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KLIWAS: Impacts of Climate Change on Waterways and Navigation in Germany 2011

Second Status Conference, Federal Ministry of Transport, Building and Urban Development, Berlin 25 and 26 October 2011

Federal Ministry
of Transport, Building
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KLIWAS
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Conference Proceedings

KLIWAS

Impacts of Climate Change on Waterways and Navigation in Germany

Second Status Conference – Federal Ministry of Transport, Building and Urban Development, Berlin – 25 and 26 October 2011




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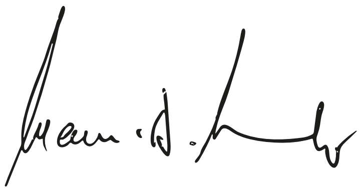
The second status conference on the KLIWAS research programme was held at the Federal Ministry of Transport, Building and Urban Development in Berlin on 25 and 26 October 2011. The objective we pursue with KLIWAS is to establish a reliable basis for taking potential climate change into account when planning future measures on the navigable waters in Germany. Against the background of the many uncertainties involved in climate and climate impact research, the KLIWAS results obtained by using the most advanced scientific methods are to provide support in an unprecedented quality to those responsible for future planning and decisions.

With its integral approach, KLIWAS focuses on the entire hydrological system in order to meet future challenges in connection with the upgrading, operation and maintenance of waterways. Since the navigable waters are of great importance also for many other action areas of our society and in connection with the obligation to provide public services, the results will be of interest not only for bodies of water in their function as waterways.

Marking the end of the first half of the KLIWAS programme (duration from 2009 to 2013), we used the second status conference to present selected interim results in the form of presentations and posters compiled specifically for individual regions such as the Rhine, Elbe and Danube river basins as well as the coastal waters. The conference helped in speedily communicating the interim results already available to the professional and political fields of action. At the same time, cross-connections with the other climate impact research programmes of the Federal Government and federal states were identified in order to encourage the increased use of synergies.

I am convinced that the conference with its wide range of contributions succeeded in providing all participants with new impetus, highlighting prospects and encouraging further cooperation. The conference clearly showed that adaptation to climate change will be a permanent task to be dealt with in the various fields of action covered by the Federal Ministry of Transport, Building and Urban Development and that, in order to enable us to do so, our departmental research institutions will clearly have to evolve our applied climate impact research.



Prof. Klaus-Dieter Scheurle, State Secretary
Federal Ministry of Transport, Building
and Urban Development

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Posters of the Second KLIWAS Status Conference, 25 and 26 October 2011

The posters of the Second KLIWAS Status Conference, 25 and 26 October 2011, are published as Heft 12/2012, KLIWAS-Schriftenreihe. To be obtained from: KLIWAS-Koordination in der Bundesanstalt für Gewässerkunde, Am Mainzer Tor 1, 56002 Koblenz; e-mail: kliwas@bafg.de.
Downloads are available on www.kliwas.de.

Introduction

Opening Speech

Prof. Klaus-Dieter Scheurle, State Secretary (BMVBS)

The KLIWAS research programme (Impacts of Climate Change on Waterways and Navigation in Germany) was presented to an expert audience at the start of its lifetime at the First Status Conference on 18/19 March 2009. Since then, the interest in KLIWAS and its progress has grown further. The Second Status Conference, which was held in Berlin on 25/26 October 2011, was attended by over 250 participants from all over Germany and by a few from neighbouring countries. They represented the following fields:

- politics;
- numerous Federal Government and federal state ministries and their executive agencies;
- shipping, ports and industry;
- water management;
- environmental protection and nature conservation;
- consulting engineers;
- academia, primarily from the field of climate change impact research;
- the Federal Waterways and Shipping Administration;
- the departmental research establishments of the Federal Ministry of Transport, Building and Urban Development: the Federal Institute of Hydrology, the German Meteorological Service, the Federal Maritime and Hydrographic Agency and the Federal Waterways Engineering and Research Institute, which are responsible for developing the contents of the research programme. By contributing their latest findings in the form of presentations and posters, they were instrumental in shaping this event.

The fact that the participants came from such a wide spectrum of activities made it possible to address the complex issue of "adapting the navigable waters in Germany to climate change" in a comprehensive and appropriate manner, involving people with the necessary expertise and responsibilities, and to incorporate the necessary experience.

Around the globe, the impacts of global warming are being observed or predicted for the near future. These include, for instance:

- a rise in sea level;
- changes in the atmospheric and oceanic circulation systems, combined with an increasing frequency and intensity of extreme weather events;
- the melting of polar ice caps and glaciers;
- periods of record hot weather, droughts, extreme high and low water events on rivers.

As in other countries, we in Germany are aware of the changes taking place in the climate and weather and the impact this has on our traditional way of life and economic activities, and we have to address the consequences for future planning at an early stage. Simply waiting to see whether we achieve or fall short of the two-degree objective cannot be described as a responsible and proactive approach.

Tackling global climate change and our measures for making our contribution to reducing emissions in the transport, building and housing sectors and arriving at more energy efficient practices in order to meet the ambitious targets of German and international climate change policy, in other words the second climate change pillar, was not addressed at the Status Conference, but of course it must not be neglected. Here, we are also undertaking great efforts for our areas of activity, but this is not the place to look at them in detail.

In recent years, climate change impact research and climate change adaptation have increasingly become issues that are of vital importance to our future, both internationally and nationally. The Intergovernmental

Panel on Climate Change (IPCC) will shortly publish a special report addressed to policymakers entitled "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (SREX). This report will describe the precautions that should be taken in addition to climate change mitigation measures to adapt to extreme climate and weather changes. In this paper, the IPCC will illustrate that there are significant trends for which we have to be prepared in terms of prevention and the provision of public services and which are also relevant to waterways and navigation. The IPCC stresses that the ongoing advance of global warming will continue to accelerate extreme events (heat waves, heavy rainfall, storms, storm surges, floods, droughts, low water), varying from one region to another, and in particular with greater impacts on water management systems and infrastructures. "Low regret" and "no regret" measures, which generate short-term benefit and reduce impact in the long term, are considered to be the most effective adaptation measures.

The European Commission has accelerated these activities at European level by publishing the White Paper entitled "Adapting to climate change". At the same time, as part of its common transport policy, it calls on Member States to develop "climate change-resilient" infrastructures and transport operations in the Trans-European Transport Network (TEN-T). At national level, the Federal Government is calling for this with the German Climate Change Adaptation Strategy (2008) and the recently adopted Adaptation Action Plan (2011).

The global conference of transport ministers, which for some years now has been meeting annually in May under the auspices of the International Transport Forum (ITF, OECD) in Leipzig in Germany with a different thematic focus each year, addressed the issue of climate change mitigation in 2008 ("Transport and Energy – the Challenge of Climate Change"). A working group has been tasked with preparing an international study on "Adapting the transport sector to climate change and extreme events", thereby laying the groundwork for one of the forthcoming international transport fora. The KLIWAS methodology and findings have already attracted great attention for the waterborne mode, because many states do not yet have any comparable strategies for the transport sector.

However, before we can responsibly invest in climate change adaptation measures, we have to carefully establish what changes we are likely to experience. Some changes in the climate, which we think we "feel", are, if subjected to a thorough meteorological analysis, part of the "normal" variability of weather patterns and cannot yet be classified as climate change. Decision-makers in the transport sector require robust evidence, especially at regional level, about the extent to which waters, and thus inland and coastal waterway navigation and infrastructure, could be affected by climate change.

The creation of scientifically sound evidence is the main task of the KLIWAS research programme. To make us better equipped to meet the future challenges that navigable waters will face, and to enable us to better fulfil our responsibility here, we thus launched the KLIWAS research programme in 2009, with a lifetime of 5 years and a budget of 20 million euros. These research funds have been wisely invested in KLIWAS, because they are also of importance to other fields of activity on waters, such as water management, environmental protection, nature conservation, coastal protection, spatial planning and urban development, and will thus generate great benefit to society. The findings will be an important basis for our future investment decisions, for the cost efficiency of the tasks ahead and for the provision of public services in all spheres related to the waters. With its comprehensive interdisciplinary approach, KLIWAS, a lighthouse project of the Federal Ministry of Transport, Building and Urban Development in the transport sector, is a major contribution to the German Climate Change Adaptation Strategy and the Federal Government's Adaptation Action Plan.

The multi-model approach of KLIWAS involves a lot of money and effort, but it is a scientifically necessary approach in climate change impact research. The departmental research establishments have evolved their impact models on discharge, oceanography, transport of sediment and pollutants, water quality and vegetation in order to couple them in a model chain to the nationally and internationally recognized climate models (ensembles). This involves looking at the entire system of waters in each case, in order to capture and understand the interactions even better – to work with the forces of nature and not against them. Thus, future water conditions can be simulated with a new quality of resolution in terms of space and time. This information will also be used to further optimize water management on the navigable canal network (for instance between the Rhine and Oder or Rhine and Danube).

The multi-model approach of KLIWAS has already attracted attention and gained recognition in the international scientific community. This is demonstrated by the fact that other action areas have likewise adopted this approach. On the Rhine, for instance, where there is the greatest lead time and accordingly the greatest progress, various bodies of the Rhine riparian states, such as the International Commission for the Protection of the Rhine (ICPR), the Central Commission for Navigation on the Rhine (CCNR) and the International Commission for the Hydrology of the Rhine Basin (CHR), have adopted the methodology and findings of KLIWAS. The Danube Commission is also interested in the KLIWAS findings. In addition, countries from further afield are also interested in applying KLIWAS findings. Thus, a Chinese delegation also attended the Status Conference, and negotiations were conducted on the sidelines of the conference regarding a collaborative scheme for the application of the KLIWAS methodology to the Yangtze.

The interim findings available today of the KLIWAS studies into possible impacts of climate change on the regional distribution of precipitation and the discharge conditions for the Rhine, Elbe and Danube water systems and for the coastal waters illustrate that changes in the discharge of major watercourses will be moderate in the decades ahead.

From this, the conclusion can be drawn that, in the decades ahead, it will not be necessary to question the usability of any waterway because of climate change. This means that our waterways will continue to be reliable, albeit under different discharge conditions. The findings available do not have any immediate and serious consequences for the forthcoming investment decisions. The climate-induced variability of the environmental parameters projected by KLIWAS for the decades ahead is moderate and can be considered using the existing planning tools.

However, in the second half of the century, the changes may be on such a scale that more far-reaching adaptation activities become necessary, not only with regard to navigation, but also for other action areas on waters. Integrated and proactive action by all those responsible for the waters will then be more necessary than ever before. KLIWAS will develop proposals for suitable water-specific adaptation measures.

So far, “no regret measures” have been the preferred means, in other words measures that are already generating benefit and at the same time can be used for adaptation to climate change. These include, for instance, measures to ensure constant discharge conditions (reducing flood crests, raising low water levels).

Policymakers now have a decision-making basis for the major navigable waters that is scientifically much improved. The integrated KLIWAS system of models now makes it possible to quickly update complex calculations on the future climate-induced condition of the water bodies and to better take new developments into consideration. Against the background of the great uncertainties that are primarily caused by the complex input variables (including emission scenarios) and the different climate models, the KLIWAS research group generates a spectrum of possible projections as a resilient basis for decision-makers.

We eagerly await, and will use, further findings over the next two years and will continue to seek answers to unresolved issues. But the Federal Ministry of Transport, Building and Urban Development and the Federal Waterways and Shipping Administration will also continue to proactively observe new findings of climate change impact research with the support of the KLIWAS research group beyond the lifetime of the research programme and integrate them into strategies for securing navigation.

However, if we are to meet the future challenges of climate change adaptation, the funds necessary for further knowledge development and adaptation measures have to be budgeted and provided. To this end, for instance, some of the revenue generated in emissions trading should be channelled into departmental research and used for climate change adaptation measures. Nor will it be possible to consolidate the newly acquired knowledge in everyday operations without additional resources.

I would like to conclude by expressing my gratitude for the pioneering work that has already been done in KLIWAS, which is now increasingly bearing fruit in theory and practice. Here, much credit is due to our departmental research establishments and the numerous scientists involved in the 30 different projects, especially to the Federal Institute of Hydrology for coordinating the research group. The 20 KLIWAS presentations and 30 KLIWAS posters at the Second Status Conference left an indelible impression of the creativity of those involved.

The Integral Approach of the KLIWAS Research Programme for Navigation and Waterways

Hans Moser (BfG)

1 Introduction and objectives of the research programme

The starting point of all deliberations for the KLIWAS research programme was the question: What impact does the warming of Central Europe have on the navigability of the federal waterways?

The term "navigability" is defined in an American textbook (Parkins & Whitaker 1939) as follows:

> *"Navigable bodies of water are bodies that are navigated in fact."*

And as if the author realized at the moment of writing that this definition is rather vague, he adds the following to the definition:

> *"Exactness demanded in scientific writings calls for a statement of the minimum depth for navigation".*

So what are the determinants on which the navigability of a waterway depends? First, it depends on the quantity of water available. This quantity of water should, wherever possible, be distributed evenly in terms of space of time. The second factor is the geometry of the river bed. As an example, Figure 1 shows an illustration of the bed of the Rhine at Mannheim from 1836. The quantity of water and the geometry of the river bed produce the water level in the river. Based on this water level, the size of the vessel is the third factor determining which waterways can be commercially navigated (*minimum depth for navigation*).

The navigability of a waterway can thus be defined as a function of the quantity of water, the geometry and vessel size. This definition of navigability relates to the purely technical requirements to be met by the infrastructure. However, the integral approach to waterways

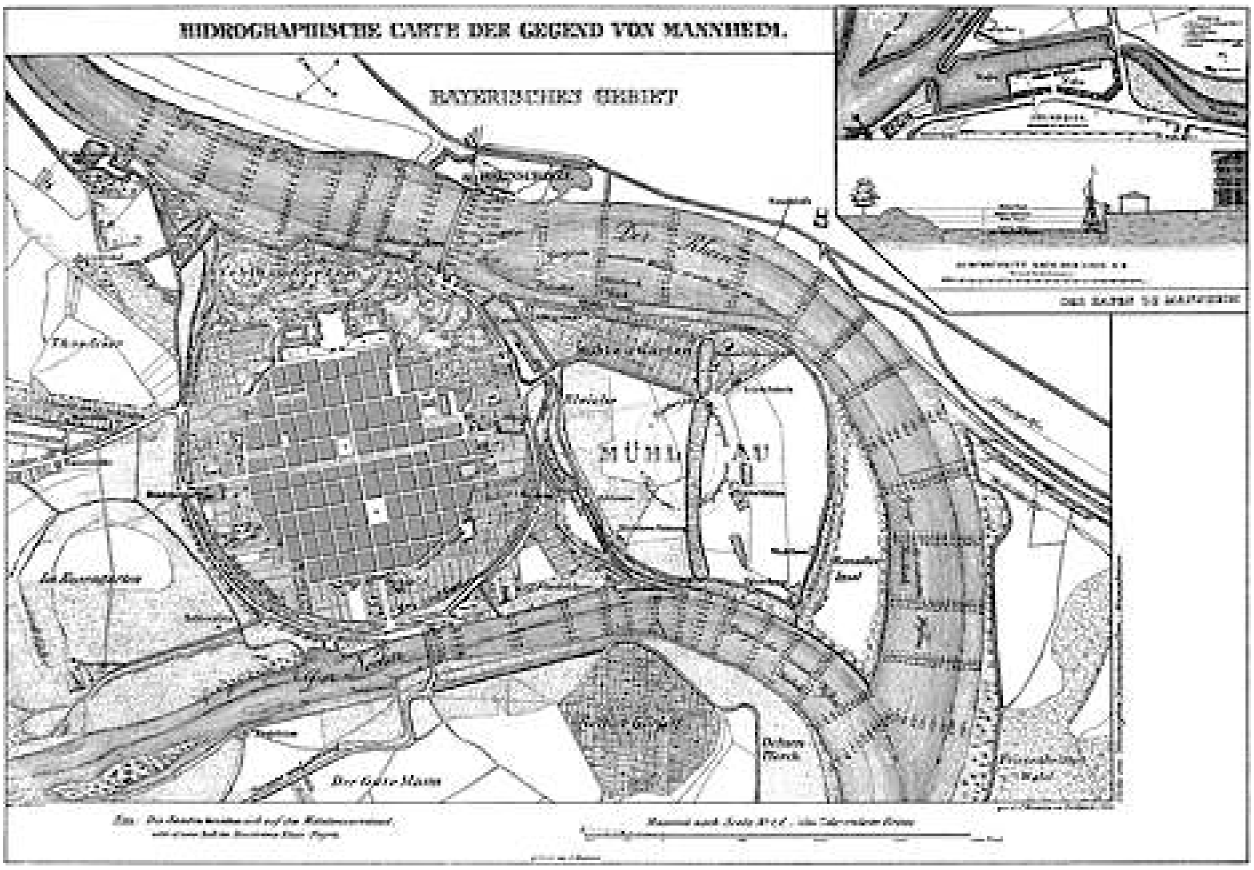

Figure 1: Illustration of the bed of the Rhine and the confluence with the Neckar at Mannheim (source: Federal Minister of Transport 1951)

and navigation calls for this definition to be widened (see Figure 2).

The quantity of water, geometry and vessel are supplemented by the quality and ecology of water as determinants. This cross-sectoral perspective is characteristic of the KLIWAS research programme. This perspective is indispensable, because the development of options for adaptations to future changes cannot be formulated on an exclusively sectoral basis for the waterborne mode.

So what does this integral approach mean for the KLIWAS research programme? KLIWAS seeks to achieve completeness in terms of space, time, subject matter and methodology.

The area studied by KLIWAS covers the coastal waters of the North Sea and the Baltic Sea and the cross-border river basins in Central Europe. The basins addressed so far in KLIWAS are the Rhine, Upper Danube and Elbe.

Hydrologically, we are surveying a period of 300 years in the KLIWAS research programme. In other words, we know what the hydrological conditions were in the past 200 years and are forecasting future trends over the period to 2100.

In terms of subject matter, the KLIWAS research programme aspires to a full analysis of the system.

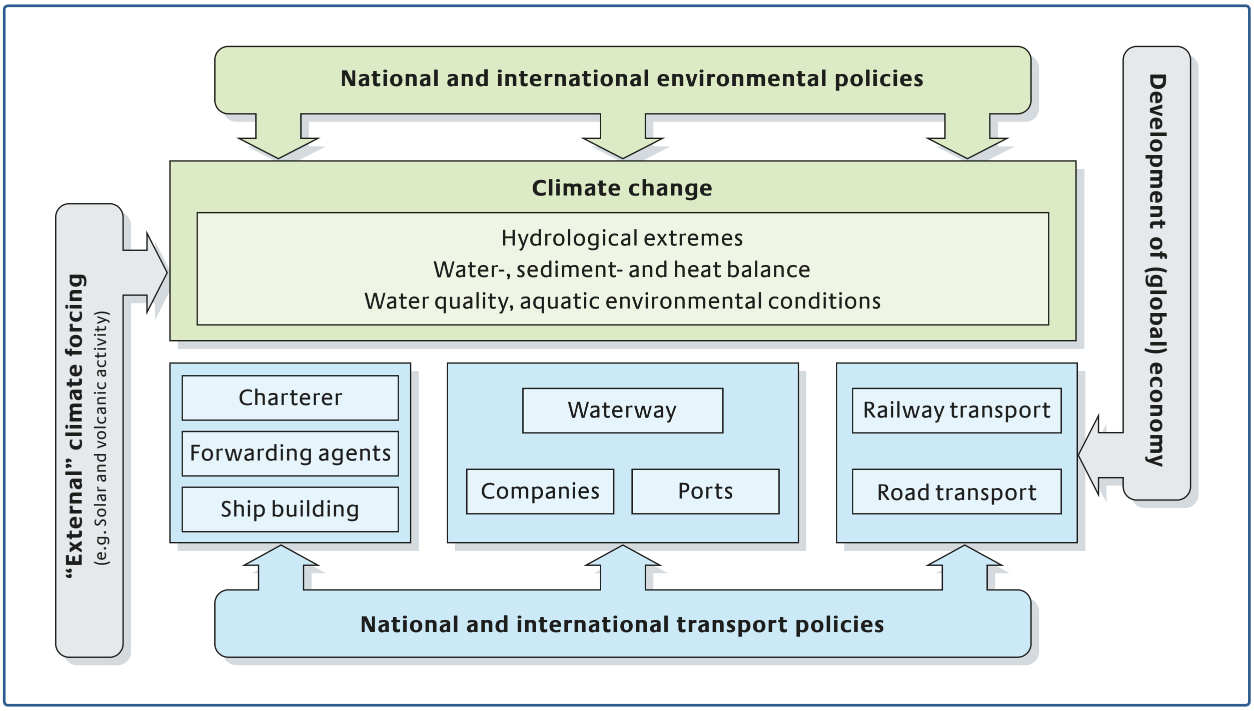

Figure 2: The waterway as a system (source: Nilson et al. 2009, modified in accordance with Via Donau 2005)

This means that, starting from physical variables, it advances via issues of water quality to the ecosystem functions in the water.

As far as methodology is concerned, the terms "model chain", "multi-model approach" and "spectrum" play a key role.

The KLIWAS departmental research programme was also designed to provide scientific advice to policymakers. Every policy decision requires reliable knowledge of the subject and a realistic idea of the options for regulation. An important basis for this is the scientific work of departmental research institutes, one of the main aims of which is to ensure that the findings are reliable and usable for practical application. By fulfilling this aspiration, we arrive at "second order knowledge".

The term "second order knowledge" has been borrowed here from the philosopher Peter Bieri. The expression reveals a sceptical attitude that has a long tradition in science and the history of ideas. Second order knowledge means that we are aware of the imperfection of our knowledge.

Specifically, this means:

- awareness of the validity of our knowledge;
- awareness of the limits and uncertainties, especially in numerical modelling;
- awareness of the origin and genesis of our knowledge;
- source criticism and source honesty;
- awareness of the tentativeness and diversity of our knowledge;
- awareness of its relevance to practical application.

And it is second order knowledge, above all, that prevents us from drawing false conclusions, because we consistently have to ask the questions "What does this mean exactly?" and "How do we know that this is the case?"

These fundamental questions form the framework within which the KLIWAS research programme estimates the climate-related changes in runoff and water levels for inland waterways. Similarly, physical variables that are changed by the influence of the climate, such as wind, currents, sea state, water levels and their impact on navigation, are studied for coastal waters. At the same time, the impact of the potentially changed hydrological states on pollution by (noxious) substances and on ecological functions is analyzed and economic aspects relating to navigation are addressed. Finally, adaptation options for a spatial scale relevant to planning are to be developed.

The core project, addressing climate change and runoff projections, started on the Rhine back in 2007. The enlarged research project, which comprises 30 projects, was launched in March 2009 and will run until 2013. During this period, around 100 scientists at the departmental research establishments involved (Federal Institute of Hydrology, Federal Waterways Engineering and Research Institute, Federal Maritime and Hydrographic Agency, German Meteorological Service) and their cooperation partners are collaborating. They are advised by a board of academic advisers. In addition, the scientists engage in an exchange of ideas and experience with the Waterways and Shipping Administration as the operator of the waterways.

2 The integral approach – regional and methodological aspects

The KLIWAS research programme pursues an approach for regional, disciplinary and methodological integration.

Regional integration means analyzing, in each case, complete catchment areas of the waterways from a climatological and hydrological angle. Inland, the study focuses on the Rhine, Elbe and Danube. The subject matter of the KLIWAS projects follows the continuity of the water system from the inland waters via the estuaries (Elbe, Weser and Ems) to the coastal waters and out into the open sea. For the waterways navigable by sea-going ships, the analyses build on regionalized oceanic and atmospheric models. One of the research objectives is to identify regions of identical vulnerability. So far, the Baltic Sea has been the subject of study in partial aspects.

The approach for **disciplinary integration** is a consequence of the multiplicity of water system components addressed, including floodplains, forelands and peripheral ocean areas (hydrology, ecology, water quality, morphology, sediment transport, economic aspects of navigation). This holistic approach reflects, among other things, the aspects that have to be taken into account for hydraulic engineering measures that have to be taken for the operation and maintenance of waterways. These aspects are being studied by scientists from 20 disciplines (primarily meteorology, hydrology/oceanography, hydraulics, limnology, biology, chemistry and engineering). Responsibility for the projects lies with the units and directorates of the four higher federal authorities, which cooperate with university and other academic institutions. Merging the disciplinary work within the projects to form an interdisciplinary approach in the KLIWAS research programme is based on a common perception of aquatic ecosystems used by humans that have to be managed sustainably (waterways, receiving bodies of water, hydroelectric power, cooling, etc.). In addition, KLIWAS pursues a **transdisciplinary** approach. Applied departmental research integrates the objectives of the Waterways and Shipping Administration, which will ultimately implement adaptation measures.

The method for implementing the integral approach of KLIWAS consists of describing and applying two **model chains** – one for inland waterways and one for waterways navigable by sea-going ships (including the estuaries of the aforementioned rivers). The two model chains are linked to each other by the "climate" and "estuaries" interfaces. Each model chain represents the hierarchical linkage of the aforementioned components of the waterway as a system. Most of the individual links of the model chain are part of the existing modelling apparatus of departmental research, represent the academic disciplines and constitute a specific application or extension. KLIWAS merges the existing models (and those to be developed) to form a model chain.

The model chain for **inland waters** is structured as follows. The global climate models, with their coarse spatial resolution, cannot satisfactorily reflect regional meteorological effects. For this reason, regional climate models are used to calculate **regional climate projections**. Subsequently, relevant hydrological and hydro-meteorological parameters from the regional climate projections are projected onto the river basins addressed with the help of scaling and interpolation procedures. They are then used – with the help of hydrological regime and hydro-dynamic models – to determine runoff-water level projections, for instance. Finally, these data are used in other models that address issues of water quality, sediment transport or climate change impacts in fields such hydraulic engineering, ecology or the economy.

In the field of **coasts and seas**, the approach is basically the same. On a global scale, oceans and the atmosphere are coupled using modelling techniques, i.e. their reciprocal impact is taken into account. It is true that global atmospheric models are regionalized on the North Sea scale. However, they have not yet been coupled with regionalized ocean models. Hydrodynamic models for sea state, tides, current and sediment transport are connected downstream of the uncoupled and coupled models. As is the case inland, other impact models follow issues relating to water quality, ecology, hydraulic engineering and economic aspects.

Each model chain is calculated several times. Here, different CO_2-emission scenarios are considered, and in the future scenarios based on different radiative forcing values (representative concentration values or RCPs) will also be considered.

The **multi-model approach** widens the methods of the model chains as a further essential feature of the integral approach of KLIWAS. In each link of the model chain, several numerical models are taken into account wherever possible. This is primarily the case at the level of the global and regional climate models, but also in every other link of the model chains outlined above. The multi-model approach reflects this great uncertainty in each of the individual models.

The information on the degree of climate change and the validation of the climate models are designed to represent the possible future deviation from the 1961 to 1990 meteorological period and from the internationally coordinated ERA-40 data (1957 to 2002). For ecological hydraulic engineering aspects and for information on water quality, reference periods that in some case deviate from this are used for methodological reasons. Looking ahead to future trends in climate change and its impacts on bodies of water, the research programme uniformly addresses the projection periods from 2021 to 2050 (near future) and from 2071 to 2100 (distant future).

KLIWAS focuses its research activities on the following action areas of the German Strategy for Adaptation to Climate Change: "water balance, water management, coastal and marine protection" and "transport, transport infrastructure". However, relationships can be established to almost all action areas using the results of each link in the KLIWAS model chain, primarily on the basis of the climate and hydrological modelling.

So far, KLIWAS has involved **external players** predominantly through linkages with different national research programmes (see Chapter 3.5 of the Adaptation Strategy). Also involved are players who take decisions on potential adaptation options (Federal Ministry of Transport, Building and Urban Development) or who implement them (Waterways and Shipping Administration). So far, the focus has been on information and discussion about the methodological approach of KLIWAS. At the KLIWAS project level, there are participative approaches that are reflected in collaborative ventures and in the formation of joint working groups (Federal Government, federal states, research community).

3 Results achieved to date and lessons learned from implementation of the integral approach

The regional integration described above is considered to be the right approach, but it entails a lot of time and effort for methodological coordination. From the perspective of the **transdisciplinary approach and methodological integration**, results have been produced and lessons learned from the active participation (dating from before KLIWAS) of the higher federal authorities in different research programmes. Here, the first example to be mentioned is the cooperation with the European ENSEMBLES project. The findings of ENSEMBLES are systematically used in the multi-model approach. In addition, it is involved at national level in, among others, KLIWA (German Meteorological Service, Federal Institute of Hydrology), KLIMZUG (German Meteorological Service, Federal Waterways Engineering and Research Institute), KfKI (Federal Waterways Engineering and Research Institute, Federal Maritime and Hydrographic Agency, Federal Institute of Hydrology) and GLOWA-Elbe (Federal Institute of Hydrology). The results of GLOWA-Elbe, for instance, are integrated as findings into KLIWAS (a statistical climate model as part of a complete set of models). One of the lessons learned from the participation in GLOWA-Elbe is that it is difficult for KLIWAS to present such (preliminary!) partial results of climate change impact research in a manner that is likely to appeal to the general public. One of the most difficult things to communicate is the considerable range of possible future states, which results from the multi-model approach. Potential users of findings are informed by KLIWAS that the (partial) results achieved so far still have to be classed in a spectrum of possible future climate states. This synopsis will be compiled by the Adaptation Strategy, for instance.

A major step in this direction was the KLIWAS contribution to the Report of the International Commission for the Hydrology of the Rhine Basin (CHR), which was published in November 2010. In this report, the results of the integral approach with the range of the multi-model approach to climate and runoff projections based on state-of-the-art knowledge for the aforementioned projection periods are coordinated with the relevant academic institutions in the Rhine states. They will now be used for the creation of further scenarios for policy-makers. The “Study of Scenarios for the Discharge Regime of the Rhine”, which was published by the International Commission for the Protection of the Rhine (ICPR) in April 2011, has continued this process.

Regarding trends in the rise in global sea levels, major prerequisites need to be clarified by basic research. These include, in particular, the behaviour of the continental ice sheets in Greenland and the Antarctic. The growth in knowledge means that statements on sea levels have to be corrected from time to time. So far, the results have always shown higher sea levels. The Federal Maritime and Hydrographic Agency and the German Meteorological Service’s Maritime Meteorological Office are working together in KLIWAS with groups of researchers to develop coupled ocean-atmosphere models for the North Sea in order to expose the possible modifications of the rise in global sea levels through atmospheric and oceanographic circulation phenomena. The development of (hydraulic engineering) adaptation options reflects this lack of knowledge by first applying specific amounts of sea level rise, initially in sensitivity studies. These assumptions will be reviewed when the results of the coupled models are presented or will be “fitted into” the range which will then be projected in more concrete terms.

One contribution towards shaping **governance processes** is the aforementioned course of action with the CHR and ICPR. Other activities in this direction are being pursued to coordinate the sea level rise scenarios with institutions in the Netherlands and the Federal Ministry of Transport, Building and Urban Development, as well as participation in the EC Water Framework Directive’s CIS process. Joint study programmes have been coordinated with the federal states to address the issue of water hygiene. Elements of **participative procedures** are currently not deployed in a targeted manner. A stringent methodological agreement on this matter will be developed.

4 Future activities in the integral approach

The German Adaptation Strategy is a good framework for KLIWAS. This process, which is continually coordinated between government departments, supports KLIWAS collaborative ventures that transcend action areas, levels and stakeholders. However, the need for coordination and collaboration identified in the course of the German Adaptation Strategy goes beyond the level estimated when the research programme was formulated in 2007/2009. The discussion that has already started on a research programme addressing the adaptation of transport infrastructure to climate change can meet this substantive and cross-modal requirement.

The multi-model approach in KLIWAS complies with the major recommendations of the IPCC. Other research projects and programmes consider their task to be to apply climate projections of individual working groups (= climate models) to develop adaptation options, and state the uncertainties at the level of the respective model. On the other hand, departmental research will, in keeping with the principle of integration, include these (partial) results and, in addition, operate available models itself, combine all findings to form a synopsis and communicate this synopsis. The waterways administration will shortly be involved more deeply in the concrete development of possible adaptation options. In addition, more intensive participation of stakeholders from other action areas of the German Adaptation Strategy is necessary. To this end, it is essential that we intensively address participative procedures and select those are suitable for the KLIWAS research programme.

The work required of us to adapt the infrastructure in Central Europe to the future climatic conditions calls for concentration, earnestness and the necessary resources. The KLIWAS research programme makes a major contribution to the objective discussion of the impacts of climate change on the waterborne sector and thus also a contribution towards reducing the agitation damage described by the sociologist Niklas Luhmann:

> *“Our modern society has to live with the possibility of disasters on the horizon, and it has to live quite normally and not get agitated, otherwise the possible disasters will not disappear but will be augmented by avoidable agitation damage”.*

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Climate and Climate Impact Research in Germany – Where Do We Stand Today?

Paul Becker (DWD)

1 Introduction

The ongoing climate change is one of the greatest challenges facing humanity.

If the calculations of the climate models are correct, serious consequences are to be expected within the foreseeable future also for Germany. Against this background, it is imperative to closely examine and evaluate the current state of play of climate and climate impact research in Germany.

2 Observation data

Reference data sets based on measured data are indispensable for estimating uncertainties in the climate model runs and for hydrological modelling. These data form the basis for the evaluation of changes in climate. The quality of such data is greatly dependent on the measured parameter and its spatial representation.

The mean annual temperature for Germany for example, which has been measured since 1901, shows that since 1988 every year – with the exception of 1996 and 2010 – was above the long-term mean value, i.e. too warm.

The recent changes in precipitation over the period from 1951 to 2006 show different trends for the seasons. While the mean precipitation in the winter months increased significantly, there was a slight decrease in the summer months. The winter trends are strongest in Northwestern Germany with an increase of up to 32%. The other regions experienced moderate increases of 8 to 20%. In the summer, the picture is not so clear. Negative trends of minor significance can frequently be observed. In Eastern Germany, precipitation decreased by an average of 12%. The number of dry days in particular in the summer months increased by 5 to 20%. The number of dry days in the winter months decreased slightly (up to 10% in Southern Germany).

By contrast, if we look at the wind speed, there was a slight decrease at the location German Bight. Wind data, however, only have a small spatial representation and are usually only applicable to the immediate surroundings of the measurement location. This is the reason why it is impossible to generalize this statement for the whole of Germany.

Measurements also indicate a rise of the temperatures at the surface of the sea. Analyses of the frequency distributions of the temperatures made by the light vessel "Deutsche Bucht" show that low air temperatures of up to about 5 °C have become clearly rarer in the last 20 years, and that high temperatures from around 17 °C upward have become more frequent.

As far as the changes in extreme events are concerned, it should be noted that the number of hot days (days with a maximum diurnal air temperature of more than 30 °C) has increased throughout Germany. Particularly strong increases have been observed in Eastern Germany with currently on average approx. 12 days per year and in the Rhine-Main area with currently on average approx. 18 days per year. The number of ice days (days with a maximum day temperature below 0 °C), however, has not changed significantly. The number of dry days (days with less than 1 mm of precipitation) has risen markedly especially in summer in Eastern Germany. Today, in comparison with the decade from 1955–1964, there are approx. ten days more per year without significant precipitation in this region. Eastern Germany is also hit hardest by winter dry periods; the changes are, however, not so dramatic.

The probability of heavy precipitation (more than 30 mm per day) has also increased over the last 50 years. In this context, the increased occurrence of such events in winter is particularly striking.

Precisely because observation data are of particular importance for the evaluation of projected changes in climate, it is important to further expand this data basis. Historic information sources are currently digitised in order to make these data usable for validation purposes.

Satellite and radar data are also used more and more for the validation of climate models. The great advantage of these types of data is that they can be recorded in fine spatial resolution and thus allow for a very good three-dimensional acquisition of short-lived local events such as intensive convective precipitation. As a result, these data can be used as a reference for evaluating the quality of climate model simulations with regard to such events.

It should be noted that in principle the data basis for climate monitoring in Central Europe is good. Problems arise in some cases with regard to parameters with a high spatial variability, for instance short-term heavy precipitation. Remote sensing, such as satellite and radar data, is increasingly supplementing in-situ observation. Examples include global radiation from satellite data and precipitation from radar data. In the case of greater availability, it will increasingly be possible to use these types of data for the validation of climate models.

3 Climate projections

To assess future climate change, the so-called "ensemble approach" is used more and more. This approach involves a model suite of several regional climate models which are driven with several global climate models.

For each emission scenario, global climate models calculate the climate for the whole earth. Regional climate models refine the calculation results for individual regions. An achievement resulting from the intensive efforts made in the area of climate research in recent years is the development of numerous new and different regional climate projection runs. The variety of climate projections allows the climate and climate impact research to deal with the ever present uncertainties and ranges in a scientifically appropriate manner.

The Deutscher Wetterdienst is currently using a model ensemble consisting of 8 driving global climate models and 11 regional climate models currently utilizing altogether 19 model combinations for the assessment of the future climate.

For instance, 15 % of these model combinations project for the period from 2071 to 2100 a change in temperature of less than +2 °C in Germany; 85 % calculate a temperature increase of more than 2 °C.

85 % of the analyzed model combinations also project for the period from 2071 to 2100 an increase in winter precipitation of up to 15 %, whereas a decrease of summer precipitation is projected to decrease by up to 20 %.

With a view to the number of hot days (maximum temperature of at least 30 °C), a considerable increase compared with the control period from 1971 to 2000 is to be expected for the period from 2071 to 2100 in particular in Southwestern Germany.

According to the latest results, at the end of the century the temperature at the surface of the North Sea will be approx. 2.5 °C, of the Baltic Sea even approx. 3 °C, higher than temperatures in the period from 1970 to 1999.

Heavy precipitation events are expected to significantly increase in frequency especially in Northern Germany. With regard to the number of winter storms, a moderate increase throughout Germany by the end of the 21st century is to be expected.

3.1 Research needs

Scientific and technological progress constantly offers new opportunities for improved operational consultancy services, such as new satellite data, seasonal forecasting, climate projections, WebMapping Services, high-resolution gridded datasets etc.

There is a steadily increasing need for reliable climate development information covering periods of several years up to even decades because planning horizons particularly in industry but also in politics and society usually cover periods of around 10 years. This information is a major prerequisite for improving the ability of industry and society to adapt to the future climate. Within the framework of the funding measure "Medium-term Climate Predictions" (Mittelfristige Klimaprognosen, MiKlip) a model system is to be developed to gain reliable information on climate development, expected changes in climate and its extreme weather conditions for said time scales. The Deutscher Wetterdienst plays an essential role in this research project.

Moreover, the existing suite of regional climate models has been validated by means of the new IPCC- (Intergovernmental Panel on Climate Change) RCP scenarios. Unlike SRES Scenarios, these scenarios have not been developed by the IPCC but by organizations in the scientific community. In an essential first step, so-called Representative Concentration Pathways (RCPs) with energy-economy-climate-land use-models (so-called Integrated Assessment Models) were designed.

Based on these RCPs and with the help of climate models, new projections of possible changes in climate in the 21st century and beyond are now being calculated. The results from the global climate models will then be used to drive regional climate models; thus, substantial adjustments and analyses will have to be made also in this field.

To sum up: There now is an extensive range of models for long-term climate change on a global and regional scale. What is missing, however, is a model system for forecasting expected changes in climate and its extreme weather conditions on a time scale of up to 10 years. It is the objective of the funding programme "Medium-term Climate Predictions (MiKlip)" to close this gap.

Climate simulation is also progressing further. The consideration of changes in human anthropogenic land use in climate projections as well as the dynamic interaction between vegetation and atmosphere will constitute an important supplement to climate projections.

Nevertheless, there will always be uncertainties in the determination of future climate. The uncertainties in climate projections result from uncertainties as to future emissions, model uncertainty and uncertainties due to the natural variability of climate.

Model uncertainties can be estimated by using various models and different model physics.

4 Adaptation to climate change

The German Strategy for Adaptation to Climate Change (DAS) adopted by the Federal Cabinet on 17 December 2008 forms the basis for all measures for adaptation to climate change in Germany. This Strategy – and its first update, the Adaptation Action Plan adopted in August 2011 – constitutes an integral approach to the evaluation of risks and requirements for action. DAS involves a range of sectors including water management and flood protection but also agriculture, energy, forestry, fisheries as well as spatial development, building, transport infrastructure and health care interests. According to a study conducted by the DWD for the city of Frankfurt am Main[1], the number of summer days (days with a maximum day temperature of 25 °C or above), for example, is likely to increase by 25–60 days per year by the end of the century. It is obvious that such developments must entail drastic changes in municipal development and infrastructure.

An example for an area that has already largely been adapted to the expected climate change is the heat warning system of the DWD which extends down to the district level. The number of heat-related deaths during the record summer 2003 in Germany is estimated at more than 7000. According to findings of the IPCC, an increase in the probability of similarly devastating events is to be expected in the future; thus, with the heat warning system civil protection has been given a platform commensurate with its importance.

In summary, it can be said that the climate services provided by the DWD meet the requirements. In particular the German Climate Atlas (www.dwd.de/klimaatlas) provides the user with a wealth of information on past, current and future climatic conditions in Germany.

1 Impact model MUKLIMO_3 (micro-scale urban climate model) of the DWD, driven with an ensemble consisting of 3 regional climate projections based on SRES Scenario A1B

KLIWAS – National and International Scientific Relevance Introduction

Franz Nestmann (KIT) & Andreas Kron (KIT)

The collaborative research programme of the Federal Ministry of Transport, Building and Urban Development KLIWAS: "Impacts of Climate Change on Waterways and Navigation in Germany" has been launched to prepare reliable forecasts about the impacts of climate change on the hydrological regime and thus, ultimately, about the upgrade and maintenance of waterways necessary in the future. The specific problem in this context is that, due to the vast variety of parameters for different influences, no unambiguous forecasts pointing in only one direction can be made. The objective of KLIWAS is to be able to quantitatively identify the spectrum of derivable consequences of climate change as a decision-making basis for the future development and/or maintenance and the use of waterways with a view to waterways engineering taking into account the fields climate and environment, hydrology, watercourse hydraulics, current-related sediment transport, ecological impact, etc.

Within the framework of KLIWAS, from the beginning great importance was attached to a streamlined structure and organisation in order to give all partners involved the opportunity to exchange and discuss their interim results and resulting questions at specified intervals. In order to provide the ongoing studies as well as workshops and status conferences with scientifically sound assistance, an international Scientific Advisory Board has been constituted the members of which are assigned as advisers to the individual component projects in accordance with their area of expertise. The Scientific Advisory Board has been supporting the KLIWAS research project from the start with great commitment and interest as the scientific issues raised within this framework are of great importance not only to waterways and shipping but also to other areas of our habitat and to environment interests. In recent years it has become apparent that the support provided by the Board is of great value for the success of the overall project. Thus, on the one hand, the workflow within the collaborative project is continually supported by constructive advice; on the other hand, the Scientific Advisory Board can make the special scientific and future technological as well as economic importance of this collaborative project more visible to the outside. In this context, it should be expressed that the members of the Board are only too willing to assist with this scientific work.

Current-related impacts on waterways engineering

Within the field of waterways engineering, just like in the entire water management, a profound change has taken place in the last few decades due to the finding that scientific interactions in the individual fields cannot be seen in isolation but must always be considered in connection with all other neighbouring technical disciplines. Changes in watercourses, be they through direct anthropogenic interventions in the geometry or through changes in discharge dynamics noted in the last few decades, strongly influence the continuous change of the overall system. Against this background, hydraulic engineering has changed its approach which focused on isolated individual investigations, e.g. of given watercourse sections, to a more holistic one.

Today, within the framework of applicable statutory provisions, interventions in hydrological networks have to be substantiated by a comprehensive analysis of parameters taking into account geometry, kinetics, dynamics, sediment transport and ecology and water quality and assessed for their effects on the stability of the overall system. The available measurement network for the different relevant parameters provides an important basis for this. Due to the decade-long work of the Federal Waterways and Shipping Administration as well as its higher federal authorities, in particular the field of waterways engineering can draw on a comprehensive, systematically collected wealth of data as well as extraordinarily wide scientific experience in managing these data. For many years now, the analysis and design of hydraulic engineering structures has not solely taken into account current but also the interaction between current and the sediments at the watercourse bottom. The majority of these physically complex processes can now be quantified by experimental tests and numerical flow analyses; from this it is also possible to make long-term predictions as to their change. Nevertheless, there are still a lot of unsolved questions which necessitate further scientific research, among others, in the field. After all, cost-effective and safe shipping is only possible based on the knowledge of watercourse and sediment dynamics as well as on predictions about changes. The processes mentioned here are of great importance in nature and technology and controlling them is essential also for safeguarding and maintaining our habitat. This is the reason why micro grain agglomerate (peloids and sludge) flow and transport processes should be set as a new scientific research priority. A sustainable use of hydraulic engineering structures (control structures, water catchments, flood retention basins, etc.), economic efficiency and operating safety require a scientific understanding and practice-oriented management of the sedimentation, erosion and transport processes of such particles in the water.

There are, however, further demands from the ecology and environment field which are to be made within the framework of the future use of navigable waterways the majority of which ultimately form part of natural watercourse systems. Since sediments and plants have become an indispensable part in the investigation of flow phenomena in the environment, it is only logical to now also include aquatic fauna in a scientifically sound way. After all, it is the animals which, through their mobility, populate the earth's water bodies and use them as habitat. This mobility is dramatically limited by hydraulic engineering structures. For this reason, engineering structures indented to ensure ecological continuity need not only be adapted to the present current and sediment transport dynamics, but must first and foremost accommodate migration patterns of fish. Based on the new scientific field of ethohydraulics, the development of fish passable structures taking into consideration the current-related behaviour of fish has unique characteristics. By means of targeted ethohydraulic studies, higher authorities of the BMVBS in collaboration with universities have recently achieved major successes as regards the design, planning and dimensioning of new fish pass structures (an example to be mentioned here is the recently opened fish pass in Geesthacht at the Elbe).

Water and energy resources in the light of climate change

As a matter of principle, the use of water resources is also strongly linked with energy resource requirements. In the end, the constantly increasing energy consumption worldwide and the water resource requirement are always directly related to climatic changes. The water and energy resources are used in accordance with the requirements of society. This is the reason why the entire water management within the hydrosphere of our planet is heavily dependent on changes in climate, society and energy, or is in direct interaction with these changes.

Given the resources already consumed and the consequences resulting from this consumption within our hydrosphere, as regards the future energy demand it must be stated that in the future the stability of our entire habitat will increasingly depend on meeting the overall energy demand in an environmentally sound way. If meeting this energy demand will continue to be linked to a continuous increase in CO_2-emissions, this will trigger a chain reaction via the dependent worldwide temperature increase and the resulting changes in the hydrological regime, which can already be quantified today, and retroactively affect all technologies which draw on the existing hydrological regime for their operation. Thus, the “design case climate change” is being taken account of in hydrology and hydraulics already today, e.g. in the determination of climate change factors. For this purpose, extreme value analyses of the results of regional climate models are used to establish factors by which the peak discharge values of the relevant region need to be increased in order to be able to also model future events. Building on this, it is possible to identify the impacts on local flood parameters (water levels, flow velocities etc.) in flood models. However, since on the one hand all analysis methods are constantly evolving and on the other hand the parameter diversity will continue to increase due to new interdisciplinary requirements (such as the ones mentioned above resulting from environment and climate research) it is to be expected that the connections will become more complex and ultimately also that complex predictions will become more uncertain.

Examples of climate-induced follow-on measures in Vietnam

Climate change and its consequences are not only a regional but a global issue. This is the reason why it should be taken account of within the implementation of the collaborative research programme KLIWAS that future findings from and results of this programme may be of importance also to the management of water systems elsewhere. Any scientific finding made in these fields could thus in the future be used as a basis for international cooperation, as the example of the master plan on flood protection of Ho Chi Min City in southern Vietnam illustrates. The largest city in Vietnam with more than 7 million citizens is located near the coast and thus highly exposed to the influence of the sea level which is predicted to rise by 1.5 metres or more this century. If this prediction proves to be correct, in the future large areas of Ho Chi Minh City will be partly under water and even more exposed to the influence of storm surges. Therefore, a belt of surge barriers consisting of 12 structures interconnected by dikes is currently being planned. The plan also provides for a barrier allowing the passage of ships. This is the reason why the design of the Ems Barrier is used as a basis for planning. Eventually, the Tu Bo barrier is to connect Ho Chi Minh City with the Mekong Delta to the south-west.

The planned shipping route through the Mekong Delta intersects the distributaries of the Mekong River at right angles and is to establish a connection to two ports in the Mekong Delta. Because of the required deep foundation level of well over 80 meters due to the peloid-like subsoil, there is great uncertainty as to the design and dimensioning of this structure. Vietnamese and German experts are already working together to solve the associated issues by way of a feasibility study.

In this context, however, reference should also be made to another interaction which does not result from the climate-induced rise of the sea level but is human-induced by the construction of a cascade of weirs in the Mekong River. Numerous weirs are currently being planned or already under construction in the upper and middle reaches of the Mekong River. Every one of these weirs is designed in such a way that the backwater of the structure extends into the tailwater of the next weir upstream. The weirs are constructed for the purpose of generating energy, using the water in agriculture and industry as well as for ensuring water supply. The derivable future change in the discharge regime of the Mekong River with regard to changes in discharge hydrographs as well as sediment transport will dramatically impact on the entire Mekong Delta. For example, the discharge in the lower and middle reaches of the Mekong River will be reduced due to the water abstraction, and flood events will undoubtedly be exacerbated as the discharge will then be artificially regulated by means of the control structures. What is more, the restriction of sediment transport will, among others, reduce the amount of sediment deposited in the Mekong Delta and thus accelerate erosion processes in the entire area. It can, therefore, also be concluded that if the mean sea level continues to increase, large areas of the Mekong Delta will disappear under the surface of the water. In all this, it must be borne in mind that the Mekong Delta is the main rice-growing area in Vietnam and the recession of the delta might also mean that Vietnam loses an essential means of existence.

This example, and many more, shows how important basic research findings made in Germany in the field of waterways engineering and water management are, or can be, for cooperation and support at international level.

Current Cross-Connections

The Dutch Delta in the 21st Century

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Abstract

A recent Dutch State Committee (also known as the 2nd Delta Committee) delivered far-reaching recommendations on how to maintain the Netherlands flood proof over the next century and even longer in the light of possible climate change leading to accelerated sea level rise and increasing river discharges. The recommendations are presented and discussed in this contribution, indicating the triggers provided by national and international debates. The Committee's recommendations are based on the necessity to upgrade the safety standards in the light of economic growth and group casualty risk. The committee underpinned the basic premise introduced by the 1st Delta Committee (1953) that a risk approach is at the basis. The most important conclusion is that the protection of The Netherlands, with two thirds of its economic value and half of its population positioned below sea level, is feasible, both technically and economically. Such an approach could provide useful elements for other low lying areas.

1 Introduction

The Netherlands is a densely populated country with a prosperous, open economy situated largely in coastal lowlands. The Dutch North Sea coast is about 350 km long. Most of the population lives directly behind the coast, in the low-lying areas of the Netherlands below sea level. This region is the centre of the nation's economy. Nearly 9 million people live in this part of the Netherlands, protected by dikes and dunes along the coast, the main rivers and the lakes, while roughly 65 % of GNP, around 350 billion Euros per annum, is generated here. The major harbours and airports on or near the North Sea are vital nodes in the international transport network as well as important locations for the goods and services industries. Estimates of potential present and estimated future economic damage due to flooding in the low-lying regions are reviewed in Box 1.

The Netherlands has a long and varied history of coastal and river flood management. The anticipation of accelerated climate change during the twenty-first century has renewed the demand for sustainable solutions to coastal vulnerability. In September 2008, a State Committee (DELTACOMMITTEE 2008), installed by the government in September 2007, delivered a number of recommendations on making the Netherlands flood proof

Figure 1: Safety standards as per current law (1995, Law on Water Defences), Note: these standards refer to a 90 % probability that the dike rings should be able to withstand a 1 in x probability of the design water level (see Box 1 for more information)

Box 1: Potential present and estimated future economic damage due to flooding

Central Bureau for Statistics Netherlands estimates the national wealth as five times the national income, without taking account of ecological, landscape and cultural values (Van Tongeren & Van de Veen 1997). Based on this definition, the national wealth was about 2,750 billion Euros in 2007. Since an estimated 65 % of this wealth lies in flood-prone areas, the total wealth that is potentially under threat due to flooding is of the order of 1,800 billion Euros. The actual, or real economic damage due to flooding in case a (part of) a flood protection system would fail has been estimated between 10 and 50 billion Euros for each individual area protected by dikes; these areas are referred to as dike rings. There are 53 dike rings in the Netherlands with protection levels varying between a 90 % probability of resisting the design water level of 1 in 10,000 to 1 in 1,250 per year (see Figure 1), implying that the flooding probability varies between 1 in 100,000 to 1 in 12,500 per year. With the identification of other failure mechanisms than wave overtopping and/or overflow, notably piping (cf. New Orleans), there now exists a strong debate on how realistic these flooding probability figures actually are. It is for this reason that the Deltacommittee (2008) suggests to interpret the design water level probabilities as flooding probabilities for the time being. This interpretation is motivated by the fact that, in practice, based on recent insights of flooding scenarios (Jonkman 2007; 2008), it is most unlikely that the (major) diked areas will be inundated completely. The location where and the physical circumstances under which a dike is breached will make a marked difference in resultant economic damage. Also, the damage caused by a flood depends on the size of the area inundated, the water depth in that area, and the duration of the episode. Aerts et al. (2008) estimated the economic damage from flooding through all dike rings as approximately 190 billion Euros, based on differentiation according to water depth per diked area. This concerns both direct and indirect damage. The estimated future potential damage would increase to 400 to 800 billion Euros in 2040 and 3,700 billion Euros in 2100 in the absence of any measures, given a sea level rise of 24 to 60 cm in 2040 and 150 cm in 2100. The factors that govern calculations of estimated future potential damage are economic growth combined with indirect damage. Prior to the Hurricane Katrina disaster, potential damage in New Orleans was estimated at 16.8 billion US$ or 12.3 billion Euros. After the disaster it appeared that just the direct damage to dwellings, government buildings and public infrastructure was 27 billion US$ or 19.7 billion Euros (IPET, 2008), illustrating that it is essential to update economic growth and indirect damage figures regularly.

for the next century. Besides the issue of flooding also low waterriver levels and fresh water availability were addressed. This contribution presents some of the findings and discusses these. Before doing so, we highlight the paradigm shift which is necessary to implement far-reaching recommendations on flood proofing in the light of possibly accelerated climate change in the modern reflective society.

2 Paradigm shift

The paradigm shift in the approach of water and coastal management which is observable during the last decades represents a major challenge for the coming century. Where in the past the challenge was formulated as to “fight” the forces of nature, today’s approach recognises the many issues other than protection against flooding and especially the multiple ecological forces that have to be accommodated and can help the processes of protection. While this issue has received attention in the western world since about two decades, it is increasingly also being recognized by the non-western world, notably the growth countries. This implies that water and coastal management have become interdisciplinary as well as transdisciplinary (Waterman 2008).

3 The State Committee on sustainable development of the Dutch coastal region

The State Committee (also known as the 2nd Delta Committee, after the 1st Delta Committee established after the 1953 flooding or Committee Veerman, after the chairman of the Committee, former Minister Veerman) delivered far-reaching recommendations (see Box 2) on how to maintain the Netherlands flood proof over the next century or even longer in the light of possible climate change leading to accelerated sea level rise and increasing river discharges. The committee was not established in response to a flood disaster in contrast to all earlier State Committees which were only established after severe floods hit the country in 1916 and 1953. Without doubt there were triggers such as the debate in the Netherlands on the delay in bringing safety up to the standards as laid down in the Water Defence Law (1995), the flooding of New Orleans (2005) and the debate on climate change. The Committee's work demonstrates the importance of a wide ranging, long term preventive approach. The Committee's recommendations are based on the necessity to upgrade the safety standards in the light of economic growth and group casualty risk meaning that the country has "more to lose". The committee underpinned the basic premise introduced by the 1st Delta Committee (1953) that a risk approach is at the basis. The most important conclusion is that the protection of The Netherlands, with two thirds of its economic value and half of its population positioned below sea level, is feasible, both technically and economically, if planned in a long term and flexible manner. Such an approach could provide useful elements for other low lying areas.

Risk approach

The mega structures such as storm surge barriers introduced by the 1st Delta Committee were innovative and impressive, but what may prove to be the most visionary aspect of the Delta Works is the statistical approach that guided the designs. How high should one build the levees? How strong should a surge barrier be? The Dutch decided to base their answers to these questions not merely on the fact that storms are destructive and the Netherlands low, but also on quantitative economics. With the help of renowned Dutch mathematician David van Dantzig (Van Dantzig 1956), the 1953 task force calculated safety levels using an equation that is now widely used by most engineers:

risk = (probability of failure) × (projected cost of damage)

This kind of risk analysis is common today in fields like nuclear power, aerospace, and chemical manufacturing. But back in the 1950s, accounting for the projected cost of damage when developing flood protection was novel. The power of this simple formula is that it produces economically rational public-safety decisions: Less value, less protection (costs of human casualties are not taken into account directly so far). Dutch law now requires this principle to be used to determine the strength of flood defences throughout the country. Since the dike ring protecting the Province of South-Holland, an economically vibrant area, against flooding due to extreme storm surge levels and/or extreme river discharges, a safety level of 1 : 10,000 is called for. More rural parts of the country require safety levels of just 1 : 1,250 or lower (see Figure 1). The underlying principle that leads to the variable levels of protection is Van Dantzig's (1956) economic optimization criterion: strive towards minimal societal costs summing the protection investment and the potential estimated damage.

The corollary is that, although not all Dutch citizens may be aware of it, their government has accepted – even legislated – unequal protection, or what engineers euphemistically call "differentiation", based on the fact that all places cannot be protected up to the same stand-

Box 2: A total of 12 concrete recommendations formulated (3 generic and 9 regional, see Figures 2 and 3; source: DELTACOMMITTEE 2008)

Recommendation 1: The standards of flood protection

Until 2050 The present standards of flood protection of all diked areas must be improved by a factor of 10. To that end, the new standards must be set as soon as possible (around 2013). In some areas where even better protection is needed, a so called *Delta Dike* concept is promising (these dikes are either so high or so wide and massive that there is virtually zero probability that the dike will suddenly and uncontrollably fail. With regard to specific or local conditions, this will require a tailor made approach. All measures to increase the flood protection standards must be implemented before 2050.

Post 2050 The flood protection standards must be updated regularly.

Recommendation 2: New urban development plans

The decision of whether to build in low lying flood prone locations must be based on a cost-benefit analysis. This must reveal present and future costs for all parties. Costs resulting from local decisions must not be passed on to another administrative level, nor to society as a whole. They must be borne by those who benefit from these plans.

Recommendation 3: Areas outside the dikes

New development in unprotected areas lying outside the dikes must not impede the river's discharge capacity nor the future levels of water in the lakes. Residents/users themselves are responsible for such measures as may be needed to avoid adverse consequences. Government plays a facilitating role in such areas as public information, setting building standards and flood warnings.

