Koninklijke Binnenvaart Nederland

Low Water Vision for Inland Shipping
in the Netherlands and on the Rhine

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1. Introduction

Inland shipping provides transportation of goods and people through inland waterways. This encompasses both direct services provided by inland shipping and supplementary services related to cargo chartering and multimodal logistics. Transportation by inland shipping serves as a sustainable component within an integrated logistics chain that competes and collaborates with other transportation modes. Passenger transportation includes both mobility (commuting) and recreational activities through day-passenger and cruise shipping.

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Efficient transportation by inland shipping contributes to strengthening the economy, improving the living environment, and reducing road congestion. Together with inland ports, Dutch inland shipping has a direct added value of 8.4 billion euros and provides employment to over 81 thousand people. Inland shipping plays a crucial role in supplying the German manufacturing industry, which is closely intertwined with the Dutch economy and prosperity, as well as the position of Rotterdam as the largest port in Europe. Inland shipping makes the Netherlands livable by contributing to a stable food and energy supply and essential products for every resident. Inland shipping is literally the driving force behind Dutch freight transport, both nationally and internationally towards Belgium and the Rhine region. Nearly unnoticed, 35% to 40% of the total transport performance in the Netherlands is achieved via inland waterways (measured in ton-kilometers). Dutch inland shipping is a global leader in this respect, with few other places in the world achieving a comparable performance. Inland shipping is unique and gives the Netherlands an undeniable advantage as a logistics service provider for Western Europe.

1.1 Low Water

One of the challenges that inland shipping faces and is expected to encounter more frequently is low water. Low water affects inland shipping because ships can be loaded less deeply during these periods, resulting in reduced cargo capacity. In extreme cases of low water, a situation can arise where navigation becomes impossible. The available water depth on rivers is mainly determined by water discharge and the river's configuration. Greater water discharge leads to greater water depth. Low river discharges and low water are age-old phenomena, but climate change is expected to make them more frequent and prolonged. This makes the shipping sector less reliable and hinders its logistics function. Therefore, dealing with low water requires a clear vision.

1.2 Assumptions and Uncertainties

The extent of the impact of low water on shipping depends on the frequency and duration of (extremely) low water levels. This vision is based on current scientific insights, which suggest that the situation will deteriorate but that waterways will remain navigable. More extreme changes

1 Figures from 2021 based on CBS and Binnenhavenmonitor 2021.
2 A good overview of this can be found in: Klimaatbestendige Netwerken: Stresstest Hoofdvaarwegennet - Deelrapport Droogte'.'

than those currently anticipated would require different solutions. Climate change also has other consequences, such as extreme high water and intensified storm conditions. This vision focuses on the effects of low water because it has the greatest impact on shipping.

In addition to low water levels, the profile of the waterway, fleet composition, transport demand, and various future changes in cargo flows also affect inland shipping's performance. The waterway profile involves the shape, width, and depth of the navigable part of the waterway. This entails a trade-off between available width and depth. Fleet composition relates to the types of ships and their specific characteristics, such as dimensions, capacity, engine power, and emissions. Cargo flows are also subject to change; for example, the transport of fossil fuels may decrease while other cargo flows have the potential to grow. It's worth mentioning that European and national policies aim to shift transportation from road to water (and rail), which could result in more ship movements. This is referred to as modal shift. All these aspects contain uncertainties.

1.3 Objective

In this document, Koninklijke Binnenvaart Nederland (KBN) outlines its vision on developments related to low water, their consequences for inland shipping, and the (desired) solutions. KBN aims to contribute to reliable, future-proof, and climate-resilient goods and passenger transportation by water.

WHERE	WHAT	SOLUTIONS	WHO
Free-flowing rivers: Rhine / Waal and IJssel	Restriction of sailing depth > reduced transport capacity	Depth measurements and forecasting tools	Knowledge institutions / governments (waterway and water managers) / private parties
		Flexibility of logistics processes	Skippers / logistics service providers / cooperatives / inland shipping entrepreneurs
		Fleet and ship modifications	Inland shipping entrepreneurs / cooperations / knowledge institutions / governments / skippers
		Climate-proof fairway	Governments / knowledge institutions
Dammed rivers/ canals: Maas / Twente canals	Lock restrictions	Water saving lock design	Governments (waterway and water managers)
		Compensatory pump capacity at weirs	Governments (water managers)
Delta / sea connections	Salt intrusion	Technical measures: bubble shield / selective salt extraction	Governments (water managers)
		Verdringingsreeks	Governments (water managers) / KBN / knowledge institutions
All waterways (particularly the IJssel)	Risks regarding nautical safety	Adaptation	Inland shipping entrepreneurs (skipper) / governments (nautical management)
		Seperation of functions	Governments

3 Regarding transport demand via inland shipping, a growth of 18% - 34% (reference year 2014) is expected by 2040 (source IMA 2021). Due to the energy transition, cargo flows in dry and wet bulk of fossil products will decrease, but new energy carriers like hydrogen will increase. The fleet (the market) will (expectedly) need to adapt to these new cargo flows.

