CCNR
CENTRAL COMMISSION
FOR THE NAVIGATION OF THE RHINE

Reflection paper

“Act now!” on low water and effects on Rhine navigation

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Summary and main conclusions of this report

In November 2019, in the aftermath of the 2018 low water event and ten years after a first workshop on “Navigation on the Rhine and climate change” the CCNR organised a workshop on low waters and their effects on Rhine navigation.

During long periods of extremely low waters, it becomes challenging to ensure the continuity of inland waterway transport. This has negative economic consequences. While low water events are not new and are not as such an exceptional phenomenon, the vulnerability of inland waterway transport towards low waters has increased.

This is the result of several factors which are both internal and external to inland navigation. Extreme weather conditions can limit efficient navigation on inland waterways in the short-term, while in the long-term, it might influence the modal choices of shippers. With climate change, this phenomenon could become even more frequent and severe in the future. In addition, over the past decades, the Rhine fleet has changed, both the size and the laden draught of vessels have increased significantly. At the same time, the integration into the logistics chains of the industry, the “Just-In-Time” principle and the associated high demand on the reliability of transport services pose great challenges to IWT. Yet, the inland navigation sector has a vital role to play in achieving the ambitious modal shift and emission reduction targets in the transport sector that have been set at international level, such as the Mannheim Declaration and the European Green Deal. Inland waterway transport will continue to be indispensable, especially for carrying large freight volumes or for the transport of heavy and oversized goods, hence the urgent need to address this challenge.

In 2019, it was concluded that, although there were no “one size fits all” solutions to address the low water challenges being faced by the inland navigation sector, many solutions were available to meet those challenges. A range of actions needs to be taken regarding adaptation of fleet, infrastructure, logistics and storage concepts, as well as implementation of digital tools, to ensure that inland navigation remains a reliable mode of transport. The majority of the required measures are already well known and available, but it is now time to take a first step towards implementation. To support this, there is consensus among inland navigation key actors that funding and financing solutions must be made available.

Another key conclusion of this workshop was the need for a platform to facilitate intensified dialogue between the relevant industrial, logistical, political and environmental organisations. The CCNR appeared as the natural exchange platform on the Rhine. This is how the idea of an “Act now!” process was born. As part of this process, the “Act Now” reflection paper was published in 2020, supplemented in 2021 by an inventory of relevant projects.

Four years later in January 2023, the CCNR organised a follow-up workshop which led to the publication of the present third edition of the reflection paper “Act now!”. During the follow-up workshop, high hopes were expressed that low water phenomena can be tackled. This workshop was timely as the 2022 low water event was a renewed reminder that this age-old phenomenon is an urgent concern, with important impacts.

Today, tangible impacts of these low water phenomena on the inland navigation sector have been observed, in particular the very high risk of a reverse modal shift or seeing certain shippers becoming more reluctant to opt for IWT. Nevertheless, concrete measures have also already been taken by some of these shippers. At the same time, inland waterway maintenance and development is put under pressure, as new environmental legislation and the need for win-win situations to share the available water with other users and for other uses, must be considered.

To improve the inland navigation sector's resilience to low water phenomena, a package of complementary measures must be implemented, in the form of four main levers:

- Digital tools: progress has been made as regards forecasting tools for water levels on the Rhine. The German authorities are now providing low water forecasts for 4 and 14 days ahead for some Rhine gauges relevant to navigation and for some up to 6 weeks. Further improvements are possible with, for example, longer term forecasts or greater forecasting accuracy. Other digital tools may yet be developed, such as 100-year projections of discharges and water levels and the development of waterway digital twins to propose alternative river routes depending on the low water situation.
- Infrastructure: these measures need to be seen in a midterm perspective. Yet they are of significant importance given the sensitivity of the Middle Rhine to low water levels. The package of measures in the "Rhine low water" action plan, which was initiated in Germany in 2019, includes two infrastructure measures for the Middle and Lower Rhine. Due to the urgency of the situation, the German authorities have also set up a commission to accelerate the project to remove bottlenecks along the Middle Rhine. In the Netherlands the development of rivers is tackled in the "Integrated River Management Programme".
- Vessel adaptation: the inland waterway operators and shippers are showing great interest in research projects to do with navigation during low water periods. Investments in newbuilds of dedicated vessels, capable of operating under low water conditions has also increased. The challenge remains to develop innovative vessels capable of operating during low water conditions while remaining economically viable also under other water level conditions. Public funding is important in this regard, such as in Germany and France where such funding possibilities are also available for retrofitting existing vessels.
- Actions at the level of shippers and logistics: such actions can include more long-term chartering contracts with operators equipped with barges still capable of operating when water levels are low, optimised handling, additional storage capacity, and well-prepared communication processes, adding barges to a pushed convoy during low water periods to transport equivalent volumes distributed among more barges, or short-term shift to other modes.

Again in 2023, the need for greater dialogue between the key actors on future measures for adapting to low water conditions and strong cross-border cooperation between the Member States was confirmed. Indeed, just as there is no "one-size-fits-all" solution, nor is there a single actor capable of solving every problem. It is therefore important to encourage private and public initiatives and to catalyse collaborative actions. To support and encourage these discussions, the CCNR will continue to organise these "Low water talks" at regular intervals over the coming years.

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List of abbreviations

B

BAW	Bundesanstalt für Wasserbau (Federal Waterways Engineering and Research Institute, DE)
BfG	Bundesanstalt für Gewässerkunde (Federal Institute of Hydrology, DE)
BMDV	Bundesministerium für Digitales und Verkehr (Federal Ministry for Digital and Transport, DE)

C

CBS	Centraal Bureau voor de Statistiek (Statistics Netherlands) (NL)
CHR	International Commission for the hydrology of the Rhine basin

D

DAS	Deutsche Anpassungsstrategie (German Climate Adaptation Strategy)

E

EDF	Électricité de France (FR)
ESO	European Skippers' Organisation
EBU	European Barge Union

G

GDWS	Generaldirektion Wasserstraßen und Schifffahrt (Federal Waterways and Shipping Agency, DE)
GlW	Gleichwertiger Wasserstand (Equivalent Water Level)
GlQ	Gleichwertiger Abfluss (Equivalent discharge)

I

ICPR	International Commission for the Protection of the Rhine
IPCC	International Panel on Climate Change
IWT	Inland Water Transport

R

RIS	River Information Services
RWS	Rijkswaterstaat (NL)

T

TEU	Twenty-foot Equivalent Unit (Container)

V

VNF	Voies Navigable de France

W

WFD	Water Framework Directive
WSV	Wasserstraßen- und Schifffahrtsverwaltung des Bundes (DE)

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1. Introduction

The first edition of the Reflection Paper was a collection of statements and information shared at the CCNR workshop on low water and effects on Rhine navigation held on 26 November 2019 in Bonn, Germany.

In 2020, the CCNR agreed to extend chapter 5 on "next steps" with an inventory of ongoing measures/projects to help inland navigation overcome the challenges related to low waters. The second edition of the reflection paper was validated by the competent committees at the beginning of 2021 for publication on the CCNR website.

Four years later the CCNR organised a follow-up workshop on "Low water periods and their impact on the navigation of the Rhine" on 18 January 2023 which took stock of the progress made since 2019. The diversity of the parties involved enabled valuable contributions to be gathered, which helped the CCNR to improve and update the reflection paper "Act now!".

The third edition of the Reflection Paper "Act now!" takes into account the outcomes of the workshop on low water of 2019 and of the follow-up expert workshop of 2023.

After setting the context (chapter 1), this paper looks at the impact of low waters on the fleet (chapter 2), the shippers and the logistics (chapter 3), the infrastructure (physical and digital) and environment (chapter 4). It also outlined some possible solutions for the future (chapter 5).

Additions to the second edition are highlighted in orange.

1.1. General information

In the aftermath of the extreme low water event in 2018, the CCNR decided to organise a workshop on low water in coordination with the International Commission for the Protection of the Rhine (ICPR) and the Commission for the Hydrology of the Rhine (CHR). In addition to these two international organisations, 150 participants, including representatives of waterway administrations, ports and terminals, associations of the shipping industry and shippers, environmental associations, engineering offices and river commissions took part. Nine presentations were made and 11 panellists shared their views on low water and discussed the challenges facing Rhine navigation today. The aim of the workshop was to help inland navigation overcome challenges associated with the low water phenomenon and stimulate discussion on strategies for coping with these situations. This was supported by the active participation of high-level attendees from industry, administration, river commissions, universities and research institutes from six European countries as well as representatives from the European Commission. The diversity of participants favoured a discussion on the challenges of low water from several perspectives and forged a unique opportunity to address the points of view from a wide spectrum of inland navigation's key players.

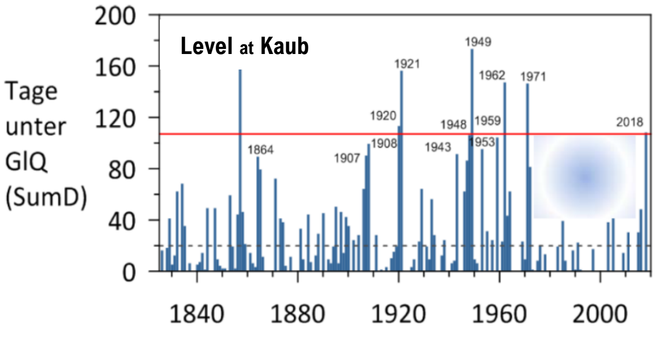
Again in 2023, the need for greater dialogue between the key actors on future measures for adapting to low water conditions and strong cross-border cooperation between the Member States was confirmed. Indeed, just as there is no "one-size-fits-all" solution, nor is there a single actor capable of solving every problem. It is therefore important to encourage private and public initiatives and to catalyse collaborative actions. Events such as the CCNR workshop make for a better understanding of these numerous challenges and are an opportunity to exchange different perspectives and develop common visions. To support and encourage these discussions, the CCNR will continue to organise these "Low water talks" at regular intervals over the next years.

Following on from the workshops held, this paper provides statistics on low water events and their impact, a catalogue of measures in progress and future projects, as well as proposals for short, medium and long-term solutions.

1.2. Hydrology and future effects of climate change

It was highlighted during the workshop that a low water event for the Rhine, with its dynamic water flow, such as that in 2018, was not unprecedented and could therefore be expected to recur. Over the past 200 years, there have been 15 years in which the Rhine has experienced an at least comparable number of days which, in terms of today's infrastructure requirements, would constitute an obstruction to navigation, and five of them were significantly more severe. Admittedly, 14 of these 15 years (2018 is the only exception) were before 1972. In terms of low water discharges, and according to the ICPR low water classification[1], the event on the southern Upper Rhine can be classified as a "rare" event (return period once in 15 years) and for the rest of the Rhine - downstream from Worms - as a "very rare" event (return period once in 40 years). With regard to the duration of low water, the event on the Upper and Middle Rhine can be classified as an "extremely rare" event with a return period of once in 50 years, and for the Rhine below the confluence with the Moselle, as an extremely rare event with a return period of once in 100 years.

Compared to other European rivers, however, the Rhine today has a relatively balanced run-off regime. Climate change effects can be expected to increase in future, making extreme events more severe in intensity and frequency. In addition to extreme events, it is also expected that the Rhine hydrological average regime will change.



- ➔ *Since 1900 11 similar or longer events*
- ➔ *No similar event since 1972 (with the exception of 2018)*

Figure 1: Days with a discharge lower than the equivalent discharge GlQ (Source: WSV)

[1] See also ICPR report on an "Inventory of the low water conditions on the Rhine": https://www.iksr.org/fileadmin/user_upload/DKDM/Dokumente/Fachberichte/EN/rp_En_0248.pdf

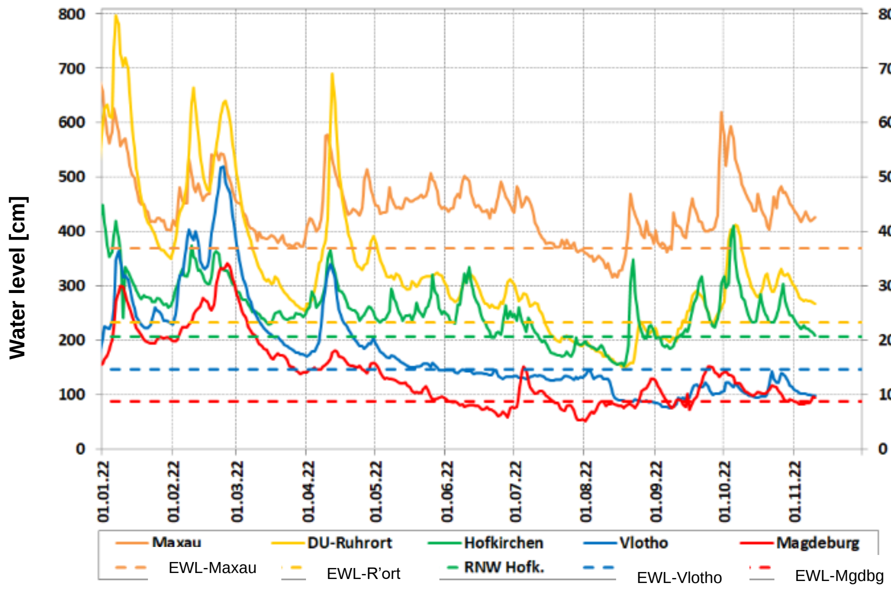


Figure 2: Hydrological situation in 2022 at different European gauge stations (Source: BfG)

Thus, when looking at hydrology and in particular at low water, for medium- and long-term actions, climate change effects need to be considered in order to avoid locking into dead end solutions.

Results from studies conducted under the umbrella of the International Commission for the Hydrology of the Rhine Basin show the effects of climate change of snow and ice melt discharge fractions for several different climate simulations.

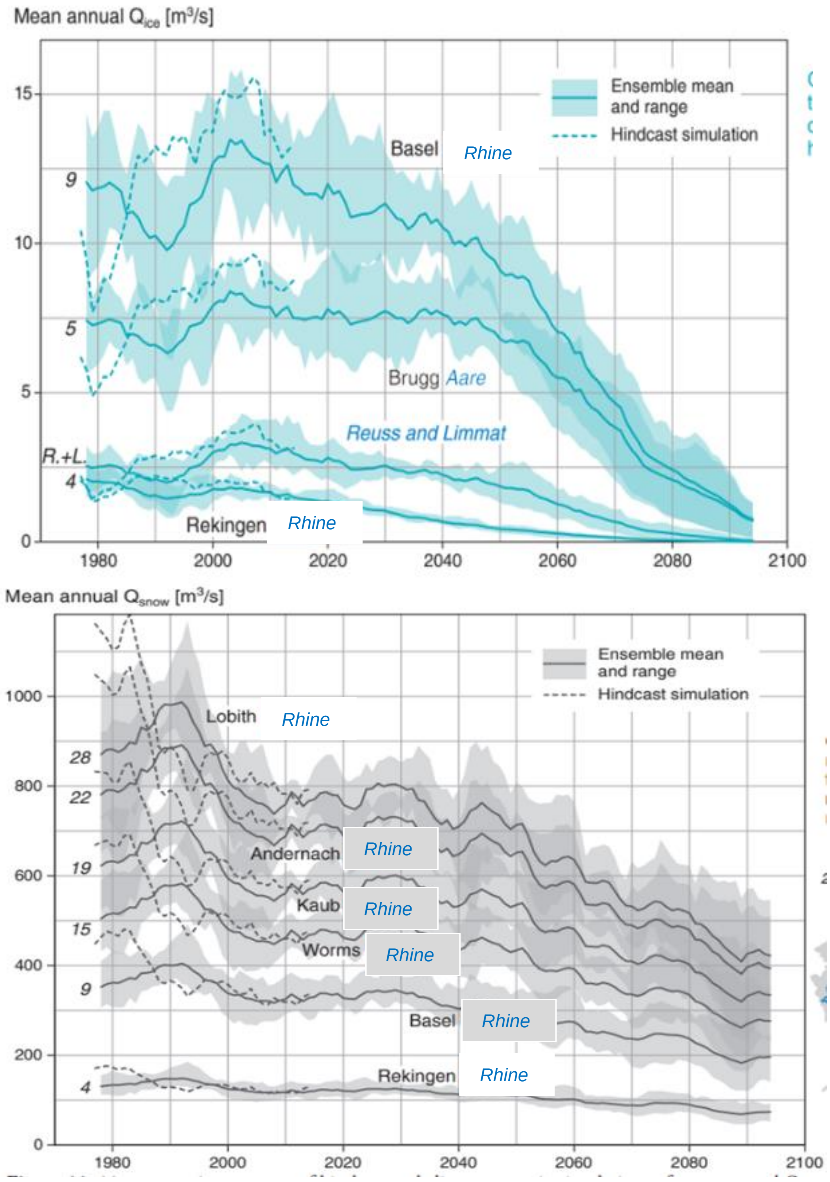


Figure 3: Snow (lower) and ice (upper) melt discharge fractions till the end of the century (Source: Deltares, CHR, Stahl, K. et al, 2022)

The turnaround for the max. contribution of ice has already passed, meaning that the maximum contribution of ice to the overall discharge has already peaked. The same applies for snow. The fraction of ice melt is rapidly decreasing after 2045 and almost disappearing by the end of the century.

