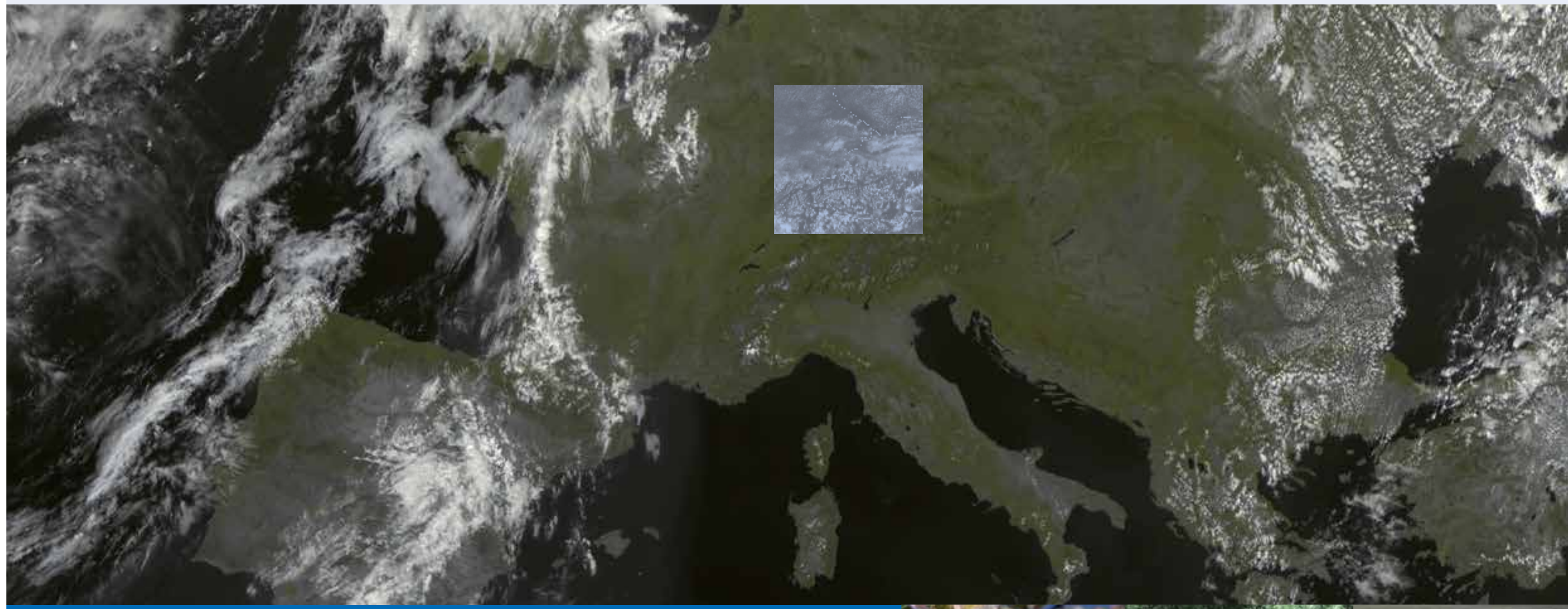
KLIWA
Klimaveränderung
und Wasserwirtschaft

Climate Change in Southern Germany
Challenges – Adaptation



CONSEQUENCES FOR WATER MANAGEMENT



Baden-Württemberg
MINISTERIUM FÜR UMWELT, KLIMA UND ENERGIEWIRTSCHAFT

Bayerisches Staatsministerium für
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Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

KLIWA STANDS FOR CLIMATE CHANGE AND CONSEQUENCES FOR WATER MANAGEMENT

KLIWA IS A COOPERATION PROJECT BETWEEN THE GERMAN STATES OF BADEN-WÜRTTEMBERG, BAVARIA AND RHINELAND-PALATINATE AND THE DEUTSCHER WETTERDIENST

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FOREWORD

Water is one of the most valuable gifts of nature. We all live from and with water. Water managers bear a heavy responsibility for the sustainability of a resource which is vital for life as well as for protecting against the dangers it can pose. Water management standards in Germany are very high. Wherever necessary we protect and improve the status of water. We have sufficient drinking water of good quality and we invest millions of euros in improving flood protection and low-water management.

But the water cycle is changing. Climate change also alters the water budget in Germany. Today we know that the Earth's mean temperature has already risen significantly worldwide and will continue to increase as a result of the greenhouse effect. Mankind will no longer be able to stop this process. At best they may be able to slow it down. We must all do our part in acting consistently and effectively to mitigate climate change.

In consequence of climate change and its regional impacts we must be prepared for an increase in extreme weather events. There will almost certainly be more intense rainfall events, heat waves and dry periods in the future. This means that those responsible for managing water need to evaluate the potential impacts and to develop strategies and ways of adapting locally to these changes.

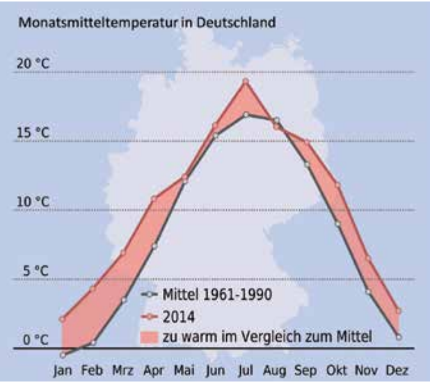
The studies performed up to now within the „Climate Change and Consequences for Water Management" (KLIWA) cooperation give us a good idea of how climate change will impact flooding, low-water events or water tables here in southern Germany. These evaluations are all subject to a high degree of uncertainty. The great challenge will be to assess the impact of climate change accurately and to set the right course for the future. A great deal of fundamental work remains to be done. How can uncertainties concerning future developments be characterised and communicated to the public? What impact will climate change have on the water quality of our streams and rivers? What adaptation measures does the precautionary principle require now and in the future?

We can mitigate the impacts of climate change by taking consistent action at the global, national and regional levels. Greenhouse gas emissions must be reduced as far as possible. However, there will be irreversible consequences that will necessitate adaptation measures. This means that climate-sensitive systems have to be prepared as well as possible for the changes ahead. This can be ensured by enhancing and reducing the vulnerability of systems. Ongoing work is needed to develop the climate change knowledge base. The KLIWA cooperation provides an important contribution to the field of sustainable water management.




Where do we stand?
The challenge of climate change

The International Climate Treaty negotiated at the World Climate Conference in Paris in December 2015 came into effect on 4 November 2016. The Paris Agreement commits the international community to limiting global warming to well below 2°C and, if possible, to below 1.5°C. This is an ambitious target and calls for huge efforts to avoid greenhouse-gas emissions.



2014 was the warmest year in Germany since the beginning of recording. Except of August, average temperatures were significantly higher in every month of 2014 than in the 1961–1990 international reference period.
© DWD: Elke Rosskamp.

KLIWA ON THE WEB

More information about KLIWA can be found at the project website at www.kliwa.de. Detailed reports on project outcomes and working methods are available in the download area ("publications").

CLIMATE CHANGE IS HAPPENING NOW

The Earth's climate has varied naturally over millions of years. At times Europe enjoyed a tropical climate, at others the continent was covered by massive ice sheets. Sediment drill samples and pollen analyses yield insights into climate fluctuations during the Earth's early history. Weather data have been collected on a regular basis since 1860. Evaluations of these data show that, over the last 155 years, the mean global temperature has risen by around 1°C, and in Germany it has risen by as much as 1.3°C since 1881. Extreme weather events have occurred in recent years: the severe flooding of 2013, the extremely dry summer of 2015 and the flash floods of spring 2016. Coincidence or climate change? Anyway, adaptation to current climate change and, as far as possible, precautionary measures against extreme weather events are essential.

GREENHOUSE EARTH

We have to thank the natural greenhouse effect for the pleasant global average temperature of +15°C. Trace gases that occur in the Earth's atmosphere, such as water vapour, carbon dioxide and methane, have the same effect as the glass panes of a conservatory: they allow short-wave solar radiation to penetrate and to some extent restrict the reverse emission of long-wave heat radiation. This is why they are called greenhouse gases. Without the natural greenhouse effect, average temperatures would be an inhospitable -18°C. The carbon dioxide content of the atmosphere, which had remained relatively constant at 280 ppm (parts per million) for centuries, has been rising since the dawn of the industrial era. The current concentration is 405 ppm. This additional anthropogenic greenhouse effect influences both global and regional hydrological cycles. This calls for regional adaptation measures.

