Estimation of the effects of climate change scenarios on future Rhine water temperature development
Summary report

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Summary

High water temperatures in the Rhine caused by summer heat periods, particularly the highest average water temperature values of between 28°C (limit set by the directive on fish waters[1]) and 29°C measured in the Middle and Lower Rhine in the summers of 2003 and 2006, led to a discussion of the subject "water temperature and climate change" at the Conference of the Ministers of the ICPR member states in October 2007. An evaluation of existing literature on research results relating to climate change up to and including the beginning of 2009 (ICPR 2009a), commissioned and conducted by the ICPR, contains, among other things, statements on the changes to the Rhine water temperature to date. These statements refer to measurements of individual water levels and limited timeframes. Due to a further commission by the conference of ministers in 2007, the ICPR conducted a scenario study of the discharge regime of the Rhine (ICPR 2011).

Until now there exists no description of the long-term development of the water temperatures for the entire course of the Rhine, and no estimation of the future development of Rhine water temperatures.

At the beginning of 2013 the ICPR published reports on the development of the Rhine water temperatures on the basis of validated temperature measurements from 1978 to 2011 (ICPR 2013a) and on the current state of knowledge on the possible effects of changes to discharge and the water temperature on the Rhine ecosystem, as well as possible perspectives for action (ICPR 2013b).

In July 2012 the expert group within the ICPR, STEMP[2] "temperature model prognoses", was commissioned to draft an assessment of the future development of Rhine water temperatures from Basel to the Rhine delta based on climate scenarios.

The basis for the assessment are the existing water balance and hydraulic wave activity models for the Rhine, which can also simulate water temperatures with a corresponding temperature model. Due to the different areas of application the models that exist for each of the Rhine sections were chosen for the simulation: the model LARSIM (LUBW[3]) for the section Basel to Worms, and SOBEK (RWS[4]) for the section Worms to the Rhine delta. The water level at Worms represents the transition between the two models. Comparative simulations were conducted with the remaining models that exist for partial sections (LARSIM by HLUG[5] and LUWG[6] from Worms to Cologne and QSim by the BfG from Karlsruhe to Lobith), to enable assessment of the model influence (see Figure 1).

[1] Directive 2006/44/EG from 6 September 2006 on the quality of freshwater that requires protection or improvement in order to preserve the lives of fish.
[2] Expert group "Temperature model prognoses" in the Materials Working Group of the ICPR
[3] Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg
[4] Rijkswaterstaat Water, Verkeer en Leefomgeving
[5] Hessisches Landesamt für Umwelt und Geologie
[6] Landesanstalt für Umwelt, Wasserwirtschaft und Gewerbeaufsicht Rheinland-Pfalz

