Memo

Date
10 February 2025

Our reference
11209638-001-ZWS-0005

Number of pages
1 of 18

Contact person
Rolien van der Mark

Direct number
+31(0)6 2153 4536

E-mail
Rolien.vanderMark@deltares.nl

Authors / contributors
Rolien van der Mark, Fedor Baart, Albrecht Weerts

Subject
Rhine discharge outlook 2023

Voorliggende rapportage is een product van het project TRANS2 ("TRANSitie naar een klimaatbestendig en duurzaam Rotterdams achterlandTRANSport"), een project met 15 partners onder coördinatie van Deltares. TRANS2 gaat primair over klimaatadaptatie: hoe kan de binnenvaart zich aanpassen aan, meer grip krijgen op een veranderend klimaat? Project TRANS2 is mede gefinancierd door TKI Deltatechnologie uit de PPS-innovatie programmasubsidie van het Ministerie van Economische Zaken.

Rhine discharge outlook 2023

Summary

The year 2022 had very low discharges, hindering an efficient inland waterway transport. The low flow could partly be explained by the small amount of snow in the Alps. A new forecast method predicts that the Rhine river discharge might be low again this year (i.e. 2023), due to a lack of snow in the Rhine basin. The amount of snow available can predict more than 25% of the discharge up to July, after which precipitation becomes the only main contributor.

This knowledge may be useful for businesses looking to transport goods cost-effectively. With the help of the new forecast method that predicts Rhine river discharge levels for the coming three months, businesses can now plan ahead and make informed decisions about shipping goods. Knowing that the discharge will likely be low in the upcoming months, businesses can adjust their shipping schedules accordingly, arrange extra vessels or other modality, or transport more goods in advance when water levels are still high enough to accommodate larger shipments. This can help businesses save costs and avoid delays later in the season when water levels are lower. The ability to plan for the next months, rather than just the next week, gives businesses a valuable advantage in managing their operations along the Rhine river.

Introduction

In TRANS2 we have generated a seasonal outlook of the Rhine river discharge, with the aim to explore whether this may be useful for the sector. This meant that in April of 2023 a forecast was made for discharges at Lobith for the coming 3 months (12 weeks) based on amongst other the available amount of snow at that time and possible realizations of the weather.

This memo has been prepared specifically for the TRANS2 project, taking into consideration the lessons learned from the 2022 year drought.

The information is primarily directed towards ports, shippers, and other parties involved in the logistic chain. The intended audience for the forecast includes:

- Ports: Port authorities and operators along the Rhine river, who rely on accurate discharge information to plan their operations effectively. This includes managing vessel traffic, determining loading and unloading schedules, and ensuring optimal utilization of port infrastructure.
- Shippers: Companies engaged in shipping and transportation activities that rely on the Rhine river as a vital logistics route. Shippers need to anticipate possible fluctuations in the river discharge to optimize their logistical planning, including scheduling vessels, coordinating with ports, and managing inventories.
- Logistic Chain Stakeholders: Various entities involved in the broader logistic chain, such as freight forwarders, warehouse operators, and distribution centres. These stakeholders require timely information about the expected Rhine river discharge to plan and adjust their operations accordingly. It enables them to ensure smooth movement of goods and minimize disruptions caused by potential changes in water levels.

This memo aims to provide a-priori estimates of the lowest expected discharge for the upcoming season. These preliminary numbers are intended to serve as a valuable reference point for the audience, enabling them to make informed decisions and take proactive measures to mitigate any adverse effects.

It is important to note that these estimates are subject to change as further data and analysis become available. Therefore, we emphasize that these numbers are preliminary and should be considered as a starting point for planning purposes. The ultimate goal is to optimize the form of dissemination, ensuring that the information reaches the intended audience in a timely and easily understandable manner.

By providing early estimates and maintaining transparency about the provisional nature of the forecast, the TRANS2 project aims to foster proactive decision-making and enable stakeholders to implement appropriate measures to navigate potential challenges arising from variations in the Rhine river discharge.