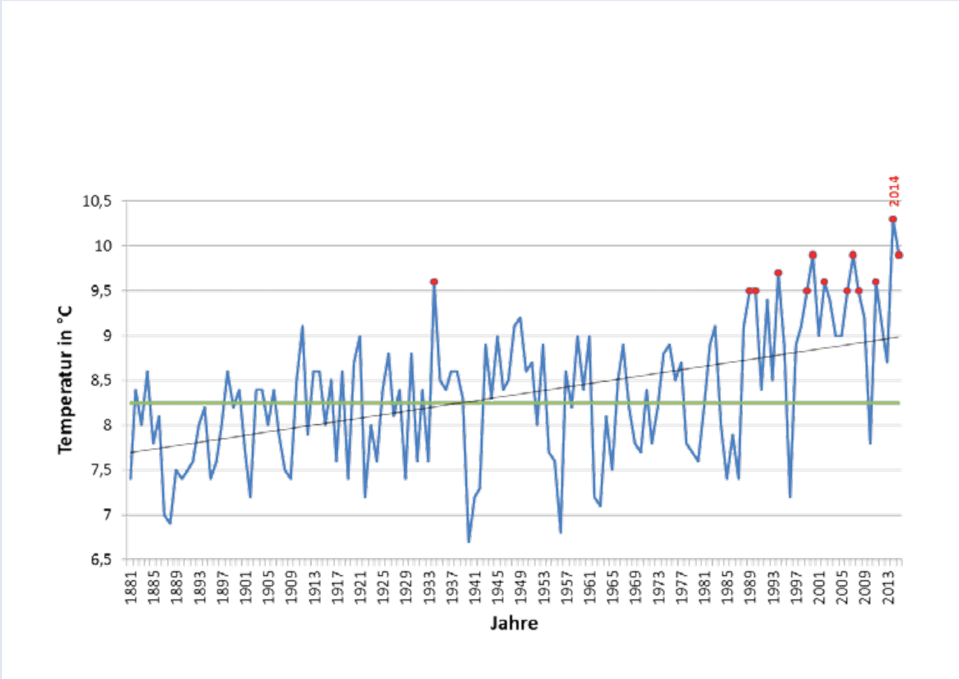
THE KLIWA COOPERATION

Are the extreme weather conditions and floods in southern Germany in recent decades unmistakable harbingers of climate change? How will regional climates change and what effect will those changes have on one of our most important resources: water? How should we respond? To address those issues, the federal states of Baden-Württemberg, Bavaria and Rhineland-Palatinate launched the KLIWA cooperation in association with Deutscher Wetterdienst in 1999. The aim of this interstate and interdisciplinary partnership project is to determine the potential impact of climate change on the water budget and ecology of river basins in southern Germany and to derive recommendations for action.

Long-term observations of meteorological and hydrological data are prerequisite for studies on climate change - the longer the better. Such data show how the climate has changed over time and are used with selected regional climate projections to estimate climatic conditions in the future. These climate data are used to simulate the future water budgets of river basins. The KLIWA studies undertaken to date have considered the issues of flooding, low water, groundwater, soil erosion and water ecology. Specific adaptation measures are based on the changes which are detected.

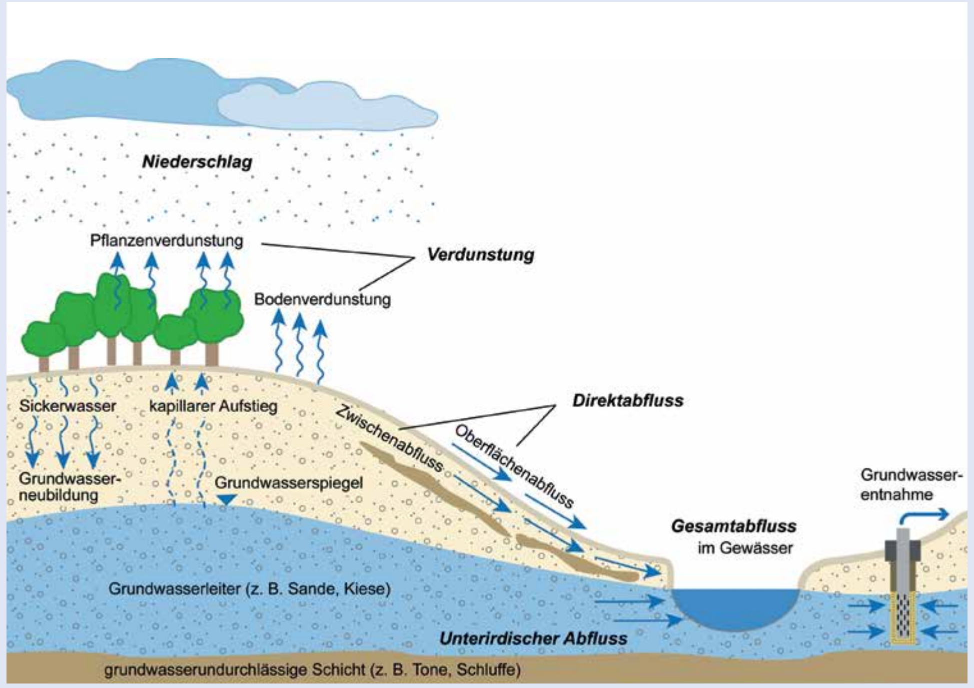
TEMPERATURE CURVE IN GERMANY FROM 1881 TO 2015

The diagram shows the deviation of the annual mean temperature from the average temperature based on the long-term mean for the period 1961 to 1990. The 1961-1990 mean is shown in green and the linear trend for the complete series in black. The figures show that the pace of global warming has accelerated significantly in recent decades. The ten highest mean temperatures since nationwide records started in 1881 are shown in red (the same mean value can appear several times). There has been a significant increase in the incidence of warm years in the 21st century.



THE WATER CYCLE

Two thirds of the Earth's surface is covered with water. Part of this water circulates around the globe in a massive cycle, in the form of vapour, liquid or ice. Water evaporating from the Earth's surface rises into the atmosphere as water vapour, condenses into clouds and falls back to Earth as rain or snow. This precipitation flows off down the earth's streams and rivers or infiltrates into the soil and so contributes to the formation of groundwater. Most water, however, evaporates again. This cycle is affected by climate change.



Climate monitoring in KLIWA
Regional changes

Climate change up to now is evaluated by first studying the available data for the past. The range of natural variability in weather data can be determined and trends can be identified from these long-term data series. Data from around 200 temperature and 900 precipitation stations in southern Germany have been evaluated and regionally standardised for KLIWA to produce a robust database for future climate trends.

Glacier recession will have a huge impact on the water budget.
© fotolia.com

IT HAS BECOME HOTTER

The global warming trend is also evident in southern Germany. The mean temperature in the KLIWA federal states of Bavaria, Baden-Württemberg and Rhineland-Palatinate rose by an average of 1.3°C between 1931 and 2015. In a total of 14 of the 15 years since 2001 temperatures have been higher than the long-term mean temperature for the period 1961-1990. With mean temperatures approximately +2°C above the long-term mean, 2014 has so far been the hottest year since records began in 1881. This means that the warming trend has accelerated even further. Since 1931 overall temperatures have increased more in the winter months from November to April than in the summer months from May to October. Over the last 15 years, however, most of this further warming has occurred in the summer.

DRY SUMMERS, RAINY WINTERS

In most areas of southern Germany annual precipitation rates remained more or less constant over the investigation period. However, the seasonal distribution of precipitation has changed. The winter months have become wetter. Between 1931 and 2015, precipitation increased by 16%-27% in some regions. Those changes have been most pronounced in the Black Forest and areas to the north-east of Baden-Württemberg as well as in Franconia, parts of the Bavarian Forest and the Eifel and Westerwald regions in Rhineland-Palatinate. Although the summer months vary in their long-term behaviour, they have in general become drier.

MORE EXTREME PRECIPITATION IN WINTER

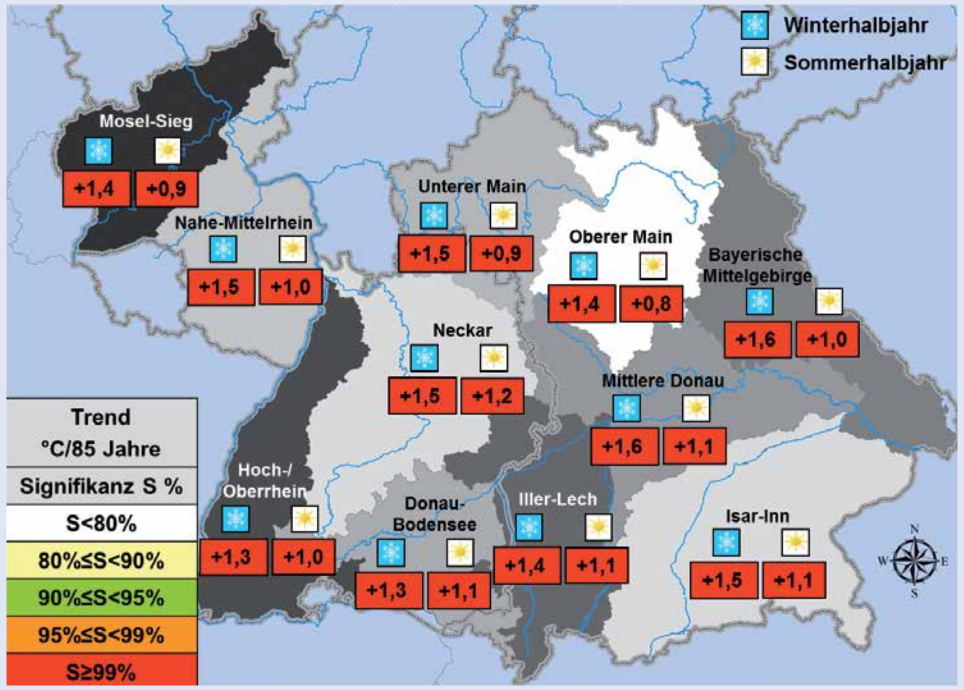
KLIWA also measures trends for maximum daily extreme precipitation. However, because extreme precipitation tends to be a local phenomenon, these trends are naturally less uniform than for areal precipitation. Still, in the hydrological winter half-year from May to October, there are clear positive regional trends (up to +33% from 1931 to 2015) throughout southern Germany; which is a precondition for an increase in winter flood situations. There is as yet no clear discernible trend for the summer half-year. Currently it is difficult to reach conclusions on long-term trends for events of less than one day's duration due to the lack of long-term records and high-resolution measuring networks. It may be possible to obtain information about precipitation from other sources in the future, such as radar measurements.

