Strategy for the IRBD Rhine for adapting to climate change

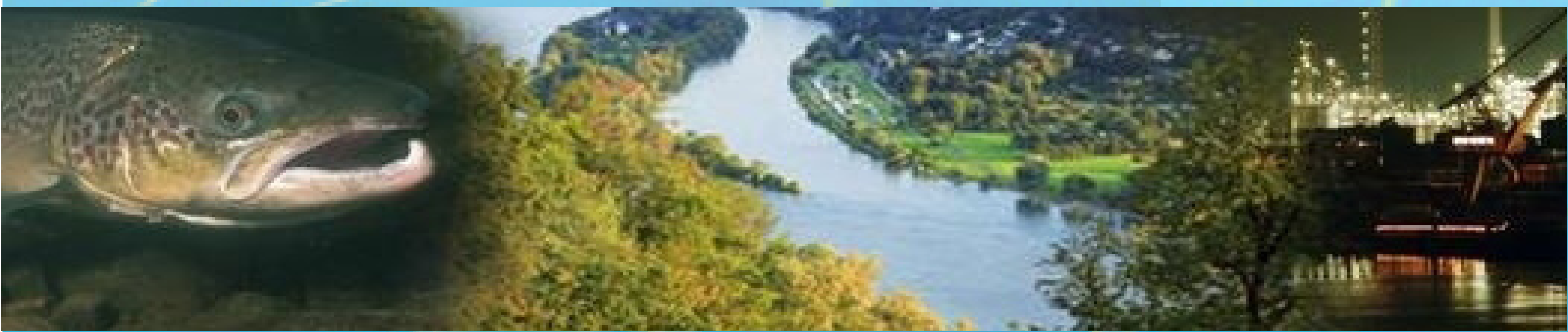
IKSR
CIPR
ICBR

Internationale Kommission zum Schutz des Rheins

Commission Internationale pour la Protection du Rhin

Internationale Commissie ter Bescherming van de Rijn

Report No. 219



Imprint

Publisher:
International Commission for the Protection of the Rhine (ICPR)
Kaiserin-Augusta-Anlagen 15, D 56068 Koblenz
P.O. box 20 02 53, D 56002 Koblenz
Telephone +49-(0)261-94252-0, Fax +49-(0)261-94252-52
Email: sekretariat@iksr.de
www.iksr.org

ISBN 978-3-941994-78-2

Strategy for the IRBD Rhine for adapting to climate change

Note to the reader

This is a "living document" which will develop along with the increased knowledge on the climate change and its effects.

Contents

Summary and future key activities

- **Initial conditions**

In the Rhine catchment, considerable knowledge is available on the effects of climate change observed during the 20th century on the discharge pattern of the Rhine and the development of water temperatures since 1978. Furthermore, during the last years, and based on climate projections, water gauge related simulations of the development of the water balance and the water temperature in the river basin Rhine have been drafted for the near future (until 2050) and the distant future (2100).

According to these projections, the development until 2050 is characterized by a continuous rise in temperatures which, for the period 2021 to 2050, compared to the period 1961-1990, will amount to an average of +1 to +2 °C for the entire Rhine catchment.

For the winter, a moderate increase in precipitation is projected until 2050. Increased precipitation during the winter which, due to higher temperatures, will more often occur as rainfall than as snowfall, may lead to a moderate increase of medium and low flows and, downstream of Kaub, of flood runoff.

Projections for the summer do not indicate any clear trend for precipitation until 2050. Compared to today's situation, runoff in summer will remain more or less unchanged.

Due to rising air temperatures, the results of the model chains considered seem to indicate that floods and extreme events will occur more often in the river basin district, that is, that the water balance will distinctly change, and this development might become more marked towards the end of the 21st century. Also, higher air temperatures (a rise by +2 °C to +4 °C is projected for 2100) will lead to higher water temperatures.

The direction of change for the **water balance**, which, in the near future (until 2050) will partly still be moderate, becomes clear when considering what is expected for the end of this century:

a. during the hydrologic winter:

- Increased precipitation in winter
- Increased discharge
- Early melting of snow/ice/permafrost, shift of the line of snowfall

b. during the hydrologic summer:

- Decreasing precipitation (but possibly more often heavy rainfall in summer)
- Decreasing discharges
- Increasing periods of low flow.

c. Increase of smaller to medium floods, increase of peak flows of rare floods seem to be possible, but their extent cannot be quantified beyond doubt.

Simulations for the near future indicate that, compared to the reference situation and in periods of low flow (Qmin), the number of days with **water temperatures** above 25 °C will increase up to the double. In the distant future, there will be a strong rise in the number of days with temperatures above 25 °C. For the distant future, this is also true of temperatures above 28 °C.

It is necessary to adapt water management to these possible effects of climate change. These measures must be considered in connection with climate change adaptation measures of other sectors and their possible interactions.

Further elements in connection with flood prevention are listed in the first flood risk management plan, IRBD Rhine, Part A, and, in connection with low flows, in the second management plan for the IRBD Rhine, Part A.

Surveillance and periodic review of knowledge

A basic requirement for recording future water management changes is to continue to intensively monitor discharge, water temperature and (chemical and biological) water quality in the IRBD Rhine. If necessary, monitoring programmes and monitoring networks must be adapted.

Today's knowledge of changes in the IRBD Rhine caused by climate change based on different studies of scenarios must be updated to eventual new findings. This should be done, when new IPCC findings are available and in compliance with the 6-years cycles of the implementation of the EU Directive (2021, 2027) in the river basin districts.

- **Possibilities to adapt to the expected effects of climate change in the international river basin district (IRBD) Rhine**

Water management adaptation measures should be targeted at granting the basic functions of protection and use of water bodies even if the climate changes. Apart from water management, surface-related measures include spatial planning and town country planning.

The integration of all planned measures into the different fields of protection and use must be strived for on a national, as well as on a transboundary (international) level.

1. Continue and reinforce measures within the framework of avoidance, prevention, crisis management, and based on measures of the Action Plan on Floods so far, and which are provided for in national and regional flood risk management plans to reduce present flood risks. Due to the expected increase of flood events and eventual more often extreme events, the planned measures to create more space for (temporary) flood retention will, in future, be even more important, just as flood prevention and comprehensively raising the awareness of the general public for flood issues;
2. Securing and keeping flood-prone areas in settlement areas free from further uses and decentralized water retention in the surface of the entire catchment area;
3. Taking into account the afore mentioned measures when drafting the Flood Risk Management Plan according to the Floods Directive (2015) and its continued elaboration (2021), this also combined with the 3rd management plan according to the WFD;
4. Draft and provide for preventive water management measures for critical periods of low flow (taking into account the problems related to water quantity and water temperature) including a transboundary co-ordination of such measures;
5. Restore/enhance as nature-near water bodies as possible and create a network of habitats according to the environment targets of the WFD. Mutual synergy effects must be used beneficially and strengthened.
6. Integrate the socio-economic developments into water management measures and co-ordinate them with corresponding measures in other fields (drinking water supply, water abstraction, power generation, navigation, agriculture, fisheries and recreation)

- **Take into account future socio-economic developments and integrate all actors**

Regarding the projected future development, regional, specific adaptation strategies will have to be developed with respect to future developments. This presupposes that they are based on an as comprehensive state of knowledge on changes in water management as possible, created with a practical application in mind.

Uses and the protection of the Rhine and its tributaries must be brought into a balance in order not to call the uses and activities of future generations into question. This is particularly relevant, since, with climate change, existing problems are likely to increase. Also, it is known that human activities impact the runoff pattern. In the course of time, this impact has increased and, among others due to the unknown socio-economic development, the future development cannot be foreseen.

The most important contents of already published international climate change related strategies (see annex 1) were taken into account when drafting this document for the Rhine catchment.

For the further development of the provisional ICPR strategy on adapting to climate change and in order to enhance the acceptance of its implementation in different fields, the exchange with the main actors, such as users (e.g. agriculture, spatial planning, navigation, the energy sector, drinking water works, etc. ...) and the accepted observers to the ICPR and with the general public will be enhanced.

Different possibilities are conceivable in order to involve stakeholders or the public to a greater extent:

- Active participation and cooperation with acknowledged observers, such as NGOs, other organisations (e.g. the Central Commission for the Navigation on the Rhine and other river commissions) in ICPR fora;
- Eventually, representatives of different fields could cooperate in a Project Group PG KLIMA yet to install, in order to cover a greater technical range and to respond to specific necessity of analysis;
- regular exchange of information in joint projects, workshops, etc.;
- Raise the awareness of the public or of other actors in communication actions, information material, via the ICPR website.

1. Introduction

Based on the then available 4th IPCC (Intergovernmental Panel on Climate Change) status report 2007, the **Conference of Rhine Ministers** underlined in **2007** that the effects of climate change were already clearly visible in the field of water management and that, in future, the precipitation pattern would change. In North Western Europe a change in flood events, longer lasting low water levels, a temperatures rise of surface waters, and a change in groundwater recharge must be reckoned with. Regionally, effects may differ. These changes not only concern water management, but also the use of water and land.

Changes of climate parameters impact hydrological processes and thus the regional hydrological regime, and the discharge regime of water bodies. Furthermore, changes in the air temperature also impact the temperature regime of water bodies.

The Conference of Rhine Ministers in 2007 underlined that, apart from taking measures aimed at reducing greenhouse gas emissions, **water management strategies aimed adapting to climate change** needed to be developed. Therefore, the ICPR was charged to develop joint scenarios for the changes in the discharge and temperature regime expected in the international river basin Rhine during the 21st century. In a second step, the effects for water management, the use of water and soil and all fields in the Rhine catchment relevant for water were to be presented. Therefore, possible adaptation measures are to be developed and coordinated across sectors.

In **2013**, the **Conference of Rhine Ministers** charged the ICPR to present a provisional **strategy on adapting to climate change** for the Rhine catchment in **2014**, which was to be based on the assessment of existing studies on the discharge regime (floods and low flow) and on water temperature. In this connection, forward-looking, sustainable precautionary concepts should be developed for water management and proposals for measures aimed at adapting to the expected effects of climate change based on the management measures available in the states/regions should be looked into.

Chapter 2 of the report at hand summarizes the information available for the international Rhine catchment on possible impacts of climate change on the discharge of the Rhine (chapter 2.1) and on water temperature (chapter 2.2).

The additional impacts on water quality and the ecosystem are mentioned in chapter 3. Chapter 4 describes the impact on today's uses of water bodies.

As a basis for the adaptation strategy, chapter 5 concerns different possible fields of action and measures to adapt to the expected impact of climate change.