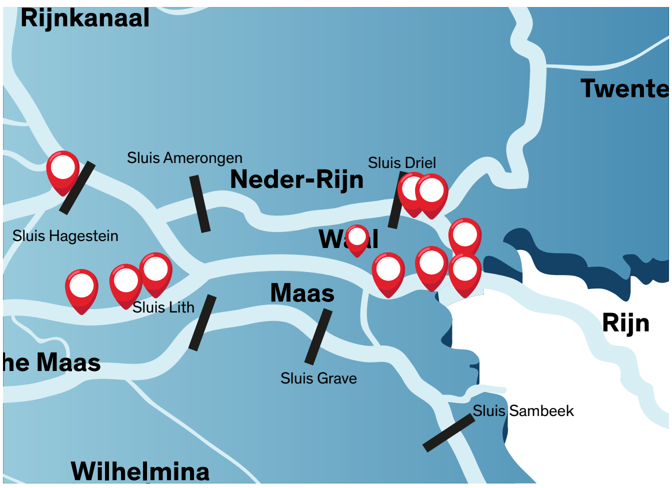
2. Implications

It is expected that lower river discharges due to climate change will occur more frequently and for longer periods. Low river discharges have several implications for shipping. The key categories are outlined below.

2.1 Water Depth (Rhine/Waal/IJssel)

Low water levels resulting from low river discharges occur in the Netherlands on the Waal, the Pannerdensch Canal, and the Gelderse IJssel. The Waal and the Rhine in Germany form the most important transport corridor connecting the ports of Rotterdam, Amsterdam, and Antwerp to the European hinterland. Over 100,000 ships use this transport route annually. Every centimeter of water depth is crucial. Depending on the ship's size and total payload, a modest decrease of 10 centimeters in water depth results in a loss of 100 to 120 tons of cargo per ship (for a Rhine ship measuring 110 meters in length). During low water periods, this translates to a reduction of around one million tons of cargo capacity per month for every 10 centimeters less water.

A minimum water depth of 2.80 meters has been agreed upon for the Waal and a significant part of the Rhine, which may not be undercut on average more than twenty days per year. This is known as the Agreed Low Water Level (Overeengekomen Lage Rivierstand). An analysis of water levels conducted at the end of 2018 revealed a structural shortfall of half a meter in water depth on the Waal due to problems with the "hard layer at Nijmegen," which has become the most significant depth bottleneck on this corridor. Efforts have been made in recent years to address these issues, but a preliminary analysis suggests that we still face a shortage of around 30 centimeters.



Other significant depth bottlenecks on the Rotterdam-Germany corridor include the Upper Waal at the location of a pipeline corridor near Hulhuizen/Gendt and the riverbed berms near Erlecom. On the Lower Waal, depth bottlenecks exist at Ophemert, the hard layer near Sint Andries, and the hard layer near Haaften. The main bottlenecks on the Pannerdensch Canal are located at the junction points, namely at the entrance of the canal at the Pannerden junction and at the end of the canal at the IJsselkop junction

4 A 'field' with bottom ridges is a kind of interrupted solid layer. Bottom ridges, like a solid layer, aim to reduce the flow surface area in the outer bend and increase the bottom roughness in the outer bend. By placing the bottom ridges not perpendicular but "scooping" in the direction of flow, a local flow pattern is generated that promotes the transport of sand from the shallow inner bend to the deeper outer bend. Bottom ridges were constructed in the Erlecom bend between 1994 and 1996.

near Westervoort, between the Nederrijn and the IJssel. Low water levels create local shallows for shipping on the Nederrijn and the Lek at Arnhem and Nieuwegein. On the IJssel, depth bottlenecks for shipping are mainly present at sharp bends such as Velp, De Steeg, Havikerwaard, Doesburg, Gorssel, Deventer, and the Vreugedrijkerwaard near Zwolle. On the Boven-IJssel, this has already led to navigation restrictions such as temporary one-way traffic. Depth limitations on the IJssel are also related to waterway width and nautical safety and will be elaborated upon specifically later.

The depth problem on these rivers is closely linked to bottom erosion. Over the years, these rivers have been engineered to facilitate navigation, including the construction of berms. This has brought significant benefits to shipping. However, the river's confinement has also led to problems with bottom erosion. This has caused an uneven riverbed because fixed layers (constructed to counteract erosion at specific points), cables and pipes, (pre)harbors, and locks do not erode with the rest.

As a result, bottlenecks have emerged in areas such as the Amsterdam-Rhine Canal, the Twente Canal, the port of Deventer, the Oude IJssel, and the Maas-Waalkanaal. Solutions will need to be found for these issues as well.