MONITORING IN KLIWA

One major aim of KLIWA is to record variability and changes in climatological parameters and water budget components. This provides the data for further comparative observations. A monitoring report is published for this purpose every 5 years (last updated 2016) at www.kliwa.de

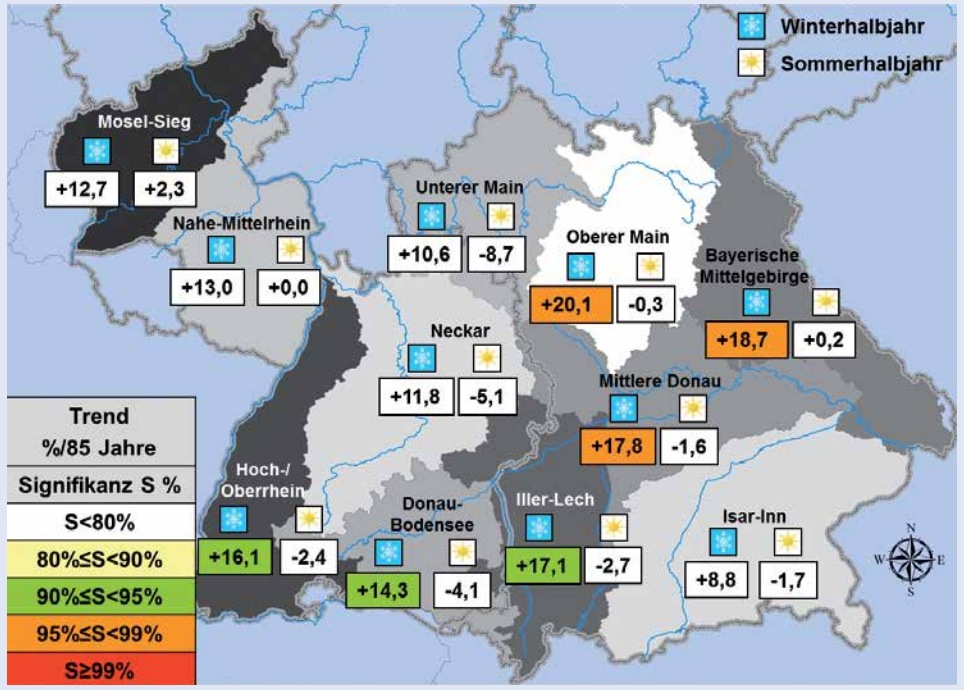
RISE IN AIR TEMPERATURE FROM 1931 TO 2015

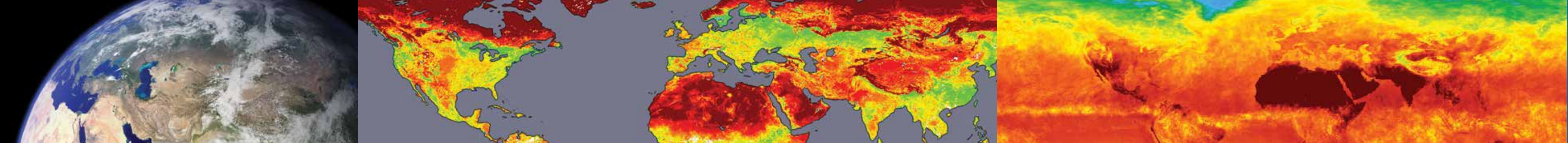
The diagram shows the change in areal mean air temperature in hydrological six-monthly periods. Temperatures have risen by more in the winter (+1.3 to +1.6°C) than in the summer (+0.8 to +1.2°C).



CHANGE IN AREAL PRECIPITATION FROM 1931 TO 2015

The diagram shows the change in areal precipitation in the hydrological six-monthly periods. The figures show clear seasonal differences: changes are uneven in the summer half of the year whereas, in contrast, precipitation has generally increased in the winter months by between 9% and 20%. In the last 15 years the trends for the winter have weakened while there has been more precipitation in the summer.



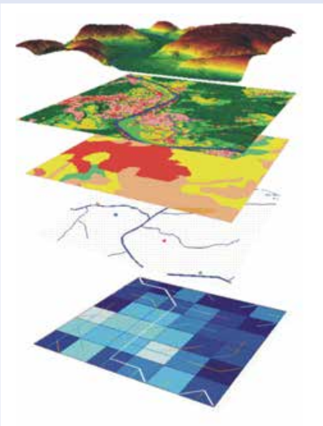


Modelling future developments
Instruments of climate research

There can no longer be any doubt that climate change is happening. The carbon dioxide which has already been released into the atmosphere will continue to have an effect there for several decades and will cause further global warming. Adaptation measures are therefore essential. Global and regional climate projections do not provide enough information on their own about the impact of global warming on water resources management. Changes in runoff, and in floodwater or low-water situations in particular, can only be determined using high-resolution water models driven by regional climate models.

DATA BASIS FOR WATER MODELS

Water models are created using extensive digital data records (e.g. digital elevation models, satellite classification of land use, soil properties and riverine networks). Up to 16 different land use scenarios are computed for each separate grid square, each with its specific evaporation and runoff characteristics.



CLIMATE MODELLING

Weather, weather conditions and climate: in meteorology and climatology these three concepts stand for processes which unfold over varying periods of time. Weather describes the condition of the atmosphere over a short period of time, weather conditions a phase of weeks or several months and climate longer periods of time, ranging from decades through to geological ages.

With today's resources, weather forecasting is a difficult task and only possible for a period of 5 to 7 days at most. Producing long-term projections of the way the Earth's climate is likely to change is an incommensurably more complex task, as many parameters and magnitudes mutually influence each other and not all processes are sufficiently well understood. Global climate models are in all cases based on an atmospheric model which is supplemented by ocean, snow, ice and vegetation models. Anthropogenic influences (the ‚human factor') are taken into consideration in the form of various assumptions regarding greenhouse gas emissions (SRES scenarios) and, in the most recent generation of climate models, radiation forcing (RCP scenarios).

The grid width of global climate models (with a grid width of about 200 km) is far too coarse for estimating changes in regional climate. Regional features such as mountain ranges and river valleys can only be captured by regional climate projections (~10 km). The studies with SRES scenarios have now been completed. Evaluations for the new RCP scenarios are just beginning and will continue to be a task for the next years in KLIWA. Even higher resolution climate projections (~2.8 km) are currently being considered in order to capture convective precipitation events more effectively.

WATER BALANCE MODELS

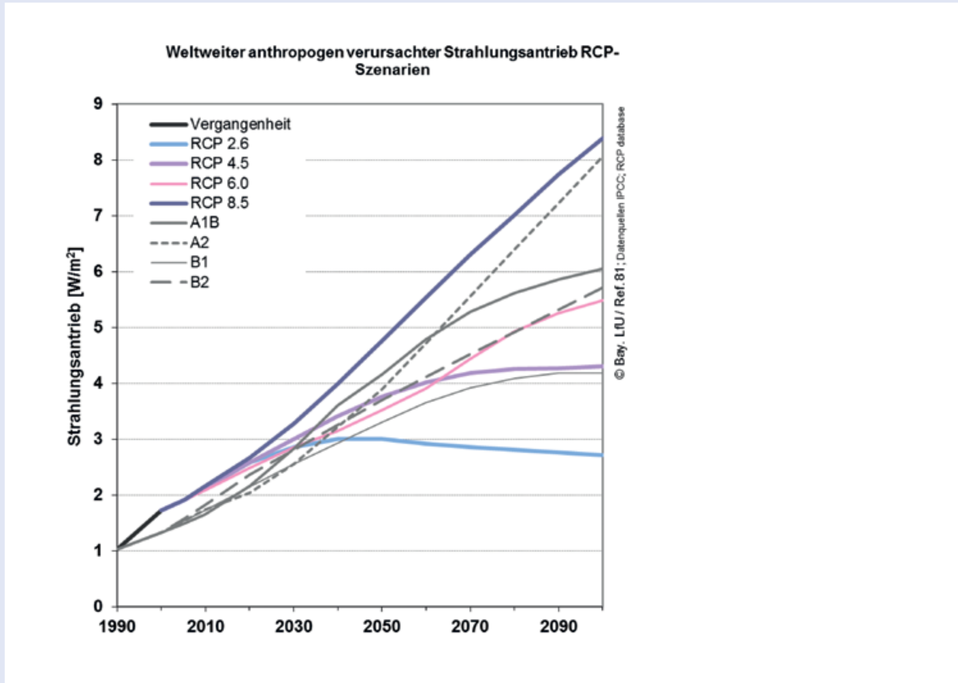
The impact of climate change on water management is evaluated using climate-driven regional projections and water balance models to simulate future discharge conditions. The link between an emission scenario – climate model – and a water model is referred to as a model chain. Water models facilitate the calculation of the spatial and temporal distribution of essential components of the water cycle – such as evaporation, seepage, water storage and runoff. These models can be used to quantify and assess the impact of changes on the water budget and to develop adaptation measures. Special soil water balance models are used in addition to determine the groundwater recharge. The findings are used to develop adaptation measures and recommendations for action, such as for low-water or flooding conditions.

