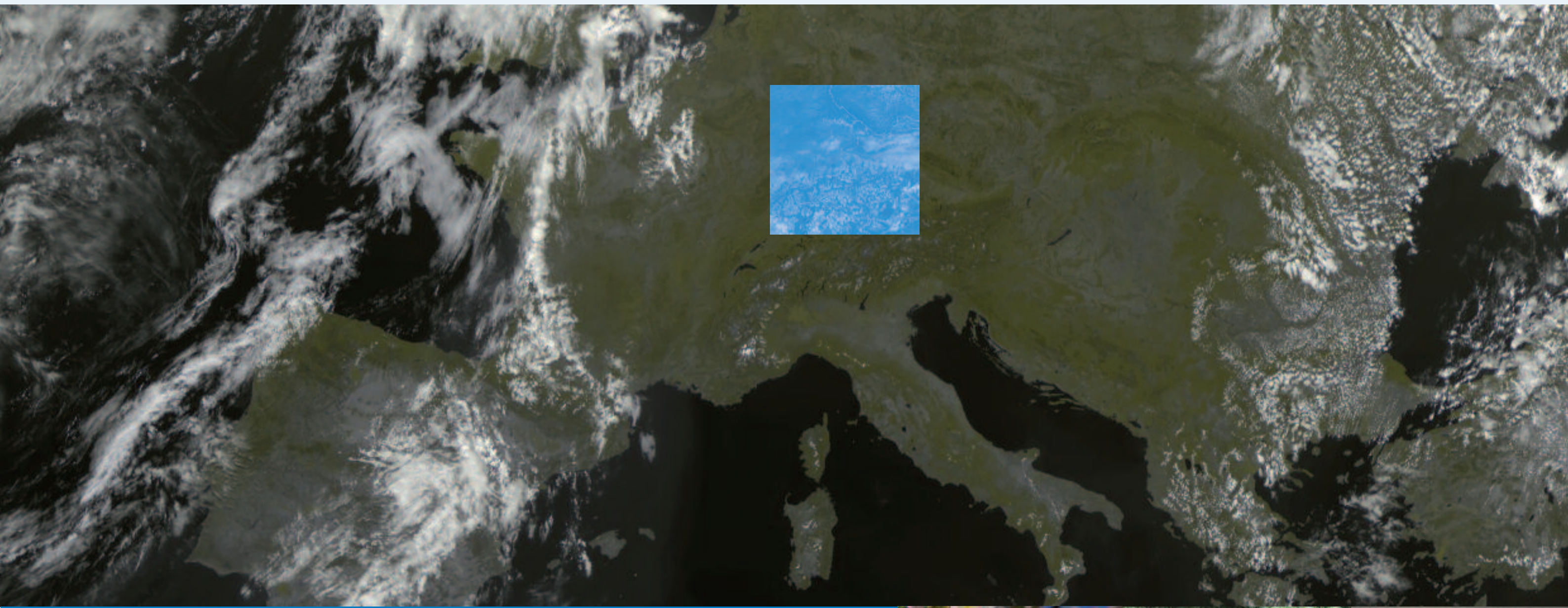
KLIWA
Klimaveränderung
und Wasserwirtschaft

Climate Change in Southern Germany
Extent – Impact – Adaptation



CONSEQUENCES FOR WATER RESOURCES MANAGEMENT



Baden-Württemberg
MINISTERIUM FÜR UMWELT, KLIMA UND ENERGIEWIRTSCHAFT

Bayerisches Staatsministerium für
Umwelt und Gesundheit

Rheinland-Pfalz
MINISTERIUM FÜR
UMWELT, LANDWIRTSCHAFT,
ERNÄHRUNG, WEINBAU
UND FORSTEN

DWD
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

KLIWA (KLIMAVERÄNDERUNG / WASSERWIRTSCHAFT) STANDS FOR CLIMATE CHANGE AND ITS IMPACT ON WATER RESOURCES MANAGEMENT.
KLIWA IS A COOPERATIVE PROJECT INVOLVING THE FEDERAL STATES OF BADEN-WÜRTTEMBERG, BAVARIA AND RHINELAND-PALATINATE AND DEUTSCHER WETTERDIENST [GERMAN WEATHER SERVICE].

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FOREWORD

Water is one of the most valuable gifts of nature. We all live by water and with water. Water management carries a heavy load of responsibility. On the one hand it must ensure that water functions as the indispensable foundation of life, on the other it must protect people against the potential threat that it represents. Standards of water management in Germany are high. We are protecting our waters and improving them wherever necessary. We have sufficient good quality drinking water, and we are investing millions in flood protection.

But the water cycle is in a state of flux. With climate change, our water resources are changing as well. We know today that temperatures are rising all over the world as a result of the greenhouse effect, and this process is set to continue. We will no longer be able to halt these developments, but we must try to keep the effects of the changes under control with the help of a consistent and effective climate protection strategy.

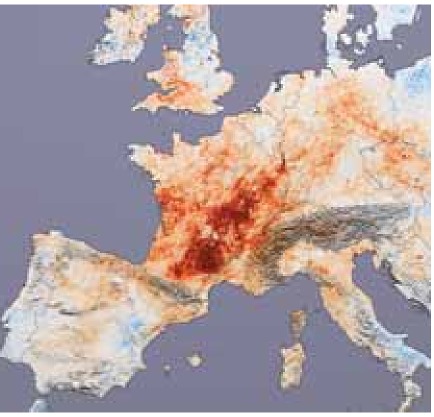
As a consequence of climate change, we must anticipate an increase in the incidence of extreme weather events. In all probability the future will see more frequent heavy rainstorms, but there are also likely to be more heatwaves and periods of drought. Water management must adapt accordingly, and try to find new ways of coping with these developments.

Thanks to KLIWA we are now in a position to estimate approximately how climate change will affect flooding, low water and our groundwater reserves. Of course there continue to be some grey areas. We must evaluate these accurately while setting the points correctly for the future, and this is a major challenge. But even in terms of fundamentals there is a need for action. How will climate change affect the water quality of our streams and rivers? What adjustments may turn out to be necessary?

A consistent climate protection strategy, at global, national and regional levels, will enable us to keep the consequences of climate change within calculable limits. The emission of greenhouse gases must be checked as far as possible. Where the effects can no longer be reversed, we must respond by making the necessary adjustments. This means preparing climate-sensitive systems for the changes in the best possible way. To ensure that this happens, the adaptability of our ecosystems must be increased and their vulnerability reduced, and we must go on consistently extending our current pool of expert knowledge on climate change and its consequences. The KLIWA cooperative project is making an important contribution in this connection.

Increasing incidence of weather extremes The Earth's climate

There was a marked increase in the number of extreme weather events in the early 1990s. In 2003, Europe groaned for weeks under temperatures as high as 40°C. Two years later, in August 2005, the Alpine Foothills were completely submerged following extreme and persistent rain. The occasionally spring-like temperatures of winter 2007/2008 were followed by snowy winter months and severe frosts in December 2010. There was literally no precipitation at all in November 2011. Is the increasing frequency of unusual weather events simply a coincidence?



Extreme weather in the summer of 2003: heatwave in Central Europe (especially in the red areas)

KLIWA ON THE WEB

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

... OR IS CLIMATE CHANGE ALREADY A REALITY?

The Earth's climate has varied naturally over the course of millennia. At times Europe enjoyed a tropical climate, at others it was covered by massive ice sheets. Sediment drill samples and pollen analyses yield insights about climate fluctuations in early phases of the Earth's history. Weather data have been recorded on a regular basis since 1860. Evaluations of these data reveal that the mean global temperature has risen by around 1°C over the last 150 years. Although this may not appear to be a very dramatic increase, it should give us pause for thought bearing in mind that the mean difference in temperature between the climate in southern Germany and the Mediterranean is around 2 to 3°C.

GREENHOUSE EARTH

We have the natural greenhouse effect to thank 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 390 ppm. This anthropogenic greenhouse effect influences both global and regional hydrological cycles.

THE KLIWA PROJECT

Are the extreme weather conditions and floods of the last two decades harbingers of climate change? How will the climate and our water resources change – and how can we respond?

The federal states of Baden-Württemberg, Bavaria and Rhineland-Palatinate are studying these issues in association with Deutscher Wetterdienst [German Weather Service] in the framework of the long-term cooperative project 'Klimaveränderung und Konsequenzen für die Wasserwirtschaft' ['Climate Change and its Impact on Water Resources Management']. These investigations first got underway in early 1999.

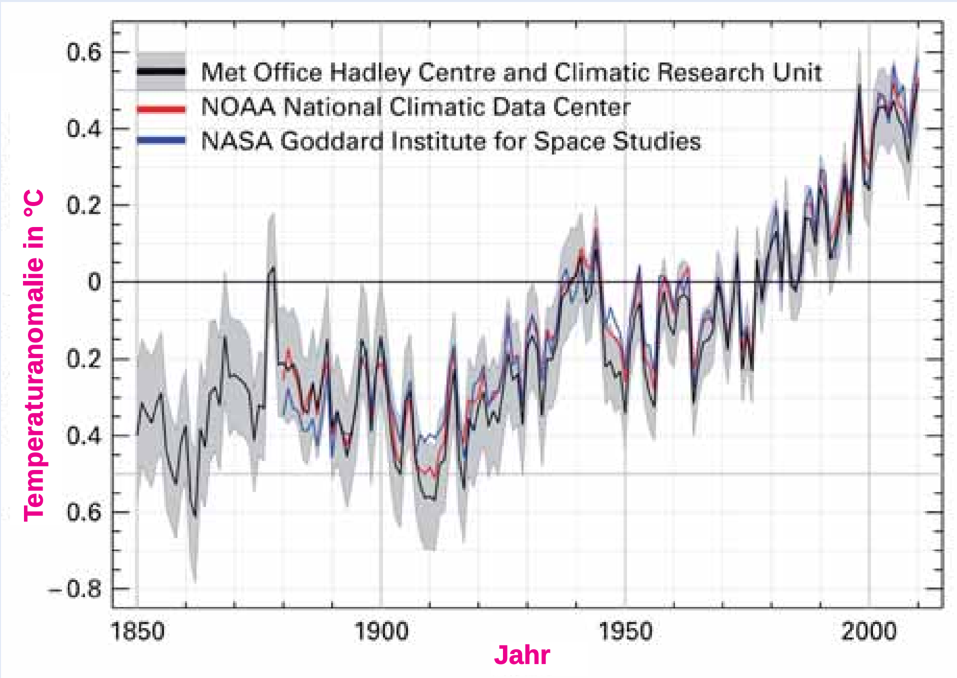
The aim of this cross-regional interdisciplinary partnership project is to determine the potential impact of climate change on the hydrology of river basins in the south of Germany, to highlight probable consequences and to propose recommendations for action.