Recommendation 4: North Sea coast

Untill 2050 Build with nature. Off the coasts of Zeeland, Holland and the Wadden Sea Islands, flood protection will be maintained by beach nourishments (see Figure 4), possibly with relocation of the tidal channels. Beach nourishments must be done in such a way that the coast can expand seaward in the next century (effectively this implies reclaiming land in the North Sea). This will provide great added value to society. Sand extraction sites in the North Sea must be reserved in the short term. The ecological, economic and energy requirements needed to nourish such large volumes must be investigated.

Post 2050 Beach nourishments continue – more or less sand required, depending on sea level rise.

Recommendation 5: Wadden Sea area

The beach nourishments along the North Sea coast may contribute to the adaptation of the Wadden Sea area to sea level rise. The existence of the Wadden Sea area as we know it at present is by no means assured, however, and depends entirely on the actual rate of sea level rise coming 50 to 100 years. Developments will have to be monitored and analysed in an international context.

The protection of the island polders and the North Holland coast must remain assured.

Recommendation 6: South-western Delta: Eastern Scheldt

Until 2050 The Eastern Scheldt storm-surge barrier keeps its function. The disadvantage of the barrier is its restriction of tidal movement and, as a result, the loss of the intertidal zone. This is to be countered by additional sand nourishment from outside (as from the Outer Delta).

Post 2050 The life-span of the Eastern Scheldt storm-surge barrier will be extended by technical interventions. This can be done up to a sea level rise of approximately 1 m (2075 at the earliest). If the Eastern Scheldt storm-surge barrier is no longer adequate, then a solution will be sought that in large restores the tidal dynamics with its natural estuarian regime, while maintaining safety against flooding.

Recommendation 7: South-western Delta: Western Scheldt

This must remain an open tidal system to maintain the valuable estuary and the navigation to Antwerp. Safety against flooding must be maintained by enforcement of the dikes.

Recommendation 8: South-western Delta: Krammer–Volkerak Zoommeer

Until 2050 Make sure that the Krammer-Volkerak Zoommeer, together with the Grevelingen and possibly also the Eastern Scheldt can provide temporary storage of excess water from the Rhine and Meuse when discharge to the sea is blocked by closed storm surge barriers.

A salinity gradient (a natural transition between fresh and salt water) in this area is a satisfactory solution to the water quality problem and can offer new ecological opportunities. In this case an alternative fresh water supply system must be developed.

Recommendation 9: The major rivers area

Until 2050 The programmes *Room for the River* (see Figure 5) and *Maaswerken* (Meuse Works) must be implemented without further delays. Subject to cost effectiveness, measures must be taken already now to accommodate discharges of 18,000 m^3/s from the Rhine and 4,600 m^3/s from the Meuse. In this context it will be necessary to conduct negotiations with neighbouring countries under the *European Directive on the assessment and management of flood risks* in order to harmonise the measures. Furthermore, room must be reserved and, if necessary, land purchased so that the river system will be able to discharge safely the 18,000 m^3/s of Rhine water and 4,600 m^3/s of Meuse water.

2050–2100 Completion of measures to accommodate the Rhine to discharge 18,000 m^3/s and the Meuse 4,600 m^3/s.

Recommendation 10: Rijnmond (mouth of the river Rhine)

Until 2050 For the Rijnmond an open system which can be closed in emergencies offers good prospects for combining safety against flooding, fresh water supply, urban development and nature development in this region. The extreme discharges of the Rhine and Meuse will then have to be re-routed via the south-western delta (see Figure 6).

The fresh water for the Western Netherlands will have to be supplied from the IJsselmeer. The necessary infrastructure will have to be built. Room must be created for local storage in deep polders. Further research into the ‘closable-open’ Rijnmond system should be initiated soon.

Recommendation 11: IJsselmeer area

The level of the lake IJsselmeer will be raised by a maximum of 1.5 m. This will allow gravity-driven drainage from Ijselmeer into the Wadden Sea beyond 2100. The level of the Markermeer lake will not be raised. The IJsselmeer retains its strategic function as fresh water reservoir for the Northern Netherlands, North Holland and, in view of the progression of the salt tongue in the Nieuwe Waterweg, for the Western Netherlands.

Until 2050 Implement measures to achieve elevated water level, which can be done gradually. The aim must be to achieve the largest possible fresh water reservoir around 2050. The measures needed to adapt the lower reaches of the river IJssel and the

Zwarte Water to a 1.5 m higher water level in the IJsselmeer must be investigated.

Post 2050 Depending on the phased approach adopted, follow up measures may be needed to actually implement a maximum water level increase of 1.5 m.

Recommendation 12: Political-administrative, legal, financial

1. The political-administrative organisation of our water safety should be strengthened by:

- Providing cohesive national direction and regional responsibility for execution (ministerial steering committee chaired by PM, political responsibility lying with Minister of Transport, Public Works and Water Management; the Delta director for cohesion and progress; regional administrators for interpretation and implementation of the (individual) regional assignments).
- Institute a permanent Parliamentary Committee on the theme.

2. Guarantee funding by:

- creating a Delta Fund, managed by the Minister of Finance;
- supplying the Delta Fund with a combination of loans and transfer of (part of) the natural gas benefits;
- making national funding available and drafting rules for withdrawals from the fund.

3. A *Delta Act* will anchor the political-administrative organisation and funding within the present political system and the current legal framework. This must in any case include the Delta Fund and its supply; the Director's tasks and authority; the provision that a *Delta Programme* shall be set up; regulations for strategic land acquisition; and compensation for damages or the gradual loss of benefits due to the implementation of measures under the *Delta Programme*.

ard and individual cost must be balanced against collective cost.

The US certainly has variable protection levels throughout the country, but there is a difference between de facto disparity and an explicit government policy of inequality. Imagine if the US Congress or the Army Corps of Engineers were to recommend protecting the French Quarter and downtown New Orleans at the 10,000-year level while giving less economically productive areas such as St. Bernard Parish only a 100-year level of protection. Applying the Dutch model of risk-based design would be a political nonstarter, if not unconstitutional, and the efforts of the Army Corps of Engineers would in no time be halted by an army of lawyers.

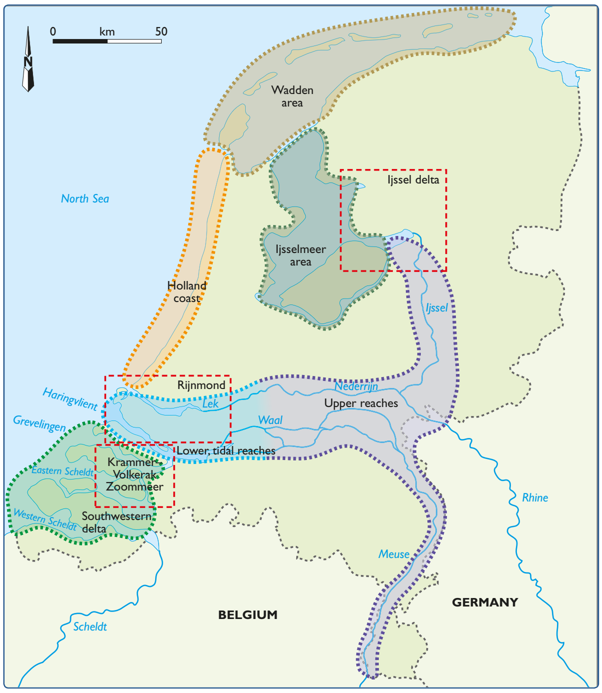

Figure 2: Challenges in the various regions

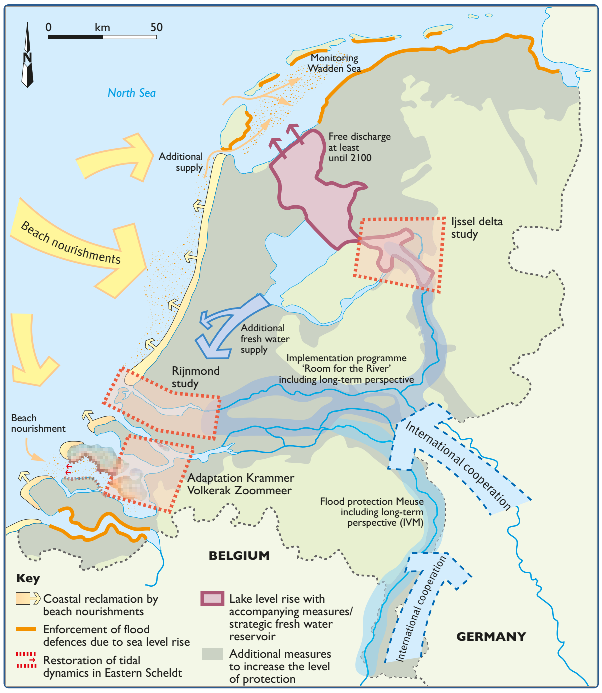

Figure 3: An impression of the Deltacommittee recommendations

Updating the standards

The standards for safety from flooding based on the risk approach however need rethinking because both individual and group risk for casualties (deaths) due to flooding is much higher than due to other external risks (Jonkman 2007; 2008). That is why the 2nd Delta Committee recommends opting for an increase in protection level with a factor 10, which is estimated to be a minimum no regret level to reduce the above-mentioned casualty risk. Concretely this implies that while interpreting present legal risk levels as probabilities of flooding based on a full risk approach (see also Box 1) should vary from 1 in 100,000 to 1 in 12,500 per year.

Climate change

In order to anticipate long-term developments, the Delta Committee has sought to base itself on the most recent scientific findings. The Committee therefore asked a team of renowned national and international climate experts (amongst whom IPCC authors who contributed to the recent Fourth Assessment Report; see Katsman et al. 2011; Kok et al. 2008 and Vellinga et al. 2008) to deliver the best possible estimates of the expected global and regional (i.e. North Atlantic Ocean) sea level rise and rainfall intensity that gives rise to river discharge changes. Their updated climate model results have resulted in a probable range of upper boundaries for the expected climate changes: sea level rise along our coast in the year 2100 could reach as high as 65 to 130 cm relative to 1990, including isostatic movement and subsidence. It is clear that these upper boundaries do not represent the most likely *probable* situation in 2100, as also has been stated by the Royal Netherlands Meteorological Institute. The reason why this figure is nevertheless relevant is that it represents an extreme case against which the committee could then try

Figure 4: Coastal extension near Rotterdam

Figure 5: Room for the river IJssel

to answer the most relevant issue, namely: can the Netherlands be kept flood proof under the most extreme scenario? That is why in the committee's advice the high-end scenarios were considered, so that a convincing and science based positive answer ("yes") could be given.

Costs

- Implementation of the entire package of measures proposed by the Delta Committee – the *Delta Programme* – will cost 1.2–1.6 billion Euros per annum to 2050 and 0.9–1.5 billion Euros per annum in the period 2050–2100.
- The summary does not include the annual sums for maintenance and management in relation to flood protection and the fresh water supply. At present, these add up to approximately 1.2 billion Euros per annum for central government, the water boards and the provinces. The total costs of growing with the climate and ensuring improved protection are 2.4–2.8 billion Euros per annum up to 2050.
- A supplementary 0.1–0.3 billion Euros per annum will be required if the *Delta Programme's* beach nourishment for flood protection is expanded so that a hundred years from now the North Sea coast of Holland and Zeeland is extended seawards by, for instance, 1 km to create new land for recreation, nature and other functions. This brings the costs of the *Delta Programme* for the period 2010–2050 to 1.3–1.9 billion Euros per annum, while for 2050–2100 it is 1.2–1.8 billion Euros per annum. Including management and maintenance, the total costs of growing with the climate and ensuring improved protection add up to 2.5–3.1 billion Euros per annum to 2050.

In absolute terms, this presents a huge monetary investment, but it translates to only about 0.5 % of the current Dutch annual GNP. The cost of integrated water safety for the future of the Netherlands is therefore far from being unbearable.

The central message of the Committee is that the Netherlands can handle even the most extreme estimate of sea level rise and river discharges, that the scientific community estimates possible based upon current knowledge. The recommendations of the Committee are feasible in terms of time, knowledge and economic means. Moreover, the measures will result in more than just safety, i.e. if they are implemented sensibly they will lead to more spatial quality, a more diverse nature and other socio-economic values such as balanced urban and recreation development, agriculture, fresh water supply and even possibly energy generation. And, if sea level rises less fast than expected, the approach allows the flexibility to delay or temper measures and hence to adjust expenditures.

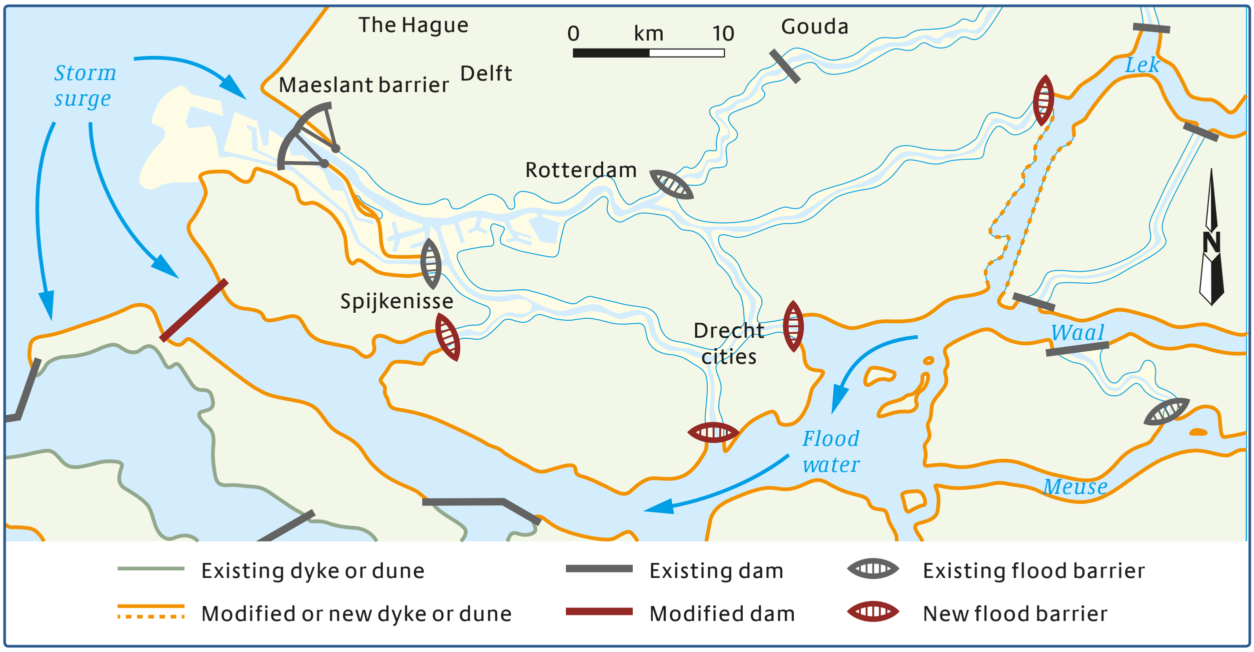

Figure 6: Rijnmond storm surge barriers

4 Discussion and conclusions

The Delta Committee recommendations became a matter of active, often passionate public, political and academic debate. Do these recommendations sufficiently reflect highly uncertain future changes, especially in climate and sea level rise? The Delta Committee introduces a concept of plausible high end sea level rise scenarios, thereby testing the feasibility of maintaining the defence strategy of the 53 dike rings, which turned out positive both in technical and in economic terms. These go hand in hand with no-regret, flexible and adaptive measures: step-wise flood protection adaptation measures which can be undertaken now and which are robust enough to accommodate new to come insights about changing climate. An example of these measures are the beach sand nourishments of the coastal line in order to protect it from rising sea levels. The important point is not to wait, but to start now, creating both a fund and setting up an implementation agency but it can be done – in a slower or faster pace – over many years to come, along with good monitoring of the actual rate of sea level rise, and taking into the account the latest scenarios of sea level rise and river discharge. In this way the uncertainty which is surrounding climate scenarios is not a reason for no action at all.

The case of Netherlands clearly illustrates that even with existing uncertainties about future climate, economically viable and responsible investments into adaptation measures in the water sector and beyond can be made, if these anticipatory interventions are flexible, can be implemented gradually and if they offer prospects for action in the short term in regional planning and development. As a result, the climate issue is gradually moving from being perceived as a threat to become an opportunity. Together with building-with-nature based innovative solutions, technologies and transitions which are quickly emerging along this paradigm, this presents a major opportunity to accelerate transition of our valuable and highly exposed Delta into its more sustainable future.

As David Wolman in the Magazine Wired (Wolman 2008) expressed it: *"Meanwhile, the water keeps coming. The Dutch are taking on the threat of global warming before anyone's feet are wet. They are showing the world that to prepare for sea-level rise and other impacts of climate change, you need, paradoxically, not dominion-over-nature bravado but patience, good data, and – above all – the long view."*

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Looking at Climate Change at the Regional Level – Funding Activities of the Federal Ministry of Education and Research (BMBF)

Katrin Ellwardt (BMBF) & Paul Dostal (DLR)

1 Introduction

Climate change and the man-made environmental changes prompt the Federal Government to take global responsibility for the protection of our environment and to actively participate in shaping the future. In the context of the High-Tech Strategy for 2020 (BMBF 2010), the German Strategy for Adaptation (Bundesregierung 2008) and the Adaptation Action Plan (Bundesregierung 2011), the BMBF is setting funding priorities. Here, the focus is on climate change and its impacts at national and regional level in Central Europe. Among these funding priorities are the two funding measures KLIMZUG (Managing climate change in the regions for the future) and MiKlip (Decadal Predictions). The research programme **KLIWAS** (Impacts of climate change on waterways and navigation – Options to adapt) of the Federal Ministry of Transport, Building and Urban Development (BMVBS) plays a role similar to that of the above-mentioned funding measures. The resulting overlaps, which can generate synergies by way of a closer linking of the contents of these research projects, are outlined in this article.

2 Funding measures of the BMBF in the field of climate change adaptation strategies and climate research since 2008

Social, economic and technical developments lead to changes in climate and environment throughout the world. This results in changes in the living conditions on earth that may cause far-reaching problems – e.g. availability of natural resources such as air, water, food, foundations of life. But the social and economic foundations of life are changing too. Germany's relationship to these changes is that of an affected party, a contributor and a problem-solver. With the High-Tech Strategy for 2020, the German Strategy for Adaptation and the Adaptation Action Plan, the BMBF fulfils this task, and it has established funding measures specially for this purpose that address research on climate change adaptation strategies and climate change in general. The current research projects are the funding measures KLIMZUG (www.klimzug.de 2008) and MiKlip (www.fona-miklip.de 2011). These funding measures have a strong regional focus and deliver results that are of great interest to similar research projects. This is especially true for the research programme KLIWAS (KLIWAS 2009a) funded by the BMVBS. This article presents the BMBF funding measures and its overlaps with KLIWAS.

3 The KLIMZUG funding measure

KLIMZUG – Managing climate change in the regions for the future:
The aim is to develop innovative climate change adaptation strategies for seven selected model regions in Germany. The funding period is five years (2008–2014; some projects will start only in 2009). Each of them is based on the concrete local requirements of the individual model region. The expected climate changes are to be taken into account in an adequate and timely manner in regional planning and development processes. Figure 1 lists the seven KLIMZUG joint projects and indicates their locations. The projects that are highly relevant to the KLIWAS programme are described in greater detail below.

KLIMZUG-nordwest2050 – Prospects for climate-adapted innovation processes in the model region Bremen-Oldenburg in North Western Germany:
Nordwest2050 is developing innovative paths to make the North West of Germany more resilient to climate change. On the basis of an analysis to determine the regional vulnerability and innovative potential, innovation processes that are to serve as examples are initiated in the economic sectors vital to the region (food, energy, port/logistics) and transferred to a Roadmap of Change for the entire region with a time horizon until 2050. www.nordwest2050.de

KLIMZUG-RADOST – Regional adaptation strategies for the German Baltic Sea coast:
RADOST addresses the changes and the resulting problems at the coasts and in the sea that are caused by climate change. The research topics include: protection of the coasts, tourism and beach management, water management and agriculture, ports and maritime industry, nature conservation in the context of uses as well as renewable energies. Implementation projects carried out jointly with the partners from the sectors serve to implement examples of adaptation measures and, in addition, show the economic opportunities of innovative answers to climate change. www.klimzug-radost.de

KLIMZUG-NORD – Strategic approaches to climate change adaptation in the Hamburg Metropolitan region:
In this joint project, partners from universities, research institutions, authorities and companies are working on the development of coordinated concepts for action for the minimization of climate change impacts that will be bundled into a master plan for the management of climate change impacts for the time horizon until 2050. The research priorities in the dynamic metropolitan region of Hamburg with its population of over four million are the fields of water management, flood protection, urban planning, agriculture, nature conservation and economy. www.klimzug-nord.de

4 Overlaps between KLIMZUG and KLIWAS

The three KLIMZUG joint projects described above are investigating partial aspects in their research projects that are thematically very similar to research tasks of the KLIWAS programme.

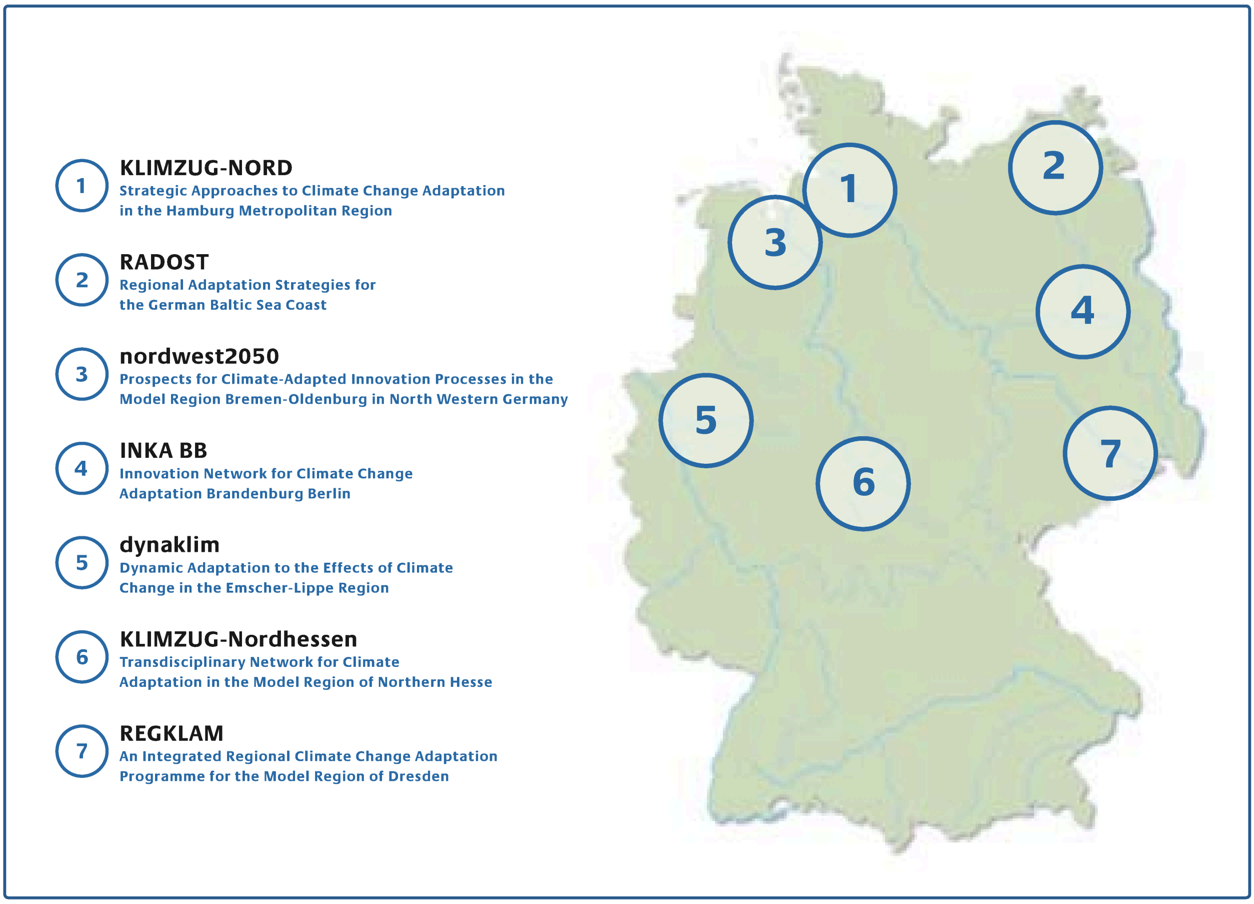

Figure 1: The seven KLIMZUG joint projects and where they are located in Germany

RADOST – KLIWAS research task 5 Water conditions (inland)

As a sub-project, the RADOST joint project is investigating the water quality with a view to agricultural processes. In the implementation project "Reduction of nutrient inputs through retention ponds", nutrient inputs (also referred to as tile drainage runoffs) that originate from agriculture and are introduced into river systems are captured by retention ponds. Thus, the water that is discharged into a river system contains fewer nutrients and is accordingly of better quality.

Research task 5 of the KLIWAS programme has a similar thematic focus. It also carries out monitoring analyses to allow for the tracking of climate change-induced water pollution. Subsequently, suitable adaptation measures are to be derived from these analyses. An exchange of the initial results between the two projects may result in synergies with regard to the preservation of the water quality in the affected river systems.

Nordwest2050 – KLIWAS Project 3.01 Uses of the sea

The purpose of KLIWAS is the assessment of potential climate-induced changes in discharges and water levels in inland waterways. In the project Uses of the sea (3.01) (KLIWAS 2009e), climate model studies are used to determine the marine and atmospheric changes and to investigate their consequences, in particular for shipping. In this regard, the investigations conducted by the KLIMZUG project nordwest2050 can be very useful. Nordwest2050 carries out vulnerability studies to identify the weak spots in specifically selected economic cycles that can occur as a result of climate change. Here, the focus of the investigations is on the port and logistics industries among other sectors. The aim of the investigations is the development of suitable adaptation measures that help mitigate or fully prevent climate change impacts. For instance, the logistics processes in an industrial port can come to a complete stop as a consequence of extreme events (floods but also low water situations as a result of droughts, such as in Autumn 2011 in Germany). The port sector has to be prepared for such situations. The investigations of KLIWAS project 3.01 can provide an excellent addition to the studies of nordwest2050. In the project "Uses of the sea", particular attention is given to extreme sea state events, as these can cause considerable damage in shipping and to offshore structures, but have not until now been included in operational forecasting. The port and logistics sectors can also benefit from these operational forecasts; in the case of extreme events, they can react in a timely manner and implement appropriate adaptation measures.

KLIMZUG-Nord – KLIWAS research task 2 and 3

The use of the coastal regions in Northern Germany will continue to intensify over the next few decades. The proportion of the population in these regions will increase and their economic importance will continue to grow. Along with this growth, the coastal protection requirements will also increase. With changing tidal dynamics in the River Elbe and the increasing silting of port areas, the need for an adapted and sustainable estuary management is now moving into the focus of scientific activities. Particularly taking into account the numerous climate change scenarios with higher water levels and wind speeds, flexible flood protection measures for coastal regions as well as environmentally compatible measures to influence the flow of water that are adapted to the regional development have to be developed (KLIMZUG-Nord, sub-project 1.3). The projects Hydraulic engineering (2.04) and Adaptation options (3.02) of the KLIWAS programme (KLIWAS 2009b and c) focus on similar areas. Together with project 3.02, the project Hydraulic engineering aims to establish a data basis of climate change information that is optimized for waterways, ports and coastal protection. Based on this, methods are to be developed that allow for the testing of adaptation options.

In the development of adaptation options, KLIMZUG-Nord and KLIWAS rely on an improved data basis to allow them to carry out a reliable assessment of the selected adaptation options and to implement the best adaptation measure on that basis.

A focus of the cooperation between KLIMZUG-Nord and KLIWAS could be to contrast the selected adaptation options and to carry out a comparative evaluation on them. Linking these research tasks would generate a major potential for synergies.

Figure 2 provides a clear illustration of the overlaps between KLIMZUG and KLIWAS.

5 The MiKlip funding measure

The need for reliable forecasts as to how the climate will develop over periods ranging from a few years to decades is growing steadily, since planning horizons, particularly in the industry but also in government and society, are usually around 10 years. Such forecasts are an essential prerequisite for improving the industry's and society's ability to adapt to the future climate.

Within the framework of the funding measure "Decadal Predictions" (MIKLIP), a model system is to be created that makes it possible to obtain reliable climate development forecasts, i.e. expected climate changes and extreme weather events, for these time horizons (www.fona-miklip.de).

Module C (regionalization) as an improved data basis for the KLIWAS programme

The innovative approach in MiKlip is the cross-linked modular structure of this research task. The improved data from global climate modelling are passed to Mod-

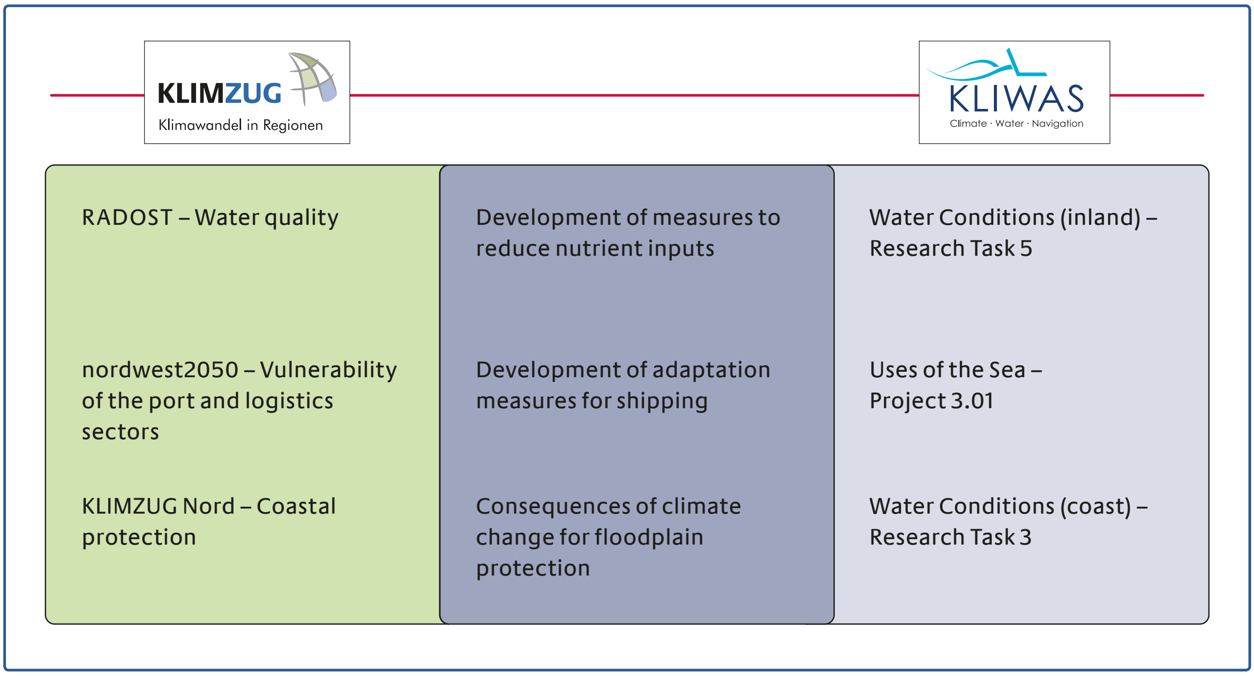

Figure 2: Overlaps between the KLIMZUG and KLIWAS funding measures

ule C (regionalization). In this module, the data from the model runs are scaled down to the regional level. These high-resolution data are made available to interested research groups and research projects. Here, the KLIWAS programme can benefit from the regional decadal climate scenarios from MiKlip. This, in particular, makes it possible to examine river catchment areas and thus also to investigate the impacts of climate change on navigation. The results as to which changes are to be expected within the next 10 to 15 years can thereby be improved and rendered more precise. So far, this has not been possible in this form; thus, it opens up a new perspective on future adaptation measures in the KLIWAS programme.

6 Summary / looking ahead

The changes in climate that are to be expected will present the environment, society and the industry with a number of problems in the future. To address the potential negative impacts, the Federal Government has initiated a number of funding measures that deal intensively with the investigation of suitable adaptation measures. Among these funding measures are the BMBF projects KLIMZUG and MiKlip as well as the BMVBS programme KLIWAS. Part of the research work examines the impacts of climate change in the same regions and with a similar thematic focus. This is particularly true for KLIMZUG and KLIWAS and results in overlaps between these programmes that should be made use of in the future. The intended objectives are improvements and more useful extensions in the individual research tasks.

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Climate Change: How Regions and Cities Can Adapt – Spatial and Urban Development Demonstration Projects (KlimaMORO and StadtKlimaExWoSt)

Gina Siegel (BMVBS) & Fabian Dosch (BBSR)

In 2010, worldwide emissions of carbon dioxide (CO_2) rose more sharply than ever before. This is reason enough to not only reduce greenhouse gas emissions, but also to prepare for the inevitable consequences of climate change. In August 2011, the Federal Cabinet adopted an action plan on the German Strategy for Adaptation to Climate Change. This **action plan** assigns specific activities to the objectives and options for action set out in the adaptation strategy. One important cross-cutting issue is urban and spatial planning. Demonstration projects are designed to support regions and municipalities in adapting to climate change.

1 Climate change and its impacts in city-regions

Climate change is already happening. The proof of this has been around for decades – sharply rising air temperatures, changing climate indicators such as the number of summer days and tropical nights (DWD 2011) and an increasing frequency of extreme precipitation events with higher levels of damage. In addition, 2011 was one of the five warmest years in Germany since 1881, as were 2000 and 2007 in the recent past.

The projections of **future climate trends** and their impacts are fraught with uncertainty, especially at regional level. Nevertheless, there is little doubt that temperatures will rise, the distribution of precipitation and wind will change, droughts and heat waves will occur more frequently, glaciers will melt and flooding will increase. The actual degree of impact, defined by the incidence of climate changes and the predisposition of an area, will vary from one region to another (cf. BMVBS 2011a, 5ff.; **BMVBS** 2011b, Chapter 3). If the regional stakeholders are consulted, it becomes apparent that they perceive a wide spectrum of spatially significant risks, with the focus on flooding, droughts, consequences of heat and extreme events (BMVBS 2011c). Regional demonstration projects (see Chapter 3.1) have analyzed how the degree of impact is calculated in regional practice (BMVBS 2011e)

The impact of climate change is especially felt in **cities**, perhaps more than anywhere else, because of their high density of development, the high level of soil sealing, their higher consumption of energy and water and the concentration of people and material assets. Even now, the climate in cities is different to that in their urban hinterlands. It is characterized by a higher level of heat retention by structures and the subsoil, the formation of urban heat islands with an increased number of very hot days and tropical nights, higher levels of particulate matter and air pollution with lower wind speeds, lower incoming global radiation and a higher number of extreme precipitation events (BMVBS 2011d). The result is a bioclimate with an adverse impact on health. Thus, for instance, the temperatures measured in the centres of large German cities at the end of a cloudless summer night are up to 10 degrees higher than those measured in the urban hinterland. The projected climate change will tend to intensify all the climate parameters that play a part in characterizing the climate of city-regions. The impacts of intensified extreme weather events can be disproportionately more serious than the insidious changes.

2 Spatial adaptation to climate change

Spatial planning plays a major, coordinating role for the protection, safeguarding and sustainable development of settlement, transport and open space structures and of natural resources. This role is set out in the Concepts and Strategies for Spatial Development. Adaptation measures often require coordination above the local level in the context of the region as a whole and individual approaches for climate change impacts that vary from one region to another. The **regional level** is ideally suited for climate change adaptation measures. Here, the mitigation and adaptation measures that are necessary above the local level can be taken and coordinated across sectoral boundaries and for the region as a whole. In this context, the medium to long-term changes in climate, as well as extreme weather events, have to be considered against the background of specific vulnerability (= exposure + sensitivity + capacity for adaptation).

Regional planning contributes to climate change adaptation by means of informal activities, including, in particular, information, advice and facilitation, the development of strategies for objectives and concepts and regional governance. Determinations are not finalized until formal processes and instruments are adopted, for instance priority areas and, at a lower level, reserve and suitable areas in the regional plan, or until the regional impact analysis or strategic environmental assessment is launched.

Spatial adaptation to climate change is a cyclical and flexible process of communication, planning and implementation and has to be supported by numerous players, institutions and sectoral plans. Its purpose is to reduce the sensitivity of natural and human systems to consequences and impacts of unavoidable climate change that have already occurred or that are likely to occur. **Spatial adaptation** presupposes that:

- stakeholders are sensitized, relevant players are motivated and networks in the region are activated;
- the information bases and necessary data are prepared and provided and the impacts for the various action areas are estimated and assessed;
- precautionary measures are developed and implemented;
- the designations in the regional plan or, for instance, in regional development strategies and other plans are framed in such a way that they are adapted to climate change;
- the changed present and future land uses are coordinated and regulated for the land users in a legally binding manner (cf. AdW, 2010).

At local authority level, **urban development** is ideally suited to take precautions, especially against bioclimatic impacts of climate change, and to coordinate and improve sectoral tasks, such as precautionary flood control measures and urban drainage necessitated by climate change. Thus, physical measures taken as part of climate-sensitive urban development, such as the restoration of pervious soil, light-coloured surfaces, green spaces, bodies of water and fresh air corridors within settlement areas ensure a tolerable climate, for instance during heat waves. These **measures** are mostly:

- the spatial control of how settlement areas and infrastructure develop by reducing land take, prohibiting development in flood-prone areas and safeguarding open spaces and greenway linkages that can contribute to climate change mitigation, for instance as cold and fresh air corridors, cold air generation areas;
- the greening of structures and design of open spaces to reduce heat retention in urban environments and the creation of linkages between these spaces;
- extensive storm water infiltration and prohibition of development on runoff possibilities in areas with soil sealing and/or low-emission settlement development.

In practice, however, adaptation is still a relatively new action area. This is due, among other things, to uncertainties in climate change impact assessment, long-term planning periods as well as the fact that there is no concentration of decision-making responsibility in regions and municipalities. However, planning action is of key importance for making regions and cities more resilient to climate change impacts, reducing the level of impacts and establishing targeted climate change mitigation and adaptation capabilities to counter the effects of climate change. This will help to prevent climate change risks, enhance investment certainty and ultimately also improve the quality of life.

Guidelines and legal requirements for climate change adaptation in rural and urban areas

When the **Spatial Planning Act** was amended in 2008, adaptation to climate change was included in the principles of spatial planning (Section 2(2)(6)). This paragraph states that one of the principles of spatial planning is that “the spatial requirements of climate change mitigation shall be taken into account by measures to tackle climate change as well as by measures aimed at climate change adaptation”.

In the spatial planning strategy for avoidance, mitigation and adaptation strategies with regard to the spatial consequences of climate change, adopted by the 36th session of the Standing Conference of Ministers responsible for Spatial Planning meeting in June 2009, the ministers issued a mandate to trial regional strategies in demonstration projects. This approach, with its three action areas in the field of climate change mitigation and seven action areas in the field of climate change adaptation, especially those that address precautionary flood control measures in river basins, coastal protection and regional water shortages, forms an important framework for action by federal states and regions, and was updated in October 2011. The action area entitled “protection against the effects of heat in settlement areas (areas with a bioclimate with an adverse impact on health)” exhibits a close link to climate change adaptation in municipalities. At local authority level, the 116th session of the Standing Conference of Federal State Ministers and Senators responsible for Urban Development, Building and Housing, meeting in April 2008, focused on “climate change mitigation in the building, housing and urban development sectors”, and the German Association of Cities’ Special Commission for Urban Development Planning, meeting in October 2011, focused on the key strategy of “climate-sensitive and energy-efficient urban restructuring”. One of the priorities of the national urban development policy is the “Building the city of tomorrow – climate change mitigation and global responsibility” area of action.

Building planning law opens up a range of urban design possibilities for adapting to climate change, for instance the opportunities provided by the local plan to determine the degree to which land is used for building purposes (Section 1(1) of the Federal Building Code) and the preservation and creation of open spaces and green areas. The "Act to Promote Climate Change Mitigation in Development in Cities and Towns" of 30 July 2011 (**Climate Change Amendment**) has introduced the following new rules and clarifications, especially with regard to adaptation to the consequences of climate change: establishment of the principles of climate change policy (Section 1(5) of the Federal Building Code and climate change clause in Section 1a(5) of the Federal Building Code); specification of the list of determinations in local plans (Section 9(1)(12) and, in particular, (23b) of the Federal Building Code); and the establishment of linkages between the provisions governing urban restructuring and climate change adaptation (Section 171a of the Federal Building Code).

3 Trialling strategies for action in demonstration projects

At municipal and city-region level, the Federal Ministry of Transport, Building and Urban Development is promoting pilot and demonstration projects that involve developing examples of approaches and solutions to climate change adaptation and trialling them in demonstration projects. The lessons learned from these projects will be used to generate examples of good practice, recommendations for action and guidance, which can also inform the evolution of the German Adaptation Strategy. Thus, for instance, climate change is the subject of demonstration projects:

- involving **transnational collaboration** at European level: over the period to 2013, more than 40 projects are addressing or will address climate change adaptation, and the number addressing climate change mitigation is even higher, in the five European INTERREG IV programme areas with German participation (cf. BMVBS 2011a);
- at **regional level:** "Spatial Development Strategies for Climate Change" (KlimaMORO), whose eight model regions are developing approaches to climate change adaptation primarily in city-regions;
- in the field of the "Experimental Housing and Urban Development" programme, addressing "Urban strategies and potentials to combat tackle climate change", with nine model projects at local authority level (StadtKlimaExWoSt), plus eight pilot projects conducted by the housing and real estate industry (ImmoKlima).

The projects are being overseen by the Federal Institute for Research on Building, Urban Affairs and Spatial Development. The "Climate and Environmental Advice" division of the German Meteorological Service, plus external climatologists, support the KlimaMORO and StadtKlimaExWoSt projects by providing advice on climatological issues, participating in conferences and workshops and performing impact modelling and measurements. In addition, the German Meteorological Service is carrying out pilot projects addressing climate change adaptation in major cities of Germany. The aim is to establish a spatial structure that is appropriate and resilient to climate change. The interim findings from KlimaMORO and StadtKlimaExWoSt are **exchanged** with other large-scale climate change impact research projects at Federal Government level, in particular with various component projects of the seven collaborative research schemes within the framework of the Federal Ministry of Education and Research's KLIMZUG (Shaping climate change in the regions in a sustainable way) funding priority.

3.1 The regional demonstration projects (KlimaMORO)

In 2008, a spatial planning study was launched with options for action and possible development paths. This study has demonstrated that a strategy mix is required that combines mitigation and adaptation strategies in a meaningful manner and in close coordination with sectoral policies (BMVBS 2011b).

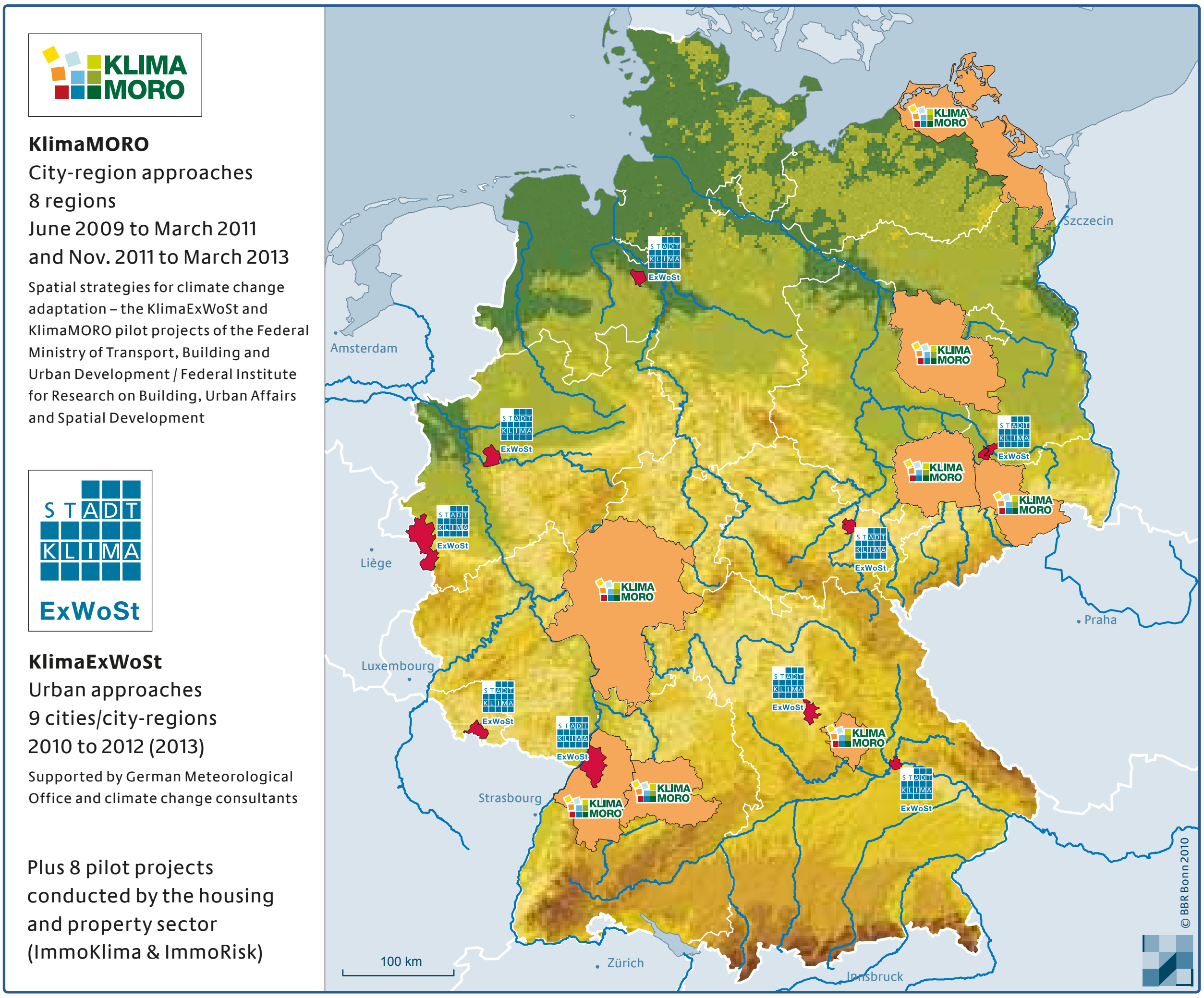


Figure 1: The regional (KlimaMORO) and local authority demonstration projects of the Federal Ministry of Transport, Building and Urban Development / Federal Institute for Research on Building, Urban Affairs and Spatial Development for climate change adaptation

The spatial planning demonstration project entitled "Spatial Development Strategies for Climate Change" (**KlimaMORO**) was launched in 2009. In eight pilot regions – Western Pomerania, Havelland-Fläming, Western Saxony, Upper Elbe Valley/Eastern Ore Mountains, Central and Southern Hesse, Northern Black Forest/Central Upper Rhine, Stuttgart Regional Association and the Neumarkt region – regional climate change strategies were developed and trialled in just under two years of intensive work up to March 2011. The intention was to involve pilot regions with a high level of climate change impact, and at the same time to cover, if possible, most of the constellations typical for Germany.

The main **action areas** addressed were coastal protection, precautionary flood control, bioclimate/settlement climate and climate change mitigation, and in all

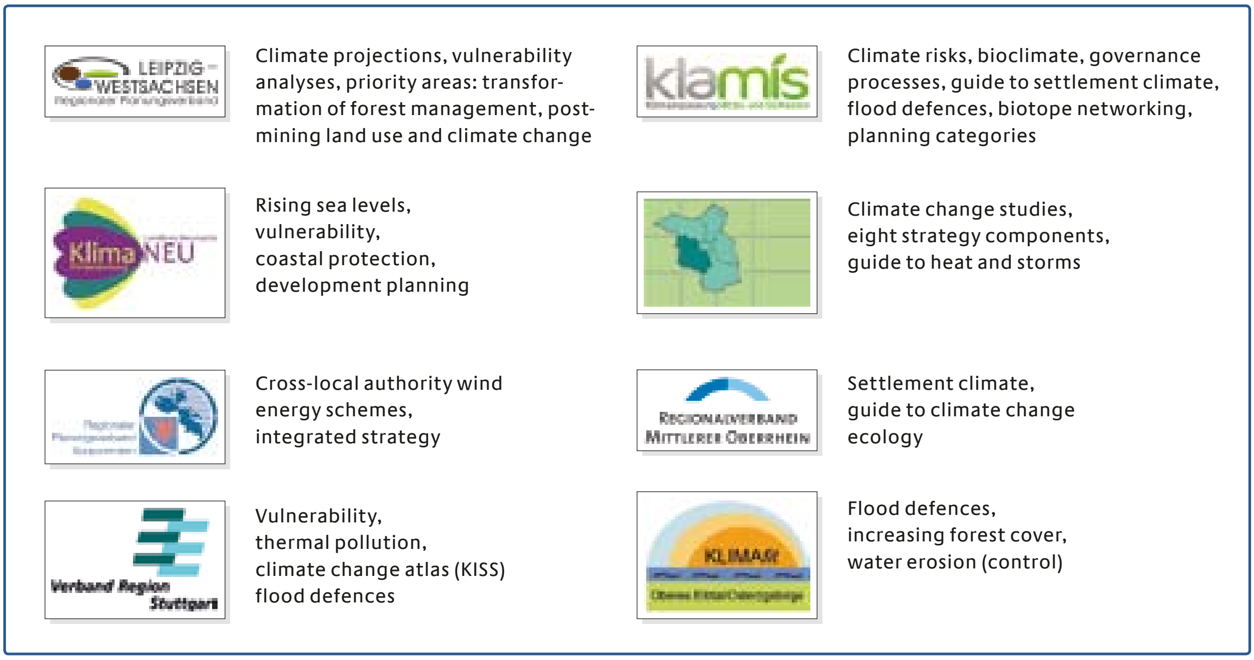


Figure 2: The key issues addressed by the KlimaMOROs

regions analyses of the impacts of climate change were carried out and demonstration projects launched. The networks in the regions and the exchange of ideas and experience among the model projects were also of key importance.

KlimaMORO will benefit from the lessons learned from KLIWAS, especially regarding the validation and assessment of climate projections, ecosystem services in catchment areas, inland waterway management and coastal protection.

The activities carried out so far in the MORO pilot regions fully corroborate the assumption that complex spatially significant challenges can only be successfully addressed by a combination of formal and informal regional planning instruments. In all the pilot regions, different groups of stakeholders are successfully involved at the actual working level. On an even wider scale, thematic workshops are held to raise their awareness and motivate them. This is based on the conviction that a broad-based regional "climate change" network will significantly support the acceptance and feasibility of regional planning requirements.

1) **Analyses:** A comprehensive analysis of existing and future climate change is necessary. In all regions, the bases of analysis relevant to climate change and the climate change impact assessment methods have been improved. One of the most important products is the sectoral vulnerability analyses (BMVBS 2011e), i.e. studies of impacts and adaptation capacity.

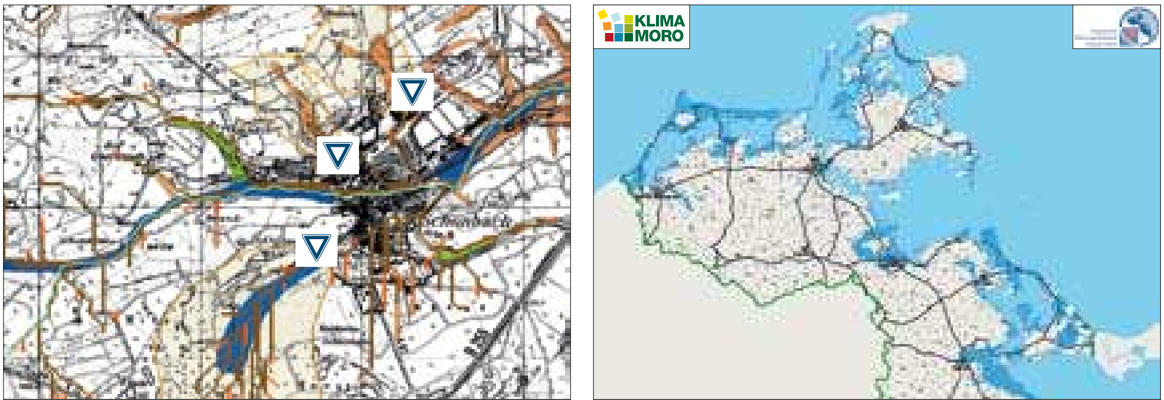
2) **Instruments:** For many action areas of spatial planning, proposals on how to evolve the spatial planning toolkit have been developed in the pilot projects, with the focus on precautionary flood control and tackling climate change in settlements, for instance via the climate change adaptation guide for local authorities in the Rhine-Main region (RV 2011), which was developed in the Central and Southern Hesse pilot region (klamis). Moreover, complex spatially significant challenges can only be successfully addressed by a combination

Central and Southern Hesse:
Are flash floods relevant to regional planning?

- Identification of runoff-sensitive areas
- Description of the risk of sudden flooding

Western Pomerania:
Changes in the hydrological regime in the coastal region as a result of rising sea levels

- Coastal protection strategy
- Land use adaptation (e.g. floodplains and boglands)
- Safeguarding groundwater resources



source: Dr. H. Ernstberger, KlimaMORO Mittel-/Südhessen

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Figure 3: KlimaMORO case examples – flash floods and coastal protection

of formal and informal regional planning instruments (BMVBS 2011b).

3) **Governance:** For this reason, a large number of stakeholders are involved in the dialogue-oriented work process in all pilot regions, with regional planners playing a lead role. This is based on the conviction that a broad-based regional "climate change" network will significantly support the acceptance and feasibility of regional planning requirements.

The results of Phase I were discussed with experts at a review workshop in June 2011 and presented at a round-up conference in November 2011 (cf. BMVBS 2011f). This resulted in **three key demands**. First, well-founded and practically relevant analyses of the degree of climate change impact are required as prerequisites for action. Second, spatial planning instruments have to be used in a more targeted and binding manner. Third, successful case-by-case solutions and innovative spatial development strategies have to be evolved, and and decisions have to be taken as to what is to be made politically binding which are. These demands will be developed in the consolidation phase of KlimaMORO over the period to 2013.

3.2 The municipal demonstration projects (KlimaExWoSt)

In the research field entitled "Urban strategies and potentials to combattackletackle climate change" (BMVBS 2010), starting in 2010 and lasting until mid-2012, municipal strategies to tackle climate change are being tested in field trials in nine pilot projects, and the findings will be analyzed over the period to 2013. The demonstration projects involved are the City-Region of Aachen, Karlsruhe Neighbourhood Association and the Towns/Cities of Bad Liebenwerda, Essen, Jena, Nuremberg, Regensburg, Saarbrücken and Syke.

The **aim** is to develop strategies, measures and demonstration projects for climate change sensitive urban development. In addition to the identification of climate change risks and climate change impact assessment, strategies for precautionary flood control, protection against extreme weather events, tackling climate change in settlements and improving the bioclimate are being developed. The local authorities involved are studying various **thematic focuses** in the fields of urban restructuring, urban design and heritage conservation, planning of green areas and open spaces, and adapting settlement development and planning for commerce and industry to climate change. This is being done at various spatial levels, from the neighbourhood to the city-region, by interlinking the sectors, through cooperation in broad-based alliances of stakeholders, through collaborative research schemes and by involving the public. The general focus is on improving the bioclimate, because here urban development is a key player in ensuring climate-sensitive urban restructuring and creating green and blue structures or ensuring that open spaces remain unsealed.

This demonstration project was preceded by a **scoping study** entitled "Climate change sensitive urban development – using urban strategies to address the causes and consequences of climate change" (BMVBS 2011d). In addition, strategies and measures have been developed addressing, inter alia, the adaptation of public utility service infrastructure, the hydrological regime and flood control, disaster control and civil protection, demographic change/health care, nature conservation and soil protection, and structural/technological measures to tackle climate change.

The following can be regarded as the current **milestones** of StadtKlimaExWoSt:

- initiation and implementation of demonstration projects with broad-based stakeholder involvement and feedback to urban policy;
- analyses and strategies for a municipal climate change adaptation process, from climate change impact assessment, through options for adaptation, to the prioritization of measures;
- planning/building approaches with urban design options and concrete measures, for instance for creating networks of green spaces and "climate comfort islands", for greening courtyards and open spaces, for creating waterborne structures, for climate-sensitive precautionary flood control, and for climate-sensitive urban restructuring, including in listed neighbourhoods;
- climate adaptation strategies specific to settlement patterns, e.g. for historic town and city centres, urban restructuring areas, business parks, open spaces and urban fringes;
- analytical/technological approaches for precautionary flood control, stormwater retention and heat abatement, structural adaptation;
- strategic approaches: the climate change amendment to the Federal Building Code and the adaptation strategy's action plan take into account the fundamentals of climate change sensitive urban development;
- applied research by means of various expert studies into, inter alia, the qualitative assessment of climate change impact, climate-sensitive urban restructuring, flexible planning and the profitability of adaptation measures.

The knowledge gained from StadtKlimaExWoSt is being progressively pooled in the **urban climate pilot**, an advice tool that can be used independently to select suitable climate change adaptation measures for local authority stakeholders. The pilot draws on a database with around 140 measures and examples of good practice.

Figure 4: www.stadtklimalotse.de (Screenshot)

It offers various retrieval options to help users select the potentially interesting measures for the local context. In addition, a module for estimating the degree to which municipalities are impacted by climate change provides a low-cost alternative to comprehensive climate change analyses.

4 Conclusion / looking ahead

In August 2011, the Federal Cabinet adopted an action plan on the German Strategy for Adaptation to Climate Change. Among other things, demonstration projects are designed to support regions and municipalities in adapting to climate change. To this end, the Federal Ministry of Transport, Building and Urban Development is promoting pilot and demonstration projects at municipal and city-region level that involve developing examples of approaches and solutions to climate change adaptation and testing them in field trials in regions and municipalities.

In the KlimaMORO regional pilot projects, the main action areas addressed are coastal protection, precautionary flood control, bioclimate/settlement climate and climate change mitigation, and in all regions analyses of the impacts of climate change are being carried out and demonstration projects launched. A review of the first phase shows that, in addition to a comprehensive analysis of existing and future change, the spatially significant challenges can be successfully addressed by a regionally specific combination of formal and informal regional planning instruments. In a second phase lasting until April 2013, the demonstration projects and pilot activities will be evolved with specific and cross-cutting issues with regard to a systematization of climate change impact assessment and a spatial planning tool kit.

By then, the deliverables of the StadtKlimaExWoSt demonstration projects will also be available, i.e. the model projects at municipal level in the research field entitled "Urban strategies and potentials to combat-tackle climate change", in which strategies, measures and demonstration projects for climate change-sensitive urban development are being developed. The knowledge gained from StadtKlimaExWoSt is being progressively pooled in the urban climate pilot, an advice tool that can be used independently to select suitable climate change adaptation measures for local authority stakeholders.