1.1 Survey of ICPR publications on climate change

1. **ICPR technical report no. 174:** Literature evaluation "Analysis of the State of Knowledge on Climate Changes so far and on the Impact of Climate Change on the Water Regime in the Rhine Catchment", 2009
2. **ICPR technical report no. 188:** Study of scenarios for the discharge regime of the Rhine, 2011
3. **ICPR technical report no. 198:** Periods of Low Flow in the Rhine Catchment in 2011, 2012
4. **ICPR technical report no. 204:** Present State of Knowledge on possible Consequences of Changes of the Discharge Pattern and Water Temperature on the Rhine Ecosystem and possible Perspectives for Action, 2013
5. **ICPR technical report no. 209:** Development of Rhine water temperatures based on validated temperature measurements between 1978 and 2011, 2013

6. **ICPR technical report no. 213:** Estimation of the effects of climate change on future Rhine water temperature development, based on climate scenarios - short version - 2014
7. **ICPR technical report no. 214:** Estimation of the effects of climate change scenarios on future Rhine water temperature development – 2014

Annex 1 gives a survey of international and national publications on climate change adaptation strategies.

1.2 Approach to drafting a strategy to adapt to climate change in the Rhine catchment

Just as within the ICPR coordination of the European Water Framework Directive (WFD, 2000/60/EC) and the European Flood Management Directive (Floods Directive, 2007/60/EC), this document is based on the network of water bodies of part A (part A = sub-basins > 2,500 km²).

The strategy for the Rhine catchment aimed at adapting to climate change is supposed to support corresponding activities at the level of international sub-basins (e.g. Moselle-Sarre) or at a national or regional level).

The ICPR working groups have analysed the possible specific impacts on the assets of protection as well as their sensitivity and the risks in the fields of water quantity, ecology and water quality. For this analysis, the working groups have used the knowledge of the studies mentioned above (observed changes of climate parameters and future scenarios in the form of projected bandwidth) and extended it to their respective fields. During interdisciplinary meetings with the participation of international intergovernmental organisations (IGO) and non-governmental organisations (NGO), an exchange of ICPR working groups took place.

During an interdisciplinary ICPR workshop staged on 30 and 31st January 2013, the expected impacts of climate change on the different fields of water management were presented and possible solutions were discussed. The results of this workshop have been integrated into this document.

The impacts of climate change and possible adaptation measures are to be taken into account when drafting the products of the ICPR concerning the implementation of the WFD, the Floods Directive and the programme Rhine 2020. In this connection, the ICPR strategy of adapting to climate change may be useful, in particular for the international parts of the plans. Wherever possible, win-win approaches[1] and no-regret measures[2] must be placed in the foreground.

The further improvement of the state of knowledge, e.g. concerning the accuracy of climate scenarios, the development of thermal discharges and cost/benefit analysis plays an important role.

Due to developments expected, more attention must also be paid to the issue of low flow, in particular in summer and possibly connected to high water temperatures.

2. Direct effects of climate change in the Rhine catchment

Changes of climate parameters impact hydrological processes and thus the regional hydrological regime, discharge regimes and the temperature regime of water bodies.

[1] Win-win: Measures serving several purposes at the same time
[2] No regret: Measures which pointing in the right direction in any case

2.1 Impact on the discharge regime of the Rhine[3]

General information

Following a literature evaluation (ICPR report no. 174, 2009), the ICPR published the results of the "Study of Scenarios for the Discharge Regime of the Rhine" in July 2011 (ICPR report no. 188). The study of scenarios has been drafted in close cooperation with the Commission for the Hydrology of the Rhine (CHR) which had carried through the project "RheinBLick2050". As a premiere for a large international river basin in Europe, this study includes specific discharge simulations for the near future (until 2050) and for the distant future (until 2100) on representative gauges of the Rhine and the Moselle.

The discharge regime describes the overall behaviour of river runoff with respect to the average multi-annual course and the characteristic development of extreme flood and low flow situations (Belz et al., 2007). In the Rhine catchment, different discharge regimes are overlapping (fig. 1).

The southern part near the Alps (Basel gauging station) is characterized by the interplay of snow cover constitution and in winter and snow melt comparatively high precipitation in summer ("snow regime" or nival regime). As a consequence, periods of low flow mainly occur in winter and flood events mainly occur in summer.

Waters draining the Central Upland region (Neckar, Main, Nahe, Lahn, Moselle, etc; Trier gauging station) are characterised by a "pluvial regime" characterized by floods prevailing in winter and low flow in summer.

Since these two regimes overlap, the downstream discharge distribution over the year ("combined regime", Cologne gauging station) is increasingly uniform.

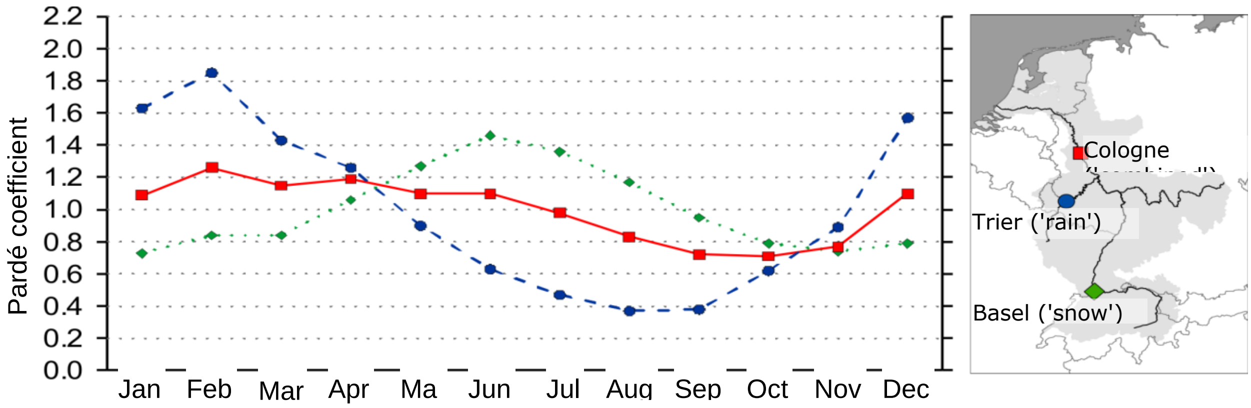


Figure 1: Typical discharge regime in the Rhine catchment according to Pardé[4]; reference period 1961-1990 (see ICPR report no. 188)

Development during the 20th century[5]

Precipitation during winter time has increased in the entire Rhine catchment (+ 10 % to +20 %). The increase was slightly less in the Alps. Summer precipitation has hardly changed (between -5 % to +5 %).

Thus, all discharge parameters MQ[6] and NM7Q[7] at the gauging stations along the main stream of the Rhine tend to increase in winter (mostly + 10 to + +15 % for MQ; + 15 %

[3] See ICPR report no. 188

[4] Pardé coefficient = ratio of multi-annual monthly discharge and multi-annual annual discharge.

[5] Comparison with observations during 1901-1930 and 1971-2000.

to +20 % for NM7Q). During summers, MQ and NM7Q decrease by up to 8 %. Mainly, this is an effect of rising temperatures (more evaporation) combined with stagnating precipitation and coincident reduced snow volume in the Alps.

The medium flood discharge (MHQ) interpreted for entire hydrological years (Nov. - Oct.) indicates an increase by about +10 %. A closer consideration of data shows that this does not seem to be due to an increase of extreme peak flows[8] but due to frequent moderate and great floods.

Development during the 21st century

According to the projections at hand, the temperature development until 2050 is characterized by a continuous rise which, in the entire Rhine catchment, and for the period 2021 to 2050 compared to the present (1961-1990) could amount to an average of + 1 °C to +2 °C and for the period 2071-2100 of +2 °C to +4 °C. In the south (Alps) it will tend to be greater than in the north.

As far as precipitation is concerned, no major changes are expected for the summers in the period 2021-2050, reduced precipitation is expected for the period 2071-2100. For the winters, a moderate increase in precipitations is projected which, along the entire Rhine, will lie between 0 % and + 15 % during 2021 and 2050 and between +5 % and + 20 % between 2071 and 2100. Thus, the trends of changing precipitation established for the 20th century continue.

In the near future, this precipitation development will be accompanied by mostly moderate changes of the discharge regime of the Rhine. Compared to the present, the mean and lower discharges (MQ and NM7Q) in summer will remain almost unchanged during the period 2021-2050. Simulations for the period 2071-2100 show decreasing medium and low flow in summer (generally between -10 % and -25 %).

Increased precipitation in winter which, due to rising temperatures increasingly occurs as rainfall instead of snowfall, will lead to a rise of the mean discharges and low flow in winter by an average of 10 % (median of spreads 0 % to +20 % and 0 % to +15 % for MQ, resp. NM7Q). For flood discharges, downstream of the Kaub gauging station, mostly recordings of -5 % to +15 %, resp. 0 % to +20 % and -5 % to +25 % are registered for "frequent", "medium" and "extreme" floods. For Basel, Maxau and Worms, due to methodic deficits, the KLIWA project does not make any statements for HQextreme.

During 2071-2100, the increase of the mean runoff and of low flow in winter largely corresponds to that of area precipitation. The increase of flood runoff will continue as for the near future.

Figure 2 shows these trends for the average monthly discharge at the Cologne gauge.

---

6 Arithmetic average of the all daily discharge values of homogenous periods of time (e.g. hydrological half-year periods, months) of the period under consideration (e.g. period 2021-2050)

7 Lowest Arithmetic average of the discharge values of 7 days during homogenous periods of time (e.g. hydrological half-year periods) of the period under consideration (e.g. period 2021-2050)

8 Here: highest daily average discharges

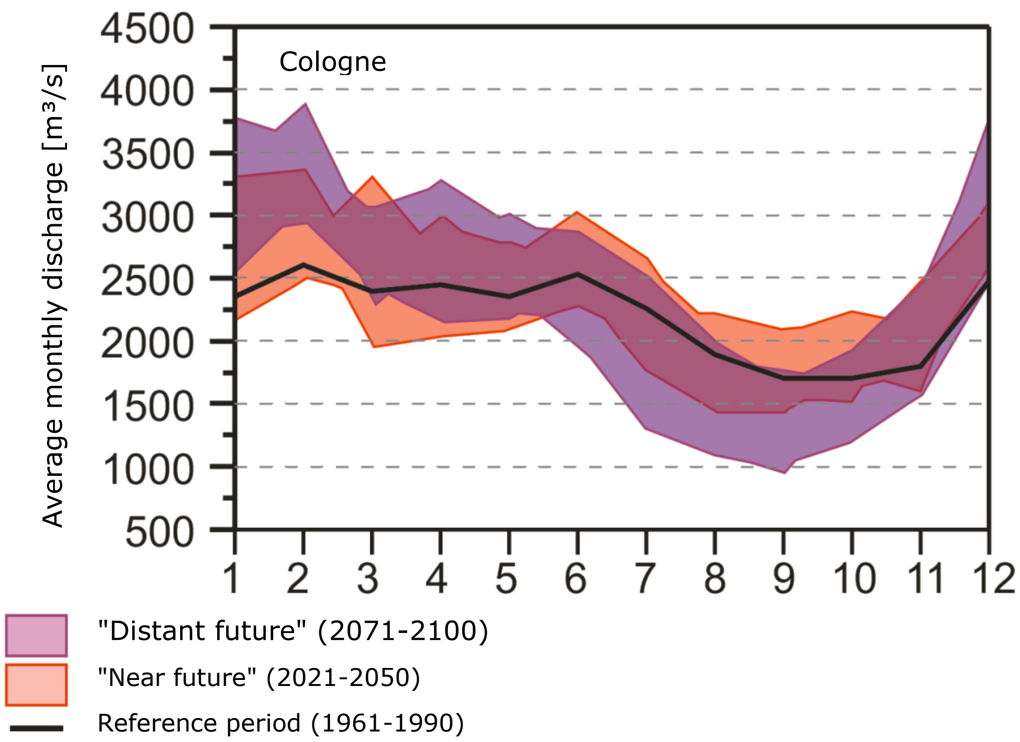


Figure 2: **Spread of simulated average discharges at the Cologne gauge** - Climate projections for 2021-2050 and 2071-2100 and reference simulation (1961-1990). Data: KHR-Rheinblick2050 (2010); diagram: BfG-M2 (2014).