The first step was to analyse meteorological and hydrological records that cover long periods of time in order to detect and evaluate trends. This data also provided the context for the estimation of possible climatic conditions in the near future (2021-2050) based on selected regional climate projections. The resulting climate data represents the basis for finely meshed hydrological, or water balance, modelling for individual river basins. The following water management issues have so far been studied: flooding, low water, groundwater, soil erosion and water quality. The aim is to propose specific adaptation measures in these areas.

GLOBAL TEMPERATURES FROM 1850 TO 2010

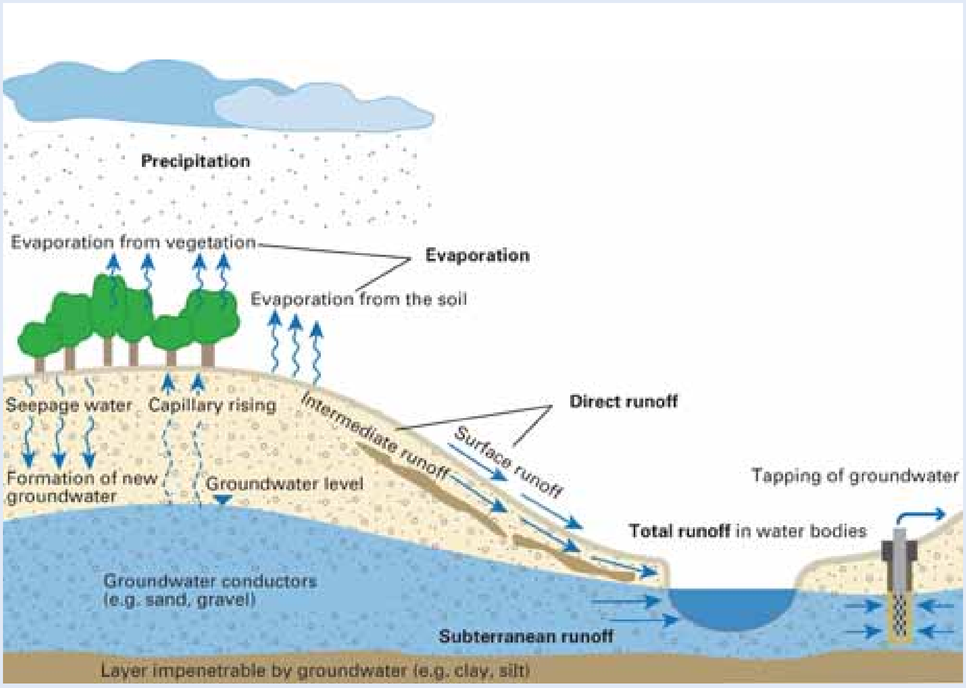
The diagram shows the deviation of the annual mean temperature from the average temperature based on the long-term mean for the period 1961 to 1990. Significant global warming became apparent in the early years of the 20th century and has speeded up considerably in recent decades.

Source: Met Office Hadley Centre, UK, and Climatic Research Unit, University of East Anglia, UK



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 that evaporates 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.




The focus of KLIWA's research: **Regional climate change**

Climate change is not a futuristic fantasy. Man-made climate change is already a reality – including here in our country. Past climate trends are evaluated by studying data from the past. The range of natural variability in weather data can be determined and trends recognised by studying time series measured over a period of several years. Data from around 400 temperature and precipitation stations in southern Germany have been evaluated as part of KLIWA with the aim of producing a consistent database regarding future climate evolution.

At the top of the Zugspitze, the retreat of the glacier resulting from global warming is clearly visible.

IT HAS BECOME HOTTER

The mean annual temperature in southern Germany rose by between 0.9 and 1.2°C in the period 1931-2010. The steepest rise in temperatures occurred in the 1990s. On average temperatures have increased more in the winter months (November to April) than in the summer months (May to October).

DREAMING OF A WHITE CHRISTMAS – CHILDHOOD MEMORIES

Milder winters generally mean less snow. Here too a clearly distinguishable trend emerges from time series measured over a number of years. Particularly in lower-lying areas (up to 300 metres above sea level) and in western parts of the country, the years from 1951/52 saw a reduction of snow cover by 30 to 40 per cent, with a 10 to 20 per cent reduction at intermediate altitudes. Only on higher ground was there actually an increase in snowfall in some areas. Above all, there have been fewer snow cover days since the beginning of the 21st century. Snow coverage is an important factor for the water cycle and has an effect on the replenishment of water bodies as well as the formation of new groundwater.

DRY SUMMERS, RAINY WINTERS

In most areas of southern Germany annual precipitation rates remained more or less constant over the period under investigation. However, the seasonal distribution of precipitation has changed. The winter months have become wetter. Precipitation in some regions has increased by up to about 30 per cent. The Black Forest and areas to the north east of Baden-Württemberg are particularly strongly affected as is Franconia and parts of the Bavarian Forest as well as the Eifel and Westerwald regions of Rhineland-Palatinate. Although the summer months continue to vary over the long term, they have become much drier on the whole, particularly in the months June to August.

CYCLONIC WESTERLY: THE WEATHER THAT BRINGS THE RAIN

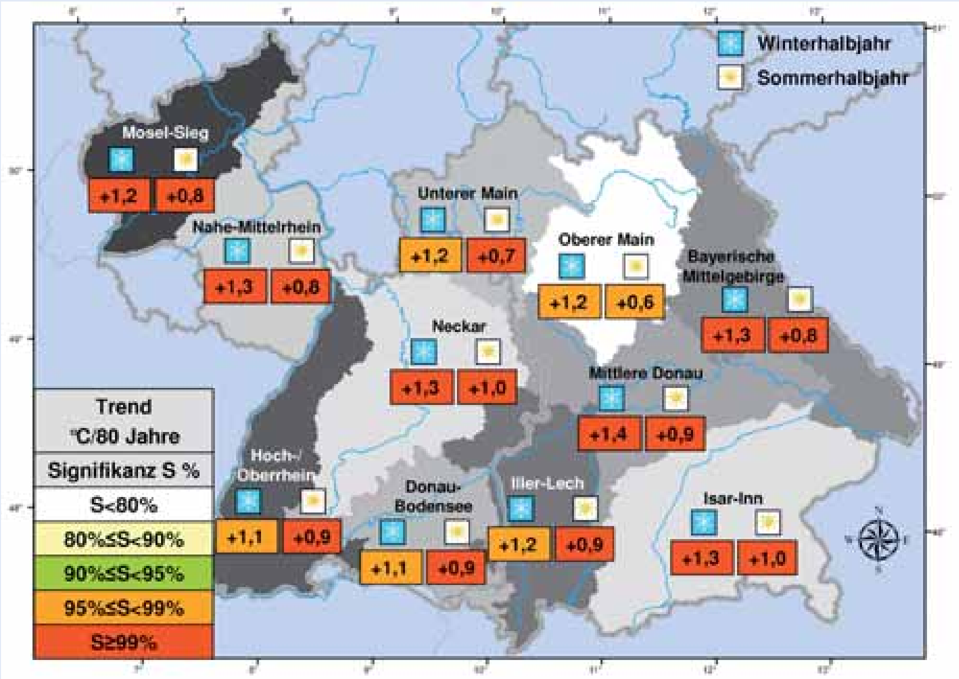
Higher precipitation rates in winter are due to the increase in certain large-scale weather patterns over Central Europe. Time series analyses dating from 1881 show that there has been an accumulation of zonal circulation patterns in the months from December to February in particular. One large-scale weather pattern which is especially significant for the water management is the 'cyclonic westerly', which is driven by high pressure in the Azores coupled with low pressure over Iceland. This current of air extends from the Atlantic to western Europe and often brings copious precipitation which – in combination with milder sea air – usually falls as rain in lowland areas. However, zonal weather patterns can also be responsible for violent winter storms. Sad examples are the storm Lothar, which wrought devastation throughout western Europe in December 1999, and more recently Kyrill and Xynthia in January 2007 and February 2010, respectively.

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 needed for further comparative observations. In this context a monitoring report is published every 5 years (last updated 2011) at **www.kliwa.de**.