In the spring of 2013, all the findings will be presented and discussed at a conference entitled "Climate Change in Cities and Regions". Thus, the urban and spatial development demonstration projects are a key building block for implementing the findings of the climate change impact research conducted by the Federal Ministry of Transport, Building and Urban Development and the Federal Government.

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Adaptation of the Road Infrastructure to Climate Change

Markus Auerbach, Carina Herrmann & Beata Krieger (all BASt)

1 Introduction

The road transport infrastructure is of huge importance to the overall economy. Currently, about 70% of the goods are carried by road and the trend is rising.

But this is not the sole challenge which the road transport infrastructure and the road transport sector have to master. We are living in a period of change: globalization, sustainability, technological and demographic change, increase of goods transport and climate change. The road transport infrastructure has to adapt to these changes. Until 2050, road transport will continue to account for ¾ of the total goods transport and will increase by 84% during the period from 2005 to 2025. An equally strong increase is forecast until 2050. The road infrastructure has to cope with this rising goods transport volume.

2 Prerequisites

The German road network comprises about 12,000 km of federal motorways and 41,000 km of federal trunk roads, constituting a federal asset of 120 billion Euro. This road network includes more than 38,000 bridges and about 220 tunnels which in turn constitute an asset to the tune of 50 billion Euro. Since the roads have an expected service lifetime of 30 to 50 years and bridge and tunnel structures are supposed to last between 80 and 100 years, it is important to adjust the guidelines for road and bridge construction already today in such a way that these structures will withstand the consequences of the projected climate change. The first impacts of climate change have already become evident. Thus, hot summers lead increasingly to rutting on asphalt surfaces and to blow-ups on concrete surfaces. Furthermore, frame bridges made of pre-stressed con-

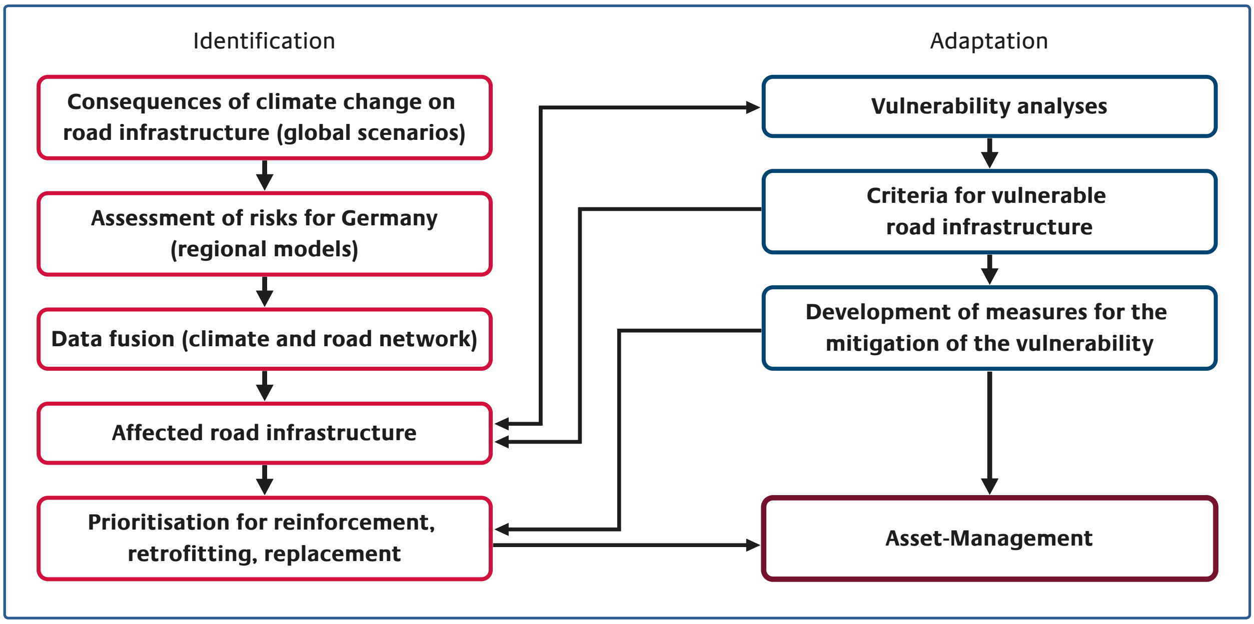

Figure 1: Flow chart illustrating the adaptation strategy

crete which were built before 1981 may be especially affected if exposed to heat.

Extreme precipitation, too, can lead to the flooding of roads and tunnels, thus leading to higher accident rates.

3 Strategy

The Federal Highway Research Institute has developed a strategy to adapt roads and engineering structures to the impacts of climate change; this strategy is illustrated in a flow chart (Figure 1).

The aim is to integrate this adaptation strategy into a holistic and sustainable asset management.

On the basis of the identification of the threats and the fusion of the climate and road network data, the road transport infrastructure which might be affected is to be determined. For this purpose, it is first of all necessary to carry out vulnerability analyses and to establish the criteria for the elements of the road transport infrastructure which are at risk. At the same time, possible adaptation measures will be developed and their effectiveness assessed in a holistic approach. Subsequently, a prioritization for the implementation of the adaptation measures can be performed for the whole network.

This strategy will be implemented in European as well as in national projects.

4 European Perspective

The Federal Highway Research Institute is involved at European level in the programme “Forever Open Road” of the FEHRL (Forum of European National Highway Research Laboratories). The aim of this programme is to develop the road of the future which is adaptable, automated and climate change resilient.

The adaptable road is based on a modular predesigned system. It is to adapt to changing traffic volumes and to changing demand for public transport. Furthermore it is to be made capable of powering vehicles, of generating solar power and even of self repair. The intention is to plan and construct quickly and cost-effectively and to carry out maintenance work all year round as well as to minimize the local and global environmental impact of road transport.

The automated road is to include a fully integrated information, monitoring and control system, permitting communication between road users, vehicles and the road. Information about the weather, the road condition and the traffic flow are to be measured and independent response action is to be taken; moreover, this information is to be passed on to the road users.

The climate change resilient road is to withstand the impact of extreme weather conditions and to adapt to climate change. The road is to monitor flooding, snow, ice, wind and temperature changes and minimize their impacts for example by integrated drainage and automatic heating and cooling systems. These data are to be transmitted to the drivers via the integrated information system.

Figure 2 shows the milestones of this programme element.

5 National Perspective

The complete implementation of the above strategy is a very complex task. For this reason, a list of open questions was first of all compiled which have to be solved with priority. This gave rise to the research project "Adaptation of the Road Transport Infrastructure to Climate Change (AdSVIS)". A total of 13 sub-projects were defined which in some cases started in early 2012. Some selected projects will be described in the following.

Risk analysis of key goods and transit axes including seaports

The objective of this project is the presentation of the risks emanating from the projected climate changes for selected road sections in the German part of the TEN (Trans-European Network), based on the methodology developed in the ERA-NET ROAD project RIMAROCC. Adaptation measures are to be defined for the identified risk areas and assessed as to their effectiveness. This project is a first approach towards the establishment of a risk management. For this purpose, the RIMAROCC methodology which is used here must be extended and evolved. In a currently planned second part of the project, the task will be to devise and create a risk management tool. Within the framework of an envisaged third part of the project, the risk analysis might be carried out for the whole network, using the modified risk management tool.

Adaptation of the regional climate predictions for road infrastructure used in "KLIWAS"

The aim of this project is to provide the climate data which are relevant to the road transport infrastructure (global radiation, air humidity, precipitation, temperature and the parameters thus derived) for further investigations. A resolution in a grid of $5 \times 5\,km^2$ is envisaged. Impact model simulations with a higher resolution can be provided for individual relevant objects of the road transport infrastructure.

Adaptation of weather dependent input parameters for the design of pavement structures

The methods currently used to take account of weather conditions for the dimensioning of road pavements (in the case of new construction as well as maintenance) are based on long-term meteorological observation series. This project is to investigate the extent to which climate change modifies the input parameters which are subject to weather conditions. This means those parameters which are integrated into the Guidelines for the standardization of pavements of traffic areas (RStO) as well as into the computational dimensioning (Guidelines RDO asphalt and RDO concrete). It is intended to prepare the relevant adaptation proposals for dimensioning (30 years as a rule).

Pilot study on the revision of standardized asphalt pavements due to changing temperature boundary conditions

Asphalt shows a strongly temperature-dependent, elastic, plastic and viscous behaviour causing potential cracking in winter and permanent ruts in summer.

On the basis of the Guidelines for the computational dimensioning of the surface of traffic areas with asphalt

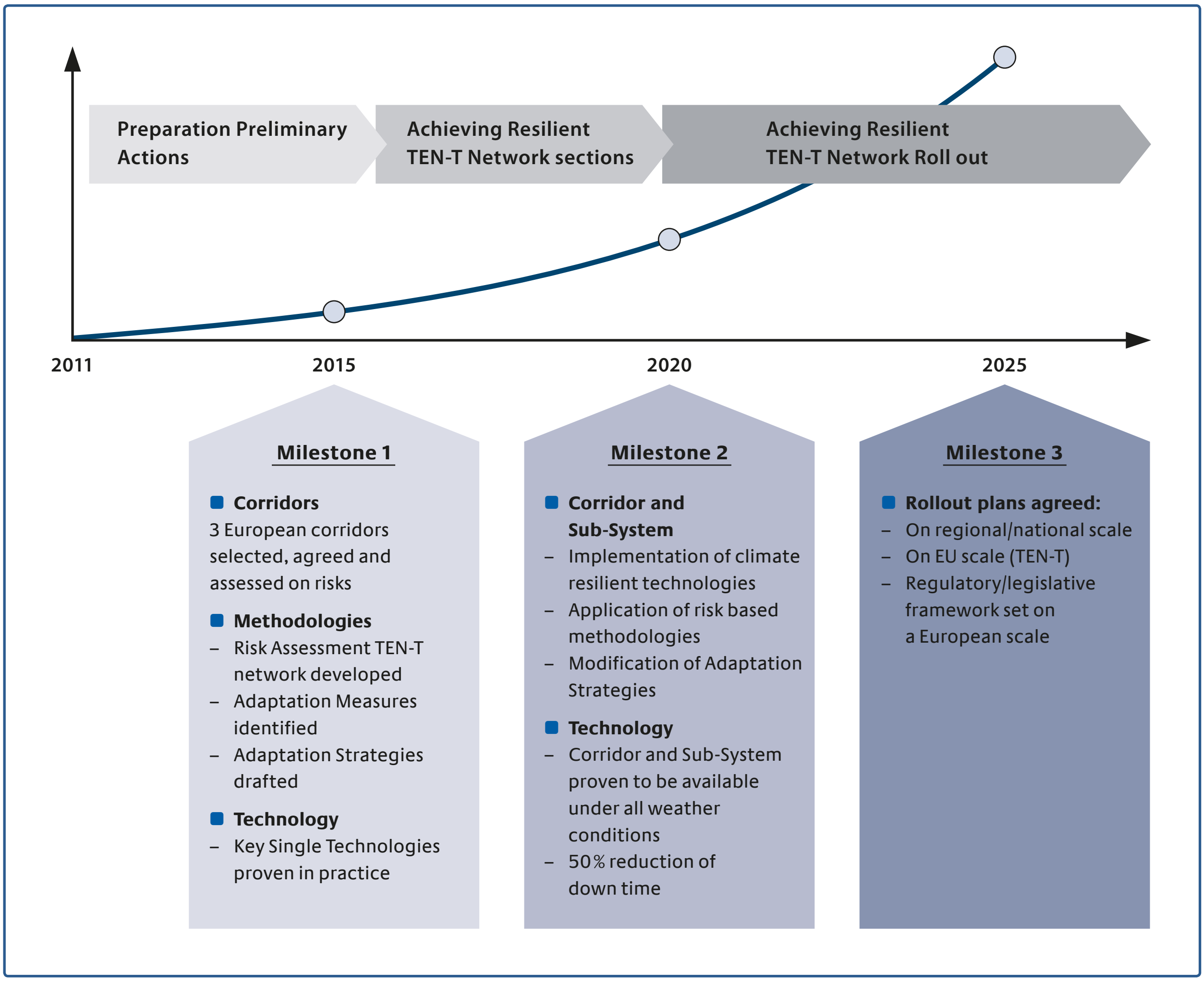

Figure 2: Milestones of the Forever Open Road programme element “Climate Change Resilient Road”

pavement (RDO asphalt) it is to be examined to what extent a rise of the average annual temperature and of the impact of traffic permit the use of standard asphalt construction methods/dimensioning in order to reach the usual service life. Failure to reach the full service life will lead to new standards for material adaptation and/or alternative binding agents.

Temperature-resistant alternative binding agents

Laboratory tests have already proven that the modification of asphalts and/or bitumen with for example epoxy resin indicates a strong resistance to deformation with higher traffic loads and temperature stresses. Within the framework of the project described here, a pilot application will be realized on the site of the demonstration, test and reference section of the Köln-Ost motorway interchange. In this way, proof of the applicability in road construction can be furnished (manufacture, carriage, installation) and its behaviour under real climate conditions, especially the impact of cold, can be monitored.

Evaluation of the design of road drainage systems regarding climate change

This project is intended to review the current dimensioning concepts in accordance with the Guidelines for the design of roads – part: drainage (RAS-Ew) and in accordance with the Guidelines for structural measures at roads in water protection zones (RiStWag) with regard to:

- hydraulic efficiency while observing soil and water protection and
- structural designs.

The results of this research project are to serve as a basis for the revision of the regulations.

Development of climate impact models and design parameters for bridges and tunnels

The result of the pilot project "Impacts of climate change on existing pre-stressed concrete bridges" was that adaptations are necessary in particular for frame bridges made of pre-stressed concrete which were built before 1981.

The planned project "Development of climate impact models and design parameters for bridges and tunnels" is aimed at determining site-related and design-relevant climate parameters in order to obtain projections of climate impact which are as realistic as possible for structures which are located in regions which particularly affected by climate change.

Vulnerability analysis of bridges and tunnels that are affected by weather extremes caused by climate change

The aim of this project is to identify critical structures so that the relevant measures can be taken at the structure in order to reduce its vulnerability. Thus, it may be possible to reduce the cost of repair or new construction of a damaged or destroyed structure.

Figure 3 shows all sub-projects in tabular form.

Project
Risk analysis of key goods and transit axes including seaports
Adaptation of the regional climate predictions for road infrastructure used in "KLIWAS"
Adaptation of weather dependent input parameters for the design of pavement structures
Pilot study on the revision of standardized asphalt pavements due to changing temperature boundary conditions
Temperature-resistant alternative binding agents
Analysis of the impacts of weather extremes on existing concrete road pavements
Evaluation of the design of road drainage systems regarding climate change
Development of climate impact models and design parameters for bridges and tunnels
Vulnerability analysis of bridges and tunnels that are affected by weather extremes caused by climate change
Analysis of measures to reduce the vulnerability of bridge and tunnel structures with respect to climate change
Development of a model for estimating landslide risk areas and development of a national hazard map
Comparison of meteorological parameters near federal roads and grid data of climatologic prediction models
Impacts of climate change on road maintenance

Figure 3: List of all AdSVIS sub-projects (situation: January 2012)

6 Summary/Looking to the Future

Currently, about 70 % of the goods are carried by road and the trend is rising. Apart from this increase in road transport, more and more weather extremes (storms, heavy precipitation, heat waves) are caused by climate change and the road transport infrastructure has to be adapted to such situations. Therefore, the Federal Highway Research Institute has developed a strategy which it implements at European level in the project "Forever Open Road (FOR)" and at national level in the project "Adaptation of the road transport infrastructure to climate change (AdSVIS)".

Within the framework of FOR, it is responsible for the sub-project "Climate Change Resilient Road". A concept was developed providing to select three European corridors until 2015 and to carry out vulnerability analyses and a risk-based analysis of the TEN-T network as well as to develop suitable adaptation strategies. Moreover, it is intended to validate individual technologies in practice. In a 2nd milestone until 2020, the climate-adapted technologies are to be implemented in individual sections of the TEN-T, risk-based measures are to be applied and the adaptation strategy modified. The aim here is to keep the road sections and corridors serviceable in all weather conditions and, thus, to reduce the fault times by 50 %. In the 3rd milestone until 2025, implementation plans at European and national level will have to be agreed upon and a legal framework to be created at European level (see Figure 2).

Among the AdSVIS projects listed in Figure 3, six projects have been launched in early 2012 (risk analysis of key goods and transit axes including seaports, adaptation of weather dependent input parameters for the design of pavement structures, pilot study on the revision of standardized asphalt pavements due to changing temperature boundary conditions, evaluation of the design of road drainage systems regarding climate change, development of a model for estimating landslide risk areas and development of a national hazard map, comparison of meteorological parameters near federal roads and grid data of climatologic prediction models). The other projects are still in the tendering or in some cases even in the planning stage.

The consequences of climate change are far-reaching and will be further pursued by the Federal Highway Research Institute within the framework of national and European projects.

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Impacts of Climate Change on the Rhine

Generation and Application of Discharge Scenarios for Water Management at the River Rhine

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1 Introduction

The KLIWAS research programme attaches special importance to the Rhine as the economically most important European waterway. Here, the work started in summer 2007 already with the project "Water Balance, Water Level and Transport Capacity" (KLIWAS 4.01). After basic concepts (NILSON 2009, KRAHE & NILSON 2009) and first results (BÜLOW et al. 2009, CARAMBIA & FRINGS 2009) were presented, significant progress has been achieved in the meantime.

This was put up for discussion in scientific research groups at national and international level and jointly published. In these studies, specific methodological issues such as the bias correction of regional climate models or the uncertainty analysis of complex model chains were dealt with (KRAHE et al. 2009, NILSON et al. 2010a, MUDELSEE et al. 2010), but comprehensive information was also provided about the data and methods used as well as about the interpretation of the results (GÖRGEN et al. 2010).

This contribution to the second KLIWAS Status Conference describes the further consolidation of the results (see section 2) and the exemplary application of the discharge scenarios (see sections 3 and 4).

2 Data bases

The ensemble of the discharge projections comprises in the meantime 26 simulations for the period from 2021 to 2050 (in the following "near future") and 21 simulations for the period from 2071 to 2100 (in the following "distant future"). The simulations are based on a corresponding number of regional climate projections which were prepared by national and international research initiatives, using different climate models (VAN DER LINDEN & MITCHELL[1] 2009; ENKE & KREIENKAMP 2006, GERSTENGARBE 2009, HOLLWEG et al. 2008, JACOB 2006, JACOB et al. 2009). The evaluation and processing system used for these data was the one described by NILSON et al. (2010b). The discharge modelling was performed in continuity with CARAMBIA & FRINGS (2009) with the semi-distributed conceptual hydrological model HBV134 (EBERLE et al. 2005).

Figure 1 shows the range of the results by way of example for the average monthly discharge at the Cologne gauge over 30 years. For comparison, the reference run of the hydrological model is presented which was based on the observed meteorological data for the period 1961–1990.

Accordingly, the following robust conclusions can be made:

1. "Near future": no significant change of the discharge regime
2. "Distant future": increase of the average discharge in winter; earlier occurrence and reduction of the lowest monthly discharges.

With reference to the entire River Rhine (not represented here), the available simulations show a tendency towards a stronger pluvialization of the discharge regimes, i.e. a more balanced annual cycle is simulated for the current nival regimes whereas the seasonal varia-

1 "The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contact number 505539) whose support is gratefully acknowledged."

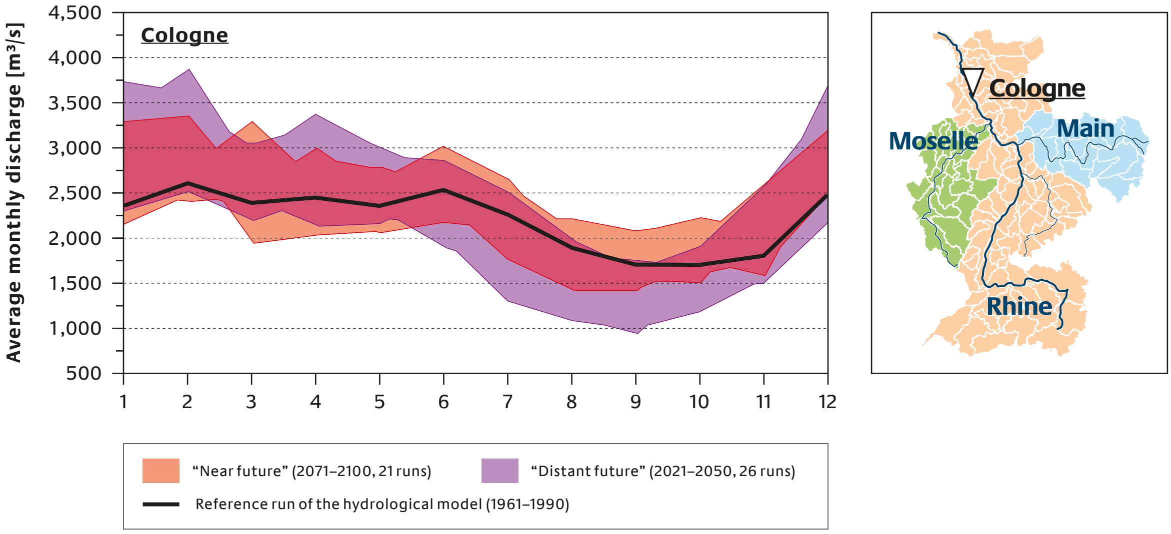

Figure 1: Average monthly discharge at the Cologne gauge for three time slices. The envelope curves extend over the whole range covered by the individual projections. For each simulation, monthly signals of change [%] were determined and set off against the reference run.

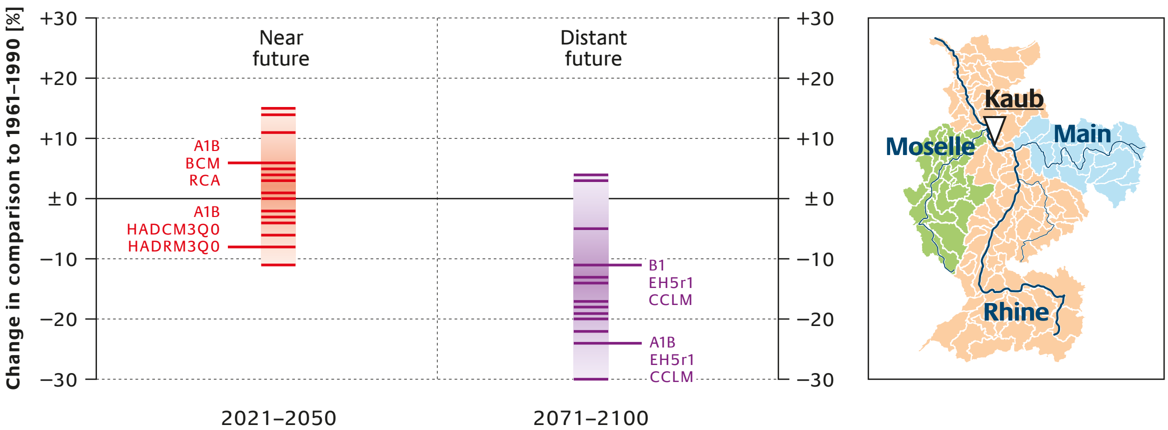

Figure 2: Average changes of the low water parameter NM7Q (lowest 7 day average value) at the Kaub gauge during the hydrological summer half-year (May–October). Ensemble of about 20 discharge projections (short lines) as well as the boundaries of the scenario corridors (long lines) and the representative simulations.

tions increase for the regimes which are already pluvial or combined today.

3 Derivation and application of discharge scenarios

The Intergovernmental Panel on Climate Change (IPCC 2007) defines a "scenario" as a plausible pattern of the possible future development. For this purpose, projections can serve as raw material. In order to take account of the uncertainties in projections, several scenarios are frequently used according to the IPCC (2007).

On the basis of this definition, so-called scenario corridors were designed for different discharge parameters within the framework of KLIWAS. A scenario corridor is defined as an area within the ensemble of discharge projections were a particularly high number of simulations provide similar results. The projections which represent the margins of a scenario corridor (so-called representative simulations) can be used as time series data for further evaluation or in other models.

Figure 2 illustrates this for a low water parameter (Example: Kaub gauge) which can be regarded as indicative of the available fairway depth for navigation. Looking ahead to the distant future, the whole ensemble shows changes ranging from +5 % to –30 %, but the peripheries of the ensemble comprise only a small number of model chains. The majority of the projections range between –10 % and –25 %. This area is therefore identified as scenario corridor. Thus, a decrease of the NM7Q by 10 % can be considered an "optimistic" scenario and a decrease by 25 % a "pessimistic" one. The "optimistic" scenario is represented by the simulation with the model chain B1_EH5r1_CCLM, the "pessimistic" scenario results from the model chain A1B_EH5r1_CCLM.

Essential characteristics of the ensemble are covered by the scenario corridors. Moreover, they offer the possibility of a substantiated selection of individual simulations from an ensemble. This is, for example, always necessary if successive models in a model chain cannot process all simulations due to computational capacity restrictions. The essential condition for the selection is that, if possible, a single discharge parameter can be identified a change of which will lead to a particularly sensitive response of the relevant model.

In the present example, the representative simulations were identified with regard to the development of the low water discharge values during the hydrological summer half-year of the "distant future". The discharge time series applying to these model runs (each simulated with HBV134) were converted into water depth and flow velocity data by means of the 1D hydrodynamic model SOBEK (Meissner 2008, Meijer 2008) and subsequently further processed in an aggregate form in shipping-related models (cf. contribution by Holtmann et al. 2012 in this volume).

4 Application of the KLIWAS scenarios in policy consultation – conclusion

It is evident that the concept of the scenario corridors is by no means an optimum approach. But even in view of the numerous projections processed within the framework of KLIWAS, there is no sufficient statistical basis for "true" ensemble statistics in the sense of a probabilistic analysis.

The concept of the "scenario corridors" has, especially due to its transparency, proved to be a suitable vehicle in order to include the subject of uncertainties in the administrative-political discussion on climate adaptation. Scenario corridors were defined together with the representatives of several hydrological institutions from the international Rhine catchment area (Switzerland, France, German federal states, BfG, Netherlands), coordinated by the International Commission for the Hydrology of the Rhine Basin (CHR), for high, mean and low water parameters at selected gauges in the Rhine catchment area (Görgen et al. 2010). On this basis, a report (ICPR 2011) was prepared by an Expert Group "Climate" and presented to the "High Water" Working Group under the umbrella of the International Commission for the Protection of the Rhine against Pollution (ICPR). The scenario horizons published in this report are for the time being set the standard for the fur-

Table 1: Scenario corridors for mean and low water parameters (MQ and NM7Q) at selected gauges in the Rhine catchment area on the basis of an ensemble of 20 (2021–2050) and/or 17 (2071–2100) projections. The blue colour indicates a mostly (~80 %) increasing tendency of the projections, the orange colour a mostly decreasing tendency, the grey colour a non-uniform signal of change of the projections (cf. NILSON et al. 2010c, DE KEIZER et al. 2010).

Parameter	Gauge	2021–2050	2071–2100
Average discharge (MQ) in the hydrological summer (May–Oct)	Basle	−10 bis +5 %	−25 bis −10 %
	Maxau	−10 bis +5 %	−25 bis −10 %
	Worms	−10 bis +5 %	−25 bis −10 %
	Kaub	−10 bis +10 %	−25 bis −10 %
	Cologne	−10 bis +10 %	−25 bis −10 %
	Lobith	−10 bis +10 %	−25 bis −5 %
	Raunheim	0 bis +25 %	−20 bis +10 %
	Trier	−15 bis +10 %	−30 bis −10 %
Average discharge (MQ) in the hydrological winter (Nov–Apr)	Basle	0 bis +20 %	+5 bis +25 %
	Maxau	+5 bis +20 %	+5 bis +25 %
	Worms	+5 bis +20 %	+5 bis +30 %
	Kaub	+5 bis +20 %	+10 bis +30 %
	Cologne	+5 bis +20 %	+10 bis +30 %
	Lobith	+5 bis +15 %	+10 bis +30 %
	Raunheim	+5 bis +25 %	+10 bis +40 %
	Trier	0 bis +15 %	+5 bis +25 %
Low water discharge (NM7Q) in the hydrological summer (May–Oct)	Basle	±10 %	−20 bis −10 %
	Maxau	±10 %	−20 bis −10 %
	Worms	±10 %	−25 bis −10 %
	Kaub	±10 %	−25 bis −10 %
	Cologne	±10 %	−30 bis −10 %
	Lobith	±10 %	−30 bis −10 %
	Raunheim	0 bis +20 %	−20 bis 0 %
	Trier	± 20 %	−50 bis −20 %
Low water discharge (NM7Q) in the hydrological winter (Nov–Apr)	Basle	+5 bis +15 %	0 bis +15 %
	Maxau	0 bis +10 %	−5 bis +15 %
	Worms	+5 bis 15 %	−5 bis +15 %
	Kaub	0 bis +15 %	−5 bis +15 %
	Cologne	0 bis +15 %	0 bis +20 %
	Lobith	0 bis +15 %	−5 bis +15 %
	Raunheim	+5 bis 15 %	0 bis +20 %
	Trier	±15 %	0 bis +20 %

ther adaptation discussion. The Central Commission for Navigation on the Rhine (CCNR), too, makes use of these data.

In Table 1 the relevant scenario corridors for mean and low water parameters (MQ and/or NM7Q) for selected gauges in the Rhine catchment area are summarized. For the "near future", no tendency of the MQ and/or NM7Q for the Rhine gauges can be determined for the hydrological summer. In the hydrological winter of the near future, however, trends towards an increase of the MQ and NM7Q are emerging. The signals of change of the MQ show for the distant future stronger increases in winter and significant decreases in summer.

The increase of the NM7Q in winter simulated for the distant future corresponds approximately to the tendencies for the near future as regards the Rhine gauges. In the hydrological summer of the distant future significant decreases can be detected for the NM7Q.

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Analyses of the Impact of Climate Change on Inland Waterway Transport and Industry along the Rhine

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1 Introduction

Forwarding companies depend on low-cost and reliable freight transport. This applies both to sectors whose main focus is on bulk cargo, for instance the energy, coal and steel, and chemical industries, and to the transport of containers. In the Rhine Corridor, this demand for freight transport is met largely by inland waterway transport. Because of the good infrastructure conditions on the Rhine, this mode is characterized by a high level of cost effectiveness and efficiency.

In this context, the impact of climate change on the availability of water resources, discharge and water depths (cf. paper by Nilson et al., this volume) may have an impact on various aspects, such as cost structures, transport capacity and reliability of inland waterway transport and, as a function of this, forwarding companies. As part of the KLIWAS project entitled “Water Balance, Water Level and Transport Capacity” (KLIWAS 4.01), this paper addresses the effects of possible climate change on cost structures and transport capacity of inland waterway transport on the Rhine and its impact on forwarding companies, taking selected companies from various sectors as examples. It implements and evolves the approaches presented by Holtmann & Bialonski (2009) and Scholten & Rothstein (2009) at the first KLIWAS status conference.

2 Impacts on the cost structures of inland waterway transport

2.1 Approach

The impact of climate change on the cost structures of inland waterway transport is primarily a function of the available water depths in conjunction with the corresponding flow velocities and their possible changes. Primarily, it is the water depth of the shallowest waterway segment that influences the possible draught and thus the maximum payload and load factor of the vessel (so-called load-limiting water depth). At the same time, low water depths and high flow velocities have an adverse impact on power demand and possible speed and thus on roundtrip times (so-called propulsion-affecting water depth). Here, the topography of the river bed, which can vary greatly within a small area, has to be taken into account.

These factors apply to each individual category of vessel, water depth (on any given day) and draught. In this project, they are analyzed with the aforementioned degree of differentiation using a model developed for this purpose. Account is taken of the various types of vessel with their different draughts and their different "sensitivity" to low-water situations.

The climate change impact projected for the future is captured using different discharge scenarios generated by the Federal Institute of Hydrology (Nilson et al., this volume). The uncertainties that currently exist in climate modelling are taken into account. For each scenario, 150 years of daily water depths and flow velocities are provided for 15 Rhine segments, based in each case on an "optimistic" and a "pessimistic" discharge scenario with regard to trends in low-water conditions. The relevant model chains used to develop the data are called "B1-EH5r1-CCLM-LS-HBV-SOBEK" and "A1B-EH5r1-CCLM-LS-HBV-SOBEK". More details can be found in Nilson et al. (in this volume) and in the literature quoted there.

Because the focus of the study is on the identification of the impacts of changeable fairway conditions, other parameters, such as fuel prices or the costs of interest payments and personnel, are deliberately kept constant. The corresponding information is based on expert interviews and calculations and research by the authors or is taken from the literature (Planco & BfG 2007) with regard to personnel cost structures.

2.2 Results to date

The sample calculations are first carried out and validated for the reference run. This involves reviewing the period from 1980 to 2007 (taking as a basis the water depths of the "actual" simulation based on discharges observed at the gauges).

When the results are analyzed, various tendencies become apparent. These tendencies are not surprising and are in line with Holtmann & Bialonski (2009):

(1) When water levels are favourable (higher), larger vessels have lower unit costs than smaller vessels, because of good load factors and high speeds. Here, economies of scale have an effect.

(2) When water levels are lower, the unit costs rise as a result of falling load factors and speed. However, they rise more sharply for large vessels than for smaller vessels. As water levels continue to fall, larger vessels tend to reach a stage where operation is no longer possible at all. In this case, their unit costs can sometimes be higher than those of smaller vessels.

The project goes on to examine the impacts of the two aforementioned discharge scenarios over the period to 2100. To be able to better identify and evaluate the trend and developments covering many years, the individual results, which are available in a very detailed form, are aggregated. Specifically, average annual values of 30-year periods in the "near future" (2021 to 2050) and in the "distant future" (2071 to 2100) are compared with a 30-year period in the past (1961 to 1990). Three types of vessel (Johann Welker, GMS and coupled convoy) are taken as examples, sailing upstream between Rotterdam and the Upper Rhine.

For the "near future", there is an ambivalent pattern (Figure 1). It is apparent that in the "optimistic" scenario, average unit costs will fall because of the rising mean water levels, whereas slightly rising average unit costs are associated with the "pessimistic" scenario. Conversely, for the "distant future", a distinct trend towards rising unit costs is apparent in both scenarios. In the "pessimistic" scenario, average unit costs are simulated to rise by around 8 % to 10 %, which is around twice as much as in the "optimistic scenario", where the increase in average unit costs will remain below 5 %

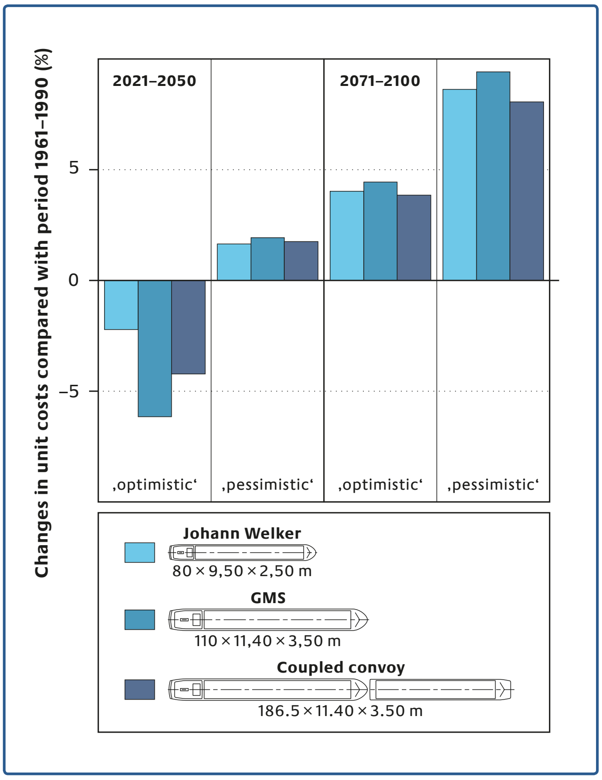

Figure 1: Changes in unit costs (multi-annual mean) for vessels sailing upstream between Rotterdam and the Upper Rhine; results of cost structures shown by way of example

3 Impacts on transport capacity on the Rhine waterway

3.1 Approach

In addition to cost structures, the capacity impacts are also analyzed in greater depth. Here, the key question is whether, and if so to what extent, the consequences of climate change have an impact on the transport capacity of the Rhine as a waterway. To answer this question, the link between the fairway conditions and the possible load factors of the various categories of vessel size is established and analyzed.

The modelling assumes that the vessels are carrying a maximum load commensurate with the water depths. Thus, an arithmetical maximum capacity dependent on water levels is considered here.

As was the case with the cost structures, an "optimistic" and "pessimistic" development of low water discharges over the period to 2100 is taken as a basis, in accordance with the discharge scenarios (Nilson et al. in this volume). Moreover, three fleet scenarios are considered which are used to take into account possible fleet trends over the period to 2100:

- "status quo" (fleet as in 2010);
- "trend: large vessels";
- "adaptation: small vessels".

The "status quo" scenario assumes that the composition of the fleet in the 21st century does not change from the current situation (2010). The "trend: large vessels" scenario assumes that the current trend towards larger vessels continues. Conversely, the "adaptation: small vessels" scenario assumes that the trend towards larger vessels will decline in the decades ahead and, starting in the middle of the century, will be reversed into a trend towards smaller vessels because of expected climate change impacts.

All the other parameters are again kept constant in order to isolate the effect of the changeable fairway conditions.

3.2 Results to date

The following graph shows the changes in transport capacity (multi-annual total), taking vessels sailing upstream between Rotterdam and the Upper Rhine as an example, and assuming two discharge scenarios and three fleet scenarios.

As was the case with the cost structures, there is an ambivalent pattern for the "near future" in the case of transport capacity as well. Whereas in the "optimistic" discharge scenario, transport capacity increases significantly as a result of the rising mean water levels, in the "pessimistic" scenario there is likely to be a slight drop in transport capacity compared with 1961–1990. In the "distant future", falling transport capacities, correlating with falling mean water levels and rising unit costs, is visible in both discharge scenarios, as was the case with the cost structures (Figure 2).

The aforementioned tendencies can be identified for all three fleet scenarios, but with different weights. Compared with the "status quo" scenario, the "trend: large vessels" scenario results in larger capacity gains when there are favourable (higher) water levels and larger capacity losses when there are unfavourable (lower) water levels, because of the higher average deadweight capacities. Conversely, and as is to be expected, the opposite trend can be identified in the "adaptation: small vessels" scenario, namely a less pronounced manifestation of the same trends compared with the "status quo".

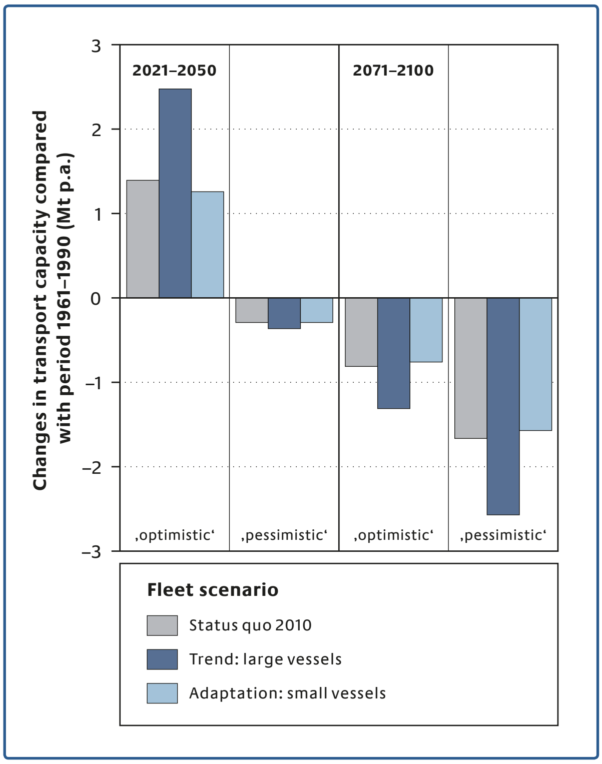

Figure 2: Changes in transport capacity (multi-annual mean) for vessels sailing upstream between Rotterdam and the Upper Rhine; two discharge scenarios, three fleet scenarios, capacity results shown by way of example

4 Impacts on forwarding companies

4.1 Approach

In addition to the impact of climate change on inland navigation on the Rhine, the project also involves exploring the extent to which the forwarding companies along the Rhine are affected and how this might affect their entrepreneurial behaviour. Here, a conscious decision was taken not to adopt a top-down approach, i.e. drawing conclusions from macro-economic developments about the behaviour of individual companies, but rather to adopt a bottom-up approach, i.e. starting with individual companies and taking their specific conditions and behaviour into account.

The methods how the data was gathered and the resulting collection of data are described in Scholten & Rothstein (2009). On this basis, an index has been derived. With this index the vulnerability of various groups of companies due to low-water situations can be quantified and compared. A detailed description can be found in Scholten & Rothstein (2012).

The parameter used to describe the impact of climate change on forwarding companies is the percentage deviation from optimum (i.e. realized under current conditions) stock-keeping. The degree to which optimum stock-keeping can be achieved in low-water conditions depends essentially on the category of vessel size chosen in each case (below 1,350 t, between 1,400 t and 3,000 t, 3,700 t or more; cf. above) and inland waterway transport's share of the transport mix of a company (less than 20 %, between 20 and 40 %, over 50 %). This information was obtained by a survey of companies.

Also on the basis of this survey, various adaptation scenarios were generated. For instance, the "2003 adaptation scenario" comprises the adaptation measures that were successfully used by shippers during the 2003 low water period. These include enlarging stock facilities (sometimes also possible at short notice, for instance by intermediate storage of finished products on fields or in ports), transferring goods to other modes of transport, deploying additional vessels and using smaller-sized vessels that are less vulnerable to low water, to name but a few. Of course, when considering the adaptation measures, the disadvantages must not be forgotten. Thus, for instance, when goods are transferred to other modes of transport, this not only results in higher costs and smaller package size, but there is also the problem of very little free capacity on the roads and railways.

As described above, data on the future low-water conditions are acquired based on "optimistic" or "pessimistic" discharge scenarios and the corresponding fairway depths. Other future trends (for instance the global economic development) are deliberately kept constant at today's level because the focus is on the sensitivity to low-water events that may occur in the future.

4.2 Impacts on a group of shippers under climate change conditions

Figure 3 shows the deviation from optimum stock-keeping in percent compared to the reference period of 1961–1990, taking the group of forwarding companies with a preferred vessel size of over 3,000 t as an example. The changes are consistent with those described in sections 2 and 3 and with the changes in the flow regime (cf. Nilson et al. in this volume). For the "near future"

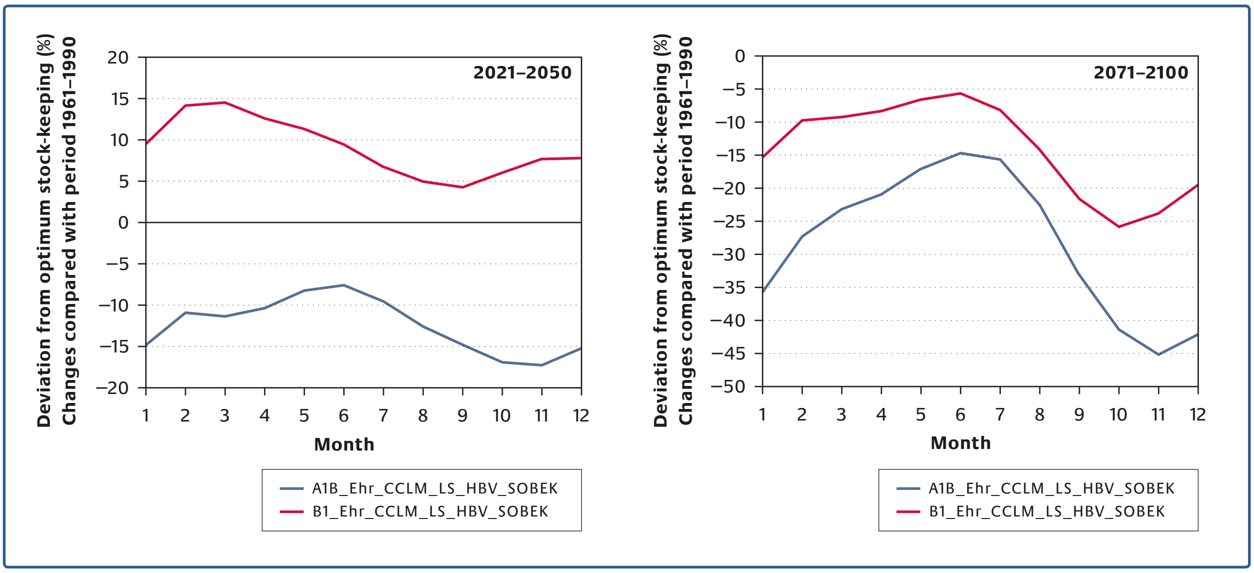

Figure 3: Monthly deviation from optimum stock-keeping (multi-annual mean): changes compared with 1961–1990 based on two discharge scenarios averaged for companies with a preference for a vessel size of 3,000 t. "No adaptation" scenario, source: own calculations based on company data and fairway width data provided by the Federal Institute of Hydrology

(2021–2050), the deviation from optimum stock-keeping appears moderate. Here, the two discharge scenarios results are in a range of ±15 % with slight fluctuations due to seasonality. For the "distant future", on the other hand, the range of the scenarios shows a negative deviation of between −5 and −45 %, with the deviations being lowest in the first half of the year or rather the middle of the year and most pronounced in autumn.

In further evaluations (not shown here), the impact of adaptation scenarios is included in the considerations. Because of the limited amount of data available, this is only possible for individual companies. Calculations show that measures such as taken in 2003, for instance, can significantly reduce the impacts on the companies but, depending on the scenarios, cannot fully compensate them. This requires both combined measures and further innovations in form of operational steps and investments (continuous operation mode, equipping of vessels), which will be studied in ongoing and future KLIWAS projects.

5 Conclusion / looking ahead

In KLIWAS project 4.01, a model chain ranging from greenhouse gas emissions over global and regional climate to impacts on the water balance, hydrodynamics (see Nilson et al. in this volume), and the waterway users, has been implemented for the Rhine. Validation experiments show a plausible overall pattern of the model results for parameters relevant to waterborne transport.

The changes in the parameters presented so far (in this case annual means of vessel-related cost structures and transport capacity plus the shipper-related deviation from optimum stock-keeping) for the middle and end of the 21st century largely follow the projected trends in discharge conditions, i.e. moderate changes (±10 %) for the "near future" (2021–2050) and significant changes with a potentially higher impact on inland waterway transport and forwarding companies in the "distant future" (2071–2100).

The model chain can now be used to study the effect of adaptation measures. This has been done for adapted fleet compositions and an adapted behaviour of the shippers (e.g. using other sizes of vessel). It is apparent that the impacts resulting from the projected changes in fairway conditions can be partly compensated.

Future work will analyze not only further variants and scenarios, but also additional adaptation options (e.g. innovative vessel designs).

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Investigations on Adaptation of Hydraulic Engineering Measures to Extreme Low Water Discharges

Sven Wurms (BAW) & Michael Schröder (BAW)

1 Introduction

For shipping, it is of crucial importance to be aware of the potential impacts on the use of the waterways that are to be expected as a result of climate change. Discharge projections for the Rhine as the most important European waterway that are the result of the research programme "Impacts of Climate Change on Waterways and Navigation" (KLIWAS) suggest that low water discharges might intensify in the distant future (2071 to 2100) (Nilson et al. 2010). More frequent and longer low water periods would, on the one hand, reduce the maximum possible draught which would have immediate consequences for the economic efficiency of waterborne transport. On the other hand, water levels below today's equivalent water level (GlW_{2002}) would lead to fairway width limitations that would affect the ease and safety with which an inland waterway vessel can navigate in bottlenecks. Therefore, the suitability and effectiveness of hydraulic engineering adaptation measures as a response to potential climate induced hydrological and morphological changes are examined within the framework of KLIWAS project 4.03 "Options for the regulation and adaptation of hydraulic engineering measures to climate induced changes of the discharge regime" (Heinzelmann & Schmidt 2010).

2 Analysis of the current low water extension status based on changed hydrological boundary conditions

To provide a basis for potential options for adapting to the impacts of climate change, the extent to which inland navigation would be affected by future potentially more intense low water discharges will be examined in a first step, taking the reach of the Rhine between Mainz and St. Goar (Rhine km 493.0–557.5) as an example. For this purpose, the current condition of the waterway is examined with the help of a high-resolution, 2D hydrodynamic numerical model using the TELEMAC-2D software (Hervouet & Bates 2000) on the basis of changed hydrological boundary conditions to thus make it possible to draw conclusions concerning potential future depth bottlenecks.

2.1. Pilot reach Mainz – St. Goar

Between Rhine km 508.0 and 557.0 in the pilot reach, there is the stretch with the shallowest fairway depth in the free-flowing Rhine that is open to shipping. This depth is 1.90 m below the GlW_{2002} and thus 0.2 m less than in the neighbouring up and downstream stretches. In the event of low and medium water levels, it is essentially this stretch of the river that imposes restrictions on the maximum possible draught and thus the economic efficiency of the inland waterway vessels that are passing through. On a 65 km stretch, the Rhine's characteristics vary strongly on this reach. While the stretch from Mainz to Bingen in the Rheingau is characterized by very little slope, very wide cross-sectional areas of flow and a multitude of bifurcations, the subsequent stretch between Bingen and St. Goar is the steepest of the free-flowing Rhine that is open to shipping. The compact cross-sectional areas of flow of this part of the reach are predominantly accompanied by steep banks and a rocky bed.

Potential climate induced changes in discharge within the pilot reach are taken into consideration in the investigation in the form of bandwidths of projected changes at the main and side gauges. To be able to further process these bandwidths, which are a result of the multi-model approach pursued in KLIWAS and thus a central methodological approach of KLIWAS, the analysis of the current extension status at low water level takes the form of a sensitivity investigation that employs low water discharges that are successively reduced to cover the bandwidth. Thus, for the Kaub gaug-

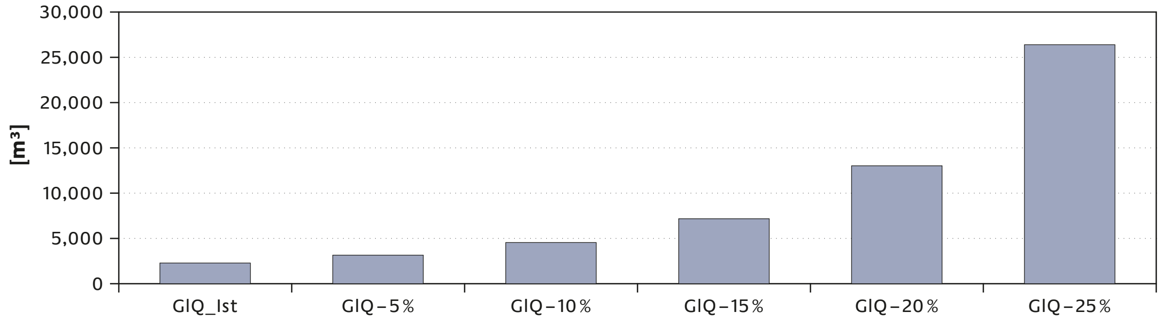

Figure 1: Total volume of shoals within the existing fairway as a result of reduced low water discharges (Rhine km 493.0–557.5; Bed 2004/2006)

ing station, which is the relevant gauging station for inland navigation within the pilot reach, a change in the low water parameter NM7Q[1] of between +10 % and –10 % is projected for the near future (2021–2050). By contrast, the projections for the distant future (2071–2100) show a clear tendency with NM7Q changes between –10 % and –25 % (Nilson et al. 2010). However, the analysis of the current extension status at low water level is conducted on the basis of the equivalent discharge (GlQ), which is relevant to the extension and maintenance of the waterway, instead of the NM7Q. The GlQ is a defined, Rhine-specific low water discharge which is 750 m³/s at the Kaub gauging station and thus only slightly lower than the NM7Q. On the basis of the projected changes in discharge, the bandwidth of the low water discharges to be investigated is therefore set at GlQ to GlQ –25 %.

2.2 Results of the analysis

The key results of the hydraulic analysis of the current low water extension status are the location and the volumes of potential future shoals, i.e. the areas within the fairway where the maintenance depth is not achieved as a result of insufficient water depths. Although the bed levels determined by sounding, which serve as the basis of this analysis, are only snapshots of the dynamic system river bed, Figure 1 clearly indicates that an increase in the intensity of low water discharges is accompanied by a non-linear increase in the total volume of shoals. Whereas a moderate reduction in the GlQ is still compensated by depth reserves within the fairway that are present in some areas, a multitude of new shoals occur within the fairway once the reduction in the GlQ reaches around 15 % (Wurms et al. 2010). The aggradation areas at the centre of the river, which – depending on the reduction in low water discharges – sometimes reach across the entire width of the fairway, thus causing a significant impact on inland navigation, account for the largest share in the total volume of shoals.

3 Hydraulic engineering adaptation options

In addition to making adjustments in the fields of shipbuilding and fleet structure, hydraulic engineering adaptation measures too are important elements in the improvement of the navigability during extreme low

1 NM7Q stands for the lowest arithmetic mean of the discharge on seven consecutive days (Belz et al. 2004)

water periods. In general, an increase in the navigable water depth can be achieved by different measures. One option is to modify the position and the geometry of the fairway. Furthermore, navigability can be improved by using training elements which can be designed to either stabilize the water level or to reduce deposition tendencies. In this context, flexible training measures that only take effect in the event of low discharges are an interesting option, since they – apart from the effects they cause within a defined discharge spectrum – have a significantly smaller impact on the overall system of the waterway than conventional training measures, such as groynes or training walls.

3.1 Adaptation of the fairway

One way of maintaining the efficiency of inland navigation even in the case of extreme low water discharges is to deepen the fairway on a limited width, taking advantage of excess depths. This results in a continuously navigable fairway that offers sufficient depth even during low water periods and that is maintained in addition to the existing fairway. Location and minimum width of the deepening are the results of KLIWAS project 4.04 "Minimum width of fairways for safe and easy navigation" (Wassermann et al. 2010). The advantage of this stepped deepening as compared to deepening the fairway on its entire width is, among other things, the reduced maintenance effort that can be expected. The aim is to confirm this within the framework of further investigations using a morphodynamic model.

Hydrodynamic investigations provide evidence of the positive effect of deepening the fairway on a limited width to a maintenance depth of 2.10 m below the water level present at GlQ −25 % plus 0.1 m dredging tolerance. Thereby, the navigable water depth of 2.10 m at GlQ −25 % can be achieved in the entire investigated area, since locally occurring drops in the water levels amount to no more than 0.02 m at the mentioned discharge. In the immediate area of the deepening, the shear stresses are a bit lower, which leads to a slight increase in the deposition tendency in the dredging areas required for the realization of the stepped deepening. The long-term aim, however, is to minimize the maintenance effort. In addition to deepening the fairway, the use of training structures to bring about an increase in shear stresses in the deepened areas has to be examined with a view to economic aspects if the deepening is carried out in dynamic areas with recurring aggradations within the fairway.

3.2 Training measures for the reduction of deposition tendencies in depth bottlenecks

In the event of reduced low water discharges, shipping is affected in particular in areas where aggradations are already occurring under current discharge conditions. Training measures that aim to increase the shear stress within the relevant aggradation areas and thus reduce deposition rates can contribute to improving this situation, either in the form of a solitary measure within such areas or as an addition to the stepped fairway deepening. The dredging history of all reaches can be consulted to identify the fairway areas that are subject to recurring depositions relevant in the context of ensuring the safety of shipping. Figure 2 shows the use of a training measure to reduce deposition tendencies taking the area of the *Kemptener Fahrwasser* as an example; in terms of their effects on water depths, training measures have to be designed in a way that they do not increase the water level during floods.

The crosscurrent, which occurs in the event of above mean discharges when the longitudinal dyke that is connected to the Ilmenaue is flooded, has been identified as the major cause of the occurrence of recurring aggradations within the fairway between Rhine km 524.6 and 526.1. The crosscurrent induces a loss of energy in the *Kemptener Fahrwasser* and thus a backwater effect upstream of the confluence that promotes the sedimentation tendency. The training measure for the mitigation of the impact of the crosscurrent, which brings about an increase in the shear stresses in the aggradation area within the fairway, consists of a training wall with a crest height of mean water level plus 0.4 m that is

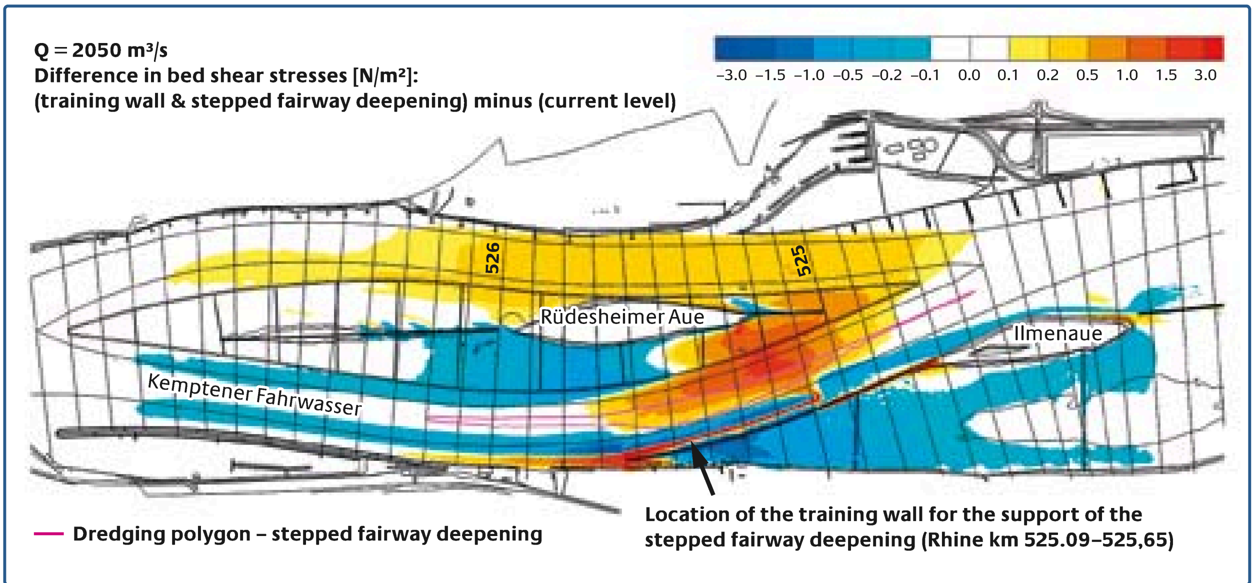

Figure 2: Effects of a training wall for the support of the stepped fairway deepening on the bed shear stresses in the case of the bed-forming discharge in the area of the *Rüdesheimer Aue*

installed on the left side in the *Kemptener Fahrwasser* between Rhine km 525.09 and 525.65 and situated 30 m beside the existing training wall. An optimization of the training measure with regard to its morphological impacts has to be carried out within the framework of subsequent morphodynamic simulations.