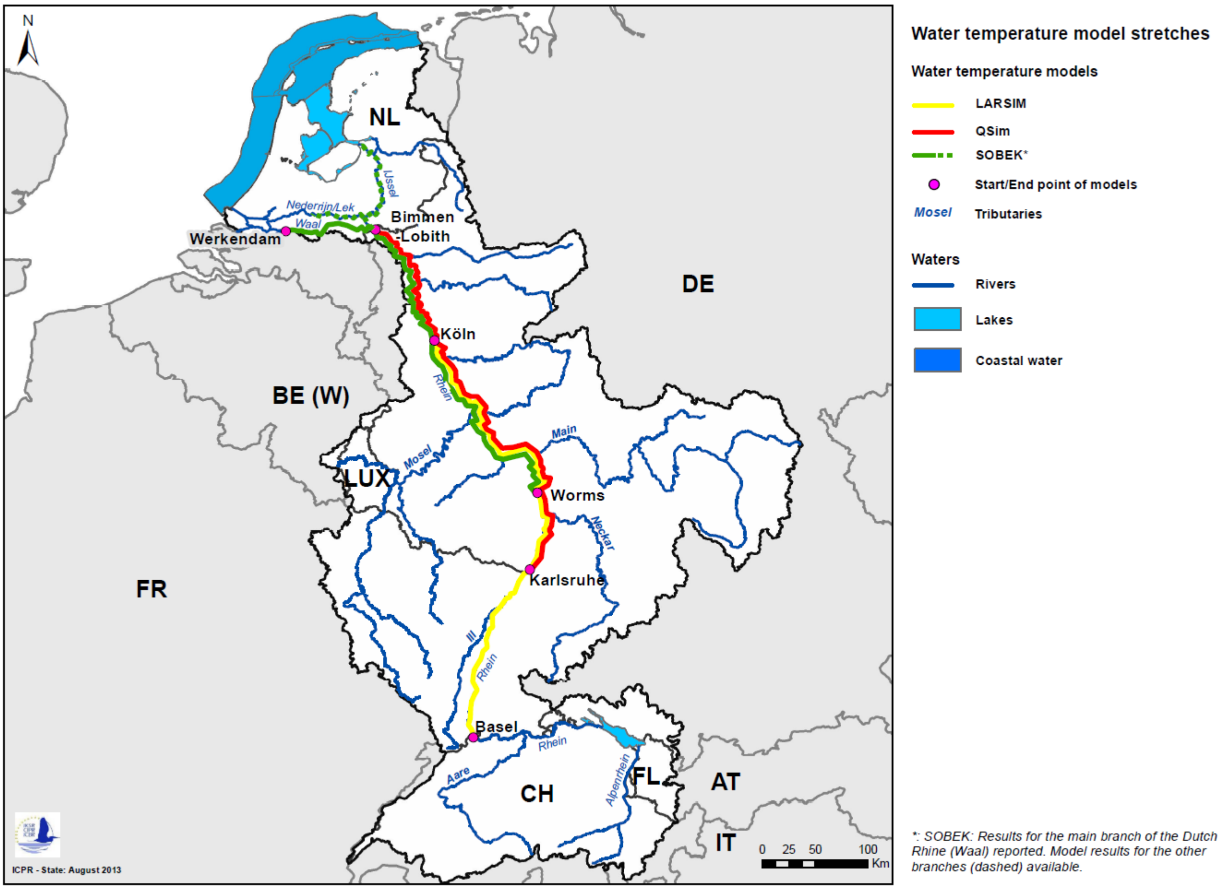


Abb. 1: Map of the area covered by each of the three models LARSIM, QSim and SOBEK along the Rhine

The period 2001-2010 was determined as the reference period. The scenario calculations refer to the climatic and hydrologic scenario studies of the ICPR (ICPR 2011) with the time horizons 2021–2050 (near future, NF) and 2071–2100 (far future, FF), cf. Table 1. Conditions adapted to these scenarios (meteorology and discharge) were calculated for the entire reference period, which is characterised by a large variance in water temperature and discharge. This allows findings to be made on the average change to water temperature in relation to the reference situation (main focus of this study) and on the range of this average value (extremes).

No.	Name	Model simulations	Period	Heat discharge	Atmosphere	Summer discharge	Winter discharge
1	Reference (Ref50)	Reference (current) with heat inputs	2001-2010	50% of permitted 2010	2001-2010	2001-2010	2001-2010
2	Ref. no heat input (Ref0)	Reference (current) without heat inputs	2001-2010	no heat input	2001-2010	2001-2010	2001-2010
3	NF+Qmax	Scenario for the near future with maximum river discharge and heat inputs as in Ref50	2021-2050	50% of permitted 2010	Average summer air temperature +1.5°C	+10%	+15%
4	NF+Qmin	Scenario for the near future with minimum river discharge and heat inputs as in Ref50	2021-2050	50% of permitted 2010	Average summer air temperature +1.5°C	-10%	0%
5	FF+Qmax	Scenario for the far future with maximum river discharge and heat inputs as in Ref50	2071-2100	50% of permitted 2010	Average summer air temperature +4°C	-10%	+15%
6	FF+Qmin	Scenario for the far future with minimum river discharge and heat inputs as in Ref50	2071-2100	50% of permitted 2010	Average summer air temperature +4°C	-25%	-5%

Table 1: Starting point for the model simulations

The model calibrations were done with the actual heat inputs and the hydro-meteorologically measured values for the period 2001 to 2010, or at least for partial periods with contiguous data within the reference period, e.g. July–September 2003.