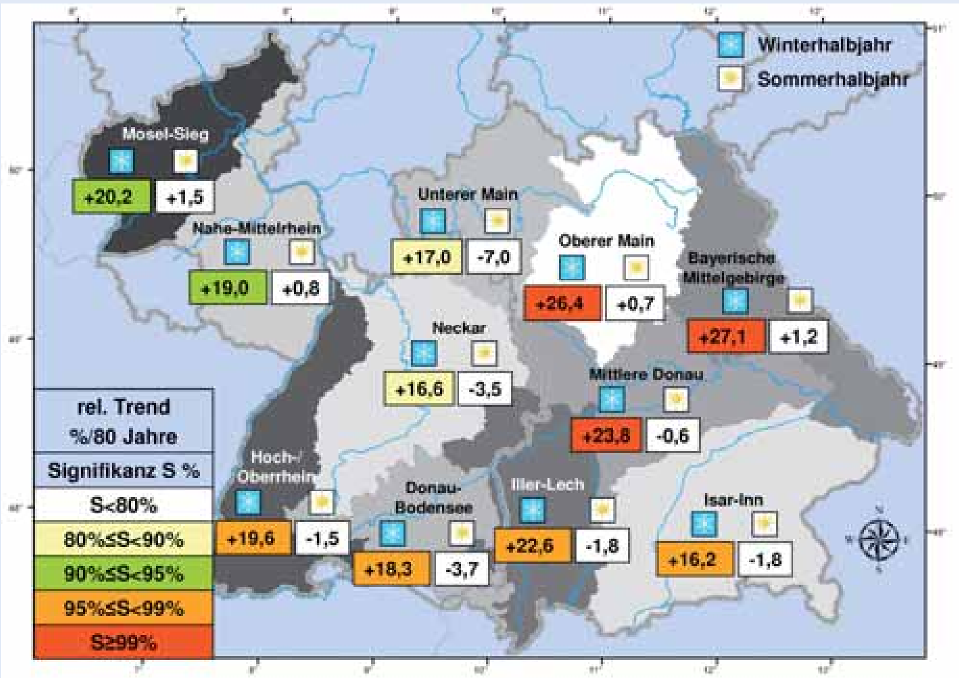
RISE IN AIR TEMPERATURE FROM 1931 TO 2010

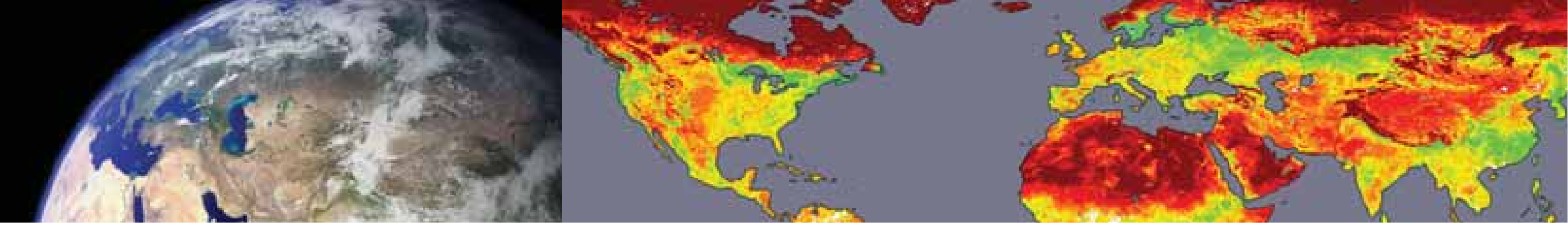
The diagram shows the change in areal mean air temperature in hydrological six-monthly periods. The rises in temperature were greater – from +1.1 to +1.4°C – in winter than in summer – +0.6 to +1.0°C – in the period 1931 to 2010.



CHANGE IN AREAL PRECIPITATION FROM 1931 TO 2010.

The diagram shows the change in areal precipitation in hydrological six-monthly periods. The figures show clear seasonal differences: in the summer half of the year there is no clear tendency, in contrast, there have been general and substantial increases in the winter months of +17 to +27% in the period 1931 to 2010.





Global and regional climate models
Instruments of climate research

There can no longer be any doubt that climate change is happening. One visible sign of global warming is the retreat of many glaciers in the Alps. Not even immediate and effective climate change mitigation action will now be able to prevent the further climate changes which are now becoming apparent: the carbon dioxide which has already been released into the atmosphere will continue to have an effect there for several decades and so continue to exacerbate global warming. Even if emissions of greenhouse gases could be reduced to zero – a utopian prospect in view of the world's insatiable energy demands – climate change would inevitably advance further. For this reason more adaptation measures need to be developed.

WEATHER AND CLIMATE

WEATHER is the momentary status of the atmosphere, but it is also influenced by the characteristics of the land surface.

CLIMATE, in contrast, describes the weather conditions which prevail over medium to large areas over longer periods of time, usually 30 years or more.

Two examples:

- Thanks to the Gulf Stream, a warm ocean current, Europe has a relatively mild climate for its latitude.
- Areas of snow and ice make the climate cooler, because they reflect sunlight.

GLOBAL CLIMATE MODELS

Weather forecasts are often difficult. It's happened to all of us: the weather forecast is for sun, but when the day comes for a planned trip, you find yourself in pouring rain. With today's resources, a reliable weather forecast is 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 have to be taken into account in computer models. How all these interacting effects work is not fully understood. Global climate models are based on an atmospheric model which is supplemented by ocean, snow, ice and vegetation models. This means that the huge number of calculations which are necessary can only be made with the help of high-performance computing resources. Anthropogenic influences (the 'human factor'), are taken into account in the form of assumptions about greenhouse gas emissions (IPCC scenarios).

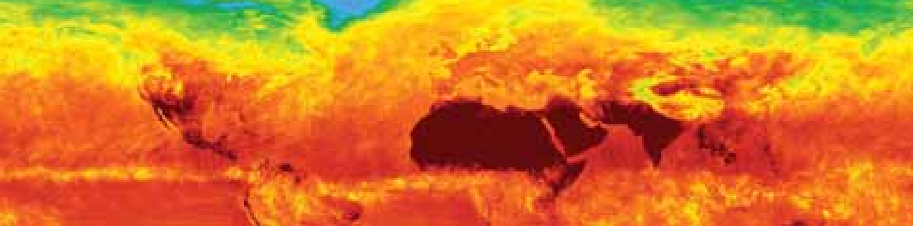
For the purposes of global climate modelling, the earth is mapped onto a grid. The computational capacities of today's computers currently allow for a grid width of around 150 kilometres. Given the uncertainties concerning the world population, economic growth, energy consumption, etc. as well as imprecision in the models themselves, temperatures and precipitation are calculated within a certain range of possible values (diagram top right). This also explains the latest figures released by the Intergovernmental Panel on Climate Change that global temperatures could rise by between 1.1 and 6.4°C by 2100.

REGIONAL CLIMATE MODELS

Global climate models are far too imprecise to be used to estimate changes in regional climates. Regional features such as mountain ranges and river valleys would not be taken into account by such models. There are various methods available, each with their strengths and weaknesses, which can be used to derive regional climate projections from global climate models with the detailed resolution that is needed.

RANGE OF REGIONAL CLIMATE PROJECTIONS

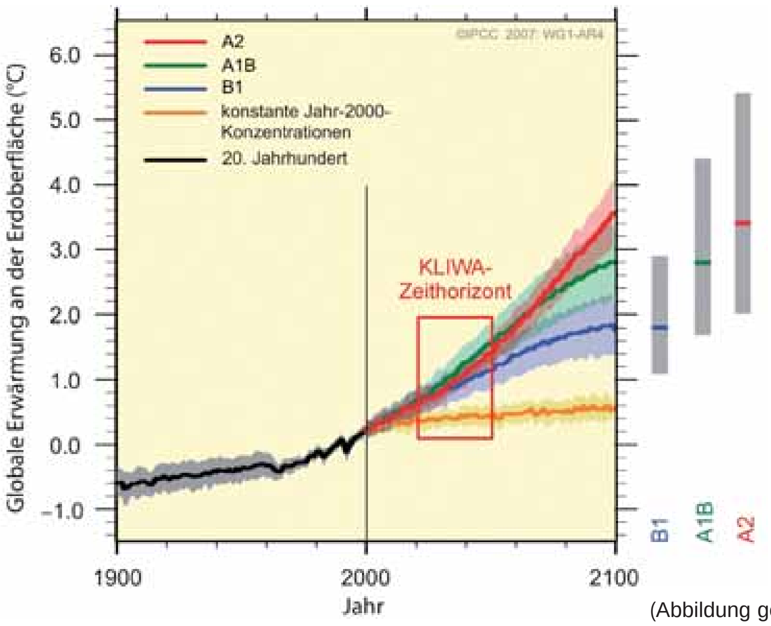
There are several different methods available, which can be applied within a model chain (see figure bottom right). Considering of a number of robust climate projections (ensemble approach) produces a range of possible future climates, the variability and uncertainties of which can then be better assessed. The selection of statistical regional projections initially used in KLIWA (WETTREG) has recently been extended to include dynamic projections (COSMO-CLM). New climate projections which are based on enhanced climate models should also soon be available. The extent to which the climate is changing can be determined by comparing actually recorded climate figures (for the period 1971-2000) with those projected for the future. KLIWA uses the near future (2021-2050) for hydrological modelling. At present the distant future (2071-2100) is considered solely on the basis of changes in climate figures.



GLOBAL WARMING ON THE EARTH'S SURFACE

Modelling results based on emission scenarios developed in 2007 by the International Panel for Climate Change (IPCC) show the possible consequences of global warming for our planet.

To date the A1B (green line) emission scenario has been used for defining the possible climatic future for the purpose of regional simulation. Scenario A1B assumes a balanced use of fossil and non-fossil energy sources in technologies of the future.



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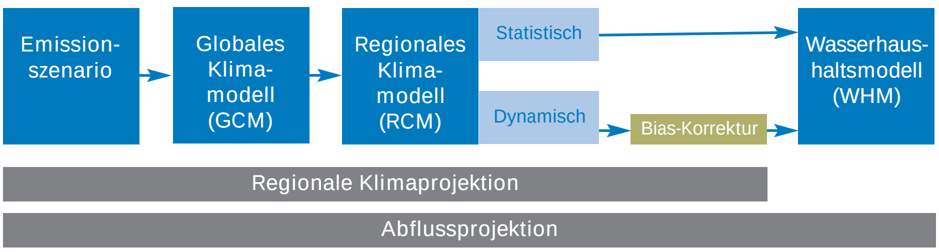
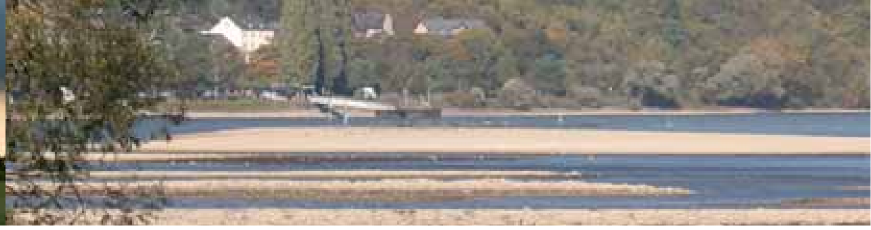
MODEL CHAIN FOR REGIONAL CLIMATE CHANGE STUDIES

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



Future simulations for our climate
Tomorrow's climate

Various climatic models are available for the simulation of future conditions. The climate projections produced by such models show a range of potentially possible temperature and precipitation values. Although the results of climate simulations for different regions for 2021-2050 differ in detail, the general trend is clear: generally hotter and wetter during the winter and drier during the summer.