Detailed results are shown in the Tables 4 and 5 in the "Study of Scenarios for the Discharge Regime of the Rhine" (ICPR report no. 188).

In short, the state of knowledge shows that climate change and rising temperatures in the Rhine catchment might lead to the changes of precipitation and discharge until 2050 and 2100 as listed below. Considering the near future, some changes remain moderate, but the direction changes might take becomes clear when considering the distant future, that is, the end of this century.

a. during the hydrological winter:

- Increased precipitation in winter
- Increased discharge
- Early melting of snow/ice/permafrost, shift of the line of snowfall

b. during the hydrological summer:

- Less precipitation (but possibly more often heavy rainfall in summer)
- Decreasing discharges
- More periods of low flow.

c. More smaller to medium floods, increase of peak flows of rare floods seem to be possible, but their extent cannot be quantified beyond doubt.

Annex 2 and Annex 3 include tables with the bandwidth of possible discharge changes in percent for different hydrological parameters indicating the possible effects of climate change at different gauges along the Rhine for the near future until the end of 2050.

The tables establish a relationship between these bandwidths and other statistical parameters, in order to point out the constraints for different uses of water bodies in particular to the authorities concerned. A comparison with the constraints thus allows to estimate possible impacts of climate change on the different areas of use.

2.2 Impact on the water temperatures of the Rhine

There is evidence that, between 1978 and 2011, the water temperature has risen by about 1 °C to 1.5 °C (see ICPR report no. 209).

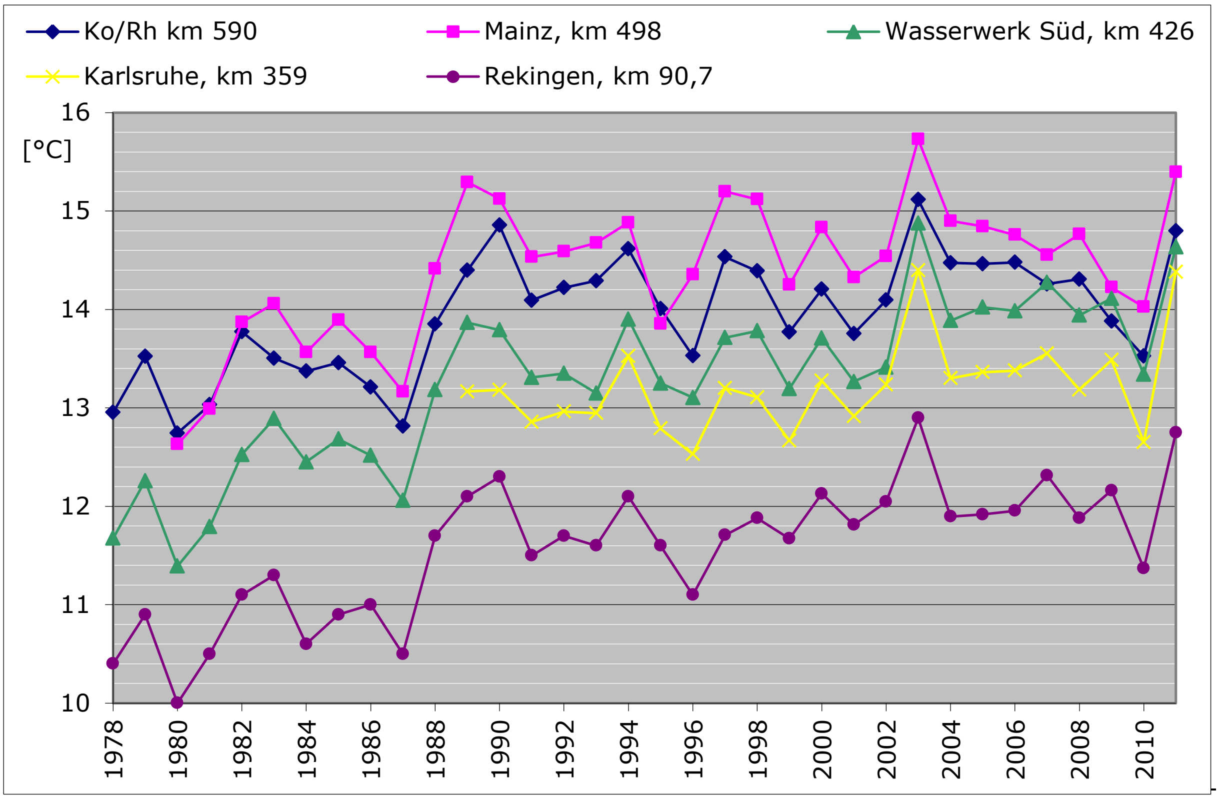


Figure 3: Annual average Rhine water temperatures between 1978 and 2011 at five monitoring stations on the High, Upper and Middle Rhine Source: ICPR report no. 209

Regionally (between Basel and Worms) anthropogenic thermal discharges contribute to a further rise in water temperatures (e.g. along the Upper Rhine, measurable by 1 °C to 1.4 °C). Without taking into account thermal discharges, the development of water temperatures reveals a gradual warming up of the Rhine between Basel and Werkendam. The decommissioning of nuclear power plants in the Rhine catchment resulted in a measurable decrease of the average rise in temperature and might have contributed to impacting the exceptionally low water temperatures during the winter 2011/2012 (11 days under 3 °C). We must wait for the further development, as the observations are only based on one monitoring year.

During the last decade and compared to the two preceding decades, the frequency analysis of values in excess of certain temperature limits, e.g. 22 °C or 25 °C shows a distinct increase in the number of days with values in excess per year (see Figure 4).

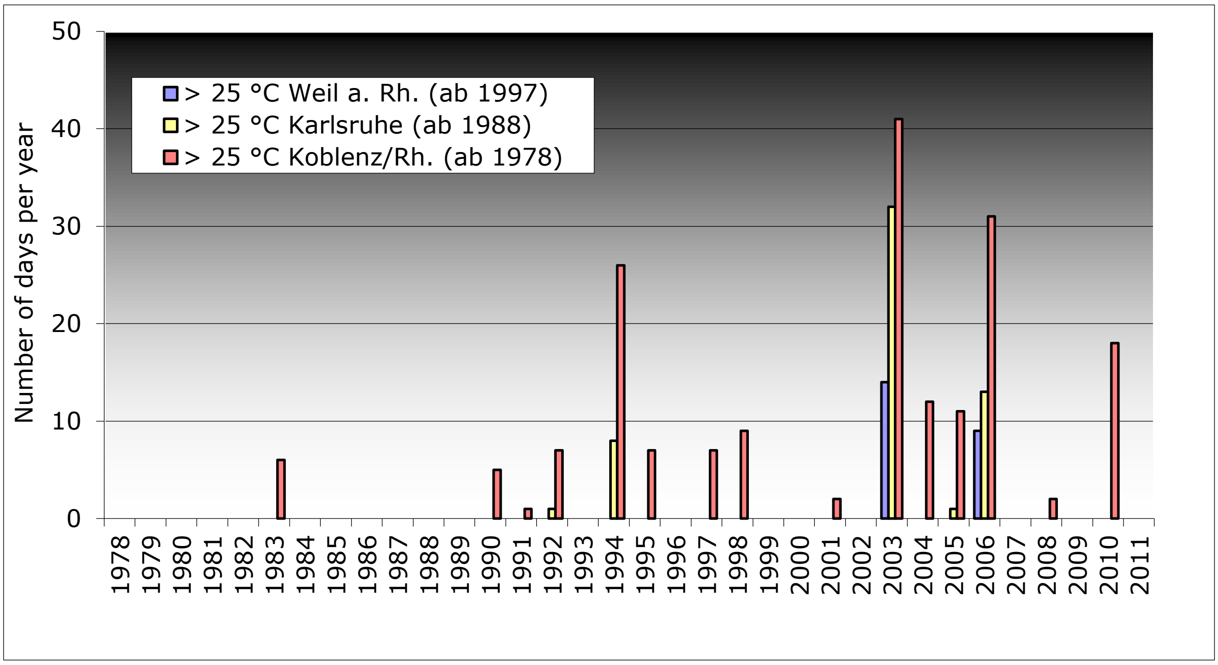


Figure 4: Periods of Rhine water temperatures in excess of 25 °C during the past three decades Source: ICPR report no. 209

In addition to the report on the longstanding development of Rhine water temperatures between 1978 and 2011 (ICPR report no. 209, 2013), the ICPR has drafted the first report for a European river district dealing with the **Estimation of the effects of climate change scenarios on future Rhine water temperature development** in the near future (2021-2050) and in the distant future (2071-2100) (ICPR report no. 213, short version and no. 214, 2014, comprehensive version). This estimation is based on the climate scenarios determined in the Study of Scenarios for the Discharge Regime of the Rhine (see ICPR report no. 188).

For the near future "NF" (2021-2050) the longitudinal profiles comparing average temperatures in August with the reference period (2001-2010) show a rise in water temperature of about 1.5 °C, while, for the far future "FF" (2071-2100) the rise in temperature of Rhine water tends towards 3.5 °C (see Figure 5). In both cases, the warming up is caused by climate without any additional effects due to thermal discharges (see ICPR report no. 214, comprehensive version and no. 213, short version).