The comparison of the validation results of the three models LARSIM, SOBEK and QSim demonstrate large agreement between the simulated and measured water temperatures, with the best agreement in LARSIM.

For the scenario observations, climate change vectors were derived from the results of the scenario study of the discharge regime of the Rhine (ICPR 2011) and these were overlaid on the meteorological measurements of the reference period. As the volume and time-related distribution of future heat inputs are unknown, the heat input for all scenarios was set at 50% of the approved discharge values as of 2010. This represents approximately the current heat input for the reference period. At the borders of the models (Rhine at Basel and inflowing tributaries, e.g. Neckar) the water temperatures were simulated with the climate parameters of LARSIM by means of regression models (dependence of the water temperature on atmospheric temperature and discharge) or, in SOBEK and QSim, estimated by means of simplified simulation models. Although the three models used different methods, the differences are small and have hardly any significance for the results.

In the case of SOBEK, results were provided for the section from Worms to the end of the branch of the Rhine, the Waal at Werkendam. The two other branches of the Rhine at the Rhine delta (IJssel to Kampen and Lek to Schoonhoven) were also modelled, but not documented in detail in this report. The model calculations for the two other branches of the Rhine provide comparable results as those for the Waal. For this reason, it was decided to address only the most important branch of the Rhine in the Netherlands in this report, which carries around 2/3 of the water in the entire Rhine delta.

Figure 2 shows selected results of the models. The water temperatures for each scenario are shown as average values for August.

In the reference period 2001-2010 the course of the water temperature – without taking account of heat inputs (Ref0) – show a gradual warming on the section of the Rhine from Basel to Werkendam, whereby the water temperature increases the most in the Upper Rhine as far as Worms. When 50% of the approved heat input (Ref50) in the reference period is considered, this leads to an additional warming of around 1°C on average, particularly downstream from Worms.

