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EurAqua Symposium

**Impact of climate change on water resources –
200 years hydrology in Europe –
a European perspective in a changing world**

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German Federal Institute of Hydrology (BfG)

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EurAqua Symposium

“Impact of climate change on water resources – 200 years hydrology in Europe – a European perspective in a changing world”

EurAqua is the leading European network facilitating improved and co-ordinated water research and thus supporting knowledge-based water-resources management practices and policies. The EurAqua symposium „Impact of climate change on water resources – 200 years hydrology in Europe – a European perspective in a changing world” was held on 9 and 10 November 2010 in Koblenz, Germany.

Germany can look back on 200 years of experience in institutionalised hydrology that started in 1810 with the enactment of the first official gauging instruction in Prussia. For EurAqua this was an inspiration to invite its partners for an exchange of experiences regarding the history and perspectives of hydrological research with respect to climate change in their countries. Today, availability of reliable hydrological data from the whole of Europe is the prerequisite of scientific research in this field. The symposium compiled the state-of-the-art and the knowledge gathered by the EurAqua partners in providing scientific policy advice and in their research on climate change and its impacts. The meeting had its focus on inland waters with the following four themes:

- Theme (1) 200 years hydrology in Europe – a European perspective in a changing world
- Theme (2) Research efforts on climate projections and scenarios for water balances and runoff regimes
- Theme (3) Research efforts on climate projections and scenarios of water-quality developments
- Theme (4) Research efforts on climate projections and scenarios regarding the ecology of rivers and other inland waters

Starting with a retrospective view on hydrology in Europe, the contributions from the German Federal Institute of Hydrology (*BfG*) to each of the Symposium themes were based on the departmental research programme “*KLIWAS*” (Impacts of Climate Change on Waterways and Navigation) of the German Federal Ministry of Transport, Building and Urban Development. This programme is embedded into the German national and European strategy on adaptation to climate change. *KLIWAS* is aimed at estimating changes in stream flow and river stages caused by climate change and the consequences for inland and coastal waterways and navigation. Moreover, it studies how climate change may influence the tidal patterns in coastal regions and in the seas. Changes in water quality and ecology will be assessed, including also economic aspects. The ultimate objective of *KLIWAS* is then to develop options for adaptation to potentially changing conditions regarding navigation as well as other water-related ecosystem services and water uses.

The symposium gave a broad overview on strategies, existing research projects, and results achieved so far. It revealed gaps in knowledge and identified fields of research for mutual co-operation and for proposals to the European Commission.

About 50 scientists and water managers from research and governmental institutions throughout Europe met at Koblenz to exchange the European knowledge about impacts of climate change on water resources and sustainable uses of water in the future. The range of experiences spanned from semi-arid regions in Italy or Spain, to the catchments in Central Europe like that of the River Rhine, and to case studies on a diversity of subjects from the UK, Scandinavia, Baltic and Balkan countries.

Much research effort is being spent on downscaling global climate projections to the scales where regional hydrological modelling is performed and on enhancing the accuracy in prognostic analyses. The overall goal is to project the state of the water system in the near and the distant future and to explore the impacts of climate change on land- and water-uses, the ecology, water quality, and on infrastructure assets, to become able to develop adaptation strategies.

Accordingly, questions dealing with increasing uncertainty in long-term predictions, the adaptation capacity of infrastructure assets, the needs for additional knowledge, and the value of long-term data records were also addressed at the symposium. Based on evidence of near surface air temperature rise, discussions highlighted the consequences of population growth, peoples behaviour regarding agricultural practices and food supplies, urban and rural developments, recreation and so on. In addition to formulating strategies on the basis of long-term climate-change projections and hydrological model outputs and given their degree of uncertainty, it might be an advantage to design adaptation strategies based on regional-scale scenarios and predictions of socio-economic developments driven by observed temperature rise so far. Furthermore, lessons learnt from semi-arid regions and other drought-prone areas in Europe and beyond will enable water managers to cope with the pressures acting on society under climate change.

This volume is a compilation of papers presented at the EurAqua symposium and it gives an overview on the-state-of-the-art of hydrological research in the light of climate change impacts and its outlooks in Europe.

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Water and climate change in Europe: think global, act local, and work together at European level

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It is quite widely recognised, according to observational records and to climate projections, that water resources, aquatic ecosystems and their uses can be significantly impacted by climate change, in addition to the influence of other global and local drivers. Amongst the most vulnerable aspects and more sensible impacts in Europe, we may expect to find :

- > droughts in the South of Europe
- > floods in Central Europe and in the Mediterranean area
- > health
- > recreation activities, tourism
- > increase of evapotranspiration and change of plant seasonality
- > energy production (about hydropower or cooling water) ...

Climate change, and more generally global change issues, will add to the questions and difficulties faced by water management, which address the three pillars of sustainable development. Natural and human "water systems" (water resources, aquatic ecosystems, and their uses) are highly open systems, influenced by many drivers and interacting with many other activities, many other sectors. Water management issues therefore often cover various space and time scales, call for interdisciplinary approaches, and involve a multitude of stakeholders including many "non water professional" (or "out of the water box") stakeholders.

Identifying, characterising and forecasting the impacts of climate change on "water systems" still require efforts from research. For instance, we need to understand how climate change induces or modifies trends, modifies hazards/variability and increases uncertainty, without forgetting that climate change is not the only non stationary driver. How will the numerous interactions in the system change, to begin with the influence of land use on the atmosphere as well as on the continental part of the water cycle ? Moreover, where do we expect evolutions and where do we expect break points, "no return" points ?

Though additional knowledge is highly needed, part of the decisions need to be made already now, in order to mitigate climate change, but also to adapt to climate change, as far as "water systems" are concerned. Adaptation requirements concern for instance improving our capacity for "management adaptation", considering the different time scales, as well as deciding about the long term infrastructure assets which are widely found in water management. This raises questions such as:

- > How to cope with the increased uncertainty when deciding about investment ?
- > How to assess adaptation capacity of assets ?
- > How to design climate proof assets ?
- > What additional knowledge to expect over time ?
- > How and when to question the initial investment ?

These requirements for both knowledge and for action create a risk of mismatch of timing between adaptation research and adaptation implementation. We need to :

- > develop ad-hoc science policy interface at various levels, global, regional and local
- > develop partnership research, decision support oriented, targeted and field specific, with a high level of collaboration between decision makers, stakeholders, scientists
- > encourage networking between site specific "experiments", in order to foster a collective learning process.

Water management therefore calls for developing more than ever capabilities for innovation and adaptability, in spite of the inherent difficulties and obstacles to its potential for innovation, such as the weight of regulations and standards, which may act as either drivers or obstacles, or the diversity of practices, policies and regulations in EU. Several types of actors lack a strong structure and organisation, whereas many technology providers show a wide diversity and a small size in average. We have also mentioned above the importance of "non water professional" stakeholders, whose commitment is required, as well as the importance of long term infrastructures, with a low replacement rate.

Pan-European networks of water scientists, water experts, water professionals, can increase the potential and capabilities for adaptation to climate change, as long as "water systems" are concerned, by joining forces and increasing the capacity to address interdisciplinary issues. At the scale of the European continent, such networks can address a wide diversity of natural and human situations, therefore enhancing and increasing capacity building and learning processes.



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Long-term time series and political advisory

Hans Moser and Peter Krahe

1 Introduction

For the benefit of the transboundary River Rhine and all its tributaries, the members of the International Commission for the Protection of the Rhine (ICPR) – Switzerland, France, Germany, Luxemburg, the Netherlands – and the European Commission have established successful co-operation with Austria, Liechtenstein, the Belgian region of Wallonia, and Italy. Focal points of this co-operation are the sustainable development of the Rhine, its floodplains, and the good state of all waters in its catchment. Within the ICPR, representatives of the governments of the states concerned jointly draft recommendations for programmes of measures which are then implemented and financed by the individual countries. The ICPR co-ordinates this work and discusses its results. Currently, work is focussing on (i) the improvement of the chemical and ecological state of the Rhine by sustainable uses and with view to mitigating the impacts in the North Sea, (ii) flood prevention and flood defence taking into account ecological requirements, and (iii) support of the co-ordinated implementation of European regulations, such as the Water Framework Directive (WFD) (drafting the international part of the management plan for the international Rhine river basin district) (EC 2003, EISENREICH 2005, EEA 2007, COM 2009, EC 2009) and the Flood Directive (FD) in the catchment of the Rhine (Directive 2007).

The programme "Rhine 2020" (ICPR 2001) defines the general policy objectives for the protection of the river and the measures required for implementing the programme by 2020. Focal aspects are the restoration of the habitat-patch connectivity along the Rhine, the improvement of flood prevention by implementing and further developing the Action Plan on Floods, the indispensable further improvement of water quality, as well as groundwater protection.

The Action Plan on Floods (ICPR 2007a) aims at improving the protection of human life and health and of riparian property and assets against floods and at the same time at improving the floodplains of the Rhine. Within the implementation of this Action Plan and in consideration of the possible effects of climate change, all realistic measures will be examined with a view to further reducing extreme flood peaks and flood-related damage.

Following the findings of the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (FAR, IPCC, 2007a, b) and the discussions around the European Flood Directive, the Conference of the Rhine Ministers commissioned the ICPR in 2007 (ICPR 2007b) to draft a scenario study on the flow regime of the River Rhine in order to analyse

which impacts the expected climate change will have on the hydrological processes and the water regime. Based on these results, decisions about adaptation strategies will be initiated within the ICPR.

The ICPR has immediately started work on this issue in its newly set up expert group (EG) KLIMA. The group has defined a working programme which consists of three main tasks:

- > analysis of the present state of knowledge on climate change and on the impacts of climate change on the water regime in the Rhine basin (as in early 2009)
- > projections of streamflow and water temperature in the River Rhine basin based on currently available regional climate projections
- > evaluation of projections and identification of changes of decision-relevant indicators describing streamflow (mean flow, flood and drought) and water temperature

To fulfil the first task, a bibliographical evaluation was commissioned mainly about observed trends in hydro-meteorological and hydrological time series and about the present state of research on hydrological climate-change impacts (IPCR 2009). The second task concerns the support and follow-up of the drafting of a scenario study on the flow regime of the River Rhine. This work comprehends the collection of actual ongoing projects and initiatives in the River Rhine basin initiated by the member states and the attendance of the Rheinblick2050 project which is a so called “meta”-project initiated by the International Commission for Hydrology of the River Rhine basin (CHR, GÖRGEN et al. 2010). Finally, some actions e. g. the set-up and launching of a questionnaire as well as discussions between the various working groups of the ICPR are initiated to find out decision-relevant indicators tackling the various interdisciplinary aspects e. g. flood management, ecology of water bodies etc.

After a short overview about the hydrology and water management issues in the River Rhine basin (cp 2) some findings of the bibliographical evaluation are reported (cp 3) and some key facts of the basin wide scenario study are given (cp 4).

2 The River Rhine basin

The River Rhine basin (Figure 1) covers an area of about 197,000 km²; the 1,238 km long course of the river is divided into six major stretches. It is the only river that connects the mountains of the Alps with the North Sea. The river basin is shared between nine countries (Figure 1). Some 58 million people live in the Rhine basin, and about 8 % of the total surface is used for settlements. From an economic point of view, the Rhine is the most important river of Western Europe. The river is one of the world's most intensively navigated inland waterways, and it is of major importance for the supply of water to large areas of high socio-economic relevance. Changes in its flow regime may have severe consequences for safety of the riparian dwellers, the availability of water for shipping, industries, agriculture, and domestic consumption, and for the natural environment and recreation.

From the climate perspective and under consideration of orographic effects, the River Rhine basin can be subdivided in three main climatic regions, namely the pre-Alps and Alps (the catchment upstream of Basle), then the low-mountain ranges and uplands (between Basle and

Cologne), and finally the North-German and Dutch lowland (downstream of Cologne). Accordingly, the flow regime in River Rhine is dominated by melt water and precipitation runoff from the Alps in the summer months and by precipitation runoff from the uplands in winter. Further downstream, the contribution from the uplands becomes predominating, so that over the whole year the streamflow is usually well balanced.

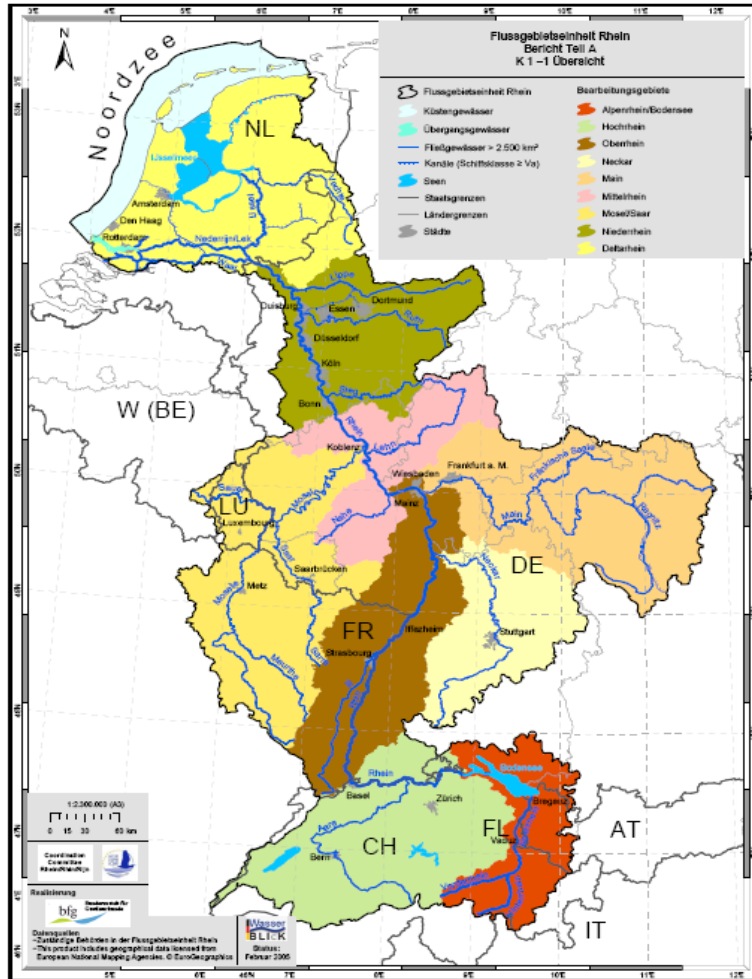


Figure 1: The River Rhine catchment with river basin units according to Water Framework Directive (total surface ~ 197,000 km²; Germany (~53 %); Switzerland, France, the Netherlands (each ~13 % - 18 %); Italy, Austria, Liechtenstein, Luxemburg, Belgium (together ~ 3 %) (Map: ICPR)

The consequences for floods which can be attributed to the anthropogenic pressure are the construction of dikes and straightening the water course resulted in the loss of more than 85 % of former overbank areas. Regional flood protection and land reclamation restricted floodplains and shortened the river course (by more than 90 km). These measures have resulted in flood waves that rise distinctly higher in shorter time. It has to be noted that in the immediate vicinity of the River Rhine, 11 million people are at risk of extreme flood events.

Considerable efforts have been made to reduce the negative impacts of flooding. Among others, additional flood-retention areas have been provided. These actions are managed under the above-mentioned programme "Rhine 2020".

3 Present knowledge about impacts of climate change on streamflow and water temperature in the River Rhine catchment

With the aim to review the existing knowledge about regional effects and possible future impacts of climate change, a compilation titled “Analysis of the state of knowledge on climate changes so far and on the impact of climate change on the water regime in the Rhine watershed” was commissioned (ICPR 2009). The survey consists of three parts:

- > survey of the general, up-to-date investigations on climate change
- > survey of the present state of knowledge on observed changes of the climate and in hydrological regimes
- > evaluation of the present knowledge (as in early 2009) about future impacts on the hydrological regime due to climate change

3.1 Observed changes in the climate regime

The survey considers exclusively precipitation and air temperature, i. e. the variables recognised to be of particular importance for the hydrological regime. The assessment of the hydrological regime itself focuses on discharge (mean, high and low flow) as well as on water temperature. The survey of the state of knowledge is based on the documents furnished by the delegations in the ICPR. All in all, 110 documents were provided and analysed. However, due to the wide scope of the literature on climate change, this survey cannot pretend to be comprehensive.

A first general finding was that the investigations made by the various groups often cannot be directly compared with one another, as the methods of assessment applied the time periods and indicators considered differ considerably. Moreover, when results are summarised, there is a loss in differentiation in time and space. The evaluation of the investigations or the formulation of conclusions are not the subject of this survey.

As far as precipitation is concerned, the analysis of climate change shows that an increase in precipitation in winter can be assumed in all regions of the Rhine basin. On the other hand, in large parts of the Rhine basin (above all those located in the south), precipitation in summer was found to decrease. However, this decrease is not significant everywhere.

Analyses of monitoring data of air temperature yielded indisputable results in all regions of the River Rhine basin. During the past 100 years, a considerable rise in the air temperature has been recorded (about +1.0 °C to +1.6 °C). However, since this rise is less significant (~ +0.6 °C to +1.1 °C) in summer, the mean annual rise of temperature in the River Rhine basin ranges between +0.5 °C and +1.2 °C, which is slightly above the global mean value of +0.56 to +0.9 °C/100 years. The rising temperatures let the glaciers in the Swiss part of the river basin retreat. Additionally, investigations into snow parameters, such as average depth of snow, reveal a negative trend. However, with increasing altitude, trends are less distinct. The results of independent investigations show that, in the Rhine basin, climate change is already detectable in monitoring data of air temperature and precipitation.

3.2 Observed changes in the hydrological regime

Analyses of changes in the hydrological regime reveal that due to rising temperatures and increased precipitation as well as reduced snow storage in winter, the monthly average runoff values of the entire Rhine basin are higher in the winter half-year than they used to be. This may be explained in connection with the “Western low-pressure circulation pattern”, i. e. a large-scale circulation pattern that is significant for the generation of floods, which occurs distinctly more often and over distinctly longer periods of time in winter.

Conversely, in the summer half-year, the mean runoff in the southern Rhine basin is decreasing. Due to the re-distribution of runoff from the summer half-year to the winter half-year, rivers dominated by a glacial-nival regime are experiencing reduced variability within the years. Thus, the annual average runoff remains constant. Towards the mouth of the Rhine in the Netherlands, the decrease in mean runoff tends to be less in the summer half-year, so that in this region the average annual runoff increases due to the more abundant runoff in the winter half-year (Figure 2). Thus, stronger variability in discharge seems to be a consequence of climate change.

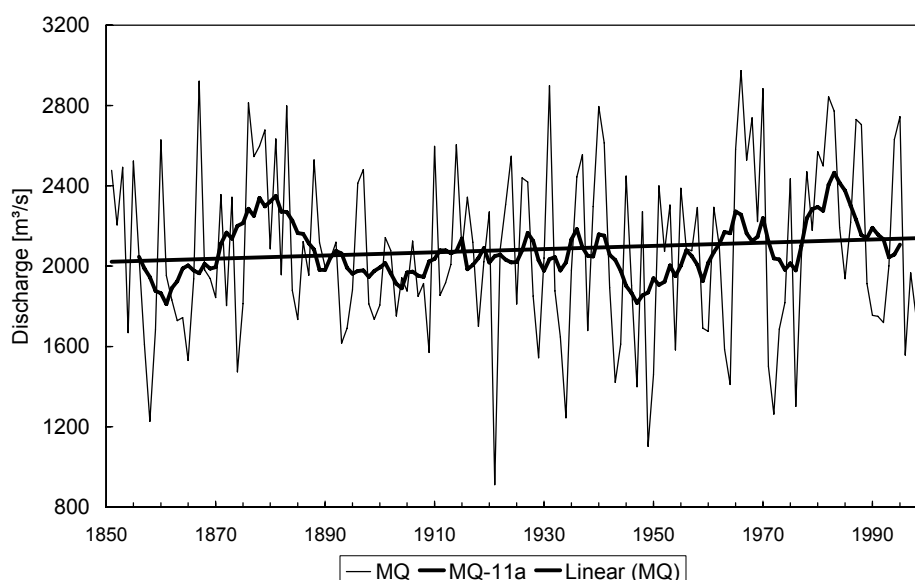


Figure 2: Long time series of observed mean annual runoff (MQ), 11a-moving average of MQ (MQ-11a) and linear trend of MQ over the time period 1851 - 2000 at gauge Cologne. The high natural interannual and decadal variability of streamflow pose a challenge for present water management and will be amplified by global climate change (data: BfG)

Regarding floods, the results, such as the trend analysis for the annual maximum runoff (HQ values), are less evident. At the gauging stations of meso-scale sub-basins, which have been closely studied by the German Federal States Baden-Wuerttemberg, Bavaria, Rhineland-Palatinate, and North Rhine-Westphalia generally no significant changes in HQ values have been observed. Increased flood peaks were recorded at the gauging stations along the River Rhine as a consequence of the increase in areal precipitation. However, a climatic effect cannot be attributed clearly by statistical analysis. Some of these changes may be explained by man-made influences.

3.3 Impacts of climate change on the hydrological regime (as in early 2009)

For the assessment of the impacts of possible climate change on hydrology and water-resource management, the survey reviewed studies that had been finalised at beginning of the year 2009 at the latest. These studies are based on emission scenarios of the so-called greenhouse gases and on climate-model runs of the coupled Atmosphere-Ocean General Circulation Models (AOGCM's) defined for the Third IPCC Assessment Report (TAR, IPCC 2001). The responsible water authorities and the participating independent research groups had applied:

- > Different methodologies for the regionalisation ("downscaling") of the coarse grid results of the AOGCM's to calculate and project the future climate on a regional scale.
- > Furthermore, different hydrological models with unknown sensitivity to climate change forcing were used to generate hydrological projections. Some of these cover only parts of the Rhine basin and just a few deal with the catchment from the sources in Switzerland downstream to the German-Dutch border (as the basin was defined for the purposes of this survey).
- > These regional climatic and hydrological projections were produced more or less independently by each group leading to different views of the future development of the climate and hydrology in the River Rhine basin.

4 Scenario study

Beyond the reviewed studies concerning climate change and the impact on runoff regime, it has to take into account that most of the water management authorities have already initiated scenario studies and some of them have also formulated climate scenarios and adaptation strategies for their territory (IPCR 2009). These scenarios are based on the knowledge base generated within the TAR (IPCC 2001).

Three ongoing investigations were identified that cover the whole River Rhine basin up to the German-Dutch border aiming to use the most recent global and regional climate projections prepared for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (FAR) (IPCC 2007):

- > "RheinBlick2050" promoted by the International Commission for the Hydrology of the River Rhine basin " (CHR), (GÖRGEN et al. 2010)
- > "KLIWAS": "Impacts of climate change on waterways and navigation – options to adapt". A research programme financed by the Federal Ministry for Transport and Urban Development (BMVBS) (MOSER et al. 2008; KRAHE et al. 2009; NILSON et al. 2010).
- > "Developing Adaptive Capacity to Extreme Events in the Rhine Basin" (ACER). The project consortium that consists of Dutch and German universities as well as research institutes and cooperates with the EU-FP 6 Project NEWATER. (HURKMANS 2009, HURKMANS et al. 2010; TE LINDE et al. 2010a, b)

The Rheinblick2050 project is a coordinated effort on the non-tidal catchment, initiated and co-ordinated by the international Commission for the Hydrology of the River Rhine basin (CHR) and early from the beginning of the project it was decided that the project will collaborate and support the ICPR scenario study. Data, methods, models and expertise of different institutions and research activities of riparian states of the Rhine River are jointly combined in this so-called meta project (GÖRGEN et al. 2010), e. g. the KLIWAS project “Hydrology and Inland Navigation” contributes to the CHR-Project by carrying out hydrological ensemble modelling and analysing the impact on low water indicators (NILSON et al. 2010).

The experiment design use a data synthesis, multi model approach where a selected ensemble of finally 20 dynamically downscaled transient bias corrected regional climate simulations is used as forcing data for a daily water balance model (Model HBV) at a daily temporal resolution and with a spatial division of the catchment in 134 sub-basins. An extensive model chain evaluation procedure, a hydrological model inter comparison and performance testing by comparing over eight different hydrological models as well as simulated discharge validation studies ensure the suitability of the methods and models used. Regional climate models outputs are mainly used from the EU-FP& ENSEMBLES project (ENSEMBLES 2009) based on A1B emission scenario and various driving global climate models. Additional runs are available from different research projects and institutions are included. Furthermore, a weather generator conditioned to regional climate change was applied to generate long time series of forcing data especially for assessing flood hazard under changing climatic situations.

The final project output (GÖRGEN et al. 2010; PERRIN et al. 2011) consisting of 150 year long runoff time series of present and future climate and descriptive statistics of changes for the near future (2021 - 2050) and the far future (2071 - 2090) relative to the reference period 1961 - 1990 for selected gauging stations along the River Rhine and for selected tributaries. The project has provided useful information and quantifiable statements (e. g. extreme-value statistics, uncertainty assessments, verification statistics) that form the basis for further policy-relevant decisions.

Together with runoff projections updated by the individual member states and corresponding often to actual but single climate projections and covering only parts of the River Rhine basin and are often restricted to the administrative borders of the according authority the EG KLIMA group starts the discussion to filter out of the available information and data those projections or scenarios which should be communicated for further decision making concerning climate change and water management planning. This ongoing process of co-ordination will be finalised in 2011.

Summary

It can be expected that even under an efficient policy of climate-change mitigation, climate change is going to have primarily negative impacts in the upcoming years in the River Rhine basin. On the other side, great uncertainties still exist about the future development of the regional climate and the consequences for the hydrology of the river. In this context, decision makers need better knowledge about the potential impacts on decision-relevant indicators including the ranges of uncertainties.

With the literature study, the collection of already existing actual projections and the results generated in the meta project "RheinBlick2050" a balanced composition with regard to the represented nationalities and scientific communities, together with the cooperation of the ICPR expert group KLIMA provides a solid basis for elaborating a common vision "(scenarios) of the future climatic and hydrological developments". The final result will be expected in 2011 while it is recognised that an updating of the findings have to be performed accordingly to the progress of climate and hydrological modelling, monitoring and data analyses.

Literature

- COM (2009): 147 WHITE PAPER - Adapting to climate change: Towards a European framework for action
- CMIP (2009): Coupled Model Intercomparison Project. URL: <http://cmip-pcmdi.llnl.gov/>
- DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the assessment and management of flood risks
- EEA (2007): Climate change and water adaptation issues. EEA Technical Report No. 2/2007, European Environment Agency, Copenhagen, Denmark
- EISENREICH, S. J. (2005): Climate Change and the European Water Dimension, European-Commission- Joint Research Centre, Ispra, Italy
- ENSEMBLES (2009): Climate change and its impacts at seasonal, decadal and centennial timescales. Final report ENSEMBLES. 164 pp
- European Commission (2003): Common Implementation Strategy for the Water Framework Directive (2000/60/EC), - Guidance Document No 11
- European Commission (2009): Common Implementation Strategy for the Water Framework Directive (2000/60/EC) -Guidance document No. 24: River basin management in a changing climate. 134 pp
- GÖRGEN, K., J. BEERSMA, H. BUITEVELD, G. BRAHMER, M. CARAMBIA, O. DE KEIZER, P. KRAHE, E. NILSON, R. LAMMERSEN, C. PERRIN, D. VOLKEN (2010): Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 project, International Commission for the Hydrology of the Rhine Basin, Lelystad, 229 pp.
- HURKMANS, R. T. W. L. (2009): Effects of climate variability and land use change on the water budget of large river basins. Dissertation Univ. Wageningen. 174 S.
- HURKMANS, R., W. TERINK, R. UIJLENHOET, P. TORFS, D. JACOB, P. A. TROCH (2010): Changes in Streamflow Dynamics in the Rhine Basin under Three High-Resolution Regional Climate Scenarios. *Journal of Climate*, 23(3): 679-699
- ICPR (ed.) (2001): Conference of Rhine Ministers 2001 - Rhine2020 Program on the sustainable development of the Rhine. Koblenz, ISBN: 3-935324-38-3
Published online June 2010:
http://www.iksr.org/fileadmin/user_upload/Dokumente_en/rhein2020_e.pdf

- ICPR (edt.) (2007a): Action Plan on Floods –Action Targets, Implementation and Results 1995-2005. Koblenz, ISBN: 3-935324-63-4; published online June 2010:
http://www.iksr.org/fileadmin/user_upload/Dokumente_en/Brochures/Bilanz_APH_2005_EN.pdf
- ICPR (edt.) (2007b): Living and linking Rhine – common challenge of a watershed. Ministerkommuniqué on the occasion of Conference of Rhine Ministers Bonn, 18 October 2007; published online June 2010:
http://www.iksr.org/fileadmin/user_upload/Dokumente_en/MIN07-02e.pdf
- ICPR (edt.) (2009): Analysis of the state of knowledge on climate changes so far and on the impact of climate change on the water regime in the Rhine watershed - Literature evaluation -State beginning 2009 Summary Report. No. 174, Koblenz
Published online July 2009: http://www.iksr.org/uploads/media/Bericht_174_e.pdf
- IPCC (2001): Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp
- IPCC (2007a): Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp
- IPCC (2007b): Fourth Assessment – Climate Change 2007: The Physical Science Basis. Contribution of Working Group I of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K. B.; Tignor, M.; Miller, H. L. (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp
- KRAHE, P., E. NILSON, M. CARAMBIA, T. MAURER, L. TOMASSINI, K. BÜLOW, D. JACOB, H. MOSER (2009): Wirkungsabschätzung von Unsicherheiten der Klimamodellierung in Abflussprojektionen – Auswertung eines Multimodell-Ensembles im Rheingebiet. Hydrologie und Wasserbewirtschaftung. Heft 5/2009. pp. 316-331
- MOSER, H., P. KRAHE, T. MAURER, E. NILSON (2008): Wasserstraßen – Handlungsoptionen für Wirtschaft und Binnenschifffahrt. Beitrag zum Symposium „Klimaänderung – Was kann die Wasserwirtschaft tun?“ am 24./25 Juni 2008 in Nürnberg. Forum für Hydrologie und Wasserbewirtschaftung der Fachgemeinschaft Hydrologische Wissenschaften in der DWA (FgHW). Heft 24.08 (ISBN: 978-3-940173-97-3)
- NILSON, E., M. CARAMBIA, P. KRAHE, T. MAURER, H. MOSER (2010): Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland. In KLIWA Symposium „Klimaveränderung und Konsequenzen für die Wasserwirtschaft.“ Fachvorträge zum 4. KLIWA-Symposium am 3. und 4. Dezember 2009 in Mainz. Heft 15, ISBN 978-3-933123-20-6
- PERRIN, C., J. BEERSMA, H. BOUDHRAË, H. BUITEVELD, M. CARAMBIA, A. DUPEYRAT, K. GÖRGEN, F. HENDRICKX, O. DE KEIZER, P. KRAHE, E. NILSON, R. SAMIE, E. SAUQUET, J.-P. VIDAL (2011): The RheinBlick2050 and Imagine2030 projects: a perspective on the hydrological impacts of climate change in two river basins in Europe. (this volume)

TE LINDE, A. H.; J. C. J. H. AERTS, A. M. R. BAKKER, J. C. J. KWADIJK (2010a): Simulating low-probability peak discharges for the Rhine basin using resampled climate modeling data. *Water Resources Research*, 46(3): W03512.

TE LINDE, A. H.; C. J. H. AERTS AND J. C. J. KWADIJK, (2010b): Effectiveness of flood management strategies on peak discharges in the Rhine basin. Accepted for publication in *Journal of Flood Risk Management*



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Hydrology: 4 centuries of French contributions

Pierrick Givone and Pierre Hubert

Abstract

The contributions of French scientists to Hydrology started a very long time ago, out of the dates range proposed (200 years) for this conference. From a pure historical prospective, three main periods can be identified from the 16th century:

- > The "water cycle period". From the Greek period, and especially Aristote, all waters of the planet are coming from the very depth of earth pushed to surface from by the intense heath of the earth core. Bernard PALISSY, a French scientist whose results are well known in the field of ceramic and pottery industry, proposed in his book "Discours admirable de la nature, des eaux et des fontaines", the concept of water cycle. But Pierre PERRAUT really made the first water budget at basin scale (on the Seine river) in his book "De l'origine des fontaines" in 1674. It was, at this period, a global "cycling movement" in science, and William Harvey proposed, for example, the concept of blood cycle in 1628.
- > The "fluid Mechanics period". From Henry DARCY (1803-1856) and Adhémar BARRE de St VENANT (water shallow equations), the French Hydrology and Hydraulics works became very much modelling driven and until now, this influence is still very important
- > The "integration and water management period". From the two previous periods, various works in different domains regarding water management, but also environment generally speaking are, more and more combined, coupled and, finally, integrated to lead to the "modern" concepts of integrated Hydrology. One of the first studies in this integrated field is the research report on "Méthodes d'étude régionale des ressources en eaux, application au bassin de l'Allier – Montpellier Sciences Faculty" in 1966. In this report, Hydrology, Geology, Geography, but also Biology, Ecology, Economy, ..., are coupled to propose an integrated vision of the water resources management.

During all these periods, and initially driven by the needs of the municipal fresh water supply networks, water quality has been a constant top question. Chemistry, Geochemistry, but also Biology, Microbiology, Ecology, ..., has been and still are important scientific disciplines involved, more and more, in hydrological and more widely water related studies and research.

As a conclusion, the next step for Hydrology is certainly in our capabilities to go across the scales, for very local to climate scales. In this respect, the basin scale, and more generally the basin as our fundamental hydrological object should certainly be re-examined.

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Floods and droughts – the shape of things to come?

Alan Jenkins

Abstract

The recent past has been hydrologically volatile across Europe with frequent floods interspersed with severe drought. There is a growing weight of opinion that this is a result of climate change. Long term hydrological records show, however, that this volatility is perhaps not exceptional in relation to the last 150 years. Indeed, there are few, if any, compelling long term trends in extreme flows, wet or dry, evident in the long term hydrological data for the UK.

Hydrometric data in the UK is held in the National Water Archive at Wallingford which comprises mean daily flows for c.1300 stations, monthly catchment rainfall, monthly instantaneous peak flows and related spatial, reference and statistical information. Many of the flow records date back 150 years, some longer, whilst rainfall records extend back c.200 years. This database provides a vital resource for assessing current and future departures from historical behaviour and, until today at least, has provided the basis for the statistical analysis that underpins flood risk, design levels, etc.

The broad changes expected for the UK in the future under a changed climate are wetter winters and drier summers but this does not necessarily imply increasing flood and drought risk. Increasing winter rainfall may actually promote more favourable water balances with fewer sequences of dry winters and hence a healthier groundwater outlook. Additionally, improved catchment and water management has reinforced the UK's resilience to flood and drought stress. Nevertheless, sustainable water management remains a considerable challenge given pressures of climate and population change.



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River science in the light of climate change

Huib de Vriend

1 Introduction

Climate change and a river's response to it are likely to be slow processes as compared to the responses to direct human interventions such as engineering works. Therefore, we have to look at timescales of centuries. Such timescales are difficult to be covered by numerical models and, moreover, uncertainties are so large that the degree of detail offered by numerical model simulations hardly pays off in terms of extra information. Therefore, we fall back on simple basic models providing first-order insight into a river's long-term behaviour. Starting from the basic drivers and controls of large-scale river morphology, we describe long-term changes as can be expected from climate change and long-lasting human interventions.

2 Drivers and controls

In order not to end up in the smallest upland streams, we confine ourselves to the more downstream parts of a river, where the slope is small and the bed is entirely alluvial. The principal drivers of a river defined this way are the amounts of water and sediment coming out of the drainage basin. The function of a river is to discharge these amounts. The water will end in a sea or a lake, in a groundwater reservoir, or evaporate, the sediment may be deposited under way, in the river bed or the riparian zone, or at the downstream end.

