented by the ECHAM4/OPYC3 control run refer to the period 1961–1995 (grey bars), to which the whole variability of the control run computed over 300 years (error bars) is added.

hand, deviations produced by the two downscaled scenario runs for the reference period lie within the range of assumed natural variability. This could also be interpreted as an adequate representation of the natural conditions within a wider time frame which makes it difficult to compare the results with measurements over a specified time interval of 35 years.

The two bars in Figure 6 representing the scenario conditions for the period 2061–2095 show a distinct increase in deviations from mean observed discharge of the reference period in all cases. This represents the impact of the projected climate change, as already pointed out in Figures 4 and 5. The comparison of scenarios derived by ECHAM4/OPYC3 and HadCM3 reveals that the data based on the first model produce far higher discharges. This can be attributed to the production of higher precipitation totals (see Figure 5). The more moderate scenario conditions as projected on the basis of the HadCM3 model are in some cases within the range of assumed natural variability (e.g., for the Main catchment in Figure 6). This would mean that the projected increase in future mean discharge does not show a significant change from present conditions, which increases uncertainty. Furthermore, the projected rises in mean discharge have to be considered against the background of their overestimation for the reference period.

3.3. CLIMATE CHANGE SCENARIOS AND CHANGES IN FLOOD DISCHARGES

In a further step, the development of the mean flood discharge was examined. First, the annual maximum discharge per hydrological year was assembled from continuous discharge data so that annual maximum series (AMS) of flood discharge were available for both measured and simulated discharge time series of the 23 individual subbasins. The course of the mean flood discharge was examined by calculating moving averages within the AMS over a period of 30 consecutive years. For example, discharge simulations based on observed climate were available for a period of 35 years (1961–1995). By averaging over 30 years only five data points remain from this series. The results for the Cochem gauge (River Mosel) are shown as an example in Figure 7.

The mean flood discharge from the AMS based on observed discharge data has already increased since 1990. This is due to two extreme floods in 1993 and 1995. The mean flood discharge from the AMS based on simulated discharge with observed climate/precipitation data only slightly underestimates the observed mean flood discharge (deviation of −10% for

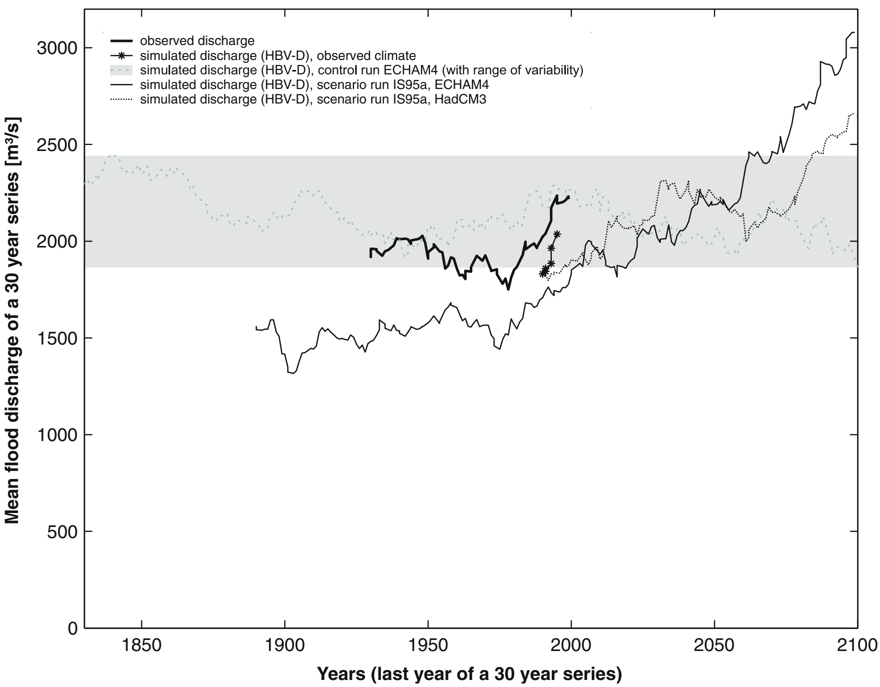

Figure 7. Development of the mean flood discharge at the Cochem gauge (River Mosel). The data points represent running averages of annual maximum discharges over 30 consecutive years. The grey shaded box encloses the assumed natural variability as constructed using a 300-year ECHAM4/OPYC3 control run (explanation in the text).

the example given in Figure 7) whereas the application of the whole modelling chain – consisting of GCM, EDS and HBV-D – clearly underestimates the observed mean flood discharge during the whole observation period. Nevertheless, a dramatic increase in mean flood discharge is simulated with both GCMs for the 21st century, with the ECHAM4/OPYC3 scenario run giving a more pronounced rise. The courses of the scenario runs leave the upper margin of the assumed natural variability (grey shaded area in Figure 7, constructed from results with the control run of ECHAM4/OPYC3) between 2050 and 2080. For the representation of natural variability, moving averages of 30 consecutive years were calculated for the whole simulation period of 300 years. The minimum and maximum values of the moving averages frame the grey shaded area in Figure 7. The mean of all moving averages was used as a representative value for the control run in Figures 6 and 8. Comparable results were obtained for the other subbasins of the investigated area.