RANGE OF RESULTS

The results of climate projections are subject to a number of uncertainties. Several climate projections (ensemble approach) can be used to produce a range of possible future climates and to assess their variability and existing uncertainties. Possible development pathways have to be considered on the basis of several projections demonstrating a range of different potential changes.

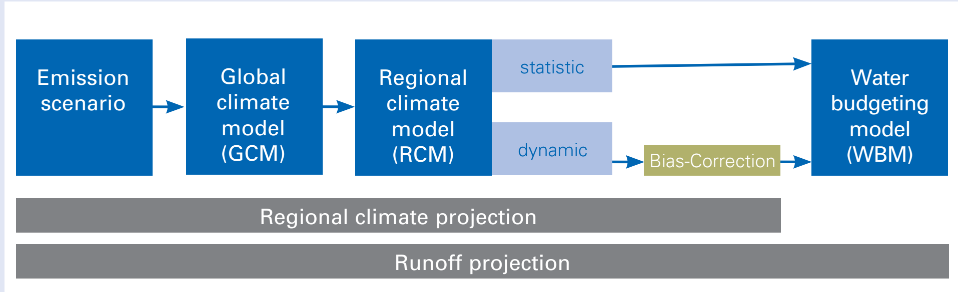
ANTHROPOGENIC DRIVERS IN CLIMATE MODELLING

RCP scenarios represent the additional radiative forcing resulting from human activity; the „old" SRES scenarios are shown in grey (sources: RCP database, IPCC 2007). KLIWA currently uses mainly the RCP scenario 8.5 and SRES scenario A1B.



MODEL CHAIN FOR REGIONAL CLIMATE CHANGE STUDIES

The necessary links between the models used to produce regional climate projections and to simulate future discharge conditions are shown schematically as a model chain.



Simulations for our future climate
Adaptation strategies

Various climate projections are available for the simulation of future conditions. Although the results of climate simulations for the „near future" of 2021-2050 differ from region to region, the general trend is the same: Warming will continue, winters will be wetter and summers tend to become drier. The resulting changes in the water budget call for adaptation strategies in water resources management.

Urlau an der Eschach flood retention area

RATHER HOT AND WITH LESS ICE

The regional climate simulations for southern Germany so far considered in KLIWA show that mean temperatures could increase by 0.6 to 1.8°C until 2050. Temperatures will, however, increase by different amounts in the summer and winter months.

The current trend towards wetter winters and drier summers will continue with up to 10% less rain in the summer in some regions and with noticeably more precipitation – in some regions up to 30% – in the winter. Precipitation will continue to be highest in the westerly oriented orographic windward areas of the KLIWA region. There will also be considerably more winter days with extreme precipitation (25 mm or more); in some regions the number of such days will even double. In contrast, there will be more summer days without any precipitation. This means that dry periods will last longer.

CONCLUSION UP TO 2050

As a result of the human-induced greenhouse effect, there will be

- a significant increase in the number of hot days (over 30°C) and of summer days (over 25°C) compared to today,
- longer lasting summer droughts,
- more extreme precipitation events in the summer with local flooding,
- an increasing number of westerly weather patterns which bring higher precipitation, particularly in the winter,
- increasingly more winter precipitation as rain rather than as snow,
- fewer frost days (temperature lows of 0°C or less) and icy days (where the temperature remains below freezing point).

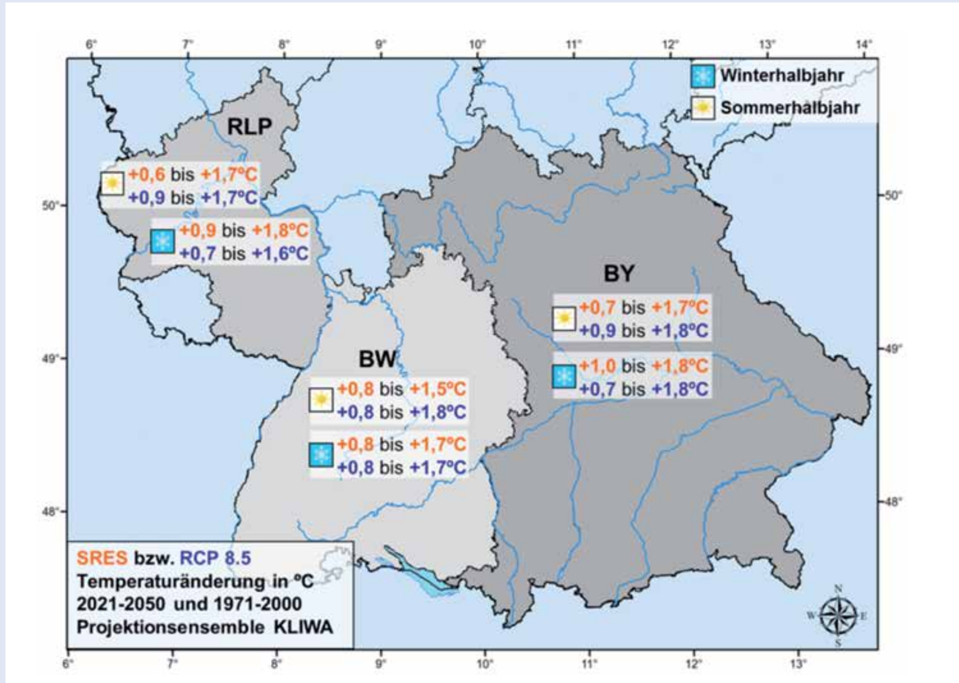
ADAPTATION STRATEGIES

KLIWA studies originally focused on flood flows. Now attention has shifted to the impact of climate change on low-water discharge, groundwater recharge and water ecology. The studies also look at the potential increase in extreme precipitation events and accompanying soil erosion.

Climate change poses a tough challenge for the federal states, local authorities and ultimately every citizen. The foreseeable and in part already perceptible impacts of climate change can only be met by concrete adaptation measures. For this reason effective and robust but flexible adaptation strategies must be developed taking into account hydrological as well as political, social and economic aspects. In this context, the principles of sustainability and environmental compatibility are equally important as uncertainties and interactions between climate mitigation and adaptation.

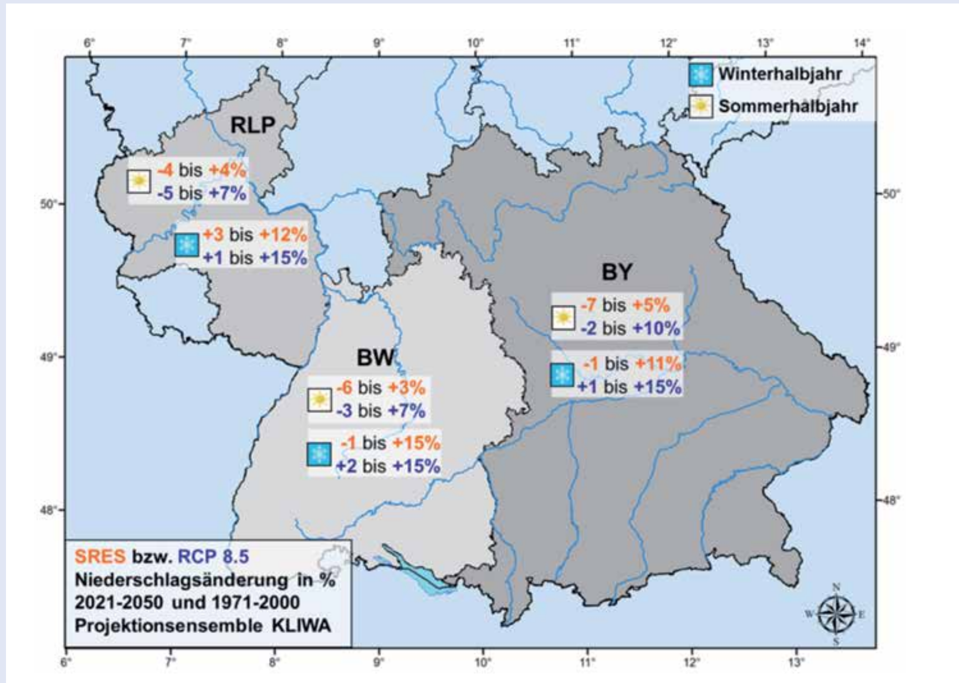
RISE IN AIR TEMPERATURE UP TO 2050

The diagram shows the change in air temperature in comparison of 2021-2050 vs. 1971-2000. These figures depict the previous basis in KLIWA with changes taken from SRES A1B compared to the changes in more recent climate projections based on RCP8.5 (15th and 85th percentile). Winter and summer temperatures will continue to rise. For the most part summer temperatures will change less than winter temperatures.



CHANGE IN AREAL PRECIPITATION UP TO 2050

The diagram shows the change in areal precipitation in comparison of 2021-2050 vs. 1971-2000. These figures depict the previous basis in KLIWA with changes taken from SRES A1B compared to the changes in more recent climate projections based on RCP8.5 (15th and 85th percentile). The changes differ according to season: on the whole, winters will be wetter and summers drier.



Our most important drinking water reservoir **Groundwater**

In southern Germany about 80 per cent of the drinking water supply is extracted from groundwater. The impact of climate change on groundwater resources is already apparent and is of particular importance for water management issues. As climatic conditions change, it is essential to ensure the supply of drinking water in the future.