Important controls of a river are the valley slope and the downstream water level. Generally speaking, the river establishes its own bed slope, but the valley slope is an important control to the alignment (e. g. meandering). Depending on the timescale of the river bed response, short-term variations of the downstream water level, such as the semi-diurnal tide, may be of little influence, whereas longer-term variations, such as the 18.6-yearly nodal cycle and mean sea level rise, may have a much larger effect.

3 Equilibrium state model

For further analysis, we reduce the river to a straight channel of constant width, B , with an alluvial bed at level, $z_b(\mathbf{x})$, in which \mathbf{x} is the spatial co-ordinate along the channel. The remaining drivers and controls are the water discharge, Q , the sediment input, S , and the downstream water level (called erosion base), ζ_0 , which are all taken constant here.

We consider the equilibrium state of this simplified ‘river’. In several instances, this approach, despite its strong simplification of reality, has been shown to give good insight into the long-term response of lowland rivers to changes in its drivers and controls. In Section 4 we will give some examples.

This simplified ‘river’ has two variables to adjust its equilibrium state to such changes: the water depth, h , and the bed slope, i_b . The formulae describing these variables in terms of Q and S (the downstream water level only determines the absolute height of the bed) follow straightforwardly from the basic flow equations, as shown below (also see JANSEN 1979, p. 119).

mass balance water: $Q = BhU$ mom. balance water: $Q = BCh\sqrt{hi_b}$ sed. transport formula: $S = aBU^b$ sediment balance: $\frac{\partial S}{\partial x} = 0 \Rightarrow \frac{\partial U}{\partial x} = 0$	}	$h = \left(\frac{S}{aB}\right)^{-1/b} \frac{Q}{B}$ $i_b = \left(\frac{S}{aB}\right)^{3/b} \frac{B}{C^2 Q}$	(1)
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in which U denotes the cross-sectional mean velocity, C Chezy’s friction coefficient, a a coefficient of proportionality which is inversely proportional to some power of the grain size and b a constant exponent, usually somewhere between 3 and 5.

These formulae help explaining many observed large-scale responses of lowland rivers. Not that for $b=3$ the second one is equivalent to what is called Lane’s balance (LANE 1955), stating that the product of the water discharge and the bed slope is proportional to the product of the transport rate and the grain size.

4 Effects of human activities

4.1 Normalisation of the main channel

River training often involves normalisation of the main channel, i. e. establishing a constant channel width, usually narrower than before in order to improve navigability. In the Netherlands, extensive normalisation works have been executed in the Rhine branches in the 19th and 20th century (see Figure 1a for the River Waal).

In order to improve navigability, the main channel was narrowed. According to Eqs. (1), this led – as intended – to a deeper channel, but also to a smaller slope, hence to an incision further upstream (Figure 1b; also see VISSER et al. 1999). This causes problems with structures such as bridge piers, bank protections and man-made or natural poorly erodible layers. One example is a coarse sill near Emmerich, near the Dutch-German border, over which navigation becomes increasingly difficult as the downstream bed level decreases. Therefore, Germany and the Netherlands have agreed that the incision of the Rhine branches needs to be stopped and the Dutch are investigating measures to achieve this (e. g. sediment nourishments).

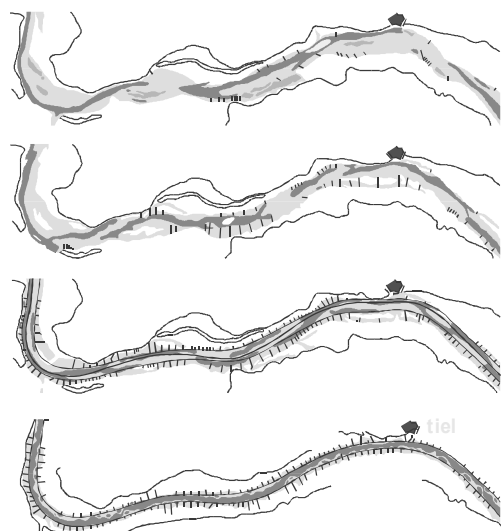


Fig. 1a: Successive normalisations of the Waal

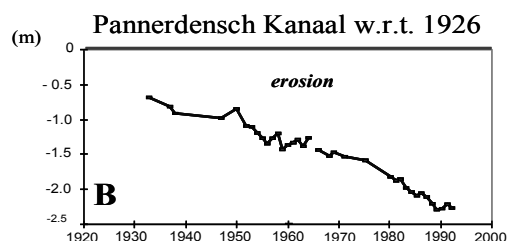
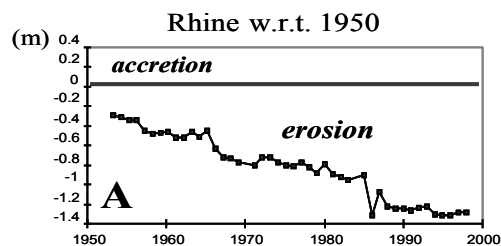


Figure 1b: Upstream response: incision

4.2 Sand mining

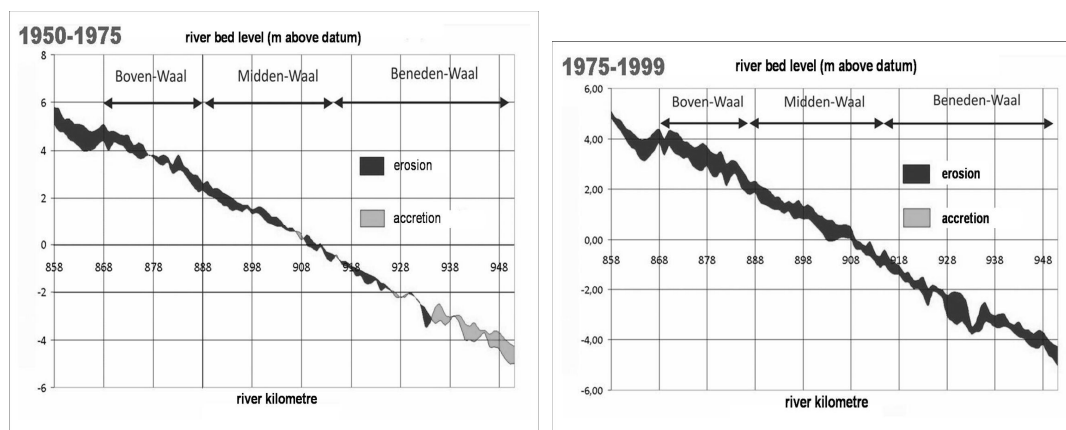


Figure 2: Profile evolution of the River Waal, before and after downstream sand mining

The tilting of the River Waal caused by the normalisations used to take place around a hinge point near Zaltbommel (Figure 2, left panel), because at the same time sea level rose and the downstream boundary shifted seawards, due to the closure of the Haringvliet estuary as part of the Deltaworks. The sand deposited downstream of Zaltbommel was allowed to be mined for commercial purposes. As a consequence, the erosion base came down to its original level and the entire river is bound to follow (Figure 2, right panel).

4.3 Water offtake

Many rivers around the world serve as a source of fresh water, used for various purposes, such as human consumption, irrigation, industrial use and to combat salt intrusion. If part of the river's discharge is taken out while the same amount of sediment has to be transported, however, the river will tend towards another equilibrium state. According to Eqs. (1), the depth will decrease and the slope will increase. Assuming the downstream boundary to remain the same, this means that the river bed further upstream will tend to rise above the sur-

rounding land, yielding a so-called ‘suspended river’. Also, the depth reduction will lead to a reduction of the river’s flood conveyance capacity. Examples of rivers behaving this way are the Lower Yellow River (see, for instance: SUO 2004) and the Indus (see http://www.bbc.co.uk/worldservice/news/2010/08/100818_indus_wt_sl.shtml).

4.4 Sediment trapping

Dams and weirs are found in the upstream parts of many rivers. Not only do they trap sediment, they also influence the discharge regime, hence the river’s transport capacity. In the highly simplified constant-discharge model described by Eqs. (1), the depth increases as the sediment supply decreases, but the slope decreases more (power $3/b$ instead of $-1/b$). The obvious and well-known consequence is river incision, starting from the sediment trapping obstacle and gradually extending downstream.

4.5 Model validity

The above examples make clear that the equilibrium relationships, despite the highly simplified model used, qualitatively explain a number of observed responses to human interventions. Hence one may assume that the same holds true for the response to climate change. As climate change is expected to affect discharge statistics, however, we can no longer stick to the assumption of constant discharge. Therefore, we will first extend the model to situations with a variable discharge.

5 Equilibrium state with variable discharge

The discharge in a river is by no means constant, it usually exhibits large variations. Therefore, and because climate change is expected to influence discharge statistics, it is important to work out the equilibrium state in case of a variable discharge, say with a probability density distribution $p(Q)$. If the upstream sediment supply remains constant, and we may assume the morphological evolution to be slow compared to the discharge variation, there exists an almost steady equilibrium state. This state can be derived in the same way as Eqs. (1), to yield:

$$h_m = \left(\frac{S}{aB} \right)^{-1/b} \frac{\left[\int_0^\infty Q^b p(Q) dQ \right]^{1/b}}{B} ; \quad i_b = \left(\frac{S_0}{aB} \right)^{3/b} \frac{B}{C^2 \left[\int_0^\infty Q^{b/3} p(Q) dQ \right]^{3/b}} \quad (2)$$

Note that for constant Q these formulae reduce to Eqs. (1), since $\int_0^\infty p(q) dQ = 1$ by definition. Also note that in case of a variable discharge, the water level will vary with the discharge, except at the mouth, where a constant level is imposed. Therefore, the equilibrium water depth can only be defined in the mouth and the equilibrium bed level has to be construed from the level in the mouth ($\zeta_0 - h_m$) and the bed slope.

6 Effects of climate change

6.1 Discharge effects

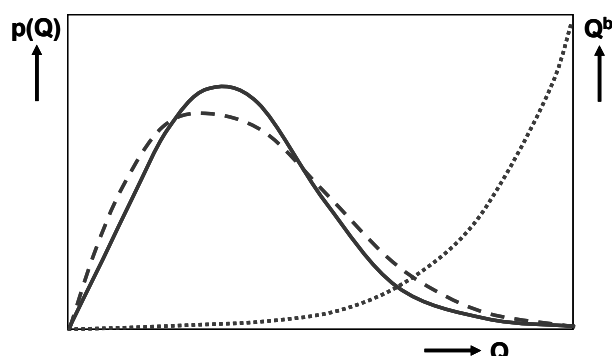


Figure 3: Climate change effect on discharge probability density function
(drawn: present; dashed: future; dash-dotted: exponential discharge function)

Climate predictions indicate dryer summers and wetter winters, meaning a relative increase of low and high discharges at the expense of the average ones. This means that the probability density function for the discharge will change as qualitatively indicated in Figure 3.

According to Eqs. (2), the equilibrium state is determined by the product of the probability density function and an exponential function of the discharge which is different for the depth in the mouth and the bed slope. Especially the increase of the higher discharges will be of influence. Generally, the predicted climate change effects will lead to an increased depth in the mouth and a reduced bed slope, and the depth will exhibit the strongest response to these changes in the discharge-pdf. Both effects lead to bed erosion and incision of the river.

6.2 Sediment yield effects

Climate change will not only affect precipitation and river discharges, but also land use and land cover. Also, rock weathering may be influenced. This means that climate change will also affect the basin's sediment yield and the sediment input into the river. Sign and magnitude of this change are difficult to predict and will depend on the region considered.

Both Eqs. (1) and Eqs. (2) indicate that an increase of the sediment supply will yield a smaller depth in the mouth and a steeper bed slope. This means: less navigable depth under low discharge conditions and a tendency towards a suspended river. A decrease of the sediment supply, on the other hand, will lead to a larger depth in the mouth and a smaller bed slope, so better navigability, but incision of the river.

6.3 Effects via the erosion basis

A third type of effect of climate change is an accelerated sea level rise. This affects the erosion base, hence the absolute level of the river in equilibrium, but it leaves the water depth in the mouth and bed slope unaltered. Note that this refers to the equilibrium state and that time is an important factor in the actual response of a river to sea level rise. In order to know more about this, we have to look into the time evolution of river morphology.

7 Morphological evolution with time

7.1 Basic time-behaviour

In a simplified model like the one considered here, the time-evolution of the bed level is a mixture of two basic types of behaviour, viz. propagation and spreading (also see RIBBERINK & VAN DER SANDE 1985). The corresponding equations read:

$$\text{propagation: } \frac{\partial z_b}{\partial t} + c_b(z_b) \frac{\partial z_b}{\partial x} = 0 \quad \text{with} \quad c_b = \frac{b}{1 - \varepsilon} \frac{S}{Bh} \quad (3)$$

$$\text{spreading: } \frac{\partial z_b}{\partial t} - K(z_b) \frac{\partial^2 z_b}{\partial x^2} = 0 \quad \text{with} \quad K = \frac{b}{1 - \varepsilon} \frac{S}{3Bi_b} \quad (4)$$

in which ε is the porosity of the bed. Generally speaking, propagation processes proceed rather fast, and – under low Froude number conditions – in downstream direction ($c_b > 0$).

Spreading proceeds generally much slower and both in upstream and downstream direction. An example clearly illustrating this is that of a 5 km long constriction (fixed banks) in the schematised ‘river’ with a constant discharge (Figure 4). If we assume this constriction to be built in no time, the short term morphological response is erosion of the bed in the constricted reach and deposition of the erosion products downstream of it. These erosion products form a rapidly expanding bed wave moving downstream. Once this has left the model domain, a much slower upstream and downstream redistribution process takes over and ultimately produces the static equilibrium state.

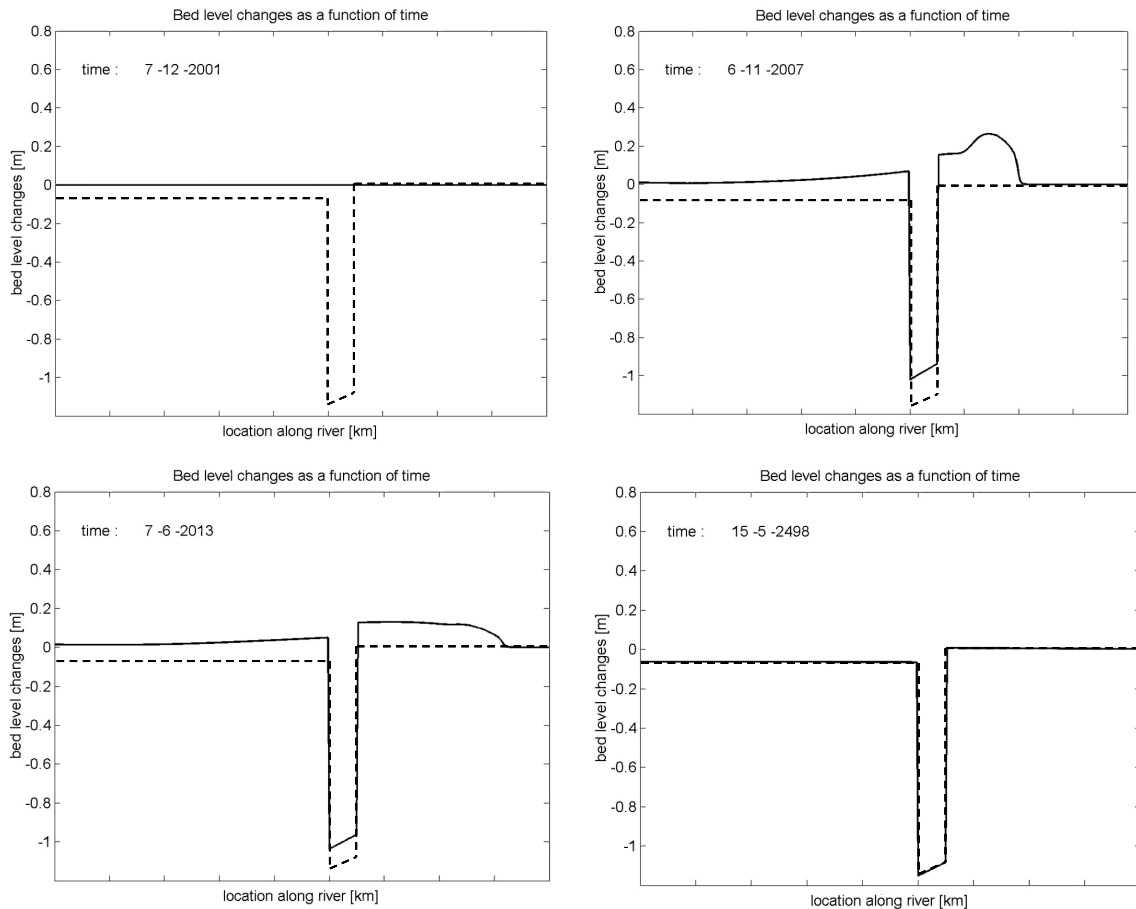


Figure 4: Numerical model simulation for a long constriction (drawn line) at different points in time, compared with the theoretical equilibrium state (dotted line). Also see VAN VUREN (2006).

7.2 Backward accretion

By nature, the propagation behaviour dominates in the first period after an intervention and the spreading behaviour manifests itself at a longer timescale. Climate change, however, is a slow process, which means that the response it causes will mainly exhibit a spreading behaviour. If sea level slowly rises, for instance, and the upstream conditions remain the same, upstream spreading will be the dominant mechanism. This leads to a gradual backward accretion of the river bed. If the sea level rise is a step function and K is taken constant, Eqs. (4) has an analytical solution which can be expressed in terms of error functions (Figure 5).

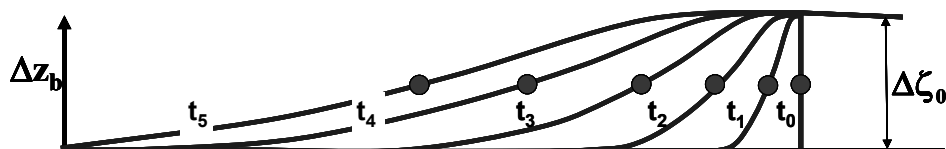


Figure 5: Solution of Eq. (4) in case of a stepwise sea level rise (flow from left to right, mouth right)

7.3. Morphological time scale

One may attribute a time scale to this solution by following the displacement of one point of the bed profile, for instance the point where half of the ultimate accretion has been reached.

The time – expressed in years – needed for this point to travel over a distance L is given by (see JANSEN 1979, p. 123):

$$T = \frac{L^2}{Y} \quad \text{with} \quad Y = \frac{b}{1 - \varepsilon} \frac{1}{3Bi_b} \int_0^{1 \text{ year}} S dt \quad (5)$$

One can use this time scale definition to compare rivers by the speed of their response to changes in environmental conditions. When doing so, it turns out that the River Waal, with its relatively coarse sediment and its mild slope, is a slowly responding river (JANSEN 1979, p. 124). This is in line with the observed slow response to the normalisation works of the nineteenth and early twentieth century: The incision is still going on.

This means that this river is probably unable to follow the rising sea level over its entire length, so that it will be out of equilibrium as long as sea level rises. It also means that, if the sea level stops rising, or some engineering measure disconnects the river from the effect of sea level rise, there will be a long aftermath in the river's morphological response.

8 Conclusions

The tendency of a lowland river's long-term response to human interventions or changes in environmental conditions can be derived qualitatively from highly simplified, elementary and long-known models, such as Eqs. (1) for the static equilibrium state at constant discharge, or Eqs. (2) for the equilibrium state at variable discharge. In this way, a qualitative estimate of a river's response to climate change can be given without complex model simulations.

Climate change affects a number of important drivers and controls of a river, such as water discharge (via precipitation and snowmelt), sediment input (via land use, land cover and rock

weathering) and the downstream water level (via sea level rise). The above models make it possible to predict the effects of each of them. As these models are basically non-linear, however, these effects cannot simply be superimposed. Combinations of effects and quantitative predictions therefore require numerical simulation models.

In long-term river morphology, time becomes an important factor if the timescale of the morphological response is similar to the timescale of change of the environmental conditions. A slowly responding river like the Rhine may therefore never reach equilibrium as long as it experiences the effects of climate change and sea level rise. This needs to be taken into account when designing climate adaptation measures.

Despite the possibility to use simple and well-known models to estimate the trend of a lowland river's response to climate change, knowledge needed for more accurate and quantitative assessments is still exhibiting important gaps. The research agenda for long-term river morphology includes items such as adequate model schematisation (pays off for long-term simulations and scenario studies), dealing with graded sediments (e. g. downstream fining and the effects of nourishments), bifurcations (including the long-term evolution of their flood conveyance capacity), sediment management (pathways, sediment as a resource) and biogeomorphology (the interaction of vegetation and morphology).

Summary

Simple, well-known models are proposed to estimate the long-term effects of climate change on lowland rivers. They concern the static and quasi-static equilibrium states of highly simplified straight fixed-bank channels with an alluvial bed, as well as the long-term limit of their evolution with time. These models are validated qualitatively against observed responses to a number of human interventions in such rivers and, subsequently, applied to qualitatively predict the effects of climate change on a number of important drivers and controls.

This leads to the conclusion that, for a slowly responding river like the Rhine, trends in the response to climate change can be identified from the equilibrium models, but that the river will probably never actually reach such an equilibrium state as long as climate changes and sea level rises.

Literature

JANSEN, P. PH. (ed.) (1979): Principles of river engineering. Pitman, London (1979) [ISBN 0-273-01139-1]; Delft University Press (1994) [ISBN 90-407-1280-8]

LANE, E. W. (1955): Design of stable channels. *Trans. ASCE*, 120: 1243.

RIBBERINK, J. S. & J. T. M. VAN DER SANDE (1985): Aggradation in rivers due to overloading—analytical approaches. *Journal of Hydraulic Research*, 23(3):273–83.

SUO, L. (2004): River management and ecosystem conservation in China. *Proc. Ninth Int. Symp. on River Sedimentation*, Yichang, China, p. 1-10.

VAN VUREN, S. (2005): Stochastic modelling of river morphodynamics. PhD thesis, Delft University of Technology, 275 pp (also: Delft Hydraulics Select Series no. 8, ISBN 90-407-2605-1).

VISSER, P. J., H. HAVINGA & W. B. M. TEN BRINKE (1999): How to keep the river navigable? *Land en Water*, 9: 25-27 (in Dutch).



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Specialisms

River flow and morphodynamics

Coastal morphodynamics

Shelf sea morphodynamics

Estuarine morphodynamics

Building with Nature

Ensemble- and multi-model-based low flow projections of the impact of climate change for the River Rhine within the research programme KLIWAS

Thomas Maurer, Enno Nilson, Maria Carambia, Peter Krahe,
Jörg Belz and Sebastian Kofalk

1 Introduction

Evidence from observations as well as projected scenarios of future developments by climatologists suggest considerable changes of our climate. In particular, higher temperatures and modified precipitation patterns are expected, potentially affecting the water cycle and hence discharge and water levels of navigable rivers.

Navigable waterways in Germany sum up to 7,300 km of rivers and canals and around 23,000 km² of coastal waterways. Among all modes of transport, inland and coastal navigation excels by its energy efficiency, thus contributing to the protection of the climate. However, the efficiency of goods and passenger transport on waterways may be severely affected by adverse consequences of climate change in the future. Users of waterways, politicians and the Waterways and Shipping Administration (*WSV*) require reliable statements on potential impacts of climate change to relevant indicators, such as e. g. for low flow and whether, when and which adaptation measures need potentially to be taken.

2 Uncertainties in climate projections and the model chain

An analysis of the state-of-the-art of climate projections and potential consequences for navigation and navigable waters in Germany was published by BMVBS (2007) highlighting the need of closing fundamental knowledge gaps. Currently available climate projections as used in the 4th report of the IPCC (2007) feature considerable uncertainties especially for Central Europe. Figure 1 from CHRISTENSEN et al. (2007) illustrates the uncertainty resulting from the ensemble of 21 global climate models (GCMs) driven by the assumption of the A1B-greenhouse gases emission-scenario (SRES 2000). While the majority of the 21 GCMs show an increase of mean precipitation in Northern Europe in the next 100 years, almost none does so in the southern Mediterranean region. In contrast, the white zones in Central Europe mark regions where projections are less clear, i. e. where approximately half of the GCMs project an increase in mean precipitation while the other half does not.

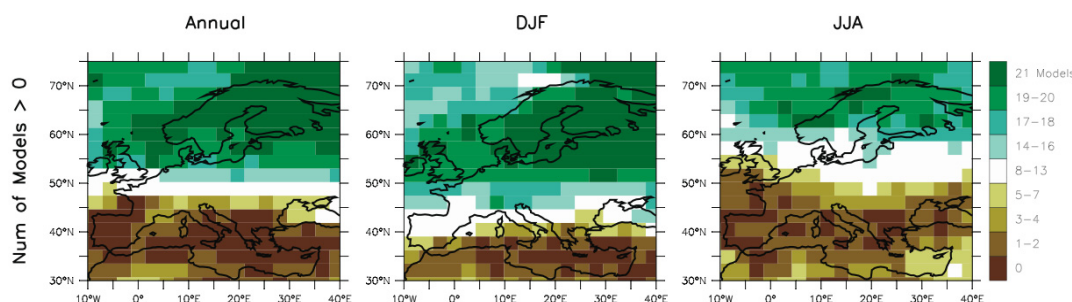


Figure 1: Number of 21 GCMs used in IPCC-4AR projecting an increased annual mean precipitation (comparison of the period 2080 – 2099 against 1980 – 1999, Multi-Model Data (MMD), A1B Scenario, grid width 2,7° x 2,7°) (CHRISTENSEN et al. 2007)

Precipitation is the fundamental boundary condition for land surface hydrological processes including river flows. The considerable uncertainties in precipitation are propagated along the “chain” of the so-called impact models (model chain, cf. figure 2) used to assess the impacts of climate change on hydrological conditions, water quality, ecology and economy. The processes within all the models of the model chain feature a complex interplay of partly positive and negative feedbacks. This together with coupling of different spheres and scales as well as the need for assuming various scenarios of potential future developments lead to what has been called „cascading pyramid of uncertainties“ (SCHNEIDER 1983) or „uncertainty explosion“ (HENDERSON-SELLERS 1993).

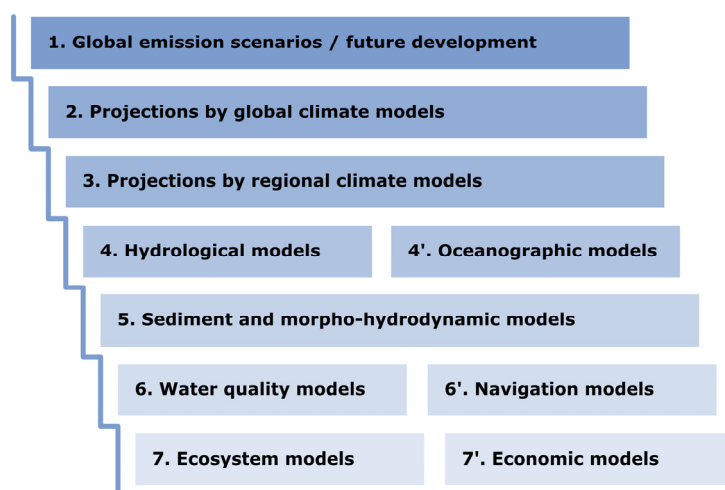


Figure 2: Model-chain relevant for the system of waterways

As depicted in figure 3, reliability of results decreases along the model chain. Likewise it is by far more problematic to project changes of extreme values such as flood recurrence intervals or rare low flow events than changes of long term annual mean values. Finally uncertainty increases the smaller the region for which a projection is required. These uncertainties as well as encountered systematic errors in the precipitation statistics of GCM simulations need to be quantified and put into relation to climate change signals as e. g. shown exemplarily in KRAHE et al. (2009)

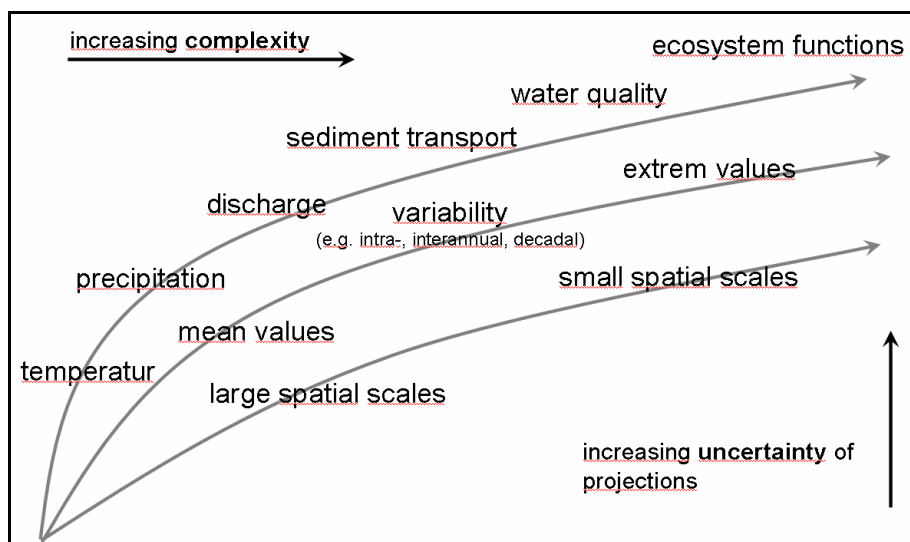


Figure 3: Reliability of projections. Increase of uncertainty with raising complexity along the model chain, increasing spatial and temporal resolution and rareness of events (MAURER et al. 2007).

3 The research programme KLIWAS

In face of many open questions, the German Federal Ministry of Transport, Building and Urban Development (BMVBS) commissioned its four subordinated research institutions

- > Bundesanstalt für Gewässerkunde (BfG, Federal Institute of Hydrology)
- > Bundesamt für Seeschifffahrt und Hydrographie (BSH, Federal Maritime and Hydrographic Agency)
- > Deutscher Wetterdienst (DWD, National Meteorological Service), and
- > Bundesanstalt für Wasserbau (BAW, Federal Waterways Engineering and Research Institute)

to analyse the potential consequences of climate change for navigation on inland and coastal waterways and to formulate appropriate strategies for adaptation to potentially changing environmental conditions in the future. This task is performed between 2009 to 2013 in the framework of the research programme KLIWAS “Impacts of climate change on waterways and navigation – options to adapt” (www.kliwas.de). Approximately 40 researchers provide for a total of around 200 person-years of research work, boosted by several national and international collaborations and co-operations in order to examine potential changes on the network of waterways as well as its sensibilities and vulnerabilities in order to develop adaptation options to potential threats. Targets of this research effort are, on the one hand, to safeguard the efficiency of this mode of transport and, on the other hand, to preserve the water quality and the habitats in rivers, canals, lakes, and coastal waters.

KLIWAS is an example of departmental research, i. e. at the interface of science and politics it aims to provide a sound scientific basis for political decisions on different proposed adaptation measures. The research programme KLIWAS following a multi-model approach as its key concept for uncertainty assessment is carried out in three successive steps, depicted in figure 4.

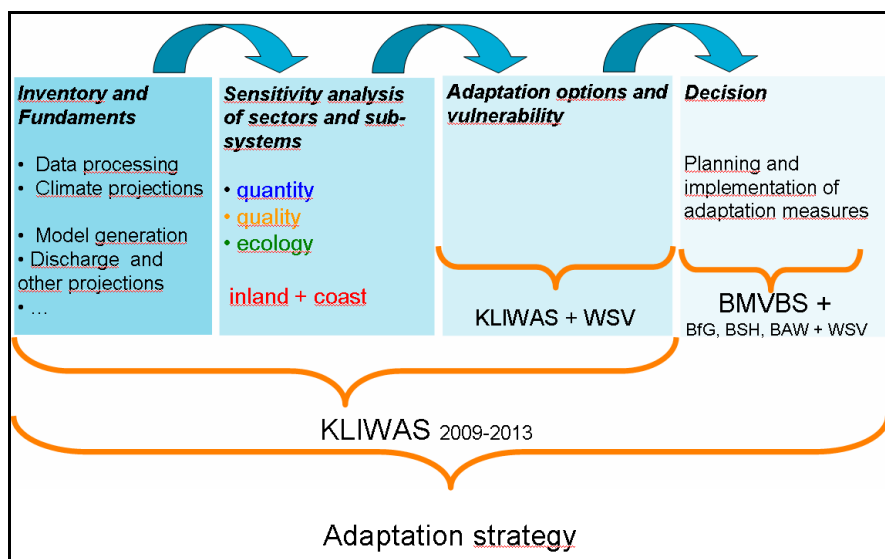


Figure 4: Steps of the KLIWAS Research Programme

1. Preparation and analysis of regional projections of variables such as river discharge and its characteristics in response to the combination of different global and regional climate models (ensembles).
2. Analysis and assessment of the changed hydrological and oceanographical situation, sensitivity and vulnerability of the systems under examination.
3. Development and analysis of adaptation measures

KLIWAS is organised in five major research themes with a total of approximately 30 projects and a coordination team. Besides exploring climate projections quantitative, qualitative and ecological themes are explored for both, inland waters and coastal zones including estuaries and the sea.

- > Meteorological climate projections
 - Theme 1: Validation and evaluation of climate projections – provision for the application on waters and navigation
- > Impacts of climate change on coasts and estuaries
 - Theme 2: Changes in the hydrological system and adaptation options for waterways and navigation
 - Theme 3: Changes and sensitivity of water body state (morphology, quality, ecology) and adaptation options for waterways and navigation.
- > Impacts of climate change on inland waters
 - Theme 4: Changes of the hydrological system (sediments, morphology) and adaptation options for waterways and navigation.
 - Theme 5: Impacts on structure, ecological integrity and management of inland waterways.

A focus regarding regions under investigation will be the Rhine, Danube and Elbe rivers as well as the North Sea and its estuaries. The remainder of this paper concentrates on findings for the Rhine River due to the fact that the Rhine basin was examined in the framework of a precursor to the KLIWAS research programme since 2007.

The findings of KLIWAS research will serve to advise the Federal government in matters of inland navigation and waterways and will contribute to the German Adaptation Strategy (DAS 2008) to climate change. Moreover, they will be beneficial for other sectors such as agriculture, energy generation, and the insurance industry. See www.kliwas.de for more information, especially also for a complete list of all publications resulting from the programme.

4 Observed changes in the Rhine basin

The Rhine basin (cf. figure 5, also see MOSER & KRAHE, this report) is shared by nine countries (Germany, The Netherlands, Switzerland, France, Luxembourg, Austria, Liechtenstein, Belgium and Italy). The total catchment area is 197,000 km², inhabited by approximately 58 million people. Flow regime ranges from nival (= snow-dominated) regime in the mountainous areas of the Alps featuring a large amplitude with highest mean monthly flows in the summer months due to snowmelt and a minimum in winter when precipitation is retained as snow cover to the almost opposite type of pluvial (= rain dominated) oceanic regime in the Mosel river with a maximum in the mild rainy winter months and a minimum in summer. The downstream gauging stations along the main river feature a comparatively balanced mixed regime (rain-snow type), as e. g. at Cologne gauging station depicted in figure 5.