As a result of climate change, apple trees will blossom up to two weeks earlier in some regions.

RATHER HOT, AND WITH LESS ICE

The regional climate simulations for southern Germany performed in the framework of the KLIWA project show that by 2050 temperatures may have increased by 0.8 to 1.7°C. The annual mean increases do, however, differ somewhat. Considerably warmer winters will be accompanied by more rain and less snow. The results of the most recent climate projections using a dynamic regional climate model are illustrated on the right. These simulation results are within the range of previous KLIWA studies.

By comparison with today, the number of summer days (days over 25 °C) will increase significantly. The number of hot days (over 30 °C) will double in almost all areas. On the other hand there will be fewer freezing days (temperature lows of 0 °C or less) and icy days (where the temperature remains below freezing point). For the most part results show that there will be only half as many icy days. The 'Ice Saints days' (cold snap in early spring) and the last late frost will occur earlier – in some regions apple trees may blossom up to two weeks earlier than at present.

WESTERLY WEATHER PATTERNS

Westerly weather patterns (especially the 'cyclonic westerlies') are responsible for high levels of precipitation today, and they will be an increasingly important factor in determining our winter weather in the future. This means an increased likelihood of floods.

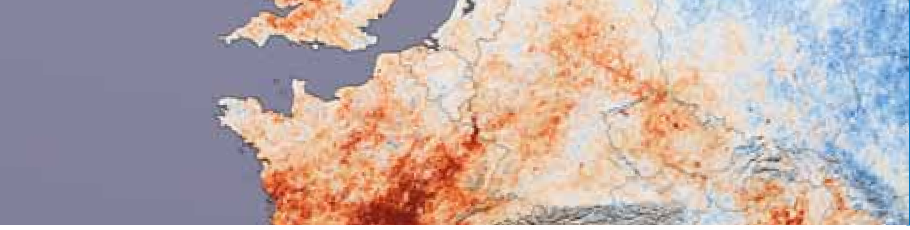
INCREASING AMOUNT OF HEAVY PRECIPITATION IN WINTER

The higher the air temperature, the higher the evaporation rate. This in turn significantly influences the hydrological cycle.

The climate simulations included in the analysis show that the trend seen hitherto, with wetter winters and drier summers, will continue. While in comparison with today there may be up to 10 per cent less rain in summer, in winter there will be a considerable increase in precipitation – in some regions up to 30 per cent. The largest amount of precipitation will occur on the orographic barriers to the west of the regions under investigation. There will also be considerably more winter days with heavy precipitation (25 mm or more); in some regions the number of such days will double. At the same time, there will be more days on which it does not rain at all and dry periods will last longer in summer. In the distant future (up to the year 2100) most climate projections show a fall in mean annual precipitation.

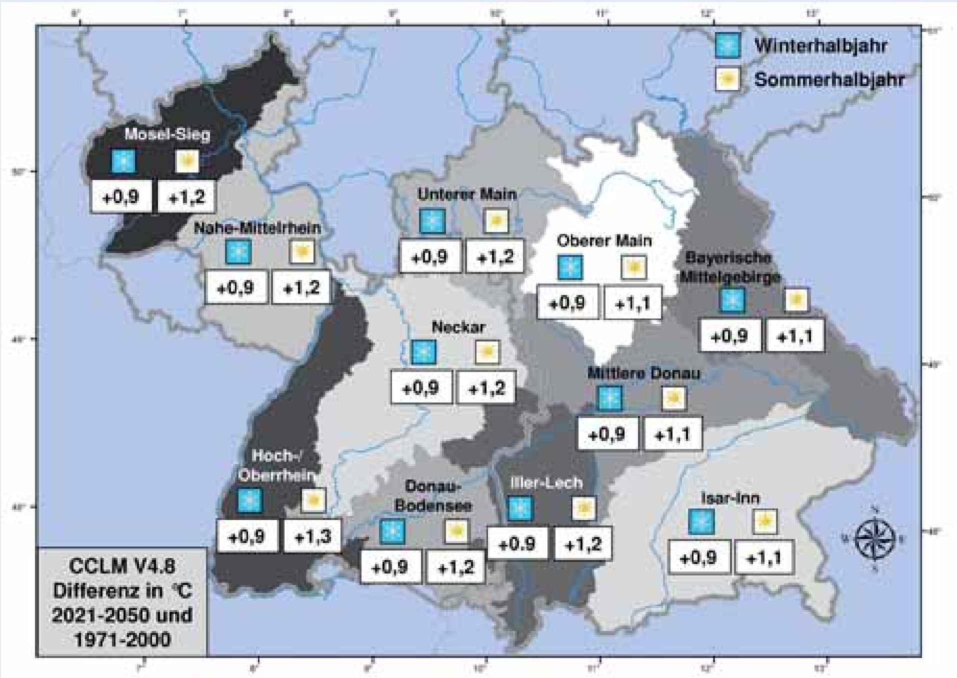
TO SUM UP: THE TREND IS SET TO CONTINUE:

- It will become generally hotter, both in summer and winter.
- Summers will be somewhat drier, winters a good deal wetter.
- Westerly weather patterns will increase, with a tendency to higher levels of precipitation. Dry weather will become more prevalent in summer.



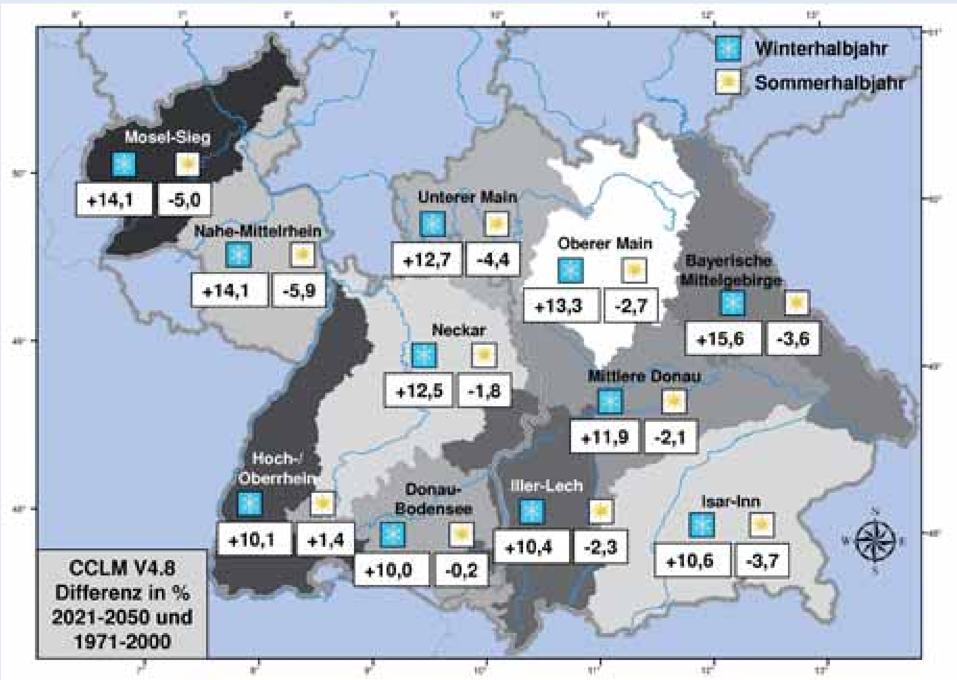
RISE IN AIR TEMPERATURE UP TO 2050

The diagram shows the change in areal mean air temperature in the period 2021-2050 compared with 1971-2000. The figures are examples of results from the CCLM Version 4.8 regional climate projection for the hydrological six-month periods. Temperatures continue to rise, whereby the change in temperature in winter is, at approximately +0.9°C, somewhat smaller than the change in summer temperature (approximately +1.2°C).



CHANGE IN AREAL PRECIPITATION UP TO 2050

The diagram shows the change in areal precipitation in the period 2021-2050 compared with 1971-2000. The figures are examples of results from the regional climate projection CCLM Version 4.8 for the hydrological six-month periods. The scale of the changes differs according to the season. The figures show substantial increases in winter of up to +15% and moderate reductions in summer of up to -6%.



Runoff simulation tools
Water balance models

Global and regional climate projections do not provide enough information on their own about the impact of global warming on water resources management. This means that it is only possible to determine runoff changes, especially the accentuation of floodwater runoff or changes in low water runoff, resulting from climate change in southern Germany if the results of regional climate models are 'fed into' water budgeting models that have a high degree of resolution.

With increasingly mild winters, there is a greater danger of flooding in the south of Germany, especially in the winter months.

ON A FINE SCALE – THE WATER BALANCE MODEL TOOLBOX

Water budgeting models are currently the favoured means of quantifying the impact of climate change on runoff. Quantification of the anticipated changes is a prerequisite for the conception and evaluation of adaptation measures. Water balance models serve to calculate the spatial and temporal distribution of essential components of the water cycle – such as precipitation, evaporation, infiltration, water storage and runoff. They help us to show and assess the effects of changes on the entire system that the water cycle represents.

Water balance models use a fine grid (diagram top right) to, amongst other things, describe the following hydrological processes: evaporation, snow accumulation, compaction and melting, soil water storage, flow patterns in bodies of water and retention of water in lakes.