The Rhine is the busiest free-flowing river in Europe. The main bottleneck is located on the Middle Rhine between Budenheim and Sankt Goar, both in Germany. This section will be addressed in the "Abladeoptimierung der Fahrrinnen am Mittelrhein" project in the coming years. The expectation is that this project will increase the water depth at OLR from 1.90 meters to 2.10 meters, extending the desired depth of 2.10 meters at OLR from Koblenz to the first lock on the German Rhine at Iffezheim. This would increase the minimum water depth on the Rhine by 20 centimeters. Such depth optimization will have a significant impact on the river's transport capacity.

2.2 water losses/lock restrictions (Meuse/ Twente Canals)

Low water can also affect shipping on dammed rivers and canals. A dam, in combination with a lock, serves to retain and raise the water to

a certain level. This creates a nearly constant water depth for navigation, allowing a dammed river to remain navigable even with reduced water discharge. The Meuse in the Netherlands is a typical example of this, as it has much lower discharge than the Rhine. Without dams and locks, the river would be mostly unnavigable. Canals like the Twente Canal also rely on dams to maintain water levels. Dams and locks are thus essential for making and keeping such connections navigable. However, during times of (extreme) drought, problems can arise at locks for shipping. When a lock is used, some water from the section above the dam flows into the section below the dam. This always results in water loss, leading to a drop in the water level in the upstream section. This drop adds to the water level decrease caused by evaporation, irrigation, and drinking water extraction. During dry periods, if there is insufficient water inflow, this can result in reduced water depth. It can also endanger the stability of dams. Preventing the water loss is important during droughts because the scarce water is essential for other purposes, such as irrigation for agriculture and cooling of power plants.

Therefore, during extreme droughts, locking restrictions are often imposed. Such disruptions have a negative impact on travel time and the reliability of logistical services. Container ships may not be able to maintain their regular schedules, resulting in longer transit times and the need for more ships to maintain a consistent departure frequency.

2.3 Saltwater Intrusion (Delta/Sea Connections)

Saltwater intrusion, or salinization, is a phenomenon that must increasingly be taken into account in recent years. In a normal situation, the salty seawater does not penetrate far inland due to sufficient counterpressure from freshwater from the rivers. However, at some points in the Netherlands, during periods of low river discharge, there is insufficient counterpressure, causing the saltwater intrusion to extend further inland than desired for drinking water extraction and agriculture. Additionally, rising sea levels in the future will causes an increase of saltwater intrusion. Locations where saltwater intrusion is currently occurring or may become a more significant issue in the future include the Amsterdam port area (IJmuiden sea lock), the Rotterdam port area (including the Park locks), the Terneuzen lock complex, the locks in the Afsluitdijk (Den Oever

and Kornwerderzand), the Tsjerk Hiddessluices in Harlingen, and the Farmsum sea lock in Delfzijl.

For shipping, saltwater intrusion mainly has indirect consequences. To prevent the salt concentration at freshwater intake points for drinking water or agriculture from rising too high, measures are taken that often have a negative impact on shipping. Sometimes, locking restrictions are imposed (to limit saltwater intrusion), or water is diverted to flush secondary waters. For example, "Waalwater" is redirected towards the Amsterdam-Rhine Canal to counter saltwater intrusion in the North Sea Canal. Water managers also desire to redirect more water via the IJssel (at the expense of the Waal) to supply freshwater to the IJsselmeer. This results in reduced water depth on the main transport route, further limiting its capacity.

2.4 Nautical Safety (All Rivers, Especially the Boven-IJssel)

Low water levels have implications for nautical safety. When water depth decreases, ships must actively follow the deeper part of the waterway to avoid touching the bottom. Additionally, the sailing speed is reduced to prevent ships from sinking deeper into the water when traveling faster. Another aspect is that the waterway becomes narrower as waterways have sloping banks. This makes it more challenging to overtake and pass other ships. In waterways with bends, complex nautical situations can arise. A typical example is the Gelderse IJssel, particularly in the section between Arnhem and Zutphen, known as the Boven-IJssel, where the river is narrow and contains many bends even in normal conditions. During extremely low water levels, it becomes nearly impossible for ships to pass each other on this waterway. Consequently, Rijkswaterstaat decided to implement one-way traffic in 2018 and 2022.

Lastly, low water affects the stopping distance of ships. Due to low cargo loads, the propeller partially protrudes above the water and becomes less effective for reversing the ship. This makes stopping more difficult, requiring more distance between ships.

2.5 Logistic Consequences

All of the above limitations disrupt inland waterway logistics. With reduced water depth, ships can carry less cargo, requiring more ship movements to transport the same amount of goods. This results in higher costs and increased CO2 emissions per ton of transported cargo in the best case scenario. In the worst case, it can lead to a shift to other modes of transportation and production losses. Additionally, a larger capacity is required at locks. Locking restrictions, closures, and other measures like one-way traffic result in longer travel times and reduced reliability of inland shipping.