These changes in snow and ice melt are not without effect in terms of discharges into the Rhine. The study shows that (given that navigation is impaired in the vicinity of gauge station Kaub at a water level below 78cm (GIW 2012)) restrictions on navigation could prevail, on average, for more than two months per year at the end of the century.

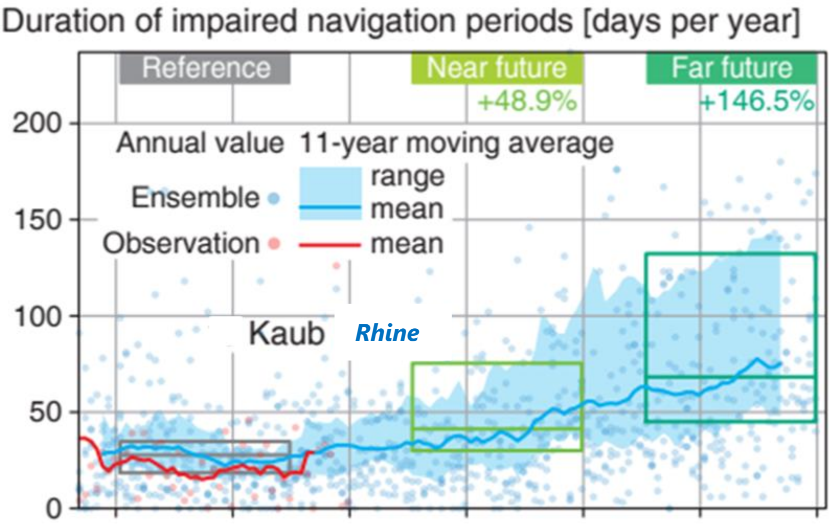


Figure 4: Impaired navigation days at Kaub (Source: Deltares, CHR, Stahl, K. et al, 2022)

The study concludes that melt water from glaciers and snow will be absent in the far future, leading to more frequent low-water events on the Rhine from Basel to the North Sea, meaning longer drought periods and more extreme events. At the same time, water demand by ecology, society and the economic sector will grow, thus increasing low flow risks.

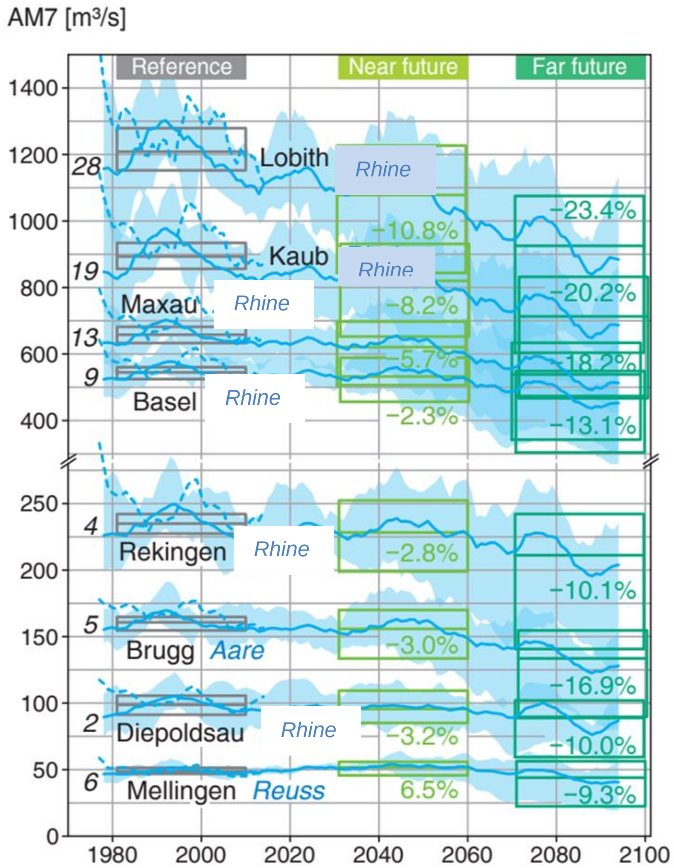


Figure 5: Time series of modeled low flows (annual 7-day-minima) (11-year moving averages). (Source: Deltares, CHR, Stahl, K. et al, 2022)

Conclusion: Based on the models and scenarios used (RCP8.5), it may be assumed that the total Rhine flow will be stable - including in the long run - and that the low flows will remain in the familiar range during the next three decades, after which they will decrease quite rapidly during the following 50 years.

Germany, in the context of the core service "climate and water" of the German Climate Adaptation Strategy (DAS-Basisdienst "Klima und Wasser") is providing 100-year projections of river flow, water levels, and water temperatures at sixteen gauge stations based on current climate model ensembles (e.g. CORDEX, RCP8.5 and other scenarios) for Rhine, Danube, Elbe, Weser, Ems, and coastal waterways with daily resolution. The DAS core service is used as climate data source for adaptation procedures by the German Waterway and Shipping administration (WSV) and supports German government adaptation strategies.

1.3. Morphology

In the shallowest section of the Middle Rhine valley, particularly between Mainz and St. Goar, the low water phenomena are an enormous challenge for inland waterway transport.

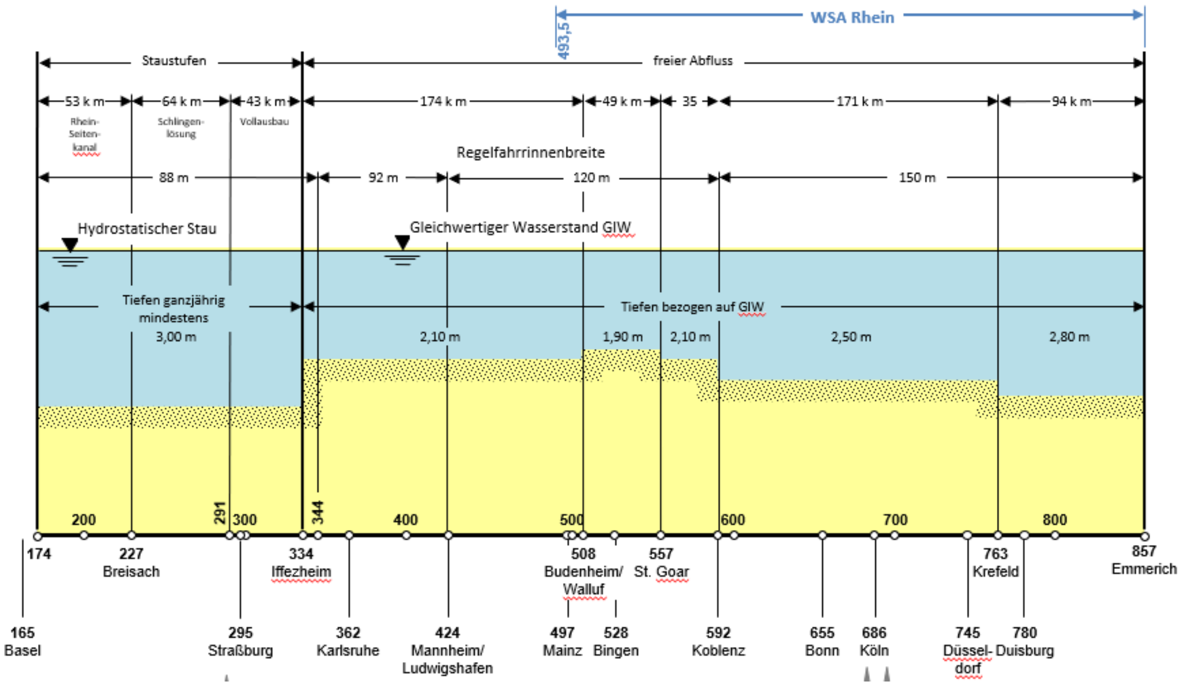


Figure 6: Longitudinal section of the Rhine (Source: WSV)

In this section, a navigable channel depth of 1.90 m is available 345 days per year, classified by the German waterways and shipping administration as a bottleneck. Nevertheless, the Rhine is the most important inland waterway in Europe and Switzerland's gateway to the open sea.

The characteristics of the river bottom differ quite significantly over the different sections, from gravel in the Upper Rhine over a rocky bottom in the Middle Rhine to sandy sediments in the lower Rhine section. These different characteristics have significant impacts on infrastructure solutions, such as dredging or construction of groynes. For more information on Rhine morphology see also the CHR report "From Source to Mouth"[1].

[1] https://www.chr-khr.org/en/publication/source-mouth?from=publications

To improve navigation conditions in the bottleneck section at Kaub, Germany accelerated the project 'Optimisation of laden draughts on the Middle Rhine'[1] to increase the guaranteed navigable channel depth by 20cm from 1.90m to 2.10m at equivalent water level. A dedicated Commission for the acceleration of the project was set up.

1.4. Inland Waterway Transport (IWT)

Since 1945 (5 million tonnes) cargo transported on the Traditional Rhine[2] has been growing constantly until 2008 (207.5 million tonnes) but has followed a rather decreasing trend, to reach 155.5 million tonnes in 2022. Nevertheless, IWT continues to play an important role in achieving the ambitious modal shift and emission reduction targets in the transport sector that have been set at international level, such as the Mannheim Declaration, the EU climate mitigation objectives and the EU's Green Deal.

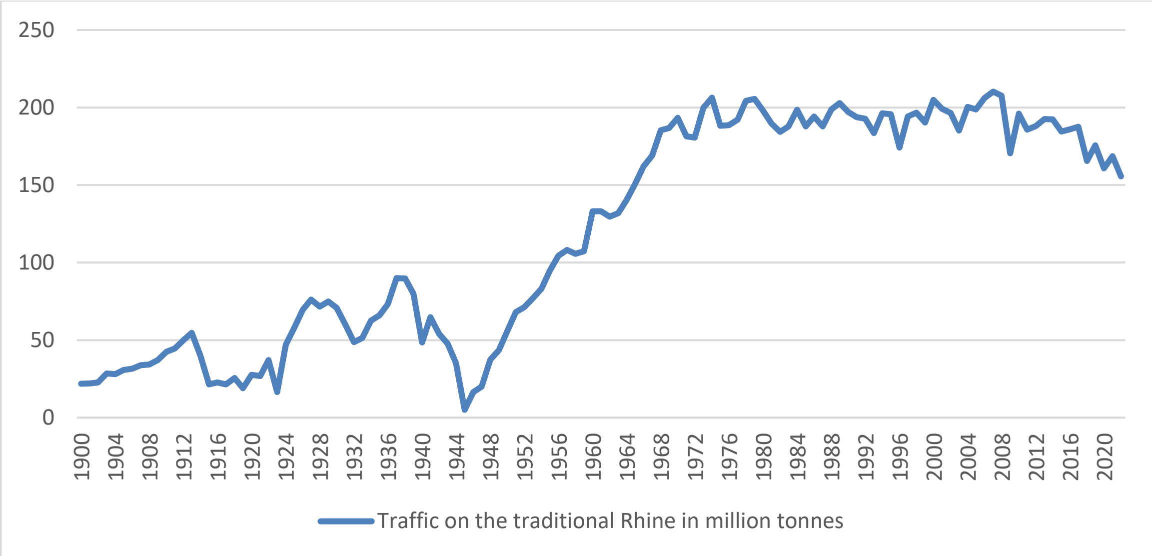


Figure 7: yearly volume of goods transported on the Traditional Rhine (from 1900 to 2022, source: Destatis, CCNR Market Observation)

In the past decades, the traffic increased by a factor of 5 to 10. At the same time, vessels on the Rhine became twice as large and the infrastructure was adapted to the increasing size of ships. However, storage capacity for riparian shippers and the industry decreased significantly. With the hydrology of the Rhine being almost constant, this has led to a significant increase in the vulnerability of Rhine navigation.

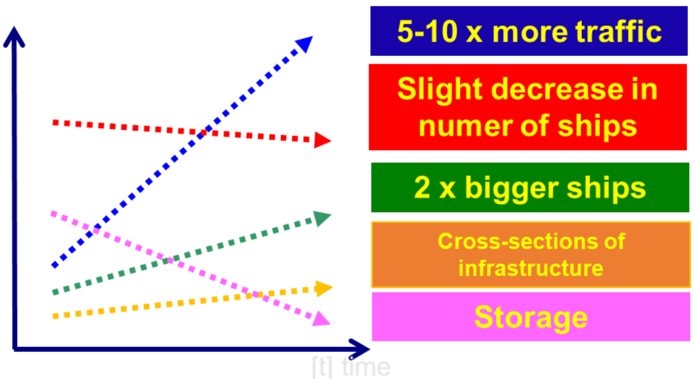


Figure 8: Developments in Rhine navigation (Source: WSV)

[1] https://www.abladeoptimierung-mittelrhein.wsv.de/

[2] Section of the Rhine from Basel to the border between Germany and the Netherlands

It is also important to clarify that:

- Low waters are by far not the only influencing factor for inland waterway transport. They stand next to influencing factors such as the overall stance of macroeconomic development, which is expressed by oil prices, trade volumes, and industrial production.
- The economic impacts of one low water event for a given river cannot be transposed to another year for the same river. The magnitude of the impact of the low water event in 2018 therefore cannot be transposed to 2022.
- Similarly, the economic impacts of one low water event for a given river cannot be transposed to another river.
- At the same time, low water levels on a given river can have strong impacts on other rivers and canals. This was the case of Flanders in 2018 whose waterways suffered greatly from the low waters on the Rhine.

A concrete example lies in the specific macroeconomic conditions in 2022 which were different from 2018 and led to a complex and quite critical situation in 2022. In addition, the 2022 low water event started as early as the second half of July, an earlier date than other low water phenomena observed in the past. Ultimately, even if the number of low water days in 2022 (41) was much lower than in 2018 (107), the negative economic impact was not negligeable.

The specific macroeconomic framework conditions in 2022 can be described as follows. They are almost all linked to the aftermath of the war in Ukraine.

- Energy crisis: sharp surge in energy prices, surge in coal transport demand due to less gas available in the energy sector and soaring oil prices.
- Tensions regarding vessel capacity in Western Europe:
    - A small fraction of vessels in the Rhine region being deployed in Eastern Europe, to help transport grain from Ukraine to Central, Western Europe and other continents. (‘*Solidarity Lanes’*). According to estimates by brokers, around 3% of the dry cargo Rhine vessel capacity was transferred to the Danube region in 2022.
    - Exceptionally high demand for coal: additional strain on vessel capacity.
- Of lesser importance but still relevant: congestion and tensions due to the Covid-19 pandemics are additional factors causing capacity constraints.

A paradox of low water events is that they can lead to positive short-term economic effects for inland navigation operators as a result of increased freight rates (see chapter 2 for more detailed information about the link between low waters and freight rates). This is true only for some inland navigation operators, meaning when navigation is still possible and/or when they can offer barges capable of navigating in low water conditions. In particular, companies operating on the spot market can benefit from low-water surcharges and a more favourable ratio between demand for vessel capacity and the supply of vessel capacity.

