Deltares

The implications of the KNMI’23 scenarios for the Rhine and Meuse rivers

In 2021, the United Nations climate panel (IPCC) published the new version of the international climate report (the Sixth Assessment Report, AR6). The report presented the latest projections for climate change worldwide. The projections are based on the latest scientific knowledge and most recent climate models. On 9 October, the KNMI presented the new Dutch climate projections – the KNMI’23 scenarios – which formulate the IPCC’s global climate projections in terms of the implications for the Netherlands.

The KNMI calculated the projections for the Netherlands and upstream countries in the Rhine and Meuse catchments using its own global and regional climate models. The four scenarios are the corners of the ‘playing field’ of change in the Dutch climate in the future. They can be used for the purposes of, among other things, Dutch climate adaptation policy and applications relating to water management. The KNMI’23 scenarios replace the KNMI’14 scenarios.

At the request of the Ministry of Infrastructure and Water Management, and in collaboration with Rijkswaterstaat Water, Traffic and Living Environment and the KNMI, Deltares analysed the effects of the KNMI’23 scenarios on the discharge regimes of the Rhine and Meuse[1]. The focus in this report is on the seasonal cycle, the mean discharge, the maximum annual discharge and the low river discharge. A second report will be published in 2024 presenting the results for extreme high-water statistics.

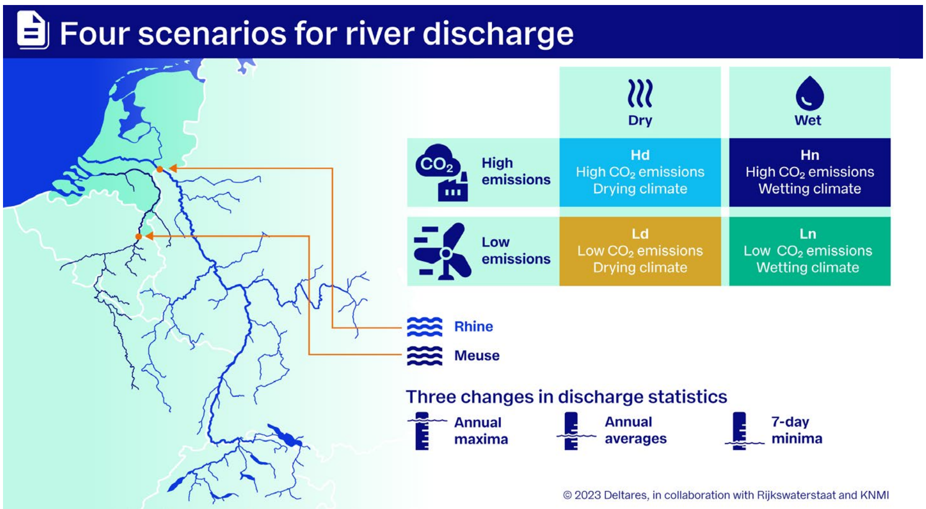

Figure 1 Schematic representation of four KNMI’23 climate scenarios and the resulting discharge projections for the Rhine and Meuse

1 Deltares (2023). Implications of the KNMI’23 climate scenarios for the discharge of the Rhine and Meuse, Deltares report.

The KNMI’23 scenarios

The KNMI’23 climate scenarios describe the possible climate in the Netherlands in 2050, 2100 and 2150. The extent of climate change is determined by worldwide emissions of greenhouse gases. The KNMI adopted two basic assumptions (see also Figure 1):

- A high emissions scenario (‘H’) in which emissions continue to increase steadily until 2080 and then level off. In this scenario, global warming in 2100 will reach almost 5°C;
- A low emissions scenario (‘L’[2]) in which emissions decrease rapidly and greenhouse gases are actively removed from the atmosphere in line with the Paris Climate Agreement. In this scenario, global warming in 2100 will reach 1.7°C. Warming is virtually the same for 2050, 2100 and 2150.

In contrast with the KNMI’14 scenarios, the KNMI’23 report does include the lowest international emissions scenario[3]. This means that these current emissions scenarios cover a larger bandwidth of emissions and, therefore, of climate change. This allows for a more complete and robust risk assessment. For specific applications, including these derived discharge scenarios, the KNMI developed climate projections associated with a moderate emissions scenario in addition to the high and low scenarios.

- moderate emissions scenario (‘M’) in which emissions gradually decrease after an initial increase. In this scenario, global warming in 2100 will reach 2.8°C.