Normal fluctuations in river discharge can be managed, but prolonged and/or extremely low water levels are detrimental to the reliability and costs of inland shipping. This is clearly reflected in the statistics on the Rhine towards Germany. After the low water in 2018, there has been about a 10% structural decline in container transport, as these have permanently shifted to other modes of transportation for reliability reasons. In the low-water year 2022, a decline in Rhine container transport is also observed, but this decline can also be attributed to global economic fluctuations and decreasing international trade. Although low water periods have an impact on Dutch waterborne transport, it is (still) relatively less affected by low water because Dutch waterways are often dammed and/or canalized, making water depth reduction less of a problem. Moreover, water depth in the river delta is partly related to sea level.

3. Solutions

Low water levels demand concrete solutions because if we do nothing, the situation will only worsen. KBN considers the following solution directions for maintaining capacity and logistical reliability on free-flowing rivers, reducing locking losses, preventing saltwater intrusion, and ensuring nautical safety.

3.1 Capacity and Logistical Reliability (Rhine/Waal/IJssel/Nederrijn/Lek)

To improve water depth on free-flowing river branches, four categories of solution directions can be identified.

3.1.1 Depth Measurements and Forecasting Tools

The first category focuses on better utilizing the current system. It revolves around providing accurate information and reliable forecasts regarding available water depth. This allows shippers and inland shipping entrepreneurs to plan well in advance. A shipper can order the necessary goods "on time" (before a low-water period), and a skipper can adjust the vessel's draft at the time of loading based on the expected conditions during the voyage. Currently, such predictions are available for up to a maximum of 1 week in advance. Ideally, this would extend to 2 to 4 weeks. Private entities like CoVadem are already collecting real-time data on water depth, which is made available (for a fee). Electronic water charts based on this data provide current information on water depth. Besides navigation, this information also presents opportunities for waterway authorities to target dredging efforts at critical points. Additionally, having a good predictability of measures due to low water, such as potential locking restrictions, the implementation of one-way traffic, or situational control of water distribution resulting in different water levels, is necessary.

3.1.2 Flexibilization of Logistics Processes

The keyword in this category is "flexibilization." This involves the option to order goods earlier or later (no just-in-time delivery). A reliable multi-week forecast of water levels is essential for this. It may also be necessary to maintain larger buffer stocks, where possible. Furthermore, there are opportunities to temporarily use different modes of transportation, including multi-modal and synchromodal transport. This requires adjustments to logistics processes. Developments in this category will mainly be initiated by shippers. Shippers do not wait but, often in collaboration with other parties in the logistics chain, take appropriate measures themselves.

3.1.3 Fleet and Ship Adaptations

This direction has already received significant attention within the sector. Traditionally, during low-water periods, capacity is increased by sailing more hours and taking barges in tandem with motor cargo and tanker ships. The use of barges during low water is effective because they have a shallower draft than motorized vessels. It is likely that barges that have been transporting coal for decades will serve as reserve capacity for containers in the future, particularly during low-water periods. During the low-water periods of 2018 and 2022, barges that normally transported coal upstream were also used for containers downstream. Additionally, work is underway to develop tugboats with a shallower draft. Therefore, it is desirable to facilitate the use of barges during low water by maintaining and creating sufficient mooring or anchorage locations.

Furthermore, the sector has been investing in lighter ship constructions and ships equipped with smaller, less deep-drafting propellers for years, i.e., ship optimizations. Further development in this area is expected.

A commonly discussed "solution" in the ship adaptation category is fleet diversification, often referring to the use of smaller ships. However, smaller ships do not necessarily perform better during low water. The optimal ship has the greatest possible buoyancy, and ship design involves finding the optimal balance between hull shape, size (surface area), and weight. Smaller ships have less buoyancy than larger ships, making them less effective. To optimize for low water, lightweight materials must be used, and the ship's length and width should be maximized while reducing the depth.

An example of advanced optimization is the extremely low-water tanker Stolt Ludwigshafen, launched in 2023 for BASF. This tanker has a length of 135 meters, a width of 17.5 meters, and a relatively low draft of 3.24 meters. Due to its large volume, lightweight construction, and the use of smaller propellers, the ship can carry over 800 tons of cargo at a very shallow draft of only 1.20 meters (at a water depth of approximately 1.50 to 1.60 meters). This is much more than typical Rhine ships. For comparison, a conventional 110-meter tanker with a draft of 3.5 meters would have approximately 200 tons of cargo capacity at a draft of 1.20 meters (excluding the fact that such ships typically require a draft of about 1.40 meters near the propeller to operate).

Adapting ships is only possible to a limited extent. Using smaller propellers can enable navigation at shallower depths (e.g., down to 1.20 meters instead of 1.40 meters). However, smaller propellers provide less power and consume more fuel under the same load. One solution could be to add an additional propeller, but this is only an option during new construction or the complete replacement of the stern.