3.3 Flexible, temporarily effective training measures for the stabilization of the water level

Another way to gain navigable water depth is the installation of training measures. Conventional, static training structures, such as groynes or training walls, are an option if they neither induce an increase in water levels during flood discharges nor cause impacts on the shipping. If this is not the case, flexible training elements could provide a remedy in the situations mentioned. These elements only take effect in a limited discharge spectrum; in the concrete case, for example, during the temporary increase of the water level in low water periods. A clear advantage of flexible, temporarily effective measures over static training measures would be that the training measure would only have a slight impact on the morphodynamics in its surrounding area, since it would only take effect in the event of low water discharges. In the following, an example of the training potential of a training measure that is targeted at specific discharge conditions will be provided, without, however, discussing its design details.

If reaches that show depth bottlenecks in the fairway under reduced low water discharge conditions are located upstream of a river bifurcation, a hydraulically suitable way to increase the water level would be to temporarily close off the side branch. Figure 3 shows the increase in water level as a result of fully closing off the side branch (*Kauber Wasser*) in the event of an extreme low water discharge (GlQ −25 %), taking the area of the *Bacharacher Werth* as an example.

Closing off the side branch could achieve a gain in fairway depth of up to 0.3 m and still around 0.14 m 1.4 km upstream in the area of a depth bottleneck that is relevant under low water conditions. However, the de-

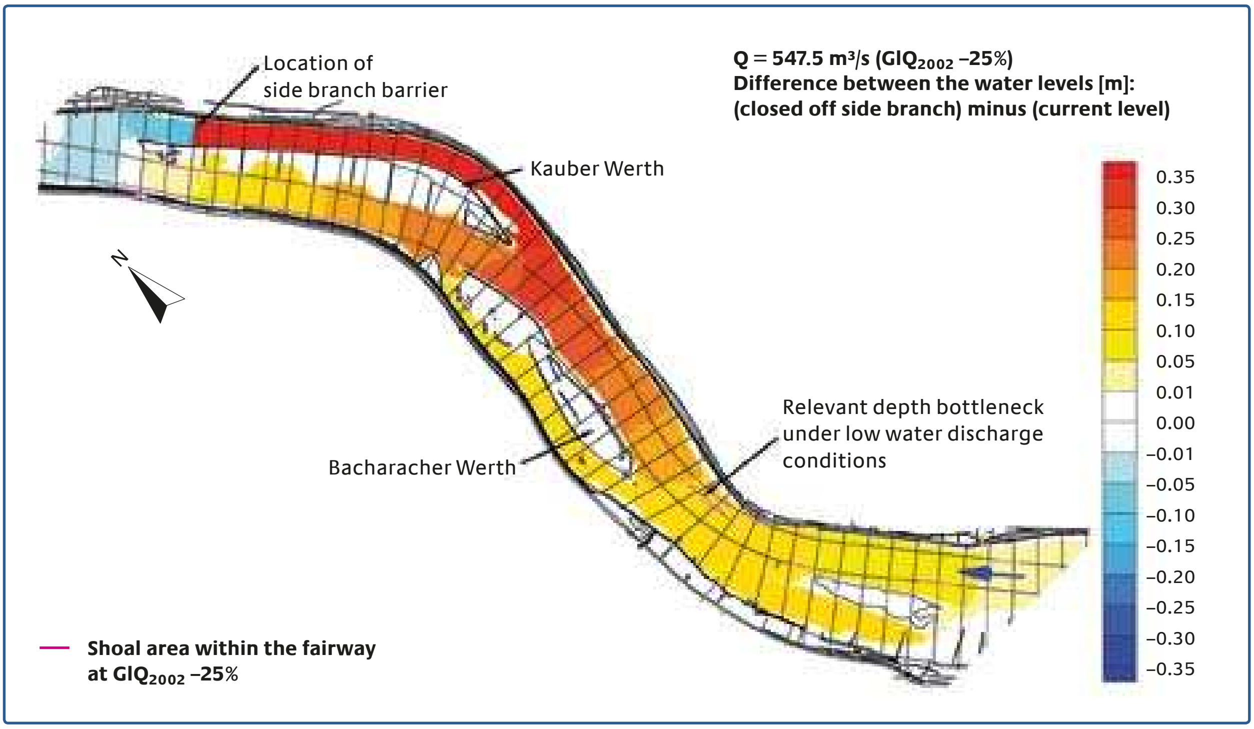

Figure 3: Effects of fully closing off the side branch of a river bifurcation on the water level in the event of extreme low water discharges

termination of the design feasibility of such a barrier structure that only takes effect in relevant low water situations requires more far-reaching fundamental investigations.

4 Conclusion/Outlook

The available projections regarding the possible discharge development as a consequence of climate changes indicate a potential increase in the intensity of low water situations in the distant future (2071–2100). This means that a hydraulic engineering based adaptation would be necessary to guarantee the ease and safety of shipping during low water periods also in the future.

Despite the pilot reach being trained almost on its entire length as a result of several upgrading phases in the past, there is still scope for hydraulic engineering based measures aimed at adapting the shipping conditions to future hydrological and morphological changes. From a purely technical point of view, deepening the fairway on a limited width is a suitable measure to achieve sufficient navigable water depths. One advantage of this approach as compared to deepening the fairway on its entire width is the reduced maintenance effort that can be expected.

An improvement of the navigable water conditions in aggradation areas within the fairway with continuously recurring can be achieved – with or without deepening the fairway on a limited width – by means of training measures that are aimed at increasing shear stresses in the aggradation areas and thus at reducing deposition rates.

Flexible training elements which only take effect in the event of low water discharges show a potential to increase water levels during such discharges that should not be ignored. However, there still is a considerable need for investigations in this context, in particular concerning design aspects.

As regards the implementation of the hydraulic engineering adaptation measures described here in other reaches of the German waterways, it is clear that, for reasons of the specific local characteristics of the pilot reach, not all measures mentioned can be considered generally suitable. Here, further investigations that are tailored to suit the conditions of the individual reach are required; however, these cannot be carried out in their entirety within the duration of the project.

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Determination of Minimum Fairway Widths by Means of Field Investigations

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1 Introduction

According to recent studies on the impact of climate change on the future conditions for shipping on the Rhine, longer and more intense phases of extreme low water are to be expected in the distant future (2071–2100) (see Nilson et al. in this volume). One possible adaptation measure to compensate for the economic losses resulting from a reduction in the maximum possible draught could be to increase the maintenance depth of the current fairway between Mainz and St. Goar by 2 dm. The present project examines relevant adaptation options from the point of view of navigational dynamics. As the limitations and possibilities of these options depend heavily on the dimensions of the fairway, the project determines the minimum fairway widths necessary to ensure safe and easy navigation. Among the adaptation options under investigation is a stepped fairway with an increased depth across the determined minimum width. Making use of existing excess water depths and the nautical possibilities of modern vessels as well as by implementing minimum widths, this adaptation option could substantially reduce the costs for maintaining the fairway depth compared to the costs for deepening the fairway over its current entire width.

The minimum widths are determined with the help of a navigational model, into which the instability of the vessel's course, the reduced rudder effect at low water levels, modern steering devices, autopilot systems and improved information systems in vessels of the future have been integrated. The impact of human skills and of a possibly increased occurrence of mistakes in case of more demanding circumstances during navigation through a bottleneck is to be taken account of by integrating a "human factor" into the autopilot system of the navigational model procedures. The autopilot system supplemented by the "human factor" makes it possible to run statistically comparable simulations for various possible future scenarios and for various adaptation options. Thus, it is to provide a basis for deciding on the design of future measures.

2 Methods

A first draft design of the course and width of a narrower and, if appropriate, graded fairway on the Middle Rhine was prepared by means of BAW's own two-dimensional navigational model PeTra2D on the basis of two-dimensional flow data. This draft is to be constantly revised in relation to further development stages of the model. The planned enhancements of the model are calibrated and validated by means of theoretical and numerical calculations on the basis of field investigation data as well as surveys of shipmasters.

In order to determine the thresholds of fairway widths in the case of reduced ease, if necessary, while maintaining safety, the required traffic space is to be mapped in a realistic manner by means of a route planning algorithm extended for 2D input data and the track control algorithm of a modern autopilot system (Institut für Systemdynamik of the University of Stuttgart, ISYS) embedded in standard optimisation models. The optimised traffic space requirement determined in this way is to be adjusted to the human, imperfect shipmaster by objectively determining section-specific safety clearances; this adjustment is achieved in cooperation with the Department of Human-Machine Systems Engineering of the University of Kassel by integrating the human factor into the track control algorithm by means of additional parameters. The modelling is based on surveys of shipmasters conducted during trial voyages on the Rhine with simultaneous analysis of the steered course lines.

3 Field investigations on the Middle Rhine

In autumn 2010 navigational field investigations were conducted between Rhine km 500 and 530. After performing a reference measurement, the fairway on the section from Rhine km 517 to 519.6 was narrowed from 120 m to 90 m in a second measurement phase.

3.1 Navigational investigations

During the navigational field investigations, 70 vessels were equipped with GPS receivers which recorded the position of the vessel every second. Thus, the track of the individual vessels was obtained. The findings from the investigations provide initial indications as to determining a minimum fairway width in straight sections with significant cross currents and thus for depth bottlenecks in the Rheingau Part of the Middle Rhine River. In accordance with current estimations, this width will be about 90 m; however, this still needs to be verified for higher water levels.

The findings also show that cross currents and the time course delayed or even incorrect reaction of the helmsman, e.g. to course deviations or instabilities of the vessel's course, have a considerable influence on the minimum width of the fairway and need to be quantified more accurately. The approach adopted here based on the interpretation of field data allows for direct dimensioning of observed standard situations. Furthermore, a spectral analysis of the vessel's movements to determine the share of turning and oscillating manoeuvres and "rudder work" allows for a pragmatic consideration of human factor effects.

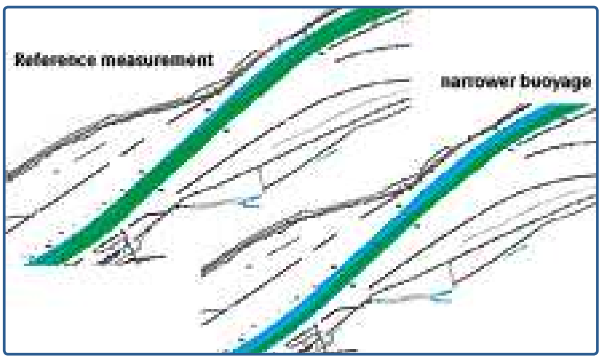

Figure 1: Tracks of all vessels moving upstream (green) during measurement phases I and II; the original fairway is shown in blue.

The data derived from field investigations, in particular on additional widths in narrow curves and in cross current fields for vessels of various widths, lengths and draughts, allow for the calibration and verification of the navigational model used. Such calibration is especially necessary in the case of high draught-to-water-depth ratios and in the case of asymmetrical vessel combinations or vessels with a high breadth-to-length ratio because the PeTra2D model reaches its application limit, so that the approaches implemented in the model to calculate force on the under water body of the vessels have to be modeled semi-empirically and calibrated by means of field and model data.

3.2 Conduct of a survey of shipmasters

In collaboration with the Department of Human-Machine Systems Engineering of the University of Kassel, a survey of shipmasters was conducted during the test voyages on the Rhine. The objective was to collect data on the subjective stress perceived by shipmasters navigating in the usual fairway or the fairway artificially restricted by buoyage on the section between Rhine km 517 to 519.5.

During the measurement phase with a restricted fairway, 28 shipmasters were surveyed. During the reference measurement with the current fairway width, 36 shipmasters were surveyed. In order to determine the subjective stress perceived by the shipmasters navigating the test section, a statistical analysis of 6 different statements was considered: physical, temporal, intellectual requirement; achieved success; required efforts and perceived frustration. These statements were weighted by the shipmaster himself.

Both measurement phases showed that, independent of the buoyage, the stress level on the test section (Rhine km 517 to 519.6) was 50 % higher than outside the test section (probability of error < 0.5 %). Presumably, this is attributable to problems connected with cross currents. In areas where cross currents occur, the track width for pushed convoys increases to up to 27 m. For comparison: In the Guidelines on standard cross-sections of canals, a value of 16 metres is mentioned. Thus, cross currents increase the required traffic space by approx. one vessel's width or by approx. 10 % of the usable fairway width in the area marked by buoys. Additionally, there may also be a cross drift which is not reflected in the track width. These comments may help to illustrate why in particular the short sections between islands with their cross currents are difficult to navigate. This is precisely where the river widens and sediment depositions in the fairway area occur. Thus, the areas where cross currents occur often coincide with those depth bottlenecks where it makes sense from the point of view of morphodynamics and maintenance to restrict the width of the fairway so that the dimensioning of the fairway must in particular take account of the influence of cross currents.

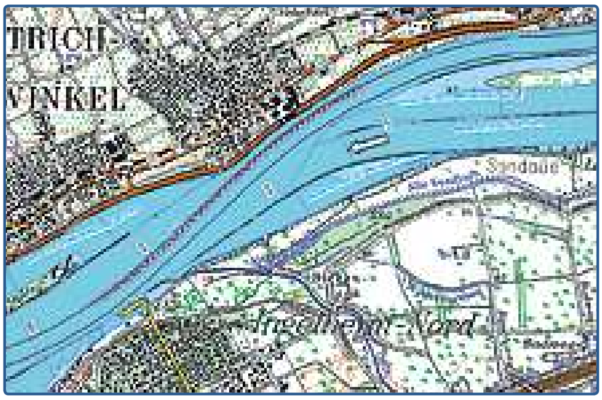

Figure 2: Test section of the trial voyages; red: narrowed fairway section; arrow: cross current from Große Gieß into Kleine Gieß

With regard to the stress of shipmasters, however, no significant difference could be detected between the narrowed fairway width and the reference measurement. This suggests that the problems due to cross currents are dominant in the test section and that the selected restriction of the width to 90 m in the section of the Rhine under investigation would be acceptable for low up to average water stages considered.

4 Conclusion / looking ahead

With the help of the findings from the field investigations, the navigational model and its task-specific further developments will be calibrated and validated. Moreover, in collaboration with the Department of Man-Machine Systems Engineering of the University of Kassel, parameters for a "man-model" are to be deduced by means of field investigations to make it possible to consider the so-called "human factor", i.e. the safety aspects in the case of "human" or even "incorrect" navigation as opposed to optimal navigation. Furthermore, the auto pilot for the fast-time-simulation with PeTra2D will be expanded to include the options optimal steering, customary steering, steering with mistakes.

By taking into account the probability of occurrence of certain navigation situations such as meeting or overtaking manoeuvres of vessels of various sizes in certain sections, using the example of the Middle Rhine a proposal for an approach to optimise the width and the course of the fairway shall be provided at the end of the project.

The aim of this project, together with the hydraulic and morphodynamic investigations carried out within the framework of project 4.03, is to identify from the point of view of navigational waterway engineering the opportunities and limits of adaptation options based on these investigations with a view to reducing the restrictions on inland navigation resulting from climate change.

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Past and Future Development of Suspended Loads in the Rhine

Gudrun Hillebrand, Thorsten Pohlert & Stefan Vollmer (all BfG)

1 Introduction

Fine sediments in the federal waterways are subject to a dynamic transport process. They are deposited in areas with reduced flow velocity and can also be eroded again. In addition, fine sediments are frequently contaminated. Maintenance measures such as dredging of fine sediments therefore often involve very high costs. Thus, potential challenges caused by the projected changes in the climate will be a key issue in sediment management.

Prior to the analysis of future trends, the current situation and the development of the past decades should be examined. First, it is examined whether, already in the past, trends could be observed which may persist in the future. In order to do so, it is necessary to take a critical look at the causes of such trends. A representative example will be shown below.

Then, the results of a first sensitivity study on the influence of climate change on soil erosion in the river catchment area and the resulting sediment input into the river basin will be presented.

2 Suspended loads in the Rhine between 1965 and 2005

The basic dataset for examining the suspended loads is provided by the permanent monitoring network for suspended solids of the Waterways and Shipping Administration (WSV). The monitoring network has been in place since the mid-1960s and was expanded to include 70 measuring stations by the mid-1990s. Each working day, a 5 litre bailed water sample is collected at these measuring stations. The sample is passed through a gravimetric filter directly at the measuring station and the filters are then temperature controlled and weighed at the sediment laboratory of the Federal Institute of Hydrology. The measurement resulting from the analysis describes the suspended-solids concentration at the site and at the time of the sample collection.

The long-term time series of daily values of suspended-solids concentration which are provided by the permanent monitoring network for suspended solids are a suitable basis for analysing trends over time. This is to be illustrated with an example. Figure 1 shows the annual suspended loads at the Maxau measuring station on the Rhine at km 362.3 in million tonnes per year plotted against the time span since the mid-1960s.

The figure shows a significant decrease ($p < 0.05$) in the loads up to the completion of the construction of the barrages at the Upper Rhine which is illustrated by a linear regression. The time series after the last barrage at Iffezheim was put into operation in 1977, however, shows no significant trend in the statistical test which is symbolized in the figure by a blue dashed line representing the averaged value of all annual loads after 1977.

The figure also demonstrates the considerable range of natural fluctuation in the annual suspended solids loads. In the years 1995 and 1999 when the discharge of

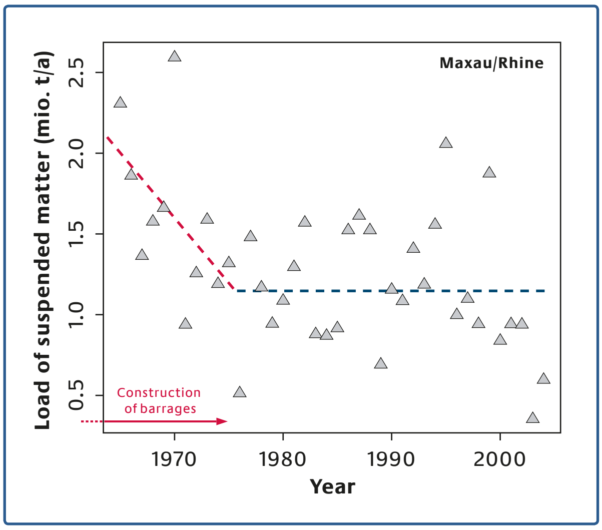

Figure 1: Annual suspended loads at the Maxau measuring station (Rhine km 362.3)

the Upper Rhine was high, the annual loads were above-average, whereas a low annual load can be observed for the low-discharge year 2003 (about one quarter of the annual load in 1999). Within this high natural variability, the data recorded so far do not provide clear indications of an impact of climate change. The presented example of the Maxau measuring station is representative in this respect. At other measuring stations, too, observed trends can be attributed to direct human interventions such as the construction of barrages or changes in land use. It is to be expected that such influencing factors will play a major role in the future, too.

3 Projections of sediment yield in the Rhine catchment up to 2100

In order to establish a projection of sediment input in large river catchments, a model system made up of two components is required. The first component is a soil erosion model, the second a sediment delivery module.

The average long-term soil erosion was calculated with the spatially distributed PESERA model (Kirkby et al. 2008) for the entire catchment area on a 500 × 500 m grid. For the reference simulation, the climate parameters required to run the model were derived from interpolated station data. For the projections, climate parameters from the comparison of three climate model chains (EH5r3_REMO, EH5r3_RACMO and HADCM3Q0_CLM) on the basis of the A1B emission scenario were used. Spatially distributed information on relief, soil properties, land cover and land use for PESERA was derived from the available national datasets for the German parts of the Rhine catchment area and from the freely accessible European datasets for the respective parts of the neighbouring countries. In order to be able to estimate the climate sensitivity of soil erosion and sediment yield, these derived basic conditions were kept constant in all model runs. The sediment input into the water network was derived from the modelled spatially distributed soil erosion rates (Ali & De Boer 2010), taking into account a spatially distributed sediment-delivery-ratio approach (SDR).

In a first step, the data on soil erosion in Germany were taken from the literature in order to validate the results of the PESERA model. The average soil erosion rates for each land use class calculated by PESERA for the period from 1961 to 1990 are quite consistent with the data provided by Auerswald et al. (2009) (Table 1). Only for the land use class “vineyards”, PESERA considerably under-predicted soil erosion in the Rhine catchment which is due to inaccurate land use classifications when the data were processed (vineyards were classified as arable land). As, however, vineyards merely account for about 0.2 % of the surface in the Rhine area, this error is negligible for the overall soil erosion in the Rhine catchment.

In a second step, the sediment yield calculated by multiplication of the sediment-delivery-ratio with

Table 1: Comparison between the present (1961 to 1990) average soil erosion rates for each land use class in the Rhine catchment according to the PESERA model, the calculations made by Auerswald et al. (2009) for the federal territory and the long-term averaged data taken from the literature on soil erosion measurements.

Land use	Soil erosion (t/ha) according to PESERA	Soil erosion (t/ha) according to the calculations by Auerswald et al. 2009	Soil erosion (t/ha) according to measurements (taken from Auerswald et al. 2009)
Arable land	8.5	5.7	15.2
Vineyards	0.0	5.2	5.4
Grassland	0.6	0.5	0.5
Forest	0.3	0.2	0.0

PESERA soil erosion and consequent summation within a sub-basin were compared with the averaged long-term specific loads of suspended sediments provided by the permanent monitoring network for suspended sediments of the Waterways and Shipping Administration for the current situation (1961–1990) (Figure 2). Agreement with the measured data was satisfactory so that an application for the projection calculations seemed appropriate.

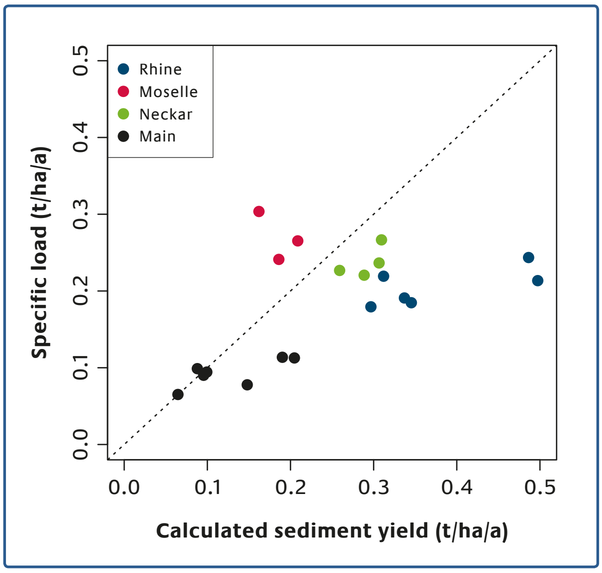

Figure 2: Scatter plot of the calculated sediment yield against the measured specific load. The line of identity is displayed as a dashed line.

The projection calculations showed that, in view of the model uncertainty, no clear climate change indicator can be identified so far for the sediment yield into the rivers Moselle, Main and Neckar in the German uplands. By contrast, a clear climate change indicator can be identified along the main stream of the Rhine, as 3 out of 3 calculations projected an increase in sediment yields for the period between 2021 and 2050 (Table 2).

Table 2: Tendency of the change. To determine this tendency, the number of projection calculations predicting an increase or decrease was counted and the relative amounts of change were related to the model uncertainty.

River basin	2021–2050	2071–2100
Moselle	indifferent	indifferent
Main	indifferent	indifferent
Neckar	indifferent	indifferent
Main stream of the Rhine	increase (3 out of 3)	increase (2 out of 3)

According to the evaluated projection calculations, there will be increased sediment delivery from the Swiss alpine region, in particular, via the Aare River to the Rhine, assuming no changes in land use will take place. The increase in sediment yield at the confluence of the rivers Aare and Rhine at Albbruck-Dogern for the period from 2021 to 2050 will be between +20 % and +100 % in relation to the current state (1961–1990) (Table 3). This modelled increase in sediment yield or modelled increase in soil erosion rates is consistent with the results of the climate models which predict a trend towards a relative increase of rain in hydrological winter for the alpine region.

Table 3: Margin of relative change in sediment yield along the main stream of the Rhine calculated with the PESERA-SDR on the basis of three climate projection calculations. The measuring stations are listed in downstream order.

Measuring station	2021–2050	2071–2100
Reckingen	+20 % to +30 %	0 % to +50 %
Albbruck-Dogern	+20 % to +100 %	−13 % to +100 %
Plittersdorf	+20 % to +80 %	−10 % to +90 %
Maxau	+20 % to +80 %	−10 % to +90 %
St. Goar	+10 % to +40 %	−15 % to +50 %
Weißenthurm	+10 % to +30 %	−10 % to +40 %
Emmerich	+10 % to +25 %	−10 % to +40 %

4 Summary and Outlook

In the measuring series of the suspended loads within the reference period, no changes can be detected which can clearly be attributed to climate change. The pronounced anthropogenic influence on the river systems, however, is clearly reflected in the suspended loads. The construction of barrages or land use changes have sometimes led to significant changes in the suspended loads in the past. It is to be expected that such influencing factors will play a major role in the future, too.

The work on the projection calculations was carried out by Scilands GmbH on behalf of the Federal Institute of Hydrology. The results obtained so far show that especially the Swiss alpine region is of major relevance for the sediment delivery to the Rhine and will react strongly to projected climate changes with an increase in sediment delivery. It is planned to continue the projection calculations and expand them to include further climate model chains.

In the further course of the project, aside from the projected changes to the sediment inputs, climate-induced changes in transport processes within the rivers will be examined. For large-scale budgeting within the river reaches, one-dimensional numerical sediment transport models are used which take account of the projected sediment yield and projected discharge parameters. For certain questions of detail, such as the sediment dynamics within the impounded reaches, three-dimensional sediment transport models are used because one-dimensional models do not allow for an adequate representation of the flow and transport situation here.

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Development of the Particle-Bound Pollutant Loads in the Rhine taking Hexachlorobenzene (HCB) as an Example

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1 Introduction

Within the framework of the KLIWAS research project "Climate Projections for Sediment Budgets and Risks due to Cohesive Sediments", model-based statements are to be made on the future development of the hexachlorobenzene (HCB) pollution of fine sediments of the Upper Rhine. For both the analysis of the causes and the model generation, knowledge of the historical pollutant development in the suspended particulate matter as well as the identification of the current pollutant reservoir are required. Accordingly, the aims of this study are to identify trends in the quality of the suspended particulate matter along the main branch of the Rhine, to determine the current reservoir of sediments polluted with HCB and to draw first conclusions regarding future sediment quality and suspended matter quality under climate change.

The sediment management plan of the International Commission for the Protection of the Rhine (ICPR) classified several sedimentation areas as "areas posing a risk" due to their high level of contamination with hexachlorobenzene (HCB) and the risk of the remobilisation of these polluted sediments (ICPR 2009). The persistent and highly sorptive HCB originates from former industrial discharges near Rheinfelden. The HCB pollution of the sediments that are deposited also affects the regional dredged material management of the Waterways and Shipping Administration (WSV). Therefore, the examination of the HCB pollution of the Upper Rhine sediments is treated as a priority within the framework of this KLIWAS project.

2 Hexachlorobenzene and pollution history

HCB is a hexa-chlorinated, highly sorptive benzene compound. Accordingly, HCB is usually present in a particle-bound state in water bodies. Under ambient conditions, the substance degrades only very slowly (persistence) and has bioaccumulative properties. Due to its high risk potential for humans and the environment, the production of HCB was banned under the Convention on Persistent Organic Pollutants (Stockholm Convention). The EU Water Framework Directive WFD classifies HCB as a priority hazardous pollutant.

The pollution of the fine sediments of the Rhine originates from historical discharges from a chemical production facility near Rheinfelden (Rhine km 148.4). In the period between the 1970s and the beginning of the 1990s, HCB occurred as a by-product in the production of pentachlorophenol and chlorosilane. In 1984, the daily discharge of HCB was around 400 g; by 1991, the amount had been reduced to less than 40 g. Since 1993, virtually no HCB has been discharged near Rheinfelden (Ständige Kommission 2007).

3 Trend of HCB pollution of suspended particulate matter

First, trend analyses of the HCB concentration in the suspended particulate matter were carried out for eight monitoring stations along the Rhine for the period between 1995 and 2008. The data originate from the ICPR and are available in the form of instantaneous 28-day measurements. The Mann-Kendall non-parametric trend test was used; it checks the null hypothesis of "no trend present" against the alternative hypothesis of "trend present" and calculates both Kendall's-τ as well as Sen's slope. At all eight monitoring stations, there is a significant decline in the HCB concentration over the survey period (negative τ values). However, this declining trend is very weak as is reflected in the low values of Sen's slope.

Table 1: Results of the Mann-Kendall trend test for HCB concentrations in suspended particulate matter (1995–2008) along the main branch of the Rhine. τ, b_{Sen} and n stand for Kendall's-τ, Sen's slope and the sample size. All values are significant ($p < 0.05$). Highly significant ($p < 0.01$) values are marked with** (Source: POHLERT et al. 2011a).

Measuring point	Rhine km	τ	b_{Sen} [ng kg^{-1} a^{-1}]	n
Weil	164.3	−0.303**	−11	156
Karlsruhe	333.9	−0.193**	−35	135
Mainz	498.5	−0.130	−19	150
Koblenz	590.3	−0.147	−11	156
Bad Honnef	645.8	−0.345**	−34	133
Bimmen	865.0	−0.454**	−50	141

The same statistical methods were then used to analyse the trend of the annual loads of particle-bound HCB for the period from 1995 to 2007. Highly significant declining trends in HCB loads could only be determined for the monitoring stations Bad Honnef ($\tau = -0.576$; $p < 0.01$) and Bimmen ($\tau = -0.576$; $p < 0.01$). At the other monitoring stations, no trend could be determined for this period. For the Koblenz measuring point, additional data were available (KELLER 1994); therefore, it was possible to analyse the annual HCB load for the period from 1985 to 2007. For this measuring point and the analysed period, the annual HCB load shows a clear decline from around 110 kg/a in 1985 to around 15 to 23 kg/a in 2007. The reason for this decline in the annual HCB load is the end of the HCB discharges near Rheinfelden at the beginning of the 1990s. Between 1995 and 2007, however, the annual HCB loads at the Koblenz measuring point stagnated at an average of around 25 kg/a. Moreover, an examination of the longitudinal river profile of the long-term average HCB load showed that the Rhine tributaries Neckar, Main and Moselle only supply negligible amounts of HCB. The major source region of HCB is the regulated Upper Rhine from which an average of around 25 kg/a of HCB is released from secondary sources (POHLERT et al. 2011a).

4 Determination of the current reservoir of HCB-polluted sediments

In August 2010, longitudinal sampling was carried out along the Rhine between Weil (Rhine km 164.3) and Strasbourg (Rhine km 290) in which grab samples of sediments near the surface (<50 cm) were taken from on board a dredger on the sections of the French Grand Canal of Alsace and the Rhine. In the case of the non-navigable river branches with weirs, the sampling was done from the banks. A total of 60 sediment samples were taken. The analysis of the sediments included the measurement of the grain size distribution by means of wet sieving in an ultrasonic bath and the quantitative determination of organic carbon, HCB and poly-chlorinated biphenyls in the total fraction (POHLERT et al. 2011b).

The concentration of HCB in the sediments near the surface of the Upper Rhine ranged from 13 µg/kg to 880 µg/kg. Around 55 % of the sediment samples showed concentrations more than four times higher than the ICPR target; this is one of the decision criteria used in the definition of an "area posing a risk" in the ICPR Sediment Management Plan. There is a clear gradient indicating an increasing HCB concentration in the sediments along the course of the river (Figure 1). At Weil (Rhine km 164.3), which is closest to the historical point of discharge, HCB concentrations are lowest (13 µg/kg). By contrast, HCB concentrations are very high in the low-flow sedimentation areas (areas with weirs, upstream lock entries, port basins) from around Rhine km 210 onwards. This is an indication of the gradual downstream transportation of HCB-polluted sediments.

5 Conclusion / looking ahead

Ending the HCB discharge at the beginning of the 1990s helped to achieve a considerable reduction in the particle-bound HCB load in the Rhine. However, since 1995, there has been no decline in HCB loads. The long-term average of HCB released from the Upper Rhine is around 25 kg/a. Studies on the HCB pollution of the sediments in the Upper Rhine showed that a considerable pollut-

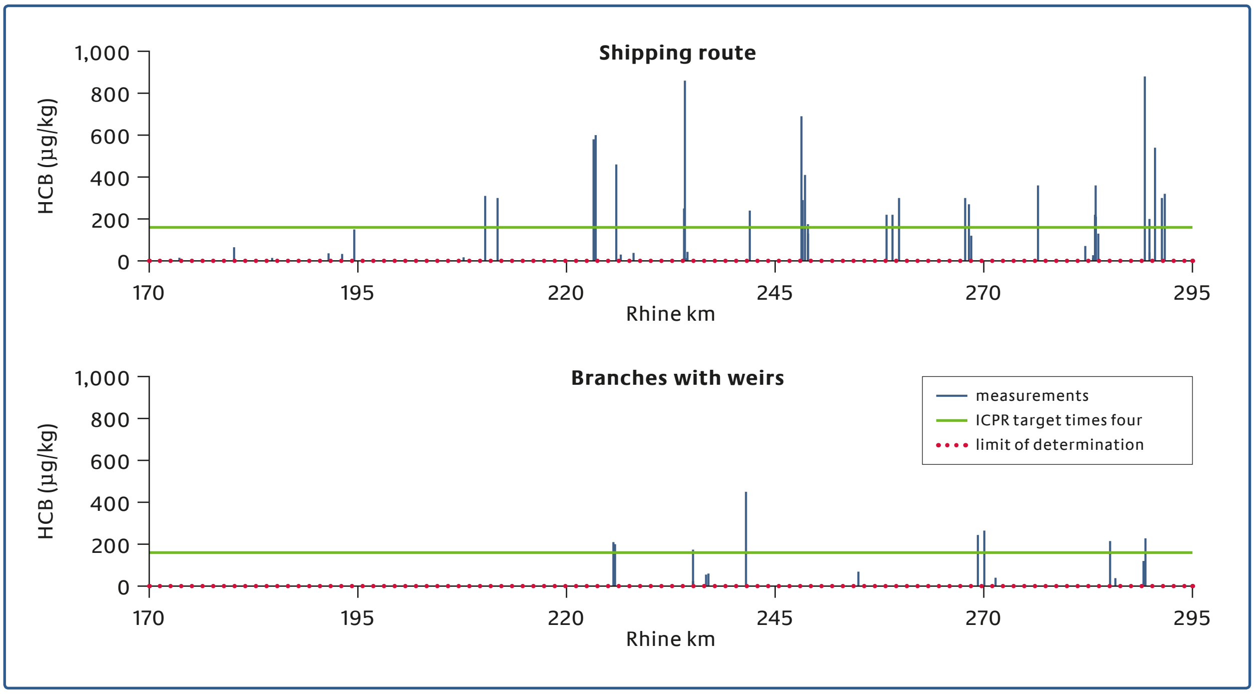

Figure 1: Longitudinal profile of HCB concentration in the sediments near the surface of the Upper Rhine along the shipping route (French Grand Canal of Alsace and Rhine main routes) as well as along the non-navigable branches with weirs (modified in accordance with POHLERT et al. 2011b)

ant reservoir is present there. For these reasons, it seems unlikely that the environmental quality objectives within the framework of the EU WFD and of the ICPR can be achieved in the short or medium term. Proposals for action on how to deal with the identified secondary sources of HCB in the Upper Rhine are provided both in the Sediment Management Plan Rhine (ICPR 2009) as well as in the BfG report 1717 (POHLERT et al. 2011b).

As part of the research project work still to be completed, a hydrodynamic 1D model for the Upper Rhine will be developed with whose help the particle-bound HCB transport under changed discharge conditions can be simulated using the advection-dispersion equation. This model fits into the KLIWAS model chain and uses the simulated discharge sequences of the hydrological model HBV for its realization. The data on the HCB pollution of the sediments are used for the parameterization of the initial conditions. The data on the HCB concentration in the suspended particulate matter or on the particle-bound HCB load serve to calibrate and validate the model.

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Modelling Water Temperature and Plankton Dynamics in the Rhine

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1 Introduction

Changes in the discharge and temperature conditions which occur as a consequence of climate change have an impact on the suspended matter content and phytoplankton dynamics in the Rhine. This impact must be analysed and quantified since different water quality parameters, such as oxygen content, nutrient content or also phytoplankton biomass may react to climate changes with a different sensitivity and may thus have an influence on the Rhine habitat. Lower discharges in summer, for example, may lead to enhanced phytoplankton growth which may entail changes within the food network and thus have an impact on the entire ecosystem. Increased sedimentation and changes in the turbidity in the free water column may also occur.

Anthropogenic factors and changes in river morphology which may have an influence on ecological variables must also be taken into account. The water temperature illustrates the interaction of climatological and anthropogenic influences (Webb et al. 2008) and plays a decisive role, not only for biological but also for chemical and physical processes. In the Rhine, the water temperature which mainly depends on the energy from solar radiation, the heat loss through evaporation and the heat exchange with the ambient air, is additionally subject to anthropogenic influences resulting from direct thermal discharges from industries and power plants (ICPR 2006, BUND 2009). Long-term observations of the average water temperatures in the Rhine have shown that they have increased by about 2.5 °C between 1970 and today (BUND 2009).

Since both climate change as well as numerous direct anthropogenic factors influence water quality, water quality modelling is a suitable method for examining these complex interactions. Water quality modelling allows for an integrated assessment of climate change impacts, water quality impairments and possible management options.

2 KLIWAS project 5.02 and QSim

The KLIWAS project 5.02 'Impacts of climate change on nutrient and phytoplankton dynamics in navigable rivers' includes both impounded waters (waters in and around Berlin) as well as largely free-flowing waters (Rhine and Elbe). Here, the QSim water quality model of the Federal Institute of Hydrology (BfG) is applied to analyse and quantify climate-induced changes in oxygen content and plankton dynamics (nutrients, algae biomass, organic and inorganic suspended matter) (Kirchesch & Schöl 1999). QSim is a process-oriented, deterministic water quality model whose individual components are subject to continuous further development (Becker et al. 2010). The model requires morphological, hydrological, meteorological, physical, chemical and biological input variables at the model boundaries in order to calculate the development of the water quality along the entire course of the river. Processes such as sedimentation, thermal balance, oxygen / nutrient content, bacterial growth and algae growth (Figure 1) are simulated.

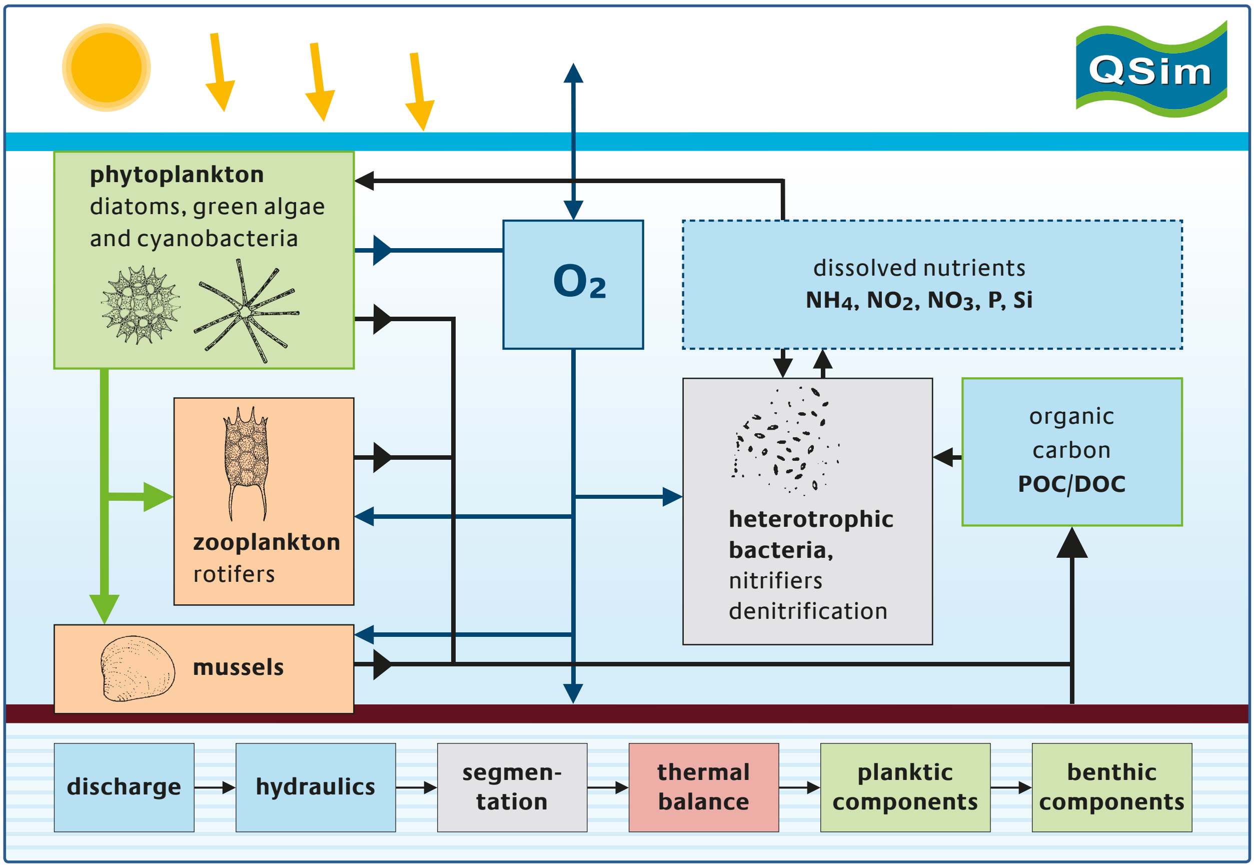

Figure 1: Model components and functioning of QSim (Schöl et al. 1999, 2002, 2006)

3 Modelling of the water quality in the Rhine

The Rhine model includes the free-flowing section of the Rhine with an overall length of 529 kilometres. The upper boundary of the model is located below the last barrage at Iffezheim (km 336.5), the lower boundary is delineated by the German-Dutch border (km 865.5). The boundary conditions of the model further include 12 tributaries. At present, 16 uses of water bodies (thermal discharges) are included, taking into consideration only the most significant thermal discharges (yearly average of over 200 MW) and using the maximum admissible quantities of heat input (ICPR 2006, BUND 2009) since no information is currently available on the actual quantity of heat input from these discharges. For water quality modelling, complete datasets of the water quality at the model boundaries, i.e. at the upper and lower model boundary as well as at the tributaries are required. These input data include, for example, measured data on nutrient concentrations, oxygen content or plankton composition. Initially, the input data are kept constant. The input data for the meteorological stations are provided by the German Meteorological Service (DWD) (Research Task 1, Project 1.01, 1.02). These are: air temperature, global radiation, wind speed, atmospheric humidity and cloud cover. Climatological input data from a total of three meteorological stations along the course of the river are used. Hydrological input data (discharge and water level) which are required at the model boundaries and the tributaries are taken from

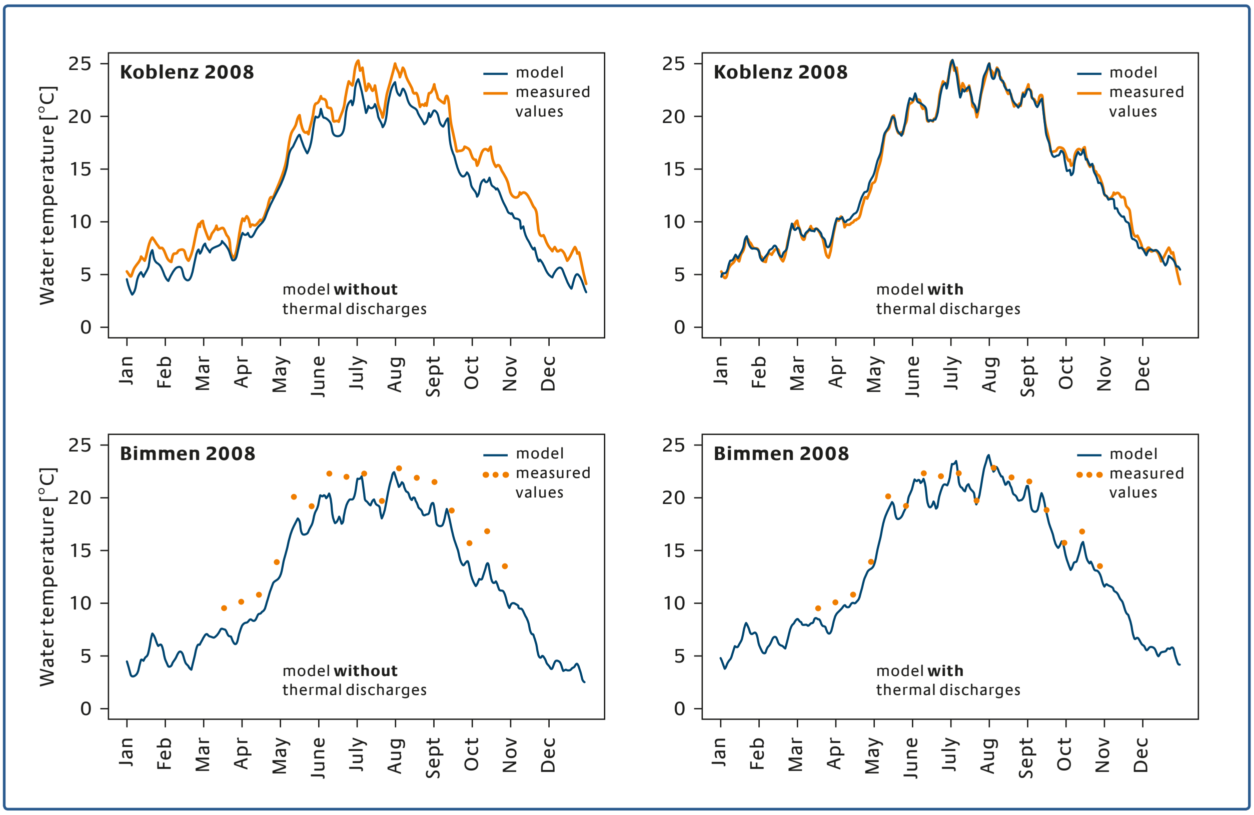

Figure 2: Temperature dynamics (2008) modelled and measured at Koblenz (km 590) and Bimmen (km 865.5)

the corresponding time series of water levels or, for projections, are calculated with water balance models (Research Task 4, Project 4.01 – see NILSON et al. 2012, this volume).

The model results on the current status of the water temperature (Figure 2) demonstrate that the thermal discharges of anthropogenic origin have a high impact on the water temperature, depending on the distance between the discharge site and the measuring station. At Koblenz, for example, the modelled water temperature with thermal discharges is 1.5 °C higher by average than the modelled temperature which does not take thermal discharges into account. This anthropogenic influence must be taken into account when assessing any future climate-induced increases in water temperature.

The annual dynamics of the oxygen content (Figure 3) are well reflected, the oxygen contents of the years 2000 and 2008 at Koblenz (about midway along the examined reach of the river) and Bimmen (at the end of the examined reach) are slightly overestimated by the model. The lower oxygen content in the summer months is a consequence of the lower oxygen solubility at higher water temperatures. In the case of a future increase in water temperature, a decrease in oxygen concentrations must be expected. However, this effect might be partly offset by an increase in algae growth. The biomass of plankton algae (phytoplankton, measured as chlorophyll content) is also related to oxygen content since higher amounts of phytoplankton biomass may lead to increased oxygen production and, after a certain interval of time, also

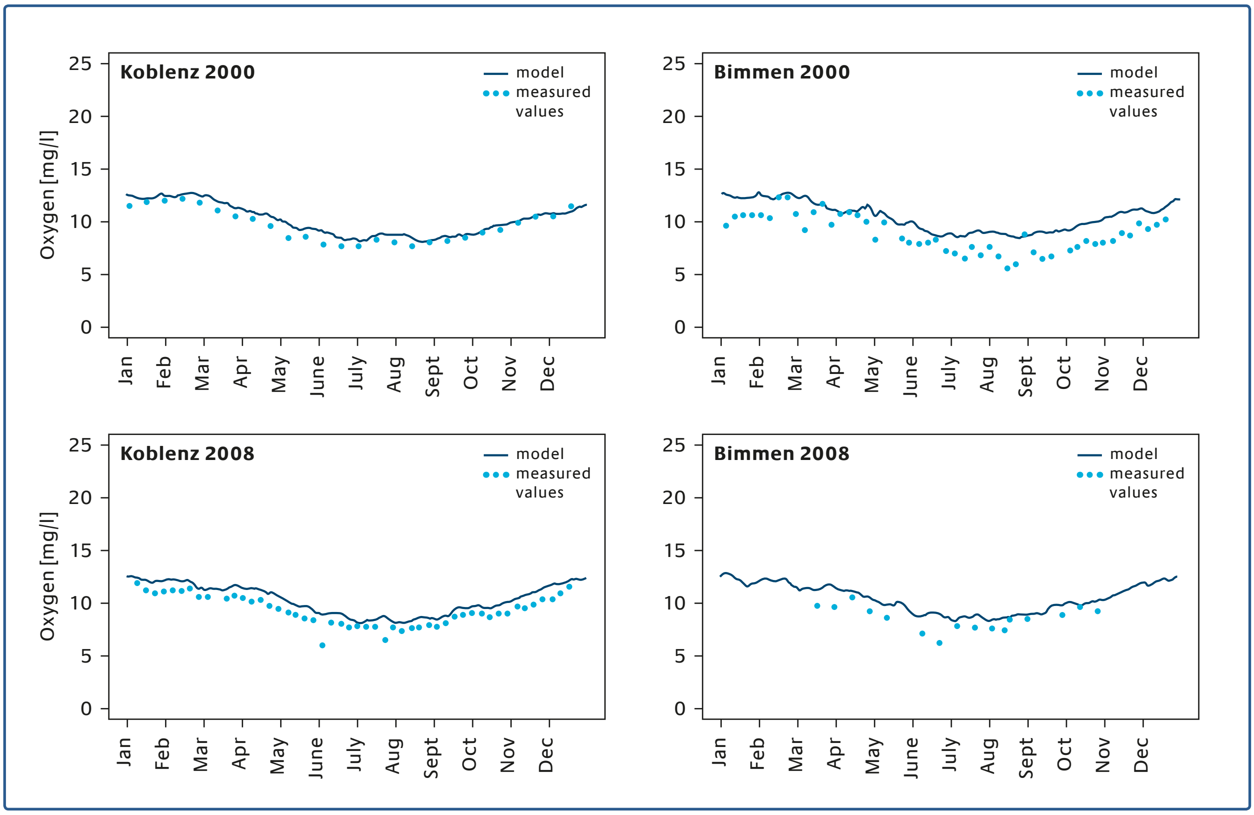

Figure 3: Oxygen dynamics (2000/2008) modelled and measured at Koblenz (km 590) and Bimmen (km 865.5)

to an increased oxygen depletion which results from the degradation of algae. Drawing on the results obtained so far in Project 4.01, a decrease in discharges during summer is expected to take place especially in the distant future which may lead to an increased phytoplankton growth in this season.

Just like the oxygen content, the current state (2000 and 2008) of the chlorophyll content (Figure 4) is very well reflected. The model calculations show the typical mass development of algae in spring, the so-called spring bloom, and an overall increase in chlorophyll content between Koblenz and Bimmen. The phytoplankton biomass doubles along the course of the river and maximum chlorophyll concentrations of 43 µg/l are reached at Bimmen.

4 Conclusion / looking ahead

The QSim water quality model is used since 1979 at the Federal Institute of Hydrology for simulating and forecasting the water quality of watercourses and serves as an instrument to assess the impacts of hydraulic engineering measures and other influences on water quality.

As the results of the modelling of the current status show, the development of the water temperature strongly depends on the extent of the thermal discharges of anthropogenic origin which could thus broaden the range of the rise in water temperature to be expected. Especially with regard to the distant future, it might be necessary to adjust the maximum admissible quantities of heat input here. Simulation calculations allow for a better assessment of the impacts of

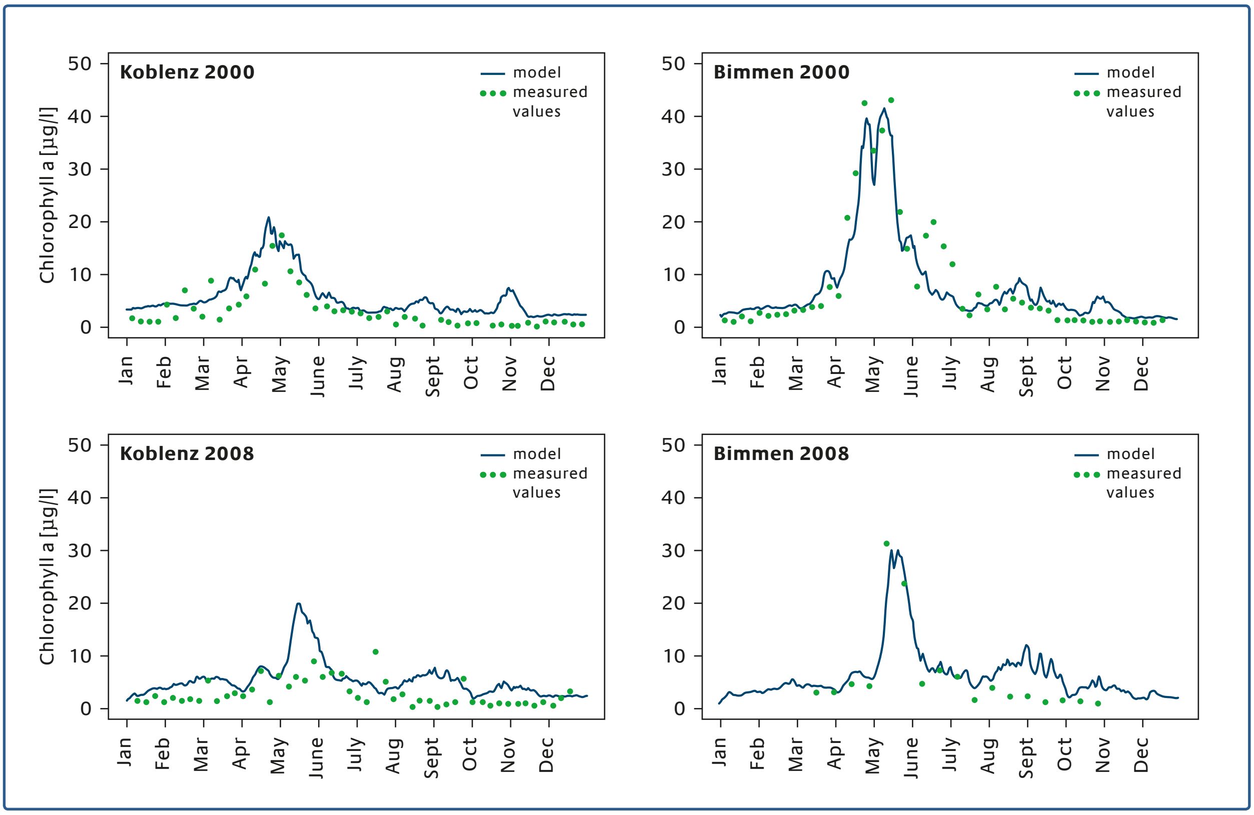

Figure 4: Phytoplankton dynamics (2000/2008) modelled and measured at Koblenz (km 590) and Bimmen (km 865.5)

such management options and the future development of the ecological situation.

The next step is the modelling of the future development of the water quality in the Rhine, taking into account different representative climate and discharge projection data from an ensemble of model chains. These selected model chains from the global and regional climate models serve as a basis for estimating the range of the possible development of the water quality in the near (2021–2050) and distant (2071–2100) future, especially with regard to the phytoplankton and water temperature development. Since algae development in the Rhine is partially determined by discharge dynamics, the NM7Q (lowest arithmetic mean discharge over 7 consecutive days) serves as a selection criterion for the model chains to be used. The results concerning the future development of water temperature which are based on climate and discharge projection data are also used in follow-up projects within KLIWAS. These projects cover the areas of microbial water quality, organic pollutants and animal ecology (Projects 5.03/3.04; 5.04/3.07; 5.07).

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Impacts of Climate Change on the Elbe

Changes in Water Balance Components in the Elbe Catchment – Challenges and Solutions

Theresa Horsten, Peter Krahe, Enno Nilson, Jörg Uwe Belz, Anna-Dorothea Ebner von Eschenbach & Maria Larina (all BfG)

1 Introduction

Within the framework of the project "Water balance, water level and transport capacity" (Project 4.01), the influence of climate change on the streamflow of the federal waterways, including, among others, the Elbe and its tributaries, is being determined. In order to estimate and assess the impacts of climate change on the water balance of a catchment, knowledge of the dominant factors that have an effect on the water balance and the streamflow regime are of fundamental importance. Due to the lack of certainty of climate projections, statements regarding the hydrological impacts of climate change should also encompass a quantification of the uncertainties. This is achieved by means of a multi-model approach.

Following a brief characterization of the Elbe catchment, this article presents the preliminary results of discharge projections for the Havel-Spree catchment.