Temperatures continue to rise in all the KNMI’23 scenarios. This increase will result in drier summers and wetter winters. The climate models differ in terms of the extent to which seasons will be wetter or drier. The KNMI therefore drew up two variants for each emission scenario (see also Figure 1):

- a ‘wet’ climate scenario (‘n’) in which winters will be much wetter and summers slightly drier.
- a ‘dry’ climate scenario (‘d’) in which winters will be slightly wetter and summers much drier.

In summary, a total of fifteen climate scenarios were analysed to determine the effects on the discharge of Rhine and Meuse (see Table 1).

2 In the case of the L scenario, the change in discharges was determined only for 2100. The change for 2050 and 2150 is nearly the same, and we assume that the change for 2100 is also representative for these years.

3 SSP1-2.6 / RCP2.6; A proposal for a new scenario framework to support research and assessment in different climate research communities - ScienceDirect

Tabel 1: An overview of the scenarios used for the calculations

Time horizon	Low	Moderate	High
2033	2033L (Paris)		
2050		2050Mn / 2050Md	2050Hn / 2050Hd
2100	2100Ln / 2100Ld	2100Mn / 2100Md	2100Hn / 2100Hd
2150		2150Mn / 2150Md	2150Hn / 2150Hd

How were the effects of the KNMI’23 scenarios on the Rhine and Meuse discharges determined?

The climate scenarios were derived by the KNMI for the entire international catchments of the Rhine and Meuse rivers and for the Netherlands.

Discharge time series for the current and future climate (2050, 2100 and 2150) were calculated using the hydrological model wflow_sbm (referred to below as wflow). In recent years, Deltares developed and validated the models for the Rhine and Meuse (see Figure 2) for Rijkswaterstaat Water, Traffic and Living Environment. The KNMI’14 scenarios still calculated river discharges with the hydrological model HBV, which schematised the tributaries using a single point. The wflow grid model makes much better use of the high-resolution datasets with global coverage from satellites and climate models that are becoming increasingly available. In addition, a grid model of this kind accounts better for spatial variation in elevation, land use and soil types.

Wflow uses precipitation, temperature and evaporation as boundary conditions. KNMI provided this data on a

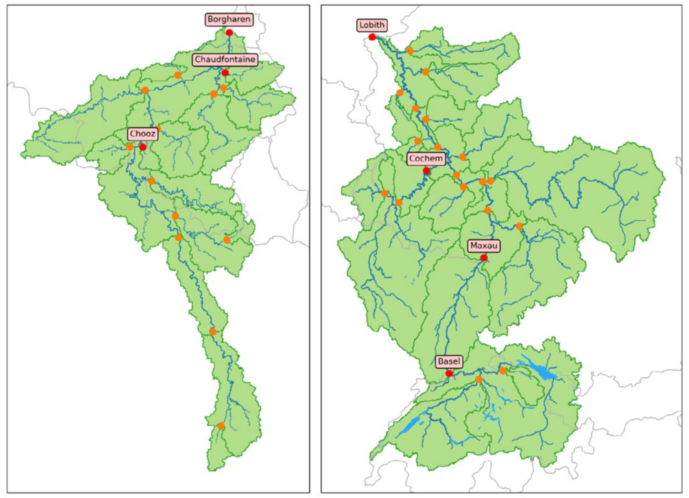

Figure 2 The Meuse (left) and Rhine (right) catchments as included in the hydrological wflow models used for these analyses with the main monitoring stations and the river network

daily basis for all the KNMI’23 scenarios described here. In wflow, precipitation can fall as snow or rain depending on the air temperature. The model also includes snow and glacier melt. For each time horizon, initial glacier volumes were calculated carefully since they will decrease over time as a result of rising temperatures. In this way, we use wflow to determine, for each of the climate scenarios, how much water goes to discharge in the catchments and what the implications of climate change are for the discharge regime in the principal Rhine and Meuse rivers at the Dutch border.

Given the much higher resolutions, the wflowmodel is able to calculate with much more realistic boundary conditions than the old HBV model. We therefore consider the results to be more reliable. Nevertheless, the validation of the model still showed discrepancies for the Rhine between the simulated and historically observed discharges. In order to make it possible to use the calculated discharges for

low-water management in the Netherlands, a discharge correction was made for the Rhine. Here, the simulated monthly discharge distribution was brought into line with the measured discharge distribution. A similar correction was made for the simulations of Rhine discharges in the future. In the case of the Meuse, the model variations were minimal and no corrections were required .