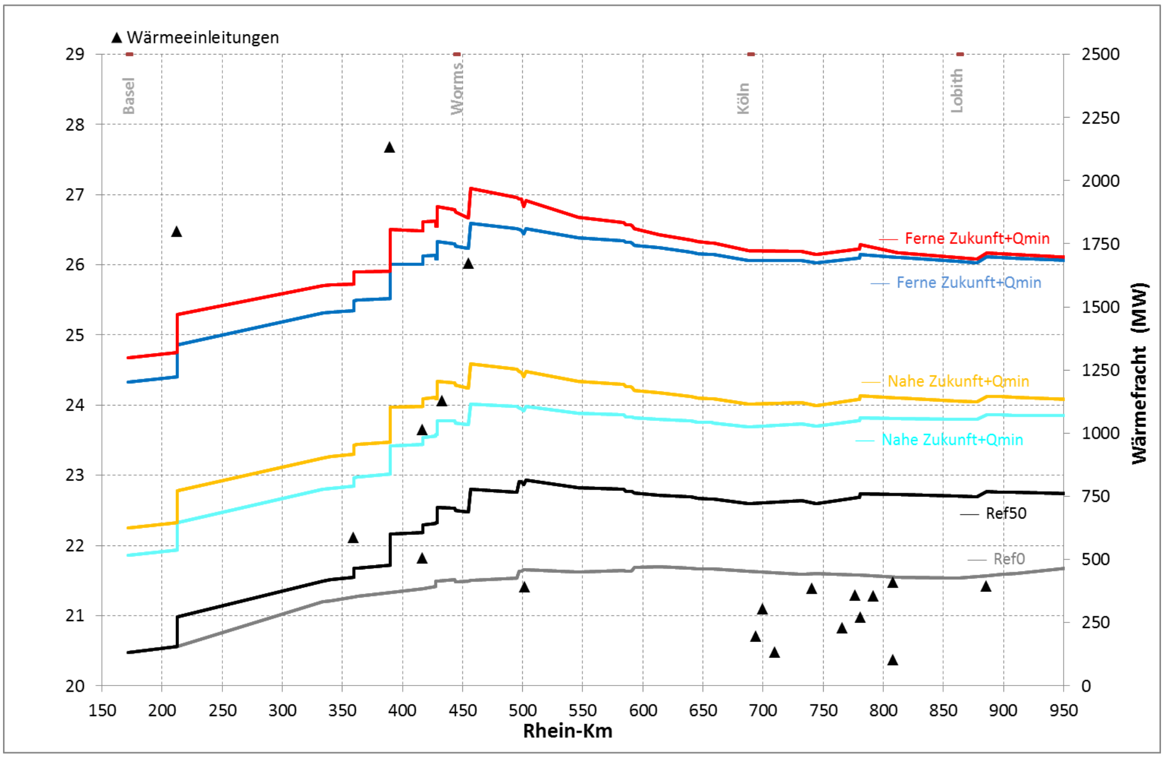


Figure 5: Longitudinal profile of average Rhine water temperatures in °C for the month of August, simulated by LARSIM (Basel to Worms) and SOBEK (Worms to Werkendam)

Source: ICPR reports no. 213 and 214, triangles = thermal discharges > 200 MW

Figure 6 (see ICPR report no. 213) shows the average number of days per year with water temperatures above 25 °C according to the simulations:

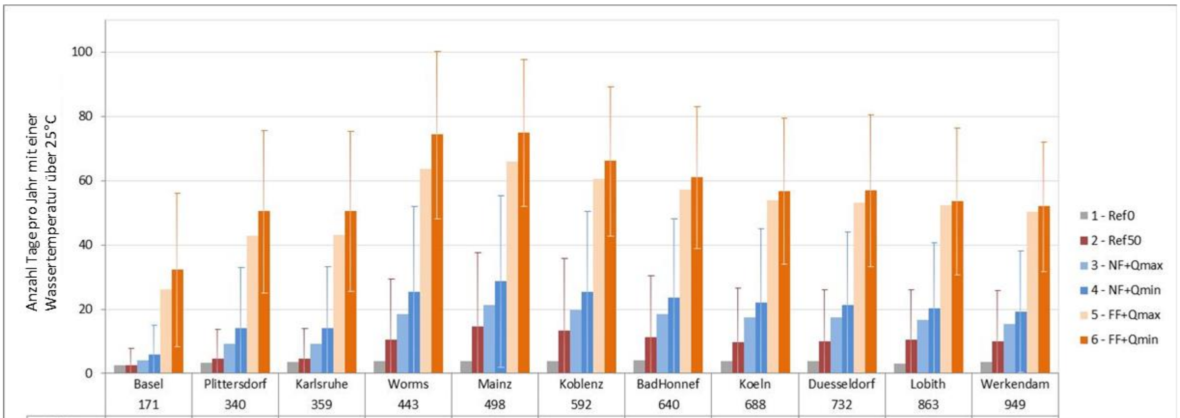
a. Simulations for the near future indicate that, during periods of low flow (Qmin) and compared to the reference situation with 50 % of the thermal discharges permitted in 2010[9] (Ref50), the number of days with water temperatures above 25 °C will increase by up to the double.

b. In the far future, there will be a strong rise in the number of days with temperatures above 25 °C. Near Worms, the number of days with temperatures in excess per year will rise from 11 to 64 to 74 in the far future. That means that, in the far future, on average the water temperature in summer near Worms will be above 25 °C for about 10 weeks.

c. On the other hand, in the far future years without water temperatures in excess of 25 °C will be very rare. In the far future, this is also true of temperatures above 28 °C.

Also, the corresponding calculations for days with temperatures below 3 °C have been made, since these phases have a positive effect on the spreading of macrozoobenthos species typical for the Rhine and drive back invasive species preferring warm water. Compared to the reference situation without thermal discharges, in the section of the Rhine around Worms, days with temperatures below 3 °C will fall from 10 to 0 days. In the section of the Rhine until Lobith which is less impacted by thermal discharges, there will be between 4 and 6 days with temperatures below 3 °C, with 50 % of the thermal discharges permitted in 2010. In the near future (NF), this number of days will fall to 1-3 and in the far future (FF) it will fall to 0 or 1.

9 Since several nuclear power plants in the Rhine catchment have in the meantime been shut down, these assumptions are already outdated. Reliable prognosis on the development of thermal discharges could further improve the water temperature prognosis.



	Basel 171	Plittersdorf 340	Karlsruhe 359	Worms 443	Mainz 498	Koblenz 592	BadHonnef 640	Koeln 688	Duesseldorf 732	Lobith 863	Werkendam 949
1 - Ref0	2	3	4	4	4	4	4	4	4	3	4
2 - Ref50	2	5	5	11	15	13	11	10	10	10	10
3 - NF+Qmax	4	9	9	19	21	20	19	17	18	17	15
4 - NF+Qmin	6	14	14	25	29	25	24	22	21	20	19
5 - FF+Qmax	26	43	43	64	66	61	57	54	53	52	50
6 - FF+Qmin	32	50	51	74	75	66	61	57	57	54	52

Figure 6: Average number of days per year with a Rhine water temperature above 25 °C in the near and in the far future. Source: ICPR reports no. 213/214

NF = Near Future, FF = Far Future; Qmin = low discharge, Qmax = high discharge; ± standard deviation (bandwidth of max. individual values) at Ref50 (with 50 % of the thermal discharges permitted), NF+Qmin and FF+Qmin

3. Effects of the changes of water balance and water temperature on water quality and the ecosystem

The effects of climate change on the aquatic and amphibian habitats in the Rhine catchment have been collected and summarized by the ICPR working group Ecology. They are presented in the ICPR report no. 204, published in 2013 under the title "Present state of knowledge on possible consequences of changes of the discharge pattern and water temperature on the Rhine ecosystem and possible perspectives for action". The reports on changes of water temperature so far and in future have been drafted by the Working Group Water Quality/Emissions and were published as ICPR reports no. 209 (2013) and 213/214 (2014). All of the ICPR results are structured and summarized below.

3.1 Effects on water quality

So far, the effects of changed discharge pattern and water temperatures on the physical-chemical and chemical quality of the Rhine and its tributaries cannot be quantified. With respect to water quality, the following may be stated:

Discharge related effects

Both high and low water discharges impact water quality.

During **high water or floods**

- considerably more nutrients and pollutants are carried downstream during a short laps of time which constitute a large share of the respective annual load;
- pollution events may occur due to the washing out of oil tanks or other damages to industrial plants, buildings etc. due to extreme events;
- sediments contaminated in the past may be remobilized. The Sediment Management Plan Rhine (ICPR report no. 175) has already pointed out 16 areas at risk of sediment re-mobilisation due to floods.

Increased precipitation

- leading to surface runoff may locally increase the pollutant and nutrient load of diffuse origin (e.g. agriculture and generally due to soil erosion) as well as of point source origin (e.g. urban wastewater treatment plants);
- may locally cause bottlenecks in urban canalization, wastewater treatment plants and rainwater overflows, thus possibly causing oxygen deficits in the receiving water body, in particular in tributaries carrying a large share of wastewater and in impounded river sections.

During **low flow**

- undiminished discharges of wastewater may, as a matter of principle, cause a rise in the concentration of all water quality constituents thus altering the water quality;
- even lesser diffuse inputs caused by soil erosion and low amounts of precipitation may flow into the water bodies;
- discharges from wastewater treatment plants may constitute a considerable amount of the discharge, in particular of the big tributaries to the Rhine with high population density;
- salinization may occur in the Rhine delta.

Temperature related impacts

Temperature is an important parameter for water quality. It determines the speed of all chemical processes, e.g. mineralization, impacts on the solubility of substances and influences the balance of the water as well as of the natural purification process.

A rise in temperature caused by climate change leads to lower dissolved oxygen contents in the water and may cause higher day-night-fluctuations of oxygen concentrations, theoretically to lower pH values and to a more rapid mineralisation. These processes release carbon dioxide, nitrate, phosphate and sulphides. Higher temperatures may also increase nitrogen decomposition due to denitrification.

The balance of calcium carbonate equally depends of temperature and pH-value. It is an important factor for water quality and the productivity of water.

3.2 Effects on the ecosystem

For most organisms in aquatic ecosystems, climate change is an additional factor of stress to those already resulting from the various anthropogenic impacts. This particularly applies to the densely settled and heavily industrialized Rhine catchment with its intensive agriculture.

Floods are natural events - floodplains are only conserved thanks to periodic flooding. A large majority of the organisms living in and along a water body is capable of surviving a flood without any problem.

During **low flow**, temperature and oxygen depletion as well as the concentration of pathogens and chemical contaminants may rise in water bodies.