Uncertainties in individual models in the global model > regional model > water balance model chain ultimately produce a range of potential changes.

Possible applications of water balance models:

- Estimate of the effects of environmental change, especially climate change or changes in land use, on the water cycle, with implications for runoff, infiltration and evaporation.
- Continuous runoff predictions for low water, medium water levels and flooding as a basis for operations – e.g. so as to improve low water management and flood precautions (flood predictions and early warning systems).
- Regional hydrological studies for river basins, in accordance with the requirements of the EC Water Framework Directive.
- Provision of hydrological input variables for water quality and groundwater models (with implications for the heat and oxygen budget, groundwater flow and transport, etc.).

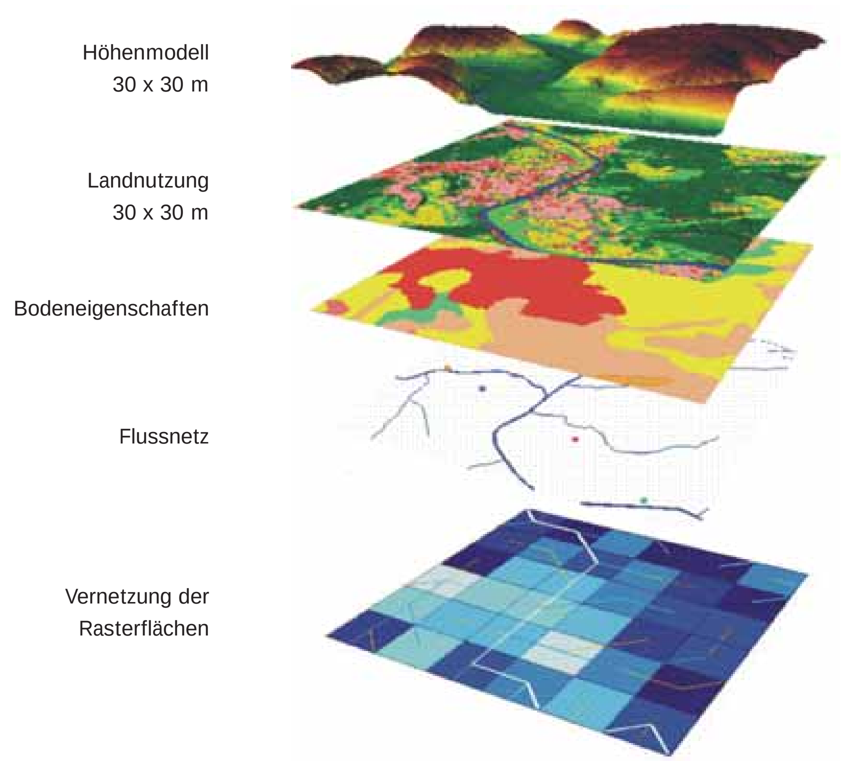
RIVER BASINS IN GRID FORMAT

Water balance models on a 1 x 1 km grid have been set up for KLIWA's river basins to estimate the effect of climate change on the water cycle. For KLIWA, the initial aim of the modelling was to investigate the expected climate-induced increased danger of flooding.

Today the emphasis is on the investigation of low water conditions. For this purpose the daily runoff from KLIWA's river basins, present and future, is being computed (diagram bottom right). This approach is supplemented by special soil water models that serve to determine the rate of groundwater replenishment.

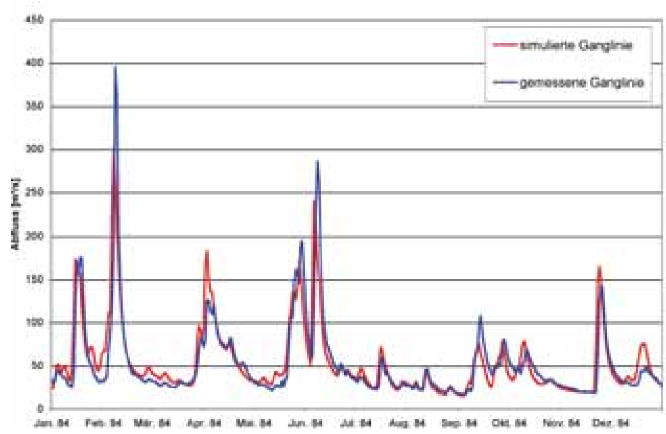
DATA BASIS FOR WATER BALANCE MODELS

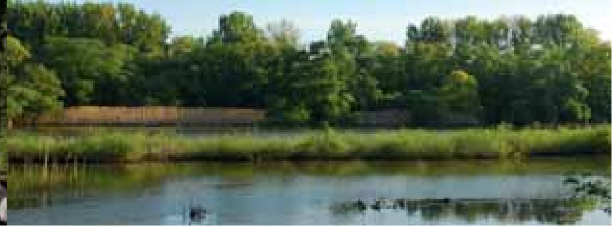
Water balance models (WBMs) are created using extensive digital data records (e.g. digital elevation models, satellite classification of land use, soil properties and riverine networks). For each separate WBM grid square, up to 16 different land uses are computed, each with its specific evaporation and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



FINDINGS FROM WATER BUDGETING MODELLING

Comparison of a measured time series for river discharge with simulated data calculated using a water balance model, for a selected gauging station for the year 1984.





Our most important drinking water reservoir **Groundwater**

In the south of Germany about 80 per cent of our drinking water comes from subterranean groundwater reserves. The impact of climate change on groundwater resources is therefore an especially important water management issue. It is essential that supplies of drinking water are secured for the future despite changing climatic conditions.

Springs are bubbling, and groundwater reserves are still being generously replenished.

FIRST CHANGES OBSERVED IN MEASUREMENT DATA

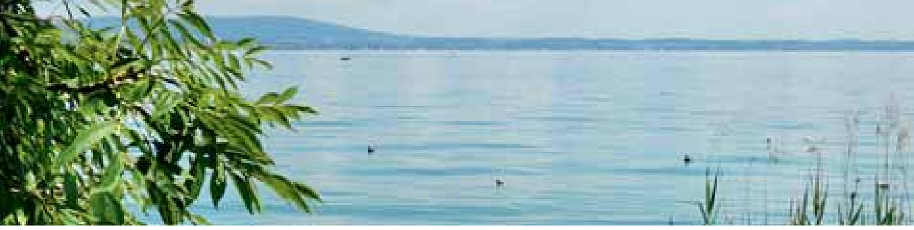
Groundwater levels and the discharge from springs have been under observation for several decades already – in some cases, readings go back over a century. Serial data obtained at observation points yield information about the long-term development of groundwater reserves and spring discharge. Systematic evaluation of selected time series for the most important groundwater aquifers in Baden-Württemberg, Bavaria and Rhineland-Palatinate shows that changes in annual patterns have already taken place in many cases. For example, the annual maximum of the groundwater level now occurs earlier in the year than indicated by the historic record mentioned above– this is a direct consequence of changes in annual temperature patterns and precipitation levels. In many cases, there is also an increase in the range between minimum and maximum values for the year.

GROUNDWATER RECHARGING

Changes in the annual distribution of precipitation – with less rain in summer and higher precipitation in the winter months – will have significant effects on the soil moisture regime. In summer there will be less infiltrating water, in winter there will be more than in the past. Accordingly, in the future, there will be less water available in the soil during the vegetation period (top right). This is reflected in an increase in the drought index for the three federal states of almost 14 days per year in the period 2021-2050.
Baden-Württemberg and Bavaria currently have an annual mean groundwater recharge of just over 200 mm, Rhineland-Palatinate of 100 mm. For comparison: Mean total precipitation in Baden-Württemberg is around 960 mm, in Bavaria about 930 mm and in Rhineland-Palatinate 780 mm. In contrast to the drought index, the average annual groundwater recharge for the period 2021-2050 is not expected to change substantially. The soil moisture regime calculated on basis of the WETTREG 2006 (ECHAM5/A1B) climate scenario produce a slight increase in groundwater recharge in Rhineland-Palatinate of up to 15 mm/a, whereas in Baden-Württemberg and Bavaria there will be reductions of up to 30 mm/a.

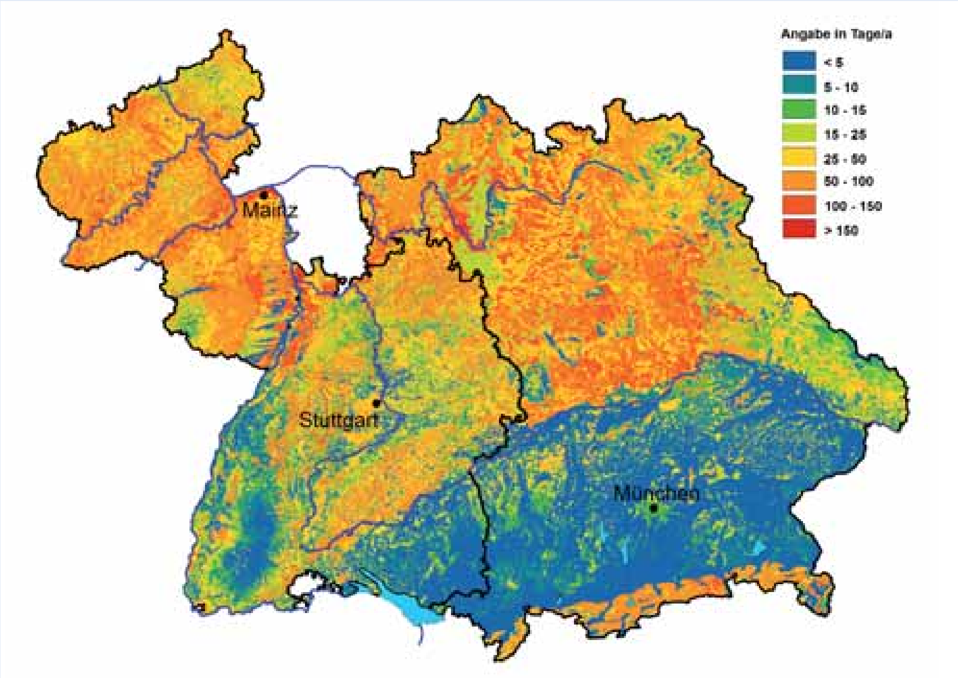
RECOMMENDATIONS FOR ACTION

The basis for sustainable groundwater management is the regular observation of groundwater quantity and quality. It is essential, therefore, that the observation network is consistently maintained to monitor the impact of climate change. Even today, extended droughts in summer may result in spatially and temporally restricted water shortages. Efforts to avoid potential water shortages will need to include regional and super-regional networking solutions to strengthen the resilience of the water-supply infrastructure. More efficient methods of calculating irrigation requirements are also needed for agricultural use. As well as extended periods of drought in summer, we can also expect to see longer periods with heavy precipitation in the future, especially during the winter. This may lead to higher groundwater levels locally. This must be taken into account when planning development areas, particularly when water saturation represents a potential hazard.