To carry more cargo, the ship's weight must be reduced. Many ships are already constructed with lightweight, high-strength steel. Advanced optimization may reduce about 10% of the ship's weight, which equates to approximately 100 tons for a 110-meter ship. The rest must come from reducing the depth, but this comes at a high cost during normal water levels. The ship can carry much less in this case. For illustration, if a 110-meter Rhine ship is designed for a draft of 3.00 meters instead of 3.50 meters, its capacity during extremely low water increases by approximately 55 tons but at the expense of about 550 tons of cargo capacity at the design draft. Lowering the design draft from 3.50 meters to 2.50 meters gains approximately 110 tons during extremely low water but costs around 1100 tons of cargo capacity in deep water. Therefore, every ton of cargo capacity gained in shallow water results in the loss of about 10 tons of cargo capacity in deep water. Economic calculations show that investing in such ships is not financially viable at typical market prices, even during years with low water like 2018 or 2022. As an insurance against industrial process interruptions, the construction of extremely low-water ships can be a suitable

5 https://www.basf.com/global/en/who-we-are/organization/locations/europe/german-sites/ludwigshafen/the-site/news-and-media/news-releases/2023/05/p-23-216.html
6 In this document, the emphasis is on low river discharges and low water, but a slightly broader approach is chosen, especially in the infrastructure part, because it is necessary to consider the waterway in a broader context. KBN is considering the possibility of also writing a vision for waterways and infrastructure that could outline this broader context more extensively (including changing cargo flows, etc.).

solution, but only if shippers are willing to commit to these ships for several years at significantly higher costs.

3.1.4 Infrastructure/Waterways

The final category pertains to adapting the infrastructure and waterways. It is essential to adopt an integrated approach in which transportation corridors are addressed comprehensively. The weakest link, the shallowest section, or the least reliable element ultimately are decisive. With such an integrated approach, all aspects need to be carefully considered. For instance, actions like narrowing the river, roughening the riverbed, and permanently removing solid layers, while potentially improving water depth, can also introduce problems. Removing solid layers can have negative effects on erosion processes, as can narrowing the river. Moreover, narrowing the river can lead to issues during high river discharge. Therefore, this vision does not present an extensive list of solutions to increase water depth during low river discharge but rather describes the prerequisites for creating a navigable waterway, the proper balance between parameters, and some promising concepts.

I) Conditions of a River Waterway

Navigation benefits from a consistent riverbed with adequate depth, even during periods of low river discharge. In addition to sufficient depth, a consistent flow is desirable, and ample width is necessary for safe overtaking and maneuvering, especially on free-flowing rivers like the Rhine, Waal, and Geldersche IJssel. To achieve this, erosion and sedimentation problems must be addressed structurally.

II) Riverbed Management

The most straightforward solution to achieve sufficient depth on soft-bottom waters like the Waal, IJssel, and parts of the Rhine is through dredging to remove depth bottlenecks. However, continually deepening the river is not a viable solution as it would exacerbate the erosion process. Moreover, uniformly lowering the entire riverbed does not add depth because water flows downhill on an inclined plane, and lowering that plane does not increase depth. Therefore, solely relying on a dredging program is insufficient; it must be part of a holistic solution. Solutions should focus on effective riverbed management where bottlenecks are addressed adequately, and the river may be reconfigured to prevent the formation of undesirable shallows. To create a consistent riverbed and maintain sufficient sediment in the riverbed, it is desirable to return dredged material to erosion pits. Information from collective depth measurements and real-time electronic water charts can contribute to

effective riverbed management by targeting critical dredging points.

III) Longitudinal Dam Concept

The construction of three longitudinal dams in the pilot project “langsdammen” was completed in 2015 to test the concept. Evaluations of this pilot project have revealed several benefits of longitudinal dams for flood safety, freshwater availability, nature, and navigability. For shipping, the advantage is increased depth during low water periods. Longitudinal dams also contribute to improved sediment management and halting bottom erosion. The main disadvantage is that the width of the waterway is reduced. Balancing width and depth remains a challenging trade-off. However, given the expected increase in and longer duration of low water levels, it may be worthwhile to consider sacrificing some width. Longitudinal dams also offer opportunities for securing the riverbed in the navigation channel (to prevent erosion) and roughening the riverbed (to create water level rise), while allowing for morphological processes in secondary channels to promote nature. Overall, the concept of longitudinal dams is promising, and KBN is willing to explore potential expansion and optimal integration of longitudinal dams in the waterway.

IV) Water Storage

Capturing water upstream during periods of sufficient water flow is another solution to provide more water discharge and, consequently, greater depth for shipping (and other water-related functions) during drier periods. However, the scale required for this approach to maintain sufficient water availability during extended dry periods is immense. Furthermore, the development costs for such interventions are substantial. Nevertheless, it may be part of the overall solution. Switzerland’s reservoirs, to some extent, already employ this concept. Along the Rhine, old lignite mines, such as those near Garzweiler, are being prepared for use as water storage basins. Increasing the capacity of existing reservoirs, such as Lake Constance (Bodensee), and identifying locations for retention basins could be considered. In these interventions, it is essential to explore synergistic opportunities and multiple-use concepts.