Our springs are still bubbling from abundant groundwater.

MEASUREMENTS REVEAL CHANGES

Groundwater levels and the spring discharges have been observed at certain gauges for decades, in some cases for even more than a century. The obtained time series contain information about the long-term development of groundwater levels and spring discharges. Systematic evaluation of selected time series for the most important groundwater aquifers in Baden-Württemberg, Bavaria and Rhineland-Palatinate reveals declining conditions at about 2/3 of the studied gauges. Simultaneously, the annual maximum value is now measured earlier in the year at most gauges - a direct consequence of warmer winters and decreasing snow cover.

DEVELOPMENT OF GROUNDWATER RECHARGE

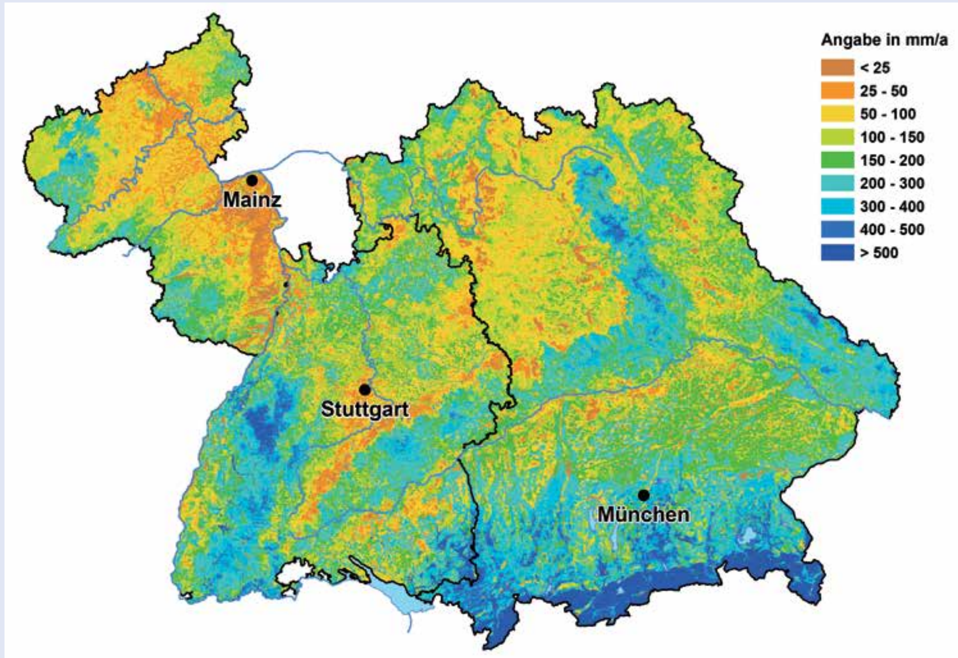
By applying a soil water balance model, joint extensive simulations for the period from 1951 to 2015 have been performed for southern Germany. The results of these calculations can be used to examine the changes in the past. Average groundwater recharge in southern Germany (see figure top right) over the entire period was 185 mm. The figures for particular years show that, in the recent past, groundwater recharge has occurred at no more than an average rate (see figure bottom right). Thus, mean groundwater recharge in 2003 was only 157 mm. Regarding the WETTREG2010 projection, mean groundwater recharge rates of 144 mm can be expected in the near future (2021-2050). Due to distinct temperature increases and decreasing precipitation throughout the entire year, WETTREG10 can be considered as „worst case" scenario. The drought index also shows an increase in dry periods. The drought index defines the yearly number of days with a soil water content below 30% of the available water capacity. No infiltration takes place during this period and vegetation suffers from severe dry conditions. While there was a deficit in soil water on an average of 52 days per year during the entire period, this figure has risen to 61 since 2003. In the near future an average of 70 days per year is anticipated (WETTREG2010).

RECOMMENDATIONS FOR ACTION

Regular observation of groundwater quantity and quality is essential for sustainable groundwater management. The observation network must therefore be maintained consistently to monitor the impact of climate change. As it already became evident in the past, extended summer droughts can lead to water shortages for short periods in particular areas. Efforts to avoid potential water shortages will need to include regional and superregional networking solutions. Above all, the increasing demands from agricultural irrigation call for sustainable concepts that avoid conflicts between stakeholders/interest groups and ensure water supply in the future. The increasing frequency of extreme weather events associated with climate change may lead to temporarily higher local and regional groundwater levels. These have the capability to damage buildings and infrastructure. This must be considered in the designation of boulding areas in potentially affected areas of high groundwater levels.

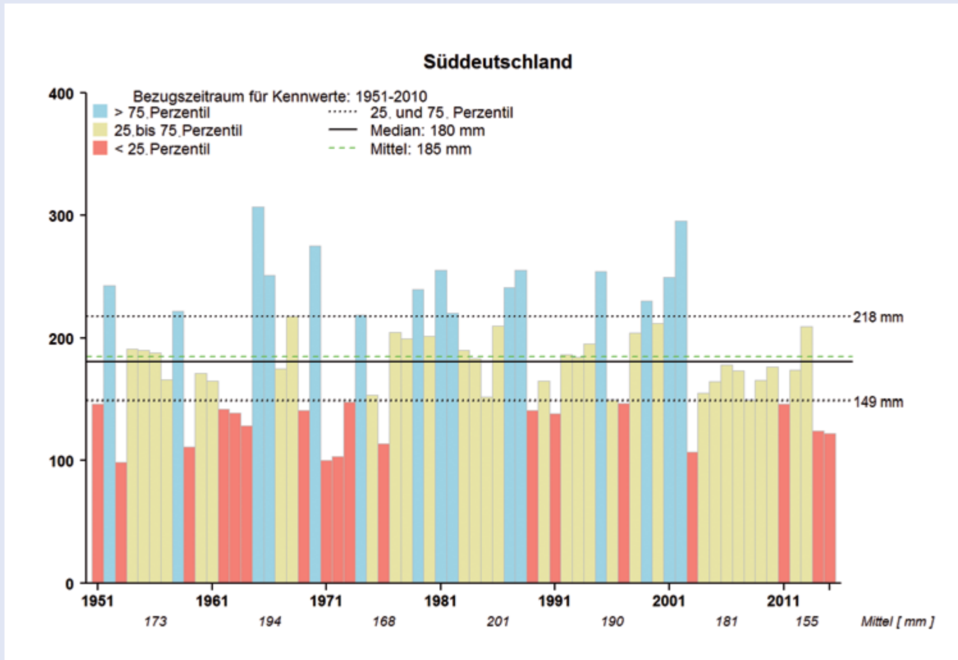
MEAN ANNUAL GROUNDWATER RECHARGE FROM PRECIPITATION – LONG-TERM AVERAGE (1951-2015)

Groundwater recharge is highly relevant for water management and is an important measure for the natural regenerative capacity of groundwater resources. Under the auspices of KLIWA, the formation of new groundwater in the period 1951-2015 has been calculated for all three federal states applying a soil water balance model.



MEAN ANNUAL GROUNDWATER RECHARGE FROM PRECIPITATION (1951-2015)

Development of annual groundwater recharge from precipitation in southern Germany (Baden-Württemberg, Bavaria and Rhineland-Palatinate) from 1951-2015. The long-term figures for the 1951-2010 period are plotted for comparison.





More frequent and longer lasting drought
Low water

The drier and hotter summers which are expected in the future will lead to lower water levels. These low-water phases not only pose difficulties for inland waterway shipping, but also afflict agriculture, the energy industry, drinking water supply as well as commercial and industrial enterprises requiring water for their production processes (e.g. the paper industry). Long lasting dry periods can have serious economic impacts and result in substantial financial losses. Furthermore, drought conditions not only affect water management, low water levels also influence and harm water ecology.

Low water on the Altrhein in November 2015.

NEGATIVE DEVELOPMENT OF THE WATER BUDGET IN RIVER BASINS

Climate change and global warming lead to an intensification of the hydrological cycle and to more frequent extreme weather events. The flash floods of 2016, with too much water at one place in a very short time, occurred in a longer period with too little water over a much greater area. Groundwater levels were already very low before the hot summer of 2015 and only recovered slightly in the following dry winter. Consequently there was much less water in streams and rivers than would normally be the case. Water management will need to adjust to such situations in the future.

LESS RAIN AND MORE EVAPORATION = LESS RUNOFF IN SUMMER

Most gauging stations in Baden-Württemberg, southern Bavaria and some parts of Rhineland-Palatinate show a long-term fall in water levels during the summer months (1951-2015). These changes are most pronounced in the months from June to October, although their actual severity varies from region to region. In contrast, water levels in northern Bavaria and parts of Rhineland-Palatinate have changed very little; in fact, low-water discharge has been even higher.