Figure 5 also shows normalised mean annual hydrographs of discharge at Cologne gauging station for four 25-year periods in the last century. All four periods were equally normalised with the mean annual discharge of the entire period 1901 - 2000. The curve representing the hydrological years from 1976 to 2000 clearly shows that the mean normalised monthly discharge in the winter months increased compared to the previous 25-year periods (increased seasonality) while the discharge level observed in autumn stayed more or less constant. However the month of lowest discharge amounts – highly important for navigation – shifted on average from October into September. Such regime changes could cause a more frequent and unfavourable superposition of extreme discharges from various parts of the catchment area and provoke the occurrence of e. g. longer low-water periods.

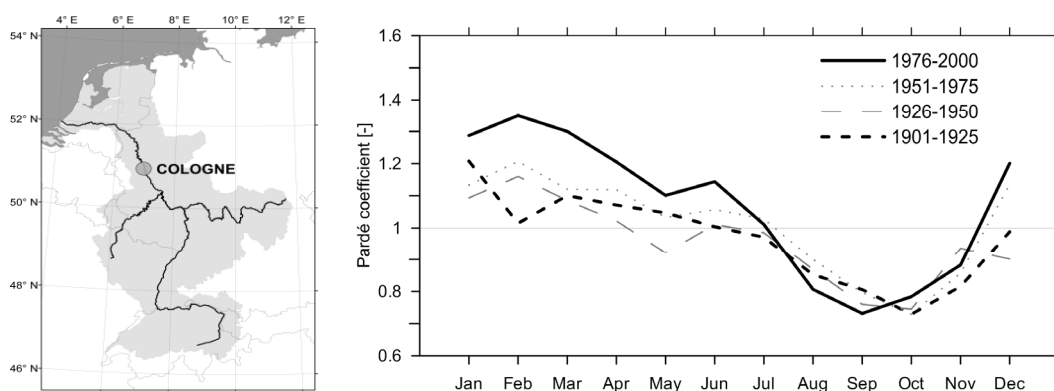


Figure 5: Changes of flow regime at gauging station Cologne/Rhine in the 20th century. Development of the average 25-year monthly discharges normalised with the mean annual discharge between 1901 and 2000 (the so-called PARDÉ-coefficients).

Figure 6 shows the development of air temperature, precipitation and discharge during the 20th century. There is a positive trend in winter for all three variables, while in summer only air temperature increases, while precipitation and discharge remain close to constant.

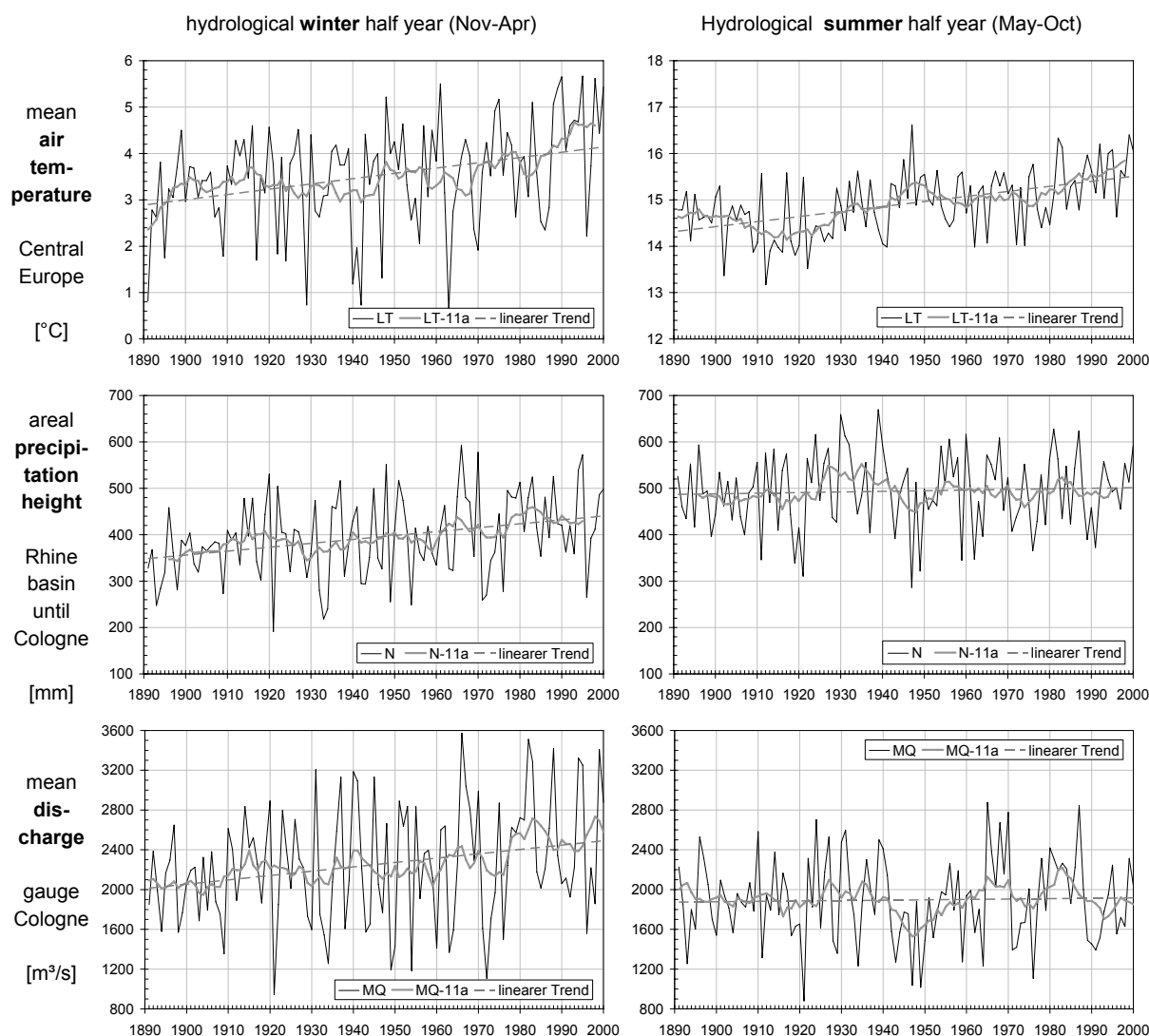


Figure 6: Observed Changes 1891 - 2000: Development of air temperature in Central Europe (top row), mean precipitation on the catchment upstream gauging station Cologne/Rhine (central row) and mean discharge (MQ) at gauging station Cologne/Rhine for hydrological winter (Nov - Apr) and summer (May - Oct) (source: BfG)

Rising temperatures during the 20th century changed the precipitation mode especially in winter. More rainfall and less snow cause a higher portion of winter precipitation more directly to become runoff and finally (winter) discharge. In the contrary this reduces snow melt contributions to discharge in summer months. In terms of the flow regimes this corresponds to an “pluvialisation” of the regime.

This development is even intensified by anthropogenic impacts due to management of large storage reservoirs. They store water in summer and release it in winter thus producing additional similar seasonal redistribution effects.

These developments causes trends of seasonal (half-year) and annual values of the low-flow parameter NM7Q (30 year mean of seasonal lowest 7-day mean discharges) at gauges with long observation series in the Rhine basin to increase over the period 1901 - 2000 as is described in more detail in the analysis of BELZ et al. (2007) in the framework of an expert group of the International Commission for the Hydrology of the Rhine Basin (CHR). Another key conclusions from BELZ et al. (2007) is, that 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 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.

5 Discharge projections in the Rhine basin

In the framework of the research programme KLIWAS BfG is developing multi-model discharge ensembles for the rivers Rhine, Elbe and Danube. So far projections for the River Rhine are the most advanced and constitute a major contribution to the collaboration project "Rheinblick 2050" of an expert group of the International Commission for the Hydrology of the Rhine Basin (CHR) documented in GÖRGEN et al. (2010). Figure 7 gives an overview of the Rhine basin, gauging station names used in the remainder of this text as well as an impression of the spatial structure of the underlying hydrological model HBV used for the results reported here.

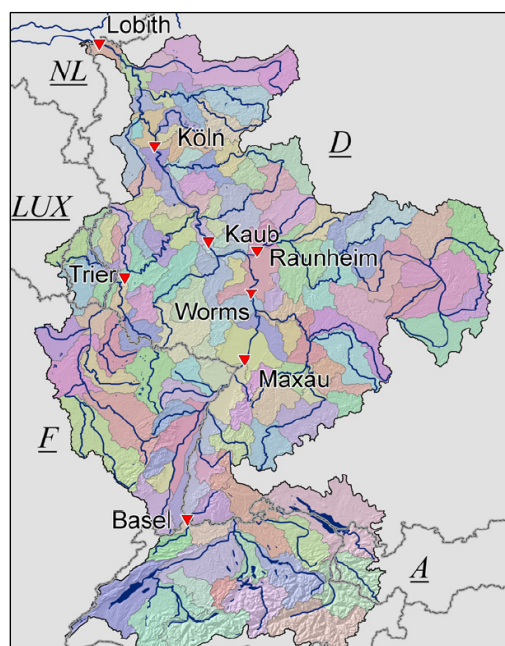
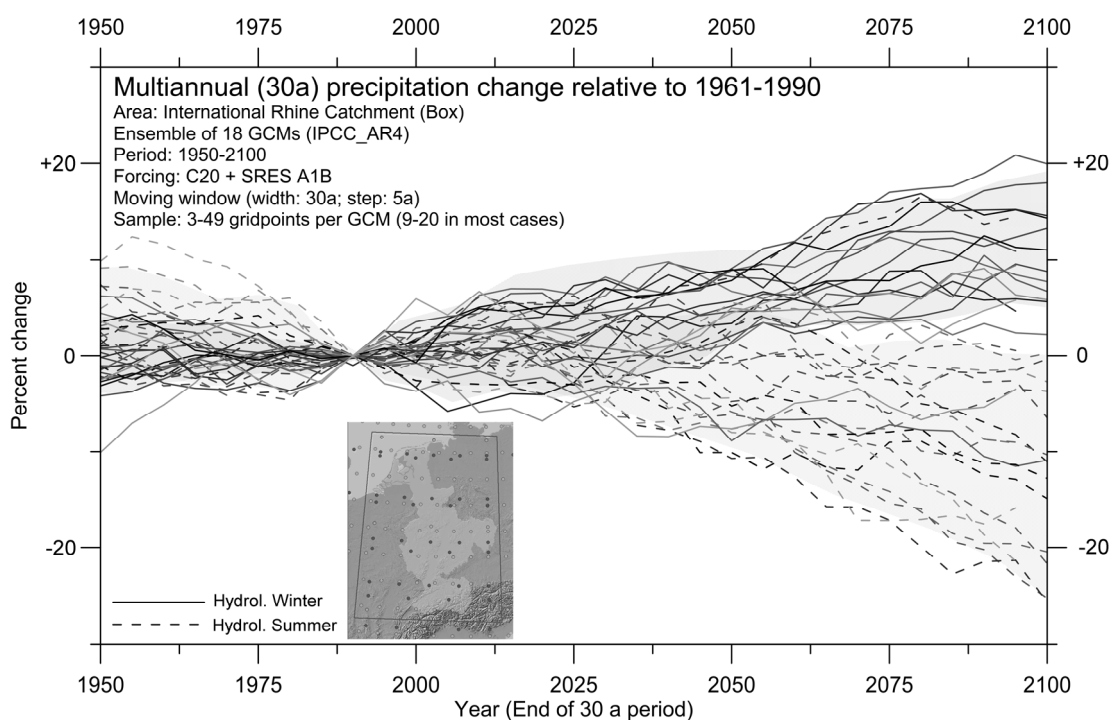


Figure 7:
Eight gauging stations (red triangles) along the Rhine River, Main River (Raunheim) and Moselle River (Trier). The background shows the 134 subcatchments used within the HBV model (from GÖRGEN et al. 2010).

The focus is on the quantification of characteristic statistical numbers describing the critical states for current and future conditions, such as e. g. the 30-year mean of the lowest annual flow during seven consecutive days (NM7Q). However, due to the large number of possible combinations of scenarios, climate and impact models as well as bias correction methods a single combination ("model chain") resulting in a single value is of somewhat arbitrary nature. As a consequence, rather the bandwidth resulting from the multi-model-ensemble will be reported – in an attempt to quantify the uncertainty of the projections.

Figure 8 shows the bandwidth from 18 GCM simulations of projected changes of 30-year means of precipitation relative to the period 1961 - 1990 differentiated by season and integrated over a bounding box around the basin of the River Rhine. As long as mean annual precipitation does not change much and no significant change in storage of water (in snow cover, lakes or ground water) happens this suggests a tendency to lower mean monthly discharges in summer and higher discharges in winter. Figure 8 also illustrates well the remarkable span between the climate simulations in the control period before 1990.



Used GCM: CGCM3.1(T47), CNRM-CM3, CSIRO-Mk3.0, ECHO-G, FGOALS-g1.0, GFDL-CM2.0, GFDL-CM2.1, GISS-AOM, GISS-EH, UKMO-HadCM3, UKMOHadGEM1, INM-CM3.0, INGV-SXG, IPSL-CM4, MI-ROC3.2(hires), ECHAM5/MPI-OM, MRI-CGCM2.3.2, CCSM3

Figure 8: Bandwidth from 18 GCM simulations (IPCC-4AR, SRES A1B) of projected changes of 30-year means of precipitation relative to the period 1961 - 1990 differentiated by season and integrated over a bounding box around the basin of the River Rhine (NILSON et al. 2010b).

For the analysis of the possible future development of the discharges 25 combinations of GCMs and RCMs from the EU-project ENSEMBLES (2009) were used. However, in view of partly considerable biases in precipitation but also temperature some combinations were discarded and all projections of climate variables had to be bias corrected in order to give valid boundary conditions for the subsequent hydrological impact model. This is far from satisfying, but is inevitable as long dynamic climate models cannot represent the temporal and geographical precipitation spectrum better in a statistical sense (cf. MUDELSEE et al. 2010).

Figure 9 shows the projected change in discharge regime for three gauging stations after DE KEIZER et al. (2010) compared to the simulation under current climate (black line). The first column in figure 9 gives a measure of the quality of the climate simulations during the control period. Ideally all 20 simulations with different model chains (grey lines) would be

congruent to the reference. The second and third column show the projected development towards the middle and the end of the 21st century. These results confirm the already observed trend of a slight increase of mean annual discharges (cf. figure 6) as well as a shift of flow from the summer into the spring (cf. figure 5). This appears plausible as a lower share of precipitation is expected to fall as snow in the Alps and snow cover itself will melt earlier due to higher temperatures.

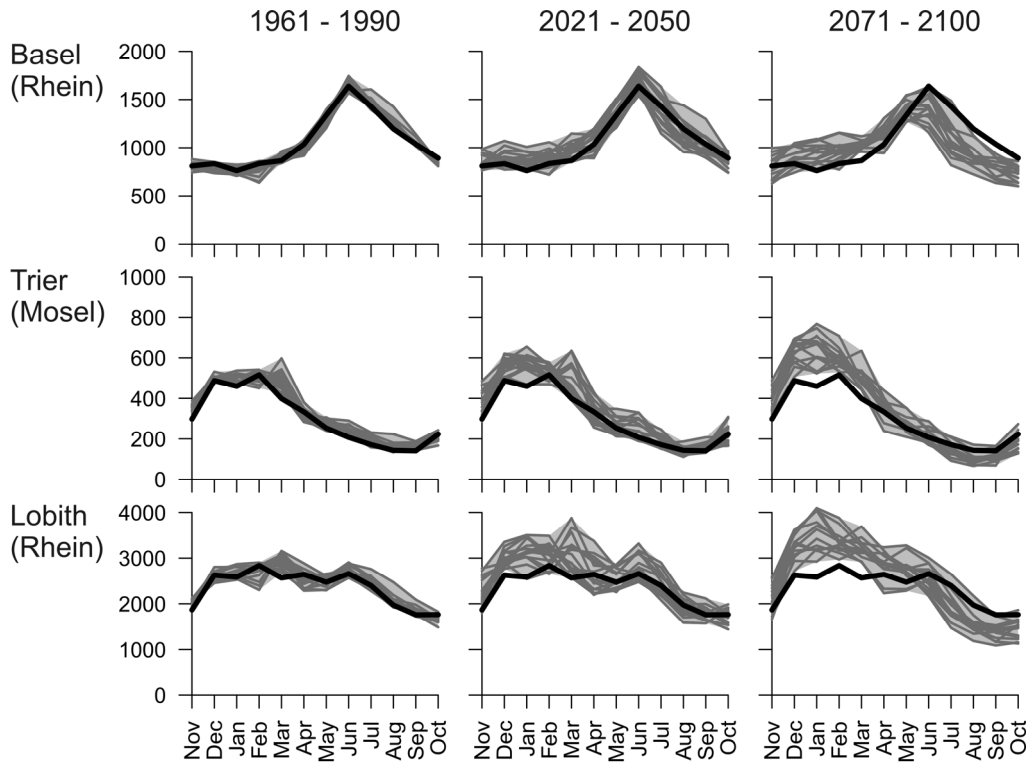


Figure 9: Change in discharge regime for three gauging stations (DE KEIZER et al. 2010). Long-term monthly mean discharge for the reference period (1961 to 1990, control), the near future (2021 to 2050, projection) and the far future (2071 to 2100, projection). Grey lines: hydrological model simulation results, 20 model chains with bias corrected precipitation, temperature and global radiation/sunshine duration. Black line: discharge regime simulated with observed meteorological forcing (1961 to 1990 period) as reference in all plots.

Finally, table 1 summarises scenario bandwidths and tendencies for low flow characteristics (from NILSON et al. 2010a). Changes are evaluated in terms of the multi-annual mean change of the lowest 7-day mean discharge (NM7Q) by hydrological season and the discharge that is undershot only on 10 % of all days of a 30-year period (FDC_Q90, i. e. the 90th percentile of the flow duration curve representing 10,950 days (plus leap years)). NM7Q integrates over several days of low flow and thus is less dependent on single day values and therefore more robust than e.g. the multi-annual mean of the lowest daily discharge. While NM7Q gives information on low flow per season, FDC_Q90 characterises low flows over the entire year.

For **summer NM7Q** the ensemble shows no obvious tendency in the mid of the 21st century (2021 to 2050). For the gauges of the Rhine River virtually half of the members show an increase (meaning less severe low flow conditions) while the other half shows a decrease. The bandwidth is around +/- 10 % (neglecting the outer most runs from the bandwidth of the entire ensemble) and increases slightly downstream from Basel to Lobith. For the Main River results for gauge Raunheim show consistently increasing NM7Q values with a bandwidth from 0 % to 20 %. Also for the Moselle River at Trier a majority of ensemble members clusters below the zero line indicating decreasing NM7Q values during summer. However, as the bandwidth is much wider (+/- 20 %), the signature “no tendency” is chosen.

Most “far future” simulations (2071 to 2100) at the main stream gauges and the Main at Raunheim show more severe low flow situations (NM7Q) in summer with a bandwidth of -30 to -10 %. This is even more pronounced for the Moselle River at gauge Trier with a large bandwidth between -50 % and -20 %.

Table 1

Scenario bandwidths and tendencies for low flow measures (periods 2021 to 2050 (“near future”; 20 members) and 2071 to 2100 (“far future”, 17 members) compared to reference period 1961 - 1990) (NILSON et al. 2010a, modified)

Target measure	Gauging station	2021 to 2050	2071 to 2100
NM7Q summer	Basel	+/- 10%	-20 to -10%
	Maxau	+/- 10%	-20 to -10%
	Worms	+/- 10%	-25 to -10%
	Kaub	+/- 10%	-25 to -10%
	Köln	+/- 10%	-30 to -10%
	Lobith	+/- 10%	-30 to -10%
	Raunheim	0 to +20%	-20 to 0%
	Trier	+/- 20%	-50 to -20%
NM7Q winter	Basel	+5 to +15%	0 to +15%
	Maxau	0 to +10%	-5 to +15%
	Worms	+5 to +15%	-5 to +15%
	Kaub	0 to +15%	-5 to +15%
	Köln	0 to +15%	0 to +20%
	Lobith	0 to +15%	-5 to +15%
	Raunheim	+5 to +15%	0 to +20%
	Trier	+/-15%	0 to +20%
FDCQ90	Basel	0 to +15%	+/- 10%
	Maxau	0 to +15%	-15 to +5%
	Worms	0 to +15%	-15 to +5%
	Kaub	0 to +15%	-10 to 0%
	Köln	0 to +15%	-20 to -10%
	Lobith	0 to +15%	-20 to -10%
	Raunheim	0 to +20%	-20 to 0%
	Trier	+/- 10%	-50 to -30%

NM7Q <season>: 30 year mean of seasonal lowest 7-day mean discharges

FDCQ90: Discharge exceeded in 90 % of all days in a 30-year period (or on 330 days per year)

Winter NM7Q values generally point to increasing values, meaning less severe low flow conditions. Most projections lie within a bandwidth of 0 % to +15 % for both, near and far future. For some gauging stations the bandwidth is slightly higher and includes also weak decreases (e. g. bandwidth of -5 % to +15 % at Lobith). For the Moselle River at Trier no clear tendency can be found for the near future.

With reference to the “near future” (2021 to 2050) the projected **FDC_Q90** values suggest an increasing tendency with a scenario bandwidth of 0 % to +15 %. This indication of less extreme low flow situations also holds true for gauge Raunheim located at River Main with a slightly larger bandwidth. For the Moselle River at Trier no clear tendency is discernible.

For the “far future” time-slice the bandwidth of simulations is similar as before, but does not show a clear direction of change for gauges upstream of Kaub. From Basel (+/- 10 %) to Lobith (-20 to -10 %) the bandwidth shifts from no tendency towards clear decreases. These regional gradients can also be found on the tributaries. For the Moselle River (-50 to -30 % at Trier) a more pronounced decrease is indicated than for the Main river (-20 to 0 % at Raunheim).

Summary and outlook

The ongoing research programme KLIWAS of the German Federal Ministry of Transport, Building and Urban Development (BMVBS) features 200 person years of research between 2009 and 2013. KLIWAS is looking at inland as well as coastal waterways, covering the large river basins of Germany with a focus on Rhine, Elbe and Danube not only from the point of view of water quantity but also water quality and ecology.

In the framework of KLIWAS and in collaboration with other supreme federal agencies as well as with several international projects the BfG examines potential changes of the impacts on the network of waterways as well as its sensibilities and vulnerabilities in order to develop adaptation options to potential threats. BfG's research activities on the River Rhine are internationally co-ordinated through the International Commission for the Hydrology of the Rhine Basin (CHR, <http://www.chr-khr.org>) in the framework of the RheinBlick2050 project.

The primary focus is on the quantification of characteristic statistical numbers describing the critical states for current and future conditions, such as e. g. the 30-year mean of the lowest annual flow during seven consecutive days (NM7Q). However, due to the large number of possible combinations of scenarios, climate and impact models as well as bias correction methods a single combination (“model chain”) resulting in a single value is of somewhat arbitrary nature. As a consequence, rather the bandwidth resulting from the multi-model-ensemble has been reported in order to quantify the uncertainty of the projections.

According to the majority of the projections from EU-project ENSEMBLES (2009) and other projects winter mean flow is expected to increase between 0 % to +25 % until the middle of the 21st century and between 5 % to +40 % until its end. The corresponding projections for the summer show no clear changes until the middle of the 21st century and a decreasing tendency (-5 % to -30 %) towards the end of the 21st century. The changes of seasonal lowest 7-day mean discharges (NM7Q) are generally very similar except that the increasing tendencies in winter for near and far future are lower (0 to +15 %).

These findings are coherent with the already observed trend in the 20th century of a slight increase of mean annual discharges (cf. figure 6) as well as a shift of flow from the summer into the spring (cf. figure 5). This appears plausible as a lower fraction of precipitation is expected to fall as snow in the Alps and snow cover itself will melt earlier due to higher temperatures.

Another focus of KLIWAS is to quantify the vulnerability of the industry dependent on the transport by barge as well as the transport sector and currently used vessel-types itself. Eventually, investment-related and operative adaptation options will be explored, such as river training as well as water management measures, but also innovative fleet guidance systems, fleet structure changes or even changes of mode of transport.

As a good example for the transformation of research into policy KLIWAS results are already fed into the political process via an expert group within the International Commission for the Protection of the River Rhine (ICPR, <http://www.iksr.de>). Thus it is ensured, that the results presented for the river Rhine serve as a rational basis for political and economical decisions, e. g. by including them in subsequent cost-benefit considerations.

Literature

- BELZ, J. U. (2007): Low Flow Conditions in the Rhine Basin – Developments in the 20th Century. In: KHR/CHR-Workshop and Expert Consultation “Low Flows and Droughts”, Book of abstracts, p. 27-34. Würzburg 2007.
- BELZ, J. U., G. BRAHMER, H. BUIVELD, H. ENGEL, R. GRABHER, H. HODEL, P. KRAHE, R. LAMMERSSEN, M. LARINA, H.-G. MENDEL, A. MEUSER, G. MÜLLER, B. PLONKA, L. PFISTER, W. VAN VUUREN (2007): Das Abflussregime des Rheins und seiner Nebenflüsse im 20. Jahrhundert – Analyse, Veränderungen, Trends. Schriftenreihe der KHR, Bd. I-22, Koblenz und Lelystad, <http://www.chr-khr.org>
- BMVBS (2007): Schifffahrt und Wasserstraßen in Deutschland – Zukunft gestalten im Zeichen des Klimawandels – Bestandsaufnahme. <http://www.bmvbs.de>
- BMVBS (2009): KLIWAS - Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland - Tagungsband der ersten KLIWAS-Statuskonferenz. <http://www.bmvbs.de>
- CHRISTENSEN, J. H., B. HEWITSON, A. BUSUIOC, A. CHEN, X. GAO, I. HELD, R. JONES, R. K. KOLLI, W.-T. KWON, R. LAPRISE, V. MAGAÑA RUEDA, L. MEARN, C. G. MENÉNDEZ, J. RÄISÄNEN, A. RINKE, A. SARR AND P. WHETTON (2007): Regional Climate Projections. In: SOLOMON, S., D. QIN, M. MANNING, Z. CHEN, M. MARQUIS, K. B. AVERYT, M. TIGNOR AND H. L. MILLER (Eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- DAS (2008): Deutsche Anpassungsstrategie an den Klimawandel. Bundeskabinett. <http://www.bmu.de/klimaschutz/downloads/doc/42783.php>

- DE KEIZER, O., M. CARAMBIA, E. NILSON (2010): Changes in Mean Flow in the Rhine River Basin. Chapter 5 in: GÖRGEN, K., J. BEERSMA, G. BRAHMER, H. BUIVEVELD, M. CARAMBIA, O. DE KEIZER, P. KRAHE, E. NILSON, R. LAMMERSEN, C. PERRIN, D. VOLKEN: Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 Project. Schriftenreihe der KHR, Bd. I-23, <http://www.chr-khr.org>
- ENSEMBLES (2009): Climate change and its impacts at seasonal, decadal and centennial timescales. Abschlussbericht ENSEMBLES. Met Office, Hadley Centre for Climate Prediction and Research, Exeter, England. 164 S. <http://ensembles-eu.metoffice.com>
- GÖRGEN, K., J. BEERSMA, G. BRAHMER, H. BUIVEVELD, M. CARAMBIA, O. DE KEIZER, P. KRAHE, E. NILSON, R. LAMMERSEN, C. PERRIN, D. VOLKEN (2010): Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 Project. Schriftenreihe der KHR, Bd. I-23, <http://www.chr-khr.org>
- HENDERSON-SELLERS, A. (1993): An antipodean climate of uncertainty, *Climatic Change* 25, S. 203-224.
- IPCC (2007): Fourth Assessment – Climate Change 2007: The Physical Science Basis. Contribution of Working Group I of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., Miller, H. L. (Hrsg.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 S.
- KRAHE, P., E. NILSON (2009): Von der Klimaprojektion zum hydrologischen Szenario: Methodische Aspekte. In: BMVBS (Eds.): KLIWAS - Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland - Tagungsband der ersten KLIWAS-Statuskonferenz. S. 109-114.
- KRAHE, P., E. NILSON, M. CARAMBIA, T. MAURER, L. TOMASSINI, K. BÜLOW, D. JACOB, H. MOSER (2009): Wirkungsabschätzung von Unsicherheiten der Klimamodellierung in Abflussprojektionen – Auswertung eines Multimodell-Ensembles im Rheingebiet. *Hydrologie und Wasserbewirtschaftung*. Heft 5/2009. S. 316-331.
- MAURER, T., P. KRAHE, E. NILSON (2007): Abschätzung der Auswirkungen des projizierten Klimawandels auf Bundeswasserstraßen im Binnen- und Küstenbereich – Hydrologie, Hydraulik und Morphologie. Vortrag am 18.12.2007, BfG.
- MOSER, H., P. KRAHE, T. MAURER, E. NILSON (2008): Wasserstraßen - Handlungsoptionen für Wirtschaft und Binnenschifffahrt. Beitrag zum Symposium Klimaänderung - Was kann die Wasserwirtschaft tun? am 24./25 Juni 2008 in Nürnberg, Forum für Hydrologie und Wasserbewirtschaftung der Fachgemeinschaft Hydrologische Wissenschaften in der DWA (FgHW), Heft 24.08 (ISBN: 978-3-940173-97-3)
- MUDELSEE, M., D. CHIRILA, T. DEUTSCHLÄNDER, C. DÖRING, J. HAERTER, S. HAGEMANN, H. HOFFMANN, D. JACOB, P. KRAHE, G. LOHMANN, C. MOSELEY, E. NILSON, O. PANFEROV, T. RATH & B. TINZ (2010): Climate Model Bias Correction und die Deutsche Anpassungsstrategie. *Mitteilungen DMG 03 / 2010*, <http://www.dmg-ev.de>, Heft 03,2010 ISSN 0177-8501

- NILSON, E., M. CARAMBIA, P. KRAHE (2010a): Low Flow Changes in the Rhine River Basin. Chapter 6 in GÖRGEN, K., J. BEERSMA, G. BRAHMER, H. BUIITEVELD, M. CARAMBIA, O. DE KEIZER, P. KRAHE, E. NILSON, R. LAMMERSEN, C. PERRIN, D. VOLKEN: Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 Project. Schriftenreihe der KHR, Bd. I-23, <http://www.chr-khr.org>
- NILSON, E., M. CARAMBIA, P. KRAHE, T. MAURER, H. MOSER (2010b): Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland. KLIWA-Heft 15, <http://www.kliwa.de>
- SCHNEIDER, S. H. (1983): CO₂, Climate and Society: A Brief Overview. In: CHEN, R. S., E. BOULDING, S. H. SCHNEIDER (Eds.): Social Science Research and Climate Change: An Interdisciplinary Appraisal, D. Reidel, Boston, 9-15.
- SOLOMON, S., D. QIN, M. MANNING, Z. CHEN, M. MARQUIS, K. B. AVERYT, M. TIGNOR, H. L. MILLER (Eds.) (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://ipcc-wg1.ucar.edu/wg1/wg1-report.html>
- SRES (2000): IPCC Special Report Emissions Scenarios. <http://www.ipcc.ch/pub/sres-e.pdf>



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The RheinBlick2050 and Imagine2030 projects: a perspective on the hydrological impacts of climate change in two river basins in Europe

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1 Introduction

The potential impacts of climate change on surface water have been an increasing concern among the community of hydrologists and water managers over the past two decades. As shown by the Intergovernmental Panel on Climate Change (IPCC 2007), the rise of global mean temperature observed in the past years will continue in the future and may result in strong regional modifications of temperature and precipitation characteristics. However the level of projected modifications seems to vary between regions and climate regimes. Therefore it can be expected that these climate changes will have various impacts on water bodies and on the water availability for ecosystems and human activities.

Many studies have been carried out over the last two decades to estimate the possible evolution of hydrological regimes in rivers that may be caused by the projected climate changes. This was done worldwide for many catchments, regions, countries or even at the continental scale (see e. g. ARNELL 1999; DANKERS & FEYEN 2008; FEYEN & DANKERS 2009 for a European perspective). The results of these various studies are often difficult to compare, as different hypotheses are made. However, it is quite interesting to compare them, especially in terms of methodology and uncertainty assessment.

Two recent research projects, RheinBlick2050 (GÖRGEN et al. 2010) and Imagine2030 (SAUQUET 2010), aimed at evaluating the impacts of climate change on surface water on two different basins: the Rhine (160,800 km² at Lobith gauging station) and the Garonne (32,350 km² at Lamagistère gauging station) river basins respectively. The two basins, though quite different in size, are characterised by mixed hydro-meteorological conditions (including mountainous conditions), a significant level of human influences (dams, abstractions) and high socio-economic stakes (water supply, hydroelectricity, waterways, agriculture, flood risk, etc.). The two basins were the subject of other climate change impact studies, indicating some significant changes on various aspects of the flow regime: see e. g. HURKMANS et al. (2010) or TE LINDE et al. (2010) in the case of the Rhine basin; CABALLERO et al. (2007) and TISSEUIL et al. (2010) in the case of the Garonne basin.

The RheinBlick2050 and Imagine2030 projects were carried out in a similar time frame by two different research groups. They adopted quite similar general approaches to quantify the possible impacts of climate change.

The objective of this article is to compare the main characteristics and outcomes of these projects. The aim is to underline what was common in these projects and what made them specific. This will also give an illustration on the levels of uncertainty that can be expected in different contexts.

The next sections present the objectives, motivations and general modelling approaches of the two projects. Then the basins studied and data sets used are shortly described. The methods and models applied are presented and the main results of each project are detailed. Finally, some concluding remarks are given on the main breakthroughs and difficulties found in these projects, before giving some prospects for future studies.

This paper is mainly based on the project final reports produced by GÖRGEN et al. (2010) for RheinBlick2050 (available at www.chr-khr.org/projects/rheinblick2050) and SAUQUET (2010) for Imagine2030 (available at imagine2030.lyon.cemagref.fr).

2 Objectives and motivations

The main characteristics of the two projects are listed in Table 1.

RheinBlick2050 is an initiative launched by the International Commission for the Hydrology of the Rhine Basin. It wished to involve the riverine countries of this transboundary basin to develop a common and consistent research framework across participating countries on the impacts of climate change on the basin. The main objective was to create state-of-the-art regional climate change projection ensembles and discharge projections (mean, high and low flows) for the near (2021 - 2050) and far (2071 - 2100) future, with a quantification of the associated uncertainties. The project established close linkages with the International Commission for the Protection of the Rhine that was interested in developing common climate change scenarios that might be used later in politically relevant climate adaptation strategies (with respect to many aspects such as navigation, flood protection, low flow alleviation, hydropower production, etc.).

Imagine2030 is a national French research project focusing on the Garonne River basin (south-western France). The focus was on characterising the risk of droughts and severe low flows on the basin in current conditions and in the future by the year 2030 (2015 - 2045 time slice). The possible future water shortages for two main water uses (irrigation and hydro-power) were also investigated, considering business-as-usual water management rules. The basin authority (Adour-Garonne Water Agency), which is quite active in developing prospective studies on the basin, took part in the project and eased the links with the various water stakeholders.

Therefore the two projects had a similar ambition to produce projections that could be useful for water managers and stakeholders for future decision making on these basins, with important stakes in both cases.