How will discharges change?

Climate change will lead to further increases in temperatures in both catchments. In the high scenarios, temperatures could rise by as much as an average six degrees by 2150 in the Rhine and Meuse catchments. The rise in temperature will result in an increase in water losses through evaporation. In addition, the climate scenarios also predict changes in precipitation. These changes vary by season and sub-catchment. The expected change in discharges for each river is explained in greater detail below. These analyses were conducted on the basis of eight time series, each covering a period of thirty years, that are representative for the baseline and for the years 2050, 2100 and 2150.

The Rhine

Water enters the Rhine directly from precipitation that falls across the catchment. In addition, snowmelt in the Alps is an important source. During the winter months, precipitation in the Alps is temporarily stored as snow that then enters the river in the spring and early summer. As temperatures rise, the thickness of the snowpack will decrease. More precipitation in the winter will then be discharged directly, resulting in higher annual winter discharges. There will also be less meltwater from snow in the early summer, and so discharges in the summer will decrease. The Alpine glaciers are a source of water for the Rhine, particularly in late summer. However, the volume of the glaciers is declining rapidly and they will virtually disappear by the end of the century.

Changes in the contributions from different sources are reflected in the derived discharge projections. The change in the mean annual discharge is uncertain. The trend depends primarily on the dry and wet variants in the scenarios. On the basis of current knowledge, the probability of these variants is considered to be equally high. The annual winter discharges are clearly larger in all scenarios and the annual summer discharges are smaller. The projections for all the moderate and high scenarios indicate an increase in the maximum annual discharges of 5 to 25% by 2100. The minimum discharge over a period of seven days (an indicator for periods of drought) will be lower in all wet and dry scenarios. The decrease varies between 10 and 30% for 2100 (see Figure 3).

Minimum discharge of the Rhine

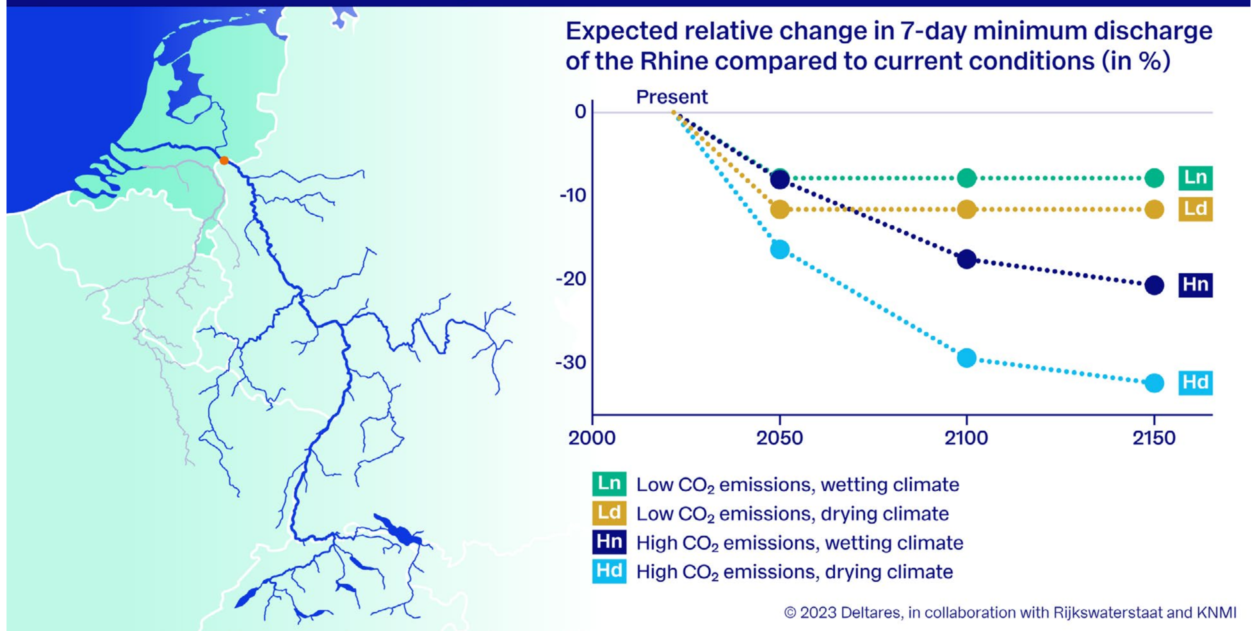

Figure 3 Change in minimum discharge in the Rhine on the basis of the four KNMI'23 scenarios

The Meuse

Most of the water entering the Meuse comes from precipitation. There is snow for several weeks a year, particularly in the higher part of the catchment. The snow can result in a temporary increase in the discharge but the effect is much smaller than in the Rhine.