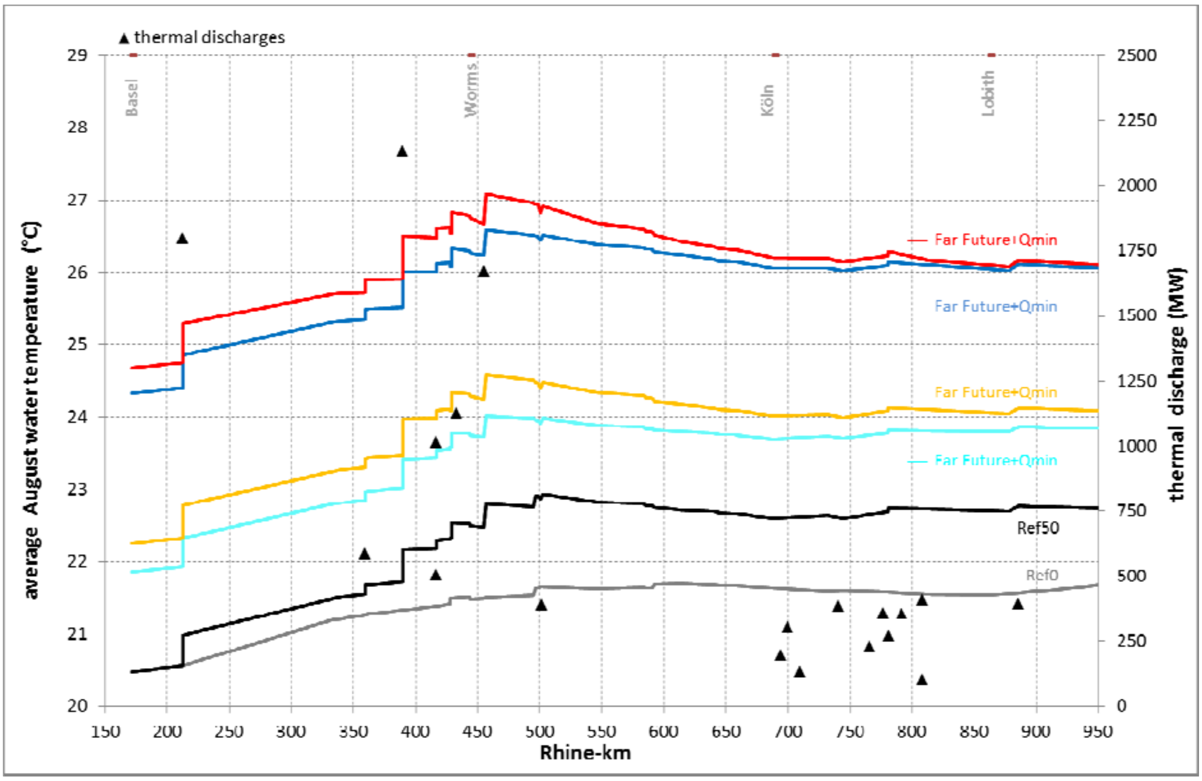


Fig. 2: Longitudinal profile in the Rhine of average August water temperature, simulated with LARSIM (Basel–Worms) and SOBEK (Worms–Werkendam).

In the near future NF (2021-2050) the longitudinal profiles show, in comparison to the reference period, an increased water temperature of around 1.5°C for the month of August, while in the far future FF (2071-2100) the increase in average August temperatures in the Rhine is in the order of 3.5°C. In both cases the warming is due to climatic factors, without any additional effect due to significant heat input. As expected, the increase in water temperatures is lower in the event of high discharge (Qmax) than with low discharge (Qmin). The effects on water temperatures resulting from the two different discharge assumptions for the future are low, compared to the absolute temperature changes due to the assumed climate changes.

The natural variability of climate and discharge values during the reference period also leads to significant variation in the water temperatures. If we compare the average August values in Ref50 with the 90-percent values of the months of August in the period 2001-2010, the latter are 2°C higher than the average August values 2001-2010; the average August values for 2003 are even 3°C higher than the average August values 2001-2010. The average August values for 2003 correspond roughly with the modelled average August values for the far future FF, so that the water temperatures from August 2003 can already be taken as a benchmark for the future water temperatures of the far future FF.

		Basel	Worms	Cologne	Lobith
Ref50: Average August values 2001-2010	T (°C)	20.5	22.5	22.6	22.7
Ref50: 90-Perzentil-Augustwerte 2001-2010	T (°C)	22.4	24.1	24.6	25.3
August 2003: Monthly average value	T (°C)	23.8	26.5	25.6	25.5[7]
FF+Qmax: Average August values 2001-2010	T (°C)	24.3	26.3	26.1	26.0

Table 2: Comparison of the simulation results (Ref50 and FF+Qmax from Fig. 2) with an alternative typology of the reference period: 90-percentile value of August 2001-2010 and monthly average value for August 2003