For animals and plants, **temperature** is one of the most important environmental factors, as it e.g. controls reproduction, growth, development and migration. Cold-blooded organisms such as fish and macro-invertebrates which are unable to regulate their temperature but always adjust it to their environment are particularly affected (see ICPR report no. 204).

Higher water temperatures might change the species composition and structure of dominance along the rivers. Species depending on low temperatures are particularly vulnerable. Their habitats could move northwards or to water regions in greater altitude. Species able to cope with great variations in temperature and species preferring warm temperatures, among others a large number of new invasive species which so far more or less settled in areas near the river outlets would be favoured and may settle further upstream in the rivers. Above all, this concerns macrozoobenthos species and fish species, but also macrophytes.

Additionally, high temperatures lead to increased metabolism. A temperature rise of 10 °C generally leads to the double of energy consumption for basal metabolism (Q10-rule). If there is not enough food, the immunological system will thus be weakened. Additionally, the spreading of pathogens, parasites etc. is being favoured.

For organisms, average temperature ranges as well as maximum temperatures are relevant, which are well documented for fish.

The critical temperature (CTMax or CTMin) is achieved, when fish are no longer able to escape from the area of the lethal temperature range. A distinct change of behaviour brought about by temperature changes is to be observed in the lower/upper critical range. There is, for example, a temperature of avoidance, a temperature of errantry and a temperature of disturbance. In the optimal range, fish feed and do not show any sign of abnormal behaviour due to temperature. The preferred temperature is the range of temperature in which fish stay within a temperature gradient.

According to the EU Fresh Water Directive[10] which has, in the meantime been cancelled, the temperature of salmonid waters (= waters, in which cold water fish / salmon and trout varieties live) may not lie above 21.5°C, that of cyprinid waters (waters, in which warm water fish /carp varieties live) may not lie above 28 °C. Oxygen contents of < 4 mg/l in cyprinid waters or of < 6 mg/l in salmonid waters are critical for the respective fish species living there.

In order to avoid interfering with the gonadal development of some fish species, the temperature of waters in which fish species reproduce requiring cold water for reproduction may not exceed 10 °C during spawning periods . These temperature limit values may be exceeded during 2 % of the time.

If water temperatures in winter do not or rarely fall below 3 °C, this enhances the reproduction and spreading of most of the invasive species preferring warm temperatures. If temperatures often and for a long time rise above 10 °C, the hibernation of many water organisms is interfered with.

Apart from maximum temperatures, the duration of warm spells is particularly decisive for the survival of water organisms. Thus, during the summer of 2003, when temperatures of the main stream of the Rhine exceeded 25 °C on 41 days, massive death of mussels and eel was observed. However, in 2006, after 31 days of warm spell, there was no such massive death.

The outlets of lakes which warm up to a greater degree than rivers may be particularly affected by high water temperatures. During the extreme heat period in the summer of 2003, a massive death of approx. 50,000 greylings (20.9 tons of fish) was observed in the section of the Rhine immediately downstream of Lake Constance. On 12 August 2003, 25.9 °C were measured at a depth of 4 meters at Stein am Rhein, near the banks temperatures even rose above 27°C.

Bed load

In European mountain ranges, the **natural bed load supply** is more and more dwindling. Partly, this is due to climate change, but mostly numerous human interferences to limit discharges of solids, e.g. by reforesting slopes have led to this development (Malavoi and Bravard 2010[11]).

---

[10] Directive 2006/44/EC of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life

[11] Eléments d'hydromorphologie fluviale – Ed Onema – Collection Comprendre pour agir – http://www.onema.fr/IMG/pdf/elements-dhydromorphologie-fluviale.pdf

Also, changes in **agricultural practices** (intensified use of farmland, less grazing and presumably increased need for irrigation) will lead to indirect changes.

4. Effects on the use of water bodies

The consequences of climate change impact different uses of water bodies. Users of water bodies must themselves look ahead and react in order to reduce, limit, compensate for or neutralize negative effects of climate change.

Floods and increased precipitation may possibly impact:

- the **quality** of raw water for **drinking water supply**: eventual deterioration;
- **land use**: flood protection for **settlements, industrial plants, business enterprises and companies in the service sector** located along the water body, since higher flood probability will lead to changed levels of protection or situations at risk;
- **hydropower**: restriction of power production if impounded river sections also serve flood regulating purposes (exceptional operation of the power plants on the Upper Rhine);
- **navigation**: More frequent restrictions or suspending of navigation when water levels are too low;
- restriction of **agricultural and recreational functions of water bodies, alluvial areas and wetlands**, as flooded areas are temporarily not available for use.

Low flow and higher water temperatures will possible impact:

- **drinking water supply**: lower groundwater tables, deteriorated water quality (e.g. bank filtrate), restrictions for drinking water production during low flow;
- **thermal power plants and industrial plants:** Production restrictions due to lacking cooling or industrial water and higher water temperature;
- **hydropower**: Restricted power production during low flow;
- **navigation**: Restricted load or restricted navigation due to too low navigable depth;
- **agriculture**: Lack of irrigation water for agriculture, in particular market gardening;
- locally or regionally **inland fishing**, eventual fish death and altered species communities.

5. Possible fields of action and measures for adapting to the expected effects of climate change

5.1 Basic principles for possible adaptation measures

The following basic principles should apply to the entire Rhine catchment:

1. As far as possible, adaptation measures should positively impact the discharge regime as a whole with both extreme situations, floods and low flow, e.g. by enhancing water retention in the catchment, the seepage of precipitation where it falls;
2. Flexible win-win and no-regret measures (in spite of eventual uncertainties, measures useful at all events) should be preferred as adaptation measures (e.g. re-

naturing, river bank strips, securing and keeping flood prone areas free of uses as a matter of precautionary land use);

3. Taking into account transboundary effects and the cooperation of all states in the catchment area are important elements;
4. Many measures are closely connected to future developments, e.g. socio-economic and demographic changes or changes in land use (e.g. increased corn growing for biodiesel) and agricultural practice. The short term effects of such changes on water quality and quantity may be greater than (longstanding) climate changes. This should also be taken into account when developing options for adaptation;
5. Measures may regionally differ, as local circumstances must be taken into account. When fixing priority measures and establishing their priority, it should equally be considered that due to regionally varying circumstances, not all measures can be implemented in the entire Rhine catchment;
6. The classification of measures may vary, e.g. according to their range of action or their implementation deadline: long term measures (e.g. until 2050), medium term measures and short term measures (e.g. 6 years cycle of the Floods Directive or the WFD);
7. On a national or even on a local scale, current and future measures should be examined with respect to their suitability for climate change;
8. The cost-effectiveness of measures should be taken into account (comparison of costs, analysis of cost-effectiveness);
9. The effects of water management adaptation measures on other adaptation and preventive measures concerning climate change in other areas than water management should equally be considered;
10. Also, positive effects of climate change on certain functions of use should be taken into account and used beneficially;
11. There should be a regular monitoring of developments / changes of the effects of climate change;
12. Climate as well as hydrological scenarios should be regularly updated;
13. Taking into account the 6 years cycles for the implementation of the EU Directives in the field of water management, the strategy should be assessed and eventually adapted.

5.2 Possible measures with respect to water quantity

Flood risk management

The 12th Conference of Rhine Ministers in Rotterdam adopted the "Action Plan on Floods" on 22 January 1998. The drafting of this Action Plan which has been part of the "Programme on the Sustainable Development of the Rhine - Rhine 2020" since 2001 was triggered by the floods in December 1993 and January/February 1995. Within the implementation of the Floods Directive and the drafting of a joint, overriding flood risk management plan, measures of the Member States in the fields of avoidance, protection and prevention are to be bundled.

Flood prevention measures taken within the Action Plan on Floods in order to reduce the flood risk point in the correct direction. In order to better assess the effects of climate change in future, the present great bandwidths for the possible developments of future flood discharges must be reduced with the help of further investigations. Considering climate change, the expected increase of the number of flood events and possibly more frequent extreme events, measures planned so far might possibly not be effective enough, so that the results of more recent investigations may be taken into account within the second cycle of the flood risk management planning.

Furthermore, the focal point will be a complete and comprehensive flood risk management comprising all options for action according to the Floods Directive. The future ICPR flood risk management plan will replace the Action Plan for Floods. Apart from numerous measures aimed at improving water retention in the entire catchment, at preserving and/or extending floodplains, at renaturation, extensification, creating retention areas, improving preventive construction, further important elements are to create awareness, crisis management and civil protection.

Possible measures or activities might be

1. Take into account climate change in the flood risk management plans on the basis of an assessment of the sensitivity of the flood scenarios considered;
2. Raise public awareness - strengthen private precaution, preventive behaviour and reduce vulnerability, preventive construction;
3. Improve flood forecasting and announcement;
4. Water retention along the Rhine: Reactivate floodplains and increase water retention, long term securing of potential floodplain areas or retention areas;
5. Decentralized water retention (on the surface, improved infiltration) and water retention in the Rhine catchment (tributaries and their catchments);
6. Land use control by reducing soil sealing and conserving floodplain areas (urban and land-use planning);
7. Technical flood protection, as far as achieving the environmental targets of the WFD will not be interfered with and the flood risk in other states up- or downstream will not be increased;
8. Financial preventive and aftercare measures; regeneration;
9. Emergency planning and coping with floods: Risk prevention, civil protection and emergency drills.

Low flow management

In 2003, aspects concerning low flow management were treated in connection with measures concerning the high Rhine water temperatures (see ICPR report no. 142 (2005) and ICPR report no. 152 (2007)) and again in 2011 in connection with measures concerning low flow (see ICPR report no. 198).

During the 15th Conference of Rhine Ministers on 28 October 2013 in Basel the Ministers in charge of the Rhine decided that, considering the development to be expected, events of low flow which particularly in summer coincide with high water temperatures must receive more attention.

Conceivable measures would be:

1. Take into account climate change when planning and conceiving measures aimed at low flow management;
2. Secure that measures aimed at low flow management are compatible and coherent with flood risk management measures;
3. Information and raising the awareness of the public (and of different users in the field of water management) - preventive/responsible action, enhance economic use of water;
4. Develop/make available/improve low flow forecasting and announcement or warning;
5. Reactivate floodplains, e.g. by relocating dikes and/or constructing retention areas (to delay discharge/retain water during floods);

6. Decentralized water retention (on the surface) and water retention in the Rhine catchment (tributaries and their catchments) enhance maintaining the groundwater level or refilling groundwater. At the same time, these measures contribute to conserve/protect floodplains/wetlands;
7. Management analysis before and after a period of low flow, taking into account the users (including administrative and legal framework);
8. Preventive construction, technical solutions (e.g. collect precipitation water), alternative uses.

In general it can be stated that many of the measures mentioned, which are important for future flood management, will also have a positive effect on low flow management.