Table 1

Main characteristics of the RheinBlick2050 and Imagine2030 projects

	RheinBlick2050	Imagine2030
Period	2008 - 2010	2008 - 2009
Project type	International (Luxembourg, Germany, the Netherlands, France, Switzerland)	National (France)
Funding	International Commission for the Hydrology of the Rhine Basin and national institutions	Ministry for Ecology, Sustainable Development, Transport and Housing (France)
Institutions involved	CRP-GL, KNMI, Rijkswaterstaat, HLUG, BfG, Deltares, Cemagref, BAFU	Cemagref, EDF-LNHE, Adour-Garonne Water Agency
Co-ordination	Klaus Görgen (CRP-GL)	Eric Sauquet (Cemagref)
Focus	All parts of the hydrological regime	Low flows Impact of irrigation and hydropower

3 General modelling framework and uncertainty assessment

The general methodology adopted in the two projects is quite classical. It consists in chaining a number of modelling steps that mainly consist in (see e. g. BOÉ et al. 2009):

- > considering greenhouse gas (GHG) emission scenarios
- > simulating climate evolution for various variables at the global scale given the GHG scenario
- > downscaling these simulations at the regional scale at a spatio-temporal resolution sufficient for hydrological modelling
- > forcing hydrological models with downscaled climate inputs and simulating corresponding streamflow values

The possible changes in various flow variables can then be quantified between a reference period (current climate) and a future one, either in relative or in absolute terms.

Obviously, each modelling step will generate uncertainties due to the imperfection of models and the prospective nature of the work. This uncertainty will progressively increase when cascading the modelling steps, which will result in a potentially large overall uncertainty on flow outputs, that must be adequately quantified and accounted for (IPCC 2005). The relative roles of the different sources of uncertainties have been studied for example by WILBY (2005) and WILBY & HARRIS (2006), indicating that the climatic part of the chain may be the main source of uncertainty, but that hydrological uncertainties cannot be neglected either.

One way to account for these uncertainties is to consider a number of modelling options at each step of the modelling chains. The resulting uncertainty on flows can then be quantified as the bandwidths of all the simulations obtained.

The two projects adopted the same approach of using a number of climate projections and hydrological models, which produced uncertainty bands for all simulated variables. Specific attention was given to the way this uncertainty should be communicated and various graphical and numerical options were chosen (e. g. showing individual simulations or only ranges, giving the results in absolute or relative terms, etc.). Some illustrations are given in sections 6 and 7.

4 Basins and data

4.1 Basin characteristics and observed data

The Rhine and Garonne River basins are located in Central and Western Europe respectively. Their location is illustrated in Figure 1 and some of their characteristics are given in Table 2. Although quite different in size, the two basins have some interesting similarities. The upper parts of the basins are located in high mountains (the Alps for the Rhine and the Pyrenees for the Garonne) with some nival regime. These mountainous zones may be particularly sensitive to climate changes, although they are also those where the uncertainties on future conditions are among the largest (see e. g. ADAM et al. 2009; LOPEZ-MORENO et al. 2009). In the two catchments, some major tributaries are located in lowland zones with pluvial regime. It means that both basins have mixed regimes at their outlet. The upper parts are influenced by dams that have a major impact on observed flows. Some specific work on flow naturalisation was done in Imagine2030 to remove dam influence. In RheinBlick2050, it was chosen to use target stations situated downstream enough of the mountainous part to have only diffuse influence.

Data were available at a daily time step. The characterisation of the basins' hydrological behaviour in current conditions was done using climatic observed data sets that were at a resolution deemed sufficient to carry out the work (see Table 2). The two projects selected a number of target gauging stations spread over the basins (on the main stream or on tributaries, see Table 2) where the influence of climate changes was quantified.

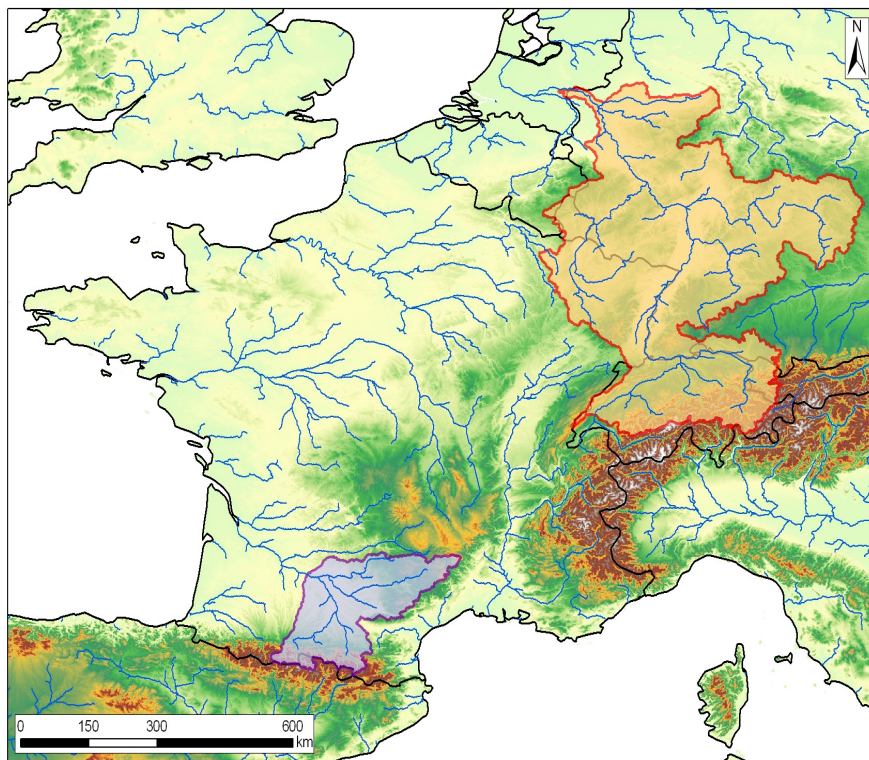


Figure 1: Location map of the Rhine basin at Lobith (in orange) and the Garonne basin at Lamagistère (in blue)

Table 2

Some characteristics of the Rhine and Garonne basins and data used

Basin (Project)	Rhine (RheinBlick2050)	Garonne (Imagine2030)
Downstream gauging station and area	Lobith (160,800 km ²)	Lamagistère (32,350 km ²)
Range in altitude	>3000 - 60 m a.s.l.	>3000 - 0 m a.s.l.
Mean annual flow	2,200 m ³ /s (1901 - 2005)	400 m ³ /s
Target gauging stations	8 stations : Rhine at Basel (35,897 km ²) Rhine at Maxau (50,196 km ²) Rhine at Worms (68,827 km ²) Rhine at Kaub (103,488 km ²) Rhine at Köln (144,232 km ²) Rhine at Lobith (160,800 km ²) Main at Raunheim (27,142 km ²) Moselle at Trier (23,857 km ²)	9 stations: Garonne at Valentine (2,230 km ²) Salat at Roquefort (1,570 km ²) Ariège at Foix (1,340 km ²) Garonne at Portet (9,980 km ²) Tarn at Millau (2,170 km ²) Agout at Lavaur (2,300 km ²) Tarn at Villemursur-Tarn (9,100 km ²) Aveyron at Loubejac (5,170 km ²) Garonne at Lamagistère (32,350 km ²)
Flow data	Observed flows	Naturalised flows
Observed climatic data	CHR-OBS reference dataset of precip., temp. and sunshine duration/global radiation distributed on 134 subcatchments (KRAHE et al., unpublished)	8 x 8 km SAFRAN gridded inputs of precip., temp. and potential evapotranspiration (QUINTANA-SEGUI et al. 2008; VIDAL et al. 2010)
Reference period	1961 - 1990	1973 - 2003
Future time slices	2021 - 2050 (near future), 2071 - 2100 (far future)	2015 - 2045
GHG scenarios	A1B (primarily), A2, B1	A1B, A2
GCM	19 GCM considered, 5 GCM downscaled (ENSEMBLES project)	~ 15 GCM considered (IPCC AR4)
Downscaling and bias correction	Dynamical downscaling with RCMs + 4 bias corrections methods	Statistical spatial downscaling + Perturbation approach for temporal downscaling
Number of projections considered	+/- 20 (depending on testing conditions)	+/- 20 (depending on testing conditions)

4.2 Climate projections and series resampling

To characterise the uncertainty in future climate conditions, the two projects adopted a similar approach by using an ensemble of projections. Some specific work was done to adapt the GCM outputs to the spatial and temporal scales necessary for the projects and to correct their bias. In RheinBlick2050, already existing RCM outputs, mainly produced by dynamical downscaling in the ENSEMBLES project (VAN DER LINDEN & MITCHELL 2009), were used as base data. In this project, the focus was on the reliability of dynamical downscaling approaches and the question of optimising bias correction. In Imagine2030 a statistical downscaling was applied to the GCM model results. The reliability of the simulations was evaluated in current conditions using a number of climatic indicators (e. g. mean precipitation or temperature). Although the regionalisation strategies were different in the two projects, they resulted in about 20 projections (control and projection timespans) that were eventually used to force the hydrological models.

Resampling techniques (based on nearest neighbour approaches, see LALL & SHARMA 1996; RAJAGOPALAN & LALL 1999; BEERSMA & BUISSAND 2003) were also applied in the two projects but with different objectives: in RheinBlick2050, they were used to generate long series for the evaluation of extreme flood events; in Imagine 2030, they were used to generate various scenarios for assessing the uncertainty in the temporal downscaling step.

5 Hydrological models

As there is a variety of existing hydrological models, a set of different modelling tools were used in each project to quantify the uncertainty related to the choice of the model structure. They correspond to various spatial discretisations (lumped, semi-distributed or distributed), conceptualisations and levels of complexity. All the selected models were already used for operational applications or climate impact studies.

RheinBlick2050 implemented the HBV134 semi-distributed model (EBERLE et al. 2005) that was extensively applied on the Rhine basin in the recent years. Some comparative references were provided by a set of seven simple lumped hydrological models. In the Imagine2030 project, two models were tested: the distributed CEQUEAU model (CHARBONNEAU et al. 1977) and the lumped GR4J model (PERRIN et al. 2003).

All models were used with a snow module to account for snow accumulation and melt on the upper parts of the basins. The models did not include specific modules to account for dams.

All models were evaluated on observed data to assess their reliability and ability to simulate the hydrological behaviour of the selected sub-basins. Some sensitivity analyses were performed, e. g. to the formulation of evapotranspiration.

A specific scheme was developed to evaluate the suitability of hydrological models to climate change impact studies. Indeed, in this context, models will be applied in future conditions that are much different from those for which they were initially calibrated. Given the underlying stationary hypothesis, models may lack robustness for applications in so different conditions. The testing scheme, based on the differential split sample test proposed by KLEMEŠ (1986), showed that blindly calibrating models under current conditions actually adds significant uncertainty to the modelling chain.

6 Main results on climatic evolutions

Projected evolutions of temperature and precipitation are illustrated in Figure 2.

On the Rhine basin, climate projections show a general increase in temperature. By 2021 - 2050, this increase ranges from 0.5 to 2.5°C in the winter season and from 0 to 2.0°C in the summer season. The change is projected to be more pronounced by the end of the century, ranging between 2.5 and 5.0°C all along the year.

In terms of precipitation, the signal is more uncertain. But the contrast between summer and winter changes is projected to increase in the far future: the winter precipitation is projected to increase (0 - 15 % by 2021 - 2050; up to 25 % by 2071 - 2100) while the summer precipitation is projected to decrease (no clear change by 2021 - 2050, 10 % to 30 % by 2071 - 2100).

On the Garonne basin, the temperature rise by 2015 - 2045 may be between 1 and 2°C, but could be more pronounced in the summer season. The change on precipitations is largely uncertain, but there may be some decrease in summer precipitation up to 10 % by 2015 - 2045.

In the two basins, the changes in climate conditions should go towards more contrasted seasons. The projected changes in temperature seem more certain than on precipitation, which is in agreement with the fact that climate models model temperature better than precipitation. The rise in temperature will have some consequences on snowfall in the mountainous areas, which will most likely be partly replaced by rainfall.

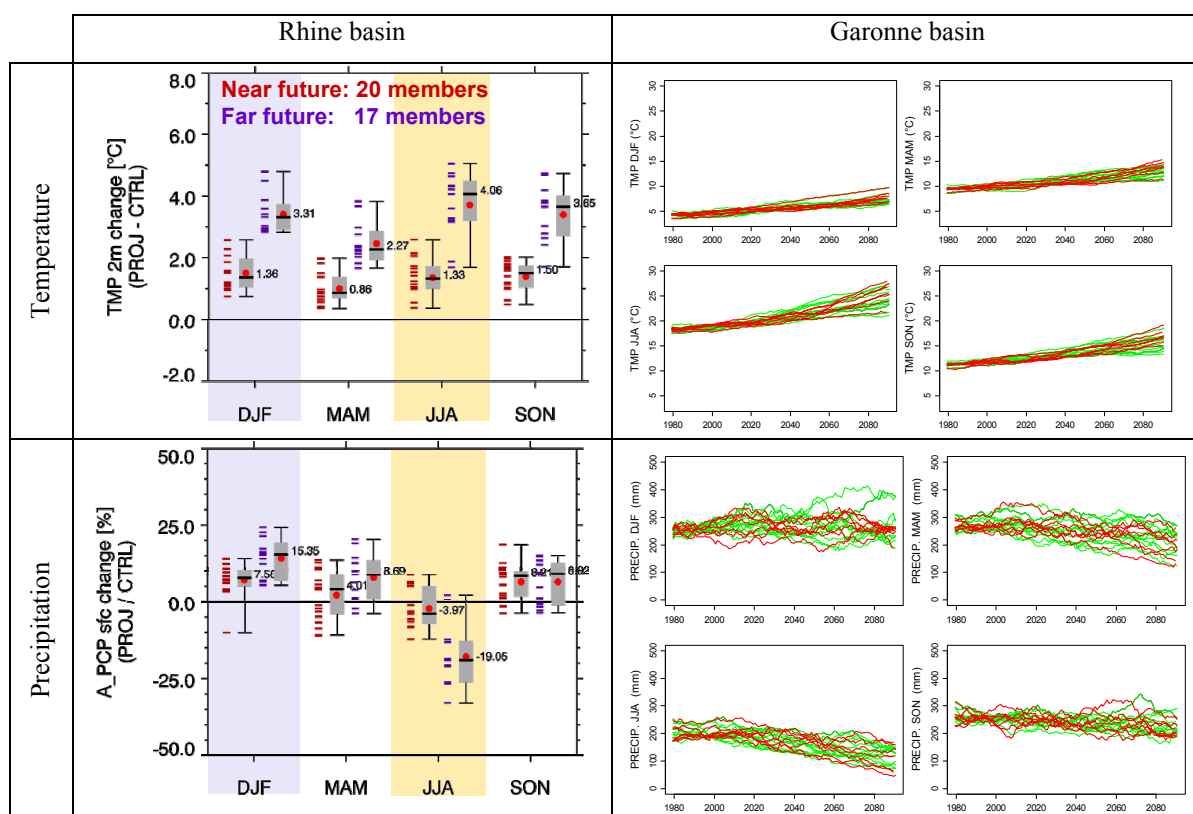


Figure 2: Seasonal evolutions of temperature and precipitation for the Rhine basin at Lobith and the Garonne basin at Lamagistère. Left: Ranges of relative changes for near (2021 - 2050) and far (2071 - 2100) futures compared to 1961 - 1990 (Source: GÖRGEN et al. 2010); Right: Evolution of the ranges of actual values over the 1980 - 2100 period (Source: SAUQUET 2010) (GHG scenarios: A2 (red) and A1B (green))

7 Main results on hydrological variables

RheinBlick2050 investigated a number of hydrological variables, characterising mean flow, flow regime, low and high flows. The Imagine2030 project investigated the same aspects except high flows, as the project focussed on water resources.

7.1 Mean flow and flow regime

The evolutions of mean annual flows are illustrated in Figure 3. On the Rhine basin, a change towards increasing mean flows can be observed on the downstream stations for the near future, but no change is simulated for the far future. On the upper stations, no significant change is observed. On the Garonne basin, there is a significant change towards decreasing mean flows on all stations (about 10 % on average).

In terms of regime, there should be a progressive shift of flow regime on the upper Rhine basin. This is mainly due to the decrease of snow cover and an earlier snowmelt. In the tributaries of the middle Rhine (e. g. Moselle), the likely increase of winter precipitation and decrease of summer precipitation will result in a more contrasted annual cycle of flows, increasing in winter and decreasing in summer. Therefore the combination of the two changes will yield a clear change on the lower Rhine (Lobith) with shifted and more contrasted flows.

On the Garonne basin, the Pyrenees part of the basin will be, like the upper Rhine, much affected by the change in snow dynamics. The reduced snow cover due to increased temperature will result in a significant decrease of spring flows. More generally, all monthly flows will be affected and will decrease, with changes between 10 to 25 %.

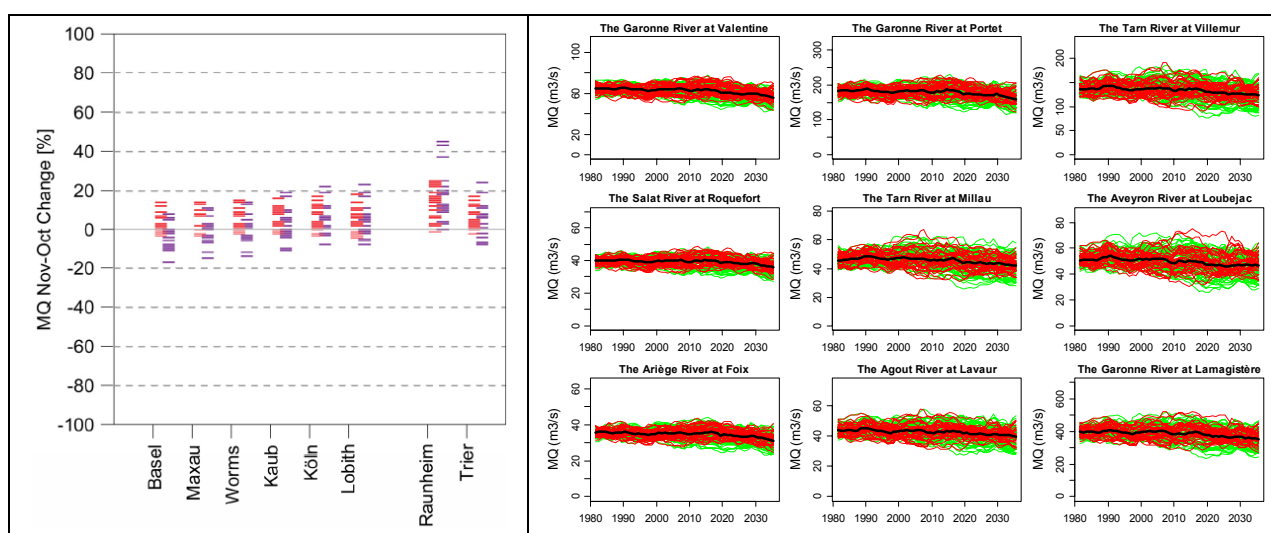


Figure 3: Left: Ranges of relative changes of mean flows (%) over the 8 stations of the Rhine basin for the near (red) and far (purple) futures obtained with the HBV134 model (Source: GÖRGEN et al. 2010); Right: Evolution of the ranges of mean flows (m^3/s) over the 9 stations of the Garonne basin over the 1980 - 2040 obtained with the CEQUEAU model (Source: SAUQUET 2010) (GHG scenarios: A2 (red) and A1B (green); median in black)

7.2 Low flows

On the Rhine basin, the projected winter low flow discharges tend to increase for the near and far futures (0 % to 15 %). Conversely, a decrease of summer low flows is discernible in projections of the far future (-30 % to -10 %).

On the Garonne basin, there is a general decrease of low flows on all sub-basins. This drop in water availability may reach 50 % on some parts of the basin by 2015 - 2045.

This lower availability of water during the dry season may cause important problems in terms of water allocation between the different users.

7.3 High flows

A specific approach was implemented in the RheinBlick2050 project to evaluate the changes in flood quantiles from the mean maximum annual flood up to the 1250-year return period flood. To estimate floods for the largest return periods, the 30-year long time slices of projected flows are not sufficient. Therefore a stochastic resampling technique (based on nearest-neighbour approach, see BEERSMA & BUIHAND 2003) was used to generate 3000-year long series of climate inputs showing similar statistical characteristics. Then these series were fed to the HBV134 hydrological model to produce long discharge time series that could then be statistically analysed. Results indicate that high flows are projected to increase in the tributary rivers and in the lower part of the Rhine river (Cologne and Lobith). For the upstream part of the Rhine River (Basle, Maxau, Worms), no clear conclusions could be drawn. It can be noticed that scenario bandwidths were larger for the far future and for the less probable events.

8 The issue of human activities

The Imagine2030 project investigated the issue of water availability for two demanding activities on the catchment, namely hydropower and irrigation. Models based on temperature were developed to estimate the evolution of electricity demand (hydropower for heating) and water demand for plants (irrigation). Water management rules were considered as unchanged in the future.

In the case of hydropower, the application was made on the Ariège basin (Pyrenees part of the basin). Results show that there should be a general decrease of hydropower production, with more frequent constraints to sustain river discharges in summer. In the reservoirs, the storages should be less variable due to lower water inputs in the spring season. This should incite water managers to adapt management rules in the future.

In the case of irrigation, an application was made on the Aveyron basin in the eastern part of the basin. Results suggest that there should be a significant increase in water demand due to increasing temperatures (between 10 to 20 % depending on the scenarios). This will increase the pressure on water resources, especially during the summer season. Note that these estimates do not account for possible changes in crops or irrigation practices.

9 Conclusions and perspectives

The RheinBlick2050 and Imagine2030 projects similarly investigated the potential impacts of climate changes on the hydrological regimes of the Rhine and Garonne respectively. These two basins show very important stakes in terms of water use. Although they were run independently, the two projects adopted similar approaches. One of these similar characteristics is that, in the perspective of quantifying uncertainties, they chose various modelling options (so-called multi-model approaches) at each step of the modelling chain leading from GHG emission scenarios to hydrological projections.

Interestingly, a few similarities can be observed in the evolution of some hydrological variables on the two basins, among which is the decrease of summer flows that may create larger constraints on water resources. Obviously, there are also some differences. Whereas lower summer flows may be balanced by higher winter flows in parts of the Rhine basin, the Garonne basin will likely experience a general decrease of flows in all seasons. This may make the Garonne basin a 'hot spot' for water management in the future years as the water demand may increase in parallel if nothing is changed in terms of water use.

Apart from the main projected changes, the two projects investigated methodological issues that are important to consider in such prospective studies. The issue of uncertainty quantification appeared crucial in the two projects. This involved an assessment of the reliability of each step of the modelling chain (climate modelling and downscaling, hydrological modelling). For example, in the RheinBlick2050 project, the reliability of dynamical downscaling approaches and bias corrections was evaluated, while Imagine2030 more focused on the whole range of GCMs. Appropriate numerical criteria and graphical representations were also proposed to communicate uncertainty. Bandwidths associated with projections are crucial for managers to fully interpret the significance and likelihood of predicted changes. Both projects were closely conducted with feedbacks from water managers, which should facilitate the use of project results for decision-making.

There are obviously still some limitations and unknowns in the results produced by the two projects, which would require further work. Among them are the needs for improved models at each step of the modelling process. Accounting for the human influences and socio-economic aspects should also be improved, along with the definition of adaptation measures. No doubt that the potential difficulties that could be induced by climate change in terms of risks and water resources management will encourage further investigations on these two basins.

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Literature

- ADAM, J. C.; A. F. HAMLET, D. P. LETTENMAIER (2009): Implications of global climate change for snowmelt hydrology in the twenty-first century. *Hydrological Processes*, 23(7): 962-972.
- ARNELL, N. W. (1999): The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environmental Change-Human and Policy Dimensions*, 9(1): 5-23.
- BEERSMA, J. J.; BUISHAND, T. A. (2003): Multi-site simulation of daily precipitation and temperature conditional on the atmospheric circulation. *Climate Research*, 25: 121-133.

- BOÉ, J.; L. TERRAY, E. MARTIN, F. HABETS (2009): Projected changes in components of the hydrological cycle in French river basins during the 21st century. *Water Resources Research*, 45: W08426.
- CABALLERO, Y.; S. VOIRIN-MOREL, F. HABETS, J. NOILHAN, P. LEMOIGNE, A. LEHENAFF, A. BOONE (2007): Hydrological sensitivity of the Adour-Garonne river basin to climate change. *Water Resources Research*, 43(7): Art. No. W07448.
- CHARBONNEAU, R.; J. P. FORTIN, G. MORIN (1977): The CEQUEAU model: description and examples of its use in problems related to water resource management. *Hydrological Sciences Bulletin*, 22(1): 93-202.
- DANKERS, R.; L. FEYEN, L. (2008): Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. *Journal of Geophysical Research*, 113: D19105, doi:10.1029/2007JD009719.
- EBERLE, M.; H. BUIITEVELD, P. KRAHE, K. WILKE (2005): Hydrological modelling in the river Rhine basin, Part~III: Daily HBV model for the Rhine basin, Bundesanstalt für Gewässerkunde (BfG), Koblenz, Germany.
- FEYEN, L.; R. DANKERS (2009): Impact of global warming on streamflow drought in Europe. *Journal of Geophysical Research-Atmospheres*, 114: D17116, doi:10.1029/2008JD011438.
- GÖRGEN, K., J. BEERSMA, G. BRAHMER, H. BUIITEVELD, M. CARAMBIA, O. DE KEIZER, P. KRAHE, E. NILSON, R. LAMMERSEN, C. PERRIN, D. VOLKEN (2010): Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 project, International Commission for the Hydrology of the Rhine Basin, Lelystad, 229 pp.
- HURKMANS, R.; W. TERINK, R. UIJLENHOET, P. TORFS, D. JACOB, P. A. TROCH (2010): Changes in Streamflow Dynamics in the Rhine Basin under Three High-Resolution Regional Climate Scenarios. *Journal of Climate*, 23(3): 679-699.
- IPCC (2005): Guidance Notes for Lead Authors of the IPCC, WMO, UNEP, Geneva, Switzerland.
- IPCC (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom, New York, NY, USA, 996 pp.
- KLEMEŠ, V. (1986): Operational testing of hydrological simulation models. *Hydrological Sciences Journal*, 31(1): 13-24.
- KRAHE, P.; M. EBERLE, M. CARAMBIA, H. BUIITEVELD, K. WILKE (unpublished): A hydrometeorological reference data set for the river Rhine ("CHR_OBS"), BfG, Federal Institute of Hydrology, Koblenz, Germany.
- LALL, U.; A. SHARMA (1996): A nearest neighbor bootstrap for resampling hydrologic time series. *Water Resources Research*, 32(3): 679-693.
- LOPEZ-MORENO, J. I.; S. GOYETTE, M. BENISTON (2009): Impact of climate change on snowpack in the Pyrenees: Horizontal spatial variability and vertical gradients. *Journal of Hydrology*, 374(3-4): 384-396.

- PERRIN, C.; C. MICHEL, V. ANDRÉASSIAN (2003): Improvement of a parsimonious model for streamflow simulation. *Journal of Hydrology*, 279(1-4): 275-289, DOI: 10.1016/S0022-1694(03)00225-7.
- QUINTANA-SEGUI, P.; P. LE MOIGNE, Y. DURAND, E. MARTIN, F. HABETS, M. BAILLON, C. CANELLAS, L. FRANCHISTEGUY, S. MOREL (2008): Analysis of near-surface atmospheric variables: Validation of the SAFRAN analysis over France. *Journal of Applied Meteorology and Climatology*, 47(1): 92-107.
- RAJAGOPALAN, B.; U. LALL (1999): A k-nearest-neighbor simulator for daily precipitation and other variables. *Water Resources Research*, 35: 3089-3101.
- SAUQUET, E. (Editor), (2010): *Imagine2030. clIMat et Aménagement de la Garonne : Quelles INcertitudes sur la ressource en Eau en 2030 ? Programme RDT volet 2, MEEDDM. Cemagref - EDF - Agence de l'Eau Adour Garonne*, 126 pp.
- TE LINDE, A. H.; J. C. J. H. AERTS, A. M. R. BAKKER, J. C. J. KWADIJK (2010): Simulating low-probability peak discharges for the Rhine basin using resampled climate modeling data. *Water Resources Research*, 46(3): W03512.
- TISSEUIL, C.; M. VRAC, S. LEK, A. J. WADE (2010): Statistical downscaling of river flows. *Journal of Hydrology*, 385(1-4): 279-291.
- VAN DER LINDEN, P.; J. F. B. MITCHELL (Editors) (2009): *ENSEMBLES: Climate Change and its Impacts: Summary of Research and Results from the ENSEMBLES Project*. Met Office Hadley Centre, UK., 160 pp.
- VIDAL, J. P.; E. MARTIN, M. BAILLON, L. FRANCHISTÉGUY, L.; J.-M. SOUBEYROUX (2010): A 50-year high-resolution atmospheric reanalysis over France with the Safran system. *International Journal of Climatology*, 30(11): 1627-1644.
- WILBY, R. L. (2005): Uncertainty in water resource model parameters used for climate change impact assessment. *Hydrological Processes*, 19(16): 3201-3219.
- WILBY, R. L.; I. HARRIS (2006): A framework for assessing uncertainties in climate change impacts: Low-flow scenarios for the River Thames, UK. *Water Resources Research*, 42(2): W02419.



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Climate change impact on mean annual river flows

Mitja Brilly, Anja Horvat, Dave Matthews and Mojca Šraj

1 Introduction

Mean annual river flows present a water balance of watersheds, and these are important for water management and water use. These are also, good indicators of climate variability in the past century, if there are no significant impacts of water use for irrigation. However, increasing temperatures and decreased moisture supply requires increases in irrigation for crop vitality. QIAN et al. (2006) examined annual discharges from the world's 10 largest rivers and compared results with CLM3 model simulations for the period from 1948 to 2002. Their time series showed a variety of results from clear trends of declining discharge from 1995 to 2004 in the Columbia (US), Congo (Africa), Changjiang (China), Mississippi (US), Lena (Russia), and Parana (S. America) to no apparent trends in the Amazon (Brazil), Orinoco (Venezuela), Yenisey, Severnaya Dvina (Russia), Susquehanna (US), and Gota (Sweden).

River flow variations depend on the precipitation and evaporation as input in the watershed system, and water storages in the watershed that represent a stage of the system. Variations in the input of the watershed system multiply the variations of river flow as output from watershed system. Percentage of the variation in yearly flows is higher than percentage of the variation in precipitation, considering same stage of the system, KOBOLD & SUŠELJ (2005). Those variations are significant and characterise particular watershed.

The stages of the watershed system normally are lowest at the end of hydrological year (end of September) rather than at the end of calendar year, but data of annual flows collected in many data bases are mainly related to the calendar year. Water managers use the data for Water Years (WY) from 1 October to 30 September.

Hydropower production is highly dependent upon water supply, thus large variations in flow will have significant economic impacts on energy production. Water use and water management are also highly dependent on annual variations. These impacts are stronger in areas where water use is fully developed, or even over allocated, as in the Western United States. Here today, variations in annual flows have large impacts on water use, water rights, and may even limit allocations for environmental protection of endangered species. Competition among consumptive use by agriculture, people, and environmental needs becomes critical in periods of drought, hence long-term planning for water conservation and storage systems is needed.

2 Methods

The annual flows are analysed on calendar year basis as they were received from relevant data bases. Data for hydrological year should be recalculated on from monthly flow data that are not always available. Data for the Colorado River basin was recalculated as natural flows, because surface water storage and water use has tremendous impact on the measured river flows in the fully developed watershed system of the Colorado River (MATTHEWS et al. 2000; CHRISTENSEN et al. 2004).

Data are simply harmonised according mean value, arranged to ten-year moving averages and plotted for different samples or part of the samples. Water balance of the Sava River and the Mura River studied in the detail and trends in the samples of input data and calculated data are presented.

Water balance of the Sava River was studied by semi-distributed water balance model WatBal. WatBal was derived in 1970s as lumped model in sub-alpine areas (LEAF & BRINK 1975). Later it was developed and expanded for use not only in water balance modelling, but also for calculation of water quality, sediment transport and climate change impacts. Modified version of the model was used for modelling of water balance of Danube River Basin (PETROVIČ et al. 2005; STRZEPEK & YATES 1997). With model WatBal we looked for the best fit regard as the tuning criteria, which should be as close as possible to zero. Calibration parameters set in following order are ATSNOW (temperature for the evaluation of snowfall), ATRAIN (temperature for evaluation of rainfall), WSFFC (soil moisture content in the balanced top layer – fine tuning), WCRIT (critical soil moisture content), MGDFAC (melting factor) and PRIESK (fast infiltration coefficient). The calibration is done when the three tuning criteria are minimised. (PETROVIČ et al. 2005). The model was used for more detail calculation of the Sava River Basin in Slovenia.

3 The Sava River Basin

The Sava is a right side tributary of the Danube River at Belgrade. In Slovenia the Sava drains an area of 10,764 km², which is 53 % of Slovenian territory. For Sava was made the water balance model (WatBal) as part of a project Basin – Wide Water Balance in the Danube River Basin (PETROVIČ et al. 2003). The input meteorological data for model are runoff depth, monthly precipitation totals, monthly means of air temperature and monthly means of air humidity. For the purpose of potential evapotranspiration estimation it is necessary to define zones of basin, which are defined by height of the terrain. The basin in Slovenia was divided into two parts controlled by water station Litija and Čatež.

Later on we divide Sava river basin in twelve zones, Figure 1. At the beginning of flow the Sava River is created by two headwaters, Sava Dolinka River (left) and Sava Bohinjka River (right) which joins between the Slovenian towns of Lesce and Radovljica. The Sava Dolinka River (area 501 km²) starts in the Planica Valley and goes underground and breaks out again near Kranjska Gora village. The Sava Bohinjka River (area 387 km²) originates under the Komarča Ridge from underground sources drained from the Triglav Lakes Valley.

First two left tributaries of the Sava River are the Tržiška Bistrica River and the Kokra River, which zone is named Sava – Kranj in model (area 640 km²). First right tributary is Sora (area 647 km²), which has a mountain nature. The Ljubljana River some 20 km of its course lies

underground in caves, so the river has seven names. Area of The Ljubljanica River basin is estimated at 1,883 km². The Ljubljanica River is a right tributary of the Sava River, with the confluence of the three rivers lying about 10 km downstream from Ljubljana. The third river at confluence is a left tributary The Kamniška Bistrica River (area 657 km²), which is an Alpine river in northern Slovenia. East of Ljubljana, the Sava flows through a 90 km long gorge and afterwards the Krško Field. This zone of The Sava River basin is in model named as city it crosses – Litija and measures 523 km². Afterwards there are two tributaries divided in two parts: left tributary Savinja river is in model divided on zones of town Celje (area 1,193 km²) and village Veliko Širje (area 660 km²) and right tributary The Krka River, also divided in two zones Dvor (area 1,105 km²) and Podbočje (area 1,145 km²). The Savinja River (area 1,853 km²) is situated in north-east Slovenia and flows mostly in the Upper and Lower Savinja valley. It flows into The Sava River at Zidani Most. The Krka River (area 2,250 km²) originates around 25 km south-east of town Ljubljana, before flowing south-east to meet the Sava River at town Brežice near the Croatian border. Zone between the left and right tributary is in model named Čatež and it measures 757 km². Data of the watershed characteristics are in table 1. Watershed is mainly covered by forest 68 %, agricultural land 28 %, urban area only 2 % and surface water less than 1 %.