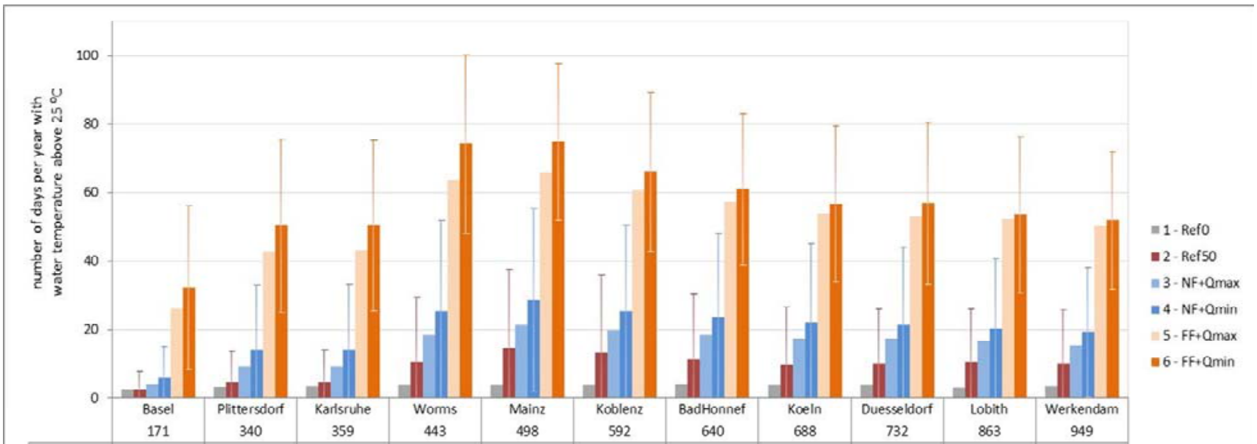
Organisms can function fully (e.g. reproduction) only within a certain temperature range. Temperatures >25°C can cause stress for flora and fauna. For example, if certain fish species are exposed to temperatures >25 °C for a longer period of time, their life expectancy decreases significantly.

Figure 3 shows the days, calculated from the modelled scenarios, on which the water temperature is above 25°C. In the near future NF, the simulations show that the days on which the water temperature is above 25°C increase compared to the reference run Ref50; by up to double in the case of low discharge (Qmin). In the far future FF, the days exceeding 25°C increase greatly. At Worms, for example, the number of days exceeding this temperature will increase in the far future from 11 to between 64 and 74 compared to the reference run Ref50.
In other words, in the far future FF the water temperature at Worms will be above 25°C on average around 10 weeks in the summer.

Figure 3 shows the exceeding days for the different scenarios and the range in which 80% of the calculated results fall in the period 2001-2010. This should illustrate clearly that there will continue to be years without exceeding days in the near future NF. In contrast, there will be hardly any years in the far future FF in which 25°C is not exceeded. The same applies in the far future (FF) in terms of temperatures above 28°C.

Furthermore, corresponding calculations were conducted for days that fall below 3°C, as these phases have a positive effect on the spread of macrozoobenthos species that are typical to the Rhine, and invasive thermophilic species are driven back. In comparison to Ref0 without heat input, the days in the near future on which there is a lower deviation from the temperature on the section at Worms will decline from 10 to 0 days, while on the section to Lobith, which is less influenced by heat input, the number of days with lower temperatures in Ref50 is between 4 and 6, which will reduce in the near future to 1-3 and in the far future to 0 or 1.

[7] The average monthly value of discharges in August 2003 at Lobith was 1013 m^3/s, which is 55% lower than the average discharge in the reference period 2001-2010 (2264 m^3/s) and 50% lower than the average discharge in the scenario NF+Qmin and 40% lower than the average discharge in the scenario FF+Qmin.



	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

Fig. 3: Average number of days per year with a water temperature of more than 25°C in the Rhine profile, calculated by means of LARSIM (Basel-Worms) and SOBEK (Worms-Werkendam). Range in the diagram applies only to the scenarios Ref50, NF+Qmin and FF+Qmin, shows 80% of the calculated variation in the period 2001 -2010. That means that 80% of the values calculated fall within this range.

This summary provides a brief overview of the relevant results of the English-language report “Estimation of the effects of climate change scenarios on future Rhine water temperature development” (cf. CIPR Report No 214). The bibliography can be found in this comprehensive report.