2 Characterization of the water balance in the Elbe catchment

The Elbe river basin is located in the temperate climate zone in the transition area between a maritime and a more continental climate. Thus, it is different from the Rhine river basin, where the maritime influence is stronger (cf. Table 1). The more continental climate is reflected in the greater temperature differences between winter and summer periods as well as in the comparatively low annual precipitation of around 630 mm (Rhine: around 950 mm) (ICPER 2005).
This leads together with a high potential evaporation to significantly less water availability and therefore less

Table 1: Main characteristica of the Havel, Elbe and Rhine catchments (source: ICPER 2005, Belz et al. 2007)

	Havel catchment	Elbe catchment		Rhine catchment		
Catchment area	23,858 km²	148,268 km²		185,000 km²		
Length of river	334 km	1,094 km		1,239 km		
Population	4–5 million	24 million		60 million		
Mean discharge (MQ), river mouth	~114 m³/s	~860 m³/s		~2,500 m³/s		
		CZ	D	DE	CH	FR+LU
Proportion of discharge		~36 %	~64 %	~47 %	~40 %	~12 %
Proportion of area		~34 %	~66 %	~55 %	~15 %	~30 %
		1.06	0.97	0.85	2.67	0.40
Water balance (as regards the entire catchment area, long-term average)						
Precipitation	~560 mm	~630 mm		~950 mm		
Evaporation	~410 mm	~450 mm		~550 mm		
Discharge = water yield	~150 mm	~180 mm		~400 mm		

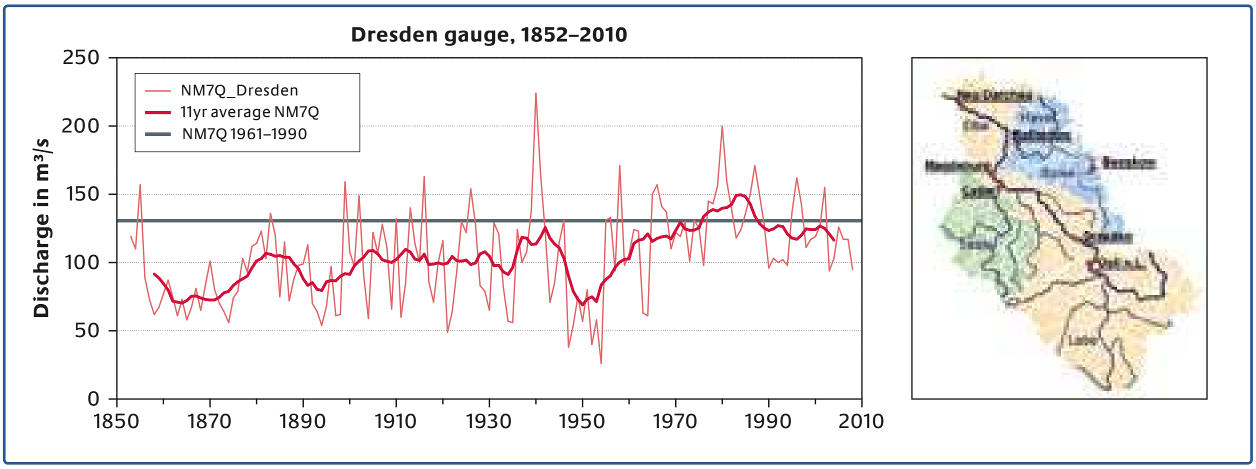

Figure 1: Development of low water discharges (NM7Q – lowest 7-day average) at the Dresden/Elbe gauge

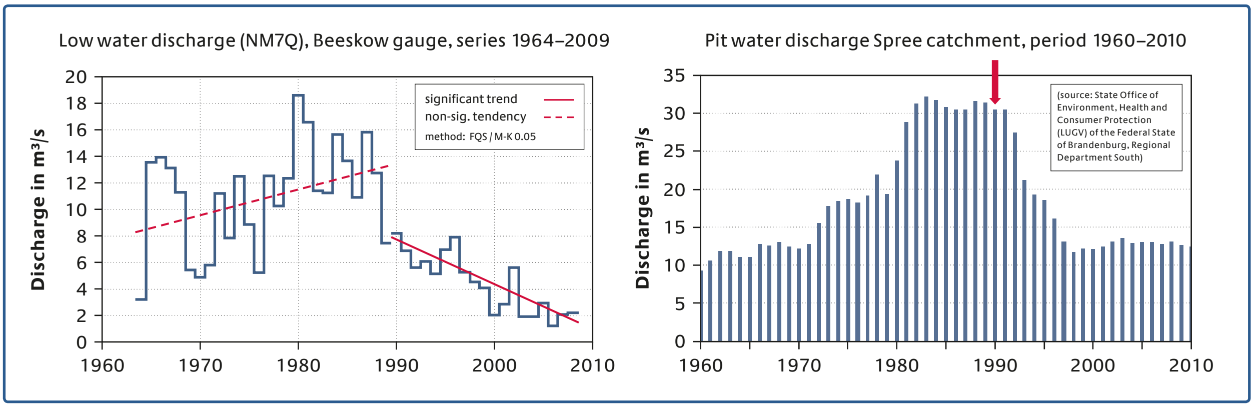

Figure 2: Development of low water discharges (NM7Q – lowest 7-day average) at the Beeskow/Spree gauge (left) and of pit water discharges in the Spree catchment (right)

discharge (cf. Table 1) in the Elbe river compared to the Rhine river.

Historically and also today, the natural discharge conditions in the Elbe catchment show intensive anthropogenic influences as a result of various interventions. An example of this is the so-called Vltava cascade (a system of reservoirs in the Czech part of the Vltava), which saw its greatest increase in volume in the 1950s and 1960s and whose effect in terms of increasing low water levels is clearly noticeable at the Dresden gauge.

The series of the low flow parameter NM7Q (lowest discharge averaged over seven days) at the Dresden gauge provided in Figure 1 shows a significant increase in low water discharges in the 1950s and 1960s.

The release of water from surface mining is a further example of how anthropogenic interventions change the discharge conditions. Figure 2 shows the series of the low water discharges (NM7Q) for the period from 1964 to 2009 at the Beeskow/Spree gauge as well as the development of the annual mean pit water discharges

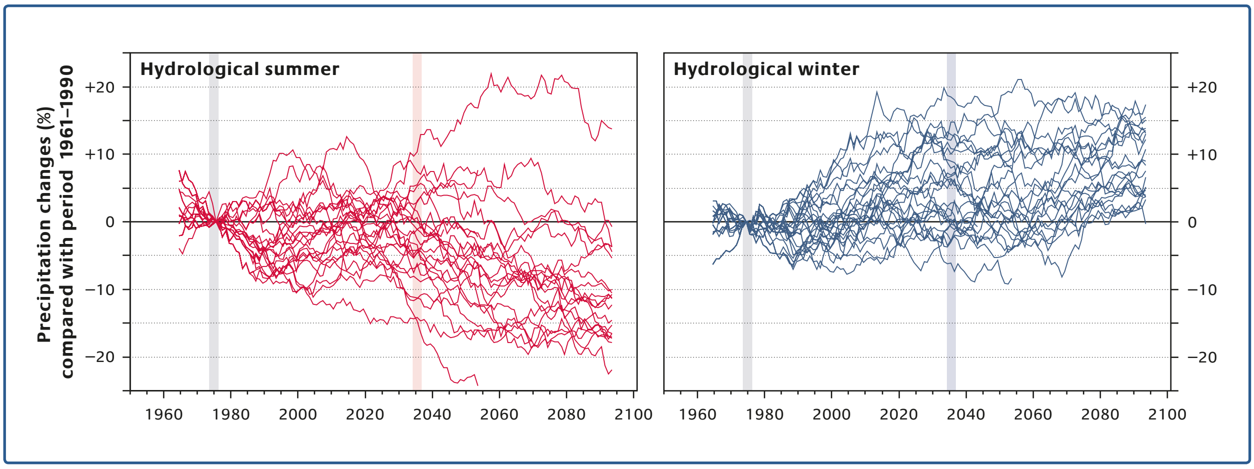

Figure 3: 31-year moving average of the seasonal precipitation changes in the catchment upstream of Rathenow/Havel gauge as compared with the reference period 1961–1990 (grey bar) based on an ensemble of currently 24 climate projections that still is to be expanded further[1]. The period from 2021 to 2050 is highlighted in the form of a red/blue bar.

in the Spree catchment for the same period. In both cases, discharges began to decrease from around 1990. The decrease in pit water volumes can be regarded as an important explanation for the reduction of low water discharges.

3 Water balance modelling

Following the same approach as for the Rhine river, discharge simulations are created for the Elbe for the period 1950 to 2100 with the help of the HBV-D water balance model using the model and processing chain described in Nilson et al. (2010). The model implementation is based on a model that has been calibrated for 20 gauges with a total of 120 sub-catchments on the basis of daily measurements (Lautenbach 2005). Since the model is so far only available for the German, non-tidal part of the Elbe catchment, results can initially only be evaluated for the German Elbe tributaries (e.g. rivers Saale, Spree, Havel). To allow for the analysis of discharges at the gauges of the Elbe main river, simulations are also necessary for the Czech part of the Elbe catchment. A corresponding expansion of the model is in progress.

For the purpose of analysing changes in the streamflow regime under the conditions of an expected change in the climate, the HBV-D water balance model is used to determine the quasi-natural water balance. The model does not take into consideration anthropogenic measures, such as reservoirs, water discharges or abstractions, amelioration measures or the like.

As an example, Figure 3 shows the changes in the areal precipitation in the catchment upstream of the Rathenow/Havel gauge, which were deducted from an ensemble of various climate projections (Van der Linden & Mitchell 2009[2], Enke & Kreienkamp 2006, Gerstengarbe 2009, Hollweg et al. 2008, Jacob 2006, Jacob et al. 2009). Based on the data evaluated so far, there is no indication of a clear decrease in precipitation until

1 For the “near future” (2021–2050): 12 statistic and 12 dynamic regional climate projections; For the “distant future” (2071–2100): 9 static and 11 dynamic regional climate projections with the emission scenarios A1B, B1, A2

2 “The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged.”

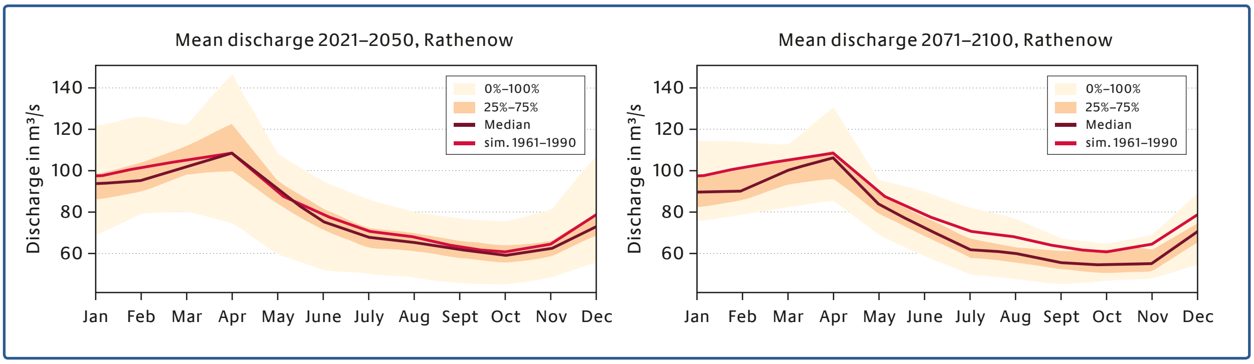

Figure 4: Range of possible discharge changes in the near (left) and distant future (right) for the Rathenow/Havel gauge

the middle of the 21st century, as shown by previous studies. However, an increase in winter precipitation is confirmed.

Figure 4 shows the range of the corresponding discharge projections for the Rathenow/Havel gauge deducted by means of HBV-D. The “near future” (2021–2050) and the “distant future” (2071–2100) are shown separately, and for comparison the monthly discharge of the reference period (1961–1990) is depicted.

The figure shows that the median of the average monthly discharges in the “near future” deviates only very slightly from those of the reference period. For the “distant future”, there is a clear tendency towards reduced discharges. This reduction is observable more or less consistently in all months of the year except April. At the same time, the two diagrams in Figure 4 show the margin of uncertainty resulting from the various climate projections. The slightly darker area encompasses 50 % of the discharge projections while the lighter area encompasses the entire ensemble evaluated up to now.

4 Conclusion / looking ahead

For the German Elbe tributaries, various discharge projections have been generated by means of the HBV-D water balance model and evaluated with a view to changes in the discharge regime. So far, there is no indication of a sharp precipitation and a resulting discharge reduction during the summer months, as shown in previous studies for the middle of the 21st century. However, the results are still incomplete, since, up to now, not all available climate projections have been taken into consideration. Further simulations are in progress. Apart from further climate models, these also include further hydrological models.

For the Havel-Spree catchment, quasi-natural discharges have been determined in a detailed study by means of the spatially detailed model ArcEGMO (Pfützner 2002) for three selected climate projections. In the further course of the study, managed discharges will be added with the help of the WBalMo model[3]; they too will be determined using the three selected climate projections and additionally with the help of scenarios regarding the development of water management.

The present HBV-D model is currently being expanded by the Czech catchment for the entire (non-

3 WBalMo (DHI-WASY): Interactive Simulation System for Planning and Management in River Basins; http://wasy.eu/wbalmo

tidal) Elbe catchment. In addition, the Central Europe-wide water balance model LARSIM-ME will soon be available. With the integration of the mentioned models, a comprehensive ensemble of discharge projections will be available for gauges in the entire Elbe catchment. This is an important basis for assessing the current state of knowledge regarding the future development of the discharge situation and thus for a fact-based discussion of adaptation measures.

Moreover, the discharge projections will serve as a basis for the investigations of other projects in the "KLIWAS model chain". These include, among others, projects that deal with river morphology, water quality, floodplain vegetation or processes in estuary areas and that make an essential contribution to the overall understanding of the complex system "Elbe".

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Morphological Climate Projections with regard to the Various Claims to Use on the Federal Waterway Elbe

Marc Roberts, Markus Promny
& Stefan Vollmer (all BfG)

1 Introduction

The KLIWAS departmental research programme makes an important social contribution to developing adaptation strategies at federal waterways with regard to expected climate changes. Within this framework, Project 4.02 "Analysis of climate projections for sediment budgeting and river morphology" in the KLIWAS model chain, on the one hand, serves as a hinge between the meteorological/hydrological model elements and the environmental issues and, on the other hand, contributes to applying adaptation options to the river basin scale (see Figure 1).

Such climate-induced adaptation concepts have not yet been developed for the large German catchment areas of the rivers Rhine, Elbe and Danube (cf. Project 4.03; Options for the regulation and adaptation of hydraulic engineering measures to climate-induced changes of the discharge regime – by way of example at local/regional scale on the Middle Rhine), which means that there is still a considerable need for carrying out sensitivity studies and analysing climate-induced adaptation options.

2 Significance of morphology for the Elbe river catchment area

The various claims to use on inland waterways require a holistic and interdisciplinary approach to the bodies of water in order to determine the impact of a potential climate-induced system change. Possible morphological changes have an impact on the river engineering maintenance measures undertaken by the Federal Waterways and Shipping Administration (WSV) and hence on the economic viability of the transport system "inland waterway vessel" as well as the water ecology in the catchment area of the Elbe. Thus, morphological events as well as the selection of appropriate parameters for the model projections become important to quantify the sensitivity of the Elbe. The key areas which need to be reflected in the models within the framework of the KLIWAS model chain include:

a) River engineering: sediment transport, bed elevation, maintenance (dredging and dumping)

The practice-related findings of the WSV from maintenance measures as well as operational sediment management requirements have to be integrated into the adaptation options, as do results and recommendations provided by professional bodies at regional and international level. Tendencies to sedimentation and negative large-scale or long-term developments in a river bed require active sediment management in order to guarantee the fairway depths required by inland navigation. Moreover, in connection with the regulation concepts for low (NQ) and mean water ranges (MQ), possible adaptation options for the stabilization of the bed level can be considered.

b) Navigation: water depth, flow velocity

The economically viable movement of goods by means of the transport system "inland waterway vessel" is influenced to a large extent by the available water depth as well as by the prevailing flow velocities (cf. PJ 4.01: "Water balance, water level and transport capacity" – see Horsten et al. in this volume). In particular the water level and the bed level have a major impact on the draughts, degree of utilisation and fuel consumption of an inland waterway vessel.

c) Ecology: water level, bed substrate

The habitat requirements of the flora and fauna in the catchment area as well as the legally binding European Water Framework Directive (WFD) determine the ecological significance of river bed development and thus sediment management. Negative river bed develop-

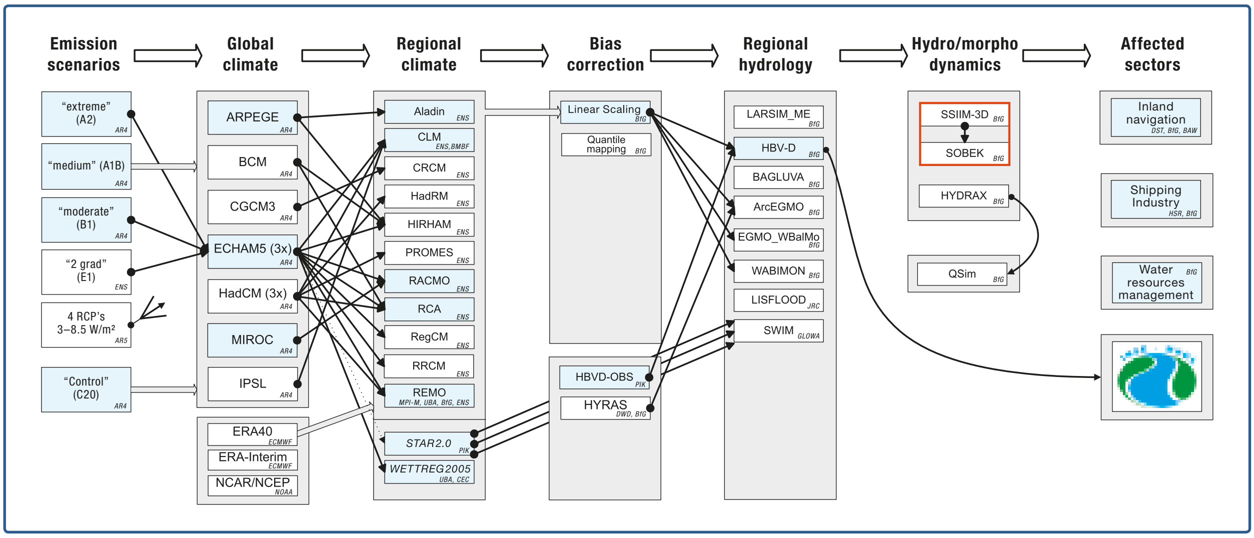

Figure 1: Classification of the impact models of PJ 4.02 within the KLIWAS model chain

ments restrict the "proliferation" of the river and thus exert decisive influence on crucial floodplain vegetation parameters, such as the size of inundation surfaces, the inundation duration and the inundation frequency, which are particularly important for the development and dynamism of riparian woodlands (cf. PJ 5.06: "Impact of climate change on the vegetation of floodplains" – see MOSNER & HORCHLER in this volume).

2.1 Methodology: model system and models

Within the framework of 1D morphodynamic modelling, the ranges of possible climate-induced changes in the river bed and water level will be calculated for the free-flowing sections of the rivers Rhine and Elbe making use of the SOBEK programme package. For different climate projections, precipitation-discharge models are used as input parameters in order to determine the impacts on sediment transport, changes in the river bed and water level and on the substrate composition, and to depict these in spatio-temporal terms. In addition to 1D-modelling, three-dimensional analyses are performed for characteristic, morphologically-active river sections (Middle Elbe km 207–222 and km 239–254) using the morphological model SSIIM 3D (see Figure 2).

The set up and calibration of the model are based on the analysis of observation data which are available for the catchment areas of the rivers Rhine and Elbe. The comprehensive data sets contain information on bed development, transported sediment loads (bed load, particulate matter) as well as substrate composition. An important module within the SOBEK programme package is the implementation of a dredging and dumping algorithm which allows for the adaptation of the bed level during the simulation run depending on the guaranteed draught with respect to the equivalent water level (GIW_{2002}). There are, however, no long projections/ discharge-time series for the Elbe yet and thus there are still uncertainties in the performance of morphological long-term calculations. Nevertheless, it is possible and plausible that the currently available provisional findings from relevant calculations performed on the Rhine can be applied to the Elbe river basin. For a scenario involving constant dredging and additions, for example, the three projections calculated so far show only subtle differences for the near future with regard to the de-

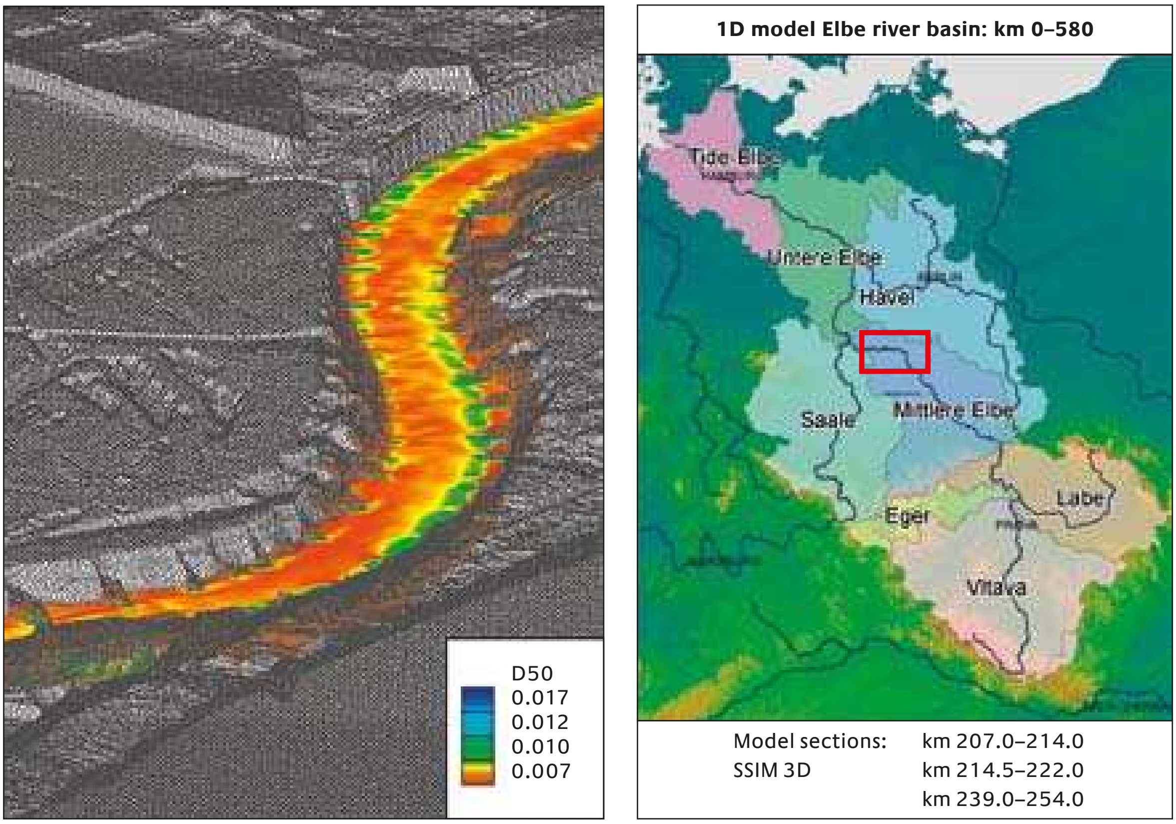

Figure 2: The morphological models SOBEK and SSIIM 3D run on the Elbe

velopment of the Rhine river bed. Significant deviations can only be seen at local level (see Figure 3).

Furthermore, it becomes evident that at least for the "near future" the selected maintenance strategy has a considerably greater influence on the development of the bed level and the sediment budget than the change caused by a climate-induced change in the discharge characteristics of the river catchment area. Overall, for the Elbe it is expected that the bed load management will have a lesser impact on the climate-induced development of the bed level because here in particular dredging and dumping operations are carried out on a smaller scale than at the Rhine. Besides a changed bed load management, the flexible management of control structures is being considered as another adaptation option (see contribution of Wurms & Schröder in this volume); this option, however, is currently not integrated into the morphological model.

The process-oriented analyses are performed on a small scale using the three-dimensional morphological model SSIIM. In these analyses, the knowledge about the sedimentological processes (commencement of transport, stochastic approaches to transport formulation, armouring, sorting, significance of transported particles) at the river bed is extended and linked up with the findings from large-scale models or applied to the

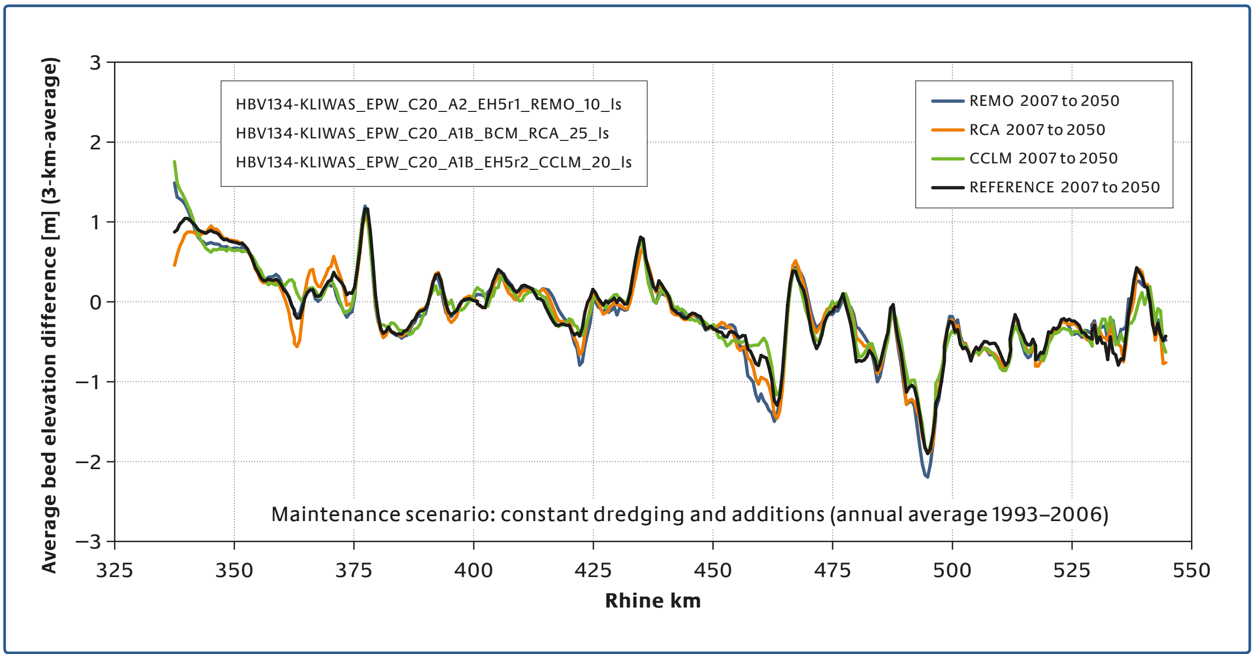

Figure 3: Development of the river bed until 2050 according to three climate projections as well as the reference run for the Upper Rhine

river basin scale. The integration of the scales is done in the order from small to large (in terms of both time and space). In this way it is possible to evaluate local adaptations against the background of the projections at river basin scale (overlay with long-term hydrological / morphological changes, variable land uses etc.). In addition, in order to include in the model SSIIM 3D the change in voids contents resulting from substrate change, an approach to calculating porosity from sediment mixtures (Frings 2011, Frings 2008) has been implemented. This algorithm makes it possible to undertake a qualitative assessment of sediments within the framework of ecological follow-up questions regarding the suitability of the bed substrate as habitat. The inundation surfaces, which are of importance to floodplain vegetation, can also be depicted by the programme package SSIIM 3D.

3 Conclusion / looking ahead

Depending on the strength of the climate change signal, the river bed development and the sediment budget on the rivers Rhine and Elbe will be influenced by the future climatic evolution. The application of morphological impact models such as SOBEK and SSIIM 3D within the KLIWAS model chain is the consistent continuation of the current climate impact research in order to understand and identify possible climate-induced changes in the overall "inland waterway" system. The morphological sensitivity studies performed on free-flowing German sections of the rivers Elbe and Rhine make a differentiated consideration possible and allow, for the first time, for a river basin-related comprehensive view of important determinants with regard to the various user interests. The rather subtle changes in discharge shown by the projections for the near future (2021–2050) give reason to expect that the climate change signal is of secondary importance in comparison with the change of the maintenance strategy. Initial calculation runs executed for the Rhine confirm this. The pronounced variability of the discharge projections for the distant future (2071–2100) raises the expectation that the climate-induced change in the river bed development on the Rhine and Elbe will be more significant. Future calculation runs of the 1D river basin models with a broader range of projections will make it easier to identify the impact of climate-induced system changes. All in all, with regard to the continuation of climate impact research there is considerable need for model implementations to be able to better understand and depict all abiotic and biotic system parameters. In particular the link-up between the legally binding hydromorphological targets of WFD as well as possible options for sustainable sediment management with regard to a good ecological vision should be the subject of further studies.

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Scenarios of the Water Quality in the River Elbe

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1 Introduction

Both the balance of matter and the development of plankton in flowing waters can be influenced in many ways through climate change. However, so far, only few studies have been made on the basis of data obtained from measurements and results obtained from models (Whitehead et al. 2010, Quiel et al. 2011). One point that is particularly difficult to forecast is the complex interaction among the numerous influencing factors upon the phytoplankton and the balance of matter in rivers. As a consequence, numerical ecological models are used for simulation.

KLIWAS Project 5.02 incorporates studies dealing with the free-flowing stretches of the rivers Elbe and Rhine as well as those stretches of the river Havel that are subject to watercourse regulation by weirs. The relevant tool is the water quality model QSim (Kirchesch & Schöl 1999, Fischer et al. 2006), which supplies processs-based simulations of the transport and transformation of matter in a defined river stretch. The model is driven by data for external factors such as weather conditions, run-off, and nutrient input. Each of these factors may be influenced by climate change. In the case of simulations of the status quo, the model input data have been obtained from measurements; in the case of climate simulations, they have been provided from a previously existing model chain.

As far as the Rhine is concerned, simulation calculations are currently being conducted using input data from the KLIWAS multi-model approach (cf. Hardenbicker et al. in this volume). No KLIWAS climate and run-off projections that could be used for modelling water-quality scenarios are yet available for the River Elbe. Therefore, the outcome of previous studies will be summarized hereunder and will be presented in a somewhat generalized form. These results are based upon simulations using the water quality model QSim, as employed in the BMBF project GLOWA-Elbe (FKZ 01LW0603I1); those simulations with their major elements and functions are discussed elsewhere (cf. Hein et al. in this volume; Quiel et al. 2011). The broad context presented here in the form of a set of hypotheses will then be verified in the further course of the project with the help of projection data gained from KLIWAS.

2 What are the effects of climate change upon plankton growth and the balance of matter?

2.1 Balance of matter and plankton dynamics in the Elbe – The status quo

The free-flowing sections of the Middle Elbe show very high concentrations of phytoplankton as well as the corresponding nutrient and oxygen dynamics. The development of the masses of plankton algae is due to a relatively high nutrient input into the Elbe as well as to favourable growth conditions. The growth of plankton can be controlled, respectively restricted, by different influencing factors, depending on the particular stretch of river under consideration. These influencing factors will be described in the following.

2.2 Water temperatures

The water temperatures of flowing waters will be controlled by the effect of the solar radiation penetrating the water, the convective exchange with the atmosphere, and evaporation. This is to say that the water temperatures will basically follow the influences of the weather (e.g. Webb et al. 2008). Anthropogenous influences, such as the use of the river's water as a cooling agent, are relatively light along the Middle Elbe, in contrast to the conditions in the Rhine and its tributaries. Thus, it is fair to say that climatic changes will exercise a direct influence upon water temperatures, without any anthropogenous imprints superimposed.

The water temperature will influence all life processes, including the growth and the productivity of the plankton algae. An increase in temperature appears to enhance heterotrophic oxygen-consuming processes occurring in water more strongly than the (autotrophic) growth of algae (Demars et al. 2011), although it should be added that the temperature ranges as well as the temperature optima vary among the various species of algae. Another effect is that the solubility of oxygen will decrease with increasing water temperatures. The oxygen saturation of freshwater at standard air pressure and at a temperature of 20 °C stands at 9.1 mg O_2/l, whereas it will go down to as little as 8.2 mg O_2/l at a temperature of 25 °C and to 7.5 mg O_2/l at 30 °C, with all other environment parameters unchanged (USGS 2006). This is to say that, with a higher water temperature, an increased oxygen demand may meet with a decreased oxygen supply.

2.3 Run-off and water retention time

Studies conducted so far have shown that run-off is an exceptionally important factor for the dynamics of plankton. A statistical relationship has been identified between run-off and plankton biomass. This relationship is due to the fact that, while the conditions of growth are quite favourable in the free-flowing stretches of the River Elbe, with their relatively shallow depths of water, the time available for growth is rather limited owing to the time any given amount of water is retained at any one place.

It should be added, however, that the relationship between run-off and plankton dynamics is heavily superimposed by the other factors mentioned here, such as grazing or the availability of sunlight. Consequently, that relationship prevails in different degrees, depending upon when and where it occurs; it usually climaxes in the Middle Elbe in the Greater Magdeburg Area during the summer months.

2.4 Nutrient concentrations

The availability of nutrients is a necessary precondition for the growth of algae. As far as free-flowing rivers with their relatively short water retention times are concerned, the supply of nutrients will in most cases not limit algal growth. This was demonstrated in the case of the Elbe by means of field data and model simulations (Quiel et al. 2011). A consequence thereof is that an increase in the supply of nutrients caused by climate change (for example, through a stronger wash-out in the event of heavy rain) would not immediately lead to an increased level of concentration of algae in the Elbe. If the input of nutrients were heavily reduced, a limitation of nutrients in the lower reaches of the Middle Elbe could be achieved and, as an additional positive effect, the quantities of nutrients washed into the North Sea could be reduced.

2.5 Input of nutrients and plankton from river sections further upstream

On Czech territory downriver to Střekov/Schreckenstein, the Upper Elbe consists of a chain of impounded river sections where, owing to long water retention times and high levels of nutrient concentration, large quantities of plankton algae biomass may develop. At the IKSE monitoring station Schmilka (at Elbe km 4), median chlorophyll-*a* (Chla) concentrations of 44 µg Chl a/l have been found (median value between 2004 and 2008, measured between April and October). This already very high level of concentration is the basis for a continued biomass development of plankton algae in the further course of the Middle Elbe: near Schnackenburg (at Elbe km 475), concentrations of 126 µg Chl a/l are reached (median value between 2004 and 2008, measured between April and October). The biomass development of phytoplankton in the Middle Elbe could be influenced by climate- or management-induced changes in the level of concentrations in the Upper Elbe.

2.6 Sunlight

Water depth and turbidity are the determining factors for the quantity of sunlight available to plankton algae in the totally mixed-up water body of the Elbe. Owing to the good growth conditions for algae prevailing in the relatively shallow Elbe, the share of phytoplankton in the whole seston may exceed 50 %. When the density of the algae is high, the algae themselves will limit the availability of sunlight by self-shading, which means a negative feedback upon the growth of algae takes place. The so-called "compensation depth" (ie, the depth to which positive algae growth is possible; usually indicated as the depth at which 1 % of surface light is still available) decreases from more than 2.0 m at Elbe km 4 to less than 0.9 m at Elbe km 503. Here, phytoplankton will spend a long period of time in conditions barring positive growth.

Increased global radiation or a reduced water depth on account of less run-off would improve the light conditions for phytoplankton and, thus, be favourable to a more rapid growth of biomass.

2.7 Grazers

Animals feeding on algae, also known as "grazers", may control the density of phytoplankton. As far as the Elbe is concerned, grazing by zooplankton takes a dominant role; the main group here is the phylum of the so-called "wheel animals" (rotifers). To be sure, however, it is only in the lower reaches of the Middle Elbe and only for rather short terms that rotifers will grow to a density of individuals such as to substantially reduce the biomass of algae (Holst 2006).

Zooplankton in the Elbe might indeed benefit from decreased discharge and increased temperatures. If and when it actually does, it would be put in a position to reduce the biomass of algae and to counter-act the favourable influences upon the biomass of algae at least in the lower reaches of the Middle Elbe (Quiel et al. 2011).

3 Conclusions and perspective

The growth of plankton and the balance of matters in the River Elbe are controlled by a multitude of factors that can be altered, each on its own or in their collusion with each other, by climate change (Figure 1). Most of those factors do not exercise a linear effect (for example, an alteration in the level of nutrient concentration will have hardly any effect upon the growth of algae when there is enough nutrients around, whereas the ef-

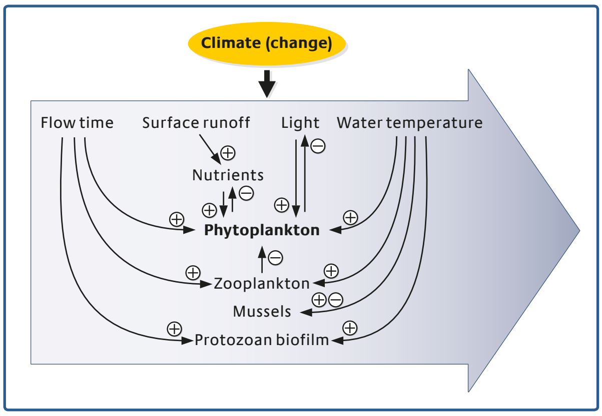

Figure 1: Selected effect flows illustrating the influence of the weather upon the development of phytoplankton The large arrow symbolizes the transport in the flowing water.

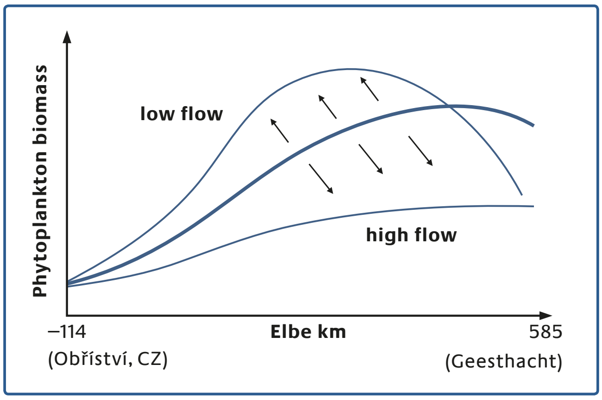

Figure 2: Schematic presentation of the effects of flow alterations upon phytoplankton dynamics in the Elbe during the spring and summer months

fect will be very strong in a scarcity situation) or they develop a negative feedback (such as a sunlight deficit on account of self-shading of algae). This is to say that a clear differentiation as to location and to time must be made when the effects are analyzed. So, for example, a decrease in the run-off may increase the plankton biomass in the upper reaches of the Middle Elbe owing to the effect flows shown in Figure 1, whereas the biomass may be reduced in the lower reaches of the Middle Elbe because grazing zooplankton achieves a high population density on account of the prolonged flowing time (Quiel et al. 2011; Figure 2). Water quality modelling using QSim will make such a complex consideration possible, as it considers the relevant effect flows and makes them accessible for analysis.

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The Potential Development of the Floodplain Vegetation along the River Elbe

Eva Mosner (BfG) & Peter Horchler (BfG)

1 Introduction

The vegetation of riparian floodplains can be described as azonal (Ellenberg 1996). Unlike vegetation types of zonal ecosystems, which are substantially dominated by macro-climatic conditions (such as temperature and precipitation), riparian vegetation types are to a large extent adapted to the specific disturbance conditions (in an ecological sense) prevailing in floodplains. Hence, the distribution patterns of floodplain vegetation are predominantly influenced by flooding and morphodynamics and also by land use (Ward et al. 2002).

In most cases, macro-climatic aspects and their modifications are used to describe possible climate change effects on species distribution patterns (Araujo et al. 2011, Pompe et al. 2008, Thuiller et al. 2005). However, many riparian species are characterized by a large-scale distribution, which sometimes stretches over several climatic zones. Consequently, approaches that are merely based on macro-climatic factors are insufficient to assess the potential threats of climate change on riparian species. Expected hydrological and morphodynamic conditions should rather be taken into account to quantify potential changes in the small-scale distribution patterns of floodplain vegetation types and plant species. This is the approach being pursued in the KLIWAS Project 5.06 entitled "Impact of climate change on floodplain vegetation".

2 Using habitat models as a methodological basis for assessing future habitat potential

The small-scale distribution patterns of many riparian species can properly be described on the basis of hydrological variables such as the relative elevation above mean water levels, water level fluctuations, etc by using so-called habitat models (Hammersmark et al. 2010, Leyer 2005, Mosner et al. 2011). Such statistical models use correlations of species distribution patterns and local, abiotic conditions for determining the ecological optima of species along environmental gradients in what is called the ecological niche space (Figure 1). If the correlation of species distribution and abiotic factors is statistically significant and correlations can explain distribution patterns to a large extent models can be used to determine the habitat potential of a given species/vegetation type on the basis of the abiotic information of a standardized reference state (→ Habitat Potential "Current Status" in Figure 1). Where, in addition, future projections of explanatory abiotic factors such as future projections of mean water levels are available, projections of the putative future distribution of suitable habitat can be drawn up on the basis of those habitat models (→ Future Habitat Potential in Figure 1).

The various projections of the habitat potential will then be intersected with the standardized reference state of the habitat potential in a Geographical Information System (GIS). As a result, spatial information can be gained showing where a given habitat potential will be retained in future, where habitats might be lost, and at which sites some habitat potential might develop. This allows to spatially explicitly quantify the future habitat availability and to estimate the potential threats for a given plant species/vegetation type due to possible hydrological changes in the floodplain. In the following, this approach is exemplified for shrubby softwood alluvial forest vegetation.

3 The future habitat potential of softwood alluvial forests

Softwood alluvial forests are one of the most characteristic habitat types of floodplains. Those forests count among the most severely threatened habitat types in Europe (UNEP-WCMC 2000) and have been listed in Annex I of the Habitats Directive (92/43/EEC) as a priority habitat type with an urgent need for conservation. Softwood alluvial forests provide quite elementary ecosystem functions. They play an important role in safeguarding water quality, stabilize sediment, and provide habitat for various kinds of animals (HUGHES et al. 2003, TOCKNER & STANFORD 2002). The typical species, i.e. various kinds of willows and the Black Poplar, are well adapted to sites featuring a high disturbance potential and long inundation periods and are, therefore, primarily found along river banks, in troughs, and around floodplain pools and depressions. Softwood alluvial forests cannot establish on higher-elevated sites owing to insufficient soil moisture and a lack of bare ground sites.

The habitat potential of softwood alluvial forests can adequately be described on the basis of hydrological variables such as the relative elevation above mean water levels and water level fluctuations (MOSNER et al. 2011). Calculations of the habitat potential of the current status show that large parts of the floodplain are unsuitable for the establishment of shrubby softwood alluvial vegetation even today because of floodplain aggradation in the absence of morphodynamic effects. Exemplary calculations for possible future scenarios made on the basis of run-offs reduced by 10 % and 25 %, respectively, show that, as a rule, habitats will be lost while only a few sites will gain suitability (Figure 2). Intersecting the various projections allows identifying the one habitat potential that is included in all projections hence being the minimum potential. Taking into account the expected large variability among the vari-

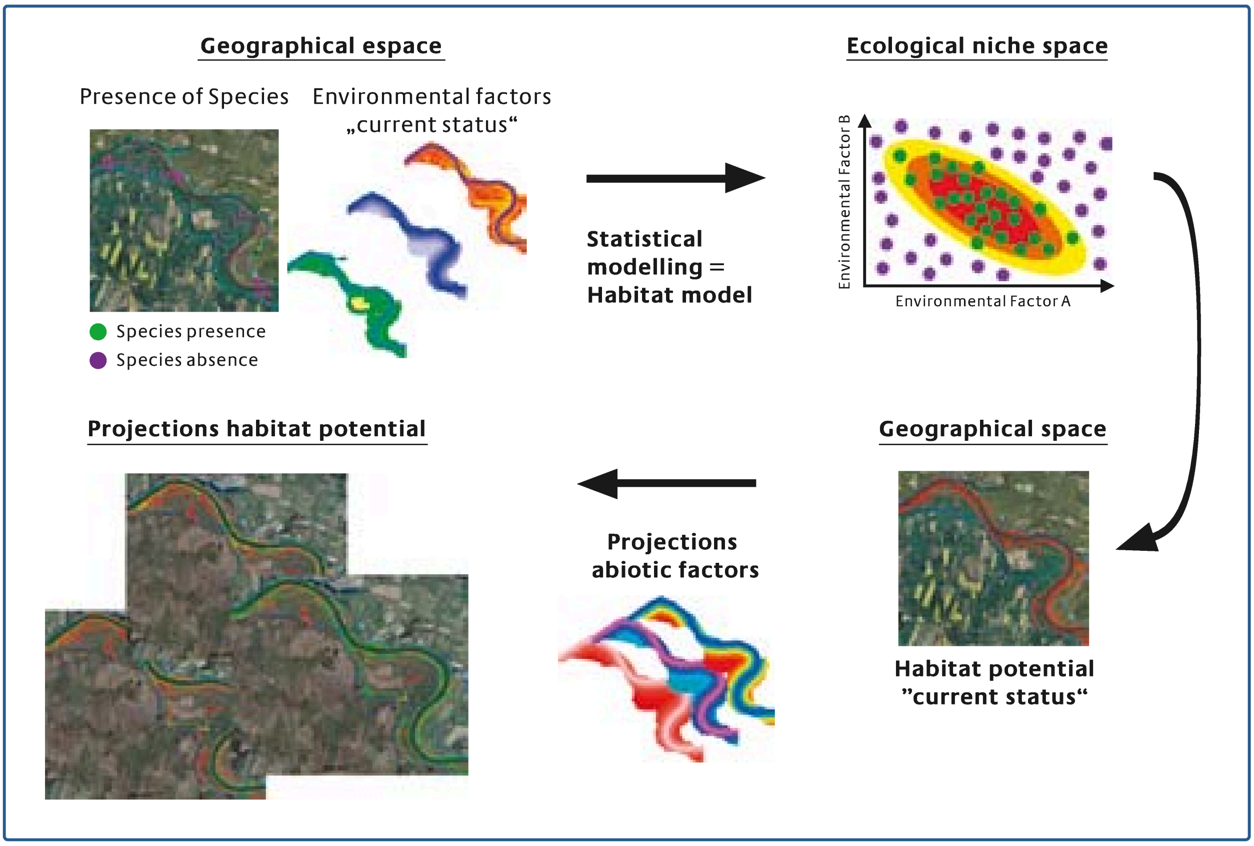

Figure 1: Illustration of the habitat modelling procedure for drawing up projections of the potential habitat distribution of plant species/vegetation types

ous projections, it is true that this approach will provide a rather pessimistic evaluation of the estimated future habitat availability; on the other hand, this will also be the most valid assumption available.

4 Summary and perspective

Habitat modelling proves to be a suitable tool for estimating possible effects of climate-induced changes of hydrological conditions of riparian floodplains upon the habitat potential of floodplain vegetation. This allows a first quantification of potential effects of climate change.

In the light of a large-scale lack of spatial heterogeneity in the floodplain due to the absence of morphodynamics only little area in the active floodplain remains suitable for the establishment of softwood forests. Any reduction in run-off quantities will additionally reduce its habitat potential. Further concluding, other groups of species occupying more humid sites in relation to softwood alluvial forest species might also experience a loss in habitat potential. Vegetation types of higher-elevated areas, on the other hand, may be expected to gain in habitat potential. Until the end of the project term, possible effects of climate change will further be quantified on the basis of habitat models and putative future projections for a number of vegetation types and repre-

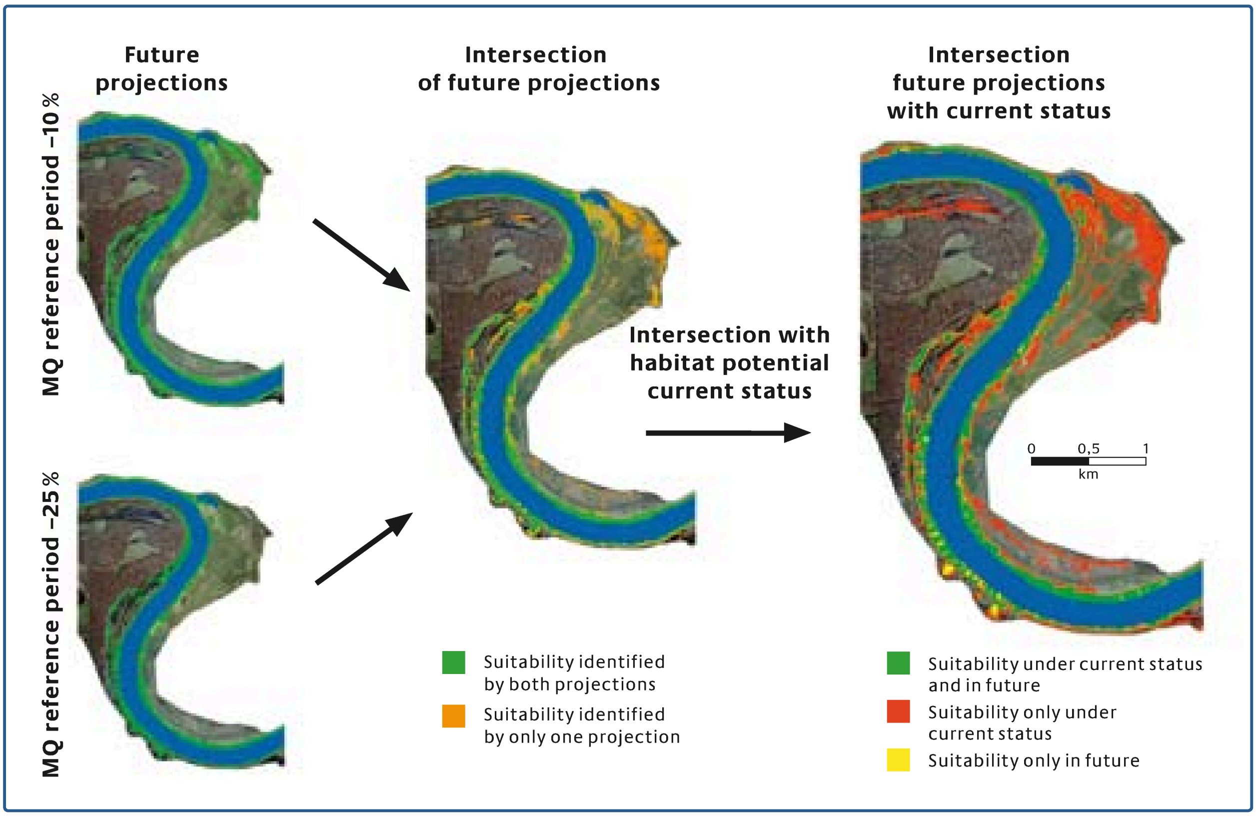

Figure 2: Evaluation of the future habitat potential of shrubby softwood forest vegetation, using various projections of future run-off conditions. Left: Estimated habitat potential using two different run-off projections. Centre: Intersection of the estimated habitat potential of both projections. Right: Intersection of future projections and current status.

sentative species along the Rivers Rhine and Elbe to gain a basis for adaptation options.

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Impacts of Climate Change on the Danube

Possible Changes of the Runoff Regime of the Upper Danube in the 20th and 21st Century

Bastian Klein, Imke Lingemann, Peter Krahe & Enno Nilson (all BfG)

1 Introduction

With a total catchment area of approximately 800,000 km² and a length of 2,857 km, the Danube River is the longest river in Central and South East Europe. The study area within the framework of KLIWAS (see Figure 1), the Upper Danube River Basin up to the gauge Achleiten at the German-Austrian border, has a catchment area of 76,600 km². Although this area accounts for only about 9 % of the total area, approximately 22 % of the total discharge of the Danube River (about 6,500 m³/s at gauge Ceatal Izmail) originates in this area (1,420 m³/s at the gauge Achleiten). Thus, this area has an important function as the so-called "Wasserschloss" for the downstream users of the Danube River. Therefore, possible changes of the hydrological regime as a consequence of climate change have major impacts on the total catchment area.

As was the case with the other river basins investigated within the scope of the project "Impacts of climate change on hydrology and management options for the economy and inland navigation" (project 4.01), i.e. the Rhine River (NILSON et al. in this volume) and the Elbe River (HORSTEN et al. in this volume), a multi-model approach was also applied to the Upper Danube River-Basin up to the gauge Achleiten in order to quantify the impacts and uncertainties of climate change on the hydrological regime.

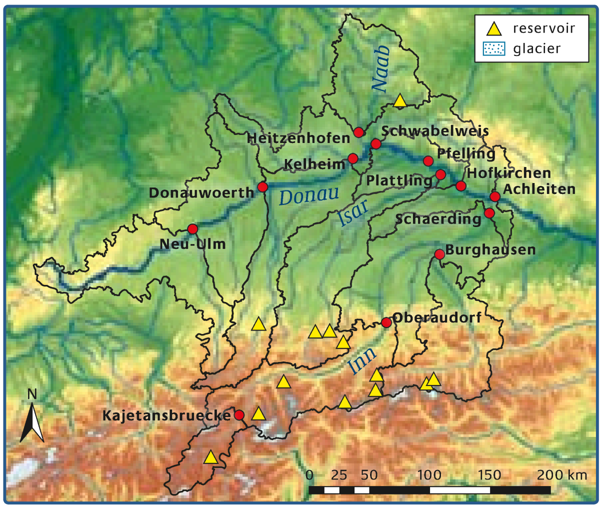

Figure 1: Study area, Upper Danube up to the gauge Achleiten

2 Changes observed in the 20th century

The runoff regime of the Upper Danube River changes in the direction of flow from a rainfall-dominated ("pluvial") to a snow-dominated ("nival") regime due to the Southern alpine tributaries (Iller, Lech, Isar and Inn). Especially the River Inn leads to an extensive change of the runoff regime, since it has a mean annual discharge at its mouth which is similar to that of the Danube River.

After its confluence with the River Inn upstream the gauge Achleiten, the Danube has a nival runoff regime with a clear maximum during summer (see Figure 2).

Figure 2 shows that the discharge regime (described here by the long-term mean monthly discharge standardized on the basis of the long-term mean annual discharge, the so-called Pardé coefficients, for different time periods) for the gauge Achleiten has changed during the last 100 years. It shows a decrease of the mean monthly discharge during summer and an increase in winter time. This may be attributable to a change in the snow and precipitation regimes in the past but also to anthropogenic influences such as the extension of dams and reservoirs. The impact of future climate change may lead to a similar modification of the runoff regime as is the case with the influence of dams and reservoirs (decrease of discharge in summer and increase in winter). Therefore, it is difficult to quantify the share of each factor in this modification.

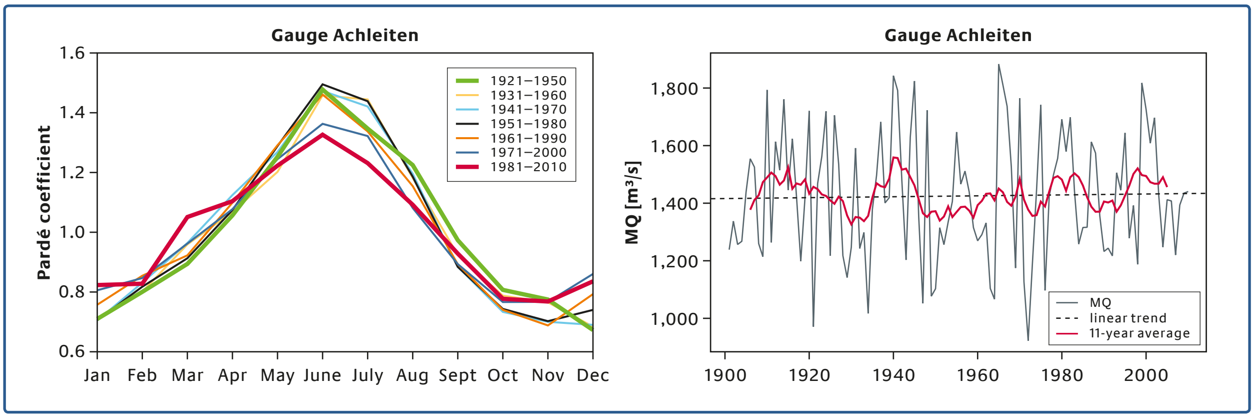

Figure 2: Discharge regime at the gauge Achleiten (left) for different time periods; mean annual discharge MQ at the gauge Achleiten (right), 11-year average and linear trend line

Focussing on the mean annual discharge (MQ) at the gauge Achleiten and at other gauges along the River Danube (not shown here), no significant trends towards an increase and/or decrease over time (Figure 2, diagram on the right) can be seen.

Focusing on the development of the lowest 7-day mean discharge NM7Q during the summer and winter seasons, changes over time are shown for the two Danube gauges at Hofkirchen and Achleiten (Figure 3). While the low flows in winter have significantly increased over time, which means generally less severe low flow situations, no statistically significant trend can be observed for the low flows during summer. As is the case with the changes in the runoff regime, the causes may be a combination of the modification of the snow and precipitation regimes and anthropogenic modifications in the catchment area. The extent of the impact of the different factors cannot be determined by a statistical analysis alone but only in connection with a detailed and spatially distributed hydrological model.

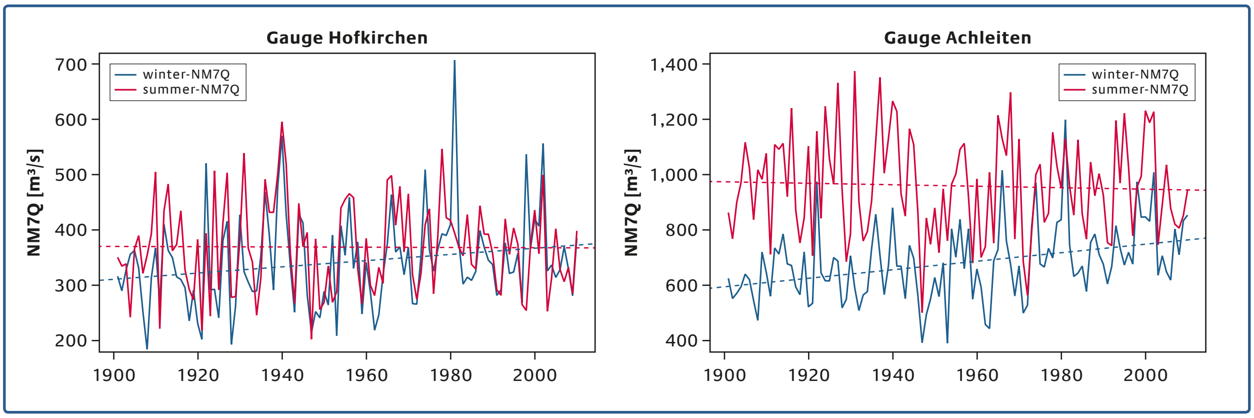

Figure 3: Temporal development of the lowest 7-day mean discharge NM7Q in summer and winter at the gauges Hofkirchen and Achleiten

3 Water-balance modelling with COSERO

To provide information about the possible changes of the hydrological regime, the water-balance model COSERO (Kling et al. 2005) was developed for the region of the Upper Danube River up to the gauge Achleiten. For this purpose, the area was divided into 12 subbasins which were each further subdivided into height zones (Klein et al. 2011). This model takes melt of glaciers into account using a negative mass balance approach. Major dams and reservoirs in the basin are also considered in the model. The monthly data of temperature, precipitation and sunshine duration of the stations of the HISTALP data base (Böhm et al. 2009) were used as observational data records. Since these meteorological observation data as well as discharge time series are available over a long period of time for some gauges in the study area, the water-balance simulation for the past was performed for the period from 1887–2007. The application of the water-balance model for this long period of time made it possible to validate the model for different time periods independent of the calibration period from 1961 to 1990 (Klein et al. 2011).

This model can be applied to investigate the influence of the glaciers as well as that of dams and reservoirs on the water balance by performing simulations with and without the consideration of reservoirs and glaciers. In Figure 4, the influence of the reservoirs on the discharge regime of the Achleiten gauge is clearly recognizable. It can be seen that parts of the snow melt is stored in the reservoirs in late spring/summer for electricity production in winter time. In contrast to this, glacier melting has no significant influence on the mean monthly discharges at the gauge Achleiten.

4 Possible changes of the discharge regime in the 21st century

The regional climate projections from the EU-ENSEMBLES project (ENSEMBLES 2009) were used as meteorological input data for the water balance simulations of the future until the year 2100. The model chain of the total of 23 regional climate projections consists of combinations of 12 regional climate models (RCM) and 7 global climate models (GCM) which are all driven by the IPCC emissions scenario A1B (representation of the model chains used see Klein et al. 2012).