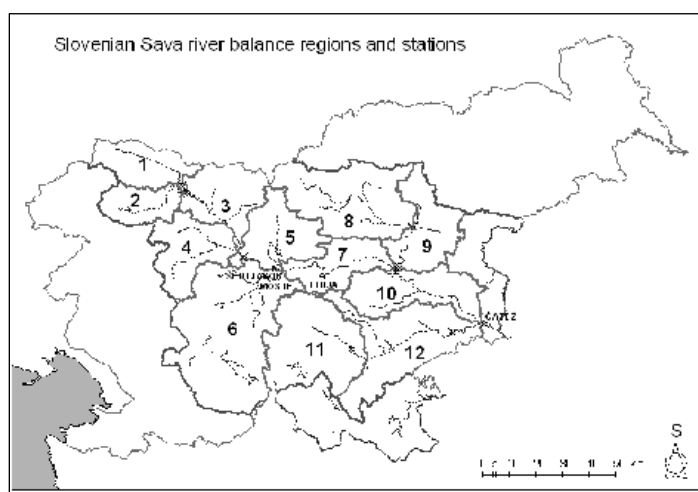


Figure 1:
The Sava River Basin with WatBal regions

Table 1

Land surface characteristics of the Sava River subwatersheds, CORINE land cover

HO_	Total_(%)	percentiles				area in square kilometres				
		urban	agric.	forest	water	Total	urban	agric.	forest	water
1	100	2.45	9.81	87.62	0.12	501.52	12.29	49.18	439.42	0.62
2	100	0.80	9.04	89.00	1.17	387.11	3.09	34.99	344.52	4.51
3	100	4.26	23.03	72.47	0.23	639.91	27.28	147.40	463.77	1.45
4	100	2.43	27.09	70.48	0.00	648.13	15.76	175.58	456.79	0.00
5	100	6.08	35.38	58.31	0.23	656.69	39.94	232.35	382.88	1.52
6	100	5.12	27.31	66.28	1.28	1884.58	96.58	514.70	1249.14	24.17
7	100	3.10	27.15	68.82	0.93	523.72	16.22	142.19	360.41	4.90
8	100	1.20	30.83	67.77	0.20	1105.46	13.32	340.83	749.14	2.18
9	100	2.36	48.37	48.89	0.37	659.73	15.60	319.10	322.57	2.46
10	100	1.56	43.68	54.05	0.71	757.32	11.81	330.80	409.30	5.41
11	100	2.92	30.73	65.99	0.36	1193.13	34.80	0.00	787.37	4.27
12	100	1.77	38.47	59.32	0.44	1144.55	20.26	440.31	678.98	5.00

4 The Mura River Basin

The Mura river is a transboundary river, flowing from Austria to Slovenia, and then along the border between Hungary and Croatia to the Drava river. The Mura River is the largest tributary of the Drava River and watershed takes 14,241 km². More than half of the watershed belongs to Austria, while the lower part lies in Slovenia, Hungary and Croatia, Figure 2. The source of the river is in the Austrian national park Hohe Tauern at 1,898 m above sea level. The river ends near Legrad in the Koprivnica-Križevci county of Croatia, where it flows into the Drava River on altitude of about 130 m above sea level.

Along the river flow The Mura River has various climate and changes river regime due to different altitudes. The head part of the watershed is in mountain alpine region above altitude of 600 meters above sea level. Lower part of watershed takes area below confluence the Mur River and the Sula River. Altitude of the watershed is below 500 meters.

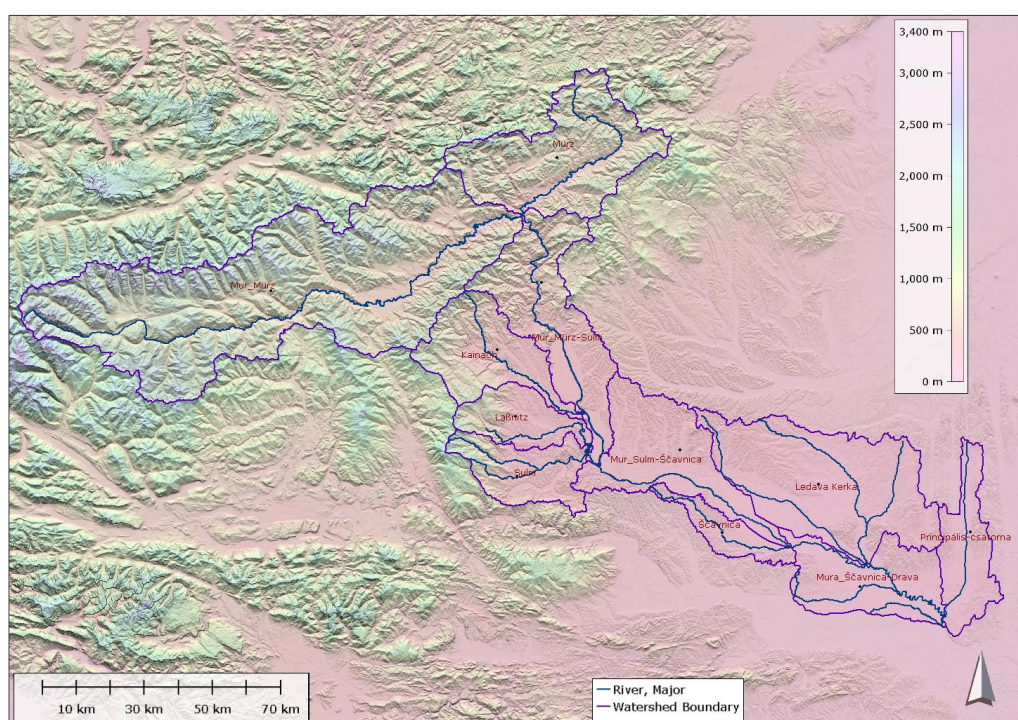


Figure 2: Watershed relief

5 Results

The WatBal model for Sava River basin was calibrated for period of 41 year from 1960 to 2000. Linear trends and ten year moving average was also calculated for the period, Figure 3. There is very well recognised descendent trend of discharges for all the period of calculation. The reason for descendent trend in discharges is in the decreasing of the precipitation and slightly increasing of evaporation, Figure 4a. The descendent trend is also not so clear on the all of subwatersheds, Figure 4b.

The Sava River watershed at water station Šentjajob has a mountainous area 2,176 km² in surface and the Ljubljanica River has karst watershed with 1,884 square kilometres of area at water station Moste. The Rivers have similar watershed areas but large differences in water

regime. Ten-year moving average of the measured discharges for the stations on the Sava River is in the Figure 5. Discharge drops down significantly on the Sava River in the past forty years. The trend is significantly lower in the past twenty years, and there are some tributaries as the Ljubljana River that have steady trend of discharges in the past twenty years.

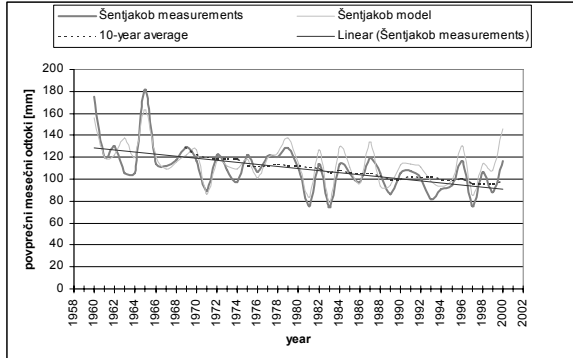


Figure 3:
Measured and validated discharge of the Sava river at water station Šentjakob

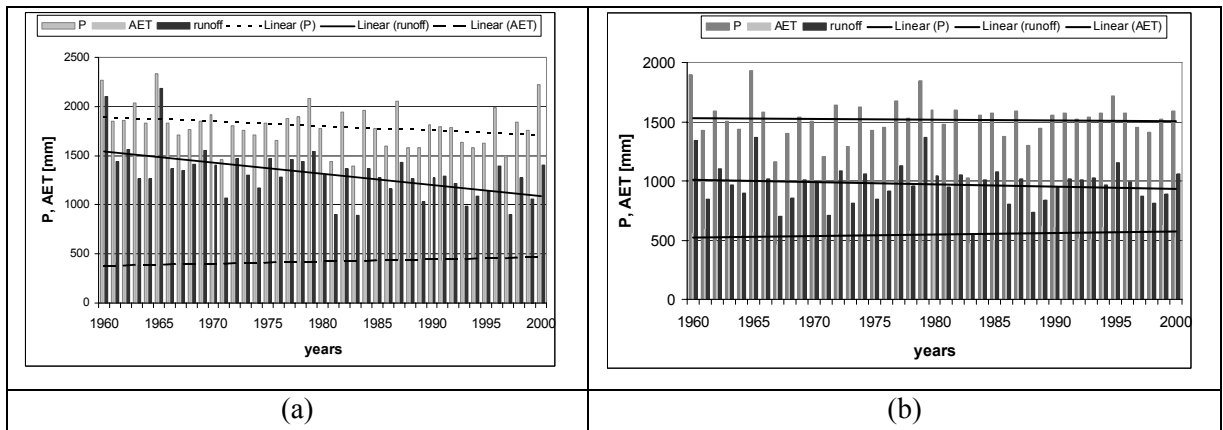


Figure 4: Water balance of the Sava River at water station Šentjakob (a) and Ljubljana River at WS Moste.

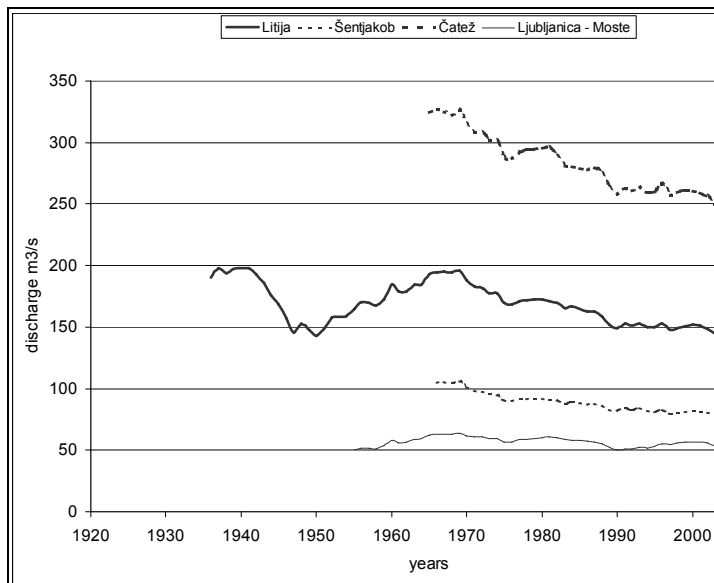


Figure 5: Ten-year moving average of the discharges on water stages on the Sava River

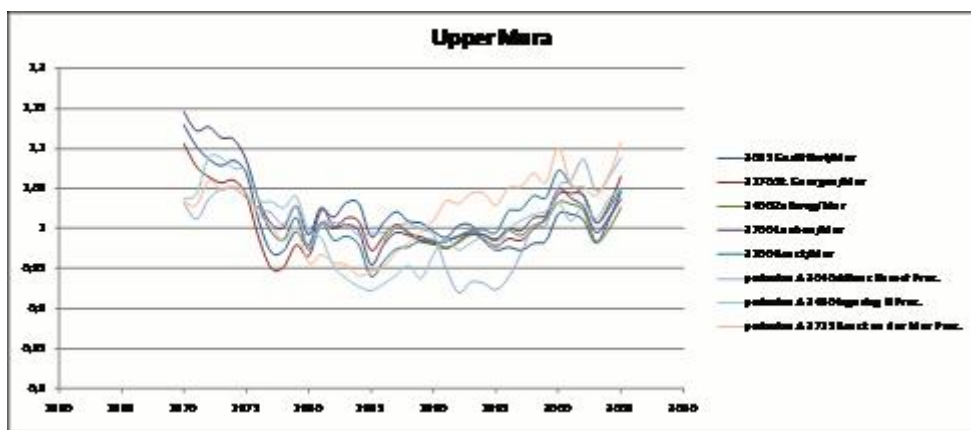


Figure 6: Ten-year moving average of the discharges on water stages on upper part of the Mura River

The water regime of the Mur River is controlled by alpine head part of the watershed. That is also clear from homogenised data, Figure 6. Water regime of tributaries in lower part of watershed is quite different. The Kerka River, The Ščavnica River, The Ledava River and the Jendrašiček River vary significantly more than the Mur River (Figure 7).

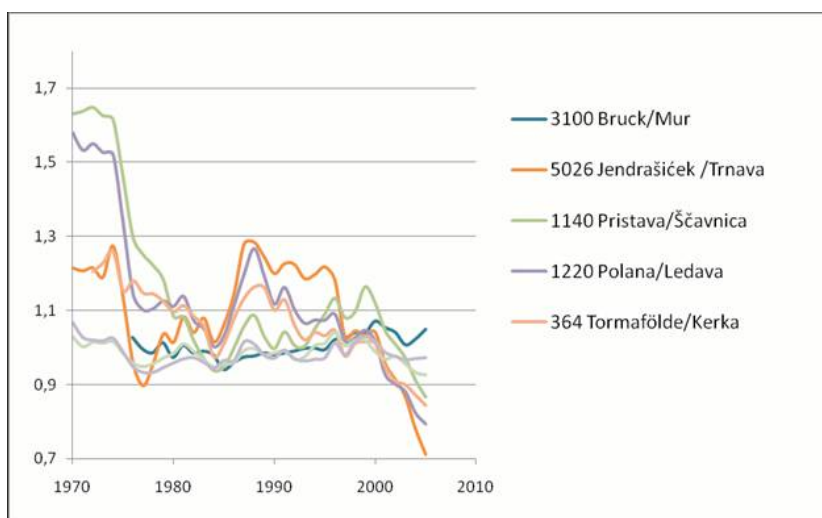


Figure 7: Ten-year moving average of the discharges of tributaries on lower upper part of the Mura River

The ratio of discharge relative to mean in period 1961 - 1990 calculated for Sava River, Mura River, Colorado River and Rhine River, fig. 8. The Mura River with headwaters in the Austrian Alps has a significant rise of discharge in the past thirty years. Rhine River with headwaters in the Swiss Alps has significant rise of discharges in past fifty years; also surpassingly regime of the Rhine River differentiates very much from regime of the Mura River.

Analyses of the Colorado River Natural Flow data show that during the past 20 years there have been large variations in extremes from floods to drought conditions. During the past 10 years the river system has been in extreme drought conditions with reservoirs now less

than 50 % of capacity. Figure 5 shows the annual WY discharge of the river (series-1) with 10-year moving averages showing the trends in natural variations. Winter snow pack provides over 80 % of the water supply for the Colorado. Warmer and dryer winters have decreased the total water supply and shifted the melt and peak runoff earlier in the spring. MATTHEWS et al. (1992) and DETTINGER et al. (2001) have noted this trend in many western US river basins. The Colorado River has also highest fluctuation in water regime. Surprisingly Colorado River (from arid regions) and Sava River (moist regions) have highest variation in comparison to Rhine and Mura Rivers.

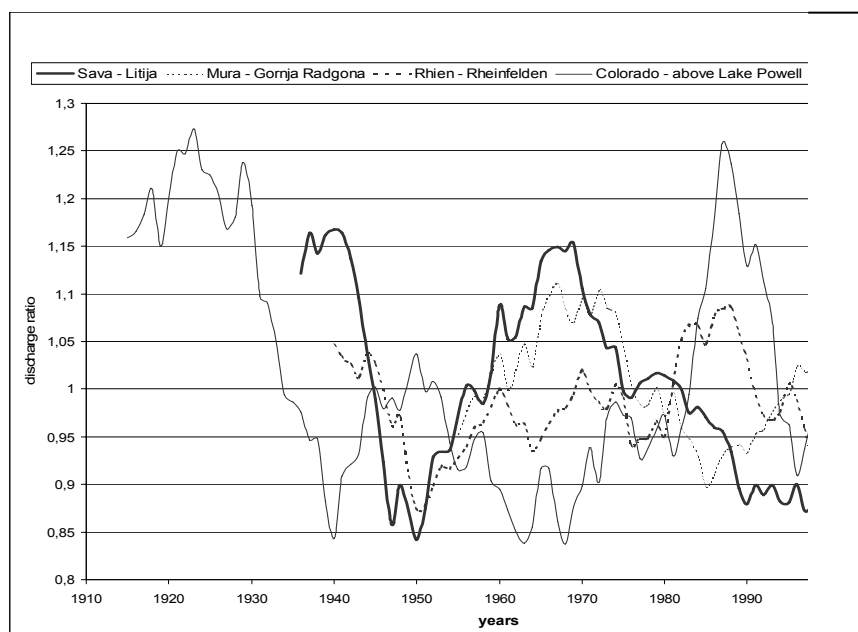


Figure 8: Ten-year moving average of discharge ratio
(annual discharge/mean discharge from 1961 - 1990)

6 Discussion and conclusions

There are no clear universal trends in the water regimes of the analysed rivers in the past century or in past twenty years also. Large differences in trends occur even in nearby watersheds. Similarity is presented in the discharge regime along the river stream.

Also fluctuation of the discharges related to average differentiate between rivers and there is no high difference between humid and arid climate, also there is no difference in amplitude in the past century and past thirty years. The Sava and Colorado Rivers have long periods when their discharge is below the long-term average discharge. This below normal trend appears to be increasing during the past 10 years. If this trend continues, it will have significant impacts on water supplies, hydropower generation, agriculture, and availability of potable water for municipal use. There is also significant difference on the Mura River watershed between lower and upper part. Last years discharges on alpine part of watershed increase and in lower part decrease.

Summary

Analyses of mean annual flow data for major Slovene rivers (Sava, Drava, and Mura) have been derived for the last thirty or sixty years, respectively. In the past twenty years, significant trends in decreasing flows have been identified. Trends in water balance were also analysed by WatBal model. Similar trends have been observed on other European rivers (Rhein) and US rivers (Colorado).

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References

- CHRISTENSEN, N. S., A. W. WOOD, N. VOISON, D. P. LETTEMAIER AND R. N. PALMER (2004): The effects of climate change on the hydrology and water resources of The Colorado River basin, Climatic change 62, Kluwer Academic Publishers
- DAI, A, K. TRENBERTH (2002): Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations, J. Hydrometeorology, Vol 3, 660-687
- DETTINGER, M. D., D. S. BATTISTI, R. D. GARREAUD, G. J. MCCABE, AND C. M. BITZ (2001): Interhemispheric effects of interannual and decadal ENSO-like climate variations on the Americas, in V. Markgraf (ed.), Interhemispheric climate linkages: Present and Past Climates in the Americas and their Societal Effects: Academic Press, 1-16
- KOBOLD, M. AND K. SUŠELJ (2005): Precipitation forecast and their uncertainty as input into hydrological models. Hydrol. earth syst. sci., Vol. 9, no. 4
- LEAF, C. F. AND G. E. BRINK (1975): Land use simulation model of the subalpine coniferous forest zone, USDA For. Serv- Res. Pap. RM-135. 42 pp Rocky Mt. For. And Range Exp. Stn., Fort Collins Co.
http://fr.cfans.umn.edu/courses/fr5153/Handout_models_2007.pdf
- MATTHEWS, D. A. , F. GIORGI AND G. BATES (1992): Use of nested models to simulate regional orographic precipitation. Proceedings, International Symposium on Managing Water Resources During Global Change. Am. Water Resources Association, Bethesda, MD. p. 671-680
- MATTHEWS, D. A., C. HARTZELL, S. MEYER AND T. FULP (2000): Environmental applications of decision support systems for river systems management: Examples from the Colorado and Rio Grande Basins. Proceedings of the ASCE Conference on Watershed Management and Operations Management 2000. Ft. Collins, Colorado, June 2000
- PETROVIČ P., K. BADUROVA, L. HOLKO AND Z. KOSTKO (2005): Water balance modeling and Mapping in The Danube River Basin, Geophysical Research Abstract Vol. 7, EGU
<http://www.cosis.net/abstracts/EGU05/10821/EGU05-J-10821-1.pdf>

STRZEPEK, K. M., D. N. YATES (1997): Climate change impacts on the hydrologic resources of Europe: a simplified continental scale analysis, *Climate Change*, Springer Netherlands, Vol. 36, Numbers 1-2 / May, 1997

T. QIAN, A. DAI, K. TRENBERTH AND K. OLESON (2006): Simulation of Global Land Surface Conditions from 1948 to 2004: Part I: Forcing Data and Evaluations, *J. Hydrometeorology* Vol 7, 953-975.



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The challenge of water balances and run-off projections in the Mediterranean hydrology

Ivan Portoghesi and Michele Vurro

1 Introduction

Understanding which processes are dominant or controlling at different scales in the different hydroclimatic regions of the Mediterranean is the key to undertake meaningful impact investigation with emphasis on the reduction of model uncertainty. Nevertheless it is difficult and not careful to attempt an aprioristic statement on the dominant hydrological processes in a given catchment. Rather it is advisable to characterise the basic interactions connecting the hydrological transformations at the scale of interest of the investigated problem. Precipitation, soil moisture, evaporation and evapotranspiration, streamflow and surface water storage, groundwater, and water infrastructures are deeply interlinked processes that modulate the terrestrial water balance in the Mediterranean region and consequently the water resources regimes. The interpretation and modelling of such processes at suitable scales is subject of huge research efforts in the field of hydro-climatology. It is therefore crucial to develop suitable model experiments to evaluate under a reasonable uncertainty framework what the basin scale response to the altered climate could be. Such modelling experiments would be tailored on the specific hydrologic behaviour of the physical system under investigation, as a response to the climatic, geomorphological and other physical characteristic of catchments.

2 From regional climate simulations to hydrological information needed for basin scale impact studies

The traditional method for assessment of water resource systems are based on the use of statistical analysis of historic records of climatologic and hydrologic variables under the hypothesis of statistical stationarity. As the evidence of global climate change continues to accumulate, the use of historic records as a proxy for possible future events becomes less appropriate (WILEY & PALMER 2008). In other words, the stationarity hypothesis in hydrological variables can no longer be invoked (e. g. MILLY et al. 2008) because of substantial anthropogenic change of Earth's climate that has altered the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers.

Most of the potential impacts of climate change (change in precipitation and extreme events, sea level rise and groundwater contamination, glacial melt-water and freshwater availability) are not the direct output of climate simulation models but rather the hypothetical product of

other model cascades adopting the altered atmospheric variables as the forcing of mechanistic process model specifically designed to describe the land surface hydrological processes.

Successful modelling of hydrological processes and the global water cycle on all three time scales would therefore require detailed representations of the physical processes controlling water and energy fluxes. The predictability of global water cycle components is typically quantified in the context of models that embody both theoretical understanding of the relevant processes and representations of all available observations. Such modelling would also require higher spatial resolution by one to two orders of magnitude than that currently used in dynamical weather forecasting models and climate change simulation models. Thus, formulating an effective modelling strategy that encompasses the diverse temporal and spatial scales is a high priority in impact studies.

A crucial step in the data assimilation for the correction of climate model output is that observations of atmospheric, hydrologic and land-surface variables are often available at more than one scale, for example, point measurements of precipitation from rain gauges, and areal averages of precipitation from radar and satellites. To validate a model, and to incorporate the knowledge of observations into its dynamics (using data assimilation), it is necessary to have a framework by which observations at different scales can be optimally merged to produce the best conditional estimates of the process and their uncertainty at the scale of interest (e. g. the hydrological model's resolution).

An example scheme for the development of climate change impact assessment is represented in Figure 1. In this scheme different data sources are assimilated into the model prediction chain to accommodate the climate model output with the resolution scale of a generic eco-hydrological impact model. According to the model theory, the assimilation of external information into the weather predictions is used to obtain more realistic variables at the resolution scale of the region of interest. The ERA-40 re-analysis by the ECMWF can be used therefore as lateral boundary conditions when a dynamic downscaling approach is adopted (through a RCM or a Regional Earth Simulator, RES) in order to filter out the model bias deriving from the approximations in the GCM. The ECMWF re-analysis is a valuable dataset for meteorological and climatological studies as it involves reprocessing observational data spanning an extended historical period using a consistent modern analysis system (UPPALA et al. 2005) to create gridded atmospheric variables with space-time resolution which is consistent with state-of-art GCMs. While re-analysis can be thought as the best estimate on many variables (such as winds and temperature) of the atmosphere, the validity of ERA-40 products has some limitations. Besides the drawbacks in the observations due to artificial changes to the input data (i. e. updates of observation platforms), not all re-analysis data are constrained by observation, but are strictly numerical weather model re-forecasting such as precipitation and surface evapotranspiration (global observations simply do not exist). Nevertheless re-analysis products are often used to validate the predictive capability of RCMs excluding the model bias resulting from the boundary conditions of the GCM. On the contrary, to validate the predictive capability of climate models, in order to use their output into impact models, traditional gauge observation of the atmospheric variable of interest are required. Moreover, historical meteorological monitoring station records represent the local information set necessary to operate the statistical downscaling of RCM simulation to the scale of the gauge station.

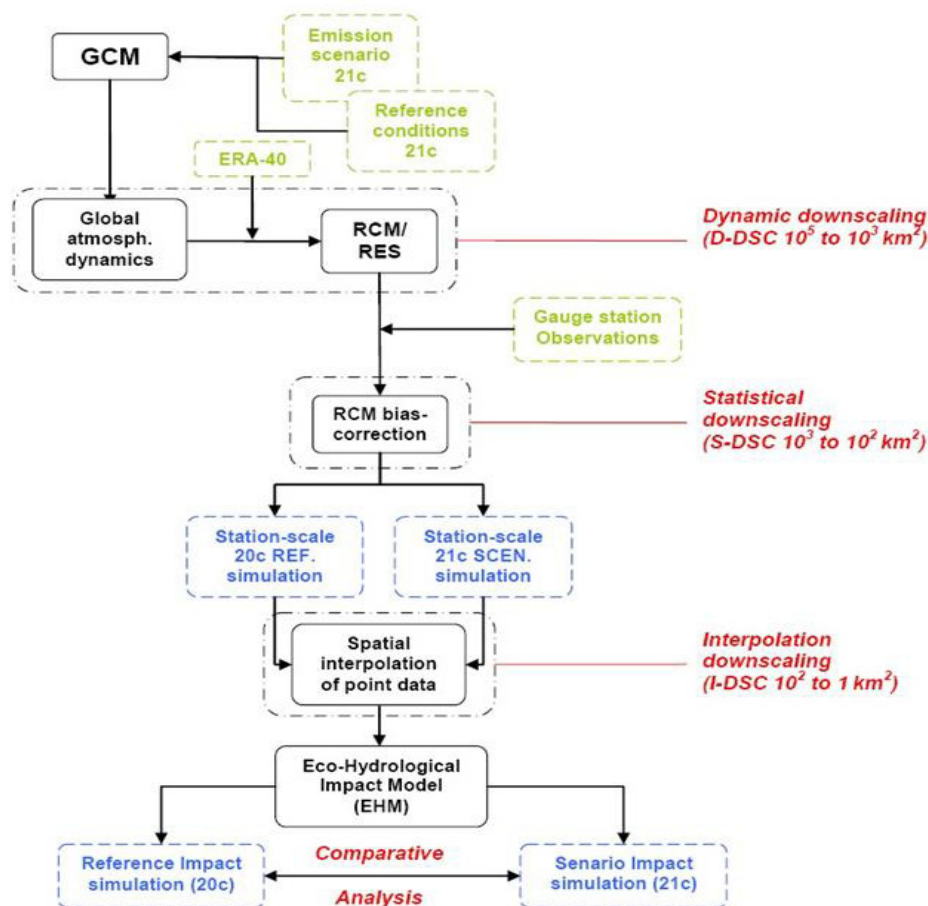


Figure 1: Scheme for the development of climate change impact evaluations on the land hydrological cycle. The assimilation of data into a suitable model cascade allows the downscaling of climate model output and its assimilation into hydrological models as meteorological forcing. Uncertainty in the meteorological forcing due to the process scheme cannot be neglected when hydrological impacts are evaluated.

The method depicted in Figure 1 and adopted in the following subsection is based on a bias correction scheme for downscaling climate model output described by WOOD et al. (2004) and often reported as quantile mapping. The statistical transfer function, through the assimilation of reference observation records (extended over a few decades) as a paradigm for the variability mode, enables to downscale the reference and scenario simulations from the computational nodes of the RCM to the scale of each available station.

Once a station-scale dataset for the reference (i. e. 20th Century reference period) and scenario conditions – both of the two obtained after the statistical downscaling of the RCM simulations nested on the GCM respectively under reference and future emission scenarios – the atmospheric forcing has to be provided at a suitable scale to match the structural requirements of the adopted hydrological impact model (i. e. space-time resolution of the input data). As in the case of historical station records some spatial interpolation technique has to be adopted either using deterministic or statistical models. In the general framework of the climate change impact studies, spatial interpolation techniques operate a high resolution downscaling also through the assimilation of various landscape attributes as prognostic co-variables of the spatial variability of climate over the study domain. As an overall result of the downscaling and

bias-correction scheme represented in Figure 1, the assimilation of historical meteorological records, and the use of suitable interpolation techniques allows to downscale from the RCM resolution (about 10^3 km^2) to the scale of the hydrological process model (about 1 km^2). At the end of this process the various sources of uncertainty of each model component and data manipulation are combined yielding a dataset of meteorological forcing (for reference and scenario conditions) that obviously implies a certain degree of uncertainty that should be quantified and taken into account when it is propagated through the impact model. Due to persistent uncertainty which is due, by a relevant amount, to the bias inherited from the GCM, the evaluation of impacts should be preferably undertaken through a comparative model simulation using reference and scenario conditions which are both generated from the global model. The methodology presented in Figure 1 was applied to a southern Italy region, the Apulia region, which is a particular case study of the EU project called CIRCE aiming at a regional assessment of climate change in the Mediterranean.

3 Assessment of climate change impact on the hydrology and water resources in a Mediterranean region: the Apulia case study

Apulia region is located in the south eastern part of Italy (Figure 2) and its extension is of $19,500 \text{ km}^2$. It is mainly dominated by agriculture, that is a vital economic resource for the region, with more than 70 % of the total area occupied by cropped land. Water resources are supplied mostly through conveyance systems built between 1970 and 1990 to transfer water from the bordering regions. Moreover, a fast growing trend in the last four decades towards irrigation farming has led to a massive exploitation of groundwater resources. As a result, the groundwater level has dramatically decreased in the river plain aquifers while sea water intrusion is observed in most of the coastal zones.

The climate variables, and rainfall in particular, exhibit a marked inter-annual variability which makes water availability a permanent threat to the economic development and ecosystem conservation of the region. The hydrological regimes characterising both surface and groundwater resources are the outcome of the complex interactions between climate, landscape geo-morphology, and soil-vegetation continuum, controlling the hydrological response across scales. Further complexity is due to the substantial lack of measurements regarding the hydrological processes in the region. Only about 15 % of its extent has been regularly monitored for the stream flow, while in the rest of the region groundwater table measurements are discontinuous in space and time. It is therefore quite obvious how crucial is to investigate the possible impacts of climate projections in such a hydro-climatic and context.

3.1 The impact model

The adopted model named G-MAT (PORTOGHESE et al. 2005) was proved suitable for the evaluation of hydrological water balance in semi-arid conditions. This model was originally developed for the sustainability assessment of water resources with particular emphasis on groundwater-dependent regions. It considers the major landscape features that determine the soil water balance such as the vegetation activity through the season and the soil moisture storage and flux processes adopting simple parameterisations. Moreover, the subsoil characteristics are considered as well in the model, so that natural groundwater recharge can be evaluated thus enabling further investigations of aquifer dynamics under different natural and

anthropogenic forcing. G-MAT yields natural groundwater recharge on a monthly basis, through the distributed application of the soil water balance equation, evaluated as the difference between the inflows (rainfall, irrigation) and the outflows (evapotranspiration, surface runoff). The spatial resolution of the water balance model is 1 km² thus assuring a feasible representation of the spatial heterogeneity of soil, sub-soil, and vegetation features as well as a realistic description of catchment morphology. The monthly time step was chosen as a compromise between the data availability over large domains and the uncertainty introduced by the various data manipulations necessary for the downscaling of climate scenarios through the observation-based corrections. It is true in fact that daily time step is the first choice for water balance evaluations through hydrological process models. But on the other hand, the use of daily data provided by the available climate models would have required much more complicated and unreliable data correction schemes particularly for intermittent variables such as precipitation.

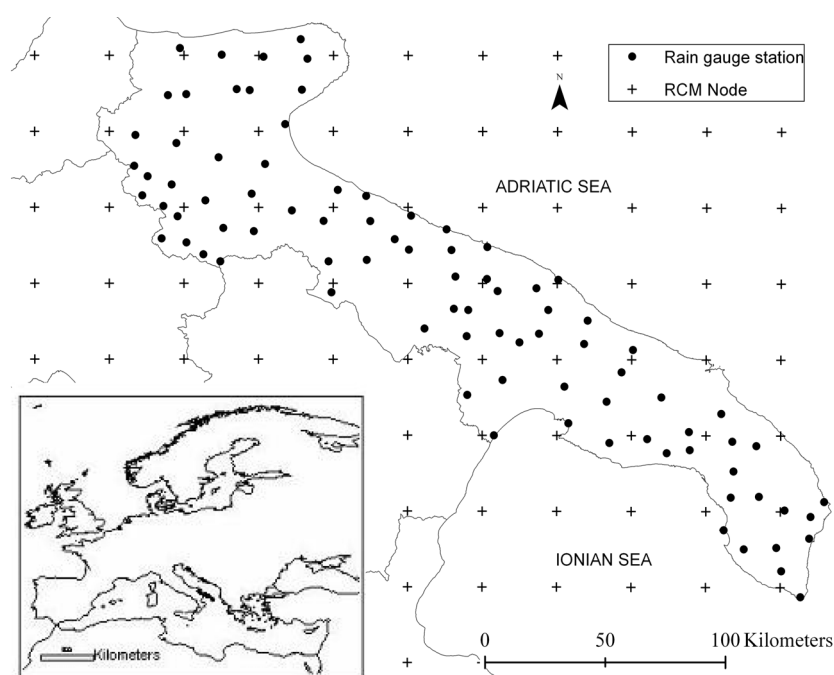


Figure 2: The Apulia case study with the RCM grid nodes and the weather observation network

3.2 Downscaling of meteorological forcing

The meteorological forcing for the water balance analysis of the Apulia region, was obtained through the downscaling of some of the atmospheric variables produced by one of the Regional Earth System models developed within CIRCE (PROTHEUS, ARTALE et al. 2009). The adopted variables at the ground level are air temperature at sub-daily scale, and daily total rainfall. These data were extracted from the climate model runs concerning the control simulation (assuming the ERA-40 1958 - 1999 dataset as boundary conditions of the regional model), the 20th century simulation (1953 - 2000), and the A1b 21st century scenario (2001 - 2050). Temperature data were analysed finding maximum and minimum daily temperature within the adopted RES simulation. From the RES simulation 32 nodes were selected as representative of the entire region. These nodes were associated by proximity rules to the corresponding weather stations scattered throughout the region. Monthly mean maximum and

minimum temperatures as well as monthly rainfall totals were considered from the available gauge network (83 temperature and 112 rainfall gauge stations). Concerning the nesting of climate models and the consequent downscaling technique the adopted methodology can be summarised as follows. The Global Circulation Model (ECHAM5-MPIOM in this study) forces the RES model (PROTHEUS) which is used to feed the water balance model G-MAT. The objective of the statistical downscaling (S-DSC) step is to correct RES output for local bias (mainly due to the raw approximation of land use and topography in RES) and thus obtain realistic meteorological forcing at each of the gauge stations for local impact studies. Since the water balance model adopts a monthly time resolution, the S-DSC method, which consists in a variable correction method based on the quantile algorithm (DÉQUÉ 2007), is applied accordingly to the monthly dataset of station records and RES model simulations, namely mean monthly temperatures and monthly rainfall totals. To improve the significance of the statistical correction, a 3-months time window centred on each month was used. The quantile algorithm was estimated by comparing the reference ground station records with the control RES simulation forced by ERA-40 (1958 - 1999). The resulting correction algorithm was then applied to the output of the coupled GCM-RES model for the both past (1953 - 2000) and future (A1b, 2001 - 2050) GCM scenarios in order to filter out the local systematic bias of the RES. The correction of the RES model bias has the advantage to preserve the temporal and spatial dynamics of the GCM projections, also enhancing the comparability between future and past scenarios, since both time series has been filtered using the same algorithm. Moreover, the downscaled dataset obtained for each station was interpolated with the inverse distance weight algorithm (IDW) in order to get the monthly input maps for the water balance calculations at a resolution scale of 1 km². In particular, temperature maps were interpolated with a two-steps method based on the correlation between temperature measurements and station elevations and then used to estimate potential evapotranspiration (HAMON 1963). The climate map archive that was finally developed is more consistent than the raw climate simulation for a wide range of local scale applications. In Figure 3, for example, the spatial interpolations of monthly temperature observations and downscaled 21st A1b scenario reveal an unprecedented increasing trend in minimum and maximum temperature, while in the historic period only the minimum temperatures were observed to increase.