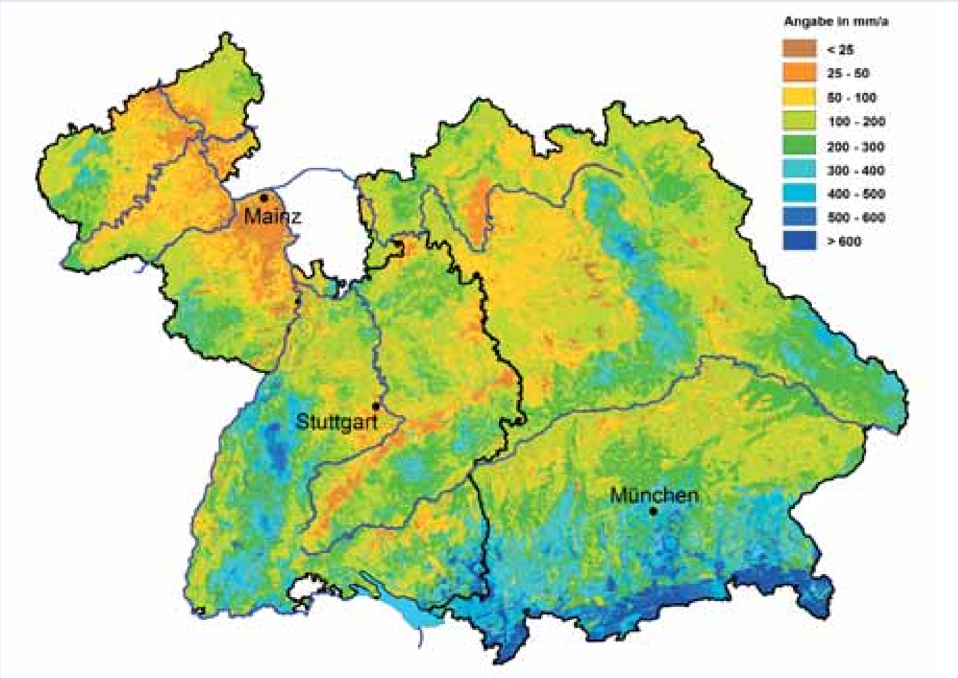
MEAN ANNUAL DROUGHT INDEX TODAY (1971-2000)

In KLIWA, the drought index for the period 1971 to 2000 was calculated for the investigation area with a soil water model. The drought index describes the duration of periods in which soil water content is less than 30% of the storage capacity. No infiltration takes place during this period and vegetation suffers from excessively dry conditions.



MEAN ANNUAL GROUNDWATER RECHARGE FROM PRECIPITATION TODAY (1971-2000)

Groundwater recharge is of utmost importance for water management and is an important measure of the natural regenerative capacity of groundwater resources. In KLIWA, the formation of new groundwater in the period 1971-2000 was calculated for the investigation area using a soil water model.



More frequent and longer lasting drought
Low water

The drier and hotter summers to be expected in future will mean lower water levels. These low water phases will not only mean difficulties for inland waterway shipping, but will also bring problems for agriculture, the energy industry and the supply of drinking water. The economic consequences are potentially severe: The persistent drought period in 2003, for example, inflicted higher economic costs on Germany than recent catastrophic floods along the Rhine, Oder and Elbe. Drought conditions not only affect water management, they also impinge on flora and fauna and have an extensive impact on low water levels.

Long periods of drought desiccate the soil and mean loss of harvests.

FALLING WATER LEVELS DESPITE EXTREME WEATHER CONDITIONS

Climate change and global warming lead to an intensification of hydrological cycles and to more frequent extreme weather events. These changes must be reflected in the way water resources are managed: drought periods (such as the hot summer of 2003, when streams and small rivers dried up, inland waterway shipping ground to a halt in some places and groundwater levels dropped severely) are accompanied by floods caused by persistent heavy rain.

LESS RAIN AND MORE EVAPORATION = LESS RUNOFF IN SUMMER

Climate models predict increased precipitation during the winter and lower precipitation in the summer – the precipitation regime throughout the year is undergoing a process of change. At the same time, evaporation will increase as a result of the higher air temperature. The likelihood of serious drought occurring in southern Germany, for example, has increased significantly since 1985.

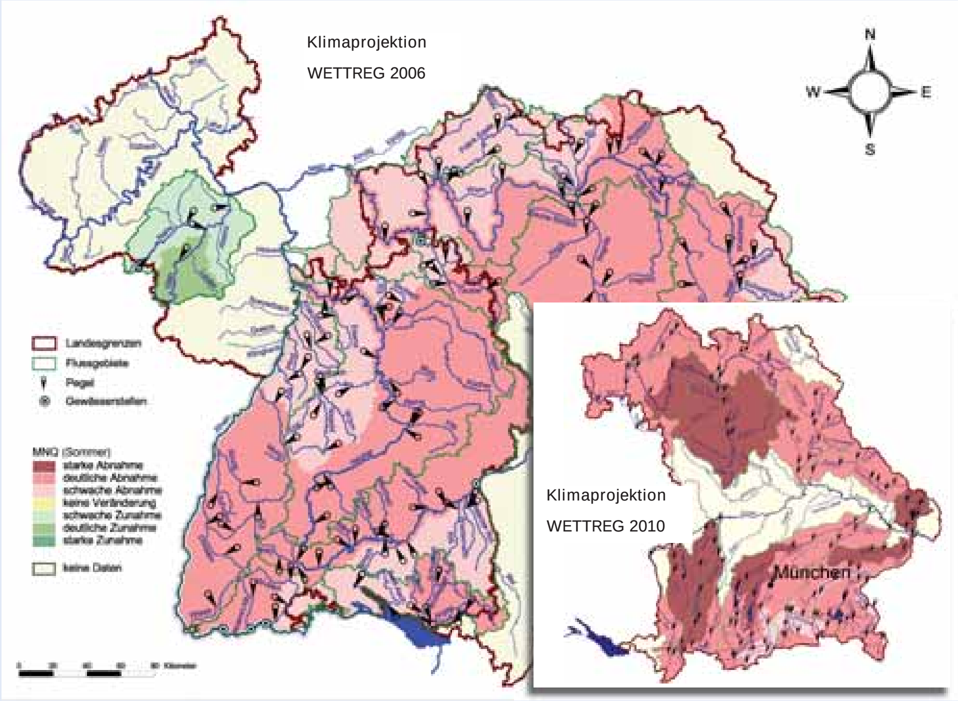
Available runoff simulations show a significant decrease in mean monthly low water discharge from June to November in the river basins studied in southern Germany. The medium decrease in many catchments is greater than 10 per cent. The only area in which an increase in runoff is found is in the catchment area of the Nahe (Rhineland-Palatinate). Nonetheless, there is a clear and general tendency towards lower runoff (above right). The sharpest decline is likely to be found in the autumn months from September to November. With 21 per cent less low water discharge in the month of September, the decline is most marked in the tributaries to the Rhine in the southeast and southwest of Baden-Württemberg (diagram bottom right). The annual low water discharges for the Rhine River itself tend to be higher in the future scenario. This means that, as things currently stand, no increase in mean low water discharges is expected from the water level of the Rhine up until 2050. The next step is to investigate extreme low water discharges. In most regions low water periods will last longer; south of a line drawn between Karlsruhe and Coburg up to 50 per cent longer and to the north of this line (including the Nahe catchment area) 25 to 50 per cent longer. Experts believe that the reason lies in the greater frequency of large scale dry weather systems over wide geographical areas.

WORST CASE NOT COVERED

The runoff simulations show that low water conditions are strongly influenced by future changes in mean air temperatures and precipitation. Regional climate projections may, however, vary widely (between 1.0 and 1.8°C) depending on the emission scenario and climate model used. Low water discharges and periods could therefore actually turn out very much worse than predicted. One of KLIWA's tasks is therefore to estimate future low water developments and to produce appropriate proposals for adaptation measures.