Despite the constant improvements which have been made in the last few years, the climate models still show systematic biases in comparison to the observations. Therefore, the results of the regional climate models cannot be directly used as meteorological input in the

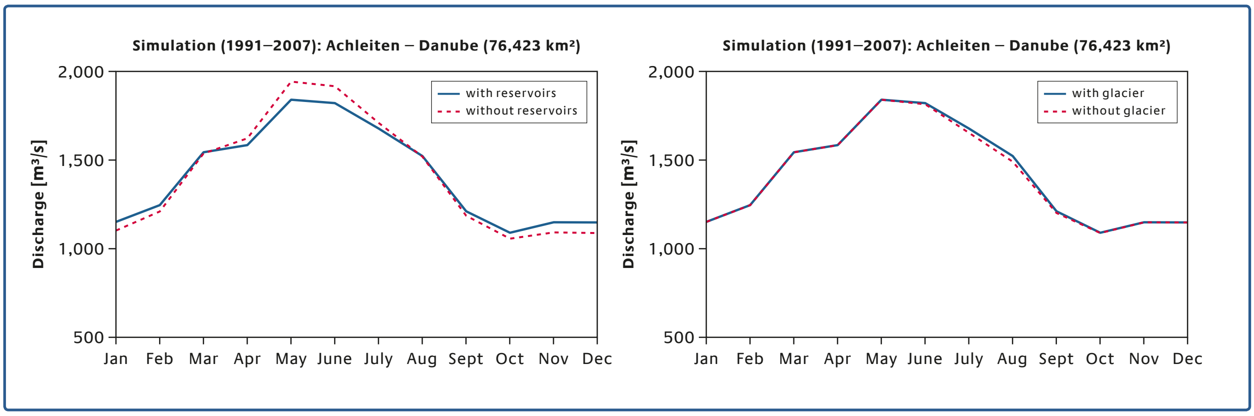

Figure 4: Simulated long-term mean monthly discharge (1991–2007) at the gauge Achleiten. Simulation with and without the influence of dams and reservoirs (diagram on the left) and simulation with and without the influence of glacier melting (diagram on the right).

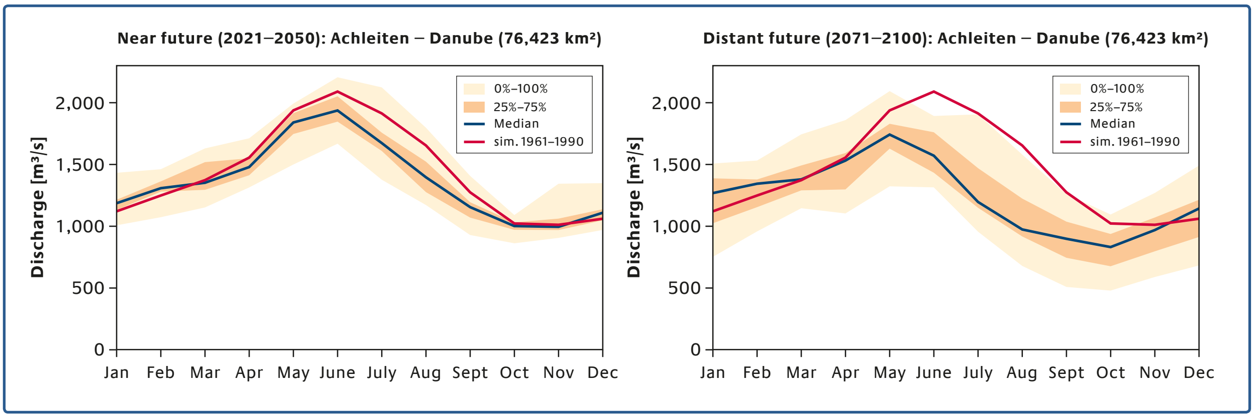

Figure 5: Quartiles of the simulated long-term mean monthly discharge of the near (2021–2050) and distant future (2071–2100) compared to the simulated values of the reference period (1961–1990) at the gauge Achleiten

water-balance model (KLEIN et al. 2012) but correction methods have to be applied in order to correct this systematic error (MUDELSEE et al. 2010). For water balance modelling currently performed for the Danube River within the framework of KLIWAS, the "delta-change" approach (e.g. FOWLER et al. 2007) is applied to the meteorological variables temperature and precipitation of all regional climate model runs. By applying the delta change method the monthly change signals between the period 1961–1990 and 2021–2050 and 2071–2100 respectively are calculated for each hydrological response unit. These change signals are attached to the original observed time series from 1961–1990. For three of the 23 climate projections, the systematic errors were, however, so large that, after an in-depth validation, they could no longer be used in the further investigations.

Figure 5 shows the comparison of the projected long-term mean monthly discharges at the gauge Achleiten for the near and distant future together with the simulated values of the past (1961–1990). The span of possible changes is represented by the minimum and maximum values, the 25 % and 75 % quartiles as well as the median of the values of the ensemble of discharge projections for each month.

In the near future, the results show a moderate decrease of the discharge in summer. The band of uncertainty 25 %–75 % where the results of 50 % of the discharge projections can be found, is relatively narrow. For the distant future (2071–2100), this band of uncertainty is significantly wider. For this period, the results indicate a clear decrease of the discharge in summer. The earlier occurrence of the highest month is an indicator of the change of the discharge regime. The underlying causes are changes in the snow accumulation and snowmelt processes due to the projected higher temperatures and the projected change of the precipitation regime (higher precipitation in winter time) in the future.

Figure 6 shows the changes of the mean annual discharge in the near and distant future for all sub-basins and all discharge projections in comparison to the reference period (1961–1990). The changes projected for the near future range between +10 % and −20 %. The findings for the distant future indicate for almost all projections and all sub-basins a decrease of the mean annual discharge MQ ranging between −40 % and 0 %. Only the gauge Heitzenhofen on the River Naab shows for the near and distant future no clear trend towards an increase or decrease of the discharge quantities. The Naab springs from the upland region north of the Danube and is, therefore, unlike the other catchment areas with nival character, influenced by the rainfall regime.

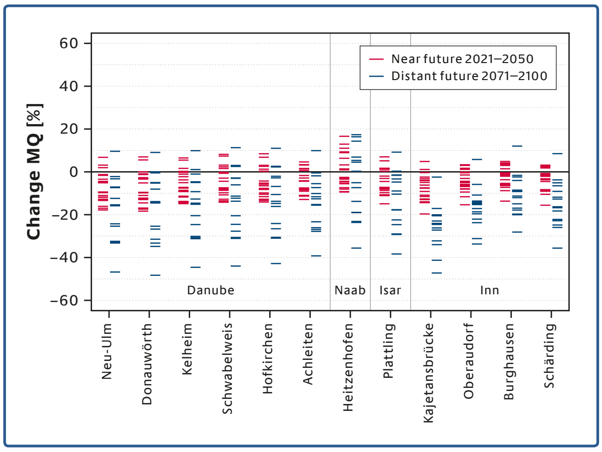

Figure 6: Projected relative changes of the mean annual discharge MQ in the near (2021–2050) and distant future (2071–2100) compared to the reference period (1961–90). Every line corresponds to the projected change of a climate projection chain of emission scenario SRES, global climate model GCM, regional climate model RCM and hydrological model COSERO.

5 Summary/Outlook

The analysis of the possible impacts of climate change on the hydrological regime of the Danube was performed in KLIWAS using a multi-model approach as was also used for the river basins Rhine and Elbe. Only with this approach the uncertainties about the possible climate evolution in the future can be taken into account and quantified. For the first analysis of the impacts of climate change on the hydrological regime of the Danube, monthly simulations were carried out using the water balance model COSERO. When simulating the past from 1887 to 2007, the model proved to be capable of plausibly representing discharges in different periods of time.

The simulations with regional climate projections show in the near future no significant changes of the mean annual discharge and for the distant future a tendency towards a decrease of the mean annual discharge. For the near future, the majority of the projections indicate a decrease of the discharge during summer which will intensify towards the end of the century. The results show a change of the discharge regime from a snow regime towards a more rainfall-dominated regime.

The tendencies of the KLIWAS results comply with those of other research projects investigating the impacts of climate change at the Danube River such as GLOWA Danube (2010), but there are clear differences among the projects as regards the extent and the timing of the possible changes.

Since only monthly values have been investigated up to now, it is not possible to draw conclusions on high water on the basis of the results and only indirect conclusions on low water (e.g. the duration curves of the monthly values) in the future. In the further course of KLIWAS, these aspects will be thoroughly investigated for the Danube catchment area on the basis of the temporally and spatially detailed hydrological model LARSIM_ME which is currently being set up.

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Impact of Climate Change on the Vegetation and Fauna of the Danube between Straubing and Vilshofen

Jan Peper (BfG) & Michael Schleuter (BfG)

1 Introduction

As from autumn 2012, the DONAUKLIMA research project is to investigate the impact of climate change on the biological communities of the Danube and its floodplain between Straubing and Vilshofen. For some decades already, this last still free-flowing section of the federal waterway Danube has been the subject of ecological studies. Thus, in the period from 1993 to 1995, mappings of the vegetation, flora and fauna were prepared within the framework of a planned upgrading of the shipping lane (Schaller 1996). Special attention in this connection is paid to the mouth area of the River Isar near Deggendorf. On behalf of the Federal Agency for Nature Conservation, further detailed surveys were carried out concerning vegetation, flora and molluscs (Foeckler et al. 2010, Binder 2011) in order to highlight the huge nature conservation significance of this section.

In the KLIWAS project 4.01, hydro-meteorological reference data are now evaluated and projections for run-off rates and water levels which have to be expected in the future are to be established (www.kliwas.de). But up to now, no analysis of climate-related ecological modifications by KLIWAS has been envisaged for this area. In order to close this gap, it is necessary to know the current incidence and ecology of the groups of organisms to be modelled. It is, however, possible to use the mappings prepared in 2010 and 2011 as part of the EU study on “Variant-Independent Research on Upgrading the Danube between Straubing and Vilshofen”. In the following, an overview of the current surveys is given and the working framework for the planned DONAUKLIMA project is defined.

2 Area under study and upgrading options

Between Kehlheim and Passau, the Danube is used as a shipping route and for energy generation. For this purpose, a major part of the route is regulated by dams. Only the section between Straubing and Vilshofen in the Dungau region is still free flowing on a stretch of about 70 km. In this connection, the mouth of the Isar with its alluvial fan is of special ecological importance. Here still exist some significant remnants of the softwood alluvial forest which has been destroyed at other sites in particular due to the construction of dams. Moreover, ephemeral gravel and mud banks can be found here and the hinterland of the embankment is covered with botanical treasures such as *Adenophora lilifolia, Gladiolus palustris* or *Cypripedium calceolus*. Owing to this extreme wealth of natural assets, the mouth of the Isar as well as the floodplains of the Danube were designated as Natura 2000 areas and partly also as nature reserves.

For inland navigation, it is mainly the area downstream of the mouth of the Isar which presents a challenge since the channel here is in some places of a very limited width with strong current and some very narrow curves. Nevertheless, in order to ensure the use of the waterway all year round and with a low accident risk, two upgrading options are being planned and discussed.

Option A provides for a river-regulating upgrading, among other things, including the renewal and addition of groynes and longitudinal dykes. Option $C_{2.80}$ is the alternative to option A. Here, by installing a rubber dam near Niederalteich, backwater is to be generated beyond the mouth of the Isar. At the weir, a lock canal is then to bypass the Mühlhamer Schleife and join the Danube again near Winzer.

For the purpose of performing a situation analysis of the changes to be expected by the construction measures for the ecosystem within the framework of environmental planning, mappings in the entire floodplain were commissioned. The study area extends over a surface which would be covered by water without dams in the case of a 100 year return period flood – this corresponds to about 180 km².

3 Data basis

In order to quantify the ecological impacts of the options in the ongoing EU study, apart from the biotic components, extensive abiotic locational factors are also surveyed or shown as an appropriate areal model. The core element in this respect is an up-to-date digital terrain model which was established with high accuracy by airborne laser scanning, orthophotos, terrestrial measurements and soundings in shallow water.

Moreover, the Federal Waterway Engineering and Research Institute is calculating three-dimensional hydraulics models for 11 different run-off scenarios. This provides the data for flow velocity, water levels and, thus, indirectly also for the duration of flooding. In addition, a decisive factor for the composition of the vegetation are the groundwater conditions. In this connection, ground water level situations in the entire floodplain are modelled for five ecologically important runoff situations.

Pedological parameters such as soil class and soil type can be derived from more than 26,000 boring rod applications and ram core samples. The same applies to the thickness of the clay surface of the floodplain. Furthermore, water structures such as groynes, gravel banks and steep banks are mapped separately.

For this project, flora and fauna were investigated as extensively as perhaps for no other river basin in Germany. In table 1 the most important groups of animals and plants are listed. The data contained in former maps are of special importance to the understanding of the floodplain since they make it possible to investigate the changes which occurred during the last few years.

Vegetation types were mapped on an area-wide basis and maps of the types of biotopes, flora and fauna habitats and the types of land use derived therefrom were prepared. More detailed results are available for plant species contained in the Red List of Bavaria and of Germany. Each individual occurrence of these plants is surveyed by GPS. Thus, a data set is available which records 30,000 habitats of 299 species.

Table 1: List of selected mapped animal and plant groups and vegetation indicating the year of the survey of former studies as well as of the current study.

Group mapped	Old data	New data
Vegetation	1993–95; 98/99; 03/04	2010/11
Flora	1993–95	2010/11
Phytobenthos		2011
Phytoplankton		2010
Birds	1993–95	2010
Amphibians	1993–95	2010
Fish	1994/95; 06	2010/11
Makrozoobenthos	1987–97	2010
Aquatic insects	1993/94	2010
Butterflies	1993–95	2010
Riparian ground beetles	1993/94	2010
Saproxylic beetles	1993/94	2011
Alluvial molluscs	1987–89; 93–95	2010

As quality components of the Water Framework Directive, among other things, phytoplankton, phytobenthos, makrozoobenthos and fish were mapped. Thus, 44,000 fish divided into 52 species were caught and measured. Furthermore, data on several groups of insects, molluscs, amphibians with their spawning habitat, on bats as well as on breeding and resting birds are now available for the area of the floodplain. Furthermore, home ranges of otters and beavers were investigated.

4 Analysis of the data

Apart from approaches relying exclusively on expert opinions to forecast changes due to the effects of constructional measures, the EU study makes use of statistical procedures to analyze some data records. Here, among other things, the Integrated Floodplain Response Model – INFORM (Giebel et al. 2011) is applied. Thus, the module MOFIR (Model of Fish Response) can represent the current and the future suitability of a habitat for selected types of fish. Similar modules are available for riparian ground beetles and macrozoobenthos.

As regards vegetation, an empirical model is additionally being prepared on the basis of the data which are currently collected and which can be used to identify the local potential for the vegetation types which are typical for floodplains. Besides the modelling of ecological niches for individual species, indirect ordination, cluster analysis and further statistical procedures are applied. These models are applied in order to evaluate the habitat suitability after the implementation of the options. From these findings, the extent and quality of the changes can be derived.

5 What is the aim of the DONAUKLIMA project?

The DONAUKLIMA project is carried out by the BfG (Department U2) and is to review the existing data, irrespective of the improvement planning. This project is to build on the findings of the run-off projection of the Danube from KLIWAS 4.01. At the same time, gaps existing in KLIWAS are to be closed. This includes the fact that the impacts of climate change on the fauna and flora of the Danube have up to now not been investigated. Furthermore, changes in the habitat suitability for aquatic animal groups which are attributable to climate change have not yet been considered within the framework of KLIWAS.

In addition to the identification of the future development it is also intended to carry out retrospective analyses. The findings from these "long-term data" can in turn be of considerable importance to projections for example in order to be able to better assess the impacts of land-use changes.

For the time being, the project is planned to last one year and is divided into a geobotanical and a zoological part. The following questions are to be answered in the geobotanical part:

(1) How does the site potential for typical floodplain vegetation types and thus, types of biotopes, change due to climate-induced changes in the discharge during the two time horizons until 2021–2050 and 2071–2100?

(2) How has the vegetation changed since 1993?

(3) Can differences in the vegetation be derived from the analysis of time series of the ground water level at level measuring sites?

In the zoological part, the following questions will be analyzed:

(1) How will the habitat suitability for fish, macrozoobenthos, molluscs and riparian ground beetles change due to climate-induced discharge changes in the two time horizons until 2021–2050 and 2071–2100?

(2) How have the occurrence and frequency of individual species of the above-mentioned animal groups changed since 1993?

By means of the analyses, the already existing models of the BfG are to be extended and improved. In summary, the influences on the degradation of the area which are caused by navigation are to be compared with those not caused by navigation and subsequently discussed. In addition, the success of the remedial measures which have already been implemented can be discussed and those measures which have been functioning in the long run can be identified.

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The Danube River Basin in Change: The ICPDR and the Climate Adaptation Strategy

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1 Introduction

A healthy River Basin environment is the basis for economic, social and cultural development. The Danube and the network of its tributaries connect some of Europe's wealthiest with some of the poorest regions. Shared by 19 countries, the Danube River Basin is the most international river basin in the world and home to more than 80 million people. The lives of these people and the environment are dynamic, driven among other things by climate change. In order to prepare for this change in the decades to come, a ministerial conference asked the International Commission for the Protection of the Danube River (ICPDR) in February 2010 to prepare a Climate Adaptation Strategy for the Danube River Basin. Actions related to such an adaptation are also supported through the EU Strategy for the Danube Region. Germany was nominated as lead country to steer this process within the ICPDR. To provide a basis for the elaboration of the strategy, Germany first financed a Danube Climate Adaptation Study, developed by the Ludwig-Maximilians University Munich. This study was based on a collection of scientific information on climate change projections as well as possible impacts in the Danube River Basin and conducted a meta-analysis of this data. The strategy will follow this study and build on other areas in which the ICPDR is active in an integrative manner. In this publication, we give an overview on the work of the ICPDR in general and the development of the Climate Change Adaptation Strategy for the Danube River Basin in particular.

2 The International Commission for the Protection of the Danube River (ICPDR)

From spring to Black Sea, the Danube is approximately 2,800 kilometres long, making it the second-longest European river after the Volga. Its catchment area, the Danube River Basin, extends into the territories of 19 countries and comprises of more than 800,000 square kilometres or about 10 % of Continental Europe. This part of Europe is highly diverse: The Danube passes a variety of cultures, landscapes and ecosystems (ICPDR 2011).

Historically, these ecosystems were under pressure through human activities: households, industries and agriculture contributed to a decrease in water quality for decades. Problems built up that could not be addressed by individual countries alone. With the fall of the Iron Curtain in 1989, a new window of opportunity opened for the Danube countries: As the divide between Eastern and Western Europe disappeared, the need for cooperative water management was more obvious than ever.

The Danube River Basin is the catchment area of the Danube River, outlined by natural watersheds. Of the 19 countries that have territories within this basin, 14 have more than 2,000 square kilometres. These main Danube countries – some of which are not situated at the river, but within the basin – recognized their responsibility to align their efforts in the environmental field. On 29 June 1994, the main Danube Basin countries signed the "Danube River Protection Convention" in Sofia, Bulgaria (ICPDR 1994). Rivers do not know borders, and therefore, river management ought to reach beyond single countries, too. In this spirit, the convention defined three main areas that required action: The protection of water and associated ecological resources; the sustainable use of water in the Danube Basin; and the reduction of inputs of nutrients and hazardous substances. Today, the Danube River Protection Convention has 15 contracting parties: 14 countries and the European Union. Together, they form the International Commission for the Protection of the Danube River. The permanent secretariat of the ICPDR is based in Vienna and started its work in 1998.

In 2000, the European Union adopted the EU Water Framework Directive (WFD) (European Commission 2000). It requires water management according to the outlines of natural river basins rather than national or other administrative borders. Alongside with the implementation of the EU Flood Directive (EFD) (European Commission 2007) of 2007, the WFD enjoys highest priority for the ICPDR, as all its contracting parties, including the non-EU countries, agreed to its implementation. This involved the development of a Danube River Basin Management Plan (ICPDR 2009), based on the assessment of the environmental conditions in the basin. The analysis led to the identification of four problem areas, so-called "Significant Water Management Issues" (SWMIs) (ICPDR 2008): organic pollution, nutrient pollution, hazardous substance pollution and hydromorphological alterations. Today, the Danube River Basin Management Plan and the 17 Flood Action Programs (ICPDR 2004) list hundreds of measures and policies through which the ICPDR and its contracting parties work towards healthier river environments. The monitoring of these measures and their effects is also coordinated by the ICPDR, through a Transnational Monitoring Network (TNMN). It includes 79 monitoring locations with up to three sampling points across the Danube and its main tributaries. Formally launched in 1996, it was revised in 2006 to meet all provisions of EU directives. The TNMN aims to provide not only a well-balanced overall view of pollution, but also collects data on long-term trends in water quality in the major rivers of the basin. With the growing awareness for climate change driven development, such assessment of long-term trends is crucial.

3 The Climate Adaptation Strategy for the Danube River Basin

The Danube Declaration (ICPDR 2010) is a policy document adapted by a ministerial meeting in 2010. It asks the ICPDR to develop until the end of 2012 a Climate Adaptation Strategy for the Danube River Basin. Actions related to climate adaptation in the Danube area are also identified in the frame of the EU Strategy for the Danube Region. Within the ICPDR, the River Basin Management Expert Group comprising of national experts, is responsible for the coordination of this activity. Germany was nominated as the lead country and a team of scientific experts was established. To provide a scientific basis for the development of the strategy, Germany financed a Danube Climate Adaptation Study (Prasch et al. 2012), done by scientists from the Ludwig-Maximilians University in Munich. This study was done as a meta-analysis, which relied on findings from other, often local scientific studies targeting areas throughout the Danube River Basin. In total, it involved 93 ongoing and finalised research and development projects and studies as well as 60 adaptation strategies, EU activity and guidance documents, national communications under the UNFCCC, reports and adaptation projects for water related impacts of climate change.

A meeting of the "Team of Experts on Climate Adaptation" took place on 12 September 2011 in Munich, where the interim results of the study were presented and discussed. Following the meeting, the study was further elaborated and updated accordingly. The main conclusions can be summarised as follows:

- Climate change impacts will be of different magnitude in the Danube River Basin regions and the water related sectors triggered by a north-west to south-eastern gradient of the temperature increase and the north-southern transitions zone of precipitation changes.
- Uncertainty is not a reason for doing nothing. Instead, win-win and no-regret adaptation measures should be considered. The implementation of the well-established Water Framework Directive "Program of Measures" is a step towards adapting to climate change.
- The study already identified a preliminary set of measures with options for basin-wide and transboundary coordination.

- There is a challenging interdependence among impacts, adaptation measures, different interests and human impacts in water use (hydropower, agriculture, water supply, water quality and others).
- Building on the "Danube Study – Climate Change Adaptation", the ICPDR Adaptation Strategy will define next steps towards the integration of climate adaptation issues in the DRBM Plan 2015 and beyond. The ICPDR Strategy should identify main impacts for individual sectors, address remaining uncertainties and propose and prioritise possible adaptation measures.
- With regard to the preparation of the DRBM Plan 2015 and due to the broad and cross-sectoral nature of climate change impacts, the involvement of other ICPDR expert groups will be needed.
- The ICPDR Adaptation Strategy should be based on existing information, mainly in the CIS Guidance No 24, information in river basin management plans and existing national and regional adaptation strategies.

The authors of the study identified a range of challenges. The Danube River Basin is located in the transition zone between likely increasing (Northern Europe) and likely decreasing (Southern Europe) future precipitation and runoff. There is a broad range of applied hydrological and climate models in the analysed publications, including different temporal and spatial resolutions as well as different areas of interest. Only in some studies the hydrological and climate models applied are directly coupled. The question whether calibrated models can be used under changing climatic conditions in order to model future impacts is yet to be answered.

Accordingly, the preliminary results for the future impacts in the Danube River Basin are difficult to summarise and have to deal with many uncertainties. Particularly uncertain are projections for runoff, droughts and low flow events as well as flood events. However, other aspects such as trends in air temperature or snow cover changes can be predicted with more certainty.

4 Summary and Prospect

In general, it is expected that more research on climate change impacts on the water resources in the Danube River Basin will not completely close existing knowledge gaps on the subject. Due to this fact and despite existing uncertainties, actions are required to adapt to climate change impacts. Current activities include the finalisation of the study until the end of January 2012. An ICPDR Climate Adaptation Workshop in the end of March 2012 will be the forum for discussing the study results, possible adaptation measures and the main elements of the adaptation strategy. This will lead to the elaboration of the Danube Climate Adaptation Strategy during 2012, with a first annotated draft structure to be discussed at the RBM Expert Group meeting in May 2012. It is planned that the strategy will be adopted by the ICPDR in December 2012. Thereafter, it will provide an important basis for decisions on climate adaptation measures to be part of the second Danube River Basin Management Plan as required by the WFD and the first Flood Risk Management Plan as required by the EFD to be finalised by 2015.

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Impacts of Climate Change on Waterways in Estuaries, on Coasts and in the Sea

Sea Level Projections for the North West European Shelf

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1 Introduction

Apart from the future weather conditions, it is the rise in sea levels that deserves special attention when it comes to the subject of climate change on the coast. The safety of coasts and ports is affected by the sea level rise. Impacts on the estuarine waterways as well as on the foreshore areas (mud flat and cliff coasts) as a consequence of increasing water depths are to be expected, among other things due to changes in the sedimentation conditions.

The climate projections available so far are still very vague in their predictions on sea level changes. In particular the behaviour of the great continental ice shields, Greenland and the Antarctic, is not sufficiently taken into account in the models. It seems to be possible to determine the impacts changes in temperatures and wind conditions have on the oceans quite well; however, for shelf seas, such as the North Sea, this is only true to a limited extent. KLIWAS examined the reliability of the climate projections from the IPCC Assessment Report 2007 for the North West European shelf and has initiated improvements together with research partners.

This article provides an overview of the causes that lead to sea level changes and of the latter's predictability, it presents initial KLIWAS results from the cooperation with the Max Planck Institute for Meteorology, Hamburg and discusses aspects of further action concerning this subject.

2 The "sea level machinery"

Four essential factors contribute to changes in the sea level. They are:

(1) the increase in the volume of the water as a result of rising temperatures,

(2) changes in the driving effect of wind systems (surge),

(3) fresh water input from mainland ice shields,

(4) changes in the gravitational force of the ice shields.

Due to the lack of knowledge regarding points 3 and 4, current predictions concerning the sea level rise still have to be considered very provisional.

2.1 Temperature increase

The sea level rise caused by an increase in water temperature follows a simple physical principle and is easy to model. First, the layers close to the surface are warmed up; then gradually the deeper waters. However, the latter is a process that may take many centuries to millennia. As a rule of thumb, a 1 °C increase in the average ocean temperature corresponds to a one metre rise in the sea level. At present, half of the current rise is attributed to the warming of the oceans.

2.2 Surge

Wind is an important driving force for the surface currents of the seas; thus it causes a horizontal transport of volume. At coasts, on the leeward side of wind-driven currents, there are usually set-up effects that lead to increased water levels; on the windward side, the opposite effect occurs. Therefore, the impacts climate-induced changes in the wind or in wind systems have on the sea level differ from region to region. The changes occur immediately. Climate models can identify such changes quite reliably.

2.3 Fresh water input from ice shields

The greatest contributions to the rise in sea levels can occur as a result of the loss of larger ice masses in Greenland and the Antarctic. Three processes are at work: ablation, i.e. the evaporation of the ice; thawing due to surface warming and, the sliding off of ice masses. The first two processes can be reproduced rather reliably in current climate models. The sliding off of ice masses, however, is an extremely complex process that is still very poorly understood and accordingly still requires intensive research. Therefore, this contribution cannot be quantified reliably at present. Paleoclimatic investigations have shown that such events can lead to a very sharp rise in sea levels within a few decades (Arz et al. 2007). Moreover, the impacts of changes in the ice shields on the overall climate system are as yet only rudimentarily included in climate models (Ganopolski 2003, Alley 2003, Hai Cheng et al. 2009).

2.4 Changes in the gravitation field

Changes of mass on continents result in changes in the gravitational force these land masses exert on the water of the oceans. If, for instance, Greenland and/or the Antarctic lose ice, their weight (mass) changes, which in turn leads to a redistribution of ocean water (Kopp et al. 2010). A loss of ice accordingly means that the gravitational force decreases, that the sea level falls at these coasts and that it rises at the continents that are free of ice. If, for example, only Greenland lost significant amounts of ice but not the Antarctic, water would be redistributed from the northern to the southern hemisphere, which would result in a fall in the sea level in the North. This effect and its consequences for the sea level depend on the future loss of ice and are thus very difficult or even impossible to project.

3 KLIWAS work

The impacts of changes in sea temperature and wind systems on the North Sea and the Baltic Sea cannot be reliably determined with the available climate projections, since both the global climate models and the uncoupled regionalizations (downscaling) deducted from the former have an insufficient spatial resolution and ultimately deliver a range of outcomes that is too large for them to serve as a basis for determining options for action. KLIWAS is now attempting an ensemble approach to develop, jointly with various cooperation partners, improved climate projections on the basis of coupled atmosphere-ocean models. First results of the cooperation with MPI Hamburg suggest that, until the end of the 21st century and assuming that the 2 °C target is met, the warming of the oceans and changes in the wind systems may cause sea levels to rise by 25–30 cm in the North Sea and 30–35 cm in the Baltic Sea (Figure 1).

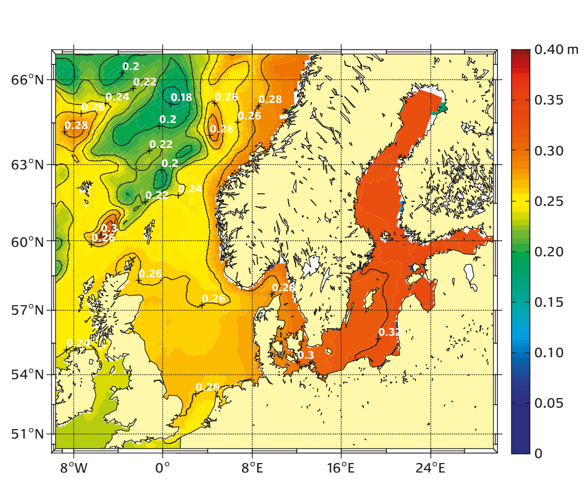

Figure 1: Rise in the average sea level from the period 1970/1999 to the period 2070/2099 (Combination REMO–MPIOM, basis: Scenario A1B). Only the impacts of increases in temperature and wind changes have been taken into account.

4 Outlook

The climate change-induced rise in sea levels cannot be reliably predicted at present. It is assumed that sea levels will rise more sharply until the end of the century than described in the report "IPCC AR 4" in 2007. The reason for this are significant deficits in the representation of the large ice shields in the climate models; here, research (which cannot be performed by KLIWAS) is urgently needed. This requires, in parallel, a good observation of the relevant atmospheric and oceanic climate variables so as to, on the one hand, allow for the determination of the deviations from the model results or of their occurrence and to, on the other hand, improve the data basis required for the development of the model. The still insufficient knowledge of climate must not result in delays to the development of adaptation options. The time should be used productively to conduct case and sensitivity studies such as those carried out in KLIWAS. It should not be neglected to look into the economic, ecological and social consequences of the different sea level rise scenarios.

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Tidal Characteristics and Wave Statistics – an Analysis of Trends

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& Anette Ganske (BSH)**

1 Introduction

On the coast and in estuaries, the global rise in sea level is the greatest challenge with regard to the changing climate. It has been demonstrated that global sea levels have risen by 15 to 20 cm over the past hundred years, and it is likely that this rise will accelerate (Church et al. 2011). However, projections into the future are still uncertain. The Intergovernmental Panel on Climate Change comes to the conclusion: "Understanding the past history of sea level change is the key to better prediction of its future" (IPCC 2010).

However, the *global* sea level is of no significance to tasks of regional planning, coastal protection or local ecological concerns. Rather, reliable statements have to be made on the extent to which a historical *regional* rise in sea level can be demonstrated on the German coasts as well. Future trends are to be estimated. The regional change in sea level is characterized by totally different features compared to global mean sea level rise. At a regional level, the atmospheric effects, changing currents and natural oscillations of oceanographic and offshore basins produce a significant variability that cannot be neglected. One example among many is that the systematic seasonal variation in the regional sea level on the German North Sea coast is around 25 cm to 30 cm (Dangendorf et al. 2012). Several studies (incl. Wahl et al. 2011) confirm secular rates of sea level rise of around 15 to 25 cm (including subsidence) for the German Bight. In recent years, there have been reports of an increase in the rates of sea level rise (incl. Wahl et al. 2011). However, these studies only address the rise itself and not the understanding of underlying processes. On the German North Sea coast, there needs to be a deeper understanding of many individual processes and interactions to enable robust predictions for the future to be made.

The significance of the change in the regional sea level is that this level causes a non-linear alteration of the statistics of tidal characteristics and the sea state on the coasts. A changing mean sea level always means a change in the natural oscillation, both of the North Sea and of the individual estuaries. There are great local differences in the statistics of high tide, low tide and tidal range. In addition, the changes in sea level and wind fields necessitate an adjustment of wave statistics.

Tidal characteristics and wave statistics are major indicators of climate change in coastal hydrology and studies on these topics are of fundamental importance for coastal protection, foreshore vegetation, the oxygen balance, sediment management and the transport of harmful substances.

2 From measurements to a trend

The studies of the changes in sea level are based on the data captured by the Federal Waterways and Shipping Administration (www.wsv.de) and its predecessor organizations. Time series of high tides and low tides are available, some of which cover more than one hundred years. These datasets are among the spatially densest in the world that document climate change, including the spatially differentiated changing processes. The regional daily Mean Sea Level (MSL) is defined as the "water level of the horizontal centroid of a tidal curve", i.e. MSL cannot be measured directly. For longer time series, the regional sea level can be reconstructed. To do so, the "k value" (Lassen & Seifert 1991) has to be calculated as a scaling factor between the daily mean sea level and high tide or low tide.

However, this pragmatic solution to calculating regional sea level is disputed, because the k value may change as a function of the MSL. One way of checking this and identifying uncertainties is the digitization of the existing analogue tide gauge sheets. Section M1 at the Federal Institute of Hydrology, which is responsible for coastal hydrology, has addressed this issue, and has conducted a trial that involved digitizing 100 years of tide gauge measurements. The test data will be used primarily for the development of a) standards for digitization and b) procedures and standards for the quality assurance of digitized tide gauge measurements. One important lesson that has been directly learned is that quality assurance is necessary and, above all, involves just as much effort as the digitization of the data themselves. Here, KLIWAS project 2.03 is participating in the "automatic determination of tidal characteristics" project (AuTiBe) of the Federal Institute of Hydrology's coastal hydrology section. This project addresses automated quality assurance procedures. It is apparent that, in order to appraise the impact of climate change, the quality requirements to be met by the measurements are becoming more stringent. It will be the responsibility of departmental research to develop improved procedures for the automatic validation and the determination of uncertainties of long-term datasets.

After the scoping studies have been carried out and the appropriate time series, including the estimated sea level uncertainties (cf. Hein et al. 2010a) are available, breakpoint analyses should demonstrate the homogeneity of the data. Here, the Federal Institute of Hydrology's coastal hydrology section is cooperating with RWTH Aachen University to develop stochastic procedures, some of them new (Jenning et al. 2012). For the regional mean sea level, several tide gauges can be combined to form a representative virtual tide gauge. However, this procedure can only be carried out for MSL and not for other tidal characteristics. It was carried out using sophisticated new methods for the southern German Bight (Hein et al. 2011b), with the MSL of the virtual tide gauge being calculated as the most likely monthly value in a region. For the first time, tide gauge measurements are being virtually extended backwards using modern stochastic procedures. To avoid computational artefacts, only time series of the same length may be used when determining a virtual tide gauge. Accordingly, an extension of the measurement time series is helpful for those tide gauges that are only available for short time series. With the procedures developed in KLIWAS 2.03 (Hein et al. 2011b, c), it is possible to bring the time series to a uniform length. As a result of this new procedure, this length is determined by the longest time series available and not, as previously, by the shortest time series available. Hein et al. (2011b) also describes how subsidence is taken into account.

3 Examining the trend

Figure 1 shows the regional mean sea level of the southern German Bight. The calculation was based on the International Hydrographic Organization's definition of "mean sea level". Accordingly, the regional mean sea level is a 19-year mean of the sea levels at a gauging site (in this case the virtual tide gauge of the southern German Bight, Hein et al. 2011a, b). This kind of filtering makes it possible to keep fluctuations of short duration, be they through atmospheric influences or the influence of the long term tides, out of the consideration. The graph illustrates that the regional sea level is rising. In the last 100 years, the trend is around 11 cm / 100 a to 17 cm / 100 a. For the period before 1900, the only data available are those from the tide gauge "Cuxhaven". No conclusions should be drawn for that period.

The trend ascertained is in the order of magnitude of that ascertained by Woodworth et al. (2009) for the UK coast (14 cm / 100 a) and is thus thoroughly plausible. As the same time as the sea level was rising, the land in this region subsided by around 4 to 16 cm over the past 100 years. However, the subsidence is spread very unevenly from one place to another. The pronounced up and down of the blue line illustrates that the trend ascertained is definitely not linear. The rates of sea level rise are subject to continuous changes (Moser et al. 2011). Calculations of the trend of *global* sea levels show an acceleration (incl. Church & White 2011). This does not apply to German waterways of a maritime character. For the time being, *no significant acceleration* of sea level rise can be demonstrated (Hein et al. 2011b).

The rates of rise (Figure 2a) show the high degree of natural variability of the regional sea level. In the 1970s, for instance, the sea level fell. In the past 20 years, the

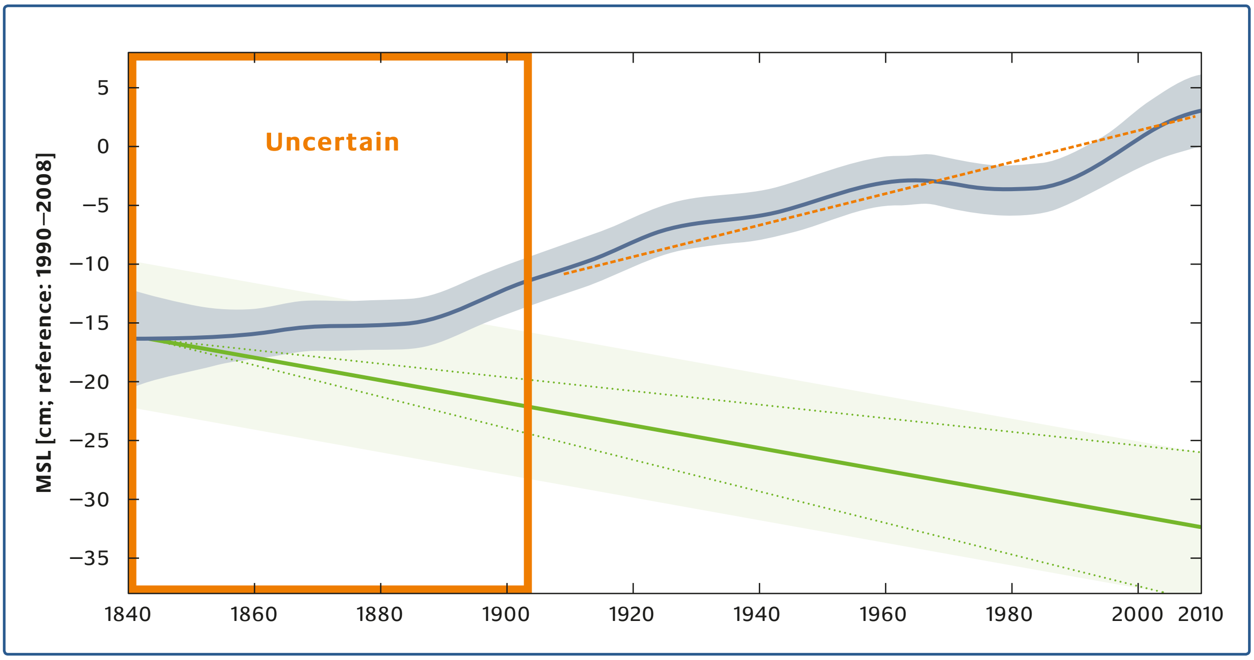

Figure 1: The regional rise in sea level (blue curve) and uncertainties (grey strip); the linear trend (orange dashed line); subsidence with uncertainties (green).

rate of regional sea level rise has increased. An impression of the processes that account for the non-linear changes can be gained from a multi-scale analysis. Here, the Federal Institute of Hydrology's coastal hydrology section has evolved various procedures. In addition to simple spectral methods, other procedures used include singular system analysis, detrended fluctuation analysis and wavelet transformation.

By way of example, the results of a wavelet transformation are shown (cf. Hein 2011a). Figures 2b to 2d illustrate three of the major periodicities of the natural fluctuations. It must be pointed out that reducing the results of the wavelet transformation to the three main periodicities is a simplified representation of the natural processes. For instance, significant periodicities of less than 19 years are not taken into account. More importantly, these graphs do not illustrate the special ability of the multi-scale analysis procedures to also reveal those periodicities whose frequencies change over time as a result of natural processes. This would go beyond the scope of this paper, and we would like to refer to a publication on which work is currently in progress.

Our analyses show, inter alia, periodicities of around 20 to 30 years, of 35 to 40 years and a periodicity of 60 to 80 years. This provides, for the first time, a process-oriented insight into the long-term changes in the regional sea levels. For instance, the 35 to 40 year cycle is a typical period of our weather patterns and was described by Francis Bacon as long ago as 1625 (Gregory 1930). Given the length of the time series, the periodicity of 60 to 80 years should be treated with caution. However, the Atlantic Multidecadal Oscillation (AMO) has a very similar periodicity (Kerret al. 2000). If the three periodicities illustrated are superimposed on one another, most of the fluctuations in the MSL can be explained. In particular, it becomes clear that the apparent acceleration of the past 20 years was probably caused by

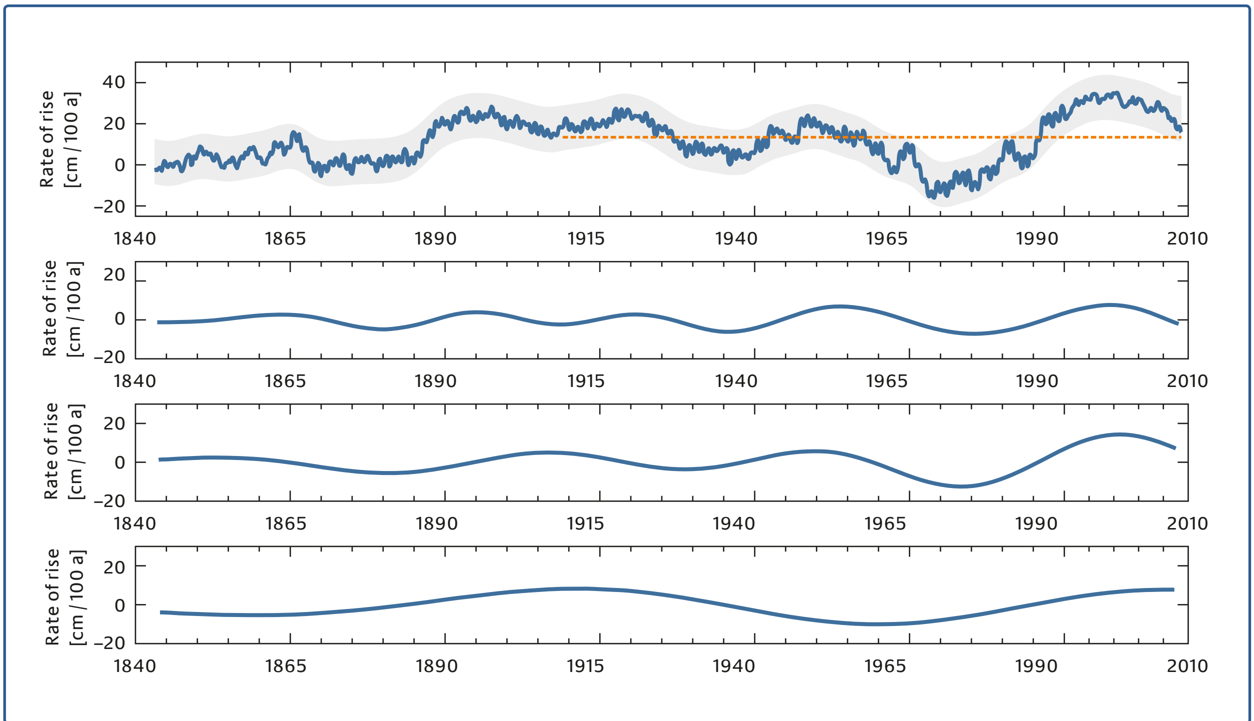

Figure 2: Rates of regional sea level rise (blue line) and uncertainties (green strip); b–d) three major periodicities from the multi-scale analysis.

a simple interference between the different periodicities and was probably not part of climate change.

The possible increase in variability that is apparent in Figures 2b and c is worthy of note. What is not apparent in Figure 2 is that the increase in variability is associated with a change in the frequency spectrum. This must be verified more precisely, because an increase in variability means an additional challenge to adaptation – sea levels will behave more unpredictably than compared with a frequently assumed constant rise. Although we are unable to note any significant proof of an acceleration of the rates of rise in recent decades or within the past 100 years, this does not mean that the German coasts are not at risk. However, on the basis of what is known today, it can be stated that the future rise in sea levels in this region will be less than the global mean.

4 Wave statistics

On the coast, *no* series of measurements of sea state are available that are long enough to enable climate change statements to be made. Initially, there may have been no technical capabilities. Even when these were available (Barjenbruch & Wilhelmi 2008), the sea state was continuously measured at only a few locations. Nevertheless, statements can be made by analyzing selected periods. For instance, Figure 3 shows the exceedance probability of waves measured at the tide gauge "Alte Weser Lighthouse". The study found that neither the model customary in deep water nor the distribution customary in shallow water are able to adequately depict the exceedance probabilities of wave heights (Mai et al. 2010).

Significant wave heights can be depicted well by using parametric sea state models (Mai 2008, Hein et al. 2010b). Initial results for the German coast are available (Hein 2011c). For these wind speeds from several regional climate model runs from the ENSEMBLE project (Hewitt et al. 2004) were analysed. These results can be used in further investigations as boundary conditions for wave models (sea state model chain). From the results of regional climate models frequencies of medium and high wind speeds were calculated for each year. The analyses essentially show two things: Firstly, a great inter-annual variability, and secondly, a great difference between the various climate models, in each case for both the medium and the high wind speeds. From this, it can be deduced that all parameters that are directly associated with the wind (sea state, sea levels, et al.) have to be observed over long periods of time in order to be able to make reliable statements about the possible impact of climate change. The large range of results from different climate models means that in future there must be continuous updating and that each new model generation must be integrated and hydrologically assessed.

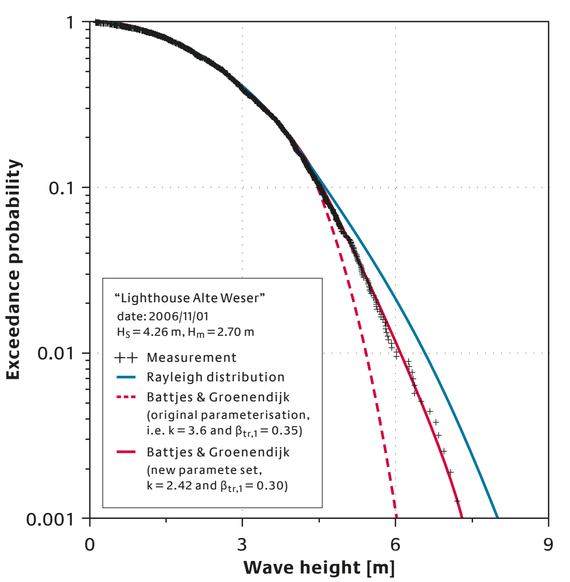

Figure 3: Exceedance probability of wave heights, from measurements and different model approaches

5 Answers and outlook

The regional sea level in the southern German Bight is rising – in the past one hundred years it has risen by around 11 cm to 17 cm. Unlike the global rise, however, we cannot currently detect any acceleration of the trend. Rather, we have identified a pronounced inter-annual and decadal variability. Together with a possible increase in this variability, this is a serious challenge, because the response time to take action might be reduced. Here, the underlying processes have to be understood in order to make reliable statements. However, there are still many gaps in knowledge about global processes, and basic research will not be able to bridge these gaps until the decades ahead. KLIWAS Project 2.03 marked the first step towards an understanding of the system in long-term regional processes.

As a response to climate change, studies identify three options for action:

(1) Measuring. If we wish to be able to make reliable statements about future trends in tidal characteristics and wave statistics, they have to be recorded in a resolution that is sufficient in terms of time and space.

(2) Quality assurance. As one consequence of climate change the demands on the quality of the measurements increase. It is even more important that the quality of the measurements be assured and that their homogeneity be ascertained. Possible uncertainties must be documented. Automatic quality assurance procedures are to be evolved. The digitization of historical tide gauge measurements is one method that can be used to determine uncertainties. Future generations of model chains are to be updated and hydrologically verified with regard to tidal characteristics and sea state.

(3) Continuous scientific/hydrological assessment. Building on identified trends and multi-scale analyses, departmental research must investigate in a better understanding of regional processes. In the dec-

ades ahead, sensitivity test and future generations of regional and global climate models (model chains) must be continuously integrated, verified and in accordance with scientific standards hydrologically analyzed.

In the course of the year ahead, Project 2.03 will increasingly look at future trends in tidal characteristics. On the basis of the KLIWAS model chain, for the first time, three-dimensional hydrodynamic models will be used that are able to reproduce estuarine processes on climatological time scales (i.e. decades). Latest stochastic methods will be used and evolved in order to link measurements and models. Initial reliable statements, including the existing uncertainties, will be made for the near future (2021–2050) and the distant future (2071–2100).

Prof. Charles Finkl, editor-in-chief of the Journal of Coastal Research, summarizes the current state of play of international climate research as follows: "Models get better over time, and we need to use them, but with a grain of salt. We should instead use our brains and hard or real data to make interpretations". In other words, we should reliably document the necessary data and place the analyses of changes in tidal characteristics on a permanent basis, which have been irregular in the past (cf. Rohde 1968, Führböter & Jensen 1985), so as to be able to continuously follow climatological changes in sea levels. If the results of today's climate models with regard to the future trends in sea levels are taken with a grain of salt, it is apparent that the "prevailing sea level may be the source of some surprise in the *near* future" (Cazenave & Llovel 2010).

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Storm Surges in the Elbe, Jade-Weser, and Ems Estuaries – A Sensitivity Study against the Backdrop of Climate Change

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1 Introduction

In the light of the climate change in this century and beyond, the German Federal Ministry of Transport, Building and Urban Development has commissioned a number of research projects into possible effects of climate change upon navigation and waterways. In the search of options for adaptation to climate change it is necessary both to understand the present situation and to analyze potential future conditions. To give an example, it is, of course, not possible today to predict the actual effects of climate change upon the sea level or the wind conditions in the German Bight in, say, the year 2050 or 2100. However, the SRES scenarios provide guidance regarding the bandwidth of change for a number of parameters that will be crucial for the height of a storm surge. In the light of this guidance, it is possible to consider the impact upon the Federal waterways of a change in those parameters in the event of a storm surge. As an example, this paper presents the results of a sensitivity study dealing with storm surges in the Elbe, Jade-Weser, and Ems Estuaries. It is the objective of this sensitivity study to create a better understanding of the bandwidth of variation in peak water levels during storm surge in both present and potential future conditions. The study results will contribute to identifying the vulnerability of areas along the waterways in the Elbe, Jade-Weser, and Ems Estuaries, to analyze similarities and differences among the three estuaries, and find, in co-operation with the Federal Waterways and Shipping Administration (WSV), suitable adaptation options.

2 Storm surge scenarios

Storm surges occurring in the Elbe, Jade-Weser, and Ems Estuaries are not only influenced by tidal dynamics and wind set-up in the German Bight but also by processes in those estuaries (which, it should be noted, extend up to 100 km landwards into the North German Lowlands). The changes in the water level in the German Bight, the local effects of the wind above estuary waters, the river runoff into the estuary, and each estuary's topography are all among the factors influencing the parameter HW (which denotes the peak water level having occurred during a storm-surge period) throughout each estuary. A sensitivity study on storm surges is investigating scenarios that are intended to highlight central elements of a possible future (Kosow & Gassner 2008). Becker (in this volume) quotes an increase of precipitation in winter and a higher run-off volume resulting therefrom (Horsten et al., in this volume) during the storm-surge season as two of the central elements of a potential future situation. Heinrich et al. (in this volume) quotes a rise in the sea level in the German Bight as a central element of climate change. The results of the following scenarios will be presented as examples:

- Increase in river runoff Q: Storm surge scenarios will be combined, on the one hand, with the actually measured runoff and, on the other hand, with three variations of virtually increased runoff (i.e. 2,000 m³/s, 3,000 m³/s, and 4,000 m³/s for the Elbe and Jade-Weser Estuaries and 350 m³/s, 700 m³/s, and 1,200 m³/s for the Ems Estuary). The highest value under consideration is equal to the current HHQ (highest recorded value) of the estuary in question.
- Sea level rise in the North Sea slr: Storm surge scenarios will be combined with a virtual sea level rise by 25 cm, 80 cm, und 115 cm, respectively (for an appraisal of those values, see Gönnert et al. 2009).

The sensitivity study is based on two very high historical storm surges (viz, the storm surge of 3 January 1976, referred to as "SF76", in the Elbe and Jade-Weser Estuaries, and the storm surge of 1 November 2006, referred to as “SF06”, in the Ems Estuary). The use of hydrodynamic-numerical models, also referred to as “HN models” (viz, UnTRIM, CASULLI and WALTERS 2000 respectively BAW 2004) allows to look at the influence of each processes in question upon the changes in the water level during a storm surge individually. Wind force and direction data were provided by Germany’s National Meteorological Service (DWD).

3 Results of the sensitivity study

Figure 1 shows the influence of a sea level rise upon the change in water levels during a storm surge in the storm-surge scenario SF76 for the location Brake (Unterweser). It is shown that the heights of Tidal High Water Thw and Tidal Low Water Tnw as well as the times of their occurrence are changed as a result of the sea level rise on the day preceding the storm surge. The sea level rise also increases the peak water level during storm surge HW and makes it occur at an earlier point in time. The duration of high water levels is shown to last longer.

Time of occurrence of the peak water level during storm surge

With reference to a given location, in e.g. the mouth on the Ems Estuary, HW will occur at Emden after 100 minutes in reference scenario SF76. HW will occur about 5 minutes earlier when the sea level rises by 25 cm, about 20 minutes earlier when the sea level rises by 80 cm, and about 25 minutes earlier when the sea level rises by 115 cm. This means that, with a sea level rise in the event of a storm surge, warning times for the defence of dykes, for the evacuation of port areas, or for issuing a general warning to the population at large are expected to be shortened.

Duration of high water levels

Drainage installations and sluices without pumps are dependent upon a gradient in water leves to function. Port facilities, too, cannot operate when water levels are very high. Locks and flood barriers will be closed in the event of a storm surge. This is to say that shipping traffic will be restricted. Looking at a 24-hour period in reference scenario SF76 for the location Hamburg, water levels above NN +3.50 m will occur for 11.5 hours. This period of time will be lengthened by about 30 minutes when the sea level rises by 25 cm, by about 5 hours when the sea level rises by 80 cm, and by about 6 hours when the sea level rises by 115 cm.

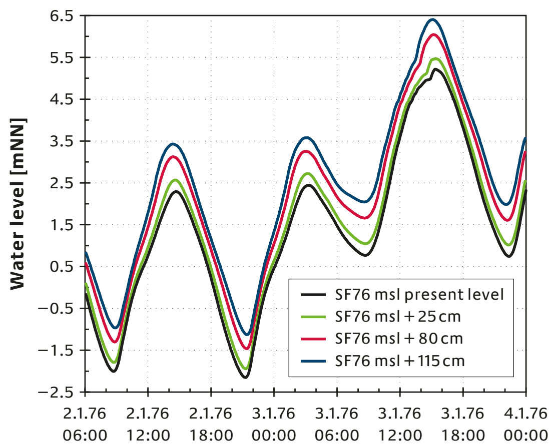

Figure 1: Time series of water levels at Brake (Weser km 40) for storm-surge scenarios featuring a rise in mean sea level

Peak water level during storm surge HW

Variations in the sea level or in fresh water discharge will influence the peak water level during storm surge prevailing along estuaries in different ways. HW in the seaward reaches of estuaries will not be influenced by an increase in fresh water discharge. However, HW will be some centimetres higher in the middle reaches of estuaries, and even some decimetres higher in their landward reaches. On the other hand, an increase in the sea level will lead to increased values of the peak water level during storm surge throughout the estuaries, including their innermost reaches.