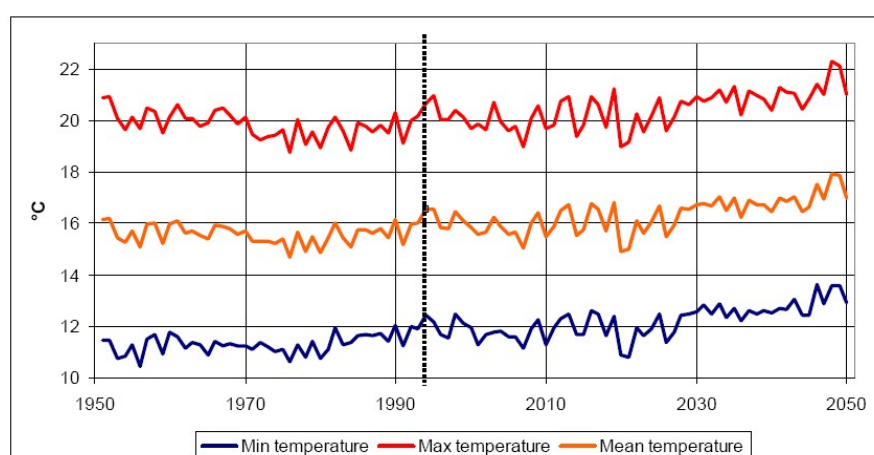


Figure 3: Spatial averages of interpolated maps of minimum, maximum, and mean annual temperatures over the Apulia region, obtained from station records for the period 1951 - 1994 (ending at the dotted line), 20th and A1b 21st century with S-DSC, respectively for the periods 1995 - 2000 and 2001 - 2050.

3.3 Model results and regional water balance projections for the 21st century

The climate maps for the historic and 21st period were then used to force the G-MAT obtaining monthly evaluations of runoff, groundwater recharge and irrigation.

A comparison between the water balance reconstruction for the historic period and the 21st century is reported in Figure 4 in which the inter-annual variability of precipitation shows an increased standard deviation in the annual values. This increased variability of precipitation in the 21st century is intrinsically related to the dynamic of the global circulation model used as lateral boundary condition to the RES model which is preserved by the downscaling algorithm. Consequently, runoff and groundwater recharge which are controlled by rainfall regime are similarly projected into the 21st century with an increased variability while preserving a decreasing trend. It is therefore arguable that the downscaled rainfall projections suffer from some degree of inconsistency inherited from the GCM and that both river runoff and groundwater recharge may be more rapidly decreasing in the 21st century, somehow in agreement with the trend observed in the second half of the 20th century.

Due to the substantial difference between the observation-based simulation of the regional water balance and the 21st century simulation, separate annual trends were used for these two subsets to highlight both the historical and projected trends of all water balance components. Moreover, a general trend for the mixed 100-years dataset of annual precipitation was plotted to remark the significant stationarity resulting from this combination (with a slight decrease of 0.35 mm/yr across the two centuries). Consequently, it is interesting to note that major water balance variables such as evapotranspiration – counting for more than 60 % of the mean annual rainfall – and irrigation show a non-significant trend throughout the investigated periods thus suggesting a minor sensitivity of the simulated evapotranspiration processes to the projected perturbations in rainfall and temperature as a consequence of the soil moisture capacity which acts as a limiting factor of plant transpirable water.

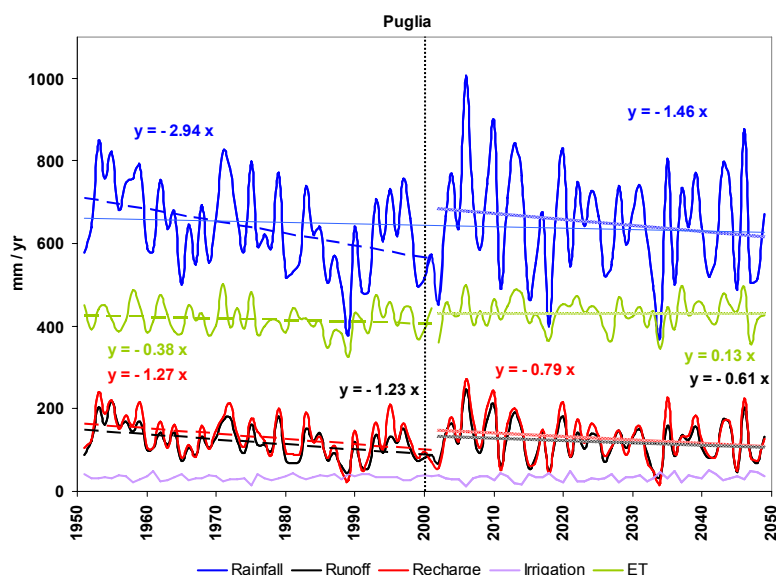


Figure 4: Annual patterns of water balance components for the Apulia region.

From the basic statistics in Table 1 it is clear therefore that the adopted climate scenario causes an evident increase in the variability of the available water resources corresponding to surface runoff and groundwater recharge though preserving the long term average amount of each water balance component. Such a result is certainly a water management issue that has to be addressed in terms of adaptation to meet future water resources requirements. The increased variability of the available water resources is even more severe under the point of view of drought occurrence (and conversely of extremely wet years).

Table 1

Summary statistics of water balance components for the historic and 21st century.

Variable [mm/year]	Period	Mean	Standard deviation	Coefficient of Variation
Rainfall	1951 - 2002	637.49	107.63	0.17
	2002 - 2050	651.91	136.82	0.21
	1951 - 2050	644.49	122.23	0.19
Runoff	1951 - 2002	118.34	39.61	0.33
	2002 - 2050	121.50	47.27	0.39
	1951 - 2050	119.87	43.30	0.36
Recharge	1951 - 2002	131.58	48.80	0.37
	2002 - 2050	130.01	57.91	0.45
	1951 - 2050	130.82	53.14	0.41
Irrigation	1951 - 2002	34.01	6.28	0.18
	2002 - 2050	34.01	8.81	0.26
	1951 - 2050	34.01	7.57	0.22

4 Conclusions

Three decades of studies on the effects of climate change on water resources indicate that atmospheric variables, mainly temperature and precipitation, have direct effects on the timing and magnitude hydrological regimes, and that the response of a given system is highly variable and non-linear based on basin characteristics and local and regional climate combined at various scales with catchment characteristics.

In the Mediterranean hydrology the impact modelling is conditioned by the capability to capture the hydrological response of large river basins discharging into the Mediterranean sea as well as the need to develop suitable representations of small-medium scale river basins representing almost half of the entire discharging basin. Groundwater regime is equally crucial for the closure of hydrological cycles this representing a fundamental water resource for Mediterranean countries.

From the results presented above for the Apulia case study, some general remarks can be summarised. First of all it is important to develop suitable mathematical models to represent the non-linear processes such as the unsaturated soil processes, including the role of vegetation coverage, which dominate hydrological predictions in Mediterranean catchments. Then, the downscaling and bias correction issues affecting climate models have to be thoroughly evaluated in order to compare the water balance signatures derived from observation-based climate forcing with those obtained using downscaled climate scenarios.

According to adopted climate model simulations, the evaluation of water resources availability in a water-scarce region has highlighted some peculiar response of streamflow and groundwater recharge to the predicted temperature and rainfall alterations. In particular, no specific trends were detected in the annual water balance components but a marked increase in the variability of the system as a result of the increased rainfall variability predicted for the 21st century. The increased variability of the hydro-systems in the Mediterranean is therefore confirmed as one of the main water management issue in the near future.

As a general remark regarding the future regimes of fresh water bodies in the Mediterranean region, there is evidence that the stationarity assumption which is basis of water system design and management has been definitely compromised by various anthropogenic disturbances including climate. The CIRCE project has strongly developed the modelling capability to close regional water and energy budgets in the Mediterranean basin. Nevertheless limitations in the models' ability to represent the space-time variability of present and future precipitation inputs (e. g. storm amount, intensity, and duration) are still persistent regarding the detail necessary for hydrological process models. Moreover and more importantly, the greatest uncertainty when predicting future climate trajectories and their probable impacts lies in the assumptions that are made with regard to social and economic development. Besides the emissions of greenhouse gasses, the socio-economic scenarios will also drive all other landscape modifications and water resources exploitation policies that will certainly exert major influences on future water resources.

Summary

A climate change impact study was presented with regard to a meaningful case study in southern Italy (the Apulia region is among the rural case studies of Circe) in which surface and groundwater resources are heavily exploited for irrigation and drinking purposes. Monthly mean temperatures and rainfall totals were considered from the available gauge network (83 temperature stations and 112 rainfall gauge stations) to develop a local downscaling starting from 32 nodes of the PROTHEUS model for the control run (ERA-40 reanalysis 1958 - 1999 as boundary conditions), the 20th century simulation (1953 - 2000), and the A1B scenario (2001 - 2050) runs. Monthly interpolation maps were obtained for rainfall and precipitation and used to force a water balance model for the simulation of surface runoff, groundwater recharge and irrigation demand. The increase in mean annual temperature and the enhanced variability according local climate scenario has highlighted a marked increase in the variability of water resources availability and irrigation demand in a water-scarce region. The increased variability of the hydro-systems in the Mediterranean was therefore confirmed as one of the main water management issue in the near future.

References

- ARTALE, V.; S. CALMANTI, A. CARILLO, A. DELL'AQUILA, M. HERRMANN, G. PISACANE, P. M. RUTI, G. SANNINO, M. V. STRUGLIA, F. GIORGI, X. BI, J. S. PAL, S. RAUSCHER (2009): An Atmosphere-Ocean Regional Climate Model for the Mediterranean area: Assessment of a Present Climate Simulation. - *Climate Dynamics* DOI 10.1007/s00382-009-0691-8.
- DÉQUÉ, M. (2007): Frequency of precipitation and temperature extremes over France in a anthropogenic scenario: model results and statistical correction according to observed values. - *Global and Planetary Change*, 54, 1-2, 16-26.
- HAMON, W. R. (1963): Computation of direct runoff amounts from storm rainfall. - *Int. Assoc. Sci. Hydrol. Pub.* 63: 52-62.
- MILLY, P. C. D.; J. BETANCOURT, M. FALKENMARK, R. M. HIRSCH, Z. W. KUNDZEWICZ, D. P. LETTENMAIER, R. J. STOUFFER (2008): Stationarity is dead: Whither water management? - *Science*, 319, 573–574, DOI: 10.1126/science.1151915.
- PORTOGHESE, I.; V. F. URICCHIO, M. VURRO (2005): A GIS tool for hydrogeological water balance evaluation on a regional scale in semi-arid environments. - *Computers & Geosciences*, 31-1, 15-27.
- UPPALA, S. M.; P. W. KALLBERG, A. J. SIMMONS, U. ANDRAE, V. D. BECHTOLD, M. FIORINO, J. K. GIBSON, J. HASELER, A. HERMANDEZ, G. A. KELLY, X. LI, K. ONOGI, S. SAARINEN, N. SOKKA, R. P. ALLAN, E. ANDERSSON, K. ARPE, M. A. BALMASEDA, A. C. M. BELJAARS, L. VAN DE BERG, J. BIDLOT, N. BORMANN, S. CATRES, F. CHEVALLIER, A. DETHOF, M. DRAGOSAVAC, M. FISHER, M. FUENTES, S. HAGEMANN, E. HOLM, B. J. HOSKINS, L. ISAKSEN, P. JANSSEN, R. JENNE, A. P. MCNALLY, J. F. MAHFOUF, J. J. MORCRETTE, N. A. RAYNER, R. W. SAUNDERS, P. SIMON, A. STERL, K. E. TRENBERTH, A. UNTCH, D. VASILJEVIC, P. VITERBO, J. WOOLLEN (2005): The ERA-40 Re-Analysis. - *Quart. J. Roy. Meteor. Soc.*, 131, 2961-3012.
- WILEY, M. W.; R. N. PALMER (2008): Estimating the Impacts and Uncertainty of Climate Change on a Municipal Water Supply System. - *ASCE, J of Water Res Plan and Mngt*, 134 (3), 239-246.
- WOOD, A. W.; L. R. LEUNG, V. SRIDHAR, D. P. LETTENMAIER (2004): Hydrologic Implications of Dynamical and Statistical Approaches to Downscaling Climate Model Outputs. - *Climatic Change* 62, 189-216.



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Climate change impact on the river runoff series in the Baltic countries (past and future)

Jurate Kriauciuniene

1 Introduction

Analysis of changes of river runoff is very important in order to learn effects of the climate change and human activity. Results of this analysis depend on the availability of long-term data series. Systematic measurements of runoff in the European rivers started two centuries ago. The longest time series of the river discharge are available in the Goeta River (data from 1807), Nemunas (1811), Rhine (1816), Dnieper (1818), Weser (1821), Danube (1840), Vuoksi (1847), Elbe (1851), Neva (1859) and Loire (1863) (PEKAROVA et al. 2006). The long-term discharge time series at Smalininkai in the Nemunas are one of the oldest data related to the runoff of the big river (catchment area at Smalininkai is 81,200 km²) in Europe. In 2011 the Lithuanian hydrologists will mention the 200 year anniversary of hydrological investigations in the Nemunas River.

Changes of climate elements (temperature and precipitation) influence directly conditions of river runoff formation. According to the data of the World Meteorological Organization, a significant climate change has already started (www.ipcc.ch). The global average annual temperature increased about 0.6 - 0.9 °C, comparing the temperature of the end of the 19th with the end of the 20th century (SOLOMON et al. 2007). The average temperature of winter and spring seasons increased at the mid-latitudes. Winters are warming in North of Europe (LINDSTRÖM et al. 2006) and in the Baltic States. Global warming affects the fundamental variations of the hydrological regime and water resources. According to the climate change scenarios, the increase of air temperature as well as changes of precipitation and total evaporation might influence the annual distribution of river runoff and cause changes of the extreme runoff elements (BELDRING et al. 2008; BERGSTROM et al. 2001; HISDAL et al. 2006; KRASOVSKAIA & GOTTSCHALK 1993; KRIAUCIUNIENE et al. 2008).

River discharge time series were extensively studied in many countries. The Baltic Sea drainage basin is one of the regions where variations of hydrological parameters are well investigated (HISDAL et al. 2007; LINDSTRÖM et al. 2006). The changes in river discharge of the Baltic States were also investigated by individual national studies (KLAVINS et al. 2008; KRIAUCIUNIENE et al. 2008). However, only some papers analysed the changes of river discharge in the Baltic countries according to the common methodology (REIHAN et al. 2007). In order to evaluate changes of meteorological and hydrological parameters in large territories, it is necessary to perform a regionalisation of the territory. However, that kind regionalisation is still absent for all territory of the Baltic countries.

The main aim of this research is to evaluate the past and future changes of the rivers' runoff in the Baltic countries using the database of meteorological and hydrological observation, modern climate change models, statistical methods and hydrological modelling. This paper addresses: (a) the variability of long-term regional series of temperature, precipitation and river discharge for a long time period (1923 - 2007) in the Baltic countries; (b) the climate change impact on hydrological processes in the Nemunas River catchment in the 21st century.

2 Materials and methods

2.1 Description of hydrological regions in the Baltic States

The Baltic countries are Estonia, Latvia and Lithuania; their total area is 175,117 km². This territory is relatively small, but hydrometeorological differences are very big. We divided this territory into 10 hydrological regions (Figure 1a), depending on the conditions of river discharge formation, which could be expressed in percentage of the sources of rivers' feeding.

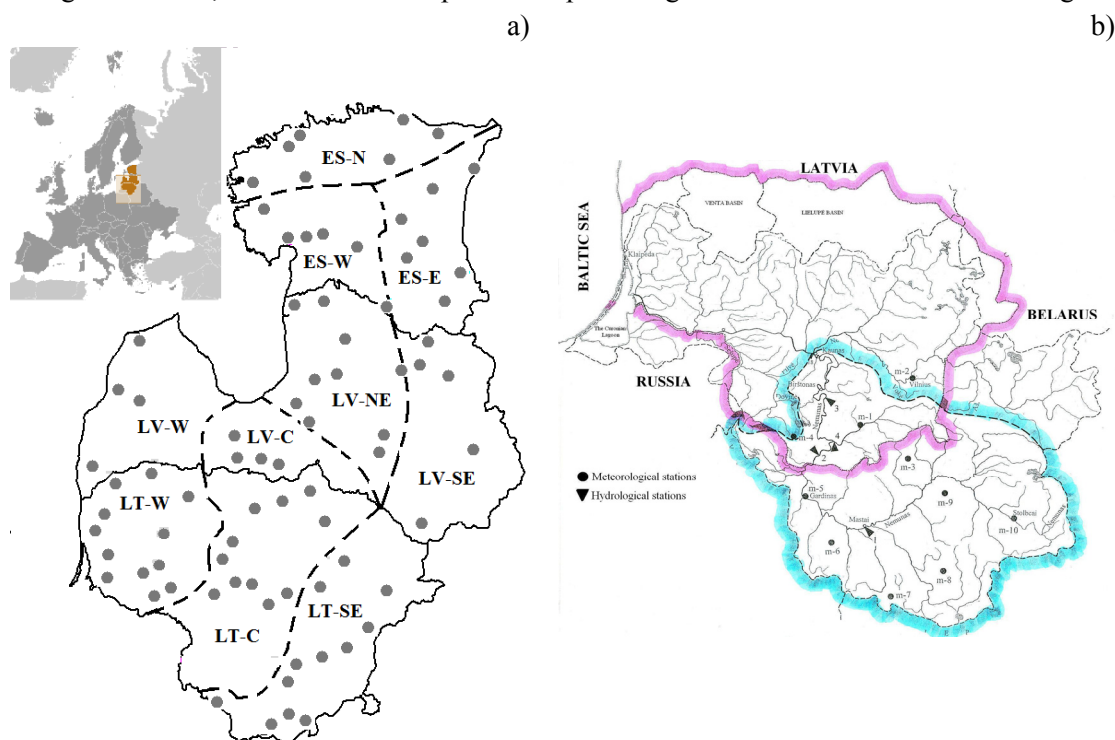


Figure 1: Objects of investigations: a) hydrological regions of the Baltic States: Lithuania (LT) – western (W), central (C), southeastern (SE); Latvia (LV) – western (W), central (C), northeastern (NE), southeastern (SE); Estonia (ES) – northern (N), western (W), eastern (E). Water measurement stations are marked as points; b) the catchment of the Nemunas River.

The main source of river feeding in western Latvia and Lithuania is precipitation (50 % and 53 %). The maximum discharges resulting in the rain floods often exceed discharges of spring floods. Spring floods dominate in the central Lithuania and Latvia (43 - 50 % of the total water discharge), and the smallest part of discharge is generated from groundwater. Continental type of climate is characteristic for southeastern Latvia and Lithuania as it has the longest duration with snow cover and the coldest winters. The rivers of this region have prevailing subsurface feeding (40 - 45 %). The main river feeding sources in the northern Esto-

nia are snowmelt (40 %) and precipitation (40 %). The eastern Estonia is the most continental part of Estonia with the coldest winters and the longest duration of snow cover. The main river feeding sources are snowmelt (50 %) and groundwater (30 %). Spring floods dominate in this hydrological region. Marine type of climate prevails in western Estonia. The main source of river feeding in western Estonia is precipitation (41 %). Rain floods often exceed the discharges of spring floods.

Climate change impact on water resources was evaluated for the the Nemunas River catchment from its headwaters to the WMS of Nemajūnai (Figure 1b). The Nemunas River is typical river of southeastern Lithuanian region. It is natural regulated river with a prevailing sub-surface feeding. The annual runoff of the Nemunas is distributed rather equally – the part of the spring flood runoff is only from 20 % to 30 % of the total annual runoff.

2.2 Methods and data used for analysis of the variability of regional series

The variability analysis of regional series was done using anomalies of time series of temperature, precipitation and rivers' discharge. Anomalies of precipitation (P) and discharge (Q) (expressed by %) were calculated by division of long-term series with mean values of reference period (1961 - 1990), whereas temperature (T) anomalies (°C) were normalised by subtracting the mean and dividing by the standard deviation. The regional series of anomalies of T, P and Q were calculated as the average of the standardised individual series. To study the long-term variations in the regional series of P and Q, integrated curves with a 5-year moving average were used. An integrated curve is the sum of anomalies of P or Q from the reference period 1961 - 1990 (KRIAUCIUNIENE et al. 2008). For the calculation of regional time series of discharge, long-term historical data series were used from 77 water measurement stations (WMS) (32 stations in Lithuania, 23 – in Latvia and 22 – in Estonia) (Figure 1a). Regional series of temperature and precipitation were compiled on the basis of data from 59 meteorological stations (17 stations in Lithuania, 32 – in Latvia and 10 – in Estonia).

2.3 Methods and data used for forecast of the changes of river runoff

Climate change impact on hydrological processes of the Nemunas River has been evaluated using Global Climate Models (GCM), greenhouse gas emission scenarios, and hydrological modelling. Projected changes in river runoff are linked to changes in the temperature and precipitations according to different climate scenarios in long-term perspective. Hydrological modelling of the Nemunas river was carried out using global circulation models ECHAM5 and HadCM3, and according to emission scenarios such as A1B, A2 and B1. Climate scenarios were adapted to the Lithuanian conditions. A common method for determination of climate change input to hydrological models is the delta change approach. The semi-distributed conceptual HBV model developed at the Swedish Meteorological and Hydrological Institute (BERGSTROM 1995) was applied to estimate the Nemunas runoff changes in the 21st century. Hydrological modelling was done in the Nemunas basin from its headwaters to the WMS of Nemajūnai (Figure 1b). The area of this basin is 38,541 km² (the bigger part of this basin is in territory of Belarus). The Nemunas catchment was divided into four sub-basins such as the headwaters of the Nemunas – Mosty, Mosty – Druskininkai, Druskininkai – Nemajūnai and watershed of the River Merkys. Model calibration was carried out in the year 1975 - 1979 and validation - in the year 1980 - 1984. Daily discharge data of four WMS stations (Mosty, Druskininkai, Merkys and Nemajūnai) and daily data of temperature and precipitation of eight meteorological stations comprised basic hydrometeorological information.

3 Results

3.1 Variation of regional series of temperature, precipitation and discharge

The chronological variations of anomalies of annual regional temperature series are synchronically in the Baltic countries. A significant change in regional temperature series has been observed since 1988, i. e. anomalies increased to 1 °C in average for all regions in the Baltic countries (Figure 2a).

Analysis of the integral curves of precipitation anomalies enabled to determine the long-term variations of dry and wet periods (Figure 2b). The average period of the long-term variations is 26 - 30 years including the average wet and dry periods of 13 - 15 years. Only in the period of 1991 - 2007, the nature of cyclical alternation of P changed: instead of the dry P phase, a marginally positive P (2 %) anomaly of P occurred. The years of conversion from wet to dry periods usually coincide in most of the Lithuanian and Latvian hydrological regions, but there are some discrepancies in Estonia.

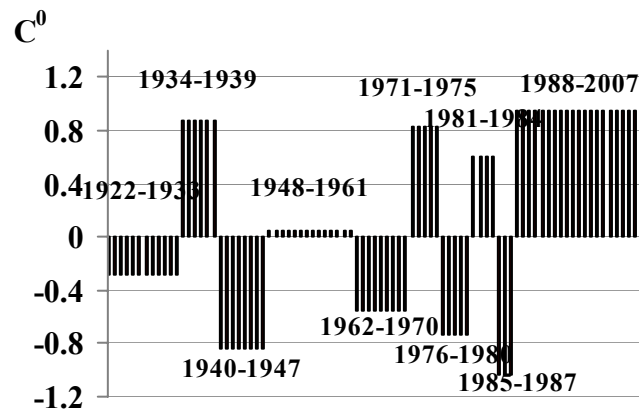
When analysing the anomalies of regional annual discharge series in the period of 1922 - 2007, the alternation of wet and dry periods emerged (Figure 2c). There are three periods with dry and wet phases in the regional discharge time series with an average duration of 28 years. In the Baltic States the wettest period of the rivers' discharge was in 1922 - 1932 (average anomaly of all regional series is 32 %) and the driest one in 1963 - 1976 (-21 %). Since 1996 the river discharge in the Baltic States could have been in the dry phase; however, because of the transformed nature of the temperature and precipitation, the river discharge differs only by -3 % from the average discharge of the whole period (1923 - 2007).

Changes in regional series were found comparing the period of most recent years of 1991 - 2007 with the reference period 1961 - 1990. The average annual temperatures in the period of 1991 - 2007 were larger almost 1 °C from those in 1961 - 1990 (Table 1). In 1991 - 2007, positive temperature anomalies occurred in all seasons. The winter season T anomalies were similar in all three Baltic States (0.5 - 0.6 °C). The regional series of the spring season T slightly differed depending on the geographical latitude. In Lithuania and the western and central parts of Latvia, the temperature anomaly of this season was around 0.7 - 0.8 °C, while in Estonia only 0.4 - 0.5 °C. Even more considerable anomalies of T occurred in the summer season. T anomalies of autumn season were marginal in all the Baltic States (0.1 - 0.2 °C).

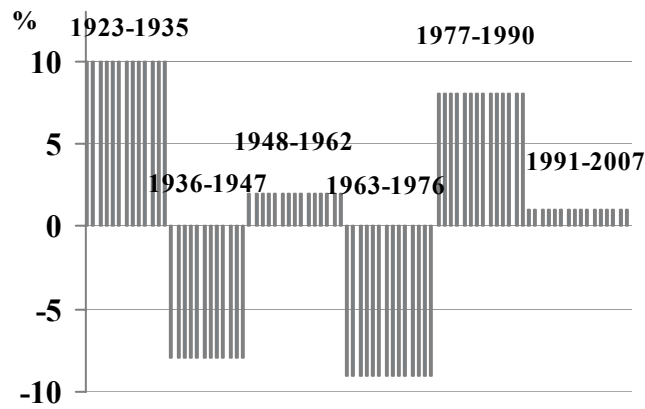
There were no considerable changes in the regional time series of precipitation comparing the period of most recent years of 1991 - 2007 with the reference period 1961 - 1990 (Table 1). In recent years the amount of winter season P increased in all the Baltic States. In the western and central regions, the amount of P increased by 5 - 16 %, while in the eastern regions it increased as much as by 9 - 29 %. The anomalies of the spring season P are different in individual regions. The summer season P decreased the most in the western and central parts of Lithuania (by 6 % and 4 % respectively). In 1991 - 2007 the autumn season P decreased the most in the western regions of all countries (by 6 - 11 %).

In 1991 - 2007, positive annual anomalies of discharge were found in almost all regions of the Baltic countries (Table 1). In recent years the discharge of winter season increased considerably in all the Baltic States (by 20 - 66 %). In the summer season, both positive (up to 30 % in northern Estonia) and negative (up to 11 % in western Lithuania and western Latvia) anomalies of discharge occurred in comparison with the reference period. The discharge anomalies in autumn were negative in all regions of the Baltic countries.

a)



b)



c)

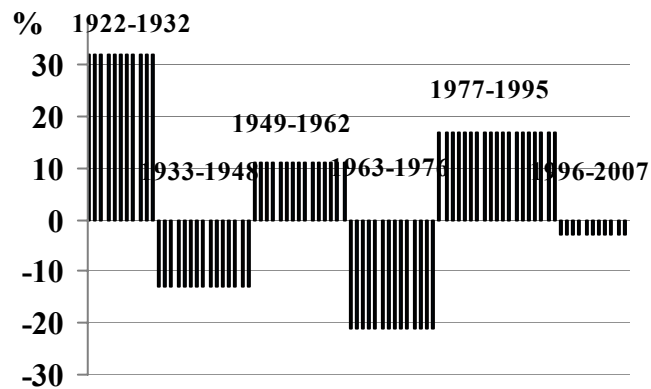


Figure 2: Variability of annual temperature anomalies in $^{\circ}\text{C}$ (a), and wet and dry periods in the regional series of annual precipitation and discharge (average anomaly of all regional series, %) (b, c).

Table 1

Annual and seasonal regional anomalies of temperature (°C), precipitation (%) and river discharge (%) in 1991 - 2007 relative to the mean of 1961 - 1990

	LT-W	LT-C	LT-SE	LV-SE	LV-NE	LV-C	LV-W	ES-N	ES-E	ES-W
T, annual	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.8	0.9
T, winter	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
T, spring	0.8	0.7	0.6	0.6	0.6	0.7	0.7	0.5	0.4	0.4
T, summer	1.1	1.1	1.1	0.7	0.9	1.0	1.0	0.7	0.6	0.5
T, autumn	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1
P, annual	-3	-1	4	4	9	0	3	2	5	2
P, winter	5	6	9	15	29	10	16	7	10	6
P, spring	0	-3	3	7	12	-4	4	8	13	9
P, summer	-6	-4	1	-3	-1	-1	0	4	-3	2
P, autumn	-11	-4	3	-1	-3	-4	-7	-8	2	-8
Q, annual	0	5	7	8	5	5	-1	2	8	5
Q, winter	45	60	25	40	41	66	36	20	33	51
Q, spring	-14	-17	0	1	2	-13	-11	-6	1	-10
Q, summer	-11	0	8	1	9	-12	-10	30	14	11
Q, autumn	-23	-22	-3	-7	-26	-16	-25	-34	-11	-31

The most remarkable changes have occurred in the winter season. Positive anomalies of winter T and P are found in all regions of the Baltic countries. The rise of T and P results in an increased river Q in winter. The beginning of the spring flood shifted to an earlier time, contributing snowmelt to the winter season. Thus, the increase of T has influence on the snow storage and duration of days with snow cover. We determined that in the period of recent years (1991 - 2007) the annual Q distribution became more even because of the increase in winter season Q and decrease in spring season Q in all hydrological regions of the Baltic States.

3.2 Climate change impact on the Nemunas River runoff

The air temperature in the territory of the Nemunas catchment will rise intensively in the 21st century in comparison with the baseline period (1975 - 1984): in 2011 - 2020 – 0,8 - 1.2 °C, in 2031 - 2040 – 0.9 - 1.9 °C, in 2051 - 2060 – 1.6 - 2.5 °C, in 2071 - 2080 – 2.8 - 3.9 °C and in 2091 - 2100 – 2.6 - 4.8 °C. The average air temperature will rise about 0.4 °C in every 10-year period. The most significant changes of temperature have to occur in winter season. In 2091 - 2100 the average temperature should rise by 3.7 - 5.5 °C in this season in comparison to the baseline period. The amount of forecasted annual precipitation has various tendencies in 21st century. The largest increase of precipitation has to be in the period of the year 2091 - 2100.

Modelling of the Nemunas River runoff according to six climate scenarios was done for every decade in 21st century. The results of calculation show a decrease of the Nemunas river runoff in average by 17 % according to all climate scenarios in the end of 21st century. In the period of 2031 - 2040 the spring flood will decrease (Figure 3) and according to the A2 emission scenario it will not only decrease, but occur earlier – in February. In the period of 2051 - 2060, according to all scenarios, the Nemunas river discharge decreases intensely and the spring flood not only moves to the earlier month, but also decreases greatly. The average

maximal discharge will decrease the most according to the ECHAM5 A1B climate scenario, even by 415 m³/s in comparison with the baseline period. Also, all of the scenarios show that the flood will occur earlier and will be smaller. In the period of 2091 - 2100, the largest decrease of discharge is forecasted. The minimal discharge value according to six scenarios would be 85 - 117 m³/s (the minimal discharge value of the baseline period is 177 m³/s).

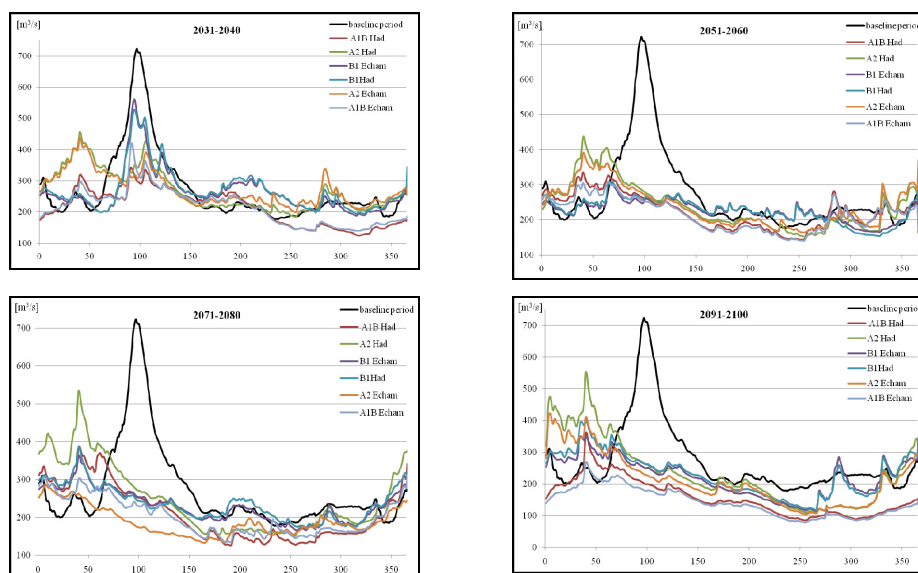


Figure 3: Forecasted changes of the Nemunas River runoff discharges according to six climate scenarios in comparison with the baseline period (1975 - 1984)

Average and extreme river discharges will have decreasing tendencies depending on the emission scenario in the 21st century. This proves the statement that in the 21st century the runoff of the Nemunas River in Lithuania will decrease and the spring floods will occur earlier (averagely they will move to January - February). Also, the maximal flood discharge values will decrease intensely. Minimal discharge values will decrease by 26 - 59 m³/s. The largest decrease of average and extreme discharges should occur in the period of 2091-2100.

Summary

The analysis of long-term regional series of temperature, precipitation and discharge was performed for 10 hydrological regions of the Baltic countries. The long-term variations in the regional time series of precipitation and discharge are typical for all regions. The average period of the wet and dry phases is 27 - 30 years, including the average wet period of 15 years and the dry period of 14 years. A comparison of all the regional series of the period of recent years (1991 - 2007) was done with the data of the reference period (1961 - 1990). The increase of annual and seasonal temperature was found in all regions of the Baltic countries. Comparing the precipitation of 1991 - 2007 with the reference period, we observed positive anomalies (5 - 29 %) in the winter season in all the Baltic countries. The anomalies of regional discharge series depend on the type of climate (marine or continental) and sources of river feeding. The winter season discharge increased in the recent years by 20 - 66 %, comparing with the reference period. A 10 - 20 % decrease of spring season discharge occurred in the western regions of all the Baltic countries (marine climate zone), but there were no sig-

nificant changes of spring season discharge in the continental part of the countries. In the period of 1991 - 2007 the annual Q distribution became more even because of the increase in winter season Q and decrease in spring season Q in all hydrological regions of the Baltic countries. Therefore, there are no significant changes in the annual discharge in the recent year period.