The scenarios do not provide a consistent picture with respect to the change in the maximum annual discharge (see Figure 4). More scenarios indicate a decrease in the mean annual discharge of the Meuse rather than an increase. Most scenarios predict a rise in the annual winter discharge and all scenarios predict a fall in the annual summer discharge. All the scenarios show a decrease for the minimum 7-day discharge. The largest decrease of 30% for 2150 is seen in the dry H scenario.

Main differences compared to the KNMI'14 scenarios

To understand the possible implications of the new scenarios for water management, we compare the discharge projections based on the KNMI'23 scenarios with the earlier projections based on the KNMI'14 scenarios. As was also pointed out in the introduction, several steps have changed since the drafting of the climate projections for the KNMI'14 scenarios, and that also applies to the derivation of the discharge scenarios. As a result, the KNMI'14 and KNMI'23 projections cannot be compared in a straightforward way. However, it is possible to compare the trend, rate of change and internal consistency of the scenarios as a whole.

Rhine

Both the KNMI'14 and the KNMI'23 scenarios forecast almost no change in the mean annual discharge of the Rhine.

In the case of the minimum 7-day discharge, there are some differences in the direction of change in the KNMI'14 scenarios. According to all KNMI'23 scenarios, the minimum 7-day discharge will fall (see Figure 5). However, the largest decrease based on the KNMI'23 scenarios (30% for 2100) is of the same order of magnitude as the decrease based on the KNMI'14 scenarios.

In the case of the maximum annual discharge, the increases in 2100 based on the KNMI'23 scenarios are smaller than the increases based on the KNMI'14 scenarios in 2085. In the KNMI'23 scenarios, these increases will not be reached until 2150. However, the scenarios are policy-neutral, meaning that no substantial interventions in water management in the international catchment (such as building new reservoirs) are included. It is therefore not yet possible to determine the effect on the climate adaptation agenda of this delay in the increase by comparison with KNMI'14.

Meuse

The KNMI'14 scenarios mostly indicated an increase in the mean annual discharge of the Meuse. The new KNMI'23 scenarios are less consistent in this respect: there are differences in both the direction and magnitude of the change (see Figure 6).

There is more uniformity in the projections for the low discharges. In contrast with the KNMI'14 scenario set, all KNMI'23 scenarios now indicate a decrease in the minimum 7-day discharge. However, the 30% decrease based on the KNMI'23 scenarios is smaller than that indicated by the driest of the KNMI'14 scenarios (55%). Since the Meuse discharge is already small at low water, these are small absolute changes.

Finally, the KNMI'23 scenarios indicate a lower increase in the maximum annual discharge of the Meuse than the KNMI'14 scenarios.