For instance, the Flemish government reported in 2023 that the Flemish inland navigation fleet managed to generate extra turnover in 2018 due to the low water levels, which was however partially offset by additional fuel and labour costs. For shippers, however, the damage was much greater. Negative modal shift was also observed in Flanders, in particular in the container and construction materials segments. Ports and large multinationals were also affected due to production restrictions. Lock restrictions also affected the Port of Ghent. Ultimately, an increase in GHG and air pollutant emissions was also observed in Flanders owing to less efficient inland transport operations, This example however supports the affirmation that the positive impact of low waters is only true in the short term and for a specific category of actors. In the long run, low waters have a negative impact on inland waterway transport in the form of huge costs, lack of reliability and reverse modal shift. Thus, it is vital for inland navigation transport to address the low water issue. Ultimately, this situation undermines European environmental and transport policies, the economic vitality of the Rhine area, and affects major industries in Europe, which depend on a seamless supply of goods via waterways, while tourism on waterways is of increasing economic importance.

1.5. Transversal key takeaways

Knowing that the Rhine hydrology is to a large degree a given factor, the solutions to strengthening inland water transport resilience must originate from other factors. However, there are **no "one size fits all" solutions**, therefore a combination of measures is needed. **Measures need to be taken** regarding adaptation of fleet, infrastructure, logistics and storage concepts, as well as the implementation of digital tools, in order to ensure that inland navigation remains a reliable mode of transport and to avoid a permanent shift away from inland waterways to other transport modes. At the same time, the extreme low-water event in 2018 has also shown that such events, with regard to the industrial processes concerned, cannot be controlled by short-term modal shift.

Although water management options are studied for the whole Rhine catchment, it is as yet unclear if such measures can unleash their full potential when draught is affecting the whole catchment and water has to be shared among other users and uses.

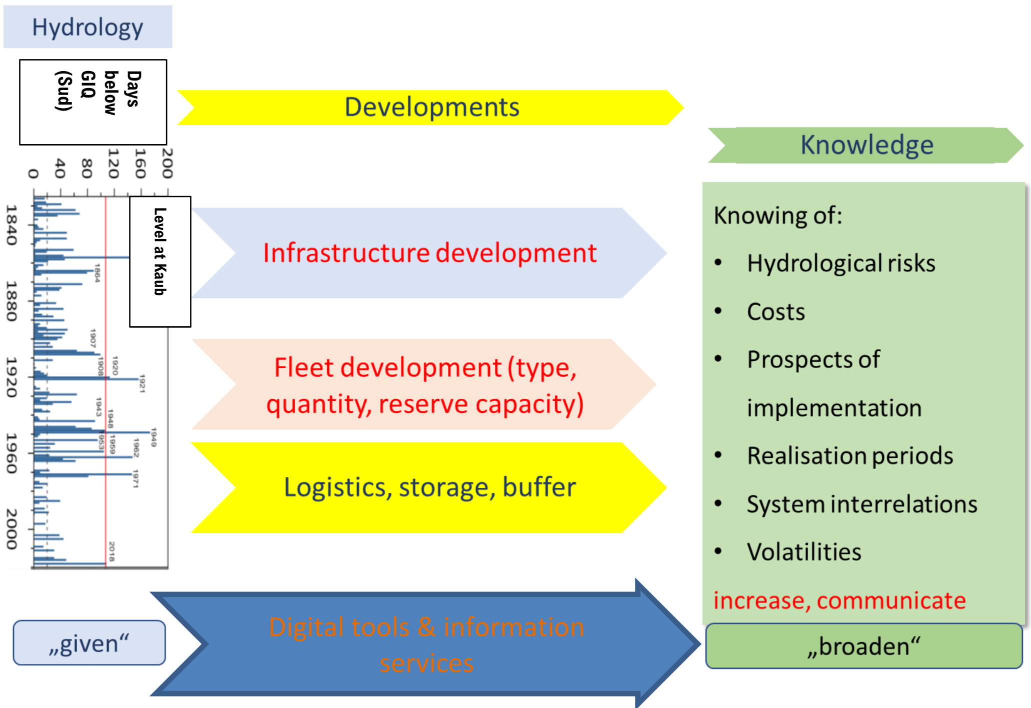


Figure 9: Fields of future activities (Source: WSV, adapted by the CCNR)

The workshops also identified the need for a **continuous intensive dialogue between industrial, logistical, political and environmental stakeholders**. In particular, it is essential to allow these players to put their ideas and visions for the future at the forefront so as to find the right balance between infrastructure and fleet development on the one hand, and preservation of biodiversity and water protection on the other hand. The CCNR could be a platform for this exchange on the Rhine.

The low water in 2018 was a **wake-up call**. Despite their negative consequences, they also allowed the sector to take adaptation measures. The objective is to **act now** and prepare for the future. Initial adaptation measures taken were presented during the 2023 follow-up workshop, demonstrating the resilience of the Rhine ecosystem.

2. Fleet

2.1. Impacts

If the water depth decreases, the ratio between water depth and draught (h/T) also decreases, leading to more resistance and thus a higher demand for power and energy. A decrease in water depth also has further, more dynamic effects on resistance, owing to the squat effect. For a moving vessel, this effect leads to a dynamic sinking of the vessel into the water. The squat effect is stronger the faster the vessel is sailing and the smaller the distance between the vessel's keel and the bottom of the river.[1]

Therefore, less keel clearance at the same speed leads to an increasing sinkage of the vessel and a reduced speed. These effects can be taken into account when discussing design considerations. However, the broader the mission and the operational profile, the harder it will become to optimise a vessel design for specific conditions.

Low discharges on the Rhine lead to low navigable channel depths in the free-flowing sections of the Rhine. The decreasing navigable channel depth has impacts on transport safety, affecting insurance policies, energy consumption and voyage times. It limits the maximum cargo-carrying capacity of a fleet and thus reduces efficiency with further effects on stock and stock management.

[1] See: Rawson, Kenneth J., and Tupper, Eric C. (2001), Basic Ship Theory, Combined Volume, 5th edition. Oxford: Butterworth-Heinemann, p. 561.

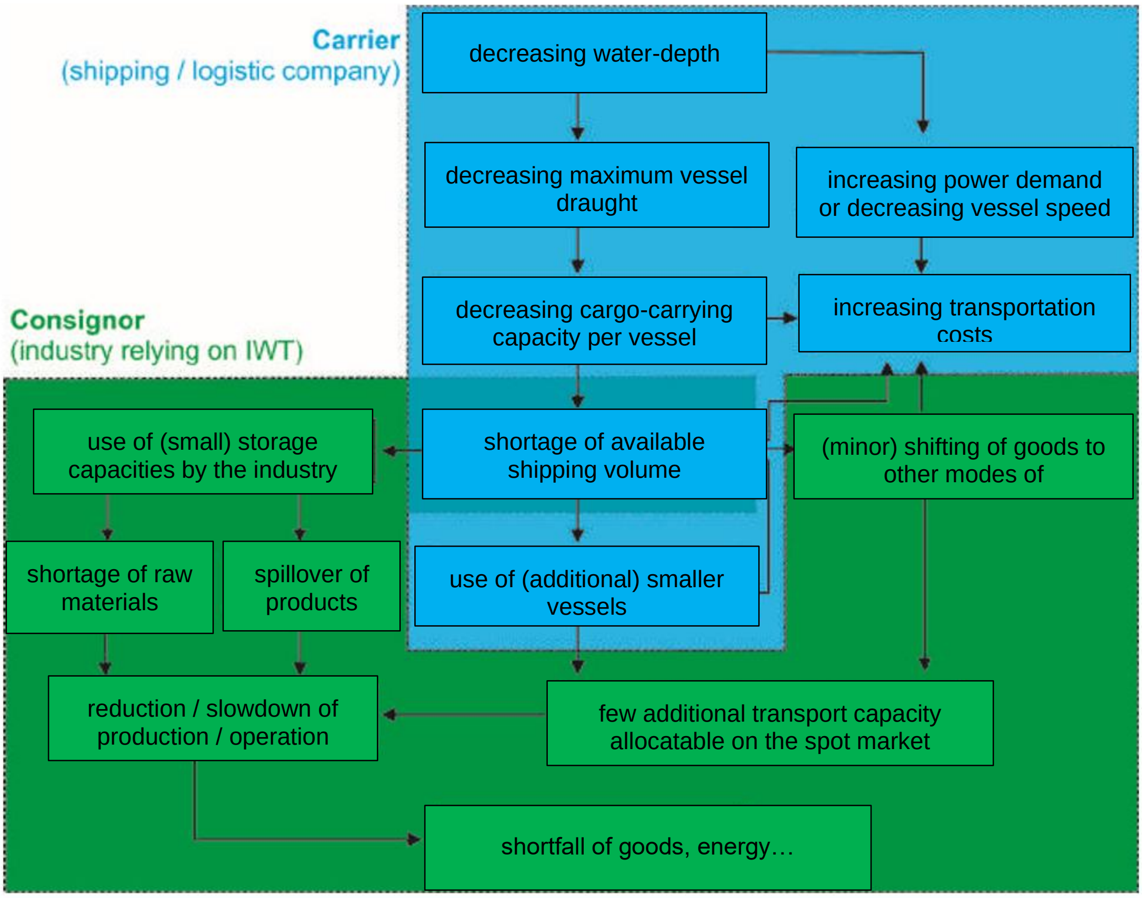


Figure 10: Schematic representation of the functional chain of the vulnerability of IWT due to low water (Source: RWS, IMPREX)

Some vessels simply cannot navigate anymore. In fact, data from the German Waterway and Shipping Administration analysed by the CCNR Secretariat showed that the average vessel capacity of vessels in operation diminished during the low water event of July and August 2022. Indeed, during this low water event, some of the largest vessels could barely use the Middle and Upper Rhine, resulting in a lower average vessel capacity in the observed operational figures. Reduced capacity can also be caused by the use of different types of vessels. For instance, in 2023, thyssenkrupp reported that their transportation capacity was significantly reduced by the use of motor cargo vessels instead of pushers (pushing 4 barges).

Low water also leads to nautical challenges for inland navigation as regards security or keel clearance, narrow fairways, congestion, and thus complex navigation.

Figure 11: Rhine navigation at low water (Source: ESO)

In addition, the loading degrees of vessels can be considerably reduced because of low waters, resulting in a lower volume of goods transported per voyage. This reduces the profitability of inland waterway transport, as there is less income to cover the fixed costs of transport in parallel with rising unit costs, especially because of rising fuel costs (owing to more resistance). These effects are shown in the figures below relating to the 2018 and the 2022 low water events.

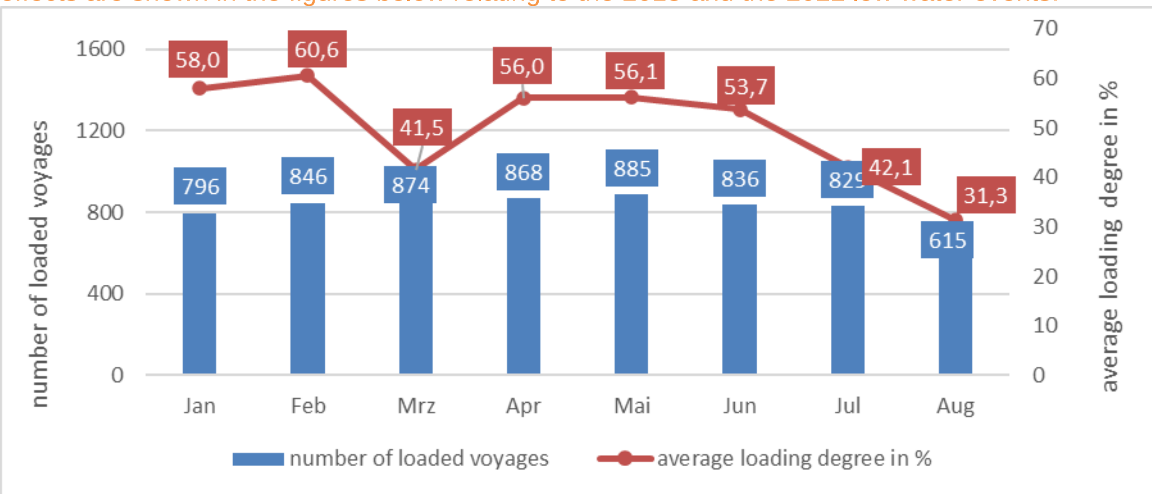


Figure 12: Number of loaded voyages and average loading degree per vessel voyage for dry cargo vessels at the Iffezheim lock in the first eight months of 2022 (source: CCNR analysis based on data from the German Waterway and Shipping Administration)

With the onset of the low water event in July 2022, the average loading degree of vessels decreased.

In August 2022, water levels decreased even further. This is reflected by a further decrease in the average loading degree of vessels. Navigating conditions had become more difficult than in July, which is also reflected by a reduction in the number of voyages that could be made.

As a result of reduced loading degrees in both months, and fewer voyages in August, the months of July and August saw a strong decline in the total amount of goods transported on the Upper Rhine. The reduction in waterside goods handling in main Upper Rhine ports in July and in August 2022 due to the impact of the war in Ukraine and low waters is also clearly identifiable in Figure 13 in the form of a V-shaped reduction.

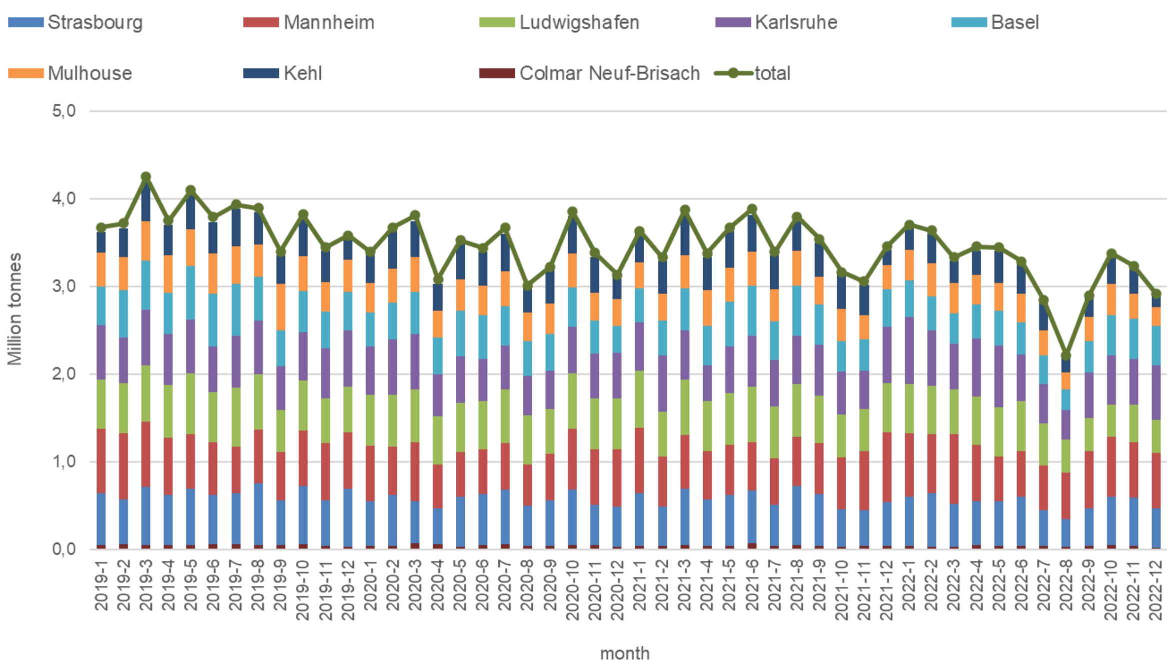


Figure 13: Waterside goods handling in main Upper Rhine ports between 2019 and 2022 (Source: CCNR analysis based on data provided by the ports)