V) Locks, Weirs, and/or Canals

Adapting infrastructure is inevitable to keep waterways navigable in the face of extremely low water discharge. The placement of longitudinal dams can create an additional 15 centimeters of depth. While this difference is significant in the current situation, if discharge conditions deteriorate further and ships can no longer navigate, it may eventually be necessary to further canalize the Rhine. The inland shipping industry is not currently in favor of canalization, but if the situation worsens significantly, canalization may become necessary in the second half of this century. The ideal scenario is to have an open, lockable river with lock complexes alongside the waterway, which only come into operation during low water conditions. This would help the river maintain its natural character as much as possible. Given the size, costs, and complexity of such projects and the long lead times for developing large infrastructure projects, it is essential to explore canalization options now and take them into account in spatial planning policies.

3.2 Reducing Locking Losses

Locking losses are inevitable. As previously described, it is undesirable for shipping if locking restrictions are imposed due to drought. There are possibilities to minimize and/or compensate for these losses. When constructing new locks, it is advisable, from the perspective of shipping and water availability, to dimension them in a way that limits locking losses. This can be achieved by building a savings lock or twin lock, which can save 20% to 50% on locking losses. Another option is to use lock chambers by emptying the lock in the upstream section instead of relying on natural inflow to the downstream section, although this approach is time-consuming, energy-intensive, and costly. Additionally, ship lifts, which move pairs of ships up and down without causing locking losses, could be considered. Furthermore, new or renovated weirs could be equipped with pumps to compensate for locking losses. This could be combined with energy generation during periods of sufficient water flow. Several examples of such systems can be found in neighboring countries. The realization of this solution lies within the “Replacement and Renovation” program, which will address weirs on the entire Meuse River in the coming years.

7 In places where the riverbed is rocky, such as on the Rhine between Koblenz and Mainz, dredging is impossible. Riverbed management requires a different approach in these conditions. The project ‘Abladeoptimierung der Fahrrinnen am Mittelrhein’ is a good example of ‘riverbed management’ in these circumstances.

3.3 Preventing Saltwater Intrusion

Dealing with saltwater intrusion is complex. Technological possibilities are limited to date. The options available, such as the construction of "selective salt extraction" at sea locks or the use of bubble screens, can mitigate saltwater intrusion but do not solve the problem entirely. Saltwater intrusion is inevitable in open connections to the sea like Rotterdam, given low river discharge and rising sea levels, but it also poses problems in closed connections like IJmuiden locks. Investing in solutions to counter saltwater intrusion is valuable for shipping.

Addressing saltwater intrusion requires an integral approach. It is impossible to prevent all saltwater intrusion, so some damage will have to be accepted. The question is which functions and sectors will be affected by the consequences, requiring a careful consideration of priorities. The Dutch government employs a displacement hierarchy (verdringingsreeks) for water distribution issues, which weighs the interests of various water-related functions against each other. Safety against flooding and the availability of sufficient fresh water have the highest priority. It is also essential to make nuanced decisions that consider all relevant (chain) effects for water-related sectors.

The consequences for shipping have not been fully assessed. It is still unclear what impact adjusting (or "restoring") the discharge distribution on the Waal and IJssel would have. Such "restoration" would be undesirable for shipping due to the immense logistical importance of the Waal, at least without sufficient compensatory measures to guarantee depth on the Waal (see the section on nautical safety for further elaboration). Additionally, there are uncertainties regarding the use of the displacement hierarchy (verdringingsreeks) because sectors in category 4 (including inland shipping) may have interests in other categories. Inland shipping, for example, plays a crucial role in energy supply (category 2). The question is how to comprehensively assess these interests. KBN advocates for a balanced displacement hierarchy that adequately considers the societal interests of shipping.

3.4 Ensuring Nautical Safety

Safety on and around the waterway is, of course, a important aspect for inland shipping and for KBN. During low water conditions, certain risks associated with navigation increase, and there are various ways to anticipate and address these risks.

The primary factor for nautical safety is the behavior of waterway users in combination with the characteristics of the waterway itself. Inland ship operators are skilled enough to navigate their vessels safely during low water conditions. They take into account each other's space and communicate using means like VHF radios to coordinate passage in areas where it is necessary. Based on their expertise, they assess how deep they can load their vessels and whether an alternative route should be chosen if needed. Prolonged periods of low water require increased vigilance and expertise.