Maximum discharge of the Meuse

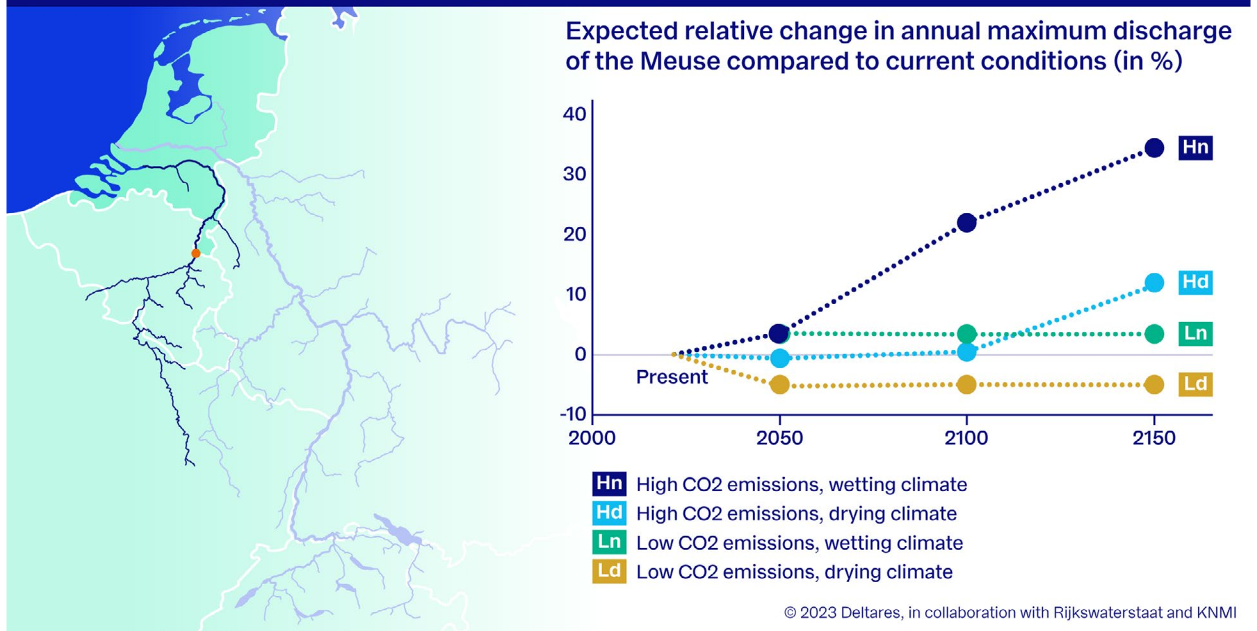

Figure 4 Change in maximum discharge for the Meuse for the four KNMI'23 scenarios

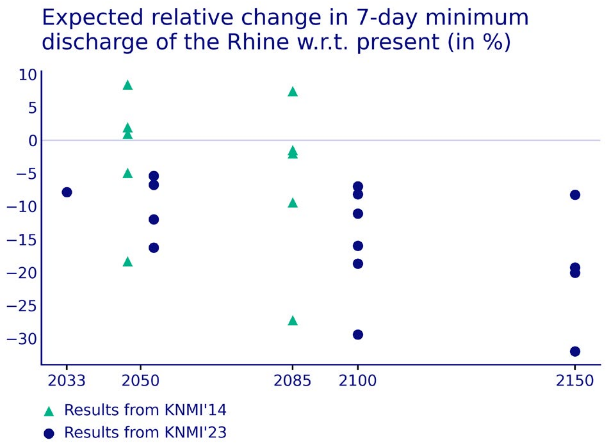

Figure 5 Change in minimum discharge in the Rhine based on KNMI'14 and KNMI'23

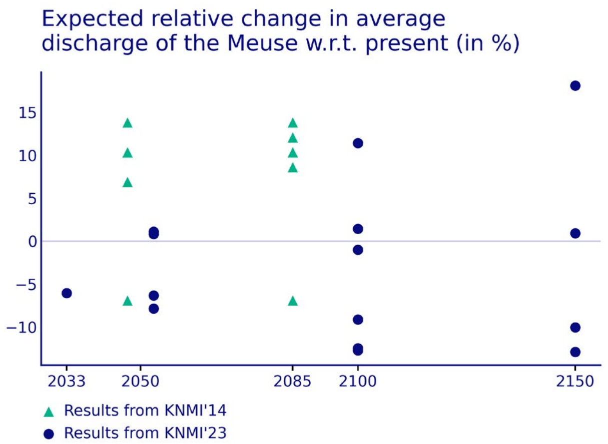

Figure 6 Change in mean discharge for the Meuse based on KNMI'14 and KNMI'23

How can the KNMI'23 discharge scenarios be used?

This study summarises the effects of the KNMI'23 scenarios on mean discharge, the 7-day minimum and the maximum annual discharge. The full report, the underlying simulated time series for daily discharges for the current climate and all future scenarios can be accessed using the link below:

KNMI'23 discharge scenarios Rhine and Meuse - Waterinfo Extra (rws.nl) (in Dutch)

The series can be used for further analyses of climate impact and climate adaptation, for example in the context of the Delta Programme.

The following considerations should be taken into account when using the results for other purposes:

- These future scenarios include only climate change (precipitation, temperature, evaporation). They do not look at the effect of climate adaptation or socioeconomic changes such as changes in river management (reservoirs, for example) or upstream water use;
- The discharge simulations for the Rhine were corrected. Both the corrected and uncorrected series are available for the Rhine. For applications relating to water management, we recommend using the corrected series; the uncorrected series may be more interesting for research purposes.
- The series are intended for analyses of mean and low water conditions. Separate calculations are still being made for high-water statistics. Those calculations will be published in the spring of 2024.

Deltares is an independent institute for applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Deltares is based in Delft and Utrecht.

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