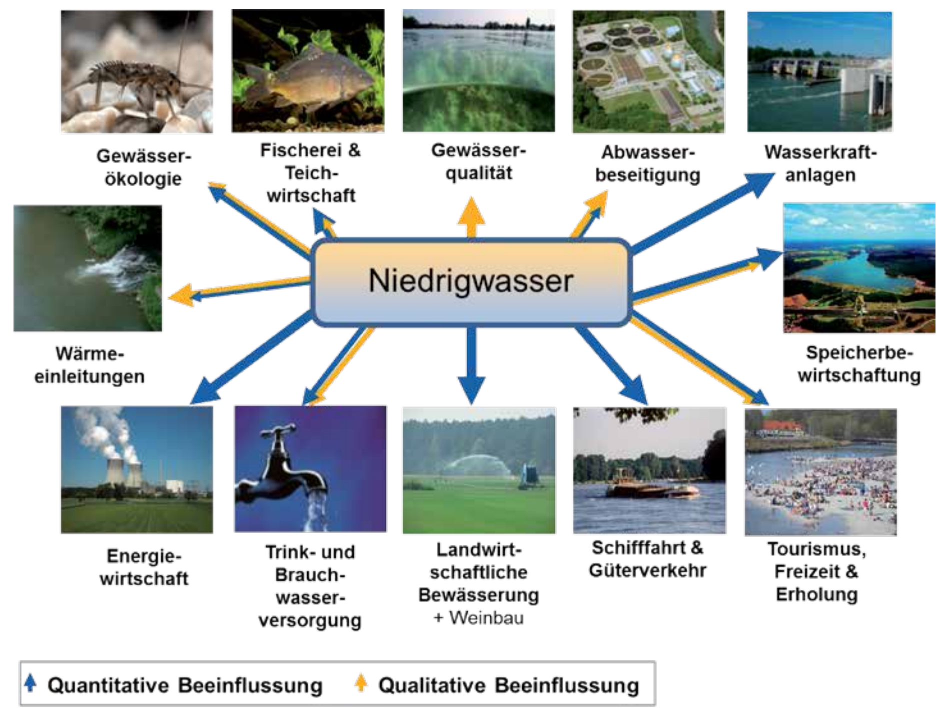
In relation to the common KLIWA ensemble of runoff projections for southern Germany, climate change is producing regional variations in low water in the summer half-year exemplarily shown at selected gauging stations. Most gauges tend to show a small reduction in low-water discharge of around 15%. However, some gauges may not show any clear change or just slight increases in runoff. In the near future there will be very little change in the low-water situation during the winter half-year. Throughout the course of the century the low-water situation is expected to become more critical throughout southern Germany during the summer half-year, i.e. with lower runoff and more frequent phases of low water.

WHAT NEEDS TO BE DONE?

A package of measures will be needed to mitigate the impact of more frequent low water and dryness. These may be short-term operational measures, such as restricting or prohibiting water abstraction during particular low-water situations. However, long-term measures, such as supporting seepage or increasing of large scale water retention, are also needed in order to have a preventive effect on future low water events. This will require coordination with all the affected stakeholders in order to lower conflicting use as far as possible. KLIWA studies the effects, conflicts and options for action on low water in case studies. Stress tests which simulate particularly extreme low water conditions provide input for discussion on the appropriate responses to such situations.

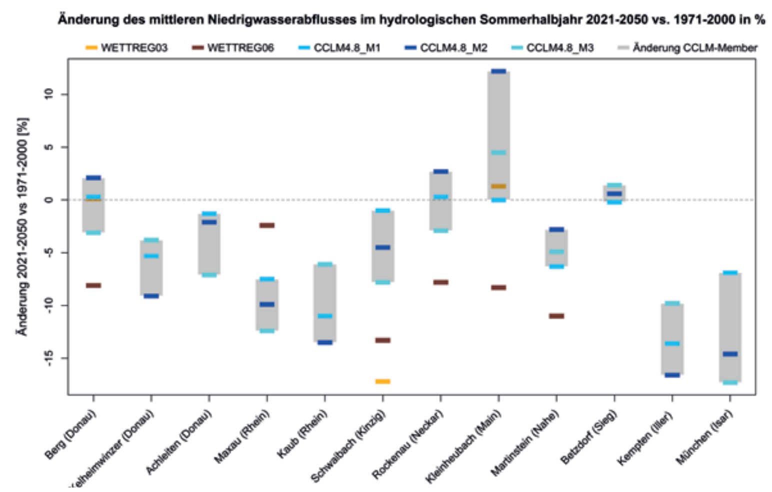
INFLUENCE OF LOW WATER ON ECOLOGY AND ECONOMY

Many water management uses and ecological functions may be impaired by low water, either because they require a sufficient volume (quantity) or type (quality) of water. There are also complex interactions between these types of use. A reduction of water availability consequently leads to conflicts of interest.



CHANGE IN MEAN LOW-WATER DISCHARGE IN THE NEAR FUTURE

Change in mean low-water discharge in the hydrological summer half-year (May to October) comparing the near future (2021-2050) and the reference period (1971-2000). Selected gauges in Baden-Württemberg, Bavaria and Rhineland-Palatinate are shown.



„Flexible and no regret“ strategy
Flooding

The prospects on possible climate developments for the next few decades is afflicted with uncertainties. However, all the flooding studies carried out to date do show that there will be more flooding events in the future. Flexibility and the precautionary principle are appropriate given the spread of possible results in relation to adaptation. Adaptation does not, however, mean building protective walls everywhere. Preference must be given to flood risk management measures which are effective in the long term, which cover a broad spectrum and, as far as possible, are also useful for other aspects.

FLOOD PROTECTION – WHAT DOES IT MEAN IN PRACTICE?

Example Flood embankments:
Embankments will be built as originally planned leaving an area on the outside clear so that they can easily be broadened and raised if necessary.

Example Bridges:
The regional climate change factor will be taken into account when bridges are planned as subsequent adaptation is often impossible for technical reasons.

Example Retaining walls:
New retaining walls will be designed to enable additional height to be added easily in the future if needed.

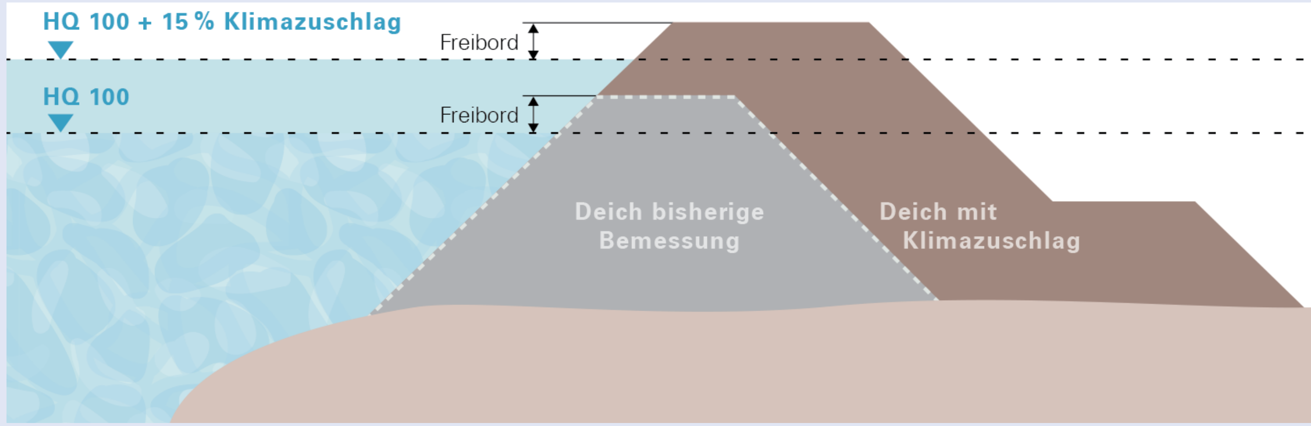
INCREASING RUNOFF, MORE FLOODING EVENTS

Concerning flood discharge, climate change is statistically detectable since around the mid 1970s. Simulations based on water balance models for the river basins in the three KLIWA federal states show that flood discharge levels will continue to increase in almost all regions, especially in winter. Since the beginning of the 2000s, strategies and stipulations have been implemented when planning new flood protection measures, on how climate change could already be accounted for in their dimensioning. Along the River Neckar, for example, the figures for a 100-year flood (HQ100) must now be multiplied by a climate change factor of 1.15. In other words, in the future flood protection systems must be designed to cope with a 15 per cent higher discharge than today's values indicate, or at least be planned in such a way that they can be adapted to meet higher requirements. HQ100 is the flood discharge which, statistically, is only exceeded once every 100 years (see image top right).

ADAPTATION MEASURES FOR CLIMATE CHANGE

The impact of climate change on flood discharges varies from region to region. For example a climate change factor of 1.25 has been calculated for the Upper Danube area of Baden-Württemberg. Smaller floods, and floods of moderate severity, are also expected to increase. The HQ5 discharge for a flood on the Upper Danube – which today can be expected to occur on average every five years – has gone up by 67 per cent. This means that, in the future, the current HQ5 value for the Upper Danube must be multiplied by a climate change factor of 1.67. The HQ5 climate change factor for the area around the tributaries to the Upper Rhine is 1.45, for example. The factor is lowest (1.24) in the Upper Swabia / Lake Constance region.

A climate change factor based on the first KLIWA 2004 study findings has also been introduced in Bavaria – here the statistical value of HQ100 was increased by 15% statewide. Plans for new flood protection measures are therefore already taking account of the expected effects of climate change. The fundamentals of the climate change factor are continuously reviewed and expanded by further research. So far, these results have confirmed the 2004 stipulations. In Rhineland-Palatinate flood protection measures are always dimensioned according to the actual side constraints which apply in each individual case, with a particular focus on the threat to the population, the potential damage caused by flooding and considerations of economic viability. Runoff studies have been carried out in recent years for the whole of Rhineland-Palatinate and for the Middle Rhine. Initial results for the Upper Rhine in Rhineland-Palatinate show that there will be a significant increase in smaller flood discharges, i.e. discharges with a higher probability of occurrence, in the „near future“ (2021 to 2050). These discharges (which are expected to increase in frequency) already occur in areas which are protected by dykes, and are manageable with flood retention and technical flood protection measures.