A graph depicting both the sea level rise and the increase in the river runoff (Figure 2) shows that, as far as the seaward reaches of the estuaries are concerned, the height of the peak water level during storm surge will

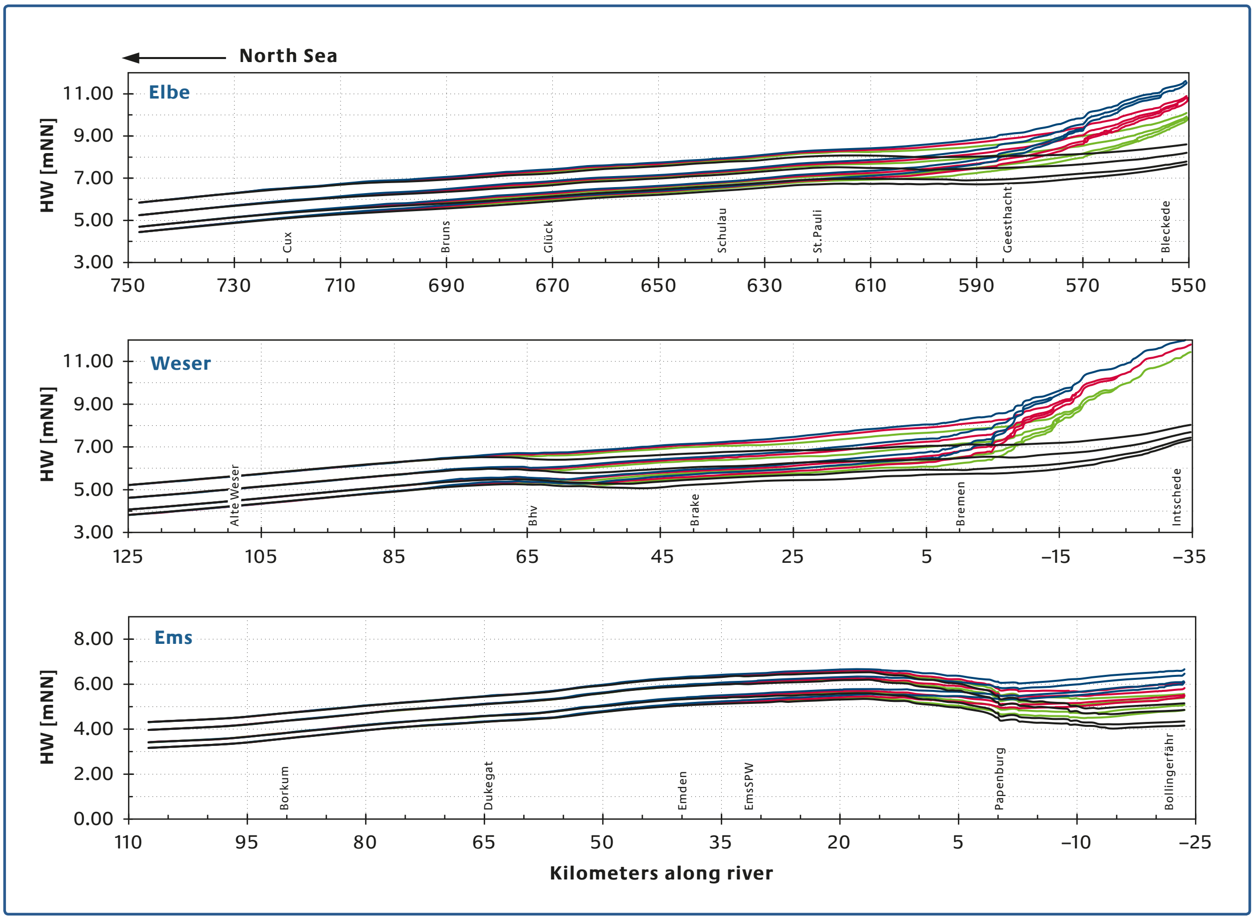

Figure 2: Influence of a sea level rise (to-day's water level msl, plus virtual levels msl + 25 cm, msl + 80 cm, and msl + 115 cm) and of the river runoff (measured runoff in black, plus three variations of virtually increased runoff, viz, 2,000 m³/s for the Elbe and Jade-Weser Estuaries and 350 m³/s for the Ems Estuary in green, 3,000 m³/s for the Elbe and Jade-Weser Estuaries and 700 m³/s for the Ems Estuary in red, and 4,000 m³/s for the Elbe and Jade-Weser Estuaries and 1,200 m³/s for the Ems Estuary in blue) on the peak water level during storm surge.

be influenced by the sea level rise. In the middle reaches of the estuaries, the height of the peak water level during storm surge is shown to be under the influence of both the sea level rise and the increase in runoff. In the landward reaches of the estuaries, it is mainly the runoff that determines the height of the peak water level during storm surge. Using the results of the present study, it is possible to identify areas along the estuaries where variations of the mentioned parameters will significantly change the peak water level during storm surge.

Adaptation measures

Flood barriers provide protection against storm surges. To give an example already in operation, the Ems Barrier near Gandersum is protecting the Ems Estuary from storm surges. The following consideration covers the four sea level scenarios from the above figure and combines them with the four runoff scenarios from the same figure. Other than shown in Figure 2 above, Figure 3 below gives the peak water levels during storm surge to be found along the Ems Estuary with the Ems Bar-

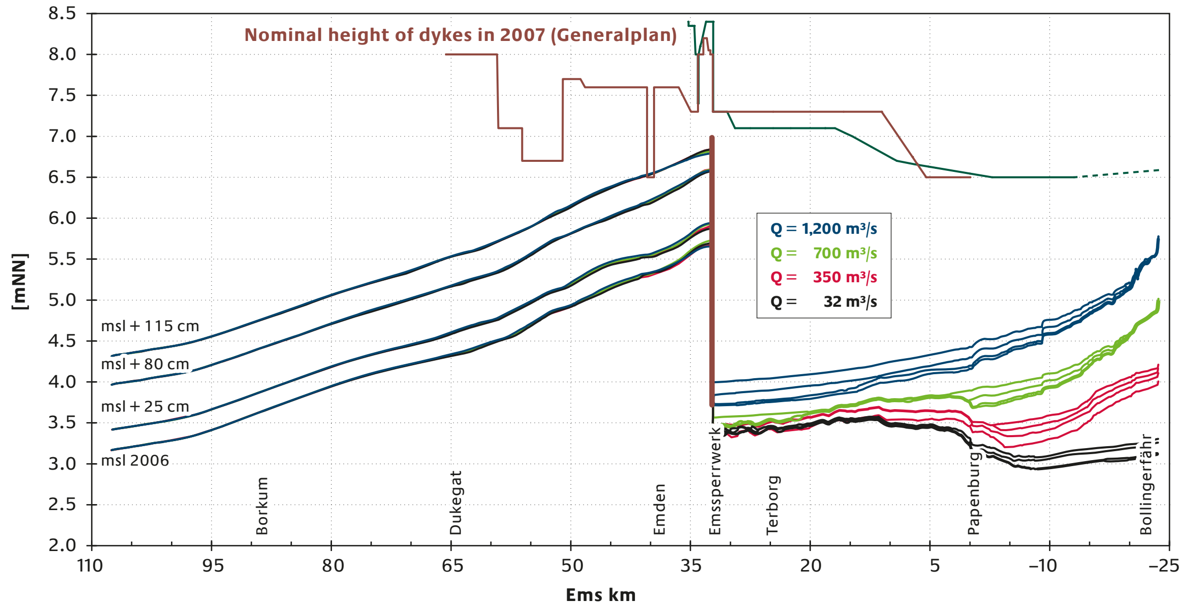

Figure 3: Influence of a sea level rise and of river runoff upon the peak water levels during storm surge to be found along the Ems Estuary with the Ems Barrier closed

rier closed. Figure 3 also gives the current design dyke height (left and right bank). The land upriver from Gandersum is nicely protected when the Barrage is closed. Peak water levels are relatively low and are dependent upon the river runoff and upon the length of the period during which the storm surge barrier is closed. The highest water levels found on the seaward side of the Ems Barrier will not be influenced by the river runoff but merely by the sea level rise. A comparison between the design dyke heights and the peak water levels during storm surge as taken from the present sensitivity study goes to show that the Ems Barrier constitutes a suitable adaptation measure in nearly all scenarios considered. However, some areas along the Ems Estuary can be identified where the barrier will not eliminate the vulnerability in the event of a storm surge, for example, because local dykes are not sufficiently high.

4 Summary

A sensitivity study dealing with storm surges in the Elbe, Jade-Weser, and Ems Estuaries looks into systematic variations of those parameters that may be changed as a result of climate change. Table 1 below summarizes the estimated changes in the peak water levels during storm surge. In the mouth of the estuaries, the peak water level during storm surge will be determined by the conditions prevailing in the North Sea, i.e. the storm surge and the sea level rise. In the middle and landward reaches, the height of the peak water level during storm surge will be determined both by the conditions prevailing in the North Sea and by those prevailing inland (runoff).

All scenarios considered will feature increased peak water levels during storm surge, an earlier occurrence of such peak levels, and a longer duration of high water

Table 1: Changes in the peak water levels during storm surge along the Elbe, Jade-Weser, and Ems Estuaries in each of the scenarios considered

Scenario	**seaward** reaches of the estuary in question	**middle** reaches of the estuary in question	**landward** reaches of the estuary in question
river runoff Q	±1 cm	5–30 cm	10–100 cm
sea level rise slr	+ slr	+ (slr ± 10 cm)	+ (slr ± 10 cm)
Q and slr combined	+ slr	≤ (slr + Q)	≤ (slr + Q)

levels. It seems fair to assume that the well-known problems arising in any storm surge will become more serious as a result of climate change.

The case of the Ems Barrier serves as an example how to use the results of a sensitivity study in order to identify, in co-operation with the German Federal Waterways and Shipping Administration (WSV), those areas along Federal waterways that are vulnerable to climate change and to find suitable adaptation measures.

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Impacts of climate-induced Changes in the River Discharge on the Algale Growth and the Oxygen Budget in the Elbe Estuary

Birte Hein, Jens Wyrwa & Andreas Schöl (all BfG)

1 Introduction

Today, already pronounced oxygen minima can be observed in the freshwater region of the Elbe estuary. These oxygen deficits which occur mainly during summer are of major ecological significance as they can have a negative impact on the benthic community or may even cause fish mortality (Bergemann et al. 1996).

The oxygen balance of the Elbe estuary is governed to a large extent by the input of organic and inorganic matter from the Middle Elbe. Thereby, river discharge is a determining factor (Kerner 2007). The algal biomass transported from the Middle Elbe into the estuary dies mainly due to deteriorating light conditions in the region of Hamburg harbour (Schroeder 1997, Yasseri 1999). By the microbial degradation of the algal biomass oxygen is consumed and as a consequence a significant oxygen depletion in summer is developed (Bergemann et al. 1996, Kerner 2007, Yasseri 1999).

This study means to provide a first estimate of the impact of climate-induced changes in river discharge on the input of organic matter from the Middle Elbe and, as a consequence, on the water quality in the Elbe estuary.

2 Test study: Projection of the oxygen contents in the Elbe estuary

2.1 The water quality model QSim

The simulation of the oxygen budget for the Elbe estuary and the Middle Elbe is carried out with the deterministic one-dimensional water quality model QSim (Kirchesch & Schöl 1999, Schöl et al. 2006a, Schöl et al. 2006b). A preceding hydraulic model (Oppermann 1989) calculates the water levels and flow velocities for the German part of the Elbe River. The hydraulic conditions determine the residence time of a system (Monsen et al. 2002). The residence time, in turn, has an effect on algal growth, i.e. a longer residence time due to a decreasing flow might support algal growth (Jassby et al. 2002, Salmaso & Braioni 2008). Based on the hydraulic conditions, QSim simulates the water quality of the system. The model represents the main processes determining the oxygen and nutrient budget as well as the algal and zooplankton growth in an aquatic system.

2.2 Input data for the climate projections

For testing the QSim model for further use within the KLIWAS research programme, climate projections provided by the GLOWA II project of the Federal Ministry of Education and Research were used for the Elbe River. Based on the projection for the future climate as well as the future runoff for the period from 2004 to 2055, input data were generated for three different projections each for the course of one year. For this purpose, 10 model years with high (90-percentile), medium (50-percentile) and low discharge (10-percentile) were averaged to ob-

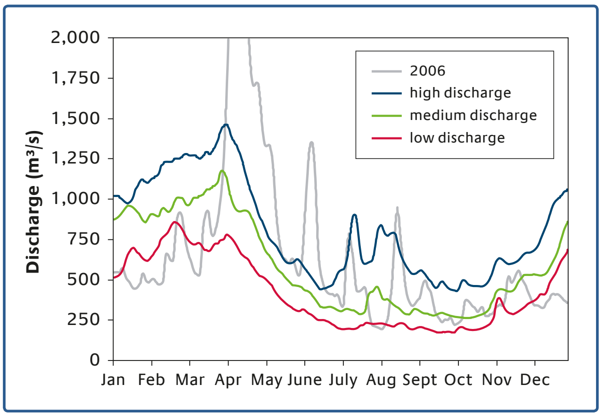

Figure 1: Annual cycle of the discharge [m^3/s] for the three projections (high, medium and low discharge) compared with the year 2006 at the gauge of Neu Darchau (km 536)

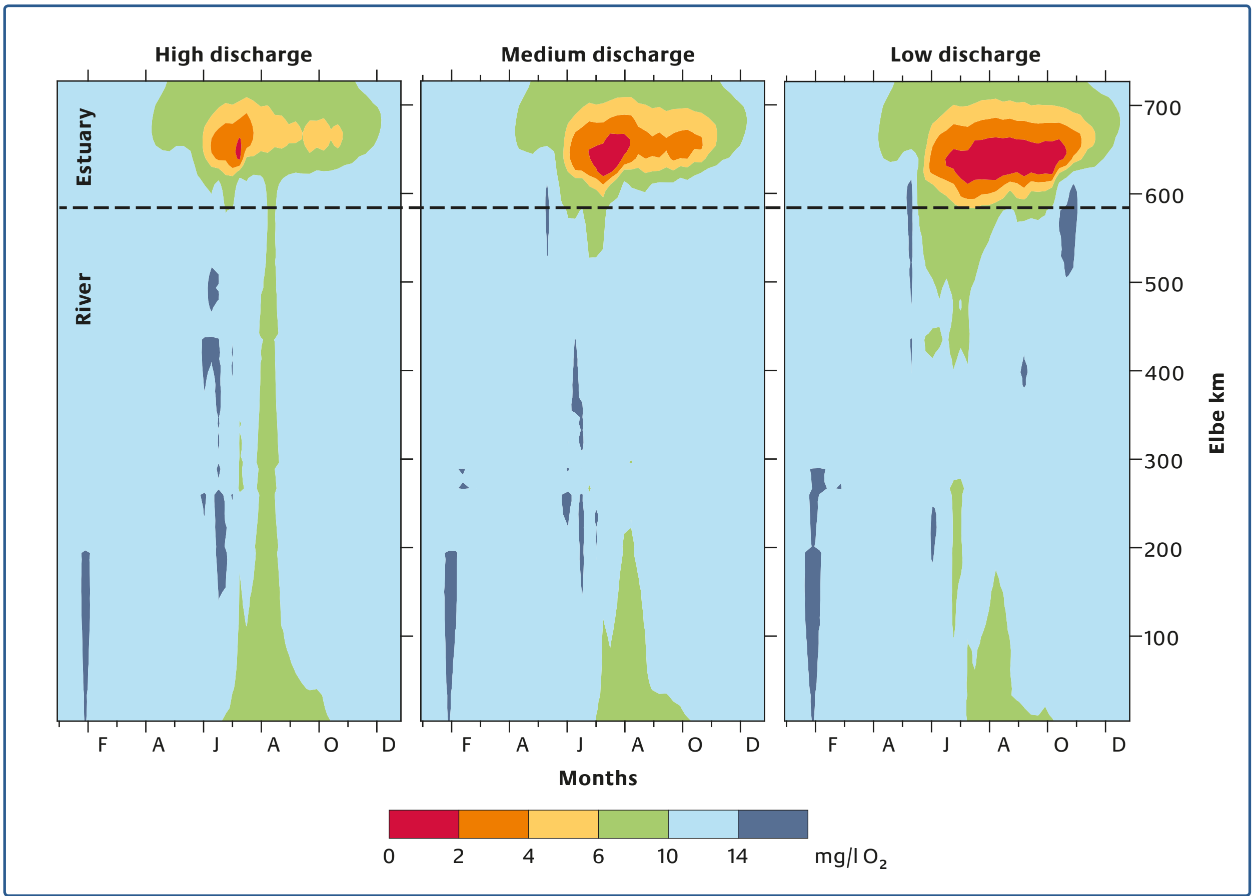

Figure 2: Climate projections – oxygen concentrations [mg/l] under the projection of high, medium and low discharge. The forcing data were provided by the GLOWA-Elbe II project (QUIEL et al. 2010) of the Federal Ministry of Education and Research.

tain the forcing data for QSim (QUIEL et al. 2010). As can be seen in Figure 1, this approach causes a smoothing of the river discharge curve. The results of these simulations provide a first estimate of the interactions between river discharge, algal growth and oxygen concentrations in the Elbe estuary.

2.3 Results

The results show a direct impact of the river discharge on the oxygen concentration in the Elbe estuary (Figure 2). On the one hand, the oxygen concentrations under the projection of low discharge along the Elbe estuary are lower (between km 585 and 727) than the oxygen concentrations under the projection of high river discharge. On the other hand, the oxygen minima under the projection of high discharge occur further downstream than under the projection of low discharge. In the Middle Elbe (between kilometre 0 and 585), all three projections do not show any oxygen deficits. Only minor differences between the projections can be noticed.

Regarding the chlorophyll a concentrations which are an indicator for algal biomass (Figure 3), the following can be deduced: the projection of low discharge

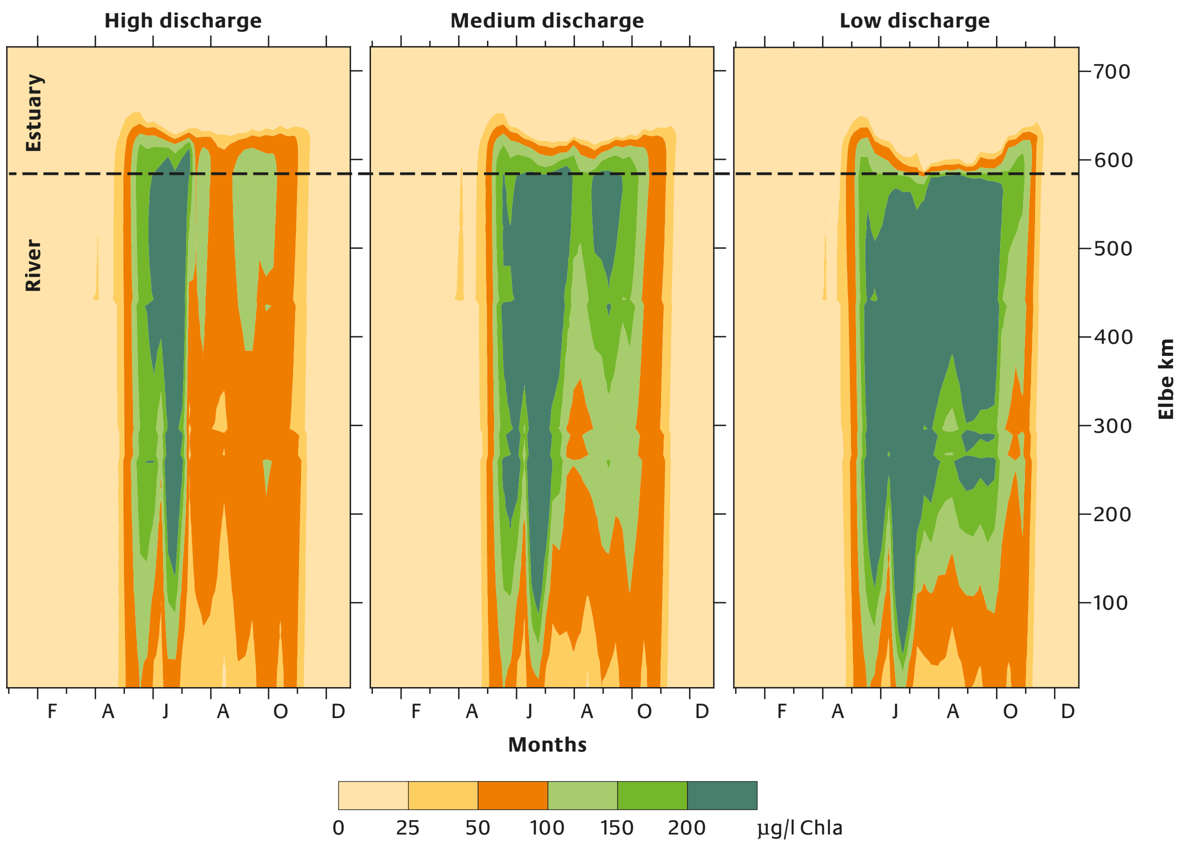

Figure 3: Climate projections – chlorophyll a concentrations [µg/l] under the projection of high, medium and low discharge. The forcing data were provided by the GLOWA-Elbe II project (Quiel et al. 2010) of the Federal Ministry of Education and Research.

shows significantly higher chlorophyll a concentrations und and thus significantly stronger algal growth in the Middle Elbe than the projection of high discharge. The die-off of the algal biomass occurs further downstream under the projection of high discharge compared to the projection of low discharge.

In order to explain the relationship between algal biomass and oxygen concentrations in the Elbe estuary, it is necessary to take the residence time into account. A decreased river flow leads to a longer residence time in the system which, in consequence, might support the algal growth (Jassby et al. 2002, Salmaso & Braioni 2008). In the Middle Elbe, the increased amount of algal biomass causes a strong biogenic oxygen input. However, the increased algal growth in the Middle Elbe also leads to a higher input of living and already dead algae via the Geesthacht weir into the Elbe estuary. A model parameter which shows this relationship is the $CBOD_5$ at Geesthacht weir (at km 585, transition between Middle Elbe and Elbe estuary). This parameter indicates the amount of organic carbon which is easily degradable for heterotrophic bacteria. The projection of low discharge shows a higher $CBOD_5$ than the projection of high discharge (not shown here) at the Geesthacht weir, i.e., higher amounts of easily degradable organic carbon enter the Elbe estuary under the projection of low discharge. The living algae then die off due to light limitation in the Elbe estuary and serve as substrate for heterotrophic bacteria (Bergemann et al. 1996, Yasseri 1999). In the presence of oxygen in the aquatic system, bacteria consume the algal-born organic carbon and thereby cause oxygen depletion or rather a decrease of the oxygen concentrations.

3 Summary and Outlook

This study demonstrates the successful application of the water quality model QSim to simulate climate projections for the Elbe estuary and shows how QSim is integrated into the KLIWAS model chain. A strong influence of the river discharge and the related carbon loads on the oxygen concentrations in the Elbe estuary was demonstrated.

As a next step, the water quality in the Elbe for the current period (from 1997 to 2010) is to be determined. When the KLIWAS projections are available, first the calculations for the climate reference period (1961–1990), then for the "near future" (2021–2050) and afterwards for the "far future" (2071–2100) will be performed. In addition, solutions must be developed to generate scientifically-based input data (nutrients, algal biomass) for the climate projections for the Elbe River. As these parameters have a great influence on the model results, they are of particular importance for the model study. These simulations are to serve as a basis to determine the impact of climate-induced changes in river discharge and input of organic matter from the Middle Elbe on the oxygen budget in the Elbe estuary.

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Estuarine Vegetation and Floodplain Protection

Eva-Maria Bauer, Maike Heuner, Elmar Fuchs, Uwe Schröder & Andreas Sundermeier (all BfG)

1 Introduction

Estuarine vegetation holds important ecological functions, both for man and the ecosystem itself. For example, it provides natural erosion protection, habitat for protected species (Dinse 1989, Stiller 2010), contributes to the self-purification of the surface and subsurface waters, has been supplying reeds (thatch material) and bulrushes for a long time (Fürst 2000, Gemeinde Seestermühe 2008) and comprises, moreover, numerous protected habitats (Drachenfels 2011).

Structure and species composition of the estuarine vegetation obviously have been shifted successively by agriculture, hydraulic engineering, and water management. Climate change will possibly expose additional pressure on the vegetation habitats and their functioning. If, for example, hydrological extreme events become more intensive (Alcamo et al. 2007) or if the tidal range increases, this might presumably affect the dynamics of the bank and floodplain vegetation. Especially the location and extension of reed beds which are important to bank protection may be affected.

2 Objectives

Within the framework of the project "Vegetation shift in German estuaries due to climate change and consequences for bank protection and maintenance" (KLIWAS 3.09), we will study to what extent climate change may cause an alteration of the floodplain vegetation of the German North Sea estuaries of the rivers Elbe and Weser as well as the respective ecological functions of tidal floodplains. Floodplain areas of these estuaries have to be identified possibly being sensitive to future climatic conditions. For this purpose, remote sens-

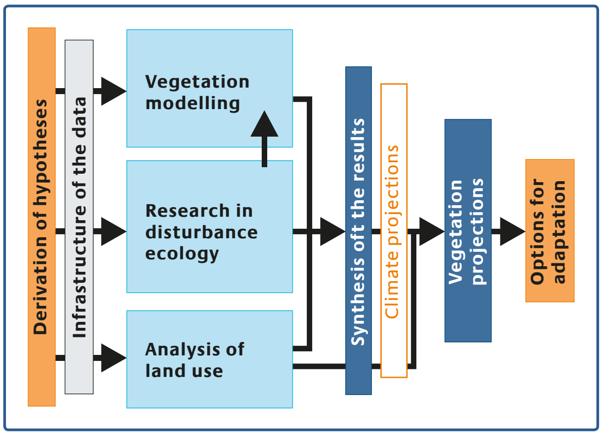

Figure 1: Schedule of the project

ing methods will be combined with field studies. Habitat and population models will provide an impression of how future climate scenarios may affect the bank and floodplain habitats. Furthermore, the impact of land use will be analysed. In all work packages, rules are derived under which conditions which vegetation types occur. On the basis of projections of the future conditions (e.g. tidal parameters) which are prepared by other KLIWAS projects, projections of the vegetation to be expected in the future will then be lined up (cf. Figure 1).

Finally, options for adaptation will be derived for the maintenance of the estuaries and their floodplains, so that in the future both the waterway as an environmental friendly mode of transport and the function of the bank and floodplain vegetation can sustainably be secured.

3 Selected results

In terms of setting up vegetation modelling, it was investigated which abiotic site factors are responsible for the patterns of the stand-forming reed bed species.

The most important model variables are the relative elevation in relation to the mean tidal high water level (MHW) and the distance to the centre-line of the navigation channel. An additional model variable for the vegetation boundary to the tidal flat at the Lower Elbe is the hydraulic stress on the banks. Here, the distribution of the reed beds along the marsh edge on banks outside a river bend differs from banks inside a river bend (Figure 2). On the banks outside a river, a clear pattern can be found. The flow-tolerant bulrush grows on significantly lower heights than the reed. Banks inside a river bend on the other hand, are to a far lesser degree exposed to the current hydraulic pressure. Here, the flow-sensitive reed can prevail over the other reed beds species, in many places even on low-lying river banks.

At the Weser, it is being investigated how reed harvest in winter affects the structure of the reed bed and the occurrence of invasive plant species in this habitat. Figure 3 shows that mowing affects the stand structure as well as the biodiversity of the habitat. The total shoot number and the proportion of panicle-bearing shoots increase after mowing. According to current investigations, the mowing of reed at the Weser does not promote invasive plant species.

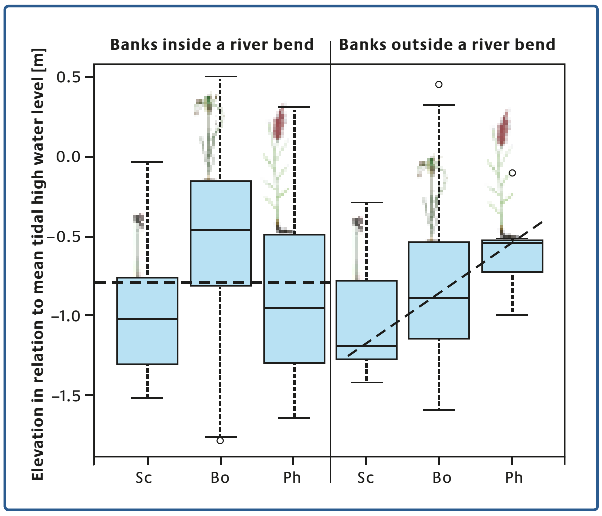

Figure 2: Box-plot for occurrence of selected reed bed species of the Lower Elbe in dependence of site factors "elevation to mean tidal high water level" and bank slopes; the dashed lines represent the relative elevational position of the species to each other. Sc = *Schoenoplectus tabernaemontani*, Bo = *Bolboschoenus maritimus*, Ph = *Phragmites australis*

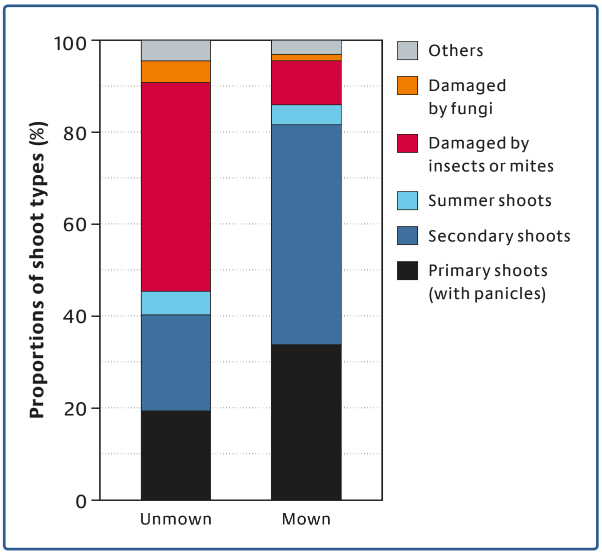

Figure 3: Impact of reed harvest on the stand structure of reeds at the Lower Weser

4 Outlook

Within the project progress the projections on climate-induced changes of the habitats will be prepared and the impacts of land use on the habitats will be analysed. From these findings, options for floodplain management will be derived, for example concerning the possible use of riparian vegetation for bank protection as well as options for use and maintenance of the floodplain in terms of erosion control and ecological value of the habitats. Recommendations concerning the future management of invasive plant species are being elaborated. Furthermore, comments are made on selected WFD measures against the background of the project results.

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Studies on the Influence of Climate Change on the Budget and Quality of Sediments, Using the Example of the Tidal Elbe

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Introduction

In the research programme KLIWAS the projects 3.03 and 3.06 investigate the impact of climate change on the budget and quality of sediments in the estuaries of the North Sea. For this purpose extensive analyses of nature measurement data and time series of measurements were carried out. The results were then discussed in detail against the background of climate change. For the further duration of the project these results compile a knowledge and data base on climate-relevant relationships of effects which will continue to be analysed until the conclusion of the KLIWAS project at the end of 2013. This study aims at reliable and if possible also quantitative determinations on the possible effects of a changing climate on the sediment budget in estuaries. This paper is presenting the results of two main areas of the study at the tidal Elbe.

Regarding the methodological concept of the study it should be mentioned that the sediment balance of estuaries and the dynamics of its processes as well as the quality of the sediments are not directly influenced through climatic parameters like precipitation or air temperature, but indirectly through other climate-sensitive factors. Literature describes headwater discharge as such a factor (e.g. GKSS 2007 or BfG 2008), that is the inflow from the Elbe catchment into the estuary. A second factor is water temperature. It is a controlling influence factor in a number of partial processes which can have an impact on the current quantitative as well as qualitative status of the sediment balance. The influence of climate or, to express it more precisely, the influence of weather conditions – or the hydrological parameters occurring as their consequence – on the status of the sediment budget has been investigated on the basis of measurement time series of headwater inflows and the water temperature observed. Of special interest are situations which could occur more frequently and more extremely in the future under a changed climate, e.g. hot summers with long periods of low headwater inflows or winters rich in precipitation. The future development of the sea water level is another climate-sensitive factor which could have an influence on the budget and quality of the sediments.

Dynamics of sub-aquatic transport body structures in the tidal Elbe

The first focus of the study is about the dynamics of sub-aquatic transport body structures (dunes). These structures are over long river sections characteristic for the river bed of the tidal Elbe. The direction, speeds and geometrical parameters of their movement are important spatial and time indicators of the sandy sediment loads carried near the bottom. Once there are records of this dynamics over a long time and over large distances it is expected to deduct morphodynamic trends for the estuary from them. Such transport body structures can impair the safety and ease of shipping, since they can occur in the area of the maintained depth. Individual shallows created by this are then eliminated, for example through water injection procedures. On an annual average, about 1.5 million m³ of sediments annually have been dredged in this way in the area of the channel of the tidal Elbe (Entelmann 2010).

One study area is located in the Elbe section near St. Margarethen between Elbe km 685.5 and 689.8, approximately 5 km upstream of the Kiel Canal near Brunsbüttel. The coloured area depicted in Figure 1 was recorded eight times by multi-beam echo sounding in the period between March and August 2010. The processing of these soundings or the comparison of two subsequent soundings with the help of the software Dune Tracking 2D (see Wesseling & Wilbers 2000) makes it possible to analyse the length and height of all

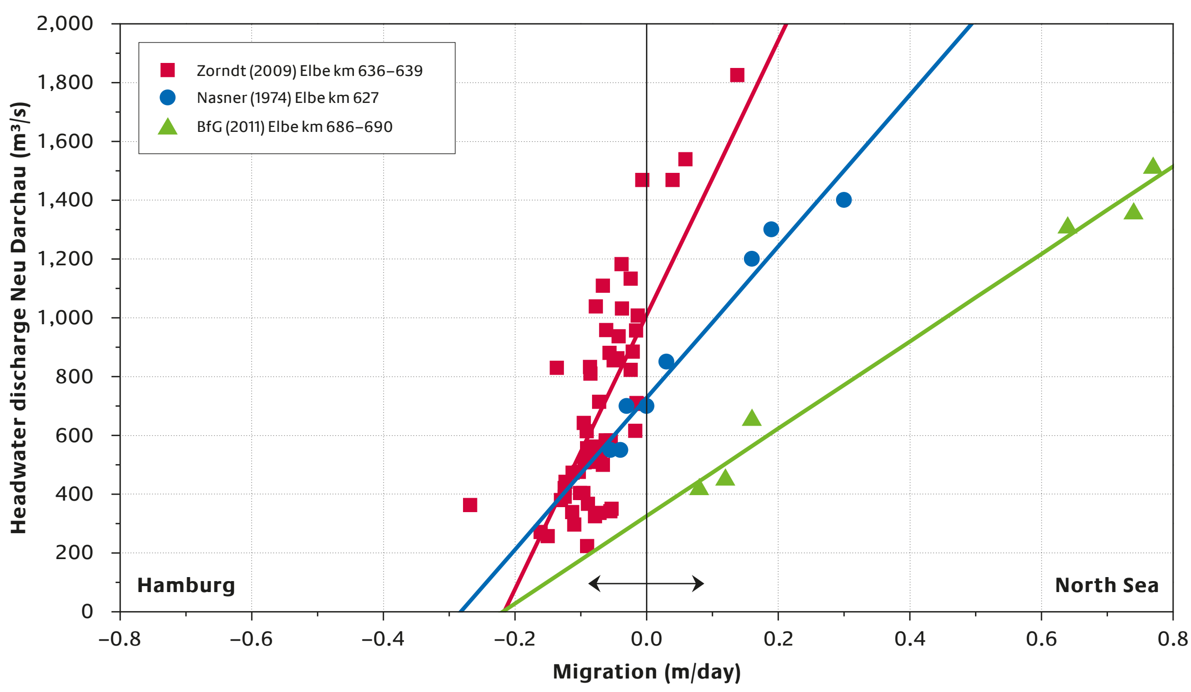

Figure 1: Dependence of the migratory speeds of transport bodies on headwater inflows in three investigated sectors of the tidal Elbe, from BfG (2011).

transport body structures and their movements. The results from two additional and methodologically comparable analysis of transport body structures at Elbe km 627 (NASNER 1974) and between Elbe km 636 and 639 (ZORNDT 2009) complete the depiction of results in Figure 1. Both study areas are situated in the Elbe section between Hamburg Harbour and the town of Wedel. This figure shows, differentiated according to study area, the average migration speeds of the structures covered in relation to the headwater discharge at the time of the sounding.

In case of little headwater discharge it can be observed in all three study areas that the transport body structures migrate upstream in the direction of Hamburg Harbour or that such a movement can be expected. In case of higher headwater discharge the direction changes and these structures thus migrate downstream in the direction of the North Sea. Figure 1 shows this site-specific limiting discharge. The aim of the further project work at the tidal Elbe will be to supplement the figure shown here by evaluation results of other river sections. As soon as the KLIWAS projections of headwater discharge for the Elbe catchment area are available (elaboration through KLIWAS Project 4.01) it will be possible to assess projections for future sediment loads on the basis of these results. However, the results already confirm that changes in discharge regime of the inland Elbe will have an impact on the sediment budget of the tidal Elbe.

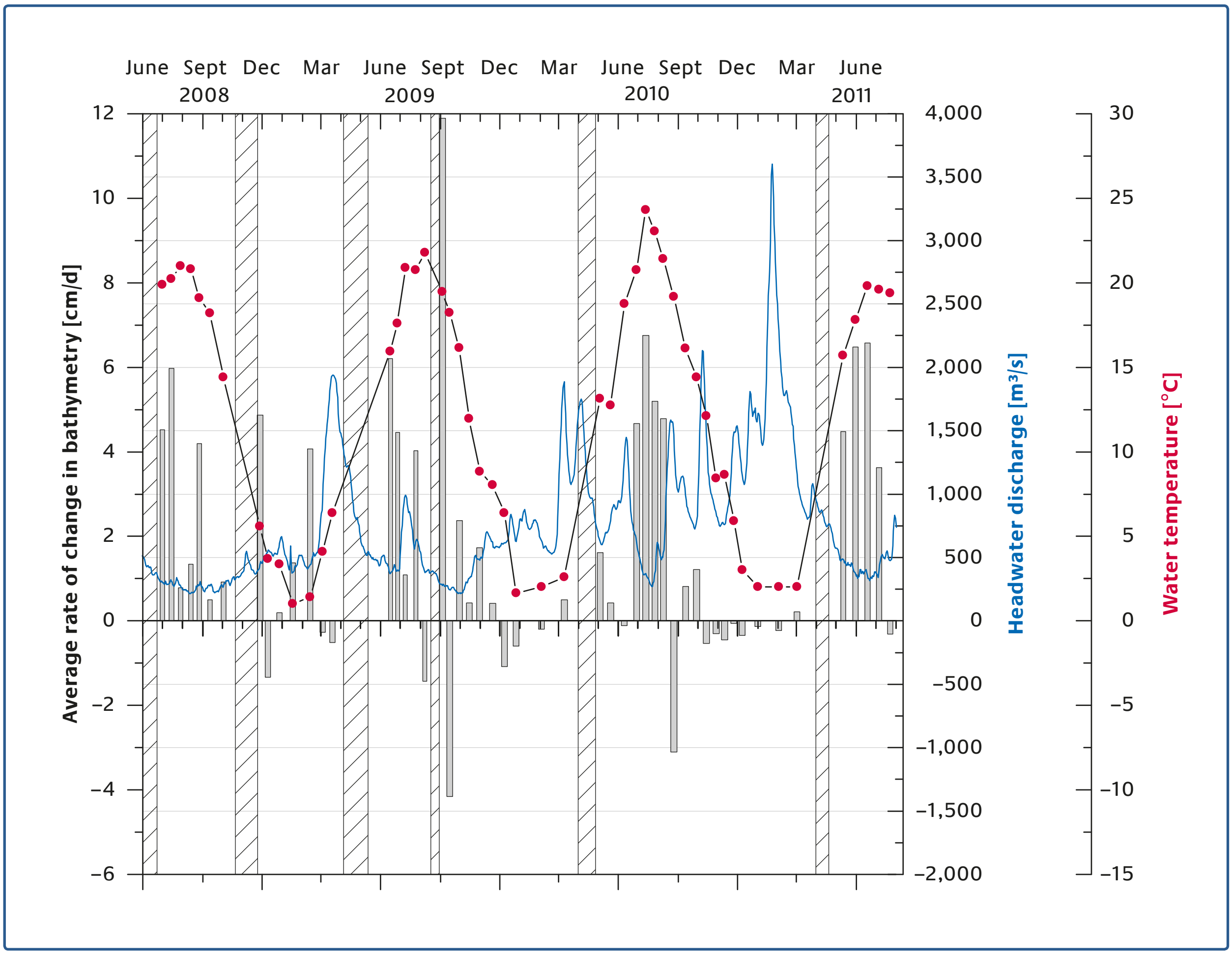

Figure 2: Development of the average change in bed height in the area of the main sedimentation in the Elbe section before Wedel.

Studies on the dynamics of the fine sediment balance and the quality of its sediments

The second focus of the study deals with the dynamics of the fine sediment budget in the Elbe section before the town of Wedel at Elbe km 642/643, approximately 15 to 20 km downstream from Hamburg Harbour. The sediments of the river bed in this section can be described as a pulpy mix of silt with admixtures of fine sand with various strengths. For fine sediments this section is known to be a major dredging point of the Waterways and Shipping Office Hamburg, and at the same time the Hamburg Port Authority has installed a sediment trap here (see http://www.tideelbe.de).

Figure 2 shows the average change rates of the bed heights for this dredging section. Since spring 2008 these rates were recorded twice weekly by means of multi-beam echo sounding as element of a sediment trap monitoring programme. At times when sediments were dredged out of the sediment trap no soundings were carried out. These periods are shown as hatched in the figure.

Any change in the elevation of the river bottom must be understood as an integral factor consisting of the parts deposition, erosion and consolidation of sediments. The exact proportions are variable in time and unknown. Solely the total change in the elevation of the river bottom is known. Considerable research efforts are needed at the level of the process dynamics; its partial processes can be structured roughly, but sufficiently into the following categories: (1) Sinking behaviour of the individual grain and of flocs, (2) interaction current and bed, (3) soil mechanism, (4) physical and chemical processes at the particle-particle level (micro-scale) and (5) biological processes.

The time series pictured in Figure 2 show that high sedimentation rates always occur at times of low headwater discharge, but also at times of high water temperatures. Low headwater discharge effects a shift of the estuarine turbidity zone upstream and an increased tide stream-oriented entry of sediments in these areas. This effect is shown by model calculations and measurements and it is also sufficiently described in literature (see for example GKSS 2007 or results in KLIWAS projects 2.04 and 3.01). Conversely in a phase of high headwater discharges a decrease of the bed height or only little changes of the bed height can be observed. It is not known whether this decrease is due to increased erosion or consolidation of sediments already deposited or only to a strongly reduced deposition at constant erosion or consolidation rates. Furthermore, on this basis of data the relative impact of water temperature on the shares of erosion, deposition and consolidation hardly can be assessed. For the partial processes water temperature is a factor which must be taken into consideration. The water temperature, for example, impacts density and kinematics viscosity of water and thus changes the sinking behaviour of suspended sediments and solid suspended matters. However, the integral effect over all partial processes is unknown. All in all the influence of the headwater discharge seems to be dominant, since a flood event in summer as well as in winter, regardless of the clearly different water temperature, always results in a negative or strongly reduced development of the bed height change. However, in those summer periods strongly favouring a net increase of the bed height, extremely "negative" change rates or greatly abrupt changes between two subsequent change rates can be observed. This abrupt, extremely non-linear system behaviour has to be the consequence of the complex interaction between the partial processes.

But the composition of the sediments and therefore the composition of potential dredged material, too, is subject to the influence of headwater discharge and water temperature. From the analysis of sediment samples of the river bottom in this Elbe section Wedel it was found that low headwater discharge in connection with high water temperatures results in an increase of the proportion of fine grains in potential dredged material. This is now the time to also look at the quality of the potential dredged material, because it is mainly heavy metals tied to solids and the organic pollutants investigated in the project which accumulate in the fine grain fraction <20 µm of sediments and solid suspended matter. Corresponding analysis also show a dependence between headwater discharge and the resulting contaminants load together with solid suspended matters, which is swept down from the upper reaches of the river. This contaminant load is being recorded and analysed along the tidal Elbe at various permanent measuring stations of BfG and of the Flussgebietsgemeinschaft Elbe (River Basin Community Elbe). The region which is the source of most of the pollutant groups is the catchment area of the Elbe. Higher discharge leads to an increase in the entry of the pollutant load of suspended matter. Figure 3 covers in addition the pollutant loads recorded at the permanent BfG measuring stations Geesthacht and Wedel, using the example of cadmium.

The station Geesthacht which is situated at the entry of the Geesthacht weir records the contaminant load that is swept down from the upper reaches of the river into the estuary. Further downstream in the Elbe section Wedel contaminant loads are being recorded at the permanent BfG measuring station Wedel. Compared to station Geesthacht, the concentrations at station Wedel are lower. The reason for this is the mixing of fluviatile with

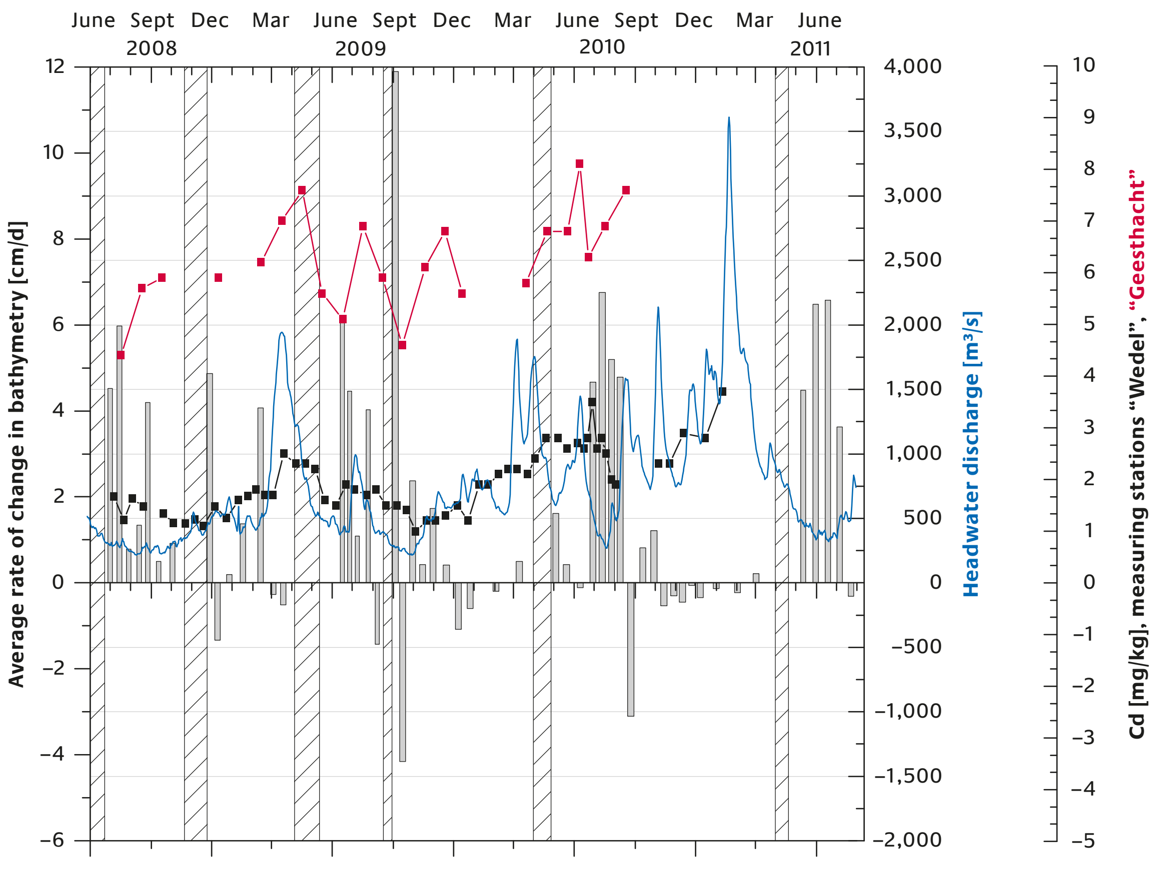

Figure 3: Influence of headwater discharge on change of bed height and pollutant load of suspended sediments using the example of cadmium

solid suspended matters of marine origin. The latter one has a lower contaminant load and is transported upstream by the effect of "tidal pumping". In case of high headwater discharges, however, the increase of the contaminant load can be clearly recognised. On the one hand there is a more mobilisation of polluted fine sediments in the catchment area. On the other hand the high headwater discharge mitigates the upstream transport of marine suspended matters into the Elbe section Wedel (see also explanations on Figure 2). If one compares the time series of contaminant loads recorded at Wedel station with total change of the elevation of the river bottom in the Elbe section Wedel, one can see that the trends of both curves develop in opposite directions, that is to say that low sedimentation rates occur at times of higher contaminant loads and vice versa.

Conclusions

Quantity and quality of the potential dredged material define key values for the management of dredged material. A first result presented clearly mean that a changing climate will have an impact on the budgte and quality of the sediments, and therefore also on potential dredged material. So the investigations carried out up to now in the projects 3.03 and 3.06 have shown the necessity of adapting the concepts or strategies on which dredged material management is based. The type and extent of the adaptation options will depend on the intensity of the climate change signal and the projections of future headwater discharges, water temperatures and sea water levels.

In summary the results of the investigations show that, assuming as often is done that summers in the future will be warmer and have less precipitation, it is possible that the quantities of maintenance dredging in the Elbe section Wedel will increase and that probably finer grain sizes in the dredged material can be expected. For this assumption, however, no negative effects on the quality of the sediments to be dredged have to be expected. In case of winters with higher precipitation and with higher discharges in the Elbe catchment area, however, it has to be expected that increased contaminant loads are carried into the estuary. What was not taken into account in the wording of this first qualitative impact forecast was the sea level which will change in the future and is being investigated jointly in KLIWAS project 2.04. But until completion of the project at the end of 2013 KLIWAS has the intention of supplementing the study by this aspect.

Acknowledgement

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Sensitivity Study into the Impact of Modified Run-off Quantities on the Transport of Salts, Pollutants and Sediments in the North Sea Estuaries, plus a Perspective on Adaptation Options

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1 Introduction

Large areas of the German coastal waters of the North and Baltic Seas, including the estuaries, are used as navigable waterways. Climate change may substantially affect shipping and the state of waterways. Relevant catchwords include dyke safety; changes in water levels; an increase in the strength of currents; large unwanted shifts of sediments; an increase in the volumes of dredged sediments more efforts needed in the maintenance of banks, embankments and structures; modified navigational access to ports. The hydrological situation as modified by climate change entails a host of consequences affecting the operation, maintenance, and upgrade of navigable waterways. This is why those responsible for waterway management will look for scientific insight to assist them. Any major political decisions concerning the long-term development of maritime traffic will need a set of well-founded facts that has been made available in good time.

As some variety of different developments in climate change may reasonably be expected, so must some variety of adaptation measures be developed. Such measures can be taken into account already at present when a comprehensive set of planning and management measures is put into practice for navigable waterways as well as for ports and harbours and for new or enlarged industrial zones. In this context, it is essential that a sound basis is conceived for planning and deciding upon precautionary measures that will be implemented at some time in the future.

2 How this study is conceived

The mean sea level has been and will remain the dominant factor when describing the hydrological conditions along the German coastline. The predicted values for this essential parameter, as seen in the context of a potential climate change, are most uncertain (Heinrich et al. in this volume). There is quite some bandwidth of potential modifications (Gönnert et al. 2009). To enable those responsible to consider whether, and if so, in which circumstances, the waterways in the German Bight, in the North Sea estuaries, and in the Baltic Sea may be affected by climate change, the whole bandwidth of possible modifications, as identified in the process of research into the consequences of climate change, is an object of KLIWAS sensitivity studies (Kwadijk et al. 2010). Such studies cover all those parameters that are of relevance to the safety and easy flow of shipping traffic, such as the water level, currents, salinity, and the transport of sediments.

The present sensitivity study is conducted using prediction models for the North and Baltic Seas and for the Ems, Jade-Weser, and Elbe Estuaries; these models have proved their worth in a number of studies conducted on behalf of the Federal Waterways and Shipping Administration. The results of those studies are available for any calculation point and any point in time; they are analyzed and represented as tidal characteristics values. The tidal characteristics can then be set into a meaningful relation to the evaluation parameters of waterway infrastructure elements with a view to determining how these may possibly be affected. The determination of the degree and the manner of how waterways are affected just as well as the development of adaptation measures can only be done in co-operation with the Federal Waterways and Shipping Administration. To this end, all required data should be made available to the Federal Waterways and Shipping Administration in such a way that, for example, they can be processed with the help of geo-information systems.

Not only the bandwidth of a potential rise in the sea water level will be reflected in the model-based sensitivity studies but also the bandwidth of potential wind speeds (BECKER in this volume) and the changes in the run-off quantities gathered from the Modellkette Binnenland (HORSTEN et al. in this volume). Besides, the various influence parameters will also be combined with each other.

3 Sensitivity study "Rise in the Sea Level"

To investigate the influence of an estimated rise in the sea level of the Atlantic Ocean upon the tidal conditions prevailing in the North Sea, two simulation exercises, using the mathematical model of the North Sea, have been carried out and their results have been compared with each other. In the first exercise, the current state was simulated, in the second one, the expected state in the event of a rise in the sea level. The expected rise is simulated by adding 80 cm at the "Atlantic" end of the North Sea model to the serial values of the sea level fed into the model. These values, which are taken from the survey for the German Bight made by GÖNNERT et al. (2009), are fully in line with current estimates by the Intergovernmental Panel on Climate Change (IPCC 2007).

It should be noted that such a linear rise in the water level shown at one end of the North Sea model does not continue in a linear way into the German estuaries. Figure 1 goes to show how a rise in the sea water level by 80 cm will influence the level of low water (LW) in the German Bight including its connected estuaries. Wherever in the German Bight white areas have been marked, the LW value will only rise by the height of the rise in the sea level. Areas marked red are those where the LW value will rise by more than 80 cm, whereas areas

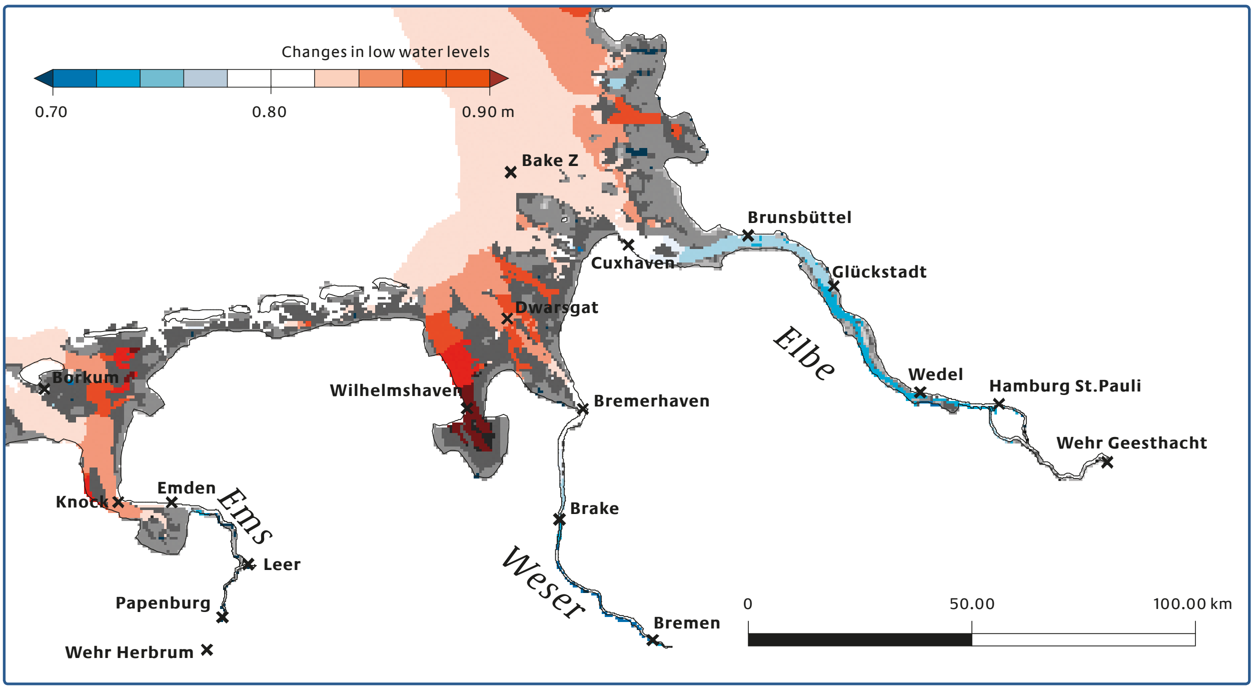

Figure 1: Changes in low water values with a rise in the sea level by 80 cm

marked blue are those where that value will go up by less than 80 cm.

There are blue-marked areas in the region of the Brake Gauging Station in the Lower River Weser (Figure 1), which serves as an indication that the low water value will be heightened by less than 80 cm. By the same token, an analysis of the high water (HW) values shows that these will be raised by a little more than 80 cm, which will lead to a somewhat increased tidal range. What is more, there will be a shift in the time of occurrence of HW, which means that the tidal curve's flood gradient will be steeper. This will enhance the tidal curve's asymmetrical build. The shift in the times for the occurrence of the tipping points testifies to the fact that the duration of the flood-stream will have been shortened. This is why the flood current velocities will be greater than the ebb current velocities.

For the simulation of the situation with the estimated rise in the sea water level, a comparison of the mean contents of suspended matter shows lower values in the area of the Blexer Bogen and higher values in the area of Brake. These changes indicate a shift upstream of the turbidity maximum. This spells an unfavourable situation as far as waterway maintenance is concerned, because there would be more dredging work required in the landward reaches of the estuary.

Tidal dynamics, as modified by a rise in the sea water level, will lead not only to a shift upstream of the turbidity zone but also the brackish-water zone will be re-located accordingly. This might result in the following restrictions:

- as far as the River Elbe is concerned, in restrictions for the anti-freeze irrigation of orchards and for the use of Elbe water as process water for industrial purposes,
- as far as the River Weser is concerned, in restrictions for the use of Weser water as livestock watering, and
- as far as the River Ems is concerned, in restrictions for the dumping of dredged sediments ashore, because a limit in sediment salinity must be observed in the Ems Estuary.

The effects of a rise in the sea level are quite comparable for the three German North Sea estuaries. However, the estuaries' characteristics are different, which is, above all, due to their respective location and estuary geometry. Another point to be taken note of is the reciprocal effect of a rise in the sea water level and the run-off volume.

4 Sensitivity study "Fresh Water Discharge"

The effects of changes in the run-off volume are comparable among all the estuaries in question. Any different characteristics do not only depend upon each estuary's geometry but also upon the run-off itself, which is essentially characterized by the catchment area of the respective river. Both location and size of each catchment area will determine both quantity and quality of the run-off, which will flow over the weir as fresh water discharge

- into the tidal reaches of the River Elbe near Geesthacht,
- into the tidal reaches of the River Weser near Hemelingen, and
- into the tidal reaches of the River Ems near Herbrum.

In natural conditions, the location of the brackish-water zone will be determined by the volume of fresh water discharge and by the tide. The brackish-water zone will adapt by itself to modified environmental conditions; for example, it will shift upstream when the volume of fresh water discharge decreases. It should be noted that any re-location of brackish-water zones as a result of advection and turbidity will not happen instantaneously but will rather be subject to some degree of inertia. A quasi-stationary location of the brackish-water zone will not come into being until the volume of fresh water discharge as well as the spring-and-neap cycle will have remained stable and uniform, respectively, for some time (the time span will depend upon the history in combination with the current and previous run-off). For locations within the brackish-water zone, the maximum value of salinity will then be dependent upon the height of the incoming tide.

The volume of fresh water discharge and the sea level will not only influence the brackish-water zone but also the turbidity zone. This influence has been analyzed for all three estuaries. The figures for the mean values of concentrations of suspended matter in the River Elbe for a variety of volumes of fresh water discharge as found along the centreline of the fairway from the mouth of the River Elbe up to the Weir near Geesthacht have been excerpted from that analysis to be shown in Figure 2. Upon calculation, the results go to show that, as the volume of fresh water discharge increases, the turbidity maximum will be shifted downstream. A general conclusion that may be drawn from this fact is that great volumes of fresh water discharge from inland will lessen the burden of waterway maintenance, which is especially true for the upper reaches of the estuaries.

On the other hand, it is true that increasing quantities of some pollutants, including cadmium, mercury, zinc, hexachlorobenzene, and compounds of the DDT group, which have their origins in the upper reaches of the River Elbe, will be carried into the tidal reaches of the river by of fresh water discharge when the latter's volume is increasing (Ackermann & Schubert 2007). As those and other pollutants are hosted by suspended matter, they will be deposited in zones with low currents, such as port basins, with the obvious result that dredged spoils from there will be contaminated accordingly.

5 A perspective on adaptation options

With a view to reducing the quantity of suspended matter carried upstream, the Hamburg Port Authority and the Federal Waterways and Shipping Administration have jointly developed a concept for the good management of the River Elbe, which consists of the following three pillars:

- sediment management to be optimized, account being taken of the system as a whole,
- mitigation of the tidal energy pushing upstream by a set of countermeasures to be taken in the river's estuary, and
- set-up of flood basins in the upper part of the estuary.