In this study the projections of climate change impacts on hydrological processes are based on scenarios from two global climate models (ECHAM5, HadCM3) and three emission scenarios for greenhouse gases (A2, A1B, B1). The average annual runoff of the Nemunas River should decrease in average by 17 % in the end of 21st century. The decreasing of runoff should be determined by high temperatures (the chance of snowfall decreases, only minimal cover of snow is possible). In the winter season, the runoff will increase and in the spring season it will decrease according to all of the emission scenarios. In the summer and autumn seasons, the runoff will have both increasing and decreasing tendencies.

Statistical analysis of the climate elements and river runoff in the 20st century and forecast of the change parameters in the 21st century shows the same change tendencies. The redistribution of river runoff in different seasons occurs because of the temperature increase and the change of precipitation amount. The analysis of temperature, precipitation and river runoff shows that the strongest relation between them is in the winter season.

Acknowledgments

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Literature

- BELDRING, S., T. ENGEN-SKAUGEN, E. J. FORLAND (2008): Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological station sites. - *Tellus*. 60A, 439-450.
- BERGSTROM, S. (1995): The HBV model. - In Singh, V.P. (Ed.), *Computer Models of Watershed Hydrology*. Water Resources Publications, Highlands Ranch, 443-476.
- BERGSTROM, S., B. CARLSSON, M. GARDELIN, G. LINDSTROM, A. PETTERSON, M. RUMMUKAINEN (2001): Climate change impacts on runoff in Sweden: assessment by global climate models, dynamic downscaling and hydrological model. - *Climate Research* 16, 101-112.
- HISDAL, H., E. HOLMQVIST, J. F. JÓNSDÓTTIR, P. JÓNSSON, A. JÄRVET, G. LINDSTRÖM, T. KOLCOVA, J. KRIAUCIUNIENE, E. KUUSISTO, L. LIZUMA, D. MEILUTYTE-BARAUSKIENE, A. REIHAN, L. A. ROALD (2007): Climate change signals in streamflow data in the Nordic and Baltic region. - *Proc. of the Third International Conference on Climate and Water* (ed. Mari Heinonen). Edita Prima Ltd. Helsinki. August 2007: 182-187.

- HISDAL, H.; L. A. ROALD, S. BELDRING (2006): Past and future changes in flood and drought in the Nordic countries. - Proceedings of the Fifth FRIEND World Conference, November, 2006, Havana, Cuba.
- KĻAVIŅS, M., V. RODINOV, A. TIMUKHIN, I. KOKORĪTE (2008): Patterns of river discharge: long-term changes in Latvia and the Baltic region. - Baltica. 41-49.
- KRASOVSKAIA, I., L. GOTTSCHALK (1993): Frequency of extremes and its relation to climate fluctuations. - Nordic Hydrology, 24, 1-12.
- KRIAUCIUNIENE, J., D. MEILUTYTE-BARAUSKIENĖ, M. KOVALENKOVIENĖ (2008): Regional Series of temperature, precipitation and runoff for Lithuania. - XXV Nordic Hydrological Conference. Reykjavik, Iceland August 11-13, 2008. NHP Report No. 50. Vol. 2: 638-645.
- KRIAUCIUNIENE, J., D. MEILUTYTE-BARAUSKIENE, E. RIMKUS, J. KAZYS, A. VINCEVICIUS (2008): Climate change impact on hydrological processes in Lithuanian Nemunas river basin. – Baltica, 21, 51-61.
- LINDSTRÖM, G., S. BERGSTRÖM (2004): Runoff trends in Sweden 1807–2002. - Hydrological Sciences Journal. 49(1): 69-83.
- LINDSTRÖM, G., H. HISDAL, E. HOLMQVIST, J. F. JÓNSDÓTTIR, P. JONSSON, E. KUUSISTO, L. A. ROALD (2006): Regional precipitation, temperature and runoff series in the Nordic countries. - EURENEW 2006. Reykjavik. Iceland June 5-9 2006 (ed. by S. Árnadóttir). CE-Report No. 2: 155-158.
- PEKAROVA, P., P. MIKLANEK, J. PEKAR (2006): Long-term trends and runoff fluctuations of European rivers. - Proceedings of the Fifth FRIEND World Conference, Havana, Cuba, November 2006. IAHS Publ. 308, 520-525.
- SOLOMON, S., D. QIN, M. MANNING, Z. CHEN, M. MARQUIS, K. B. AVERYT, M. TIGNOR, H. L. MILLER (2007): Climate Change. The Physical Science Basis. - Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge. Cambridge University Press. 2007.



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Climate and Energy Systems. Nordic Energy Re-
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European procedures for flood frequency estima-
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On the use of water scenarios in the Dutch Delta Programme

Ad Jeuken, Aline te Linde, Lineke Woelders and Jaap Kwadijk

1 Introduction

In the Netherlands, climate change is expected to exacerbate the current water management problems through a combination of rising sea level and higher river peak discharges. Lower river discharges and long drought periods in the summer may lead to salinisation problems. Long-term historic relative sea-level rise (SLR), which largely reflects tectonic subsidence, is about 10 to 20 cm/century in the coastal region. Additionally, as a result of artificial drainage, peat compaction and oxidation have caused ~ 3 - 4 m of surface-lowering since the Middle Ages. This process continues today at rates of up to 10 mm/year in areas with a peaty subsoil.

In 2007, the Dutch government set up a committee chaired by former Minister Cees Veerman to investigate the potential risk of climate change for the Netherlands. This so-called Delta Committee made recommendations regarding the way in which, in the century ahead, our country needed to improve its water safety and maintain its fresh water supply, taking into account climate changes and social developments. In just one year the committee came up with an assessment of risks and recommendations for adaptation. According to the Committee, the issue of water safety and supply was not acute in the Netherlands, but urgent. It was suggested to implement a long-term Delta Programme supported by a legal act and a fund to safeguard future maintenance and execution of necessary measures. The government largely accepted the recommendations and started the Delta Programme (www.deltacommissaris.nl); a national programme that has to come up with 5 'delta decisions', regarding the adaptation strategy to follow in 2015.

Large scale circulation pattern

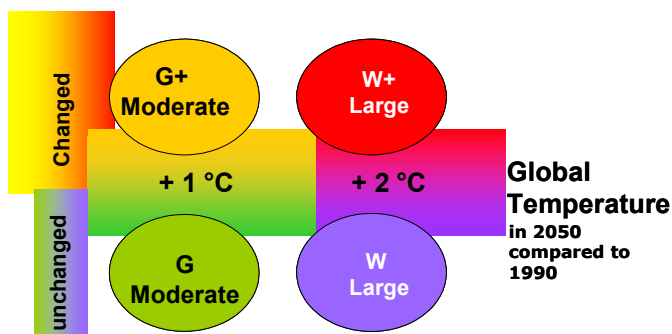


Figure 1: Four climate scenario's according to KNMI 2006. The scenario's are downscaled from ensembles of GCM's, distinguishing between changed and unchanged circulation patterns and more or less temperature increase (VAN DER HURK et al. 2007).

General characteristics of the Dutch Delta (BUCX et al. 2010)

- Area and elevation – The Rhine-Meuse delta plain measures ~7500 km². Large parts of the lower delta plain lies below sea level (down to -6 m).
- Discharge of delta rivers – Mean annual discharge of the Rhine is 2300 m³/s; mean annual discharge of the Meuse is 230 m³/s.
- Catchment areas of delta rivers – The Rhine catchment measures 185,000 km²; the Meuse catchment measures 36,000 km².



- Flood protection – The delta plain is protected by coastal dunes and an extensive system of dams and dikes. Safety levels are 1/10,000 per year for the coastal defence and 1/1250 per year for river dikes.
- Population, major cities and infrastructure – A population of 6,5 million inhabits the (urban) delta zone between Rotterdam and Amsterdam, which represents 40 % of the population of the Netherlands. The delta plain hosts the four largest cities of the country as well as Europe's largest seaport (Rotterdam) and fourth largest airport (Schiphol).

These decisions involve the updating of the safety standards for dikes and other water defences (1), the availability and distribution of freshwater (2), the level of the IJssel Lake (3), the way in which the Rhine Estuary-Drechtsteden region can be kept safe without harming its economic value (4) and how water-related risks can be taken into account in the building of cities and villages (5). The Programme will use measurements and scenarios developed by the Royal Netherlands Meteorological Institute (KNMI) in 2006 (<http://www.knmi.nl/klimaatscenarios/>). The main contours of how to use these scenarios are discussed in the Programme. Questions like: 'How can the use of scenarios contribute to the analysis of the problem, how may it help to assess the urgency (not acute but how urgent) or how can they be a means for valuating different adaptation options' are not yet answered.

In this paper we try to answer the following question:

Given the uncertainty involved, the investments at stake and the message to be communicated, what is the best approach of using climate scenarios? Three approaches will be discussed:

- > Low probability – high consequences
- > Adaptation tipping point analysis
- > Robustness assessment

2 Low probability – high consequences: the safest Delta in the world

With 10 million people in flood-prone areas and its deepest locations between 6 and 7 meters below sea level, the Netherlands have a high vulnerability to flooding. At the same time, flood protection standards are among the highest in the world. The resulting flood risks are small, but potential consequences of a flood are high. A solid and reliable reputation as safe

place to invest is crucial for the Dutch economy. Sea-level rise and growing investments will however increase flood risk. When a few years ago climate change became a publicly recognised threat all over the world, partly stimulated by ‘an inconvenient truth’ of Al Gore, also in the Netherlands the parliament started to question the climate robustness of long term investments.

At that time the risk of climate change and sea level rise was not the flood hazard itself, but the image that the Netherlands might not be safe anymore for investments.

The Delta Committee (Deltacommissie 2008) basically tried to answer four questions. The answers are summarized below:

1. What is the maximum plausible SLR between now and 2100?

Since available scientific knowledge did not agree on the magnitude of climate change and SLR, the commission asked international top scientists to discuss possible scenarios, taking into account all relevant physical processes. The Delta Committee came up with a maximum estimate for the end of the century of 130 cm relative SLR (relative to about 10 cm subsidence), which was way above the maximum estimate of 85 cm KNMI had given in their scenarios (VAN DER HURK 2007). These 130 cm could however be qualified as plausible but with a low probability (VELLINGA et al. 2008).

2. Are we able to defend the Netherlands to that rise with low probability and potentially high consequences?

Different adaptation options were explored and discussed in the final report. The main message is: ‘yes we can!’ In some key areas like the IJssel Lake and the Rhine-Meuse estuary we have to rethink existing protection strategies. In other areas like for instance the coast the current strategy, we will be able to keep up with sea level rise. In addition, an increase of safety levels was advised.

3. What will be the costs of all necessary measures?

The costs were very roughly estimated at about 1 billion Euro per year until the end of the century.

4. Are these costs affordable?

Again the answer is yes. According to the Dutch National Bank (De Nederlandse Bank 2007, before the economic crisis) the future costs of coastal defence will decrease compared to the growth of the GDP. The question of affordability was not directly asked to the Committee but serious steps are currently undertaken to establish the suggested fund with the necessary budgets.

By using rather extreme climate scenarios a strong message could be communicated: ‘We are able to prepare ourselves for the most pessimistic climate estimates while building on an even safer and more attractive country’.

3 Adaptation tipping point analysis: At what point will the strategy fail?

Climate adaptation involves dealing with predictability of climate change (some aspects of climate change can be predicted with reasonable confidence like temperature rise, while others are surrounded by more uncertainties); non climatic conditions (it occurs against the background of current and future use of the area); timing (proactive or reactive) and time horizon (short or long term actions) (SMIT et al. 1998). Planned adaptation focuses on the use of information about current and future climate to review the suitability of current and planned management.

To assess the durability of current or planned water management strategies KWADIJK et al. (2010) and TE LINDE & JEUKEN (2011) propose the methodology of adaptation tipping points (ATP's). ATP's are defined as points where the magnitude of change due to climate change or sea level rise is such that a strategy will no longer be able to meet its objectives. This gives information on whether and when a water management strategy may fail and other strategies are needed.

An ATP analysis starts from the perspective that a water system provides the natural boundary conditions for living and working in a region, summarised as the boundary conditions for socioeconomic activities. The system needs to be managed to maintain the proper conditions and achieve objectives for living in the delta. In case of climate change and sea level rise these conditions change, resulting in the possibility of failure of the current water management strategy. At that moment an ATP is reached. Exceeding an ATP does not mean that water management is not possible anymore and that we might face catastrophic consequences.

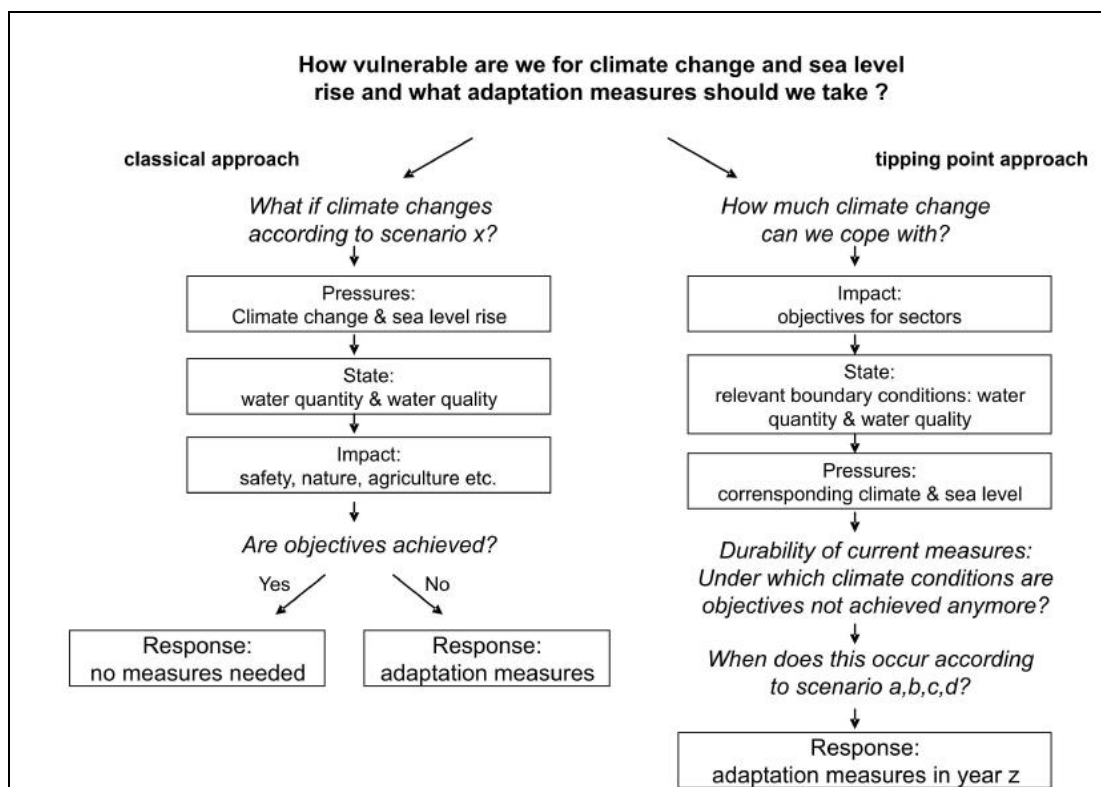


Figure 2: Classical 'what if' approach versus ATP approach

It simply means that alternative strategies are needed to manage the system. From this viewpoint adaptation to climate change in itself has no value; it is done to sustain our activities and preserve ecological values. Climate change only becomes interesting for policy makers if it would lead to other decisions about water management strategies. In other words, the driver for taking action is not climate change, but failing to meet the objectives.

Climate scenarios are used to define the moment in time when an ATP may occur. If one wants to stay on the safe side a pessimistic climate scenario is used resulting in an earlier occurrence of a ATP in time or if one can accept a certain risk one could use an optimistic scenario resulting in a later occurrence. When showing both moments in time, the uncertainty expressed by the scenarios is translated in a time range: the range between the earliest and latest moment a strategy has to be changed because of climate change.

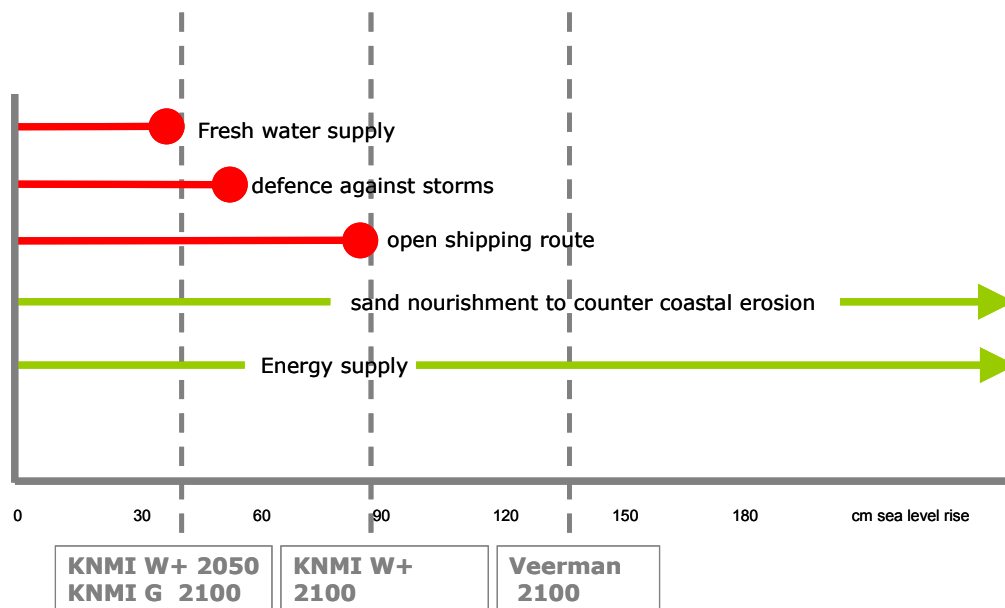


Figure 3 ATP's for the Rhine-Meuse estuary. Red bullets indicate endpoints of a strategy, green arrows indicate the strategy can cope with larger sea levels. In grey the climate scenarios used in the Netherlands are plotted (JEUKEN et al. 2010).

In the Netherlands this method has been applied on different scales and for different purposes. Figure 3 shows some results for the Rhine Meuse estuary (JEUKEN et al. 2010). It is shown that the current strategy for fresh water supply fails at 35 cm sea level rise and that this could occur already before 2050 following a pessimistic scenario that projects dry summers (KNMI W+). With an optimistic scenario (KNMI G) the current water supply strategy could hold until the end of the century. The figure also shows that strategy of coastal defence through sand nourishment will hold past the end of the century even if the low probability scenario of the Delta Committee is used (see also Section 2).

In the first step of the ATP analysis climate scenarios are not used at all. The yield is insight in the vulnerability / sensitivity of the managed system. In the second step climate scenarios are introduced to produce a possible time range. The advantage of this approach is that when new climate models produce better insights and lead to new scenarios only the second step needs to be repeated.

4 Robustness assessment: Testing the robustness of strategies using the Delta scenario's

In this approach, we ask ourselves the following questions: ‘What kind of future are we preparing for?’ *What can we do, if this happens?* Which (external) events, circumstances and (autonomous) developments are critical for water management in the Netherlands, in particular for flood protection and fresh water supply? Which can be critical and plausible developments in the 21st century?’ These are the questions that were asked to derive requirements for scenarios to be used in the forthcoming years in the Delta Programme, e. g. to assess impacts and to evaluate different possible adaptation strategies.

In the Delta Programme so-called Delta Scenarios are proposed to be used as a means to quantify uncertainty in such manner that they describe the critical corners of plausible developments (BRUGGEMAN et al. 2010). They certainly are not meant to be used as predictions on which measures could be designed. Not only climate change but also socio-economic developments should be taken into account, and this should not result in too many scenarios. In addition, the so-called corners of possible developments should be normative for certain problems. To tackle this challenge climate and socio-economic scenarios are combined along two axes (see Figure 4).

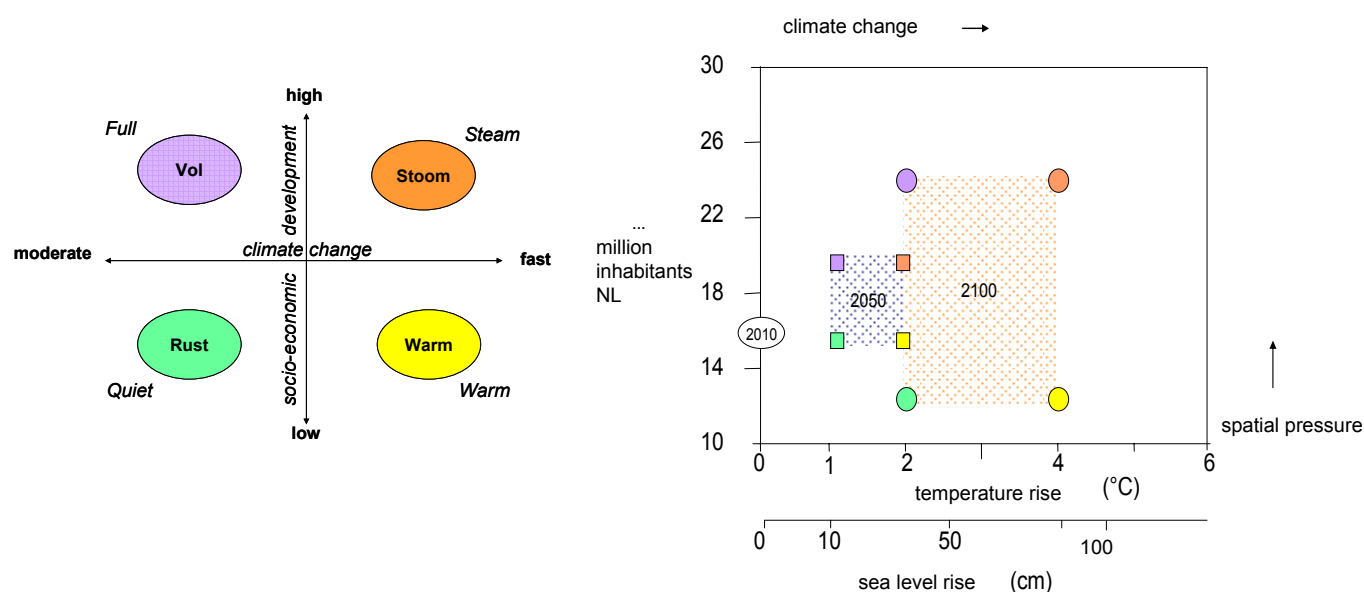


Figure 4: Delta Scenarios put together from socio-economic and climate scenarios (left). Right: socio-economic developments with according number of inhabitants, climate change with according temperature and SLR.

One axis describes the climate change and the other the socio-economic change. For the corners of climate change two out of four of the afore mentioned KNMI 2006 scenarios are used and for the socio economic changes the two out of four of the so-called WLO scenarios (JANSEN et al. 2006) are used. The combination of both results in four Delta Scenarios being normative for the main challenges of the Programme.

For flood risk management strategies, the most normative scenario is the ‘steam’ (Stoom) scenario. It consists of an optimistic economic scenario (‘Global Economy’) and a pessimistic climate scenario (KNMI W+): There is a strong increase in population and value of assets that can be flooded by increasing (winter) water levels. On the other end of the range the ‘quiet’ (Rust) scenario with low socio-economic growth (‘Regional Communities’), the population is declining, and moderate climate development (KNMI G) will be the minimum to adapt to.

For fresh water supply other combinations define the challenge. A society developing along the regional community scenario in which the agricultural sector and the demand for fresh water is expected to grow will face the biggest challenge under increasing dry summer conditions (KNMI W+). As a result, the warm scenario will be the most normative and the full scenario the least.

Scenarios defined in this way as corner stones are ideal to test the robustness of adaptation strategies: e. g. will the strategy perform well under a range of conditions?

In this stage of the Delta Programme, in which we just have started to develop outlines of adaptation strategies this seems a sound approach. An approach which is already difficult enough. Climate scenarios have been translated using hydrological and hydraulic models, statistics and time series to produce water scenarios and future boundary conditions for water management. The scenario development is an elaborate job and too much to discuss further in this paper (see for more information BRUGGEMAN et al. 2011).

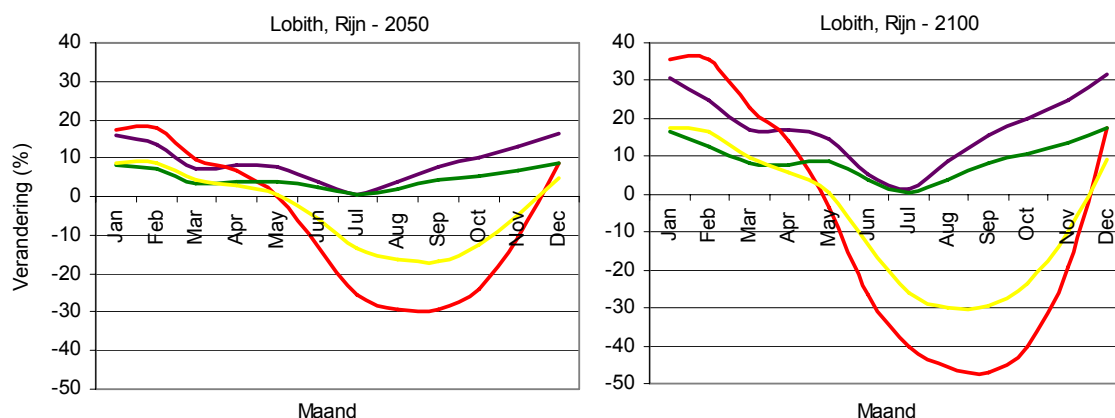


Figure 5 Example waterscenario: % change of monthly mean discharge of the Rhine at Lobith compared to the reference climate (1990) (BRUGGEMAN et al. 2011).

5 Discussion and outlook

We have presented three different ways to use climate scenarios in the context of the national Dutch adaptation programme, all three having its strength and weakness. The first approach, using a ‘low probability – high consequences’ scenario, appeared to be powerful in communicating that we will manage to stay in our Delta, but is useless if strategies have to be developed and evaluated. The approach in which scenarios are set up to test the robustness of strategies will be more difficult to communicate but will give good insight in between which ‘corners’ adaptation strategies will have to be effective.

The adaptation tipping point approach will at least provide better insight in the vulnerability of the managed system. Uncertainty is expressed in time, and can be well understood by policy makers, which think in terms of ‘time to act’. In addition, it can be used to evaluate different adaptation strategies using the corner stone scenarios. On the other hand, it has some practical limitations when different external developments have to be taken into account (KWADIJK et al. 2010). The examples clearly show that the context, the phase, the main questions determine what approach is best to use.

Whatever approach is followed, the output of currently available different GCMs still results in large uncertainties to deal with. Uncertainties are of such magnitude that it will be very difficult too design strategies which are effective for all scenarios, and at the same time do not bear the risk to be overdone (and too expensive). These large uncertainties might require adaptive strategies which can be accelerated when climate change speeds up and can be delayed when climate change develops slower as expected.

Summary

Given the uncertainty involved, the investments at stake and the message to be communicated, what is the best approach of using climate scenarios? Three approaches are discussed in this paper: low probability – high consequences approach, adaptation tipping point analysis and robustness assessment. Examples of use in the Delta Programme are given and the pros and cons encountered.

Literature

- BRUGGEMAN, W., S. HOMMES, A. TE LINDE EN R. TEN BRUGGE (2010): Deltamodel 2010, deltascenario's voor robuustheidsanalyse van maatregelen voor zoetwatervoorziening en veiligheid, concept Deltares, december 2010
- BUCK, T., M. MARCHAND, A. MAKASKE, C. VAN DE GUCHTE (2010): Comparative assessment of the vulnerability and resilience of 10 deltas – synthesis report. Delta Alliance report number 1. Delta Alliance International, Delft-Wageningen, The Netherlands
- Deltacommissie (2008): Working together with water: A living land builds for its future. Findings of the Deltacommissie 2008
- DEFRA (2009): Accounting for the effects of climate change. Supplementary green book guidance. June 2009
- De Nederlandse Bank (2007): Gevolgen van klimaatverandering voor de Nederlandse overheidsfinancien. Kwartaalbericht, september 2007, Amsterdam
- JANSSEN L. H. J. M.; V. R. OKKER, J. SCHUUR (2006): Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040', Centraal Planbureau, Planbureau voor de Leefomgeving
- JEUKEN, A., N. SLOOTJES AND N. VAN OOSTROM (2010): Klimaatbestendigheid en opties voor adaptatie in de regioRijnmond-Drechtsteden, Deltares/HKV report 2010

- VAN DEN HURK, B., A. KLEIN TANK, G. LENDERINK, A. VAN ULDEN, G. J. VAN OLDENBORGH, C. KATSMAN, H. VAN DEN BRINK, F. KELLER, J. BESSEMBINDER, G. BURGERS, G. KOMEN, W. HAZELEGER AND S. DRIJFHOUT (2007): New climate change scenarios for the Netherlands. *Water Science & Technology*, 56, 27-33
- KWADIJK, J. C. J., M. HAASNOOT, J. P. M. MULDER, M. M. C. HOOGVLIET, A. B. M. JEUKEN, R. A. A. V. D. KROGT, N. G. C. V. OOSTROM, H. A. SCHELFHOUT, E. H. V. VELZEN, H. V. WAVEREN AND M. J. M. WIT (2010): Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change*, 1(5): 729-740
- SMIT, B., I. BURTON, R. J. T. KLEIN, R. STREET (1999): The science of adaptation: a framework for assessment. *Mitig Adapt Strateg Global Change* 4:199–213
- VELLINGA, P., C. A. KATSMAN, A. STERL AND J. J. BEERSMA (2008): Exploring high end climate change scenarios for flood protection of the Netherlands: - an international scientific assessment. 2008



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Impact of climate change on patterns of emerging pollutants in rivers

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Introduction

Recently, so called “emerging pollutants” have been detected in the aquatic environment at concentrations of up to several microgram per liter. Prominent examples of emerging pollutants are pharmaceuticals, estrogens, ingredients of personal care products, biocides, flame retardants, antioxidants, benzothiazoles, and perfluorinated compounds (RICHARDSON & TERNES 2005, RICHARDSON 2009). Climate change might lead to extreme water conditions such as floods and draughts, while the intake loads of emerging pollutants such as pharmaceuticals will frequently not be altered. As consequence, the concentrations (mol/l) of emerging pollutants will increase in rivers and streams if the draughts leading to reduced flow rates. On the other hand, floods might mobilise those pollutants which are sorbed to sediments. However, it can be expected that climate change will also influence the consumption and usage of certain pollutants and substances. For instance, raising temperatures and increasing nutrient discharges are likely to attenuate in combination with a reduced flow rate to foster the algae growth, and thus to increase the occurrence of algae toxins. Due to their extremely high toxicity, algae toxins are problematic for aquatic organisms and swimming persons. Furthermore, elevated temperatures might for instance also increase the consumption of biocides and will change the application of pesticides. Many materials contain substances, which show biocidal effects, to avoid the microbial degradation of the products and to increase the duration of the product stability (MOHR et al. 2009). The application of insecticides and herbicides should increase as well, because elevated temperatures will have an impact on agricultural practices.

Study approach

The preliminary tasks of the BfG project for the impact of climate change on patterns of emerging pollutants in rivers is the development of appropriate analytical multi-methods for biocides, herbicides, insecticides and further emerging contaminants using LC tandem MS detection. After the development of appropriate analytical methods for water and suspended matter/sediments, the loads and concentrations of the selected emerging pollutants will be monitored in German rivers and streams, in order to identify their main sources. Furthermore,

antidepressants and their metabolites were included into the monitoring program, because it can be expected that in Germany their consumption will further increase due altered living styles and the proposed demographic developments. Concentrations up to 400 ng/L of individual antidepressant metabolites were found in streams with an elevated percentage of discharges of wastewater treatment plants (WWTPs) by METCALF et al. (2009) and SCHULTZ et al. (2010). The impact of climate change on sorption and degradation of emerging compounds and the prediction of the consumption of individual compounds in future, offers the basis for modelling approaches for the potential concentrations present in German rivers within the next 20 - 50 years.

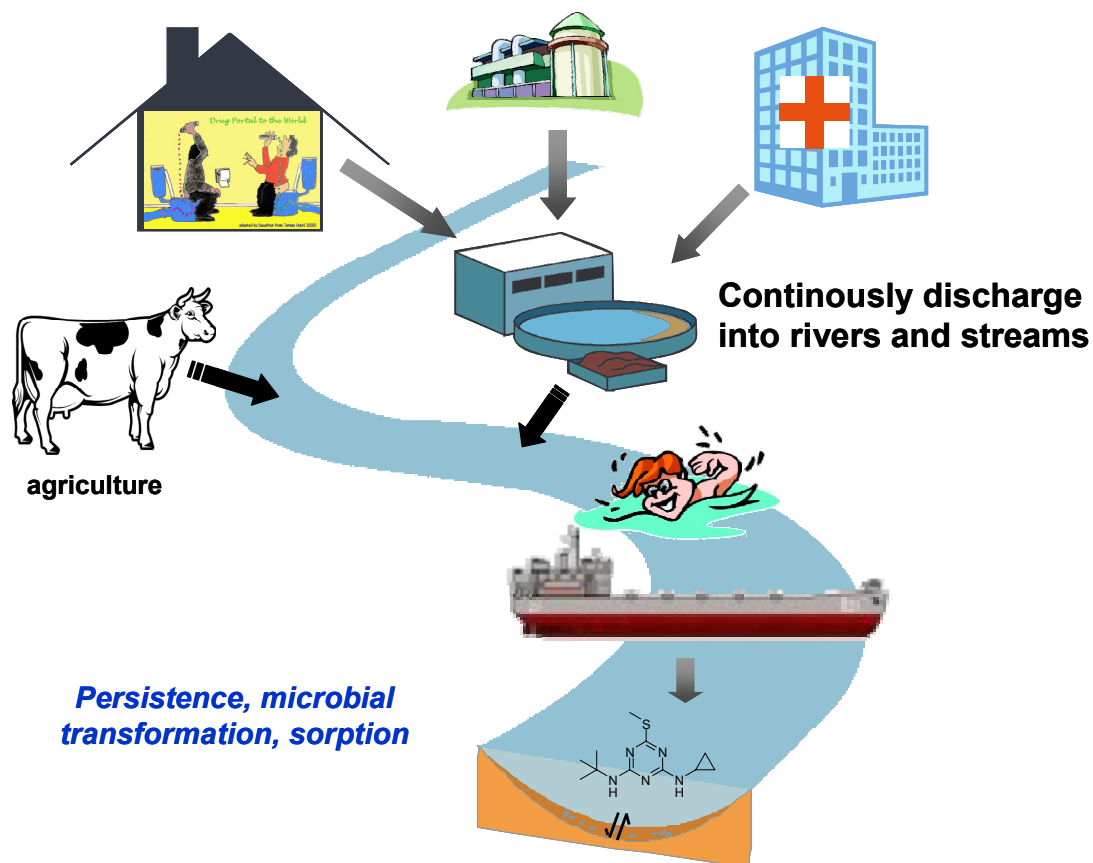


Figure 1: Sources contaminating rivers and streams; wide-spread application of biocides and UV filters/stabilisers

Analytical methodology

Extraction of aqueous samples were performed by solid-phase extraction (SPE). Water samples were filtered through glass fiber filters (GF 6, Whatman). For SPE 100 mL of raw wastewater, 200 mL of treated wastewater, and 1 L of surface water were adjusted to pH 6.3 with 3.5 M sulphuric acid and spiked with 200 ng of each surrogate standard. Oasis HLB cartridges (200 mg, 30 μ m, Waters, Milfort, U.S.) were conditioned with 1 x 2 mL heptane, followed by 1 x 2 mL acetone, 3 x 2 mL methanol and 4 x 2 mL groundwater (pH 6). The water samples were then passed through the pre-conditioned cartridges at a flow rate of approximately 5 mL min⁻¹. The solid-phase material was dried by a continuous nitrogen

stream for approximately 1 h. Elution was accomplished with 4 x 2 mL of a mixture of methanol and acetone (60/40, v/v). The extracts were evaporated to 500 µL and filled up to a final volume of 1 mL with 0.1% formic acid.