5.3 Possible measures with respect to water quality

Efforts concerning water quality range among the oldest tasks of the ICPR and received an enormous impetus with the Rhine Action Programme drafted after the Sandoz accident in 1986, which was followed by the "Programme on the Sustainable Development of the Rhine - Rhine 2020". Possible fields of action to preserve and improve water quality are already being followed by the ICPR within the framework of current work.

Due to the effects of changed discharges and water temperatures on water quality caused by climate change, additional or new measures must eventually been taken, completing the ongoing measures. These should aim at reducing the negative impacts on water quality, such as unwanted values of physical-chemical parameters such as temperature, oxygen, salt, nutrients and specific pollutants, such as micro-pollutants including pesticides.

Present fields of action are:

1. The **improvement of water quality** ranges among the management targets for the IRBD Rhine. Substances in the Rhine water may not have any detrimental effects on the biocoenosis of flora, fauna and micro-organisms, neither on their own, nor in interaction and water quality must be such that drinking water production is not hampered. This target also applies considering climate change.
2. In spite of unchanged intensive use of the Rhine catchment, the water quality of the Rhine and of many of its tributaries has distinctly improved. Largely, this is due to the **reduction of pollutant and nutrient inputs from industry and municipalities**, e.g. due to the construction of wastewater treatment plants, secure stocking of substances hazardous to water, avoiding accidents, etc. The programmes of measures under the first WFD management cycle (2009-2015) are targeted towards a further reduction of substances discharged into waters. As not all reduction objectives will be met by 2015, within the 2nd Management Plan (2016-2021) according to WFD and the further implementation of the programme "Rhine 2020" increased attention will be paid to measures reducing substance inputs and their interaction with other policy fields.[12]
3. Given the possible increase of heavy rainfall and flood events, the pollution reduction of **diffuse origin**, among others nitrogen, regionally also phosphorous, plant protection agents, PCB, PAH, zinc and copper present a particular challenge. In this connection, there are further measures, e.g. optimizing the use of fertilizers and plant protection agents and enhancing organic farming (measures also concerning other fields).
4. More frequent floods will possibly increase the risk of **remobilising contaminated sediments**. 8 of the 22 areas at risk identified in the Sediment Management Plan

12 Communiqué of Ministers 2013, points 12 and 13

Rhine (2009) have been cleaned up. In 2013, the Ministers in charge of the Rhine confirmed their determination to implement the measures proposed in the Sediment Management Plan Rhine for all areas at risk.

5. The **Warning and Alarm Plan Rhine (WAP)** serves to warn all Rhine bordering countries, in particular those downstream, if considerable amounts of pollutants flow into the Rhine. This helps to identify polluters.

6. Since 1954, **pollutants and nutrients are monitored** at 6 monitoring stations, since 2012 at 8 main monitoring stations along the main stream of the Rhine and at further locations along the rivers Moselle and Sarre (ICPMS), and the annual monitoring balance is published on internet (http://maps.wasserblick.net:8080/iksr-zt/). At numerous further monitoring stations national water monitoring is carried out, also along the Rhine tributaries. In future, more attention should be paid to the connection with the effects of floods and low flow, water shortage and an increase of water temperatures.

7. During periods of extreme heat and concomitant low flow, **thermal discharges** (e.g. by thermal power plants) may contribute to values in excess of ecologically relevant guidance values for sensitivity (water temperature, oxygen content). During periods of low flow, regionally increased surveillance procedures may be implemented. Users and the press will be informed in due time. Eventually, measures aimed at reducing water intake and discharges might be taken. Regionally, thermal models (e.g. thermal models for the rivers Neckar, Lower Main, Upper and Middle Rhine) or alarm plans (e.g. R. Main Alarm Plan, action concept for reducing thermal discharges into the big rivers in Rhineland-Palatinate during periods of high water temperature) have been drafted and are aimed at triggering relevant measures in periods of critical water quality.

5.4 Possible measures concerning the ecosystem

In the field of ecology, as in the field of water quality, the ICPR is already monitoring several possible fields of action, in order to mitigate the impacts of modified discharge and temperature patterns on the flora and fauna caused by climate change. In particular, meeting the ecological targets of the WFD may contribute to raise the resilience of waters with respect to changing climate conditions. For areas of protection depending on water, this also applies to the targets set by the Habitats Directive and the Birds Directive (NATURA 2000). Mutual synergy effects also with the Floods Directive should be used.

Given the many measures already taken to increase the resistance of the ecosystem, it is important to consider for each future measure, how the effects of floods and low flow as well as of rising water temperatures can be further reduced (e.g. by creating shaded areas, accessible refuge areas, increasing water retention and, above all, by intensive monitoring during critical periods). Here some examples for relevant possibilities:

1. Protect and renature habitats: Flora and fauna habitats are to be protected and to be made more nature-near. Examples along the Rhine and its tributaries are

- freely flowing sections, in particular those with redds for rheophile fish species;
- oxbow lakes, bypasses and other backwaters connected to the main stream;
- brackish water sections (more nature-near transition from freshwater to salt water);
- more nature-near redesigned banks (along smaller and medium tributaries it is recommended to plant shrubs or to let them spread naturally, in order to create shade limiting the rise in water temperature;
- all replacement habitats for habitats vanished due to training measures in the riverbed and their qualitative improvement.

2. **Habitat network connectivity:** In periods of critical water temperatures and oxygen deficits, most fish and invertebrates are capable of migrating to a more suitable environment, as far as available and migration routes are unobstructed. In this process, the Rhine valley between the Upper Rhine and the Delta Rhine plays a particular role as extensive migration corridor. Also, it is important that higher lying river sections in the Rhine tributaries and lateral connections to backwaters in the floodplain are available, as, during hot spells in summer, their shade and cold groundwater seepage offer local areas to withdraw to. Also, terrestrial habitats along the water bodies should be interconnected. The creation of a „Habitat Patch Connectivity along the Rhine“[13] and the restoration of free migration in the programme waters of the Rhine catchment for migratory fish[14] will be important contributions.

   Examples of **national programmes in the Rhine catchment** dealing with these fields of action:

   - - "Flussrevitalisierungen" in Switzerland[15]
   - - „Trame verte et bleue“ in France[16]
   - - "Integriertes Rheinprogramm" in Baden-Württemberg/Germany[17]
   - „Aktion Blau Plus“ in Rhineland-Palatinate[18]
   - - „Lebendige Gewässer“ in North Rhine Westphalia
   - "More Room for the River" in the Netherlands[19]

3. **Ecological flood protection:** From the point of view of nature protection, wherever possible, flood protection measures taking into account the ecological functionality of the riparian structures and the floodplains should be preferred to technical flood protection. Ecological flooding of polders or relocations of dikes are to be considered as win-win measures, enhancing biodiversity and reducing the damage potential and risks in flood-prone areas.

4. **Water quality:** Since polluted water or water with poor oxygen content means an additional stress factor to climate change, water quality should be kept up or further improved (see above).

5. **Water temperature:** Additional anthropogenic increase of water temperature due to thermal discharges should be limited to a minimum and should not prevent achieving the good ecological status or the good ecological potential. If backwaters are connected to the main stream, fish living in the Rhine will locally have the possibility of withdrawing to cooler branches and lateral water bodies (e.g. disposing of more shadow).

6. **Monitoring of biocoenosis:** Modifications of the biocoenosis due to climate change will possibly only occur on the long run. Therefore, a solid data basis comparable to that of the existing ICPR "Biology" monitoring programme is of great

---

13 www.iksr.org – Documents/archive - Brochures – "Habitat Patch Connectivity along the Rhine", ICPR 2006

14 "Master Plan Migratory Fish Rhine" - ICPR report no. 179 (2009) & "Progress in Implementing the Master Plan Migratory Fish in the Rhine Bordering Countries between 2010 and 2012" - ICPR report no. 206, www.iksr.org

15 see BAFU / EAWAG 2010 *Precisions will follow*

16 see www.legrenelle-environnement.fr/-Trame-verte-et-bleue-.html

17 see www.rp.baden-wuerttemberg.de/servlet/PB/menu/1188090/index.html

18 see http://www.wasser.rlp.de/servlet/is/2038/

19 **see** www.ruimtevoorderivier.nl/

importance for the future development of instruments for targeted climate monitoring.

5.5 Possible measures concerning other fields

This chapter describes possible measures which, from an ICPR point of view, are connected with other uses (fields) and do not concern the above mentioned fields of flood risk management, low flow management, water quality and ecosystem. These considerations do not concern the way in which the different fields react to climate change or which socio-economic developments are expected (development of population composition, eventual changes in land use, future power supply).

The ICPR is charged to take into account socio-economic developments when drafting an adaptation strategy to climate change. Therefore, possible measures in these other sectors are mentioned:

Possible measures concerning:

1. **Drinking water supply**: Connection of supply networks, water management, reduce losses;
2. **Water abstraction during low flow**: Regulation of quantities, exceptional regulations;
3. **Energy production in thermal power plants**[20]: Use of cooling towers, consideration of the security of supply and of environmental effects. Check/adapt discharge permits and derogations for discharging cooling water from thermal power plants and industrial plants; eventually restrict production during low flow;
4. **Hydro power generation**: Determine a biological minimum water flow for hydropower plants in bypass rivers, in order to secure life, migration and reproduction of the species living in the water bodies. In such cases, hydropower plants must stop operating when the river discharge falls below the value determined;
5. **Inland fishing:** Interdiction to catch one or more fish species in specific river sections or in certain standing waters in cases in which this is justified during dry periods or hot spells to protect the fish fauna;
6. **Navigation** / Shipping Lanes: Less load or restriction of navigation during low flow, adapt the size of ships, deepen the navigation channel, thus granting navigation even during low flow;
7. **Agriculture**: Adapt existing practice (recovering of precipitation water, choice of suitable plant species requiring less water, use of irrigation techniques using less water, e.g. drip irrigation, etc.);
8. **Recreation**: Use Water Nature Trails to attract the attention to the abundance of nature and to the development of climate change, to flood risks, etc.

In future, within the ICPR or within bilateral arrangements, international coordination concerning the planned approaches should be further intensified in the entire catchment, in particular in transboundary areas. This above all concerns an exchange of information before implementing national measures during extreme events along border waters. In order to avoid doubts of users, similar regulations should apply simultaneously on both sides of border waters.

[20] In Germany, due to the nuclear phase-out and the extension of renewable sources of energy, power production in thermal power plants is already changing and, in future, this trend will continue. Due to the impact on thermal loads, reliable prognosis of the further development would be an important basis to improve the prognosis of temperature developments of rivers and would offer a basis for decisions on required measures in this field.

For national authorities, a good basis for decision-taking, suitable emergency concepts and good communication concerning decisions made are important.