Specifically for the Geldersche IJssel, there are several possibilities to enhance nautical safety during low water conditions. Implementing one-way traffic on certain sections (which is already done in some areas) is an effective way to ensure safe navigation while maintaining transport capacity. Furthermore, there is an opportunity for improving navigation in the Boven-IJssel within the framework of the Integral River Management program. This program aims to make a structural choice regarding the distribution of water between the Waal and the IJssel. Adjusting the water distribution can have significant consequences for shipping. A reduced water discharge and

navigable depth on the Waal can reduce the transport capacity on this critical transport route to Germany. When considering the “restoration” of water distribution, any loss of navigable depth on the Waal should be compensated for through other hydraulic interventions such as the use of longitudinal dams. Adjusting water distribution positively affects navigation in the Boven-IJssel by directing more water through the IJssel than is currently the case. The last option for improving nautical safety on this narrow stretch is to use smaller vessels that can pass each other more easily. However, KBN believes this option is undesirable. In practice, experienced skippers can navigate safely even with reduced navigable depth, and they pass each other where possible. Furthermore, it is up to the logistics and the sector to choose the appropriate ship size. A systematic reduction in the navigational class leads to capacity reduction and an inverse modal shift, especially for container inland shipping, which already faces considerable restrictions in draft and clearance height.

A potential long-term solution, according to KBN, is separating functions. Constructing a lateral canal along the Boven-IJssel, similar to the Julianakanaal along the Meuse, offers opportunities for freshwater supply, nature conservation, recreation, and navigation.

8 The discharge towards the IJssel compared to the Waal has decreased over the past forty years due to autonomous riverbed development.
9 Additionally, this also has a positive effect on the issue of saltwater intrusion in the IJsselmeer. By increasing the supply through the IJssel, lock restrictions at the Stevinsluis in Den Oever or Kornwerderzand lock can be limited.

4. Stakeholders

Dealing with the various facets of low water conditions requires a range of solutions. The possibilities and responsibilities do not rest with one party or institution alone. A joint effort is needed, with each stakeholder having a unique role and responsibility, while seeking opportunities for collaboration with other water-related functions.

4.1 Koninklijke Binnenvaart Nederland (KBN)

KBN plays various roles related to low water conditions. First and foremost, it serves as a knowledge partner with insights into the chain of effects that low water conditions bring and the possible solutions to facilitate continuous navigation. KBN actively contributes to knowledge projects like TRANS2 and provides input in discussions, such as those surrounding the water distribution issue within the Integral River Management (Integraal rivier management) program and the Climate-Resilient Freshwater Supply Main Water System (Klimaatbestendige zoetwatervoorziening hoofdwatersysteem) strategy. KBN is also involved in discussions on sea level rise and saltwater intrusion.

Additionally, KBN acts as a sparring partner and provides information about expected developments. It particularly informs its members about current low water situations. It constantly gathers knowledge from practical experience and collects the needs of waterway users. This knowledge is compiled and shared with waterway managers and other policymakers to help address the challenges posed by low water conditions.

Furthermore, KBN assumes a constructive role in engaging with politics and society to create a realistic perception of low water conditions. It identifies necessary adjustments and informs political decision-making about the need for these changes. In this way, KBN actively supports and represents the interests of the inland shipping sector concerning low water conditions.

4.2 Inland Shipping Entrepreneurs

Inland shipping entrepreneurs play a crucial role in ensuring reliable and sustainable inland shipping. As part of the logistics chain, they collaborate with shippers and freight forwarders to create suitable solutions. This can involve optimizing vessels and aligning their operations with customer preferences. Inland shipping entrepreneurs are already investing in modifications to make their vessels more suitable for low water conditions, such as using lightweight materials, smaller propellers, barges, electronic navigation charts with real-time depth information, and utilizing available forecasts of expected water levels.

When cost-effective, these investments result in vessels optimized for low water conditions. They are also exploring the use of pushboats that can operate in shallower waters. By investing in sustainability and climate resilience of vessels, inland shipping entrepreneurs ensure that the sector has modern, sustainable vessels capable of serving customers effectively even during low water conditions. Smart use of digital tools can further enhance the optimal planning and utilization of vessels and infrastructure, streamlining timely information delivery to customers.

4.3 Shippers and Logistics Service Providers

Shippers and logistics service providers are responsible for integrating inland shipping reliably into their logistics chains. This can be achieved partly by using vessels that perform better during low water conditions but also by optimizing the logistics system, increasing inventory capacity, and capitalizing on opportunities in multimodal and synchromodal transport (selecting the best combination of available transportation modes for each shipment).

Regarding inland shipping, shippers and freight forwarders can contribute to the sustainability and climate resilience of vessels by establishing long-term transportation relationships and providing long-term commitments to ship owners. This can be done by offering multi-year transportation contracts, providing loans, or even investing in new vessels and necessary modifications to existing vessels. Such commitments enable investments in sustainable and climate-resilient vessels and ensure shippers of a high-quality transportation solution.