Seasonal variation in Rhine discharge

Variation of the Rhine discharge

The information in this section is taken from Buitink et al. (2023). In general, the Rhine discharge fluctuates over the year as shown with the grey bands in Figure 1. The river Rhine is fed by rain that falls over the entire river basin. Furthermore, snow melt in the Alps is an important source of water. The rainfall in the Alps is stored as snow in the winter months, and discharges in spring and early summer. With the rising temperature in the future, the snow coverage becomes less thick and less extended. More precipitation in the winter will directly discharge into the river, leading to higher winter discharges. Also, there is less supply of melt water from snow in the beginning of the summer, leading to a decrease of summer discharges. The Alpine glaciers are a relevant source of Rhine water in the late summer. However, the glaciers retreat rapidly in volume and will have disappeared by 2100, causing a reduction of late summer discharges of the Rhine. The yearly winter discharges will become higher in all KNMI’23 climate scenarios, and the summer discharges lower in all scenarios.

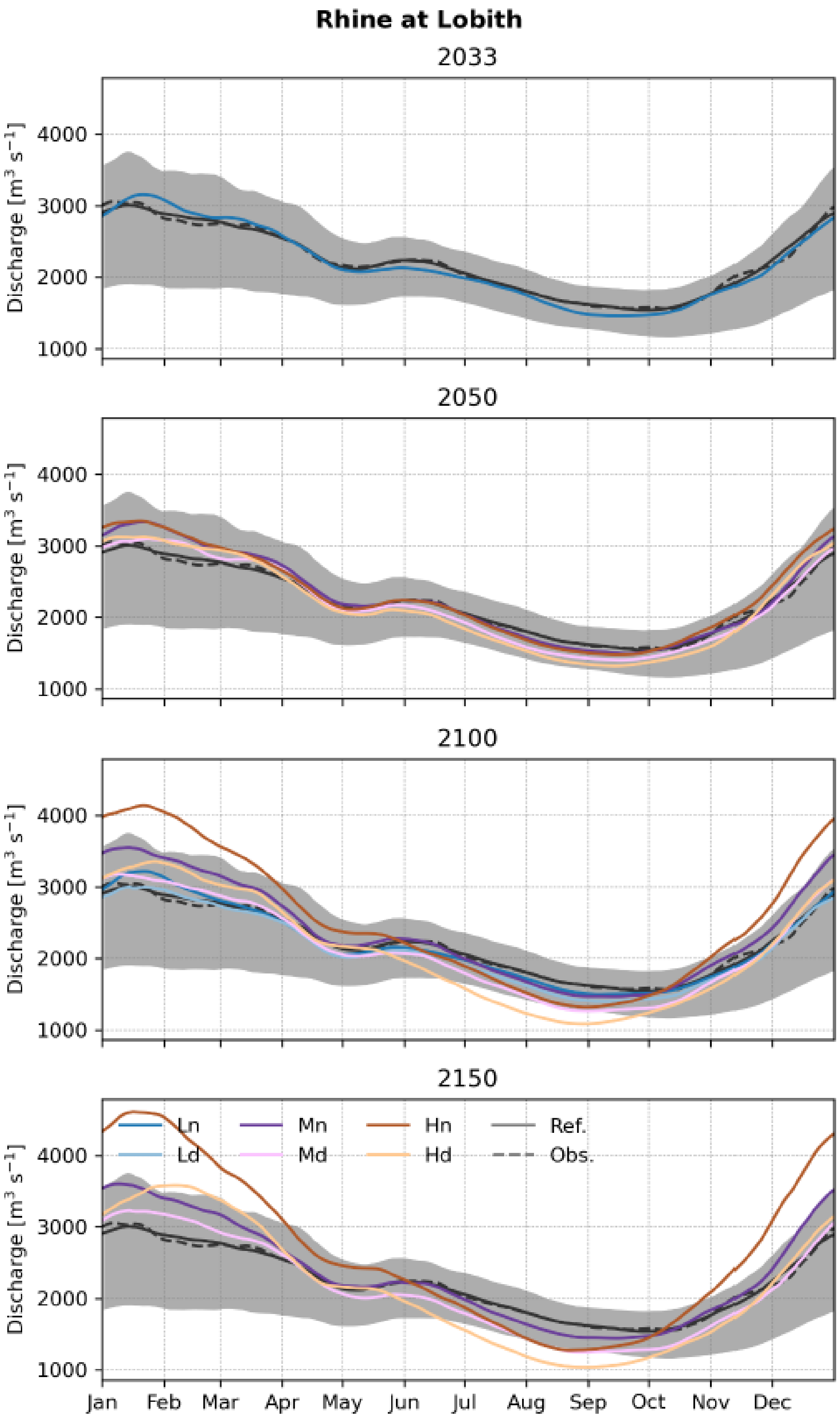


Figure 1 *Average discharge in the Rhine at Lobith. The top panel contains the results for the current climate including the interannual variation (grey bands representing the 25% to 75% range), the reference climate simulation (black line) and the Paris scenario (blue line). The other panels display the future KNMI'23 climate scenarios for the years 2050, 2100 and 2150. Source: Buitink et al. (2023).*

Trends in low discharge

Low discharge events are not new. The lowest-ever recorded annual discharge dates to 1929, but this was due to freezing. There is no trend in the lowest annual discharges. But if we split the discharges into summer and winter discharges, there is a shift from low discharge events in the winter to low discharge events in the summer (Figure 2).

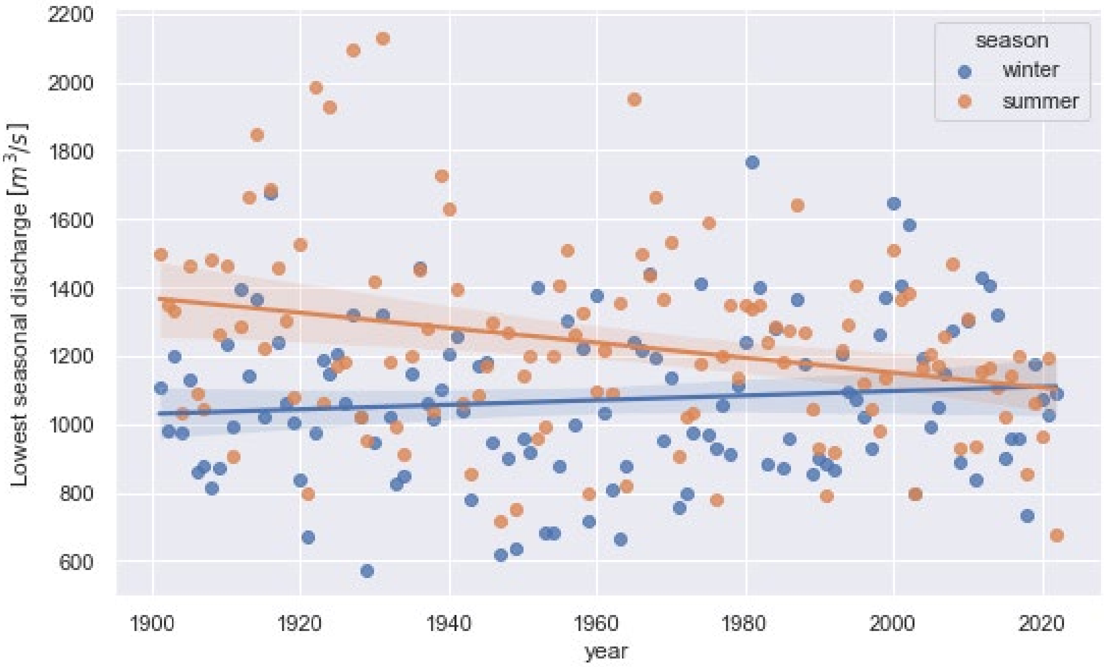
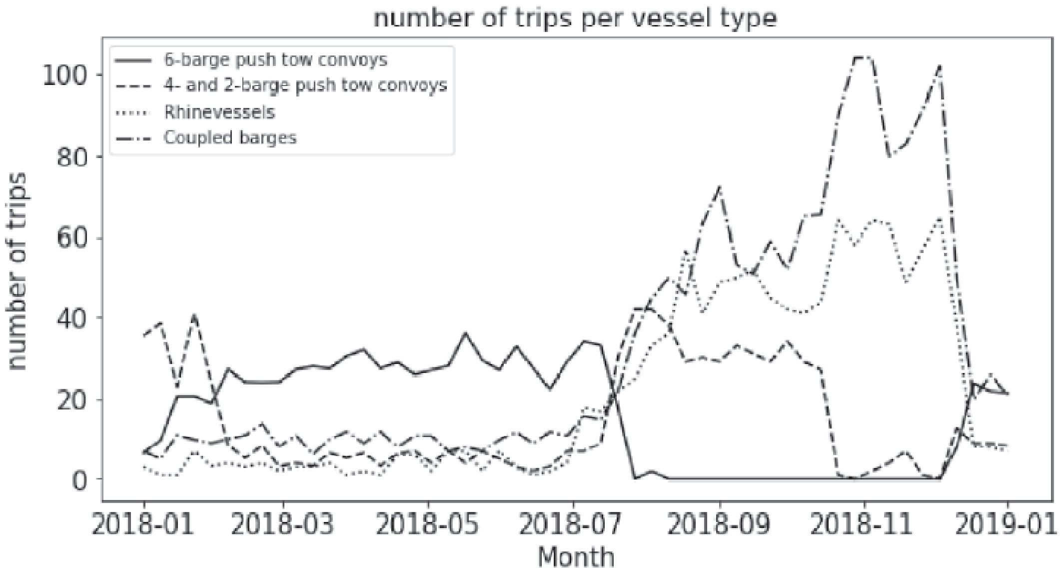