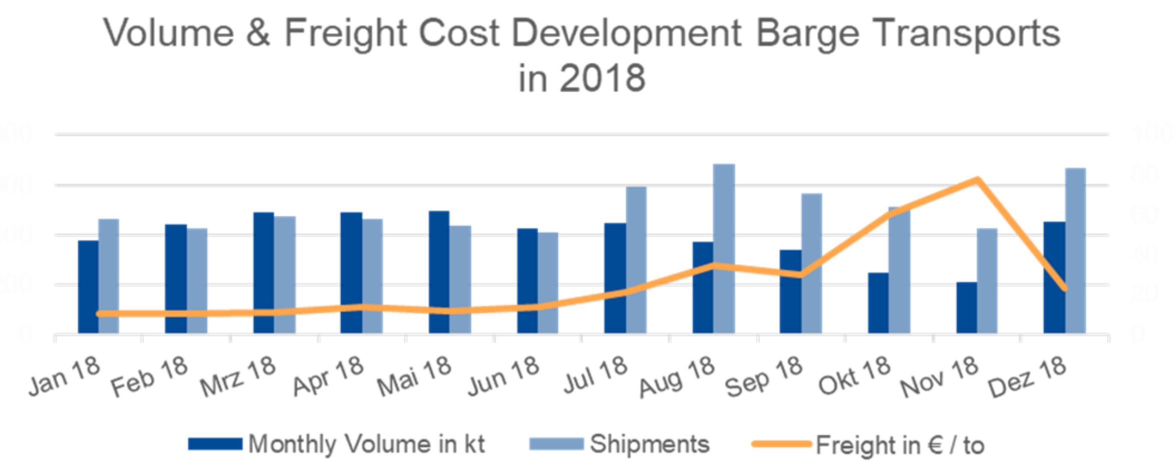


Figure14: Volume and freight cost development in 2018 (Source: BASF)

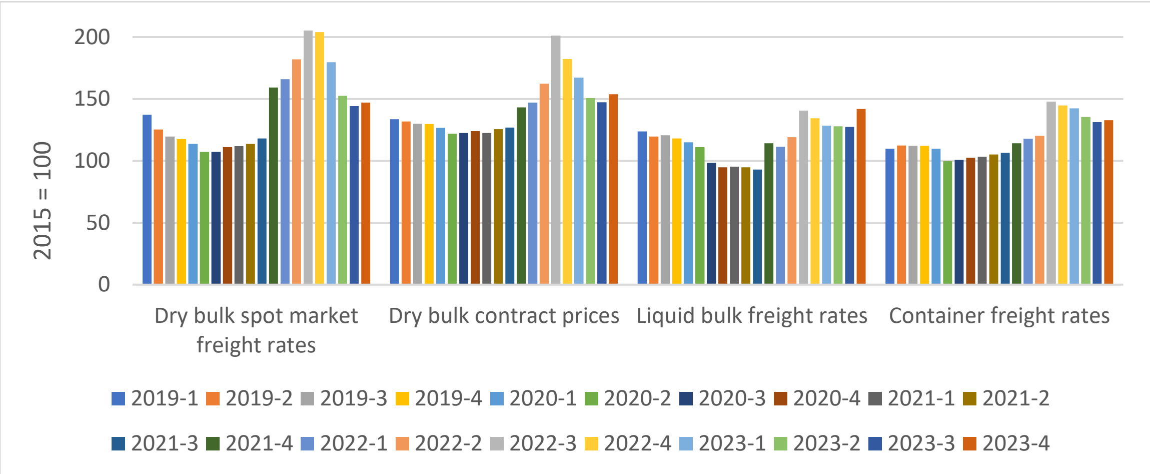


Figure 15: Freight rate evolution per quarter between 2019 and 2022 (Source: CBS)

Regarding the period 2019-2022, it is important to note that freight rates were pushed up for all market segments during the low water events in 2021 and 2022. Regarding dry bulk freight rates specifically, it is important to consider also the boom in coal transport and the transfer of vessel capacity from the Rhine to the Danube region (3% of Rhine dry cargo fleet capacity). Liquid bulk freight rates grew in 2022 under the effect of low waters alone, and not attributable to any structural factors.

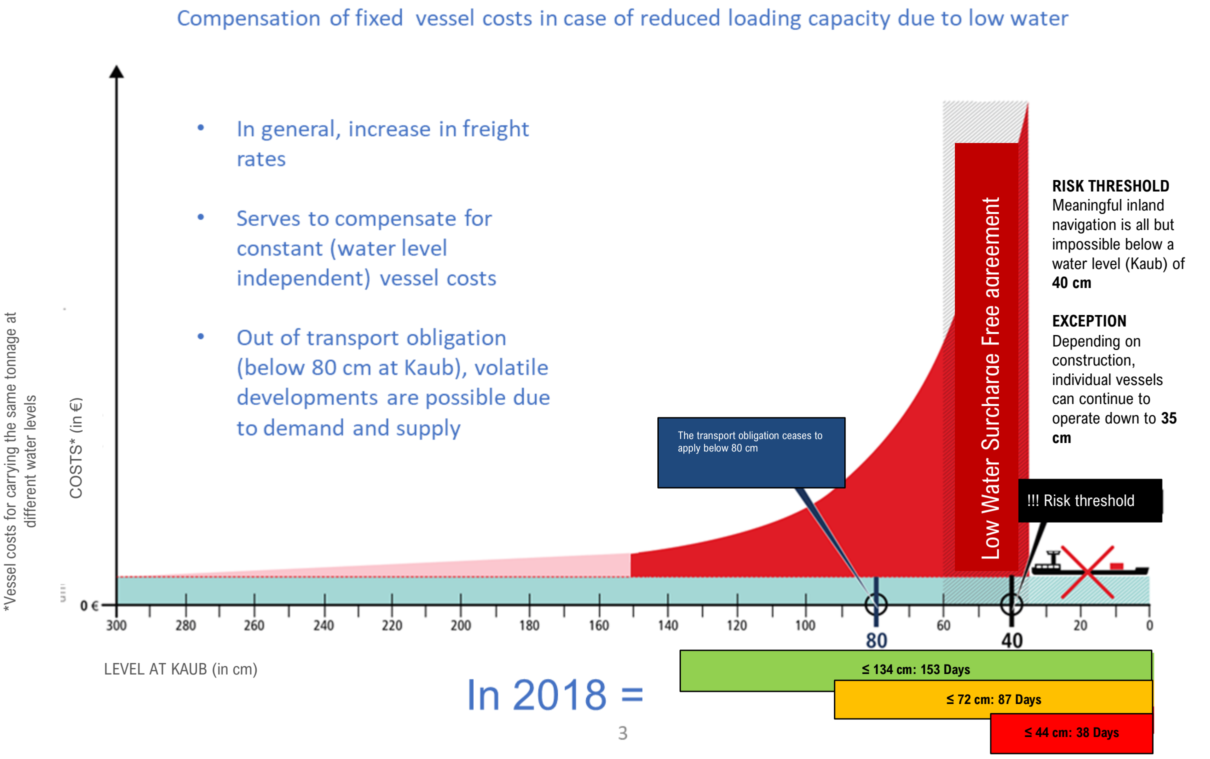


Figure16: Compensation of fixed vessel costs in case of reduced loading capacity due to low water (Source: RHENUS Logistics)

This affects not only the transport of dry and liquid cargo but also container transport. The figure below shows that at an indicated gauge depth of 2.50 m at Kaub, a standard container vessel with a load capacity of 208 TEU can carry 100% of its capacity. If the indicated gauge depth at Kaub drops to 75 cm, this leads to a decrease of loading capacity of 75%. Thus, four vessels or four voyages are needed to transport the same volumes of cargo. If the indicated gauge depth at Kaub drops further to 55 cm, six vessels or voyages are required to complete the transport.

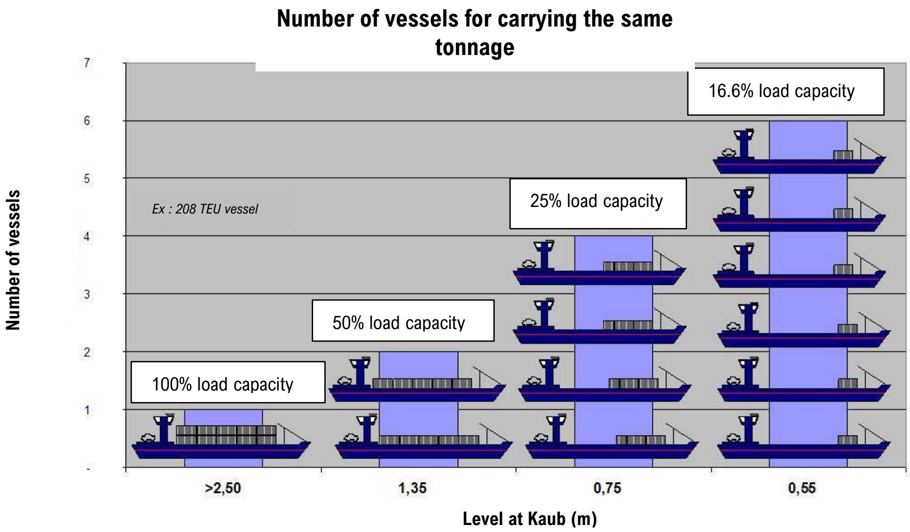


Figure 17: Amount of ships required to transport a fixed amount of cargo (Source: CONTARGO)

A similar conclusion can be drawn for a dry/tanker fleet with average capacity. Below 134 cm, 72 cm and 44 cm, it can navigate respectively at 50%, 25% and 15% of their capacity (source: Rhenus Logistics, see also figure 18 below). At an indicated gauge depth of 40 cm at Kaub, inland waterways transport simply cannot take place, despite some vessels which are adapted to navigate up to an indicated gauge depth of 35 cm.

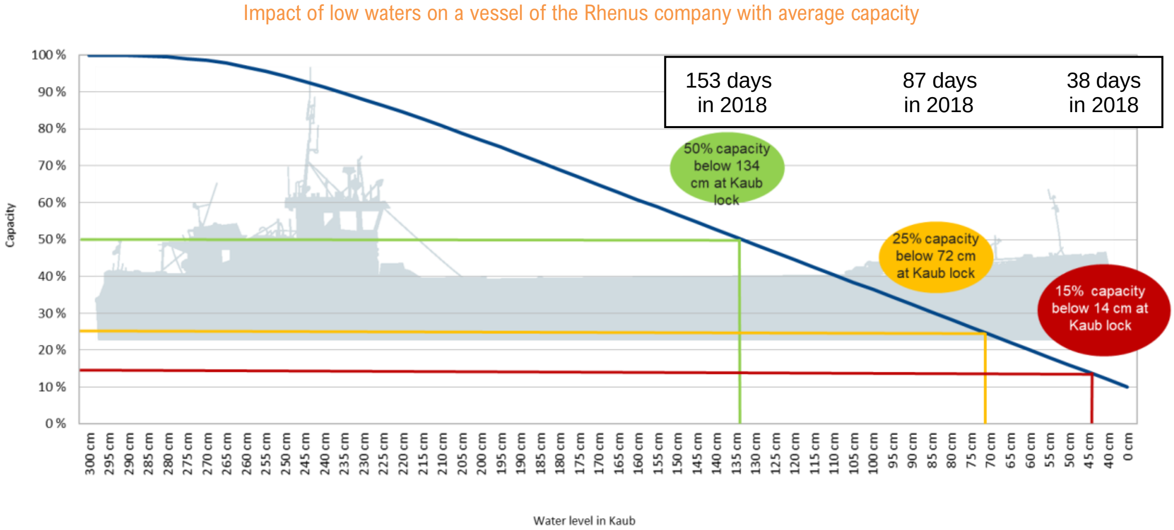


Figure 18: Fleet capacity vs water levels at Kaub (Source: Rhenus Logistics)

2.2. Solutions

<u>Low-water-optimised Vessels</u>

Whether a vessel can be used efficiently at low water or not depends on:

- Vessel construction (design for low weight construction)
- Vessel draught
- Construction of the vessel's aft ship
- Size of the propellers
- Pressure on the propellers.

Hence, the vessels' design, such as hull and propulsion system, is an essential aspect if transport in low water conditions is envisaged at the design phase. As already stated above, there are no one-size-fits-all solutions. Newly designed vessels need to be optimised for defined operational profiles. Therefore, several options are already available, such as:

- Optimised bow design to minimise wave making and resistance for the different loading conditions (based on operational profile)
- Optimised propeller(s) with smaller diameter to reduce draught
- Application of modern propeller design and nozzle
- Installation of two or more propellers in order to increase energy efficiency at lower draught
- Prevention of air suction to the propeller by installation of tunnels, flex tunnels or cover plates
- Weight and size optimisation

Improving the resilience of retrofits against low water is also possible. Adaption measures have increased since 2018 by focusing on propulsors, aft ship and added buoyancy as reported in 2023 by experts from the Novimove project. More precisely, the Novimove project is looking at the concept of added buoyancy. The idea is to adapt the physical properties (buoyancy) of vessels while maintaining an economically feasible payload at low water conditions.

Figure 19: Optimisation of vessels' aft and propellers (Source: CONTARGO)

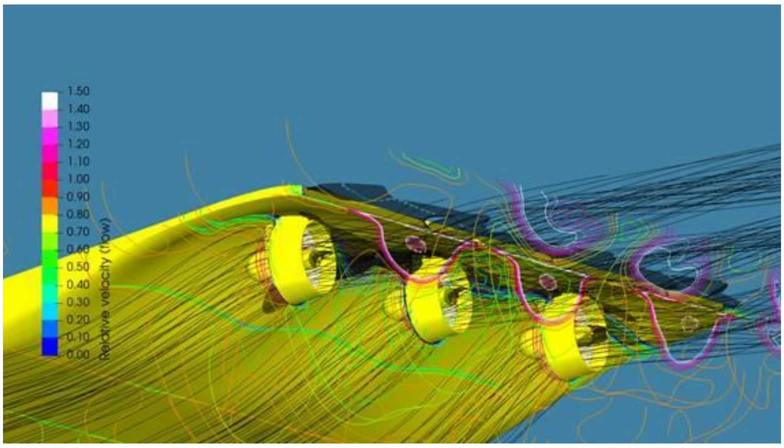


Figure 20: Analyses of aft ship design with Computational Fluid Dynamics (source MARIN)

Figure 21: Aft ship design with 3 thrusters, reducing propeller diameter for low water operation (Source: MARIN, Photo: S. Oudakker, Oudcomb)

Figure 22: First concept of added buoyancy suitable for newbuilts and retrofits (source: Novimove project)

The 2018 workshop concluded that all necessary means to better adapt to low water were already available. However, some demand for research remained in order to further improve model predictions, such as:

- Interaction of aft ship with propellers, nozzles, rudders, tunnels etc. in (extreme) shallow water
- Ship / waterway interaction
- Ship / ship interaction
- Shipping traffic in confined waterways.

Since 2018, greater interest is being seen for research projects dealing with navigation during low water phenomena both in commercial and public research projects and to work on low water adapted vessels.

In 2018, it was also highlighted that there are limits to such adaptation measures. Indeed, inland navigation vessels should also be versatile and adapted to most economically significant situations (not only low water situations). This challenge remains valid today and was highlighted once more by the workshop participants in 2023.

Fleet

Diversification of the fleet would be desirable to better adapt IWT to low water, a meaning that a dedicated part of the fleet would be optimized for use in times of high or low water. However, this would lead to additional costs in IWT since parts of the fleet would operate outside their design parameters. These costs have to be internalised within the transport price. It also leads to the question of whether these vessels would be operated outside their design parameters at all or kept at berth until needed.

The workshops identified further solutions to adapt the fleet to low water, such as:

- Optimisation of existing vessels, as described above;
- Use of smaller vessels in coupled formations;
- Optimised new builds;
- Adding barges to a pushed convoy during low water periods to transport the same quantity. The suitability of this option would however need to be analysed, particularly in light of crew regulations.