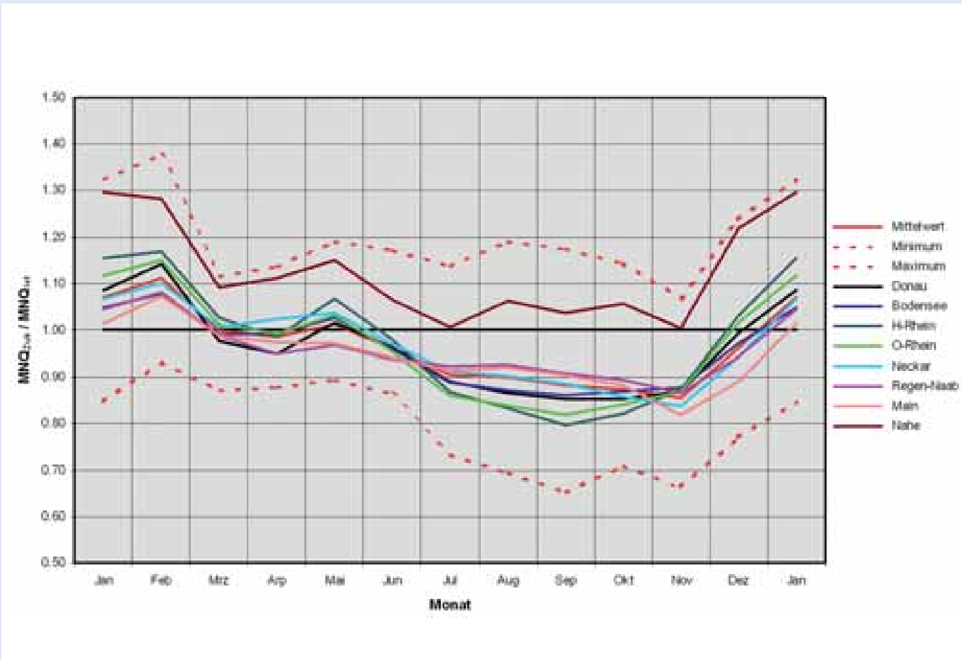
FUTURE CHANGES IN LOW WATER DISCHARGES DURING THE SUMMER

The two maps show the geographical distribution of the anticipated changes in mean low water discharge (MNQ/MLQ) for the summer period of June to November, derived from the monthly low water discharge levels for the river basins under investigation. The various colours illustrate the percentage change in the period 2021-2050 compared with 1971-2000. The results are from two different climate projections: the results for the map on the 'left' are based on the WETTREG 2006 model and those for the map on the 'right' on the WETTREG 2010 model for Bavaria.



ANNUAL PATTERNS OF LOW WATER DISCHARGE

The diagram shows the changes in mean monthly low water discharge in various river catchments as well as the mean value for all gauging stations included in the study and the minimum and maximum changes calculated. The diagram shows the percentage change in the monthly mean values in the period 2021-2050 compared with the period 1971-2000. The results are based on the WETTREG 2006 climate projection.



„Flexible and no regret“strategy
Flooding

Even if the chain leading from the global model to the regional model and thence to the water balance model is subject to uncertainty, the findings nonetheless indicate that we can expect to see more flood events in future. A flood response strategy has therefore been developed as a precautionary measure. In this context adaptation does not mean building new metre-high river embankments everywhere. Instead measures need to be developed which mitigate the expected impact of climate change – measures that will be effective in the long term and that can be modified at relatively low cost. Flood prevention measures have a particularly important part to play in this respect.

FLOOD PROTECTION – WHAT DOES IT MEAN IN PRACTICE?

Example, flood embankment:
The embankment is built as originally planned, but a strip on the outside is left clear to allow the dam to be broadened and raised in the future if necessary.

Example, bridge:
The regional climate factor will be taken into account in the planning of a bridge from the very start as subsequent adaptation is often impossible for technical reasons.

Example, retaining wall:
The statics of a new retaining wall have been designed in such a way that there will be no difficulty if additional height is needed in future.

THE CLIMATE CHANGE FACTOR

The planning of flood protection facilities is generally based on the HQ100 value. HQ100 is the flood discharge which statistically speaking will be exceeded just once in 100 years. This means that embankments constructed in accordance with this value should be able to cope with a ‘flood of the century’. Simulations based on water balance models for the river basins of Baden-Württemberg and Bavaria show that flood discharge levels are likely to increase almost universally, especially in winter. For this reason both federal states have decided – as a precautionary measure - that plans for new flood protection facilities must include a climate change factor to take into account the effects of climate change. The simulation for the Neckar, for example, is based on a discharge for a 100-year flood (HQ100) which will rise by 15 per cent between now and 2050. This means that the HQ100 value must now be multiplied by a climate change factor of 1.15 – in other words, the flood protection systems must in future be designed to cope with a 15 per cent higher discharge than today’s values indicate, or at least planned in such a way that they can be adapted to meet heightened requirements.

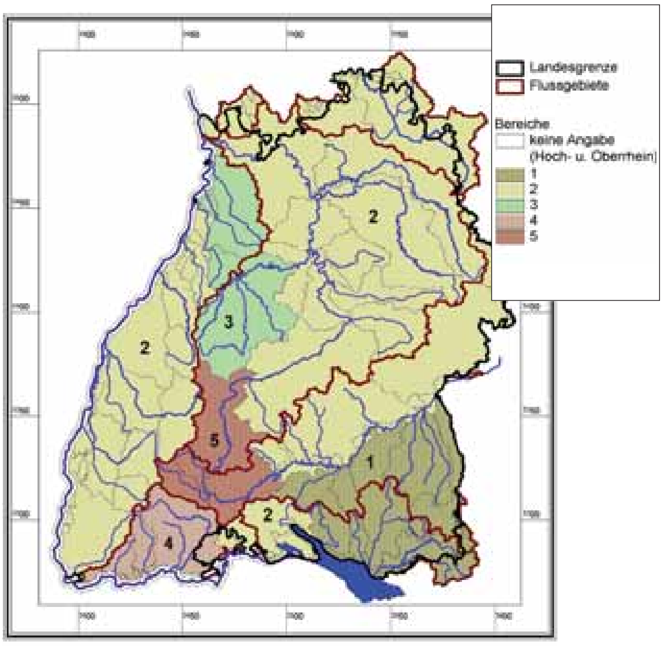
DIFFERENT CLIMATIC CONSEQUENCES AND CLIMATE CHANGE FACTORS

All the river catchments in Baden-Württemberg have now been very carefully scrutinised. Regional climate change differences have consequences in terms of expected flood discharges (see image top right). A climate change factor of 1.25 has been determined for the Upper Danube area, for example. Smaller floods, and floods of moderate severity, can also be 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 will have to 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 has also been introduced in Bavaria based on the earlier WETTREG 2003 study findings – here the statistical value of HQ100 is increased by 15 per cent right across the board. On this basis the expected effects of climate change are already being taken into account in the planning of new flood protection measures. The fundamental data underlying the climate change factor are still subject to refinement and further research. This may lead to regional fine tuning in future.

In Rhineland-Palatinate flood protection measures are always planned according to the actual peripheral conditions 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. The studies for the ‘special case of the Upper Rhine’ will be followed up by runoff studies for the whole of Rhineland-Palatinate and the Middle Rhine which should show whether further adaptation measures are required in Rhineland-Palatinate.

KLIMAANDERUNGSFAKTOREN IN BADEN-WURTTEMBERG



Klimaänderungsfaktoren $f_{(T,K)}$

T (Jahre)	1	2	3	4	5
2	1,25	1,50	1,75	1,50	1,75
5	1,24	1,45	1,65	1,45	1,67
10	1,23	1,40	1,55	1,43	1,60
20	1,21	1,33	1,42	1,40	1,50
50	1,18	1,23	1,25	1,31	1,35
100	1,15	1,15	1,15	1,25	1,25
200	1,12	1,08	1,07	1,18	1,15
500	1,06	1,03	1,00	1,08	1,05
1000	1,00	1,00	1,00	1,00	1,00

Bemerkung: Für Jährlichkeiten T>1000 a ist der Faktor gleich 1,0

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 serves to prevent breaching of flood protection barriers (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 incoming runoff 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 runoff studies performed as part of KLIWA. Robust climate projections are now available for the entire Rhine catchment area – including Switzerland – as well as suitable water budgeting/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 (watershed area of approximately 69,000 km²).
The flow of water down the Rhine as far as Worms is influenced particularly strongly by the runoff in the Swiss Alps as well as the seasonal cycle of snow build up and thawing. As a result the largest volumes of water occur in the hydrological summer half-year from May to October.
Initial 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 flows. With the exceptions of the months of May and October, results even show a slight decrease in mean flood flow volumes for the summer half-year, during which the highest discharges occur. In the winter from November to April increases of less than 10% are simulated. This means that, as things currently stand, no increases in mean flood flows are expected for the water level of the Rhine up to 2050. The next step is to examine potential changes in extreme flood flows.

When it rains it pours
Heavy rainfall

Rising temperatures and increasing evaporation are accentuating the atmospheric hydrological cycle. As a result, more frequent heavy rainfall may be anticipated. Intense localised rainfall events are more and more frequently exceeding the capacity of drainage systems in built-up areas. They also lead to more intensive soil erosion on unprotected farmland. Owing to the lack of available measurements, these changes can currently only be estimated by modelling.

Durch Starkregen überlastete Kanalisation (Quelle: itwh)

URBAN DRAINAGE

Rain water which does not seep into the soil or flow into surface waters in the vicinity of a built-up area is directed into drainage systems installed in developed areas. Urban drainage problems occur when very heavy precipitation events or sudden downpours pose a threat of flooding. The evidence is that such events are occurring more frequently and more intensively at the regional level. There are, however, no long-term and representative all-encompassing records.

However, using the extended simulation method which is applied as standard in planning practice it is possible to produce very precise statements about the way canal systems will cope under future climate conditions. Artificial precipitation patterns are required for this purpose and can be generated with the NiedSim computer programme which is used by KLIWA partners.

The latest version of NiedSim-Klima takes account of the most recently available findings from climate research. This means that precipitation patterns can be produced which are representative for climate conditions for any number of years up to 2050. New findings will be integrated in NiedSim-Klima as soon as they are produced by climate research.

Local authorities are already carrying out comparative studies on the performance of their drainage systems in the years 2010, 2030 and 2050. In addition, fundamental investigations should also be undertaken to produce general statements about the anticipated impact of climate change on water management in built-up areas.