CLIMATE CHANGE MARKUP

In planning the dimensions of flood protection facilities, a markup on the current value for flood discharge takes account of the possible effects of climate change. The freeboard margin prevents the breaching of a flood protection barrier (e.g. as a result of higher water levels caused by waves and wind).

THE SPECIAL CASE OF THE UPPER RHINE

Owing to the special situation for the Rhine, such as discharge from Switzerland and water regulation measures along the river's upper reaches, the stretch of the Rhine from Freiburg to Mainz was not included in the first discharge studies performed as part of KLIWA. Robust climate projections are now available for the entire Rhine catchment area – including its Swiss part. There are also suitable water balance models which cover the retention effect of Lake Constance, the large lakes on the edge of the Alps and the entire Rhine catchment area up to Worms (approximately 69,000 km²). The flow of water down the Rhine as far as Worms is strongly influenced by the runoff formation in the Swiss Alps and therefore the seasonal cycle of snow build-up and thawing. The largest discharges occur in the hydrological summer half-year from May to October. Analyses of relative changes between the future scenario 2021-2050 and the current status 1971-2000 for the water level of the Rhine show that no substantial changes are expected for mean flood discharge. With the exceptions of the months of May and October, results even show a slight decrease in mean flood discharge for the summer half-year during which the highest discharges occur. Increases of less than 10% are simulated in the winter half-year from November to April. From today's point of view no increases in mean flood discharges are discernible at Rhine gauges up to 2050. The values for extreme flood discharges tend to be higher. Nonetheless they are significantly lower at gauging stations in a nival (i.e. influenced by snow melt) regime than at gauging stations in a pluvial (i.e. influenced by rain) regime. The increase in HQ100 at gauging stations in a nival regime on the Upper Rhine, for example, reaches from +3% to +5% (Basel, Maxau, Worms) and is as such significantly lower than at gauging stations in a pluvial regime, like at Rockenau (Neckar) with +12%. These Upper Rhine trends are passed on for the most part to the Middle Rhine (Mainz, Kaub) although even higher extreme flood flows may occur below the mouth of the Mosel.



A growing danger?
Extreme precipitation

Extreme precipitation events are characterised by a large amount of rainfall in a short period of time. They usually occur in a small area and the risk of flooding is hard to estimate. Climate change and the warming projected in the future significantly increase the potential for higher volumes of precipitation and thus the risk of more frequent and more extreme precipitation events. However, these are also countered by other meteorological factors, such as changes in weather patterns.

Extreme precipitation eventin Braunsbach, 29 May 2016

EXTREME PRECIPITATION

Long-term trends in the frequency and intensity of extreme precipitation can only be distinguished from natural variability with measurements taken over many decades. Trend analyses concerning extreme precipitation are more difficult because those events are not always captured by the precipitation measuring network. Maximum one-day areal precipitation quantities have been studied in KLIWA. These increased throughout almost all of southern Germany in the period 1931–2015, although statistical certainty and strength (maximum +33%) vary greatly between regions. There is as yet no clearly discernible trend for the summer half-year. Flash floods and soil erosion are usually triggered by short-duration events which may constitute a part of the studied daily precipitation but which cannot be clearly separated from it.

The available data to analyse precipitation over periods of less than 24 hours is much worse. Analyses of the radar data available in Germany for the last 15 years clearly point to a regional increase in short-lived bursts of extreme precipitation. However, owing to the short length of the available time series these results are still climatologically inconclusive. Still, they can usefully supplement the evaluation of station data and be compared with a subperiod, for example. Further research is required to produce more robust findings. This also applies to climate projection data. Models which allow for convection should certainly be used in this context for short-duration precipitation. While projections of this kind already exist, the existing data for ensemble evaluations are only just being successively created.

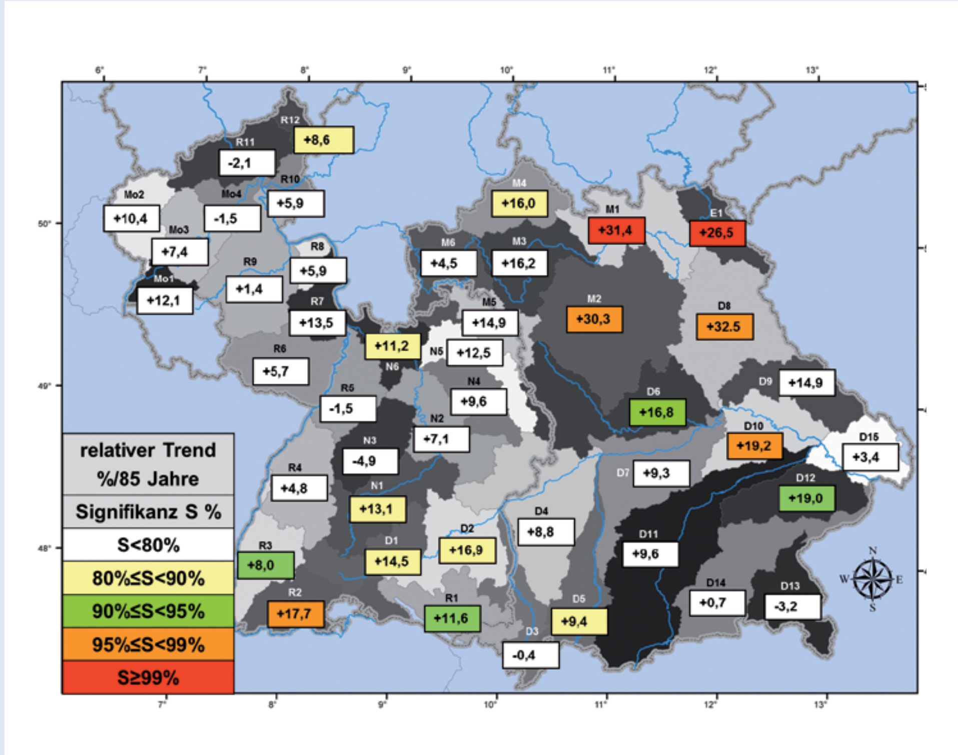
ADAPTATION – WHAT CAN LOCAL AUTHORITIES DO?

As convective precipitation falls locally and is difficult to predict it can, in principle, affect any community. Local authorities should therefore consider the potential dangers arising from extreme precipitation to people and damage to buildings and infrastructure and should take suitable precautionary measures. Diverse activities are being undertaken at the state level in this respect: Baden-Württemberg and Rhineland-Palatinate have published a joint guide entitled „Heavy rainfall – What can local authorities do?". Land use can be adapted to minimise the risk of erosion and related impacts as far as possible (see also „Codes of good practice" for agricultural land).

A further guideline on the management of extreme precipitation events by local authorities has also been produced in Baden-Württemberg. This guideline offers local authorities a standardised procedure for the analysis of dangers and risks as the basis of a local authority action plan. Local authorities can use extreme precipitation maps to predict where surface discharge will accumulate and where it will run off. On this basis measures can be developed to avoid damages as far as possible in cases of emergency. The focus throughout is on public institutions, infrastructure, housing estates, commercial and industrial estates and on informing the public and all stakeholders about the risk of extreme precipitation.

CHANGE IN MAXIMUM AREAL PRECIPITATION FROM 1931 TO 2015

Development of maximum one-day areal precipitation volumes in the hydrological winter half-year, relative trend (change stated as percent, deviation from 1931-2015 mean).



EXTREME PRECIPITATION AND SOIL EROSION

The risk of soil erosion varies greatly from region to region depending on a number of influencing factors (precipitation, land and ground properties and management). The frequency and intensity of heavy rainfall are the triggering factors, however. Any future change in these factors can be expected to increase the risk of soil erosion and the associated threats. Soil erosion causes long-term ecological and economic damage. Fertile soil is lost on the areas affected and soil functions are impaired. Neighbouring areas and structures are affected by deposited soil material. Nutrients and pollutants attached to soil particles find their way into other ecosystems, e.g. waters. Changes in precipitation intensities are studied in KLIWA in high-resolution data time series and climate models.

Impact on water quality
Aquatic ecosystems

Climate change affects inland waters and the animals and plants that live in or around them. Rising temperatures and falling discharge or water levels strain the oxygen balance and change the composition of biotic communities. This could have an enduringly negative impact on the good status of our waters. However, what has in fact changed and what changes can we expect in the future? Conclusions are difficult to reach owing to the intricate and entangled interactions between water characteristics and ecological systems as well as the relative paucity of specific data.

The European bullhead needs high concentrations of oxygen and low water temperatures. It is therefore strongly affected by climate change. Photograph: Fisheries Research Centre Baden-Württemberg

VARIETY OF INFLUENCES ON WATER ECOLOGY

Climate change alters some of the fundamental factors in streams, rivers and lakes, such as water temperature, the depositing and dispersion of fine-grained sediment, the concentration of nutrients or their blending in lakes. All this triggers an entire chain of processes which can ultimately affect water habitat flora and fauna with some species becoming rarer and other new plants colonising the areas. Changes take place in biotic communities and the functionality of the aquatic resources. While the impact of climate change on water resources in southern Germany has already been comprehensively modelled, until now changes in water ecology are only known to have occurred in smaller areas. For instance, a tendency of biotic communities to move upstream in rivers and streams could already be proven locally.