Subsequently, the relative deviations from the observed mean flood discharge of the reference period 1961–1990 were calculated for each simulation run. This serves for a better comparison of the orders of magnitude of model error, assumed natural variability and simulated projections of the

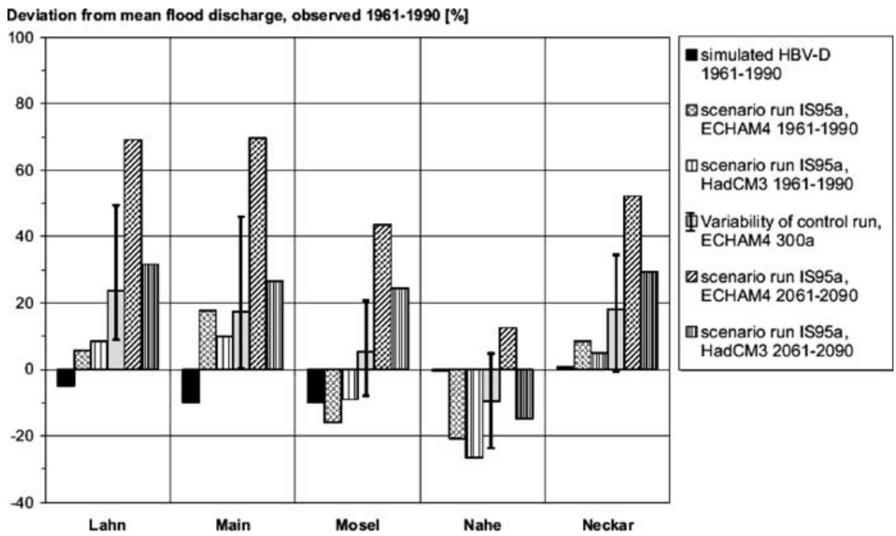

Figure 8. Deviations (in %) between mean flood discharge determined by measurements and simulations using HBV-D with measured (black bars) and downscaled climate input, respectively. The database represents annual maximum series from daily measured and simulated discharge. Selected time intervals are the years 1961–1990 (reference period) and 2061–2090 (projection period). The data represented by the ECHAM4/OPYC3 control run refer to the reference period (light grey bars), to which the whole variability of the control run computed over 300 years (error bars) is added.

mean flood discharge. The results are shown in Figure 8 for five selected subbasins.

In analogy to the mean discharge conditions (Figure 6), the error of the hydrological model related to the representation of mean flood discharge totals to an acceptable maximum of ±10% for the reference period 1961–1990. For the same reference period, the error of the whole model chain is larger in all cases and amounts to a maximum of ±25%. However, the total model error is almost within the range of the assumed natural variability of the ECHAM4/OPYC3 control run. As could be expected, this variability is far higher than the variability of mean discharge conditions that are given in Figure 6. Furthermore, Figure 8 shows that the extremes tend to be underestimated in the reference period (e.g., for the Main and Mosel basins), whereas the mean discharge tends to be overestimated (e.g., for the Main and Neckar basins; see Figure 6). This can be explained as follows: The analysis of the mean discharge considers all simulated daily discharges within a year or a 30 year series, whereas the analysis of the extremes builds upon only one (maximum) daily discharge value per year. It is therefore far more difficult to meet the extreme value statistics of the observed AMS than the mean discharge conditions.

For the projection period 2061–2090, the scenario run based on the ECHAM4/OPYC3 model clearly exceeds the upper margin of the assumed natural variability, which can be interpreted as a clear signal towards an