Several fleet operators already have experience with optimization measures. CONTARGO reported that during the 2018 low water peak, three of their upgraded coupled formations were still able to navigate on the Middle Rhine section, each with two additional barges to compensate for the lower loading degree.
As reported in 2023, BASF, for its part, invested in the newbuild of dedicated vessels, capable of operating under low water conditions

Figure 23: BASF Newbuilding of specialized low-water barges. (Source: BASF)

As reported in 2023, options to reduce the draft of the thyssenkrupp SE group pushers are also being evaluated.

Overall, since 2018, investments in newbuilds of dedicated vessels, capable of operating under low water conditions have increased. The positive developments are proof of the inland navigation sector’s adaptability.

The importance of public funding to support such developments should not be underestimated. Public funding can take several forms:

- funding for research, for instance Horizon Europe funds at EU level
- funding for the modernisation of the fleet, with best practice examples in Germany (Förderung der nachhaltigen Modernisierung von Binnenschiffen) and France (Plan d'aide à la modernisation et à l'innovation de la flotte - PAMI). The German Federal Ministry for Digital and Transport reported that in autumn 2022, two applications for funding were submitted to the Federal Waterways and Shipping Agency (GDWS) to replace the aft section of a vessel with a newly built section to optimize freight vessels for low water levels (funding requested approx. 5 million euros per application) and that further applications had been announced. In fact, such measures were provided for in the German Rhine Low Water” Action Plan (8-point plan).

In scenarios where sheer optimization of the fleet is not sufficient, further measures such as fleet management or multimodality have to be taken into account.

3. Shippers and industry

3.1. Impacts

The impacts of the low water event in the second half of 2018 should not be underestimated. This phenomenon is not new but the vulnerability of inland waterway transport to low water seems to have increased. Indeed, despite 2018 being the second shortest out of the seven most severe low waters events in the last 100 years, 2018 was also the year when, from an economic point of view, inland waterway transport suffered the most.

For Kaub, on the Middle Rhine, data on the number of days with a discharge of less than 783 m^3 per second (which is the equivalent flow value, corresponding to the equivalent water level of 78 cm at Kaub) are modelled statistically dating back to the year 1820. The aim of this procedure is to compare today's flows with the past. The resulting values show that years of severe low water periods (before 2018 and 2022) also occurred in the past.

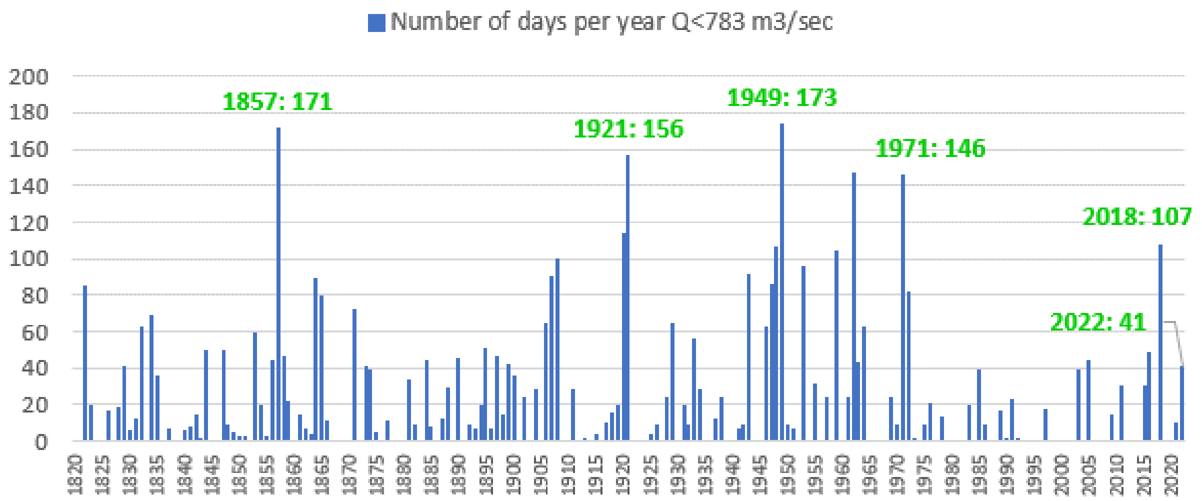


Figure 24: Number of days per year with a discharge q < 783 m^3/s at Kaub, middle Rhine

Source: German Federal Office for Hydrology, CCNR Market Observation

** Corresponds to a water level of 78 cm (equivalent water level)*

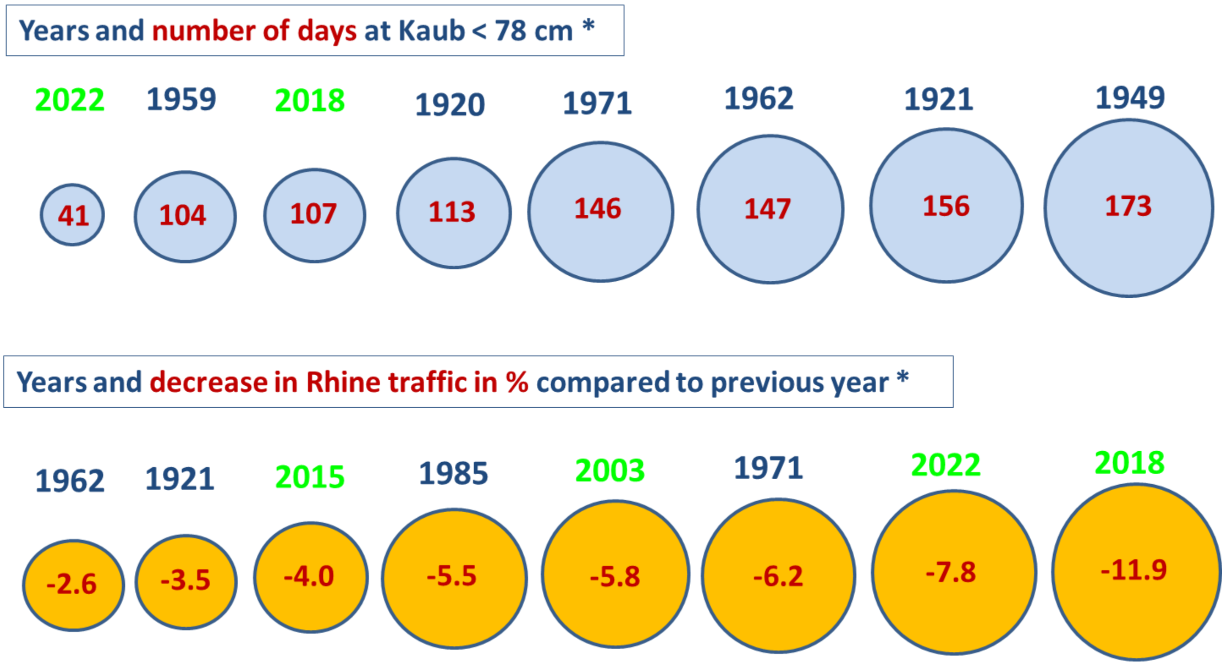


Figure 25: Number of low-water days vs impact on Rhine traffic (Source: CCNR calculation based on data provided by Destatis and German Federal Waterways and Shipping Administration, provided by the Federal Institute of Hydrology. In the context of this figure, note that the year 2022 is far from being the eighth longest-lasting low-water event in the last 100 years. However, as it ranked second in the low-water years which had the most severe economic impact on inland water transport on the Rhine, it was decided to make a reference to this year in the first row of this figure and to mark it in grey.

* World war years (1914-1918; 1940-1945) and economic depression years (1919, 1923, 1931, 1932, 1975, 2009) are excluded. In 2022, the decrease in Rhine traffic is also linked with the consequences of the war in Ukraine.

Table 1: financial impact Netherlands and Germany of low water

		Nederland	Duitsland	Totaal
Financial impact inland shipping sector	Net revenue	+ 378 million euro	+ 95 million euro	+ 473 million euro
	Additional costs	- 302 million euro	- 76 million euro	- 378 million euro
	Net profit	*+ 76 million euro*	*+ 19 million euro*	*+ 95 million euro*
Financial impact shippers	Transport costs	- 245 million euro	- 243 million euro	- 488 million euro
	Production reduction	- 60 million euro	- 2.1 billion euro	- 2.2 billion euro
	Strategic stocks	- 66 million euro	- 65 million euro	- 131 million euro
	Total negative impact	*- 371 million euro*	*- 2.4 billion euro*	*- 2.8 billion euro*
Total financial impact		***- 295 million euro***	***- 2.4 billion euro***	***- 2.7 billion euro***

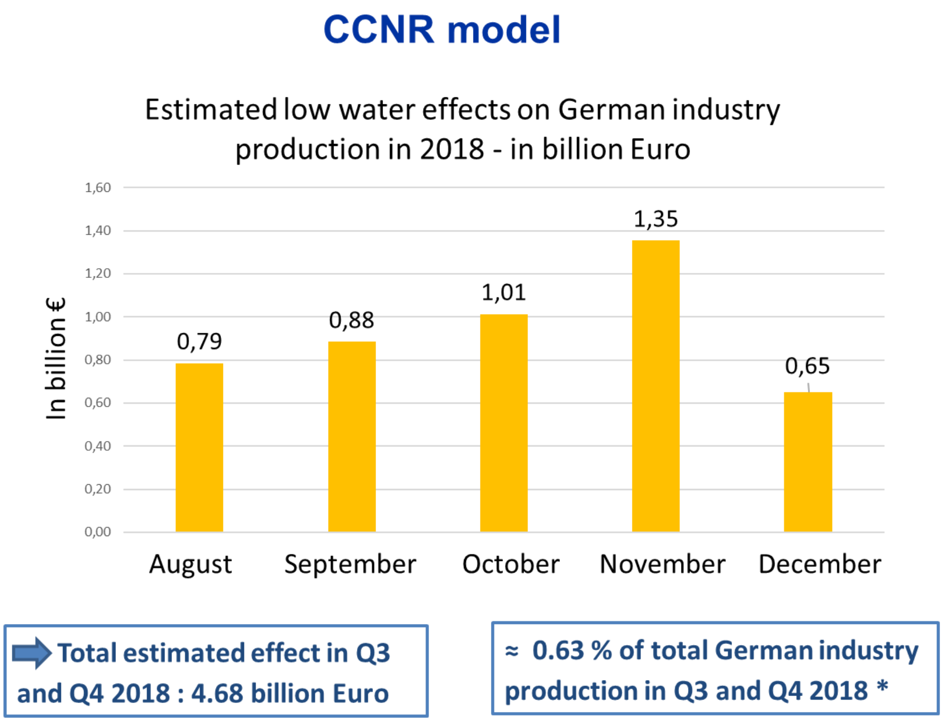
Figure 26: Economic and financial impact of the 2018 low water event in the Netherlands and Germany, presented by IWT Platorm (source: Economische impact laagwater, Erasmus UTP)

As explained in previous chapters, the reason for these more severe impacts can be linked to many aspects, such as fleet development, infrastructure, but also logistics. Indeed, the principle of “Just-In-Time” logistics is preferred, whereby raw materials, products and parts are received as they are needed, rather than having them in stock. It allows businesses to cut storage costs by not having to store as much material. However, it puts IWT at a disadvantage in case of incidents such as low waters.

The interruption in the logistics chains caused by the low-water event in 2018 caused considerable economic losses. For Germany, this disturbed the delivery of raw materials (in particular iron ore, coal and basic chemicals) as well as final products of the chemical, metal and petrochemical industry, which resulted in a decrease inf German industrial production by almost 5 billion Euros.

Low waters had a particular impact on the German companies BASF and thyssenkrupp[1] for which Rhine navigation plays an important role. Indeed, when final products cannot (or only in limited quantities) be shipped and raw materials cannot be supplied, ultimately, a reduction in production becomes unavoidable. This was highlighted again in 2023 by thyssenkrupp, given that their production needs to be adjusted to raw material supply. In the long term, both see low waters as a threat, for the BASF major integrated chemical complex in Ludwigshafen and the thyssenkrupp blast furnace site in Duisburg respectively. Supply shortages for customers in case of low waters are also detrimental to such companies.

Some industry representatives went as far as stating that the sites at the Upper Rhine are in question because of unclear future developments. Thyssenkrupp reaffirmed in 2023 that, in the long run, it was seeing potential risks for the operation of their production site in Duisburg.



Source: CCNR calculation. According to destatis, Fachserie 4 Reihe 3.1, production in German manufacturing accounted for 739.2 billion Euro in Q3 and Q4 2018.

Figure 27: Estimated effect of low waters in German industrial production (Source: CCNR calculation based on Destatis)

The logistics chain also needs to adapt to other follow-up effects of low waters, such as the handling of unforeseen stock in maritime and inland ports, with goods being stored for longer time periods than expected, and delays in loading and unloading activities not only for inland waterways transport but also for other modes. For companies like the thyssenkrupp group, which also operates dedicated ports for the shipment and handling of their goods and raw material supply, low water phenomena require increased handling efforts onsite and come with additional costs.

[1] The chemical company COVESTRO was also impacted by the crisis.

In addition, smaller freight vessels - more resilient to low waters – need to be used to maximise transport volumes, implying modifications of the transport chain. Indeed, three to four vessels may be needed to carry the same volume of goods generally transported on one single vessel.

In times of low waters, IWT therefore becomes a costly and unreliable option:

- increase in freight rates (up to seven times higher than at normal water levels), directly linked to the shortage of barge capacity and limited availability of barges that can navigate at low water levels,
- major increase in the number of voyages needed to transport equivalent volumes of goods,
- cost increases driven by the use of alternative modes of transportation and other inefficiencies (e.g. additional unloading capacity, handling),
- increased risk of accidents (low water levels combined with additional vessels on the waterways), thereby increasing insurance costs,
- production losses, for which a significant amount of energy is needed for companies to decrease or increase the full continuous production at chemical or steel companies, leading to additional financial losses,
- and bottlenecks in distribution / customer, which all adds up on the balance sheet.

A modal shift to other modes, in particular rail and road, is also a direct consequence of low waters, especially for market segments where there is strong multimodal competition, such as container transport. This is shown by the evolution of waterside container traffic in the Swiss Rhine ports. In the first half year 2018, a modal shift from rail to IWT took place because of the Rastatt accident (interruption of the railway line on the Rhine axis). However, the low water event in the second half of 2018 led again to a modal shift, but this time in the form of a loss of market share for inland waterway transport, resulting in a 16% reduction of Rhine container traffic in the first half year of 2019 compared to 2018. An even more serious problem is the possible lasting effect of such incident-related modal shifts, given that shippers may become more reluctant to choose inland waterways as a mode of transport.

3.2. Solutions

Measures (including internal measures) on or near the shipper’s production site

For industries, short-term responses in case of low waters must be found and result in internal business adaptation, mainly through prioritisation across different business units, monitoring and planning. An example is the decision-making chain that takes place in BASF in case of low waters, as illustrated below. Thyssenkrupp further highlighted in 2023 that implemented communication routines proofed to be an efficient method for coping with low water phenomena.