Extraction of solid samples were conducted by pressurised liquid extraction (PLE) according to WICK et al. 2010. The solid samples were freeze-dried and grinded with a pestle. Approximately 200 mg of the dry solids was weighed into 22 mL stainless steel extraction cells filled to one half with baked out sea sand. The internal standard mix was added (500 ng g_{SS}⁻¹). After the solvent was completely evaporated, the cell was filled up with baked out sea sand. The extraction was accomplished with a Dionex ASE 200 instrument (Sunnyvale, CA, USA). The PLE conditions were: prefill method; solvent, methanol; equilibration, 5 min; static time, 10 min; flush volume, 120 %; purge time, 60 s; static cycles, 4; temperature, 80°C. The PLE extracts were diluted with groundwater to a volume of 800 mL, adjusted to pH 6.3 with 3.5 M sulphuric acid and a SPE was performed as described above for the aqueous samples.

Detection via LC tandem MS was carried out by an HPLC coupled to a tandem mass spectrometer (API 4000, Applied Biosystems, Foster City, CA) operated in the positive (method 1) and in the negative ion mode (method 2) using multiple reaction monitoring. Electrospray ionisation (ESI) were applied. Two MRM transitions for each compound were monitored for identification and quantification of all target compounds.

Results

Analytical method

A multi-residue method for the determination of 26 biocides, 5 water-soluble UV-filters and 5 benzothiazoles in raw and treated wastewater and surface water has been developed using electrospray ionisation (ESI) in the positive and negative ionisation mode. Special emphasis has been made in this work to study the matrix effects in the different sample matrices using ESI. Ion suppression could be identified to significantly reduce the absolute recoveries of most target analytes using ESI making compensation by the use of appropriate labeled surrogate standards crucial to achieve acceptable relative recoveries in the range of 75 to 125 %. This study indicate that for multi-residue methods including a broad spectrum of analyte groups applied to different complex matrices ESI is favourable. If isotope-labeled surrogate standards are not available for every analyte, the matrix effects have to be determined for every analyte/matrix combination to assure the appropriate compensation of the matrix effects.

Monitoring

The most prominent biocides in the influents of WWTPs were the anti-dandruff climbazole and the bacteriostatics chlorophene and triclosan with maximum influent concentrations of $1350 \pm 70 \text{ ng L}^{-1}$ (Wick et al., 2010). Climbazole was also the biocide found at the highest concentrations in both WWTP effluents ($443 \pm 11 \text{ ng L}^{-1}$) and in the Hessian stream Wickerbach ($530 \pm 70 \text{ ng L}^{-1}$). The concentrations of the antifouling irgarol ranged from 6 to 22 ng L⁻¹ in both WWTP effluents and streams and were therefore significantly above the environmental quality value of 2 ng L⁻¹ proposed by the German Working Group on water issues of the Federal States and the Federal Government (LAWA).

During summer time the water-soluble UV-filters BZP-4 and PBSA were detected in the WWTP influents at concentrations as high as $5130 \pm 140 \text{ ng L}^{-1}$ and $3890 \pm 170 \text{ ng L}^{-1}$, respectively (WICK et al. 2010). Maximum effluent concentrations of $1820 \pm 240 \text{ ng L}^{-1}$ for BZP-4 and PBSA, respectively, show the importance of WWTPs for the emission of these water-soluble UV-filters into the receiving water, even at least BZP-4 seems to be significantly removed by the treatment processes. Similar concentrations for BZP-4 were also reported by KASPRZYK-HORDERN et al. (2008) and RODIL et al. (2009) in wastewater from WWTPs in Wales and Spain, respectively. BZP-4 and PBSA were also the dominant analytes detected in all surface water samples. In the Wickerbach sampled close behind ($\sim 100 \text{ m}$) a discharging WWTP, stream concentrations were as high as $1980 \pm 130 \text{ ng L}^{-1}$ (BZP-4) and $3240 \pm 140 \text{ ng L}^{-1}$ (PBSA).

Conclusions

A first application of the LC tandem MS method revealed that the biocides climbazole and triclosan as well as the UV-filters BZP-4 and PBSA were the dominant analytes in the urban WWTPs as well as rivers and streams. These data indicate that in addition to the more prominent analytes such as triclosan, or the musk fragrances high amounts of ingredients of personal care products are emitted by WWTPs which are still not included in monitoring programs such as the water-soluble UV-filters or the anti-dandruff climbazole. The proposed environmental threshold value of 2 ng L^{-1} for irgarol proposed by LAWA was found to be exceeded by a factor of ten in a WWTP effluent indicating that WWTPs have to be considered as important point sources in regard to this quality norm. Thus, any increase of concentration of these organic contaminants in rivers and streams might be of ecotoxicological concern.

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References

- KASPRZYK-HORDERN, B.; R. M. DINSDALE, A. J. GUWY (2008): Multiresidue methods for the analysis of pharmaceuticals, personal care products and illicit drugs in surface water and wastewater by solid-phase extraction and ultra performance liquid chromatography–electrospray tandem mass spectrometry. - *Anal. Bioanal. Chem.* 391, 1293 - 1308.
- METCALFE, C. D.; S. CHU, C. JUDT, H. LI, K. D. OAKES, M. D. SERVOS, D. M. ANDREWS (2010): Antidepressants and their metabolites in municipal wastewater, and downstream exposure in an urban watershed. - *Environ. Toxicol. Chem.*, 29 (1), 79 - 89.

- MOHR, S.; R. BERGHAIN, W. MAILAHN, R. SCHMIEDICHE, M. FEIBICKE, R. SCHMIDT (2009): Toxic and accumulative potential of the antifouling biocide and TBT successor irgarol on freshwater macrophytes: a pond mesocosm study. - Environ. Sci. Technol. 43, 6838 - 6843.
- RICHARDSON, S. D. (2009): Water Analysis: Emerging Contaminants and Current Issues. - Anal. Chem., 81, 4645 - 4677.
- RICHARDSON, S. D.; T. A. TERNES (2005): Water Analysis: Emerging Contaminants and Current Issues. - Anal. Chem., 77, 3807 - 3838.
- RODIL, R.; J. B. QUINTANA, P. LÓPEZ-MAHÍA, S. MUNIATEGUI-LORENZO, D. PRADA-RODRÍGUEZ (2009): Multi-residue analytical method for the determination of emerging pollutants in water by solid-phase extraction and liquid chromatography–tandem mass spectrometry - J. Chromatogr. A 1216, 2958.
- SCHULTZ, M. M.; E. T. FURLONG, D. W. KOLPIN, S. L. WERNER, H. L. SCHOENFUSS, L. B. BARBER, V. S. BALZER, D. O. NORRIS, A. M. VAJDA (2010): Antidepressant Pharmaceuticals in Two U.S. Effluent-Impacted Streams: Occurrence and Fate in Water and Sediment, and Selective Uptake in Fish Neural Tissue Environ. - Sci. Technol., 44, 1918 - 1925
- WICK, A.; G. FINK AND T. A. TERNES (2010): Comparison of electrospray ionization and atmospheric pressure chemical ionization for multi-residue analysis of biocides, UV-filters and benzothiazoles in aqueous matrices and activated sludge by liquid chromatography-tandem mass spectrometry. - Journal of Chromatography A 1217(14): 2088 - 2103.



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Impact of climate change on freshwater ecosystems

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Abstract

Rivers, lakes and wetlands will undergo significant changes in the future, at both the European and global scale, as a direct response to the predicted changes in climate. Already today, recent changes in climate have had impact on run-off patterns of rivers and increased the temperature of freshwater ecosystems. Based on our research, we can predict that these changes will have implications for loss of nutrients and toxic compounds, carbon flux to the atmosphere and sensitivity of freshwater ecosystems. Increased winter discharge in the Northern part of Europe will increase the loss of nutrients due surface run-off and erosion processes, and extreme precipitation events will increase the risk of loss of e. g. pesticides to the aquatic environment. Internal loading of phosphorous in lakes will increase with increasing temperature, thereby increasing the risk of eutrophication. Moreover, temperature will change the biological structure of lakes, making them overall more sensitive to nutrients. Freshwater ecosystems are furthermore likely to be a source of CO₂ and greenhouse gasses with increasing temperature. All these impacts, together with direct effects of desiccation and flood induced habitat degradation, will degrade European freshwater ecosystems substantially if we do not adopt sustainable adaptation strategies that can counteract these negative impacts.

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Impact of climate change on phytoplankton dynamics in rivers

Helmut Fischer

1 Introduction

Most large rivers, particularly those in the northern hemisphere, are nowadays heavily modified for human use. These anthropogenic impacts on large rivers will in the future increasingly be superimposed by the various effects of climate change. However, climate change effects are difficult to detect and even more to quantify. Major uncertainties still exist with regard to (1) the characteristics of climate change, (2) its consequences for the hydrological system, (3) the sensitivity of the various water uses and river ecosystem services.

The structure and ecological condition of inland waterways are determined by chemical, physical and biological parameters, that is, by the type and concentration of dissolved substances, by temperature, bedload and sediment structure as well as by the flora and fauna of the water, the riparian zone and the floodplain. These factors influence each other and are governed in differing ways by changes in hydraulic engineering measures and by climatic changes. Usually, the direct impact of one forcing factor, such as temperature, on specific target parameters, such as fauna, is examined. However, one cause often affects more than one component in a system, and the effects produced are frequently coupled with each other, non-linear, and with positive or negative feedbacks. Climate change thus causes multifactorial effects and its impact on ecosystems is, at the same time, influenced, or possibly even hidden, by additional anthropogenic and natural stress factors. This necessitates further detailed model examination of the underlying processes.

2 Water Quality Modelling

2.1 Study site

Simulations of water quality affected by climate change have been performed for the River Elbe. With a length of 1094 km the River Elbe is the third longest river in central Europe (after the Danube and the Rhine) and drains an area of 148,268 km². Land use in the drainage basin is dominated by agriculture (60.6 %) and forests (28.6 %). The dominance of the agricultural land use is directly reflected in the nutrient inputs which amounted to 12,400 t a⁻¹ P, and 260,000 t a⁻¹ N for the period 1993 - 1997. Nitrogen mainly derives from diffuse sources (73 % of total N inputs), and these diffuse sources are dominated by groundwater N inputs to the small tributaries (115,000 t a⁻¹) (BEHRENDT et al. 2004).

While the upper 400 km of the Elbe are characterised by a sequence of 24 impoundments, the upper ones built mainly for flood control and the lower ones for navigation, the Elbe is a free-flowing river downstream of Elbe-km -37 (Elbe-km refer to the German navigation kilometers. Elbe-km 0 marks the Czech-German border; the stretch under investigation for this study reaches from the confluence with the River Vltava (Moldau) downstream of Obřístvi, Elbe-km -114 to the tidal weir at Geesthacht, Elbe-km 586. To calculate total river length, 367 km have to be added to the navigation km). This free-flowing section is separated by a weir from the tidal section at Elbe-km 586. In the free-flowing reach, relatively high nutrient inputs from the upper part of the catchment combined with anthropogenically increased water residence times in the upstream impounded sections support high concentrations of planktonic algae. Phytoplankton grows from a seasonal mean (April - October, 1994 - 2006) of $45 \mu\text{g l}^{-1}$ chlorophyll a (chl_a) at Schmilka (Elbe-km 4) to $128 \mu\text{g l}^{-1}$ chl_a at Schnackenburg (Elbe-km 475), where maximum concentrations exceeding $300 \mu\text{g l}^{-1}$ chl_a have been measured (data by ARGE-Elbe). This high productivity leads to conspicuous changes in inorganic nutrient concentrations along the river (e. g. PUSCH & FISCHER 2006, DEUTSCH et al. 2009).

2.2 Model network

The water quality model QSim of the BfG was used for the simulation of global change scenarios. It functionally describes the processes that are relevant for the water quality of a river by differential and algebraic equations without any stochastic effects (SCHÖL et al. 2006). To calculate process variables and the change of state variables, variations in flow conditions are taken into account as well as other external forcing from climatic conditions. Climatic forcing for this study was taken from a set of realisations of a statistical downscaling model (STAR; GERSTENGARBE et al. 2008). The temperature trend was taken from the IPCC SRES emission scenario A1B simulated with the global climate model ECHAM5 OM (Max-Planck-Institut für Meteorologie 2006). The corresponding discharge was calculated using the hydrological model SWIM (Soil and Water Integrated Model; CONRAD & HATTERMANN 2008). Input data for nutrient concentrations for various scenarios were derived from the nutrient emission model MONERIS (BEHRENDT 2008) (Figure 1; QUIEL et al. 2010 for details and for references of the model chain).

In order to describe a range of possible future states, a dry, medium and wet scenario was examined in detail. These scenarios have been developed based on 100 runs of STAR (STAR 2K Scenario) projected for the period 2004 - 2055. For all of the 100 scenarios, the corresponding discharge values were calculated using SWIM (STAR 2K S1). From the resulting total of 5,200 modelled years (52 years with 100 scenarios each), 10 years with low (percentile 10), 10 years with mean (percentile 50) and 10 years with high (percentile 90) annual discharge were chosen. All years of one category were averaged to obtain one “scenario year”, in the following referred to as dry scenario (ScD), mean scenario (ScM) and wet scenario (ScW). This procedure dampened the influence of specific characteristics of single years, e. g. extreme flood events and provided baselines for possible future developments.

These “scenario years” were compared to a “reference year”. This “reference year” was simulated in the form of a mean annual course by averaging the measured data from the single years 1996 - 2004.

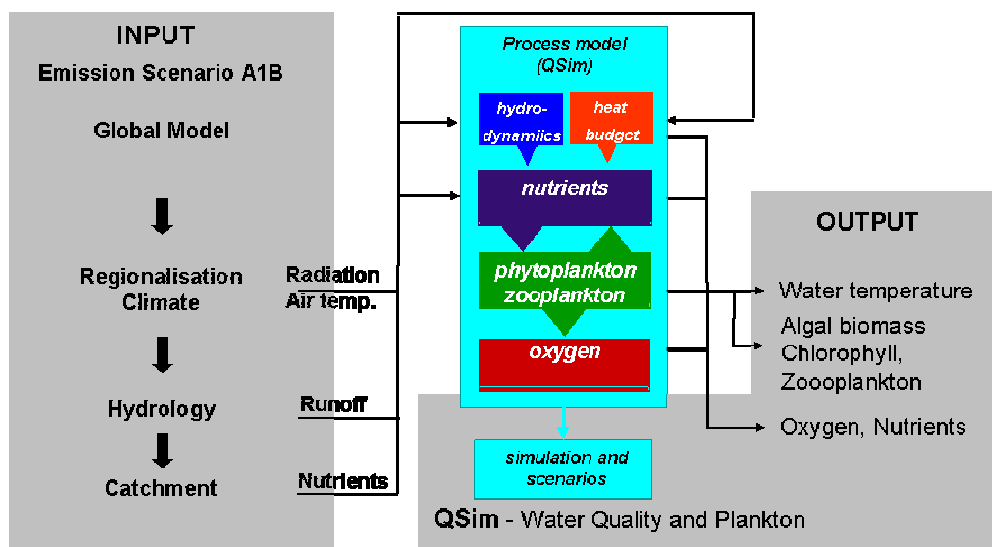


Figure 1: The water quality model QSim within the model environment for simulations of global change impacts on water quality of the Elbe.

3 Results and Discussion

3.1 Model validation

The model was validated by simulating annual courses of the years 1998, 2002 and 2003 that exhibited varying system conditions in terms of discharge and chlorophyll a (chl_a) concentrations, and comparing the results to measured data. Model efficiency and relative error were calculated to describe model performance (QUIEL et al. 2010).

The results of the simulations for the physical parameters flow and water temperature met the measured values for the validation period very well. This was indicated by high values of model efficiency and low values of the relative error. The biological parameters chl_a and nutrient concentrations (P, N, Si) differed more strongly from measured data, but were adequate for general predictions and process descriptions. Model efficiency was low for oxygen concentrations in some of the simulations, but the relative error was within acceptable limits indicating that the error was due to few divergent values. A complete set of validation data is provided by QUIEL et al. 2010.

3.2 Impacts of climate change on phytoplankton dynamics

The water quality model QSim enables detailed analyses of phytoplankton growth and loss processes as well simulations of organic matter decomposition and system respiration in the Elbe. The simulation results reveal the complex relationships between flow, nutrient concentrations and phytoplankton development. Most importantly, climate change leads to a longitudinal shift of the dominating processes (primary productivity vs. respiration) along the river continuum (Figure 2). Under reduced flow (ScD), combined with increasing air temperature and global radiation, phytoplankton biomass increases and phytoplankton maxima shift in upstream direction, followed by higher system respiration rates in the adjacent downstream

sections. In contrast, higher flow (ScW) will shift the phytoplankton maximum towards the downstream sections (Figure 2A). Intermediate conditions (ScM) still slightly increase phytoplankton concentrations, because of the generally increasing trends in temperature and global radiation.

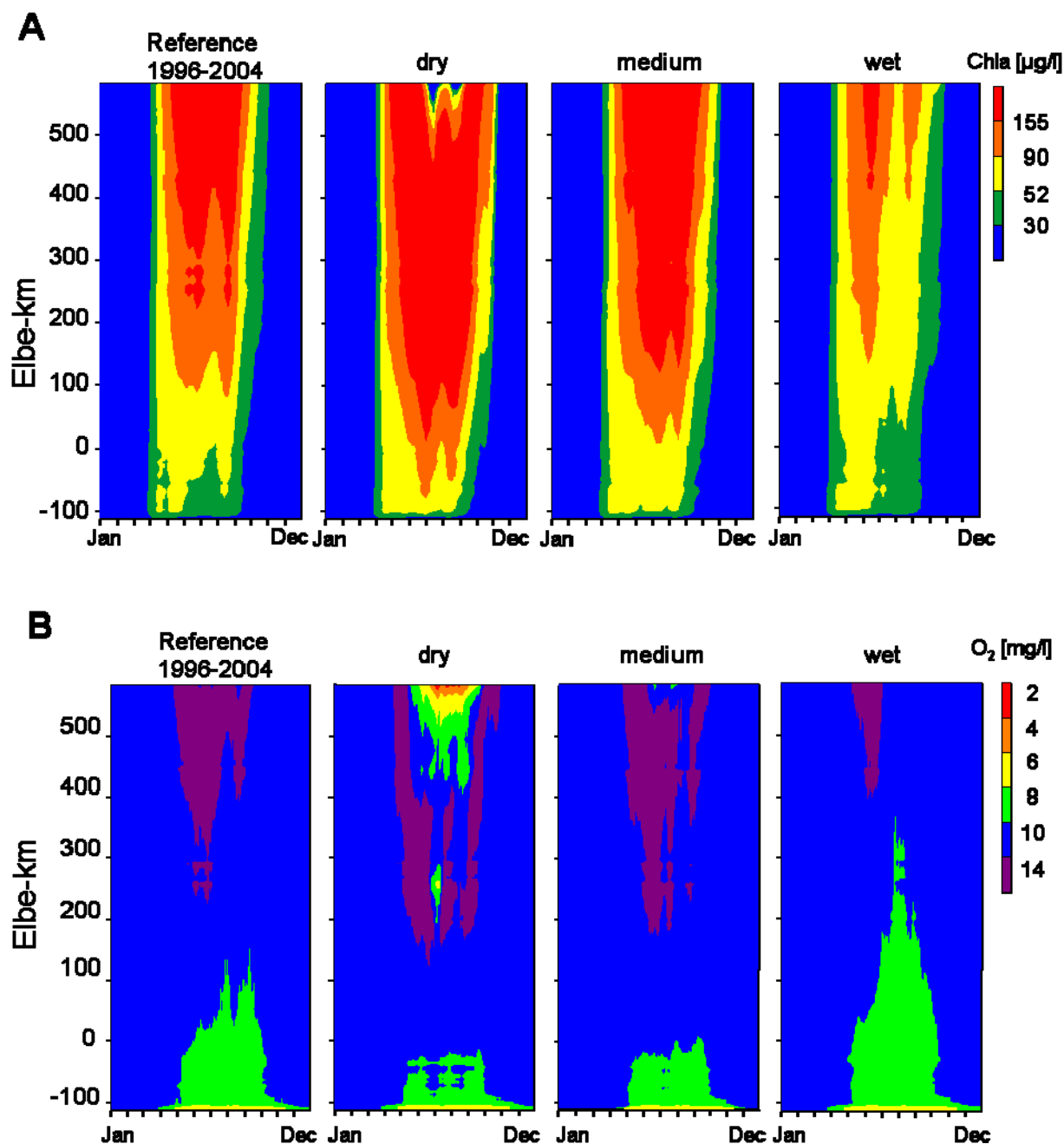


Figure 2: Spatial and temporal dynamics of chlorophyll a (chla) (A) and oxygen (B) concentrations along the modelled section of the Elbe for the reference period and for three different climate scenarios ScD (dry), ScM (mean) and ScW (wet). Km -114 indicates the start of the modelled section at Obříství (Elbe-km -114), km 586 indicates the weir separating the tidal section from the inland section. Colours in panel (A) indicate ecological state with respect to chla according to the German implementation of the Water Framework Directive.

These results reveal that due to the complexity of the relationships and the longitudinal character of the river continuum, resulting effects have to be differentiated spatially. In dry and intermediate scenarios it is probable that in upstream sections of rivers oxygen concentrations are enhanced due to intensified phytoplankton growth, while in downstream sections oxygen deficiencies will become more severe (Figure 2B). Under the scenarios ScD (dry) and ScM (mean), the riverine plankton community experienced increased underwater light supply and higher temperatures as well as decreased discharge compared with the reference period. Discharge is a major determinant of phytoplankton growth, and thus, water quality (Figure 3). Because of lower discharge, the water residence times of the water, between Elbe-km -114 and Elbe-km 475, increased from 9 days max. in the reference year to 12 days max. in ScD. Thus, more time became available for phytoplankton to grow in this river reach. Under these conditions, primary production increases and leads to higher biomass of phytoplankton in the upper part of the studied river stretch upstream of km 325. This type of eutrophication effect can generally be observed under reduced flow scenarios with prolonged residence time of the water (REYNOLDS & DESCY 1996; SALMASO & BRAIONI 2008). In contrast, water residence time is short in the wet scenario (ScW), and, in combination of unfavourable under-water light conditions with greater water depths, does not favour extensive phytoplankton growth along the course of the river (Figure 3). Flow dynamics and residence time of the water thus strongly influence the biomass of riverine phytoplankton, forming a fundamental difference compared with the impacts of climate change on phytoplankton in lakes.

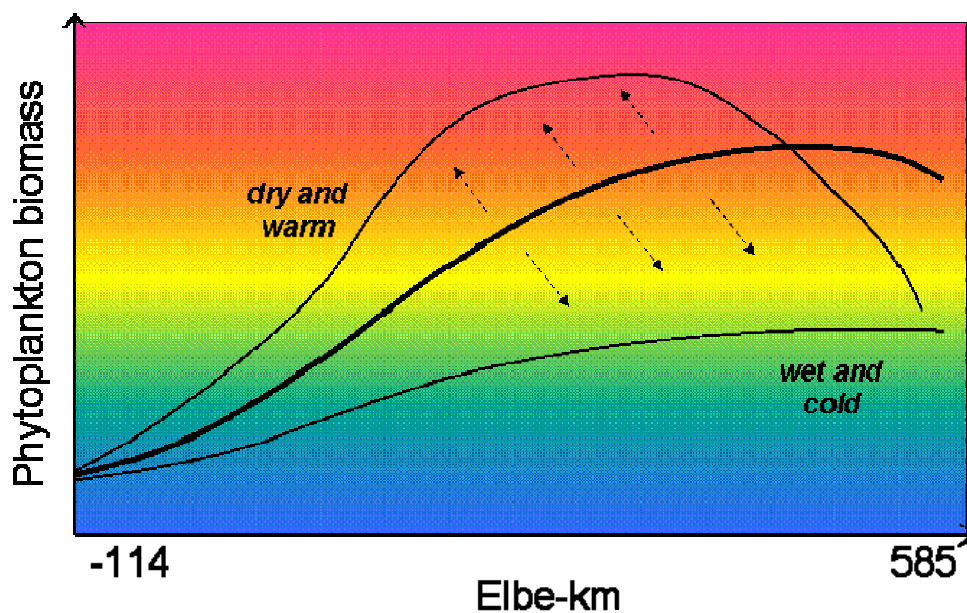


Figure 3: Schematic view of phytoplankton biomass dynamics along the Elbe under various climate change scenarios. The bold line depicts today's mean summer situation, the arrows and thin lines indicate changes due to flow reduction (1) or increased flow (2) under climate change impact. The colours indicate ecological state with respect to phytoplankton biomass according to the German implementation of the Water Framework Directive. Elbe-km as described for Figure 2.

In the downstream section, the direct effects in ScD of prolonged flow time and increased global radiation and temperature on phytoplankton are to some extent compensated by the increasing importance of light limitation through self-shading and grazing pressure by zooplankton. In the ScM, these “compensating effects” occur further downstream than in the ScD, so that the peak algal biomass also is reached further downstream (Figure 3). The main reason for this shift is the much higher grazing pressure of zooplankton in ScD which cuts the phytoplankton peak (QUIEL et al. 2010).

Surprisingly, the results of our simulation of phytoplankton concentrations did not depend on the socioeconomic developments in the Elbe catchment. Scenarios of socioeconomic change, simulated with other models of the model network, did not generate significant changes in nutrient input concentrations, so that chl_a concentrations in the Elbe river system remained unchanged. Even when various measures of nutrient management were tested, the effects of reduced nutrient inputs on chl_a concentrations were low. This is caused by the ability of phytoplankton to store phosphorus, so that phosphorus limitation of phytoplankton growth did rarely occur in our simulations.

However, given the limited possibilities to influence river flow and water temperature for phytoplankton management, an extensive reduction of nutrient inputs, especially in the upper catchment, seems to be the only practicable option to reduce phytoplankton concentrations. In these upstream section and tributaries, the starting conditions for the development along the main river are set. Here, biological control of phytoplankton loads by benthic grazers could also significantly reduce phytoplankton biomass. Reduced input of algal biomass is most likely to have an effect on the biomass in the downstream sections of the river.

Summary

The effects of changing climatic and socioeconomic conditions on the water quality of the Elbe River were investigated using the process-based water quality model QSim. Since the impact of global change on river water quality marks the endpoint of various processes in the catchment and in the atmosphere, this study was performed within a network of interacting models that determined input parameters for water quality simulations. The development of phytoplankton and nutrient concentrations under conditions of global change was modelled along a 700 km stretch of the river. The simulations revealed a strong, scale-dependent effect of climate change on phytoplankton biomass, leading to a longitudinal shift of the dominating processes (primary productivity vs. respiration) along the river continuum. Under reduced flow, combined with increasing temperature and global radiation, phytoplankton biomass increased and phytoplankton maxima shifted in upstream direction, followed by higher system respiration rates in the adjacent downstream sections. In contrast, higher flow shifted the phytoplankton maximum toward the downstream sections. Reductions of phosphorus inputs from anthropogenic sources had only limited influence on algal biomass, due to the ability of algal cells to store phosphorus. A strong reduction in P-inputs especially in the headwaters would be necessary to counterbalance the possible climate-induced effects on algal biomass.

References

- BEHRENDT, H. (2008): Auswirkungen des Globalen Wandels auf die Nährstoffeinträge und Frachten im Elbeinzugsgebiet. In: Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II, Kapitel 4.1.
- BEHRENDT, H., D. OPITZ, O. SCHMOLL, G. SCHOLZ (2004): Einzugsgebietsbezogene Nährstoffeinträge und -frachten. In: BECKER, A., LAHMER, W. (eds) Konzepte für die nachhaltige Entwicklung einer Flusslandschaft. Weißensee-Verlag, Berlin, 127-151.
- CONRAD, T., F. HATTERMANN (2008): Simulation von räumlich differenzierten Abflussdarbietsszenarien und landwirtschaftlichen Ertragspotentialen für das Elbegebiet mit dem ökohydrologischen Modell SWIM. In: Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II, Kapitel 2.2.
- DEUTSCH, B., M. VOSS, H. FISCHER (2009): Nitrogen transformation processes in the Elbe River: distinguishing between assimilation and denitrification by means of stable isotope ratios in nitrate. - *Aquatic Sciences* 71: 228-237.
- GERSTENGARBE, F.-W., P. C. WERNER, B. ORLOWSKY, M. WODINSKI (2008): Modellierung der regionalen Klimaentwicklung. In: Wirkungen des globalen Wandels auf den Wasserkreislauf im Elbegebiet - Risiken und Optionen. Schlussbericht zum BMBF-Vorhaben GLOWA-Elbe II, Kapitel 2.1.
- Max-Planck-Institut für Meteorologie (2006) Klimaprojektionen für das 21. Jahrhundert. Max-Planck-Institut für Meteorologie, Hamburg
- PUSCH, M., H. FISCHER (2006): Stoffdynamik und Habitatstruktur in der Elbe – Konzepte für die nachhaltige Entwicklung einer Flusslandschaft. Weißensee Verlag, Berlin.
- QUIEL, K., A. BECKER, V. KIRCHESCH, A. SCHÖL, H. FISCHER (2010): Influence of global change on phytoplankton and nutrient cycling in the Elbe River. - *Regional Environmental Change*, online at www.springerlink.com/content/k2231443680j7161/.
- REYNOLDS, C. S., J.-P. DESCY (1996): The production, biomass and structure of phytoplankton in large rivers. - *Archiv für Hydrobiologie Supplement* 113/Large Rivers 10, 161-187.
- SALMASO, N., M. G. BRAIONI (2008): Factors controlling the seasonal development and distribution of the phytoplankton community in the lowland course of a large river in Northern Italy (River Adige). - *Aquatic Ecology* 42, 533-545.
- SCHÖL, A., R. EIDNER, M. BÖHME, V. KIRCHESCH (2006): Integrierte Modellierung der Wasserbeschaffenheit mit QSim. In: PUSCH, M., FISCHER, H. (eds.) Stoffdynamik und Habitatstruktur in der Elbe – Konzepte für die nachhaltige Entwicklung einer Flusslandschaft. Weißensee Verlag, Berlin. 233-242.



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Projects related to climate change impacts:

2005 – 2010: GLOWA-Elbe (BMBF 01LW0603I1)
www.glowa-elbe.de

since 2008: KLIWAS (BMVBS)
www.kliwas.de

since 2010: Methane emissions from impounded
rivers (DFG)

since 2010: SCARCE (CONSOLIDER Ingenio)
www.idaea.csic.es/scarceconsolider

since 2010: NITROLIMIT (BMBF 033L041G)
www.nitrolimit.de

Diadromous fish and climate change – a case study of the integration of projective distribution maps into the decision-making process

Eric Rochard and Geraldine Lassalle

Abstract

The latest update of the IUCN (International Union for the Conservation of Nature) Red List of Threatened Species shows that 17,291 species out of the 47,677 assessed species are threatened with extinction. Some of these species benefit from special protection measures which are implemented at regional or international scales and with the ultimate aim at restoring a former pristine situation.

In most recovery plans, the environment is usually considered as implicitly stable. However it is changing, with modifications especially driven by a global increasing of temperatures and CO₂ and by regional anthropogenic pressures. Consequently, research efforts are made by climatologists to predict future climate characteristics.

All living organisms are linked to their environment following several ecological principles, the geographic distribution being the result of the environment variability experienced by each species. Therefore, modification of species ranges is one of the universal ecological response to climate change in both terrestrial and aquatic ecosystems. This could be particularly “deleterious” for threatened species whose current (or forthcoming) restoration is guided by historical references. Consequently, to prevent mismatch between conservation actions and future distribution of top-priority species, the latter should be assessed according to various climate change scenarios. This was done for the European diadromous species which are of great economical and ecological importance and which are listed in various conventions and directives.

A three-step procedure was applied to each of the 28 diadromous species identified in the Palearctic region:

- i) their “1900” distribution was assessed in 196 watersheds through bibliographic searches;
- ii) their “1900” distribution was modeled using five environmental variables suspected or known to constrain their repartition, i. e. climatic, topographic and biogeographic;
- iii) their “2100” distribution was projected using various greenhouse gazes emissions scenarios developed by the Intergovernmental Panel for Climate Change (IPCC).

Results indicated that most European diadromous species are highly sensitive to their climatic environment. 65 % of them are calculated to contract their distribution area for the end of the twenty-first century under climate change assumption. The diadromous species will probably disappear in their southern distribution range, where the climatic conditions are calculated to become unfavorable. On the contrary, they could benefit from colonization opportunities farther north, in some basins projected to turn favorable to their installation. However, these “gains” would be never sufficient to compensate the severe “losses” of habitats.

These results give concrete opportunities to adapt the decision making-process to a global changing environment. However, further works are still needed to lead to the full appropriation of the projective maps by stakeholders and policy-makers.



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Projects:

- 2000 – : Effect of global change on the Euro-
pean Diadromous Fish
- 2000 – : Conservation of the European stur-
geon
- 2005 – 2011: Comparative approach of the ecology
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Climate change impact assessment on the ecological status of Spanish water bodies

Manuel Toro, Elena Cristoba and Sergio Velasco

Abstract

A methodology for the assessment of climate change impact on the ecological status of Spanish freshwater ecosystems is being developed based on data from the Biological Monitoring Network of the Mediterranean Jucar River Basin District (43,000 km²) for the period 1999 - 2006. Data includes information about aquatic macroinvertebrates (family level) and a set of aquatic and other environmental variables from 310 sampling sites.

Ecological optimum and the tolerance and optimum ranges of all found taxa (family level) with respect to a group of environmental variables that influence their biological distribution have been estimated. The response of biological communities in a set of different future scenarios of climate change is being studied considering the results obtained with different predictive type models such as climate envelope models, generalized linear models or general adaptative models.

The sensitivity of the Spanish biological monitoring systems (biological quality element: macroinvertebrates) and of the different river water body types to climate change effects is analyzed, considering their reference conditions and the ecological quality ratios for these monitoring systems.

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Climate change impact assessment on the ecological status of Spanish water bodies

Seppo Rekolainen

Abstract

Water Scenarios for Europe and Neighbouring Countries (SCENES) has been an EU-funded project aiming at developing new water scenarios for Europe for 2030 and 2050. The methodological approach has been a combination of storylines developed by participative process with stakeholders and use of hydrological simulation models. Moreover the impacts of different scenarios have been analysed. As drivers, we have analysed the impact of changes in climate and various socio-economic drivers, such as demography, agriculture, industry, technological development. As a result, water availability will be highly affected by climate change, but socio-economic drivers will have a big impact on water use. As a combination, water stress is not only dependent on climate change, but also shows large variability depending on the socio-economic scenarios. As a conclusion, policy options and actions do matter in order to reduce water stress and water quality.

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