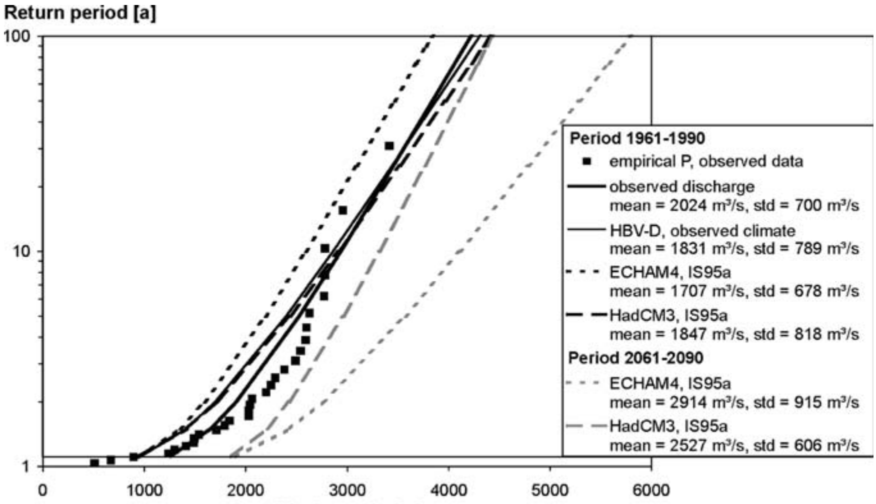

Figure 9. Extreme value statistics (Gumbel distribution, method of moments) for the Cochem gauge (River Mosel), applied to annual maximum discharge series from measured and simulated daily discharge data. Selected time intervals are the years 1961–1990 (reference period) and 2061–2090 (projection period).

increase in mean flood discharge under the scenario conditions. This is not true for the HadCM3 scenario run, which remains within the given range of assumed natural variability for most of the investigated subbasins (Figure 8). This means that the uncertainty of a future increase in mean flood discharge is remarkable when the results of both GCMs are considered equally.

In a next step the whole distribution of flood discharges was examined. For this purpose, the Gumbel distribution was adapted to the AMS of the reference period (1961–1990) and the projection period (2061–2090) by the method of moments. Figure 9 exemplarily shows for Cochem gauge (River Mosel) that the uncertainty of a future increase in flood discharge rises with the return period of a flood event. For example, the magnitude of a 2-year flood is clearly higher for the projection period 2061–2090 in comparison to the reference period 1961–1990. This applies to both GCMs for floods of small return periods (i.e., up to approximately 10-year floods).

For the projection period 2061–2090, the 100-year flood computed with the distribution based on ECHAM4/OPYC3 by far exceeds the respective value of the reference period. However, the flood of the same return period determined using the HadCM3 model projections nearly intersects the range of a 100-year flood of the reference period. Therefore, the projected increase in extreme flood discharge is even less significant than the simulated increase in precipitation when both GCMs are considered and the related uncertainty is considerably higher.

4. Discussion and Conclusions

In accordance with successful applications of the HBV model family in more than 40 countries (Bergström, 1995) this study proved that HBV-D is an appropriate tool for the reliable reproduction of discharge conditions in catchments of varying natural conditions. This applies both to the simulation of individual flood events and the proper reflection of general statistical properties. Since the model structure is not too complex and the principal input are time series of temperature and precipitation only, HBV-D can be applied for the simulation of long discharge time series (e.g., the control run spanned 300 years).

The underlying uncertainty within the application of climate change scenarios is clearly demonstrated. Since the present study could not include all sources of uncertainty, the given uncertainty bounds should be considered conditional. In principle, the uncertainty of climate change projections results from a cascade of individual uncertainties (Mitchell and Hulme, 1999). The first module of this cascade consists of the selection of a particular emission scenario from a range of available options. Secondly, uncertainty relates to the applied GCMs which deliver different input to the downscaling method EDS, the third source of uncertainty. It is important to state in this context that the detailed information delivered by EDS on the local scale cannot be better than the information provided by the coarse spatial grids of the GCMs (Cubasch, 2001). Finally, the simulated, local climate variables are used to model discharge. Therefore, the hydrological model represents the fourth level of uncertainty.

Furthermore, Boorman and Sefton (1997) point out that climate impact studies also depend on the investigated area and the indices on which the study is focussed. The present study clearly shows that the uncertainty of future projections increases from temperature to precipitation to mean runoff (hydrological regime) up to extreme flood events such as the 100-year flood. Since the errors of the hydrological model were shown to be relatively small, the highest degree of uncertainty can be attributed to the coupled application of GCM output with the EDS method.

The results from the control run were supposed to reflect natural climate variability. However, this assumption needs to be restricted to the fact that the control run includes the same level of uncertainty as the individual scenario runs. On the other hand, one can argue that the control run covers a wide range of the fuzzy background of what is assumed to be ‘‘current climate’’ (Bürger, 2002).

The pronounced increase in simulated temperature, precipitation and discharge for the scenario period is projected by both GCMs over the whole investigated area. This can be interpreted as a clear signal despite the underlying uncertainties. However, the magnitude of the projected increase is highly uncertain.

The projected development is reinforced by the trends already observed both in the Rhine catchment and beyond (see Section 1.). A similar study in the southern part of the Elbe catchment (Menzel and Bürger, 2002) indicates decreasing precipitation conditions; a fact that has already been observed in this region. Therefore, we consider the application of climate change scenarios to be a useful part of hydrological research. However, the projections given by the simulations should not be mistaken for predictions. Keeping the described uncertainties in mind, scenarios are helpful for the evaluation of possible developments and for raising preparedness against adverse conditions, such as the increasing threat of floods or droughts.

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