In order to achieve a uniform approach in extreme situations it would be helpful to draft relevant recommendations. The ICPR could act as a platform for such discussions. These recommendations should include strategies for surveillance, information strategies and criteria for issuing derogations.

Annex 1: Choice of international and national publications on the adaptation to climate change

International Commission for the Protection of the Rhine (ICPR)

„Wärmebelastung der Gewässer im Sommer 2003 – Zusammenfassung der nationalen Situationsberichte", IKSR, Fachbericht Nr. 142, www.iksr.org

„Maßnahmen bezogen auf die Wärmebelastung des Rheins in extremen Hitze- und Trockenperioden – Überblick und Zusammenstellung der Länderberichte", IKSR, Fachbericht Nr. 152, 2006, www.iksr.org

"Analysis of the state of knowledge on climate changes so far and on the impact of climate change on the water regime in the Rhine watershed" ICPR report no. 174, 2009 www.iksr.org

„Sediment Management Plan Rhine", ICPR report no. 175, 2009, www.iksr.org

"Study of scenarios on the discharge regime of the Rhine" ICPR report no. 188, 2011, www.iksr.org

„ICPR Workshop: Effects of climate change on the Rhine river district" (30 and 31st January 2013 in Bonn), www.iksr.org

"Present State of Knowledge on possible Consequences of Changes of the Discharge Pattern and Water Temperature on the Rhine Ecosystem and possible Perspectives for Action", ICPR, report no. 204, 2013, www.iksr.org

"Development of Rhine water temperatures based on validated temperature measurements between 1978 and 2011", ICPR, report no. 209, 2013, www.iksr.org

"Estimation of the effects of climate change on future Rhine water temperature development, based on climate scenarios - short version - 2014 - ICPR report no. 213, 2014, www.iksr.org

"Estimation of the effects of climate change scenarios on future Rhine water temperature development" – Extensive version (nur in englischer Sprache), ICPR report no. 214, 2014, www.iksr.org

"Communiqué of the 15th Conference of Rhine Ministers, 28 October 2013, Basel", ICPR 2013

Intergovernmental Panel on Climate Change (IPCC)

"Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", IPCC, 2012 http://www.ipcc.ch

„Climate change and water", IPCC Technical Paper VI, 2008 http://www.ipcc.ch

„Climate Change 2007: Synthesis Report", IPCC, 2007. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

UN Economic Commission for Europe (UN-ECE)

„Guidance on Water and Adaptation to Climate Change", UNECE, UN Publications, 2009 http://www.unece.org/fileadmin/DAM/env/water/publications/documents/Guidance_water_climate.pdf

UN Framework Convention on Climate change (UNFCC), Submitted National Communications

http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/4903.php

European Union

European Commission, The 'Blueprint to safeguard Europe's water resources', 2013
http://ec.europa.eu/environment/water/index_en.htm

European Commission, Guidelines on developing adaptation strategies, 2013
http://ec.europa.eu/clima/policies/adaptation/what/docs/swd_2013_134_en.pdf

EEA data base climate adaptation strategy:
http://www.eea.europa.eu/themes/climate/national-adaptation-strategies

"Background Document on the Inventory of Measures", "Inventory of Measures" Projekt ClimWatAdapt, 2010
"Full 2nd workshop report" und "Tool for the selection of adaptation measures", ClimWatAdapt workshop, März 2011, http://www.climwatadapt.eu; Tool: http://www.tiamasg.com/mDSS/wDSS1/#/Start

"Thematic workshop on Climate Change and Flooding - 8-10 September 2009, Karlstad, Sweden", Report on Proceedings and Key Recommendations, CIS/Working group F, 2011
"Draft Report of the Working Group F Climate Change Adaptation workshop" (Draft version no. 3, 04.04.2013), CIS/Working group F, 2011 https://circabc.europa.eu

„The european environment state and outlook 2010 – Mitigating climate change", EEA Report, 2010 http://www.eea.europa.eu/soer/europe/mitigating-climate-change

„River basin management in a changing climate – Guidance document No. 24", Common Implementation Strategy (CIS) for the WFD (2000/60/EC), Technical Report, 2009
http://ec.europa.eu/environment/water/adaptation/index_en.htm

"Report on good practice measures for climate change adaptation in river basin management plans", EEA-EIONET, 2009. http://icm.eionet.europa.eu/ETC_Reports/

Strategic Initiative Cluster „Adaptation to the Spatial Impacts of Climate Change":
http://www.sic-adapt.eu/

International Commission for the Protection of the Moselle and Saar (ICPMS)

Ermittlung der möglichen Auswirkungen des Klimawandels im Mosel- und Saareinzugsgebiet, Broschüre FLOW-MS, 2013
http://www.iksms-cipms.org/servlet/is/60264/Broschuere-Klimawandel.pdf?command=downloadContent&filename=Broschuere-Klimawandel.pdf

International Commission for the Protection of the Danube River (IKSD)

„ICPDR Strategy on Adaptation to Climate Change"
http://www.icpdr.org/main/activities-projects/climate-adaptation
http://www.icpdr.org/main/climate-adaptation-strategy-published-print

International Commission for the Meuse

Results of the AMICE project (state: April 2013) http://www.amice-project.eu

Alp region

"Adaptation to climate change in the Alpine Space (AdaptAlp)": http://www.adaptalp.org/

"Climate change, impacts and adaptation strategies in the Alpine Space" (CLIMCHALP): See also http://www.adaptalp.org/

Central Commission for Navigation on the Rhine

„Klimawandel und Rheinschifffahrt", Beschluss 2011-II-9 der Herbstsitzung 2011 der Zentralkommission für die Rheinschifffahrt (ZKR) vom 30. November 2011. CC/R 2011 II, S. 75. http://ccr-zkr.org/13020400-de.html

International Commission for the Hydrology of the Rhine Basin

"Socio-economic influences on the discharge of the River Rhine", Seminar 26.-27. März 2014, Bregenz (Austria) http://www.chr-khr.org

Germany

„DAS - Deutsche Anpassungsstrategie an den Klimawandel", Bundeskabinett, 2008
URL: http://www.bmu.de/klimaschutz/downloads/doc/42783.php

Strategiepapier „Auswirkungen des Klimawandels auf die Wasserwirtschaft - Bestandsaufnahme und Handlungsempfehlungen", LAWA, März 2010
URL: http://www.lawa.de/documents/LAWA_Strategiepapier_1006_d07.pdf

„Klimawandel – Herausforderungen und Lösungsansätze für die deutsche Wasserwirtschaft", DWA-Themen, DWA, 2010

„Empfehlungen zur Aufstellung von Hochwasserrisikomanagementplänen", LAWA, März 2010

„Leitlinien für ein nachhaltiges Niedrigwassermanagement", LAWA, 2007

„Anpassung an Klimaänderungen in Deutschland – Regionale Szenarien und nationale Aufgaben", UBA, 2006 http://www.umweltbundesamt.de/uba-info-medien/3545.html

„Climate change in Germany: vulnerability and adaptation of climate sensitive sectors", UBA, 2005 http://www.umweltdaten.de/publikationen/fpdf-l/2974.pdf

„Development of a „Screening Tool" for climate proofing of water management Measures", UBA, 2013

„Hochwasser-Abflussprojektionen und Auswertungen", KLIWA – 5. KLIWA-Symposium, KLIWA-Berichte Heft 19, Dezember 2013 http://www.kliwa.de

Kompetenzzentrum Klimafolgen und Anpassung (KomPass) www.anpassung.net

„Klimawandel im Süden Deutschlands: Ausmaß – Auswirkungen – Anpassung", KLIWA – Klimaveränderung und Konsequenzen für die Wasserwirtschaft, 2012
http://www.kliwa.de

„Klimawandel und Wasserwirtschaft: Maßnahmen und Handlungskonzepte in der Wasserwirtschaft zur Anpassung an den Klimawandel", Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz NRW, 2011
http://www.umwelt.nrw.de/klima/pdf/broschuere_klima_und_wasser.pdf
http://www.klimawandel.nrw.de

Regierung von Unterfranken 2012: „Alarmplan für den bayrischen staugeregelten Main" – Gewässerökologie.
http://www.regierung.unterfranken.bayern.de/aufgaben/6/3/00756/index.html

Netherlands

"Een frisse blik op warmer water", RWS/STOWA, Amersfoort, oktober 2011

"Impact klimaat op oppervlaktewater als bron voor drinkwater – van knelpunten naar maatregelen", RIVM, 2013

"Invloed van steden en klimaatverandering op de Rijn en de Maas", Deltares, 2010

"Nationaal Waterplan 2009 – 2015", Ministerie van Infrastructuur en Milieu, Dezember 2009. http://www.rijksoverheid.nl/documenten-en-publicaties/vragen-en-antwoorden/wat-is-het-nationaal-waterplan.html

"Deltaprogramma 2015", Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken, Landbouw en Innovatie, September 2014

- http://www.rijksoverheid.nl/onderwerpen/deltaprogramma (niederländisch)
- http://www.deltacommissaris.nl/english/ (englisch)
- http://www.deltacommissaris.nl/english/Images/Delta%20Programme%202015%20English_tcm310-358177.pdf (englischsprachiger Bericht)

"Water shortage and climate adaptation in the Rhine Basin", Inspiration Document Based on the International Rhine Basin Conference (29-31 October 2012, Kleve), Provincie Gelderland, 2013, www.gelderland.nl/klimaatconferentie2012

France

Project „Explore2070", Ministère de l'Ecologie, du Développement durable et de l'Energie (2010-2012), http://www.developpement-durable.gouv.fr/Evaluation-des-strategies-d.html

„Plan national d'adaptation au changement climatique 2011-2015", Ministère de l'Écologie, du Développement durable, des Transports et du Logement, Juli 2011
http://www.developpement-durable.gouv.fr/Le-Plan-national-d-adaptation,22978.html
http://www.developpement-durable.gouv.fr/The-national-climate-change.html (english)

Older studies and reports of the ONERC (Observatoire National sur les Effets du Réchauffement Climatique – Nationale Beobachtungsstation der Auswirkungen des Klimawandels) http://www.developpement-durable.gouv.fr/-Publications-de-l-ONERC-.html

Switzerland

„Anpassung an den Klimawandel in der Schweiz - Ziele, Herausforderungen und Handlungsfelder", Erster Teil der Strategie des Bundesrates vom 2. März 2012,
http://www.bafu.admin.ch/publikationen/publikation/01673/index.html?lang=de

„Anpassung an den Klimawandel in der Schweiz im Sektor Wasserwirtschaft, Beitrag des Bundesamtes für Umwelt zur Anpassungsstrategie des Bundesrates", Januar 2012
http://www.bafu.admin.ch/klimaanpassung/index.html?lang=de