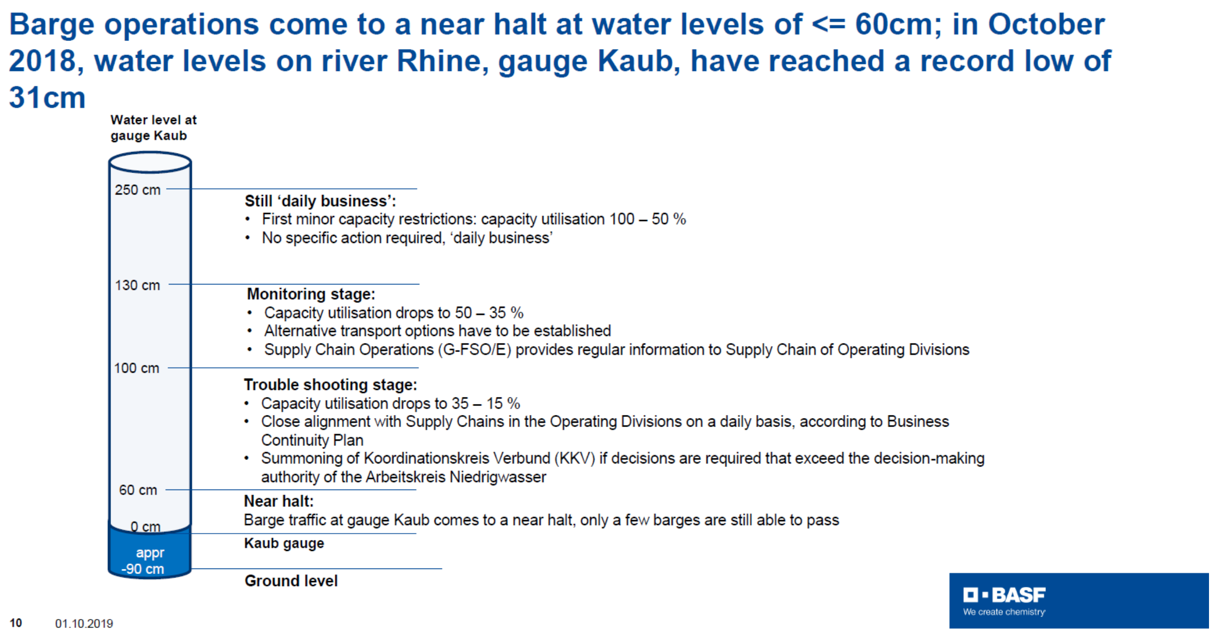


Figure 28: BASF decision-making chain in case of low waters (Source: BASF)

Other measures reported by thyssenkrupp on their production site or near site also relate to:

- Optimisation of handling capacity onsite
- Increase of onsite inventory, additional storage capacity for raw materials onsite and near site. In fact, thyssenkrupp reported that higher raw materials inventory partially mitigated the losses of transportation capacity.

Transport capacity

Beyond vessel and fleet optimization, further measures such as fleet management or multimodality entail best practice examples. Efforts to improve transport capacity and strategy have been acknowledged by the German Federal Ministry for Digitalisation and Transport in 2023.

Time charter contracts

A measure which has been tested and proved efficient during the 2018 low water event was the recourse to barges with improved tonnage capacity that can still operate even at lower water levels, under long-term time charter[1] contract. For a key industry player such as BASF, this enabled securing the capacity to transport critical raw materials, even during longer-lasting low water levels.

This same measure was proven to be efficient in 2022 too, alongside vessel adaptation measures and on-demand additional low-water barges (at Kaub <120cm), as BASF was able to double its number of available barges in the extreme low-water situation in July/August 2022. In 2022, an additional difficulty reported by thyssenkrupp was to find available capacity to compensate for the lower cargo volumes which can be transported per vessel given that many vessels were already under contract with power plants for coal transportation (which was also booming in this period).

[1] Transport vessel charter for a fixed period instead of a certain number of voyages or trips.

Multimodality

The availability of alternative modal solutions and further cooperation with other modes - rail in particular - is in any case seen as one of the available solutions for coping with possible future recurring low water phenomena. It is important to bear in mind that organizing the supply of goods (being final products or raw material) by an alternative mode in case of a crisis is not an easy process, in particular for capacity reasons (rail capacities are limited and cannot compensate for all IWT volumes in case of low water levels) as well as technical/infrastructural restriction and technical facilities for loading and unloading at the production sites. Moreover, it comes with additional costs. This was highlighted once again by thyssenkrupp in 2023. Having said that, modal shift to other modes in case of low water is particularly relevant to securing the supply of critical raw materials/final products and somewhat compensates for the volume of shortfalls of barges (not all volumes). Thyssenkrupp reported that it contracted additional long-term train transportation capacity to cope with low water situations. The Port of Strasbourg also reported that during low water events, a temporary modal shift to other modes may also be an option for enabling certain products to be transported, in particular containers. To foster multimodality in case of incidents of this kind, a swift shift to other modes at terminals must be possible, which may require the construction of new and/or modification/optimisation of loading points. In general, both transport modes can benefit from each other if interruptions or congestion on inland waterway or rail corridors occur.

Adaptation of logistics, handling and storage concepts

In addition to the above-mentioned measures, adaptation of the logistics and storage concepts are part of the portfolio of measures available to foster the resilience of inland waterway transport to low waters.

For key industry players, one solution could be the expansion of handling capacities in the ports located next to the industrial sites. However, this needs a strong hinterland connection to an alternative transport mode – such as rail – which at present does not exist for the required capacity from / towards the ARA ports (Amsterdam-Rotterdam-Antwerp). Also, the responsible states should positively evaluate the scope for increasing tank storage capacity at the chemical parks.

In the future, an increase in storage capacity will certainly be necessary to better cope with periods of low water and have sufficient material in stock even in such times. This means that the logisticians must have larger warehouses available at their final destinations. For the supply of raw materials, such storage facilities should be located as close as possible to the production sites.

The operational redesign of logistics sites (e.g. longer opening hours and usage of the weekend) could also be an option.

Strong dialogue between political/administrative parties involved, logistics and industry

Last, but not least, an intensified dialogue within the logistics community may be necessary to anticipate such incidents and to be able to respond quickly if a new crisis occurs. As an example, handbooks for International Contingency Management for railway undertakings[1] and for Infrastructure managers[2] were published in December 2019 and May 2018 respectively, in an effort to avoid major disruption to the European railway network, such as the Rastatt incident in 2017 when a tunnel under construction collapsed, closing the Rhine Valley railway for six weeks. It is worth contemplating whether, in the short to medium term, such a tool could be useful for inland waterway transport to cope better with low water levels and more generally whether a multimodal handbook could be developed in case of incidents affecting all modes of transport.

There is a strong need for an emergency plan which must be developed in advance, and which can be used when a low water level event occurs. It should involve all process partners within all transport modes.

4. Physical infrastructure

4.1. Impacts

Direct impacts on infrastructure are more likely to occur in case of high water rather than of low water. However, low water can have a significant indirect impact through higher traffic density and less under keel clearance, resulting in increased shear stress on the river bottom, causing possible obstacles for navigation. Especially in low water situations, conflicts over rare water resources might increase, as other users and uses such as drinking water supply, agriculture, industry and energy production might have a higher demand. Possible impacts might differ depending on the Rhine section and its hydro-morphological characteristics. (See also chapter 1.3 on hydrology and climate change.)

Navigable channel

A stable and resistant river bottom is preferable for inland navigation. This sets the objective for waterway administrations' maintenance works. However, natural rivers do not have river bottoms with these static characteristics. From the perspective of nature restoration and preservation, a dynamic river bottom would be more favourable. The implementation of the EU Water Framework Directive (Directive 2000/60/EC) led to an increase in communication and understanding between the different river users. As a next step, common objectives must be identified, the planning of measures needs to follow an integrated approach and be coordinated across the different uses and users. Furthermore, climate change effects need to be anticipated when identifying potential measures to stabilise navigable channel conditions, which at the same time enable dynamic processes in sediment transport.

[1] https://uic.org/IMG/pdf/railway_undertaking_s_handbook_for_international_contingency_management_1.0.pdf

[2] https://www.corridor-rhine-alpine.eu/files/downloads/european_context/InternationalContingencyManagementHandbook_RFCs.pdf

Ship locks

There may also be other low water impacts, for example on the operation of ship locks. At the Upper Rhine however, sufficient discharge is available all year round to guarantee the passage through, and the operation of, the ship locks.

Although the impact of low water is quite limited on inland waterway infrastructure, such infrastructure is an integral part of the solutions for coping with low water effects.

Interaction with other users and uses

A study by CHR/Deltares shows that melt water from glaciers and snow will be missing in the mid and far future, leading to more frequent low-water situations on the Rhine between Basel and the North Sea. Growing water demand from nature, society and economic sectors will increase low-flow risks. Cross-sectoral linkages and trade-offs in water use and allocation under climate change must be identified and incorporated in river basin planning. The CHR has asked the CCNR to provide its research questions on future discharge in the Rhine but also on the socio-economic scenarios, so that science can deliver the necessary models and results for sound decision-making.

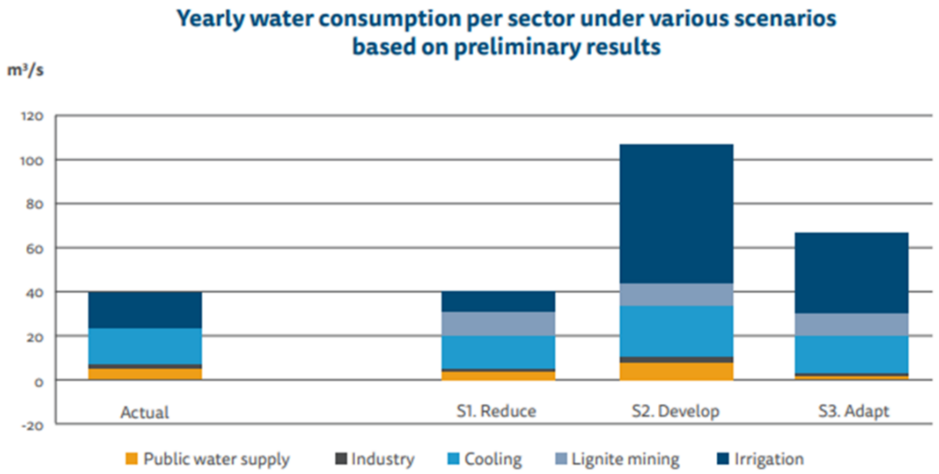


Figure 29: Yearly water consumption by sector under various scenarios

A first integrated overview of socio-economic scenarios on the discharge of the Rhine (CHR 2019) shows the effects of changes in water availability and use. Water consumption by public water supply and industry is small and remains minor. Information on water consumption for irrigation and cooling – now and in future – is very scarce, unclear, and uncertain. In the future, a significant amount of water will be needed to fill lignite mines. Under future scenarios, water consumption in the Rhine River basin could increase from 50-75 m³/s to 200-250 m³/s in summers. Thus, these sectors as well must implement measures to reduce or adapt their water need.

4.2. Solutions

When looking at infrastructure upgrades, implementation of a social dialogue was proposed as an important element in creating a level playing field among all users and uses. Germany has already done so to intensify the professional dialogue with all relevant stakeholders along the Rhine. This can support the exchange of views and ideas concerning the impact of extreme low water phenomena on the different stakeholders and the requirement for action resulting from them. It can also support the creation of public awareness and acceptance of necessary future measures to adapt to climate changes along the Rhine.

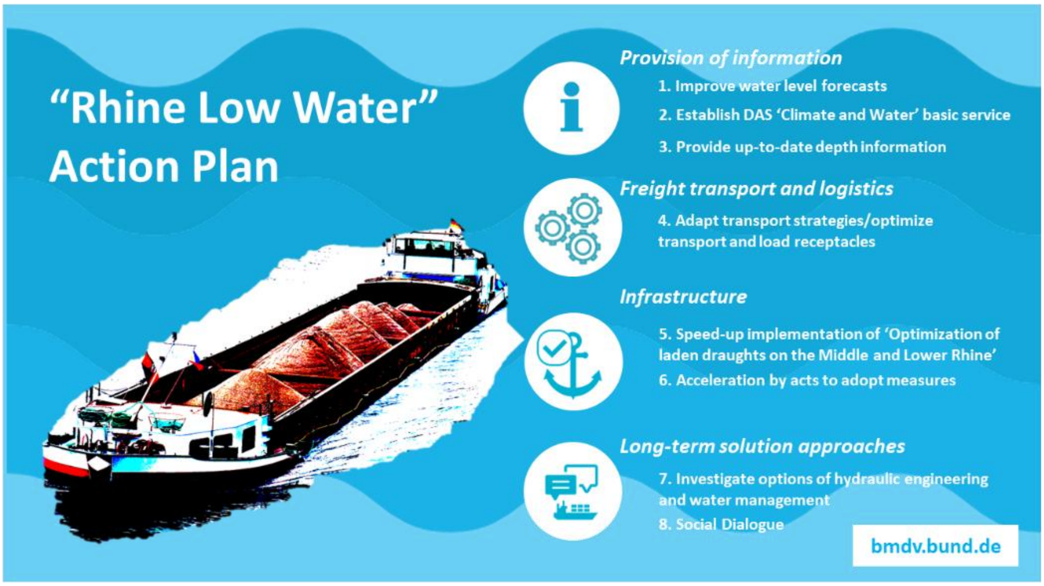


Figure 30: Rhine Low Water Action Plan (Source: BMDV[1])

In the Netherlands river developments are tackled in the "Integrated River Basin Management Programme". This includes all river activities, encompassing flood protection, water management, drinking water supply, nature development, agriculture, and inland navigation. The Programme aims at balancing all functions in relation to the predicted developments with low- and high-water periods and the expected sea level rise. The Programme is managed by the Ministry of Infrastructure and Water Management and involves other Ministries, Provinces, and Local Water Management Boards. Already there is an agreement to adapt the river bed to ensure better navigation conditions during low water.

The task of climate-adaptive waterways is urgent and complex. An international approach and knowledge sharing are desirable for possible future and integrated solutions. Current programmes both in Germany (Action Plan Low Water Rhine) and the Netherlands (Climate-proof Networks/Main Waterways Network and Integrated River Management) can help and reinforce each other to map the consequences of climate change and develop action perspectives on how to create climate-adaptive waterways for the different sections of the Rhine.

[1] "Rhine Low Water" Action plan

Waterway maintenance

Well planned and executed maintenance works are key in providing a guaranteed navigable channel during low water events. On the Rhine, these maintenance works are within the competency of waterway administrations or operators following high quality standards. These standards must also be maintained in future but might need to be adapted to the availability of a navigable channel at low water and to the effects of climate change. The maintenance measures include, among others, identification of the status quo by means of surveying as well as dredging, adaptation of existing groynes and parallel works, artificial sediment feeding, and implementation of modern concepts, such as working with nature and flexible groynes, where feasible.

Waterway upgrades

Measures for the optimization of laden draughts in the German section of the Rhine are identified in the so-called “Bundesverkehrswegeplan 2030”, which is the central planning instrument for the German transport system, covering all transport modes. The project “Optimization of laden draughts on the Middle Rhine” leads to an increase of navigable channel depth from 1.90 m to 2.10 m and the “Optimization of laden draughts on the Lower Rhine” to an increase of navigable channel depth from 2.50 m to 2.70 m/ 2.80 m. Although the transport benefits of optimizations of laden draughts are greatest in the range of normal low-to-medium water levels, they can also nevertheless help to reduce downtimes in the event of extreme low-water events. These measures should be realised as soon as possible.

In 2022, the German ministry for Digital and Transport (BMDV) established an acceleration commission for the project on the Middle Rhine. The commission serves to identify acceleration potentials in terms of a faster implementation of the measure.
Also in 2022, the Federal Waterways Engineering and Research Institute (BAW) carried out studies[1] on hydraulic engineering options, which served to initially determine the potential of different solutions to increase navigability at the Middle Rhine at low water.

A general concern was raised with regard to **environmental protection**. The multi-uses and the different users of the Rhine need to be taken into account for all projects. The Rhine is not only an inland waterway, but also a drinking water resource, a habitat for animals and plants, and an important resource for recreation. Hence, all possible infrastructure measures need to be democratically discussed, balanced, and possible negative impacts from these measures compensated, possibly leading to lengthier project authorisation procedures. It was stated that communication and cooperation between the different users had already increased, and identification of common objectives is ongoing. An alliance of the users and neighbours of the Rhine is in discussion under the umbrella of the so-called “Rhine Low Water Action plan” developed by the BMDV, together with industry and associations. Thus, win-win solutions seem to be possible if, from the beginning of project planning, an integrated approach is implemented, uses are prioritised, and natural resources are protected. Further balancing of TEN-T regulation[2] demands and WFD requirements will be essential for the further development of waterways and restauration of rivers.

[1] https://hdl.handle.net/20.500.11970/112743

[2] Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network under revision: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1315

At the same time, these project **authorisation procedures,** which are already extremely lengthy, were criticised by IWT stakeholders, who asked for a significant speeding-up of planning and authorisation processes. These lengthy procedures were recognised as a significant risk for the development of waterway infrastructure, and thus as a risk deterring industries from settling along the Rhine.