4.4 Governments

Governments are responsible for water management and waterway infrastructure management, tasks that are carried out at various levels, including municipal, regional, provincial, national, and international. In principle, making inland shipping resilient to water shortages primarily requires an international approach. Given its location in the delta of rivers, the Netherlands has a dependent position when negotiating with countries in the Rhine and Meuse river basins regarding water supply. Due to this dependency, the influence the Netherlands can exert on water supply is limited. Efforts will primarily focus on finding ways to facilitate freshwater supply and navigation given the available water supply during low water conditions.

I) Waterway and Water Management Authorities

Waterway and water management authorities play a crucial role in the management of waterways and in providing accurate and timely information to the sector. To set the right priorities and maintain navigable waterways, it is essential to involve the inland shipping sector (through entities like KBN) actively in decision-making processes. Additionally, it is crucial to inform the sector early about measures taken during dry periods and their implications for inland shipping. In addition to information about the current situation, forecasts of river discharge and expected water levels are also important. Such forecasts are already available, but the shipping sector needs even more accurate predictions. Logistics would also benefit from longer-term forecasts extending two to four weeks ahead. Such forecasts enable shippers to anticipate low water conditions more effectively.

II) Politicians and Policymakers

For decades, European and national policies have aimed to achieve a modal shift from road transport to more sustainable modes like inland shipping and rail. Availability of a sustainable inland shipping fleet and a well-functioning and climate-resilient waterway network are essential for this shift. The fleet capacity of inland shipping is certainly sufficient for this purpose. Politicians and policymakers are responsible for the state of the waterway network and its future climate resilience. They define the legal and financial frameworks for waterway management, maintenance, and infrastructure replacement. By implementing appropriate policies and making funds available, they can promote conditions for making the inland shipping fleet more

[10] *TRANSitie naar een klimaatbestendig Rotterdams achterlandTRANSport.*

sustainable and climate-resilient. Politicians and policymakers play a vital role in creating the right conditions for the sustainability and climate resilience of the inland shipping system.

4.5 Knowledge Institutions

Knowledge institutions contribute to climate-resilient inland shipping in their unique ways. With high-quality knowledge of hydrological, morphological, and logistical processes, they support waterway authorities, policymakers, and the sector in developing and implementing solutions for low water conditions. They also assist in assessing the (economic) impacts of low water conditions and evaluating the effectiveness of proposed solutions or measures. Through long-term scenarios and short-term forecasts, they provide insights into future water levels and system performance. The development of a "digital twin" environment for waterways is promising. This virtual modeling environment simulates the course of waterways, infrastructure, water levels, and ship logistics. Such models will allow for more realistic simulations of the inland shipping system and the effects of low water conditions and proposed solutions. KBN is actively involved in the TRANS2 project and its predecessor, "Digital Twin Waterways," and supports the realistic description of vessels, waterways, and logistical operations.

5. Conclusion

Inland shipping contributes to economic strengthening, environmental improvement, and congestion reduction on roads by providing efficient transportation. One of the challenges that inland shipping faces, which is expected to become more prevalent, is low water conditions. Low water conditions affect shipping because vessels can be loaded less deeply and carry fewer goods. In extreme cases of low water, navigation may be severely disrupted or halted altogether.

Problems manifest differently across different parts of the network. The most significant challenge lies in the free-flowing rivers, including the Rhine, which merges into the Waal and branches off into the Ijssel. Despite recent efforts, the water depth on the Waal still remains about 30 centimeters below the target depth of 2.80 meters at the agreed low river level (OLR). This situation will worsen further if more water is diverted to the IJssel and the Amsterdam-Rhine Canal to ensure freshwater availability and prevent saltwater intrusion. Measures such as the installation of longitudinal dams and targeted dredging might potentially gain an additional 10 to 20 centimeters of water depth, if not already

done. These efforts are essential because river discharge is expected to further decrease during dry periods due to climate change. The loss of water depth can only be compensated to a limited extent, both technically and commercially, by using push boats and constructing new extremely low-water vessels. Constructing vessels with lighter materials provides additional capacity during both low and high water conditions. However, reducing the vessel's draft to save weight results in a significant loss of cargo capacity during high water and may not be economically viable unless vessels are viewed as insurance against the shutdown of costly industrial processes, such as in the chemical process industry. Further canalization of the Rhine is generally not desirable, but if the situation worsens significantly in the coming decades, it may become necessary in the second half of this century.

On dammed rivers, the challenges are of a different nature. Here, there is generally sufficient depth available, but it is crucial to prevent the water level from dropping so low that there is insufficient water for other functions such as drinking water and irrigation. From this perspective, lock restrictions are imposed during low water, which have a detrimental impact on inland shipping. It is desirable to explore solutions to prevent or compensate for these lock losses. Additionally, when replacing infrastructure, consideration should be given to locks with reduced lock losses.

Dealing with low water is a complex issue involving many stakeholders. Each stakeholder has a unique role and responsibility. As the primary representative for inland shipping, KBN collaborates with all these parties and aims to find a solution together to keep the waterways optimally navigable in the future.

Also available in Dutch and German.