LOSING THE GROUND UNDER OUR FEET

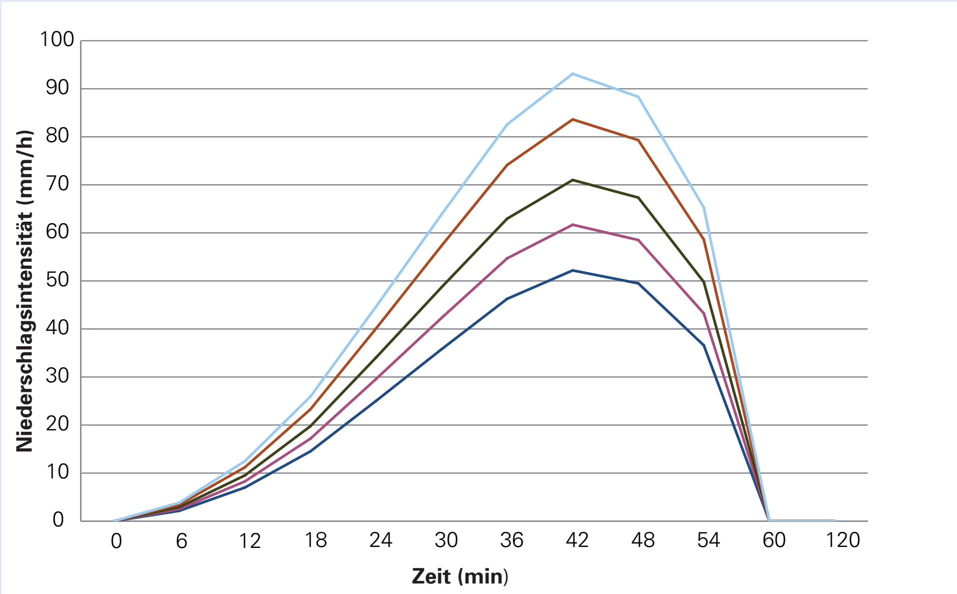
One-off, intensive precipitation, such as a thunderstorm, can not only flood cellars and streets, but can also cause huge erosion damage to unprotected fallow land or vegetation-free land. This not only results in the loss of fertile soil, damage also extends beyond the actual eroded area to cause muddied paths and streets. Bearing this in mind, one KLIWA subproject focuses on the future risk of erosion due to heavy rainfall.

CLIMATE AND EROSION MODELLING

In order to estimate the future risk of erosion a regional climate model is linked up to a soil erosion model. The precipitation data at very high temporal and spatial resolutions which are needed for this purpose are delivered by the COSMO-CLM regional climate model. A ‘nesting’ procedure involves using lower resolution model data as the boundary condition for the higher resolution of the regional climate model. This means that single bursts of heavy precipitation can be simulated at a target resolution of 1 x 1 km and 15 minutes. These precipitation records are then used as input parameters for the LISEM (Limburg Soil Erosion Model) physical erosion model which is used to calculate the amount of soil erosion and water discharge in selected, erosion prone areas.

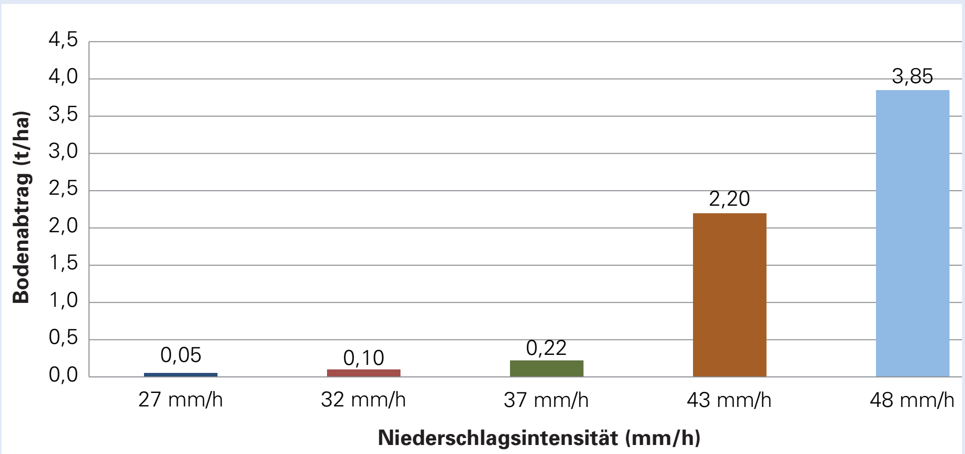
ONE-HOUR STAGE PRECIPITATION HYDROGRAPH FOR DIFFERENT RETURN PERIODS (5 TO 100 YEARS)

In addition to the input parameters for relief, soils and vegetation, the LISEM erosion model also requires data for precipitation duration and intensity. The KOSTRA Atlas (DWD, 2005) is used to generate precipitation hydrographs which then provide input parameters for LISEM. This enables studies to be made of the precipitation intensity at which the amount of soil erosion significantly increases.



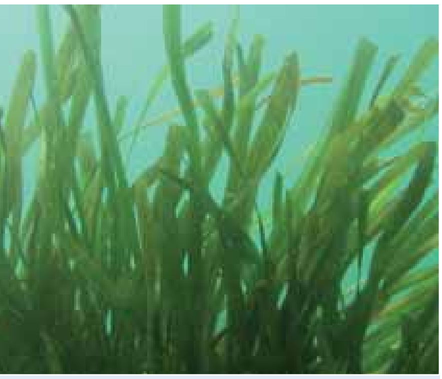
SOIL EROSION MODELLED WITH LISEM USING KOSTRA DATA IN A TYPICAL LOESS SOIL AREA

The illustration clearly shows that at a precipitation intensity of 37 mm/h and higher, the amount of soil erosion increases sharply. Although precipitation intensity only increases by 16% to 43 mm/h, soil erosion increases tenfold. The KLIWA subproject will look more closely at the extent to which there will be an increase in critical heavy rainfall in the future.



Impact on water quality
Aquatic ecosystems

Climate change affects inland waters and the animal and plant life in and around them. Rising temperatures and falling runoff or water levels have a negative impact on the oxygen balance and change the composition of biotic communities. This could have an enduringly negative impact on the good status of our waters. But what has actually changed and what changes can we expect in the future? The complex and multilayered interactions between water characteristics and ecological systems as well as the relative paucity of relevant data make it very difficult to answer this question.



TAPE GRASS

Tape or eel grass (Vallisneria spiralis) is an invasive aquarium plant in southern Germany which originates in tropical and sub-tropical regions. It is regarded as a potential beneficiary of global warming. Large stands of tape grass have now formed on the Mosel and are displacing native bur reed in some places.

KLIWA study
www.fliessgewaesserbiologie.de

GETTING INTO WARMER WATER

If the air gets warmer, so will streams, rivers and lakes. Changes in precipitation will result in different levels of runoff. However, it is not only freshwater ecology which will have to adjust. The many diverse and extensive water uses will also be affected. The water used as coolant in power stations will become too warm, for example, and will no longer serve its purpose as efficiently.

MULTIPLE INFLUENCES ON WATER ECOLOGY

Climate change will impact fundamental factors in streams, rivers and lakes, such as water temperature, discharge conditions, the build up of fine sediments or the concentration of nutrients. This sets off a chain of events which ultimately impacts aquatic flora and fauna: some species become increasingly rare or disappear altogether, while others become invasive. Biotic communities and the functionality of aquatic ecosystems change. While it is already possible to model the impact of climate change on water resources in southern Germany comprehensively, for the whole region, changes in water ecology have only been studied in smaller areas to date. There is evidence, for example, that biotic communities may be tending to move upstream in rivers and streams water.
A literature study commissioned by KLIWA, which focuses on rivers and streams in southern Germany, uses causal chain analysis to illustrate the impact of climate change on water quality at the regional scale for the three federal states of Bavaria, Baden-Württemberg and Rhineland-Palatinate. The study, with its extensive literature and sensitivity analysis, demonstrates that changes in the water quality of rivers and streams may be expected in many areas in the future, but at the same time also reveals many areas in which there are still significant knowledge gaps.

INTO THE FUTURE WITH MONITORING

It is not as yet possible to say just what influence climate change will have on the quality of our inland waters. In order to obtain robust data in this field, the latest monitoring report on flowing waters will be reviewed and appropriate evaluation procedures and methods developed.
What are the most important indicators? How often and for which water bodies will they have to be determined? The answers to these questions will provide a basis on which to address many issues in the future and to find and define appropriate adaptation measures.

INVASIVE SPECIES – BENEFICIARIES OF CLIMATE CHANGE?

Invasive species are flora or fauna which have migrated into a particular habitat owing to the direct or indirect influence of human beings. Many new species have appeared in Germany in the last two decades in particular. This phenomenon is mainly ascribable to the connections between rivers systems created by navigable channels. Many invasive species can tolerate changes in temperature, eutrophication as well as salination and therefore benefit indirectly from global warming. Thirty of these species are described in detail in a KLIWA study.

COMPLEX ECOSYSTEMS

Global warming is raising the temperature of water in cool streams and altering seasonal discharge patterns. Altered snow cover, increased heavy rainfall or long periods of drought during the summer are even in the process of changing the very nature of river beds and microhabitats. This can seriously disturb ecosystems in streams.

Future prospects / Outlook

In the future we can expect hotter/warmer and drier summers as well as milder and wetter winters. The change in the distribution of precipitation will have corresponding effects 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 concrete measures for dealing with these. Studies of the impacts on runoff in the Rhine and Danube are currently underway. The main emphasis of the investigations has now also shifted to the effects of climate change on low water discharge and the status of groundwater. Changes to the water cycle have direct consequences for the use of our water resources – 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. This is linked to the question of the effects of climate change on the quality and ecological status of our waters - currently a principal area of interest for the work in progress.

The focus will also be on the anticipated increase in heavy precipitation (thunderstorms). This heavy rainfall can cause local flooding or serious damage to agriculture as a result of soil erosion and implies additional challenges for the protection of the soil. This presents increasing problems for municipal drainage networks. As estimates of the consequences of climate change are based on data determined by means of climate models, it is essential to go on refining these models so as to minimise the factor of uncertainty. This is another area where KLIWA will be able to make its contribution.

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. The reduction of greenhouse gas emissions must be a top priority here. 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 still go on rising in the immediate future. Therefore each and every one of us must do what we can – otherwise future generations will be confronted with even more serious problems.

Climate change is the biggest challenge facing humanity today – and it affects us all. ■