Water management

A need to improve water management on the Rhine was also identified. Focus should be placed on keeping the water in the system, especially in times of high and low water, by buffering it or extending the water use cycle.

It was also suggested keeping more water in upstream lakes such as lake Constance or lakes in the Swiss Alps. Together with other affected stakeholders and organisations, possible solutions to safeguard sufficient discharge in drought periods by planning of new and extending existing water reservoirs need to be studied further as mid-to-long-term solutions.

However, the construction of new reservoirs / dams is also highly controversial and criticised by ecologists and the ICPR due to their negative impact on landscape and ecology (e.g. fish migration, disrupted sediment transport) and must also be discussed in the context of the water framework directive and the principle of non-deterioration.

Water reservoirs are important factors in the redistribution of discharge through time. The Federal Institute of Hydrology (BfG) carried out a study[1] to identify the potential of reservoirs in the Rhine River Basin for supporting of low water levels. The potential of these solutions highly depends on the needs of other users and uses.

The above-mentioned water management options do not currently take into account any changes in water availability and use. As also mentioned above, CHR is studying socio-economic scenarios under which an early trend shows that water consumption in the Rhine River basin could increase from 50-75 m^3/s to 200-250 m^3/s in the summer. Thus, other users and uses must also implement measures to reduce or adapt their water needs.

5. Digital tools and information services

Digital tools provide for solutions to support inland navigation, not only during low water events, with real-time information on available navigable channel depth, short-term and long-term water level forecasts, traffic intensity and estimated time of arrival (ETA). The further development of these solutions is partly the responsibility of the inland navigation sector and partly that of the competent waterway administrations. However, low water phenomena may stimulate the use of such digital tools.

[1] https://doi.bafg.de/BfG/2022/BfG-2100.pdf

Information availability on navigable channel dimensions and concept of a Low Water Corridor

Information on navigable channel depth is available in general through the competent waterway administrations. However, this information is often not up to date when published, because the post-production of surveys takes time. Therefore, a significant safety margin is added to the published measurement to compensate for the delay. To make better use of actual available navigable channel depth, the COVADEM project developed a system to distribute measured depth data on-board inland vessels in real-time. By using this system, the boatmaster has a better understanding of the actual situation and can thus optimise vessel loading, see www.covadem.com. As a next step, waterway administrations could integrate their measured data as reference data to further increase the usability of the system.

Figure 31: COVADEM data acquisition (Source: RWS)

In addition, a possibility which needs to be developed further is the ability of barges to exchange dynamic real-time measurements among themselves. This would allow a preceding vessel to inform the others following behind. To enable this, there is a need for comprehensive network coverage the entire length of the river Rhine. Today, certain sections are without an internet connection.

Beside private initiatives, the German waterways and shipping administration also provides a depth atlas via the Electronic Waterway Information Service (www.elwis.de) as an interim solution[1]. Since autumn 2022, the creation process for the depth layer of the Inland Electronic Navigational Charts has been tested along three pilot sections. After that, it will be gradually provided to Rhine navigation. In addition, the option to establish a low water corridor within the existing navigable channel is currently being examined. For the future, (partly) autonomous measuring is being studied to optimize the measuring and evaluation processes by using artificial intelligence and unmanned surface vehicles (USVs) (implementation is in preparation, 7-year timescale).

[1] https://www.elwis.de/DE/Service/Tiefenatlas-Rhein/Tiefenatlas-Rhein-node.html

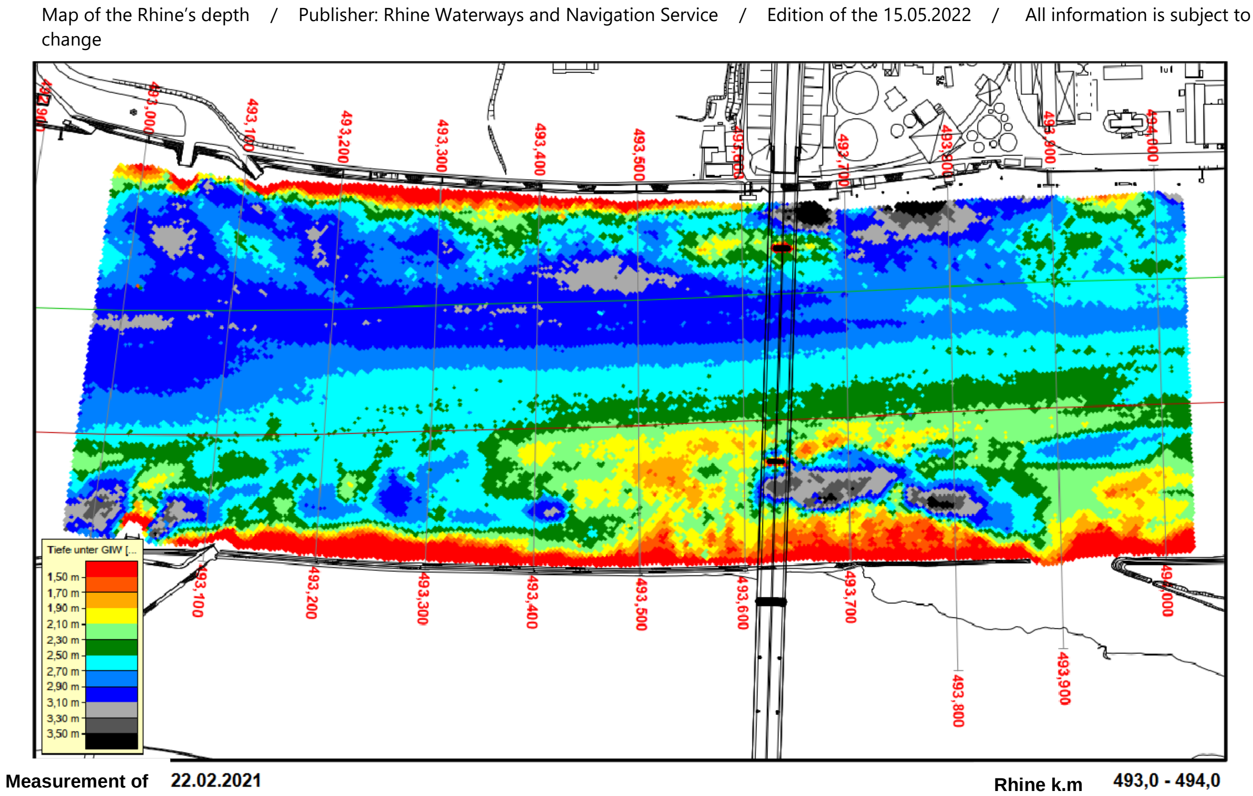


Figure 32: Depth atlas for the Rhine (Source: Elwis.de)

Water level forecasts

Since the workshop held in 2018, new information services on water level forecasts have been made available by the German administration (BfG, WSV). BASF and thyssenkrupp highlighted in their presentations the benefits of these new services for the preparation and planning of their transports and production. Unlike in 2018, it is now possible to estimate the ongoing low water flow situation on a rolling 6-week basis. Water level predictions and forecasts are available for a period of up to four days for seven relevant Rhine gauging stations.

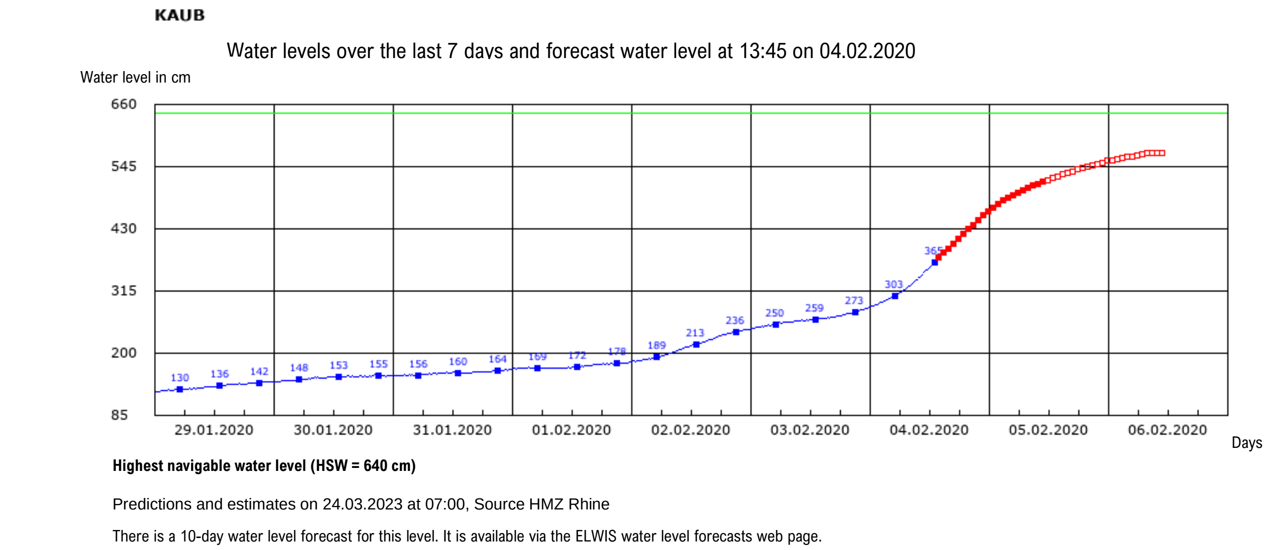


Figure 33: 4-day water level and forecast (Source: Elwis.de)

A 14-day probabilistic forecast for selected Rhine stations is a new service provided with an hourly to daily resolution. This improved forecast was developed by BfG in the context of research projects (e.g. the IMPREX project[1]) and is accessible via the ELWIS (www.elwis.de) of the German waterways and shipping administration. The forecasting system has been operational since July 2022 (replacing a 10-day forecast system operational since 2019) and updated daily.

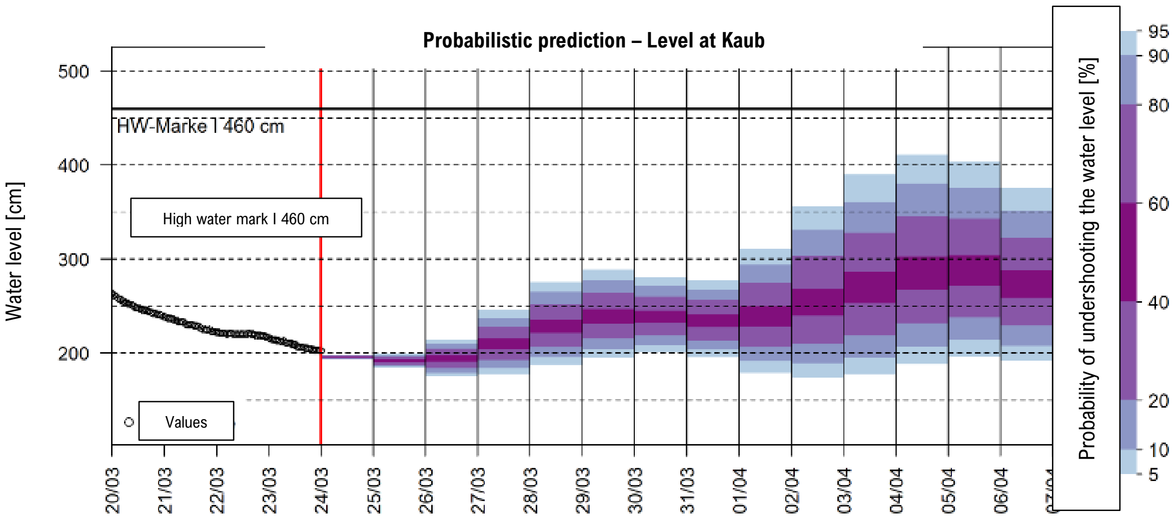


Figure 34: Improved water level forecast (14-day forecast, Source: Elwis.de)

The objective of the 14-day forecast is to support boatmasters and shippers in planning and optimising their loading and transport operations and to avoid critical voyage situations such as inappropriate vessel draught relative to the available navigable channel depth. This usually happens when hydrological conditions are misjudged upon loading and appropriate water level information is unavailable for the entire length of the voyage. The new forecast aims to help prevent this from happening.

[1] https://www.imprex.eu/central-european-rivers

Other research and development projects of BfG led to a probabilistic 6-weeks forecast system of river flow and water levels., The system has been operational for the Rhine and the Elbe waterways since July 2022. It offers weekly resolution and bi-weekly updates for three 3 Rhine gauge stations and is also available via ELWIS. The objective of 6-weeks forecast is to plan logistics such as stocks and capacity.

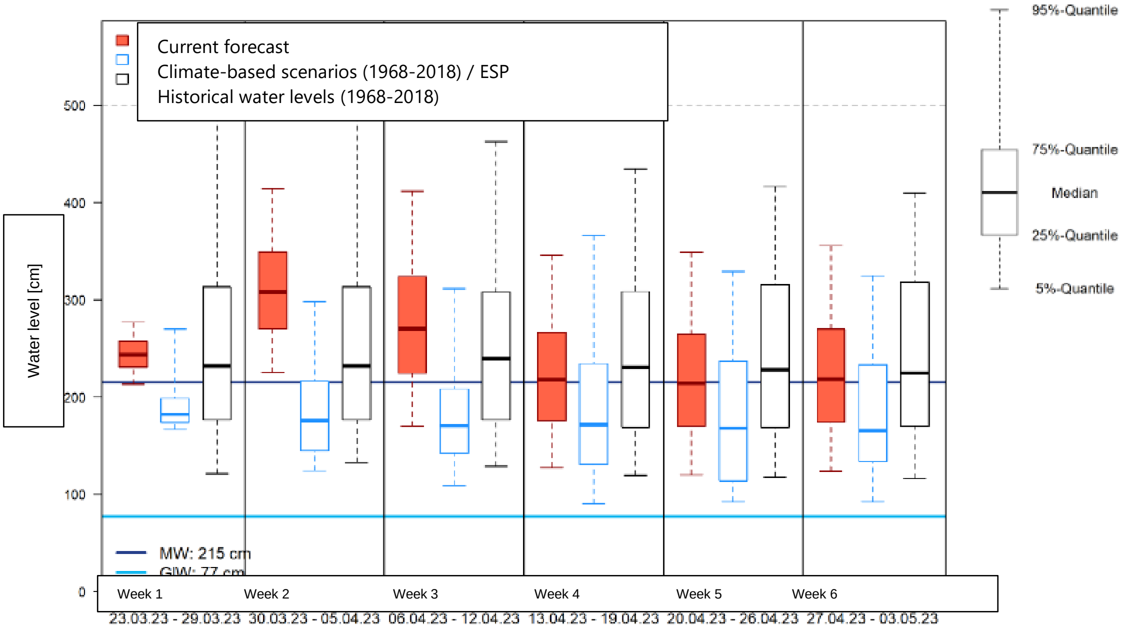


Figure 35: Probabilistic 6-weeks forecast (Source: Elwis.de)

As mentioned above (section 1.2), the basic service "climate and water" of the German Climate Adaptation Strategy (DAS-Basisdienst "Klima und Wasser") is providing projections of river discharge, water levels, and water temperatures based on current climate model ensembles (e.g. CORDEX, RCP8.5 and other scenarios) for the Rhine, Danube, Elbe, Weser, Ems, and coastal waterways with daily resolution up to 2100.The service has been operational since December 2020 and develops information products and scenarios according to IPCC cycles and the "German adaptation strategy to climate change" (DAS).