Two literature studies commissioned by KLIWA illustrate the interacting effects of climate change and the quality of rivers, streams and lakes at the regional level in the three federal states of Bavaria, Baden-Württemberg and Rhineland-Palatinate. These studies, and the extensive literature and sensitivity analyses which go with them, demonstrate that changes in the quality of water may be expected in many areas in the future, but at the same time also reveal many areas in which there are still knowledge gaps and action needs to be taken.

FUTURE MONITORING

Until today it is not possible to say just what influence climate change will have on the quality of our inland waters. The most recent monitoring programme on flowing water is to be supplemented by special climate impact monitoring in order to obtain robust data. The concept for such a programme of bodies of flowing water is almost complete. The aim of monitoring is to provide a fund of data which can be used to address many issues in the future and to find and define appropriate adaptation measures.

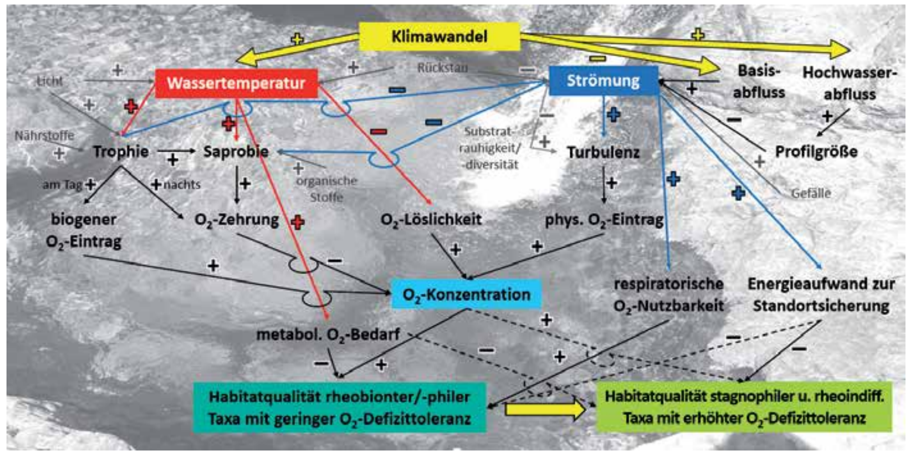
CLIMATE CHANGE INDICATORS FOR WATER QUALITY

Creating a good database is only the first step, however. Ways must be found to evaluate data which differentiate between the influence of climate change and other factors on aquatic environments. New indicators are needed for this purpose. An indicator for flowing water has already been developed in KLIWA.

The KLIWA indexMZB appears to be a suitable tool for „measuring" changes in the species composition of small organisms living at the bottom of an aquatic ecosystem (freshwater benthic invertebrate fauna). Such changes – through to species which tolerate higher temperatures and lower oxygen levels – may be anticipated as climate change in the summer worsens aeration conditions (mainly in the form of higher water temperatures and lower flows speeds). A field test is currently being run to clarify the applicability of the index.

INTERACTIONS BETWEEN CLIMATE CHANGE AND THE QUALITY OF RIVER AND LAKE HABITATS

Climate change has a direct impact on the water temperature and the flow characteristics of rivers and streams. These two factors determine a number of processes which have a critical impact on the supply of oxygen and therefore on the crucial conditions of life for water organisms. Illustration: Martin Halle / Andreas Müller



THE SENSITIVITY OF MOUNTAIN STREAMS

Small Kerbtal (notched valley) streams, like the Endertbach in Rhineland-Palatinate, have a high level of flow and substrate diversity. They are cold and well supplied with oxygen. Their species-rich invertebrates may be particularly prone to changes in the climate. Photograph: Jochen Fischer



Hot summers, warm rivers and lakes?
Water temperature

Water temperature is a key quality parameter. It determines all biological and chemical properties in a body of water. It also influences the use humans make of water in many different ways: for leisure, as a source of nutrition or as a means of cooling power stations and industrial installations. The warming of air leads to warming of streams, rivers and lakes.

Shady banks reduce the warming up of water by the sun

FLORA AND FAUNA ARE SENSITIVE TO TEMPERATURES

Water temperature has a huge influence on biological and physical/chemical processes in bodies of water and affects the speed of metabolic processes. This means that water temperature has a direct impact on all the organisms living in a water body and is also relevant to the composition of aquatic biotic communities, to effective photosynthesis, to the fish mortality rate, internal water metabolic rates, the solubility of gases and the toxicity of many environmental chemicals. Various regional guide values are available for water temperatures which are tolerable for fish in particular. These are stipulated in the federal surface water ordinance (OGewV). Fish communities may be endangered if these values are exceeded.

THE WATER IS GETTING WARMER TOO

Initial studies have been made of water temperatures measured in Bavaria between 1951 and 2009. These show that the mean annual water temperature has risen by around 1.5°C since 1980. Temperatures appear to have risen everywhere. The trend is especially apparent in the summer months from May to August. Comparable studies on the Rhine also show an accumulation of maximum summer values of over 25°C. In the last decade, water temperatures have reached daily mean values of over 28°C and daily maximum values of over 29°C. Most of the water temperature rise is due to seasonal and regional climatic influences.

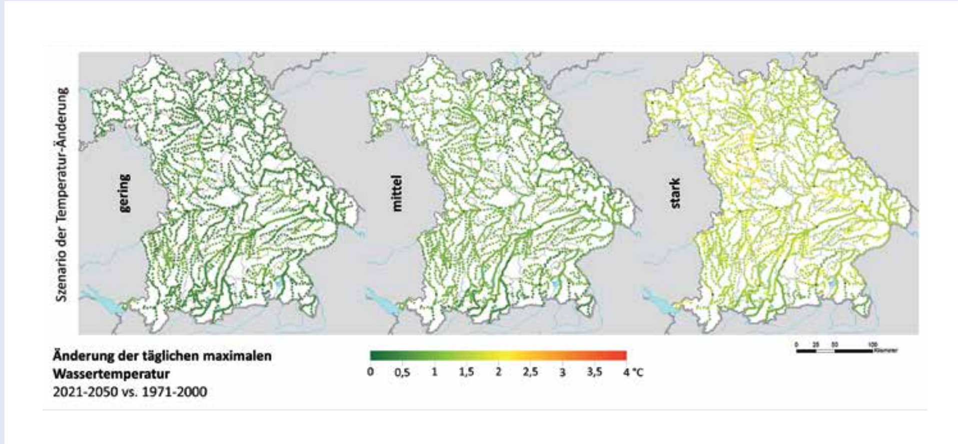
Restrictively mentioned, however, this heating is further exacerbated by human interventions, such as the discharge of heat into water or the building of damming structures. Consequently is not possible to distinguish the causes and influences entirely in every single case. A fundamental increase in the average temperature of flowing water immediately reduces the amount of warming for other uses which would be ecologically acceptable. On extremely hot summer days, for example, it is necessary to reduce the inflow of warmed waste water into water which is already hotter owing to climate influences. This is directly followed by economic consequences.

WILL IT GET EVEN WARMER?

The modelling of further temperature changes in water bodies is of great interest for statements about the future development. However modelling is difficult as many factors in addition to discharge also need to be taken into account. While a statistical approach has already delivered initial findings in Bavaria, a physically-based modelling approach with water budget heat models is being taken in Baden-Württemberg and Rhineland-Palatinate. The use of climate projections in both approaches enables some initial conclusions to be drawn about the extent to which climate change will impact water temperature in the future. Climate projections provide an important input for further study of changes in water ecology.

CHANGE IN MAXIMUM WATER TEMPERATURE IN BAVARIA

The maps show the mean change in the maximum daily water temperature between the two periods 2021-2050 vs. 1971-2000 using three climate projections. Overall the temperature rises by between +0.5 and +1.3°C.



Future prospects / outlook

We must expect increasingly hotter and drier summers and milder and wetter winters in the future. The change in the distribution of precipitation in particular will have a sustained impact on the regional water cycle and, as a result, on the water balance of our river basins.

KLIWA initially focussed on the problems presented by flood hazards and has elaborated distinct measures for dealing with these. The main emphasis of investigation has now shifted to the effects of climate change on low-water discharge, groundwater, the management of heavy rainfall and water ecology.

Changes to the water cycle have direct consequences for the many different water uses – whether as directly tapped for drinking water and agricultural irrigation, for use as a coolant in power stations or as a transport route for shipping or various leisure uses. This is linked to the question of the effects of climate change on the quality and ecological status of our waters; this is one of the main areas of work in KLIWA at present. The focus will also be on the potential increase in extreme short-term precipitation. This extreme precipitation may cause enormous local flooding and create even more problems for local authority drainage networks or, as a result of soil erosion, result in substantial damage for agriculture and high depositions in our waters.

Regional measures that seek to cushion the effects of climate change are one thing – but even more important are steps dedicated to active climate protection. Top priority must be given to reducing greenhouse gas emissions. The delayed response of the climate system means that even if emissions were to come to an immediate stop (a purely fictitious scenario), temperatures would keep rising in the immediate future. Each and every one of us must therefore take action to ensure that future generations are not confronted with even more serious problems.