„Auswirkungen der Klimaänderung auf Wasserressourcen und Gewässer", Synthesebericht zum Projekt «Klimaänderung und Hydrologie in der Schweiz» (CCHydro), 2012.
http://www.bafu.admin.ch/publikationen/publikation/01670/index.html?lang=de

„Nachhaltige Wassernutzung", Nationales Forschungsprogramm NFP61, http://www.nfp61.ch/D/Seiten/home.aspx

„Umgang mit lokaler Wasserknappheit in der Schweiz" – Bericht des Bundesrates zum Postulat „Wasser und Landwirtschaft". Zukünftige Herausforderungen". BAFU, 17.10.2012.
http://www.news.admin.ch/NSBSubscriber/message/attachments/28597.pdf

Austria

„Österreichische Strategie zur Anpassung an den Klimawandel", Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2012.
http://www.bmlfuw.gv.at/umwelt/klimaschutz/klimapolitik_national/anpassungsstrategie/strategie-kontext.html

"Anpassungsstrategien an den Klimawandel für Österreichs Wasserwirtschaft" (Langfassung), Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2010.
http://www.bmlfuw.gv.at/publikationen/wasser/wasserwirtschaft_wasserpolitik/anpassungsstrategien_an_den_klimawandel_fuer_oesterreichs_wasserwirtschaft.html

„Klima|Wandel|Anpassung": http://www.klimawandelanpassung.at/
Österreichischer Sachstandsbericht Klimawandel 2014, Austrian Panel on Climate Change, 2014. http://www.apcc.ac.at/

ÖWAV-ExpertInnenpapier "Klimawandelauswirkungen und Anpassungsstrategien in der österreichischen Wasserwirtschaft, Österreichischer Wasser- und Abfallwirtschaftsverband, 2014
http://www.oewav.at/Page.aspx?target=65710&mode=form&app=134598&edit=0&current=175698&view=134599&predefQuery=134639

Luxemburg

„Paquet Climat", Partnerschaft für Umwelt und Klima / Partenariat pour la protection de l'environnement et du climat, 2011)
http://www.developpement-durable-infrastructures.public.lu/fr/developpement-durable-infrastructures/partenariat/Paquet_Climat_integral.pdf

„Synthesedokument der Groupe de pilotage für eine nationale Nachhaltigkeitsstrategie", Luxemburg. www.developpement-durable-infrastructures.public.lu

Belgium

„Belgian national climate change adaptation strategy", National Climate Commission, 2010 http://www.flanders.be/en/publications/detail/belgian-national-climate-change-adaptation-strategy

„Plan National Climat de la Belgique 2009 – 2012 - Inventaire des mesures et état des lieux", 2008 www.climat.be/files/7813/8262/1900/PNC_2009-2012-2.pdf

Annex 2: "Guidance values for sensitivity" for floods

(Orientation values for possible adaptation measures)

Fields of action	Guidance value	Representative value	Relevant factor	Possible effects /scenarios (until 2050): Bandwidth (Basis for discussions on adaptation measures)
Flood risk management	**Level of protection/security**	**MHQ (in m^3/s)**	Lobith: 6,680 m^3/s (Dutch data)	0 to +20%
			Cologne: (MHQ year): 6,610 m^3/s MHQ (hydrological summer, May-Oct.): 4,000 m^3/s MHQ (hydrological winter, Nov. - Apr.): 6,510 m^3/s	0 to +20%
			Kaub: (MHQ year): 4,370 m^3/s MHQ (hydrological summer, May-Oct.): 3,240 m^3/s MHQ (hydrological winter, Nov. - Apr.): 4,260 m^3/s	-5 to +25%
			*Worms: (MHQ year): 3,480 m^3/s MHQ (hydrological summer, May-Oct.): 2,870 m^3/s MHQ (hydrological winter, Nov. - Apr.): 3,310 m^3/s	-10 to +20%
			*Maxau: (MHQ year): 3,240 m^3/s MHQ (hydrological summer, May-Oct.): 2,850 m^3/s MHQ (hydrological winter, Nov. - Apr.): 2,980 m^3/s	-5 to +15%
			*Basel: (MHQ year): 3,070 m^3/s MHQ (hydrological summer, May-Oct.): 2,880 m^3/s MHQ (hydrological winter, Nov. - Apr.): 2,520 m^3/s	-5 to +10%
		HQ10 (in m^3/s)	Lobith: 9,500 m^3/s	-5 to +15%
			Cologne: 8,870 m^3/s	-5 to +15%
			Kaub: 5,800 m^3/s	-15 to +15%
			Worms: 4,750 m^3/s	+7% (KLIWA)
			Maxau: 4,100 m^3/s	0 to +5% (KLIWA)
			Basel: 3,980 m^3/s	0 to +5% (KLIWA)
		HQ100 (in m^3/s)	Lobith: 12,700 m^3/s (BfG) - NL: 12,675 m^3/s	Lobith: 0 to +20%
			Cologne: 12,000 m^3/s	0 to +20%
			Kaub: 8,000 m^3/s	-5 to +20%
			Worms: 6,000 m^3/s (without use of retention facilities: 6,300 m^3/s)	+5% (KLIWA; for HQ100 and HQ200)
			Maxau: 5,000 m^3/s (without use of retention facilities: 5,300 m^3/s)	0 to 5% (KLIWA; for HQ100 and HQ200)
			Basel: 4,780 m^3/s	0 to 5% (KLIWA; for HQ100 and HQ200)
		HQextreme (in m^3/s)	Lobith: 16,000 m^3/s	Lobith: -5 to +20%
			Cologne: 15,250 m^3/s (maximum consideration, no calculation value)	-5 to +25%
			Kaub: 10,400 m^3/s	-5 to +25% *(no KLIWA data available)*
			*Worms: 7,600 m^3/s (maximum possible discharge without considering dike breaches)	-15 to +30% *(no KLIWA data available)*
			*Maxau: 6,500 m^3/s (maximum possible discharge without considering dike breaches)	-20 to +35% *(no KLIWA data available)*
			*Basel: 5,480 m^3/s (defined as HQ1000)	-20 to +35% *(no KLIWA data available)*
	Navigation	**HSQ (in m^3/s)** **HSW (in cm or m)**	Lobith: 5,675 m^3/s	0 to +20% (trends for HQ100)
			Cologne: 830 cm = 6,960 m^3/s	0 to +20% (trends for HQ100)
			Kaub: 640 cm = 5,100 m^3/s	-5 to +20% (trends for HQ100)
			*Worms: 650 cm = 4,310 m^3/s	+5% (KLIWA; trends for HQ100)
			*Maxau: 750 cm = 2,800 m^3/s	+4% (KLIWA; trends for HQ100)
			*Basel to Rheinfelden: 2,500 m^3/s	+3% (KLIWA; trends for HQ100)

Remark:
Luxemburg is not located along the main stream of the Rhine (no gauging stations indicated in the table above). All the same, certain adaptation measures have been carried out in water management.
Germany (gauging stations Kaub and Cologne): Further KLIWA-results are expected.
NL (Lobith):
- HQ100 (in m^3/s): For Lobith, 0-10% seem to be more realistic (flooding of dikes).
-HQextreme (in m^3/s) (according to Dutch statements, it is important to take HQextreme into consideration as a representative value): At Lobith, 6% are estimated for the increase of the relevant discharge by 2050.

*: For the gauges on the Upper Rhine at Basel, Maxau and Worms "no statement is possible" for possible climate effects on MHQ and HQextreme, as the bandwidth of modelling results is ≥ 50% and methodical deficits have been pointed out (see ICPR report no. 188, p. 17).
**: so far, the KLIWA project does not include any investigations for HQextrem)

Legend:
HQ10: Flood discharges with a probability of occurrence once in 10 years (highly probable floods).
HQ100: Flood discharges with a probability of occurrence once in 100 years (floods with average probability of occurrence).
HQextreme: Discharge during extreme floods (floods with low probability of occurrence).
MHQ: Arithmetic average of the highest daily discharge values during homogenous periods of time (e.g. hydrological half-year periods) of the period under consideration.
HSW: highest water level (in m)
HSQ: Discharge during highest navigable water level

Sources:
Data: "relevant factor": national data: Gauges in D: German delegation and BfG (Deutsches Gewässerkundliches Jahrbuch), Gauge in NL (Lobith): NL-Delegation, Gauge in CH (Basel): CH-Delegation

Data "Climate Effects (...)":
- ICPR report no. 188, 2011
- Results KLIWA project, state September 2014

Annex 3 "Guidance values for sensitivity" low flow

(Orientation values for possible adaptation measures)

Fields of action	Guidance value	Representative value	Relevant factor	Possible effects /scenarios (until 2050): Bandwidth (Basis for discussions on adaptation measures)
Low flow management	**Low flow management**	**NM7Q (in m³/s)**	Lobith: 624 m³/s (lowest NM7Q during the last 100 years) (Rheinblick2050) 1,150 m³/s (average NM7Q in 30 years) (KHR study)	-10 to +10% (trends for NM7Q during the summer half year)
			Cologne: 702 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Kaub: 536 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Worms: 444 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Maxau: 393 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Basel: 475 m³/s (Period 1869-2009, related to the Swiss so-called NQ-year between May and April) (CH: correct denomination would be MNM7Q, as long standing average of annual NM7Q)	-10 to +10% (trends for NM7Q during the summer half year)
	Freshwater supply	**Minimum discharge (in m³/s)**	Lobith: 1,100 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
	Navigation *The CCNR is presently developing a strategy for adaptation to climate change.*	**GlQ (in m³/s)** The ICPR applies the representative values for navigation only for benchmarking.	Lobith: 1,020 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Cologne: 145 cm = 935 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Kaub: 80 cm = 750 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Worms: 65 cm = 670 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Maxau: 360 cm = 585 m³/s	-10 to +10% (trends for NM7Q during the summer half year)
			Basel: about 490 m³/s	-10 to +10% (trends for NM7Q during the summer half year)

Remark:
Luxemburg is not located along the main stream of the Rhine (no gauging stations indicated in the table above). All the same, certain adaptation measures have been carried out in water management.
During low flow, the maximum effect is not increasing low flow but the greatest decrease of low flow.

Legend:

NM7Q: Lowest arithmetic average of the discharge values of 7 days during homogenous periods of time (e.g. hydrological half-year periods) of the period under consideration.

GlQ: Equivalent discharge

Sources:

Data: "relevant factor": national data: Gauges in D: German delegation and BfG (Deutsches Gewässerkundliches Jahrbuch), Gauge in NL (Lobith): NL-Delegation, Gauge in CH (Basel): CH-Delegation

Data "Climate Effects (...)": ICPR report no. 188, 2011