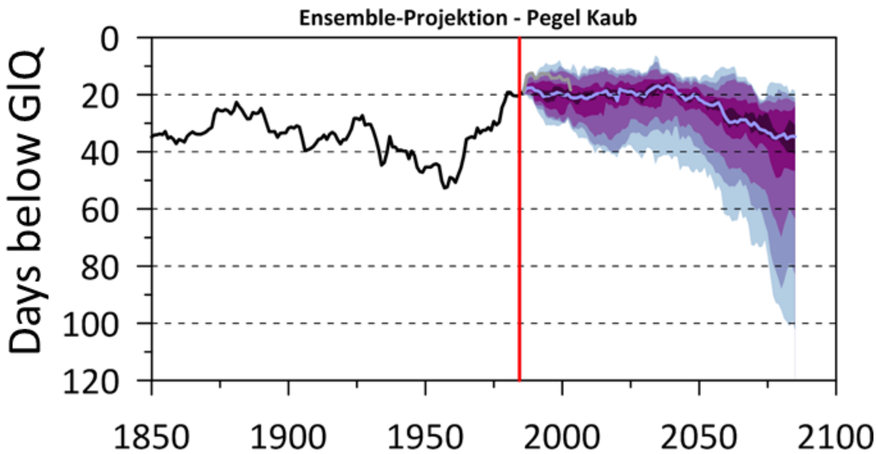


Figure 36: Probabilistic 100-years projection (Source: BfG)

Inland waterway and shipping related information of the above-mentioned service is accessible via the climate portal https://ws-klimaportal.bafg.de. Additional information can be accessed through https://www.das-basisdienst.de/. The objective is to support strategic planning, such as transport concepts and infrastructure. It is also an important pillar for the new workflow of the WSV to meet current legal requirements regarding the consideration of climate change, introduced in April 2021.

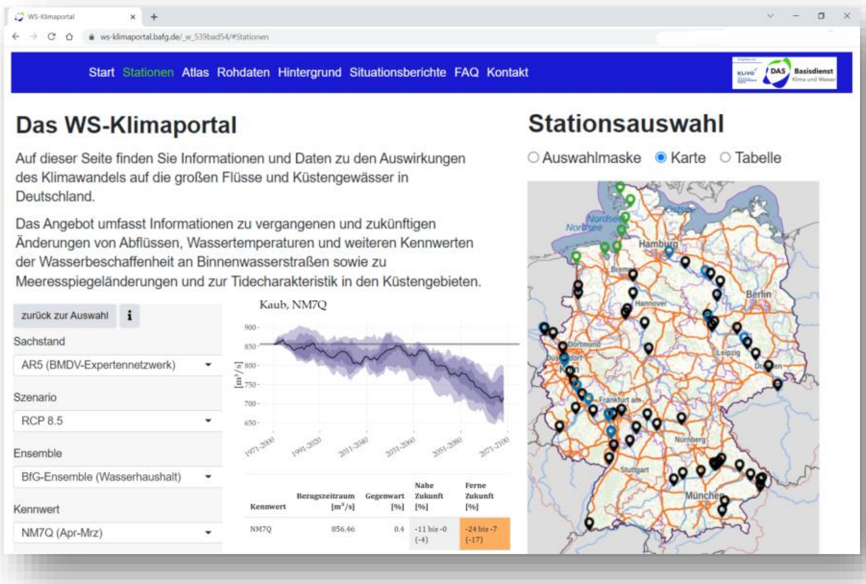


Figure 37: Climate Portal (Source: BfG)

The hydrological model system is continuously maintained and improved. For example, water management measures or water demands by various sectors are implemented, allowing links to climate and socio-economic scenarios.

Corridor Management

Corridor Management can provide tools for better managing traffic flows in a corridor. This may lead to less congestion, reduced fuel consumption, increased cargo load, better coordination between shippers, terminals and vessel operators as well as an increased overall efficiency of the whole transport chain.

Corridor Management as a concept aims at improving and linking existing RIS on a route or network to supply RIS not just locally, but at regional, national, and international levels. Therefore, Corridor Management will support route planning, voyage planning, transport and traffic management. In that respect, Corridor Management is defined as information services shared among waterway authorities and with waterway users and related logistic partners to optimise the use of inland navigation corridors within the European waterway network.

Current limitations for the implementation of the above-mentioned approaches are:

- Availability of real-time data
- Prediction lead time
- Different service providers
- Integration of information.

Information collected by administrations or operators could be integrated in a corridor approach following the example of RIS COMEX[1]. 15 partners from 13 European countries joined forces within this project, the largest RIS implementation project in Europe so far. The project was successfully completed in June 2022 resulting in the EuRIS[2] web platform, a central European multilingual RIS platform. RIS, such as EuRIS, can help boatmasters to identify available berths in case of increased demand due to low water.

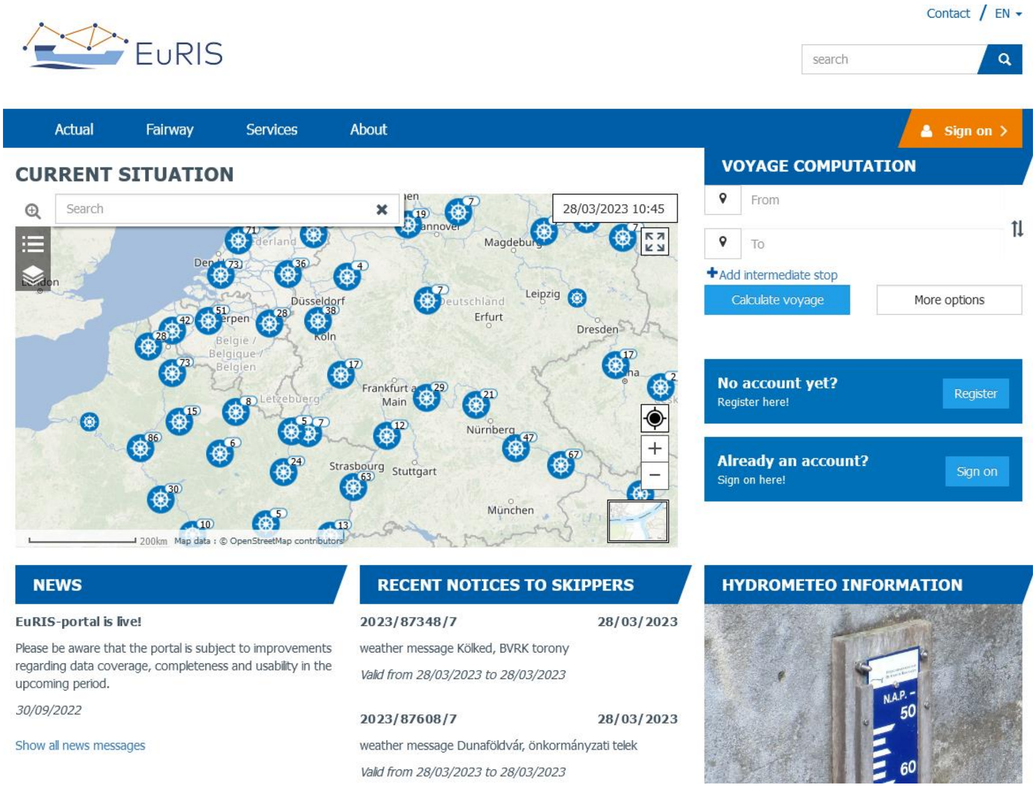


Figure 38 : EuRIS corridor management (Source : eurisportal.eu)

Following up on the corridor approach, the NOVIMOVE project developed, among other systems, the Smart River Navigation System (SRNS), consisting of two concepts, a so-called Smart Navigation System (SNS), with the objective of optimising vessel operation (reduces fuel consumption and increases cargo load) and a Dynamic Scheduling System for improving corridor management by providing optimized scheduling at locks and bridges to reduce waiting times and for having reliable journey plans. The system uses already developed services, such as navigable channel depth information on the Covadem Box and the Covadem Cloud services.

From a mid- to long-term perspective, further optimization of supply chain management (e.g. use of dynamic tracking and tracing) also appeared to be a solution.

[1] https://www.riscomex.eu/

[2] https://www.eurisportal.eu/

6. Conclusions and next steps

During both workshops, the need for strong and immediate follow-up actions was clearly articulated. IWT must prepare for longer periods of drought and more extreme events. Inland navigation must therefore become more resilient to low water events to ensure its reliability and long-term competitiveness. In order to improve the resilience of IWT to low water events, a wide range of measures implemented by different stakeholders must be considered, measures that do not only concern inland waterway transport. However, it is also clear that there are limits to the measures that can be carried out by the private sector. The private sector will not be able to cope with these developments on its own and public policies have an essential role to play.

The measures required are already well-known and available. However, the low water that impacted inland waterway transport in 2018 and 2022 shows the urgent need for action. In order to take a first step towards implementing available measures, there was a clear consensus among key inland navigation actors that adequate financial and planning resources should be made available.

The workshops have therefore shed light on the type of measures and actions that should be taken to foster the resilience of inland navigation transport to low water. Implementation of short, medium, and long-term measures is now required in the fields of infrastructure, the fleet, and shippers, logistics and industry.

The CCNR is also planning future activities, such as workshops and roundtable discussions to further support the identification and implementation of projects and measures, and to stimulate research activities.

Transversal and policy actions

Many participants in the workshop called for **EU-coordinated actions**. Indeed, despite low water phenomena generally being regional problems, the impact of low waters on inland waterway transport is pan-European. Therefore, some reflections about how to cope with such events in the future could also be discussed at EU level, possibly **at the level of other River Commissions, the Naiades Implementation Expert Group or Corridors**.

Further coordination and **harmonisation of the Water Framework Directive (WFD) and TEN-T regulation objectives** is needed. A first initiative to start the coordination process has already been initiated through PIANC's WFD Navigation Task Group. This process needs to be further developed and intensified, and stakeholders must be integrated into the harmonisation.

Intensification of the dialogue between industry, logistics, politics and environmental associations was identified as a necessary measure during the workshop. To foster and encourage such a dialogue, and to ensure sufficient monitoring of the topic, a concrete action for the CCNR could be to organise regular "low water talks" with relevant actors (for instance every two years). This was confirmed in 2023 together with the need for strong cross-border cooperation between the Rhine Riparian States.

Action plans are already being developed at national level, such as the Action Plan "Niedrigwasser Rhein". Indeed, the Federal Ministry presented the "Rhine Low Water" Action plan in July 2019 to prevent dramatic consequences for the economy and Rhine shipping caused by drought. The extreme low water period had severe consequences for companies such as thyssenkrupp, whose steel plant was running out of coal. The plan includes measures which were all discussed during the workshop such as better water level forecasts, better and more up-to-date information, the creation of new storage capacities, support for the construction of new types of shallow-water vessels and loading optimization in the Middle and Lower Rhine. (See also chapter 4.2 Solutions.)

In addition, the participants:

- called for the encouragement of private and public initiatives and the promotion of collaborative actions to ensure sustainable use of the inland waterway transport system, striking a fair balance between the many uses of the Rhine.
- asked for a social and multidisciplinary dialogue (see examples of the German Rhine Low Water Action Plan and the Dutch Programme Integral River Management).
- recommended integrating IWT with drought management systems.

Fleet actions

Regarding the fleet, **major investments** would be necessary both for commissioning newbuilds better suited to coping with future low water situations as well as adapting the existing fleet.

Since 2018, greater interest is being seen in research projects dealing with navigation during low water periods. In particular, **EU co-funding** could be made available for the purpose of research and development in that domain as well as for vessels and infrastructure development.

EU support for projects such as the IMPREX project should continue. In addition, national funding to support the implementation of such research concepts have been set up (for instance in Germany and in France) and should be considered as best practice for the development of new funding programmes. To foster the development of such national funding programmes, IWT should be recognised as a "green activity" with the EU taxonomy framework.

Shippers, logistics and industry-related actions

Apart from their efforts to optimise their fleet, many other actions have been implemented by shippers to improve their resilience to low water situations, in the form of improved communication processes, secured time charter contracts for low-water adapted barges, on or near the shipper's production site actions such as optimised handling and storage capacities. The use of alternative modes of transport has also increased. In the medium to long-term, the already implemented actions should be pursued and multimodal infrastructure could be improved to facilitate modal shift in case of disruption. In addition, handling and storage capacities in ports next to industrial sites could be expanded.

Infrastructure actions

One of the most important and urgent actions is the optimization of laden draughts in the German section of the Rhine, as identified in the so-called “Bundesverkehrswegeplan 2030”, such as the project “Optimization of laden draughts on the Middle Rhine” to increase the navigable channel depth from 1.90 m to 2.10 m related to the equivalent water level in this bottleneck section. Germany has already established an acceleration commission for the project. Participants called for the implementation of the project as soon as possible.

In parallel, other actions need to be started or continued such as those of greatest importance, including studies on water management, hydraulic engineering, and the adaptation of the infrastructure development and maintenance to climate change. As examples for related activities in Germany, the BAW further develops the concept of a low water corridor applied in times of extremely low discharge and the BfG intensifies the investigations regarding the possible use of existing water reservoirs to increase the water level of the Rhine in extreme low water periods. Overall, it is of the utmost importance to ensure reliable transport conditions on the Rhine over time.

Digital and information related actions

Further improvement of **water level forecasts** and of the hydrological model system is possible and necessary, such as the integration of water management measures or water demands by various sectors, linked with climate and socio-economic scenarios. Such improvements are also expected in relation to **up-to-date navigable channel depth** information, in particular by further developing digital solutions and the ability of barges to exchange dynamic real time depth measurements. This is a typical example of science being turned into a service to support the adaptation of IWT to low water phenomena. Similarly, **corridor management** and **supply chain control** should be further developed and optimised.

<table>
<tr><th rowspan="2"></th><th rowspan="2">What has been achieved since 2018?</th><th colspan="2">What remains to be achieved?</th></tr>
<tr><th>Medium term</th><th>Long term</th></tr>
<tr><td rowspan="6">A - Infrastructure</td><td>A1 - Setting up of a Commission for the accelerated implementation of the “Optimisation of navigable channel depth in the Middle Rhine valley and Lower Rhine”</td><td>A1 - Implementation of the “Optimisation of navigable channel depth in the Middle Rhine valley and Lower Rhine”</td><td></td></tr>
<tr><td></td><td>A2 - Integrated project planning approach</td><td></td></tr>
<tr><td>A3 - High-quality maintenance of waterways and infrastructure</td><td colspan="2">A3 - Climate change-adapted maintenance of waterway and infrastructure</td></tr>
<tr><td>A4 - Studies aiming at improving water management on the Rhine</td><td colspan="2">A4 - Improved water management on the Rhine; Study on the possibility of new reservoirs / extending existing reservoir water planning</td></tr>
<tr><td>A5 - Investigate hydraulic engineering options to ensure reliable transport conditions on the Rhine</td><td colspan="2">A5 - Implement hydraulic engineering options to ensure reliable transport conditions on the Rhine</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="4">B - Fleet</td><td colspan="3">B1 - Research in optimisation of existing vessels and new builds</td></tr>
<tr><td colspan="3">B2 - Public funding</td></tr>
<tr><td colspan="2">B3 - Assess feasibility of adding barges to a pushed convoy during low water periods to transport the same quantity</td><td></td></tr>
<tr><td colspan="3">B4 - Increase the number of low-water-optimised vessels</td></tr>
<tr><td rowspan="5">C - Shippers, logistics, industry</td><td colspan="2">C1 - Secure time charter contract for vessels adapted to low water levels</td><td></td></tr>
<tr><td>C2 - Optimisation of handling capacity and storage capacity onsite and near site, increase on-site inventory</td><td colspan="2">C2 - Expansion of handling and storage capacities in the ports next to the industrial sites</td></tr>
<tr><td></td><td>C3 - Research in adaptation of transport/storage concepts</td><td></td></tr>
<tr><td colspan="3">C4 - Efficient internal communication processes</td></tr>
<tr><td>C5 - Use alternative modes of transport (i.e. long-term train transportation capacity)</td><td colspan="2">C5 - Construction / optimisation of terminals to facilitate modal shift</td></tr>
</table>


What has been achieved since 2018?
What remains to be achieved?
Medium term
Long term
D - Digital tools and information services
D1 - Improving water level forecasting
D2 - Up-to-date information about navigable channel depth
D3 - Corridor management to optimise route & voyage planning, transport & traffic management
D4 - Optimisation of supply chain management
E - Transversal and policy
E1 - Dialogue between industry, logistics, politics and environmental associations
E2 - Cross-border cooperation between the Rhine Riparian States
E3 - Social and multidisciplinary dialogue (following the German blueprint)
E4 - Integrate IWT into ICPR drought management systems
E5 - CCNR contribution to CHR socio-economic scenarios

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