The above pillars form also the basis for similar concepts applying to Rivers Ems and Weser, such as the so-called River Ems Action Programme. All measures applied in the context of the above concepts will be analyzed as to their effectiveness in conditions modified by climate change.

6 Summary and perspective

The study results and conclusions presented in this paper have clearly shown that sensitivity studies are an adequate method for the identification of whether a given waterway may be affected by the consequences of climate change. Sensitivity studies may at any one time be adapted to the latest state of research into climate change and, when doing so, any insight gathered so far can be continued to be used.

The methods and procedures used by the Federal Waterways Engineering and Research Institute make it possible to follow and to identify the way of a signal that has originated in the Atlantic and keeps on running through the North Sea into the estuaries. The holistic approach that is needed for the studies presented above can well be implemented as the models used by the Federal Waterways Engineering and Research Institute take account of the reciprocal effects between hydrodynamics and sediment transport. This will make it possible to make use of the study results for other purposes such as oecological issues. To make it possible to fully exploit that potential, a number of study concepts addressed to certain issues will be harmonized with other KLIWAS projects. Such harmonization is practiced not only within KLIWAS but also with other partners such as Biozentrum Grindel, a department of Hamburg University that operates in the larger context of KLIMZUG-Nord, where the Federal Waterways Engineering and Research Institute is also a project partner.

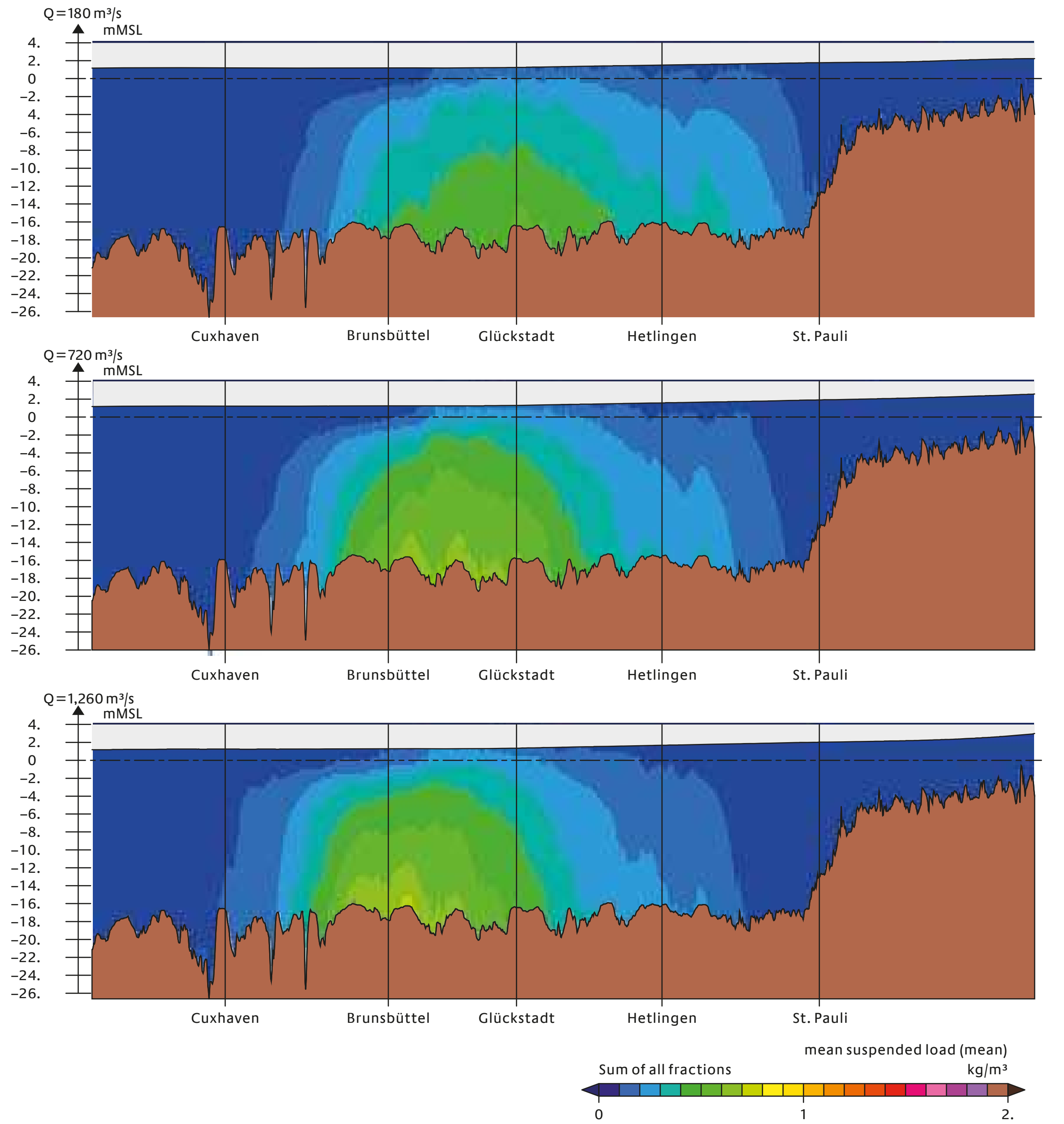

Figure 2: Mean values of concentrations of suspended matter as found along the centreline of the fairway from the mouth of the River Elbe up to the Weir near Geesthacht. The upper line represents the values at a volume of fresh water discharge of 180 m³ per second while the middle line represents values at a volume of 720 m³ per second and the lower line values at a volume of 1,260 m³ per second.

The impact of a rise in the sea level and of a modified volume of fresh water discharge on the conditions in the North Sea estuaries has been the object of research in a number of sensitivity studies. The brackish-water zone and the turbidity zone will move upstream as a result of a rise in the sea level and/or a decrease in the volume of fresh water discharge. This shift of location will have adverse effects on the maintenance of waterways in the estuaries and on the use of water from the estuaries. On the other hand, higher run-off quantities will have a positive effect, although larger quantities of harmful substances will then be carried from the upper reaches of the River Elbe into its tidal reaches.

Even today, waterway maintenance has to respond flexibly to changing run-off quantities. The possibility of flexible maintenance should be taken into account when developing a sediment management concept as part of an integrated waterway management plan with a view to climate change. Present-day waterway management measures should also be considered as to their effects in relation to conditions modified by climate change.

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Lessons Learned and Way Forward – Discussion and Looking Ahead

Transport Policy Aspects in Climate Adaptation

Karl-Hans Hartwig (University of Münster)

Theses for the brief presentation at the panel discussion

1.

Mobility is a means to overcome space for persons and goods. Thus, it is a key prerequisite for society's prosperity and growth. From the point of view of transport economics, the shipping industry – inland navigation, coastal and maritime shipping – is important to satisfy transport needs in Europe. This is particularly true for bulk cargo and containers. When used at maximum capacity, shipping is the most cost-efficient mode of transport. Its energy consumption as well as its emission levels are comparatively low.

2.

A reasonable supply of transport infrastructure, such as navigation channels and riverbeds, locks and bridges, ports and berths, dams and berthing areas, is necessary in order to ensure efficient navigation.

3.

Climate change impacts on the efficiency of any transport infrastructure. This impact results from changes of flows and water levels for inland navigation or changes of winds and currents, rough seas and levels for coastal shipping.

4.

If the low water levels appear rose more frequently due to climate change, the capacity of the existing fleet is reduced and the effective supply of transport operations decreases. When the supply is reduced, the prices on the transport market rise. Increasing prices result in a reduction of demand and shipments and hence in a change of the modal split. This effect is enhanced with a lower predictability of water levels, since there is a risk of increasing transport costs for shippers and a reduced reliability of transports from the viewpoint of their clients.

5.

The cost increase for navigation leads to a shift of transport from shipping to road and rail. Thus modal shift results in a deadweight loss, on the one hand because freight rates for all modes of transport increase and on the other hand because congestion in road and rail networks arises from increased demand and causes even higher CO_2 emissions and external costs.

6.

If transport policy wants to achieve demand-oriented and smooth traffic flows with the least environmental pollution possible, it will have to adapt to the changing environmental conditions. Improved navigation systems are one key element of such the necessary strategy.

7.

Infrastructure modifications cause high costs. Consequently, it must be ensured that the utility of these modifications exceeds its costs in order to avoid a deadweight loss for the society. Simultaneously, necessary infrastructure projects must be realized in good time – especially as planning processes requires time and payback periods of these projects last for years.

8.

For an efficient transport policy, it is necessary to have detailed knowledge of the functional chain: climate change – flows and water levels – transport costs – freight rates – adaptation reactions of shippers and the shipping industry – impact on the national economies – costs and benefits of transport policy adaptation measures.

9.

The KLIWAS research programme "Impact of Climate Change on Waterways and Navigation in Germany – Options to Adapt" addresses this functional chain. It tries to identify the interactions as precisely and comprehensively as possible. KLIWAS is a research programme which is strictly congruent with the approach of modern transport economics. Its reliable empirical findings are an important prerequisite for national transport policy in order to adapt transport industry to future changes of basic conditions.

Dealing with Uncertainties from the Point of View of Science and Political Consultation

Petra Mahrenholz (UBA)

1 Introduction

Since the mandate for political consultation in environmental issues is anchored in the act establishing the Federal Environment Agency, the communication of scientific findings to political decision-makers has for nearly 40 years belonged to the core business of its staff. Since these scientific findings often are afflicted with uncertainties – like the assessment of the effect of chemicals or projections of the future climate and its consequences – the Federal Environment Agency has a lot of experience concerning the good as well as the failed communication of uncertainties. This experience is the basis of this article and is particularly founded on own work with national and international institutions, like various interministerial working groups of the Federal Government on climate issues, the IPCC or the Subsidiary Bodies of the UN Framework Convention on Climate Change.

2 Complex problems, the demand for "complete findings" and the precautionary approach

In 2008 the Federal Cabinet adopted the German Strategy for Adaptation to Climate Change. This required that all the Federal Ministries concerned recognized climate change not only as a really existing challenge of the next few centuries, but also its extent and the extent of its consequences, and this under the framework conditions of an uncertain factual situation. This recognition is now the basis of adaptation decisions: The Federation decided in the basic principles of the Strategy to take decisions on the basis of existing knowledge and oriented towards the principle of precaution, sustainability and viability, by means of integrated adaptation concepts, accepting uncertainty (Deutscher Bundestag 2008).

Why is this the only possible way of dealing with the challenge of the one part of climate change which can no longer be avoided? We know on the one hand that politics, in times of ever scarcer resources, have to solve ever more complex problems. Political decision-makers therefore are expecting certainty of knowledge for decisions. State Secretary Klaus-Dieter Scheurle, for example, in his opening statement demanded "KLIWAS is to supply the most reliable knowledge possible on consequences of the climate". Hans Moser (Federal Institute of Hydrology) in the same context quoted the Academy of Berlin-Brandenburg: Decisions required a "reliable knowledge of the regulatory status and a complete concept of regulatory options ...". On the other hand research and development always lead, apart from knowledge, to the understanding that this knowledge has its limits. Socrates said "I know that I do not know anything". Albert Einstein was more precise: "The more I know the more I recognize that I do not know anything".

From this I deduct my first argument: "Existing uncertainty" does not mean the "absence of knowledge", but only the certainty that knowledge is limited and always will be. Climate science per se therefore cannot supply safe climate projections.

At first glance this insight seems to be a dilemma. But it is none, because we have the choice between decisions which are backed by probabilities of occurrence for risks and possibilities. It would be a dilemma if we were not able in the choice between two positive possibilities – vulnerability research offers clear options for solutions – to decide, because the necessity of choosing itself would make a result impossible. A classic example for this is the dilemma of Buridan's donkey, who found himself exactly in the middle between two equal piles of hay and starved to death, because he lacked a logical reason for eating either from the left or the right pile and could not take a decision.

But we can decide, because science offers robust trends to climate changes and their consequences and also a whole set of options for reactions to climate change in order to reduce risks and develop possibilities. What is important are updating intervals, for example for an adaptation strategy, so that this set of choice options can be further developed and implemented in a flexible manner when new findings are made.

For developing a plan of measures first the risks have to be prioritised, then the measures, and developments as well as decisions have to be continuously evaluated having regard to the political objective. The schematic presentation of the cycle of political decision-making demonstrates this procedure (Figure 1).

In this process of evaluation and prioritisation the values and interest of the decision-makers concerned play a non-negligible role. If, in the most unfavourable case, the outcome of the negotiations does not effectively solve the relevant questions originally raised, then the scientific uncertainties are joined by an additional vagueness through value judgements. In the knowledge-based decision process uncertainties remain.

Every coin has two sides. This is also true of uncertainties. Only if one knows the entire scope, for example of climate projections and their consequences, does one have an insight into the range of potential events which could be ahead of us. This leads to the possibility of prudent, precautionary action which includes both "edges" of the range. This leads to the second argument: The knowledge of the quantified and/or qualified uncertainties can motivate an implementation of the precautionary approach.

So the range of future developments can – apart from the unsatisfactory finding not to know everything – lead to much more. It contains important information for climate-robust decisions on measures. Climate-robust measures – also called no-regret measures, like warning systems – are for example effective in case of floods or low runoff events, and they can already have short-term advantages. For this reason the Federal Government has determined for the implementation of the German Adaptation Strategy that opportunities and risks must be recognized at an early stage so as to be able to carry out precautionary measures and to be fit for the future also in case of climate change (Deutscher Bundestag 2008). While the Federal Government aspires to such a sustainable, meaning economically efficient and socially re-

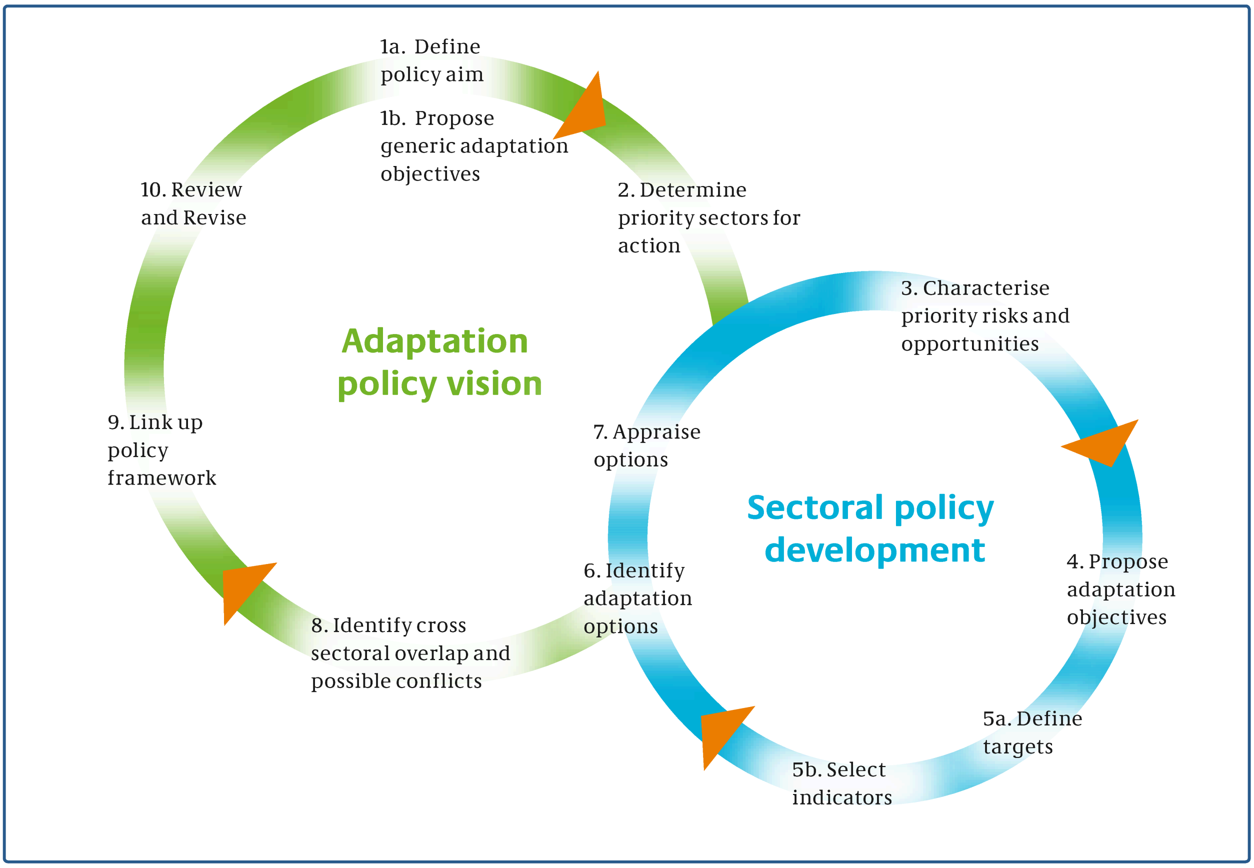

Figure 1: Cycle of political decision-making for the identification and implementation of measures for adaptation to the climatic change (HARLEY et al. 2008).

sponsible, society with an intact environment, cost and benefit of adaptation measures are to be "reasonably proportionate" (DEUTSCHER BUNDESTAG 2011). To close, through intensified research efforts, the gap which often exists here because of missing cost-benefit analyses remains a focus of the research work.

3 Daily practice and how to begin?

With the third argument I integrate the problem of uncertainty into our daily practice. Our society is used to integrating uncertainties into decision processes. During the opening of the KLIWAS Status Conference Paul Becker (Deutscher Wetterdienst) said that it was more difficult to project the economy than the climate. The driving forces, determining processes and framework conditions of both are determined or determinable to various degrees. I would like to mention here the decision of the European Council of 26 October 2011 on the debt crisis as an example of a decision under uncertainty: Half of the debts of Greece are cancelled and the European Financial Stability Facility (EFSF) is enlarged up to one billion EURO (EU CONCIL 2011).

What is important in case of uncertainties is to deal with uncertainty in an offensive way and to make the decisions transparent. This is courageous, increases trust and works if the inherent uncertainties are communicated in a precise, understandable and consistent way.

An example of exemplary communication of uncertainties is given by the Deutscher Wetterdienst (German Meteorological Service) whose probabilistic scenarios of the future climate development were, in August 2011, the basis of decisions on the action plan on adaptation of the Federal Government. "For the period 2071 to 2100 an increase of temperature of at least 1.5 °C and not more than 3.5 °C in Northern Germany or 4 °C in Southern Germany can be regarded as probable" (Deutscher Bundestag 2011). The disadvantage of such scenarios is their very high use of resources. And the user of probabilistically prepared climate information requires guidance and help for interpretation so that he can work with the data (van Pelt et al. 2010).

Both seems to be very well founded in the KLIWAS Programme, because State Secretary Klaus-Dieter Scheurle said in his opening statement: "Even taking account of the element of uncertainty, the range of KLIWAS results is a reliable basis for decisions on investments."

KLIWAS pursues an integral approach, because it looks at the entire water system. Since KLIWAS suggests adaptation measures which do not only have an impact on waterways as shipping routes, KLIWAS should also examine these impacts on nature conservation, urban planning, water balance and land use, and discharge conditions should be seen with regard to ecosystem interaction, also. The German Strategy for Adaptation to Climate Change also pursues an integrated approach. This is why the Strategy prioritizes measures which deliver synergies between various policy objectives. An open dialogue with different stakeholders assists in finding such measures (so-called win-win options). For this reason the stakeholder dialogues in KLIWAS should be continued in order to find adaptation measures which ensure the functionality of the waterways and at the same time safeguard as many interests as possible. Such win-win measures can – apart from additional enabling measures for adaptation actors, like identification, synthesis and distribution of knowledge – usefully complement the set of technical measures already considered in KLIWAS. This also clarifies the fourth argument. To try and find no-regret- and win-win measures in dialogue and to begin with the implementation of these measures is a successful strategy for adaptation to climate change.

4 Conclusion

Inherent uncertainties in climate and adaptation policies should motivate our precautionary approach. They are as such nothing extraordinary for our society. Ultimately informed, knowledge-based decisions which the Federal Government takes under a risk approach maintain our ability to act in the future.

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Concluding Remarks

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With KLIWAS, policymakers and public authorities are given a significantly improved scientific decision basis for the major navigable waterways. The KLIWAS model system now makes it possible to quickly update complex calculations on the future climate-induced condition of the water bodies and to better take new developments into consideration. The results will provide an important basis for our future investment decisions, for the cost efficiency of the tasks ahead and for ensuring services of public interest in connection with the water bodies.

The present findings do not yet have any direct consequences for the investment decisions which have to be made in the near future. The climate-induced impacts as projected by KLIWAS for the next few decades are moderate. They can be taken into account with the existing planning tools. On the basis of the new findings, we will already today start to develop proposals for ecologically and economically suitable adaptation measures since the planning and implementation of large-scale measures can take decades.

We will presumably have to expect more extensive adaptation measures in the second half of this century. Therefore, we will update the current findings on the basis of the new findings and tools of KLIWAS and will in the case of future investments take the robustness of the infrastructure against possible climate changes into consideration, using the latest data. In this respect, we will prefer “no-regret measures” i.e., measures which are already generating benefits while at the same time serving the purpose of adaptation to climate change.

For this reason, we are eagerly looking forward to the further progress of KLIWAS. At a 3rd Status Conference in the autumn of 2013 we will share, discuss and assess this progress in an open and constructive manner with all stakeholders. I would like to thank all those involved for their commitment, interest and active participation and I am looking forward to our next meeting.

List of Abbreviations

BASt Federal Highway Research Institute (*Bundesanstalt für Straßenwesen*)

BAW Federal Waterways Engineering and Research Institute (*Bundesanstalt für Wasserbau*)

BBSR Federal Institute for Research on Building, Urban Affairs and Spatial Development (*Bundesinstitut für Bau-, Stadt- und Raumentwicklung*)

BfG Federal Institute of Hydrology (*Bundesanstalt für Gewässerkunde*)

BMBF Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung*)

BMU Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (*Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit*)

BMVBS Federal Ministry of Transport, Building and Urban Development (*Bundesministerium für Verkehr, Bau und Stadtentwicklung*)

BSH Federal Maritime and Hydrographic Agency (*Bundesamt für Seeschifffahrt und Hydrographie*)

$CBOD_5$ Amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic carbon present in a given water sample at certain temperature over a period of 5 days

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

CIS Common Implementation Strategy (WFD)

DAS German Strategy for Adaptation to Climate Change (also: German Adaptation Strategy to Climate Change) (*Deutsche Anpassungsstrategie an den Klimawandel*)

DLR German Aerospace Center (*Deutsches Zentrum für Luft- und Raumfahrt*)

DST Development Centre for Ship Technology and Transport Systems (*Entwicklungszentrum für Schiffstechnik und Transportsysteme e. V.*), Duisburg

DWD German Meteorological Service (also: National Meteorological Service of Germany) (*Deutscher Wetterdienst*)

DWD-SH German Meteorological Service – Maritime Weather Office Hamburg

GlQ Equivalent discharge, defined low water discharge

GlW Equivalent water level, defined low water level

GMS Large motorised freight ship (also: large motor vessel)

HFR University of Applied Forest Sciences – Rottenburg (*Hochschule für Forstwirtschaft Rottenburg*)

ICPDR International Commission for the Protection of the Danube River

ICPER International Commission for the Protection of the Elbe River

ICPR International Commission for the Protection of the Rhine River

IKSE German abbreviation of the *International Commission for the Protection of the Elbe River (ICPER)*

IKSR German abbreviation of the *International Commission for the Protection of the Rhine River (ICPR)*

IPCC Inter-Governmental Panel on Climate Change

ITF International Transport Forum

KHR German abbreviation of the *International Commission for the Hydrology of the Rhine Basin (CHR)*

KIT Karlsruhe Institute of Technology

KLIMZUG Research programme of the BMBF "Climate change in the regions"

KLIWAS Research programme of the Federal Ministry of Transport, Building and Urban Development "Impacts of Climate Change on Waterways and Navigation in Germany" (*Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland*)

MPI Max Planck Institute

MPI-M Max Planck Institute for Meteorology

MQ Mean discharge rate averaged over one year

NM7Q Lowest discharge rate averaged over 7 days within a reference time period

OECD Organisation for Economic Cooperation and Development

REMO Regional Climate Model of the Max Planck Institute for Meteorology

SRES Special Report on Emissions Scenarios

UBA Umweltbundesamt (*Federal Environment Agency*)

WFD Water Framework Directive of the European Union

WMO World Meterological Organization

WSD (Regional) Waterways and Shipping Directorate of the WSV (*Wasser- und Schifffahrtsdirektion*)

WSV German Federal Waterways and Shipping Administration (*Wasser- und Schifffahrtsverwaltung*)

Glossary

Benthos
Benthos is the community of organisms which live on, in, or near the bottom of a body of water, also known as the benthic zone.

Chain of models
Several → models which are coupled together in a sequence, in which a subsequently added model further processes the data from the previous model

Chlorophyll
Chlorophyll is a green pigment found in plants, which allows plants to absorb energy from light for photosynthesis, to convert the light energy captured from the sun into chemical energy that can be used to fuel the organism's activities.

Circulation pattern
Typical form of (usually) large-scale (atmospheric or oceanic) flows

Climate
Climate is defined as the summation of weather phenomena which characterise the average conditions of the atmosphere at a specified location or in a larger or smaller region. It is represented by statistical overall features (mean values, extreme values, frequencies, persistent values and others) over a sufficiently long period of time. In general, a period of 30 years is taken as the basis, the so-called normal period (e.g. 1961–1990); however, it is not unusual for shorter periods to be used.

Climate element
(frequent synonyms: climate parameter, climate variable) (Primary) climate elements are climate parameters which can be measured or observed directly, e.g. air temperature, wind, cloud cover, precipitation, duration of sunshine etc.

Climate model
→ Model for → simulation of a → climate

Climate projection
→ Projection of a → climate

Climate simulation
→ Simulation of a → climate

Climate variable
synonym for → climate element

Discharge
The discharge Q states the volume related to a specific catchment area that flows through a specified cross section area in a unit of time.

Discharge projection
→ Projection of the → discharge

Discharge simulation
→ Simulation of the → discharge

Downscaling
Method for the derivation of local or regional information from large-scale models or data (e.g → global models). Two main approaches can be distinguished:
a) Dynamic downscaling uses → regional climate models.
b) Statistical (or empirical) downscaling uses statistical relationships which link large-scale atmospheric variables with local/regional climate variables.

Emission scenarios
→ scenarios of future emission volumes of → greenhouse gases, e.g. → SRES Greenhouse gas concentrations, which ultimately form the basis for climate projections, are calculated on the basis of emissions scenarios.

Ensemble (meteorological)
A group of parallel → model simulations for → projections or → forecasts. The → range of results of the individual ensemble runs permits the estimation of uncertainties. Ensembles which are based on precisely the same (climate) model, of which, however, the initial conditions are varied, characterise the uncertainties which are related to the internal variability of the system being modelled (e.g. the climate system). Multi-model ensembles based on simulation with different (climate) models furthermore demonstrate the uncertainties that are associated with diverse model versions, types and variants.

Ensembles in which individual model parameters are systematically varied (so-called "perturbed parameter ensembles") aim to provide a more objective estimation of the model uncertainty than traditional multi-model ensembles.

Estuary
Funnel-shaped area of a tidal river where it flows into the sea

Evapotranspiration
The combined amount of land evaporation, ocean evaporation, interception evaporation (evaporation from the surfaces of plants) and transpiration (biotic processes, stomatal transpiration)

Forecast
here: when a → projection is categorised as "highly probable," it becomes a forecast. A forecast is produced with the help of deterministic → models which permit statements on a reliability level.

Global model
Global climate model or GCM → climate model for the whole earth. The resolution of the GCMs on which the Fourth Assessment Report of the IPCC is based is too coarse for use for regional or local issues. For this purpose, so-called → downscaling is used.

GlQ/GLQ (Equivalent discharge)
Discharge which results at a river cross section at → equivalent water level (GlW)

GlW/GLW (Equivalent water level)
Low water level which is not exceeded on 20 ice-free days per year in the long-term mean. Important water level value for the assessment of conditions in the navigation channel

Government-funded research
Research and development activities of (German) federal and state institutions whose main task is the provision of political advice for government departments, in the form of the scientifically-based knowledge required for decision-making. Furthermore, most of these institutions provide important, research-based services in the fields of testing, licensing, formulation of regulations and monitoring that are in part defined by law.

Greenhouse gases
Gaseous components of the earth's atmosphere which cause the greenhouse effect. The gases (including H_2O, CO_2, N_2O, CH_4, O_3) are of natural and anthropogenic origin. They absorb the radiation emitted from the earth's surface, clouds or the atmosphere itself in specific wave lengths within the spectrum of thermal infra-red radiation.

Habitat
A habitat is an ecological or environmental area that is inhabited by a particular species of animal, plant, or other type of organism

Habitat potential
Availability of suitable habitat for the incidence of species/vegetation types

Model
Schematic reproduction of a system with regard to selected characteristics and processes, e.g. for a catchment area

Multi-model method
see → Ensemble

Neophytes
Plants which have been introduced purposely or accidentally, directly or indirectly, to an area in which they had not normally been found.

Nival discharge regime
Snow-dominated discharge regime

Objective classification of weather situations
The objective classification of weather situations is a method for classifying weather conditions based on data from grid point values on from weather forecasts or climate models. The criteria for categorising weather situations may vary. A procedure developed by the German Meteorological Service (DWD) includes the following criteria: a) cyclonality

or anticyclonality of flows close to the ground and in the mid-troposphere, b) large-scale direction of flow and c) moisture content of the atmosphere.

Parde coefficient
Here: described by the longstanding monthly average values standardized by the mean discharge

Phytoplankton
Plant → plankton

Plankton
Collective term for any organism floating in the water with no major self-motion

Pluvial discharge regime
Rainfall-dominated discharge regime

Prediction
here: synonym for → forecast

Projection
here: estimation of the future climate (or discharge etc.) with the aid of → models based on given → scenarios

Range
here: the maximum difference between the smallest and largest value of an → ensemble at any given time; e.g. the difference between the smallest and largest mean monthly value of the → discharge over many years

Reference climate
Climate during a → reference period (e.g. normal period 1961–1990)

Reference period
A reference period is a period from which the measurements are applied as a norm for comparison with measurements from another period of time.

Regionalisation
here: synonym for → downscaling

Regional model, regional climate model, RCM
→ Climate model which takes into account the special processes and characteristics of a selected region of the earth with a higher spatial resolution and, thus, a more refined process simulation. It is used for the → regionalisation of data from a → global model.

Scenario
A plausible and often simplified description of the future development. A scenario is based on a coherent and internally consistent bundle of assumptions with regard to the future driving forces and their interdependence. Scenarios may be derived from → projections, but frequently require additional data from other sources, sometimes in combination with so-called → story lines. The scenarios on which the current → climate projections are based are the → SRES scenarios.

Sediment-delivery-ratio approach (SDR)
Calculation approach for the determination of the share of eroded soil in the catchment area which is deposited in the watercourse as a function of the terrain relief

Sensitivity
here: Sensitivity is the degree to which a system can be influenced (negatively or positively) by climate change or climate variability. The effect may be direct (e.g., through the influence of mean annual temperature amplitude on harvest yields) or indirect (e.g., damage caused by flooding caused by a rise in sea level that is a result of climate change).

Seston
Seston is the undissolved matter swimming or floating in a water body, which is to be separated by sieving, centrifugation or sedimentation

Simulation
Use of a → validated → model to study the behaviour of a system being observed under certain conditions (e.g. → scenarios)

SRES Scenarios
SRES scenarios are emissions scenarios, the → story lines of which are defined in the "Special Report on Emissions Scenarios" (abbr.: SRES) (Nakićenović et al. 2000). They form, amongst others, the basis for climate projections of the Fourth Assessment Report of the IPCC. In the contributions in this volume, three selected SRES are considered (ref. no: A2, B1 and A1B); their story lines are based on the differing weightings between a) economic and environmental orientation of society and b) globalisation and regional development.

SRES scenario families
→ SRES scenarios which assume a similar demographic, social, economic and technical development are integrated into the scenario families (A1, A2, B1, B2).

Story line
A narrated description of a scenario which includes the essential characteristics and interrelations between the driving forces and their development dynamics.

Type of biotop
Unit of a biocoenosis in a certain region such as softwood alluvial forest or meadows

Uncertainty
An expression of the degree to which a value (e.g. a → climate parameter for the future) is known. Uncertainty may be caused by incomplete or erroneous/inaccurate information. In the context of climate impact research, uncertainties may have many sources. Not all of them can be quantified precisely and some are unavoidable.

Validation
here: testing the validity of a model. Proof of the capability of a → model to simulate the observed behaviour of the system represented by the model.

Verification
Testing of the truth content of a result or a model

Vulnerability
The susceptibility of a system in regard to alterations in conditions and its inability to cope with these conditions

Weather
Weather is defined as the physical condition of the atmosphere at a specific point in time or over a short period at a given location or in a region, as characterised by the → climate elements and their interaction.

Weather forecast
→ Forecast of the → weather

Zooplankton
Animal → plankton

KLIWAS Research Tasks and Projects

(Overview, status as of April 2012)

Meteorological climate scenarios, Research Task 1:

Validation and evaluation of climate projections – provision of climate scenarios for application on waterways and navigation

Task management: German Meteorological Service (DWD)
Dr Annegret Gratzki, Dept. "Hydrometereology", phone: +49 (0)69/8062-2989, annegret.gratzki@dwd.de

Proj. No.	Project management / contact partner		Project (Proj.)
1.01	DWD	Dr Annegret Gratzki	Hydrometeorological reference data for river basins
1.02	DWD	Joachim Namyslo	Provision of application-oriented and evaluated climate projection data
1.03	BSH- DWD	Dr Hartmut Heinrich Gudrun Rosenhagen	Atmospheric and oceanic reference data and climate projections for coastal and open sea areas

Climate change in coastal and estuarine areas, Research Task 2:

Changes in the hydrological system of coastal waters

Task management: Federal Institute of Hydrology (BfG),
Dr Stephan Mai, Graduate Engineer, Department M1, phone: +49 (0)261/1306-5322, mai@bafg.de

Proj. No.	Project management / contact partner		Project (Proj.)
2.01	BSH- DWD	Dr Hartmut Heinrich Gudrun Rosenhagen	Climate change scenarios for the maritime area und their parametrisation
2.02	BfG	Dr Astrid Sudau	Validation of climate projections for water level changes with regard to tectonic influences at the coast
2.03	BfG	Dr Stephan Mai, Graduate Engineer	Climate induced changes in tidal parameters and sea state statistics at the coast
2.04	BAW	Dr Norbert Winkel, Dr Elisabeth Rudolph	Vulnerability of hydraulic engineering systems at the North Sea and its estuaries due to climate change
ARGO	BSH	Dr Hartmut Heinrich	Array for Real-time Geostrophic Oceanography

Climate change in coastal and estuarine areas, Research Task 3:

Changes and sensitivity of the water body state (morphology, quality, ecology) and adaptation options for navigation and waterways

Task management: Federal Institute of Hydrology (BfG), **Dr Werner Manz,** Head of Department G3, as from 1.10.2009: **Dr Birgit Schubert,** Department G1, phone: +49 (0)261-1306-5312, schubert@bafg.de

Proj. No.	Project management / contact partner		Project (Proj.)
3.01	BSH- DWD	Dr Hartmut Heinrich Gudrun Rosenhagen	Impacts of climate, change on navigation and other uses of the sea
3.02	BAW	Dr Norbert Winkel	Adaptation options for waterways and ports at the German coast and coastal protection in extreme weather events
3.03	BfG	Dr Axel Winterscheid	Impact of climate change on the budget of suspended particulate matters in North Sea estuaries
3.04	BfG	Dr Werner Manz, as from 1.10.2009: Dr Georg Reifferscheid	Impacts of climate change on microbial water quality and their implications for dredged material management in coastal waters
3.05	BfG	Dr Lars Düster	Impacts of climate change on stability and environmental relevance of hydraulic engineering materials in coastal waters
3.06	BfG	Dr Birgit Schubert	Impacts of climate change on the transport behaviour of contaminated sediments and maintenance of coastal waterways
3.07	BfG	Dr Michael Schlüsener	Impacts of climate change on patterns of organic pollutants in coastal waters
3.08	BfG	Andreas Schöl	Climate change related impacts on the oxygen budget of North Sea estuaries due to alterations of river discharge and nutrient and carbon load – Potential adaptation strategies for navigation and sediment management
3.09	BfG	Eva-Maria Bauer Maike Heuner	Vegetation shift in German estuaries due to climate change and consequences for bank protection and maintenance

Climate change in inland areas, Research Task 4:

Changes in the hydrological system: sediment budgets, morphology and adaptation options for inland waterways and navigation

Task management: Federal Institute of Hydrology (BfG)
Dr Thomas Maurer, Graduate Engineer, Department M2 Water Balance, Forecasting and Predictions
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Proj. No.	Project management / contact partner		Project (Proj.)
4.01	BfG	Dr Enno Nilson	Impacts of climate change on hydrology and management options for the economy and inland navigation
4.02	BfG	Dr Markus Promny	Climate projections for sediment budgeting and river morphology
4.03	BAW	Dr Michael Schröder	Options for the regulation and adaptation of hydraulic engineering measures to climate induced changes of the discharge regime
4.04	BAW	Prof. Dr Bernhard Söhngen	Minimum width of fairways for safe and easy navigation
4.05	BAW	Dr Thomas Maurer	Process studies on the development of ice formation in waterways

Climate change in inland areas, Research Task 5:

Impacts of climate change on structure, ecological integrity and management of inland waterways

Task management: Federal Institute of Hydrology (BfG),
Dr Helmut Fischer, Department U2, phone: +49 (0)261/1306-5458, helmut.fischer@bafg.de

Proj. No.	Project management / contact partner		Project (Proj.)
5.01	BfG	Dr Gudrun Hillebrand	Climate projections for sediment budgets and risks due to cohesive sediments
5.02	BfG	Dr Helmut Fischer	Impacts of climate change on nutrient and phytoplankton dynamics in navigable rivers
5.03	BfG	Dr Werner Manz, as from 1.10.2009: Dr Georg Reifferscheid	Impacts of climate change on microbial water quality and their implications for dredged material management in inland waterways
5.04	BfG	Dr Thomas Ternes	Impacts of climate change on patterns of organic pollutants in inland waters*
5.05	BfG	Dr Thomas Ternes	Impacts of climate change on stability and environmental relevance of hydraulic engineering materials in inland waters
5.06	BfG	Dr Peter Horchler	Impacts of climate change on the vegetation of flood plains
5.07	BfG	Dr Jochen H. E. Koop	Basics for the adaptation of faunistic evaluation methods due to climate change
5.08	BfG	Dr Sebastian Kofalk	Indicators for impact evaluation of climate change and for adaptation options at river basin scale

*financed by the BMU

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1991–1997
Degree in Physics at the Albert-Ludwigs University, Freiburg

1994–2002
Degree in vocal pedagogy at the State University of Music, Freiburg

2002
Doctorate (Dr.-Ing.) of microsystems engineering

starting in 2003
Scientific staff member of the Federal Highway Research Institute (BASt) in the Environmental Protection Division (acoustics)

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BASt, Project Group on Innovations in the Road Sector, Climate Change, Head of the Working Group on Climate Change at BASt

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1990–1997
Studies in biology at the Universities of Tübingen and Freiburg (key subject: phytosociology)

1998–1999
Research at the Forstliche Versuchs- und Forschungsanstalt (Forest Research Institute) of Baden-Württemberg

1999–2006
Research at Freiburg University

since 2006
Employee at the Federal Institute of Hydrology

Project work:

2006–2009: among other things, participation in the R&D project "Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways"

since 2009: KLIWAS 3.09 "Vegetation shift in German estuaries due to climate change and consequences for bank protection and maintenance" (project manager)

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Researcher at the University of Hamburg / Max Planck Institute for Meteorology

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Civil servant at the Deutscher Wetterdienst

2005–2008
Leiter der Abteilung Medizinmeteorologie

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1994–1996
Activities in a self-employed capacity

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Working on a Doctoral Thesis at the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, and at the University of Freiburg

2000–2005
Scientific Fellow at IGB Berlin, Post-Doc Researcher at the Limnological Institute, University of Uppsala, Sweden

Since 2005
Scientific Fellow at the German Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde; BfG)

Projects related to climate impact research:

2005–2010:	GLOWA-Elbe (BMBF 01LW0603I1)
since 2008:	KLIWAS (BMVBS)
since 2010:	Methane emissions from river impoundments (DFG); SCARCE (CONSOLIDER Ingenio); NITROLIMIT (BMBF 033L041G)

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studied biology (Biological Oceanography) at the Christian Albrechts University at Kiel

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Researcher at the Federal Institute of Hydrology (BfG)

Project work:
2009–2011: KLIWAS Project 5.02, Impacts of climate change on nutrient and phytoplankton dynamics in navigable rivers

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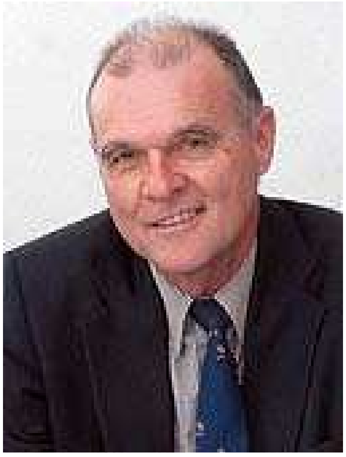

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Year of birth: 1948

1966–1967
Sociology studies at the University of Marburg

1967–1971
Economics studies at the University of Marburg

1976
Doctorate (University of Marburg)

1972–1983
Research Assistant at the Universities of Marburg, Essen and Bochum (Chair for Political Economy and Economic Research)

1983
Habilitation (University of Bochum)

1983–1998
Professor for Economics and Political Economy at the Universities of Bochum and Münster

Visiting Professor at the Oskar-Lange-University in Wroclaw and the Lomonosov-University in Moscow

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Centre for Environmental Systems Research, University of Kassel; Ecosystem Modelling

2006
Lehmann + Partner GmbH, Kirchheim – Engineering Company for Road Information; Databases and GIS

2006–2009
Centre for Marine and Atmospheric Sciences, University of Hamburg; Hydrodynamic Modelling

since 2009
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KLIWAS project 3.08:
Climate change related impacts on the oxygen budget of North Sea estuaries due to alterations of river discharge and nutrient and carbon load – potential adaptation strategies for sediment management

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1998–2002
Studied hydrography at the University of Applied Sciences in Hamburg

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Research assistant at the University of Hamburg, awarded a doctorate in oceanography, Subject: Upwelling off the coast of Vietnam

2007–2009
Research assistant at the University of Hamburg, Project officer: Sediment dynamics in the Mekong estuary and coastal region

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KLIWAS 2.03:
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Doctorate in Marine Geology at the University of Kiel
Work: 1983 Sand-gravel exploration in Schleswig-Holstein; as of 1983 at the Federal Maritime and Hydrographic Agency

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Sedimentology/Palaeoclimatology of the Northeast Atlantic

1988–1989
Sedimentology of the North Sea

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TUVAS Project (Sea monitoring project for the North Sea)

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Secretariat of the BLMP (Common Measurement Programme of the Federal Government and the Federal States) North Sea and Baltic Sea

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since 2009
Researcher at the Federal Institute of Hydrology, Division M3 "Groundwater, Geology, River Morphology"

Project work (selection):

2003–2006: Research Group of the German Research Foundation on "Peloids", laboratory studies on the transport behaviour of cohesive sediments in flows

2005–2008: RIMAX-HoT, determination of the matter retention in flood retention areas by means of field tests and morphodynamic modelling

since 2009: R&D project to examine the interaction of HCB/PCB and sediments on the Upper Rhine and Elbe

since 2009: KLIWAS project "Climate Projections for Sediment Budgets and Risks due to Cohesive Sediments"

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Berthold Holtmann

Profile

Year of birth: 1962

Graduated from RWTH Aachen University with a degree in civil engineering in 1991

1991–1997
Traffic planning and consulting in public transport, Spiekermann GmbH & Co., Düsseldorf

1997
Project engineer at the European Development Centre for Inland Navigation, now the DST-Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V. (Development Centre for Ship Technology and Transport Systems)

1998–2004
Head of the "Transport Economics" section at the European Development Centre for Inland Navigation, now the DST-Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V. (Development Centre for Ship Technology and Transport Systems)

2005–present
Head of the "Transport Systems" section at the DST Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V. (Development Centre for Ship Technology and Transport Systems,)

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Theresa Horsten

Profile

Year of birth: 1983

2003–2009
Studied Hydrology at the TU Dresden

2009–2011
Researcher at the Federal Institute of Hydrology (BfG)

Project management:
since 2009: KLIWAS "Water balance, water level and transport capacity" (BMVBS)

Bastian Klein

Profile

Year of birth: 1975

1996–2003
Degree in civil engineering at Technical University Berlin

2003–2009
Research assistant at the Institut of Hydrology, Water Resources Management and Environmental Engineering at the Ruhr-University Bochum

since 2009
Researcher at the German Federal Institute of Hydrology

Project work:

since 2009: KLIWAS Project 4.01 „ Impacts of climate change on hydrology and management options for the economy and inland navigation “ (Federal Ministry of Transport, Building and Urban Development)
since 2009: Update of the water level forecasting system WAVOS for the Danube
2009–2011: AdaptAlp (EU INTERREG IV)
since 2010: ECCONET (EU FP7)

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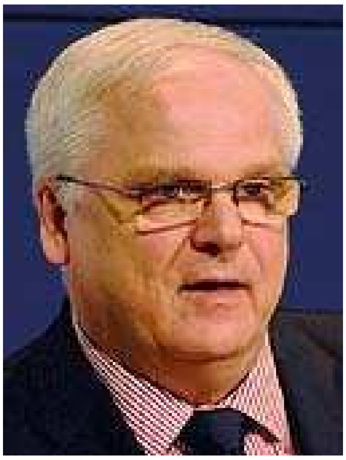

Reinhard Klingen

Profile

Year of birth: 1955

1976–1981
Degree in Law at the University of Bonn

2005–2009
Director of the Directorate Waterways at the BMVBS (Federal Ministry of Transport, Building and Urban Development)

since 2009
Director-General Waterways and Shipping at the BMVBS

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Petra Mahrenholz

Profile

1982–1987
Studies of meteorology at Humboldt University Berlin

1987–1991
Scientific employee at Deutscher Wetterdienst, Research Institute for Bio-Climatology

since 1991
Scientist at the Federal Environment Agency,
Causes and impacts of climatic changes,
Adaptation strategy and measures,
Identification, further development and implementation of the German Strategy for Adaptation to the Climate change
Work in international bodies, e.g. IPCC and UNFCCC

since 2006
Head of the Competence Centre on Climate Impacts and Adaptation, KomPass

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Hans Moser

Profile

Year of birth: 1962

1983–1989
Degree in civil engineering at the University of Stuttgart

1990–1995
Researcher at the Institute of Hydraulic Engineering and Water Resources Management of the Technical University Berlin; doctorate

1995–2001
Management responsibilities in the field of federal waterways development and construction at the Federal Waterways and Shipping Administration (WSV)

2002–2004
Desk Officer (*Referent*) in the Division "Technology, Environmental Protection and Hydrology" at the Federal Ministry of Transport, Building and Housing; official residence in Bonn

since 2004
Head of Division M "Quantitative Hydrology" at the Federal Institute of Hydrology (BfG) in Koblenz

since 2012
President of the International Commission for the Hydrology of the Rhine Basin

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Eva Mosner

Profile

1998–2004
Studies of Biology at Marburg University and at Potsdam University

2005
Scientific Assistant at Potsdam University and Scientific Fellow at the Centre for Environmental Research Leipzig, Germany (Hemholtz-Zentrum für Umweltforschung Leipzig)

2006–2009
Scientific Fellow at Marburg University

since 2009
Scientific Fellow at the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde [BfG])

Project work:
since 2009: KLIWAS Project 5.06 entitled „Impact of climate change on floodplain vegetation" ("Auswirkungen des Klimawandels auf die Flussauenvegetation")

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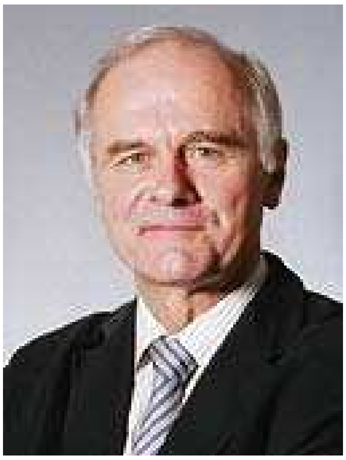

Franz Nestmann

Speaker at the advisory board of the joint research programme KLIWAS of the BMVBS. Research tasks: hydrology, hydraulic engineering, water-resources management

Profile

Year of birth: 1951

1972–1978
Civil Engineering studies at the University of Karlsruhe (TH)

1978–1986
Scientific assistant at the Institute for Hydromechanics, University of Karlsruhe (TH) – 1984 PhD degree (Dr.-Ing.)

1986–1990
Head of division 'River Engineering and Hydraulics of the River Beds' with specialization in 'mathematical models in channel flow' in the Federal Waterways Engineering and Research Institute, Karlsruhe

1990–1993
Head of department 'Hydraulic Engineering and Hydraulics' at the Federal Waterways Engineering and Research Institute, Karlsruhe and Berlin

since 1994
Appointment as a Full Professor at the University of Karlsruhe (today KIT) and Head of Institute for Water and River Basin Management

1996–2000
Dean of student affairs at the Faculty of Civil Engineering, Geo and Environmental Sciences

2000–2010
Dean of the Faculty of Civil Engineering Geo and Environmental Sciences

since 2010
President of Water Resources Management Board Baden-Württemberg

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Enno Nilson

Profile

Year of birth: 1969

1992–1999
Degree in Geography, Geology, Soil Science and Forestry at the University of Bonn

1999–2001
Consultant for GIS, software engineering and databases

2001–2007
Researcher at the Department of Geography at the RWTH University of Aachen

since 2007
Researcher at the Federal Institute of Hydrology

Project management:

since 2007: KLIWAS "Water Balance, Water Level and Transport Capacity" (BMVBS)
2008–2010: RheinBlick2050 Project (CHR)
2009–2011: Study of Scenarios for the Discharge Regime of the Rhine (ICPR)
2008–2011: AdaptAlp (EU INTERREG IV)

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Jan Peper

Profile

Degree in landscape ecology and nature conservation in 2006 and doctorate in 2010

Since 2010
Researcher at the Federal Institute of Hydrology

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Thorsten Pohlert

Profile

Year of birth: 1974

1995–2002
Studied Applied Environmental Sciences at the University of Trier

2003–2006
Researcher at the Institute of Landscape Ecology and Resource Management, Justus Liebig University Giessen, doctoral thesis entitled "Modelling of nitrogen balance for water-protection of meso-scale river catchments" (awarded Dr. rer. nat.)

2007–2009
Researcher at the Zentrum für Umweltforschung of the Johannes Gutenberg University Mainz

since 2009
Researcher at the Federal Institute of Hydrology, Division G1

Project management:
since 2009: KLIWAS research project "Climate Projections for Sediment Budgets and Risks due to Cohesive Sediments" (Proj. No. 5.01)".

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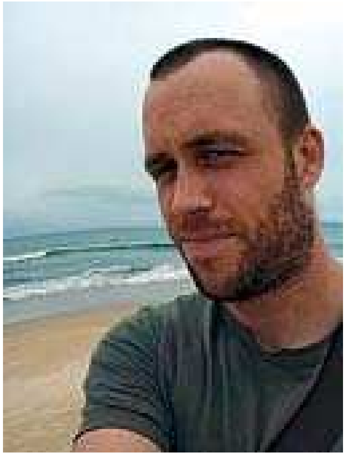

Marc Roberts

Profile

Year of birth: 1978

2001–2006
Degree in civil engineering at the Lippe and Höxter University of Applied Sciences

2006–2009
Degree in civil engineering at the Bauhaus-Universität Weimar

since 2009
Researcher at the Federal Institute of Hydrology

Project work:
since 2009: KLIWAS Project 4.02: Deployment and operation of the three-dimensional morphological model SSIIM 3D

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Profile

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1980–1988
Student of Meteorology at Frankfurt am Main University and Kiel University

1988–1994
Scientific Fellow at GKSS-Forschungszentrum Geesthacht GmbH (GKSS Research Centre, Geesthacht)

1993
Promotion an der Universität Hamburg

since 1994
Scientific Fellow with the Bundesanstalt für Wasserbau – Dienststelle Hamburg – (Federal Waterways Engineering and Research Institute – Hydraulic Engineering in Coastal Areas / BAW), Referat Ästuarsysteme II (Working Unit on Estuary Systems II)

Field of work as a professional expert:
Studies dealing with the estimated effects of storm surges upon waterway management in the Elbe, Jade-Weser, and Ems Estuaries

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Michael Schleuter

Profile

Year of birth: 1954

Degree in biology at the Rheinische Friedrich-Wilhelms Universität in Bonn and subsequently doctorate (Dr. rer. nat.)

Professional practice by multiannual work in the sector of student education at Bonn University in the field of limnology and at the Fuhlrott Museum in Wuppertal within the framework of the investigation of the impact of environmental chemicals on the fauna in forest ecosystems

Since 1986
in the Federal Institute of Hydrology and more than 20 years responsible for the animal ecology sector with the field of work at waterways controlled by weirs

Since 2006
Head of Department U2, Ecological Interactions in the Ecology Division U

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Anja Scholten

Profile

1999–2004
Studied meteorology at the Rheinische Friedrich Wilhelm University of Bonn

2005–2007
Project assistant at the Wuppertal Institute for Climate, Environment and Energy

Since 2007
Research assistant at the Julius-Maximilian University of Würzburg

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Gina Siegel

Profile

Gina Siegel is an architect and a deputy head of division at the Federal Ministry of Transport, Building and Urban Development.

Her main responsibilities are: the development of spatially significant environmental plans and measures, especially the spatial impacts of climate change and climate change mitigation through regional energy supply strategies

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Bernhard Söhngen

Profile

1970–1977
Degree in civil engineering at the TU Darmstadt

1978–1986
Research assistant at the Institute of Hydraulic Engineering / TUD (ground water and open channel flows)

1987
Doctorate on shape parameters of open channel flows

1986–1987
Agrar und Hydrotechnik Essen (irrigation systems)

since 1987
Federal Waterways Engineering
and Research Institute (BAW), Karlsruhe
1987–2001: Danube project group
since 2001: Head of Division W4

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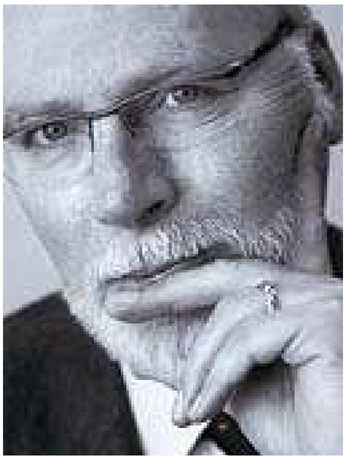

Marcel J. F. Stive

Member of the advisory board of the joint research programme KLIWAS of the BMVBS. Research tasks: coastal engineering

Profile

Professor Stive has plus 30 years experience in research and projects in the fields of hydraulic engineering, coastal morphodynamics, coastal bio-geomorphology and coastal and estuarine management. His record involves coasts, estuaries, harbours and offshore projects in Europe, Asia, Africa and America. He is advisor to the Governments of the Netherlands, Vietnam and China.

Since 2001
Professor of Coastal Engineering, Faculty of Civil Engineering and Geosciences, Hydraulic Engineering Department, Delft University of Technology

Since 2003
Scientific Director Water Research Centre Delft, Delft University of Technology

Since 2009
Department Head Hydraulic Engineering of the Faculty of Civil Engineering and Geosciences, Delft University of Technology

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Philip Weller

Philip Weller works as the Executive Secretary of the International Commission for the Protection of the Danube River (ICPDR). In this position, he is responsible for the management of the ICPDR Permanent Secretariat. The ICPDR is the forum for 14 major Danube countries and the European Commission to coordinate measures to improve water quality and water management in the Danube Basin.

He is an environmental planner by training and studied general Environmental Science at the University of Waterloo, Canada, where he received also a Masters of Urban and Regional Planning.

In his previous position as Programme Director of the Danube Carpathian Programme of WWF International, Mr. Weller was the driving force behind the "Lower Danube Green Corridor" – an agreement between Romania, Bulgaria, Moldova and Ukraine and the largest wetland protection and restoration initiative in Europe.

Previously he served as director of Great Lakes United, a unique bi-national coalition of interest groups including local municipalities, research organizations, businesses and NGOs focused on the clean-up of the Great Lakes.

Mr. Weller is author of three books on environmental topics including 'Freshwater Seas', an environmental history of the Great Lakes of North America.

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Norbert Winkel

Profile

Year of birth: 1954

1981–1989
Student in Geosciences at Hamburg University

1988–1992
Scientific Fellow at GKSS-Forschungszentrum Geesthacht GmbH (GKSS Research Centre, Geesthacht)

since 1992
Scientific Fellow at Bundesanstalt für Wasserbau – Dienststelle Hamburg – (Hamburg Office of the Federal Waterways Engineering and Research Institute / BAW), Referat Ästuarsysteme II (Section K3, Coastal Areas)

1994
Doctorate (awarded by Hamburg University)

since 2003
Head of BAW Section K3 (Coastal Areas)

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Axel Winterscheid

Profile

1996–2002
Degree in Civil Engineering at the Technical University of Darmstadt with specialisation in hydraulic engineering, geotechnics and environmental sciences

2002–2009
Researcher at the Institute of Hydraulic Engineering and Water Management at the Technical University of Darmstadt, Doctorate: Scenario technics in floodwaters risk management

2009–today
Researcher at the Federal Institute of Hydrology, Department Groundwater, Geology, River Morphology

Project work (selection):

2003–2009: INTERREG-IIIB project nofdp (nature-oriented flood damage prevention), project coordination and development of the decision support system nofdp – IDSS

2009–2011: Research at the morphological, ecological and nature conservation related impacts of a sediment trap in the Elbe estuary near Wedel, on behalf of Hamburg Port Authority

since 2009: KLIWAS project: "Impact of climate change on the budget of suspended particulate matters in North Sea estuaries"

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Sven Wurms

Profile

Year of birth: 1977

1998–2004
Studied Environmental Engineering at the University of Stuttgart

2005–2009
Researcher at the Institute of Hydraulic Engineering at the University of Stuttgart

Since 2009
German Federal Waterways Engineering and Research Institute

2010
Awarded doctorate

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Jens Wyrwa

Profile

Year of birth: 1963

1991
Graduated from the Technical University of Berlin with a degree in Physical Engineering

1992–1997
Björnsen Consulting Engineers, Koblenz

2003
Doctoral thesis on "Turbulence modelling for stable density-stratified flows in the simulation of the transport of cohesive sediments in estuaries", Technical University of Berlin

2003–2011
Free-lance work, hydroinformatics, flow simulation

since 2011
Federal Institute of Hydrology, Multidimensional quality models for tidal waters

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