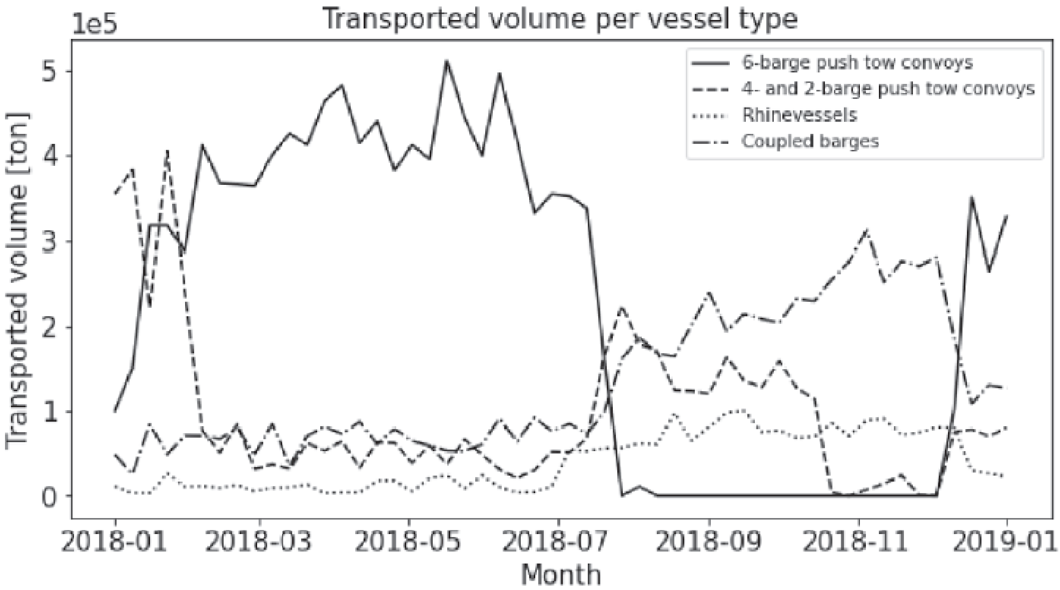
Figure 2 Lowest discharges in summer and winter seasons.

Relevance for shipping

Low discharge events have a significant impact on the transport capacity. This can result in shortages of materials in inland regions. Recent reconstructions of the effect of the 2018 low discharge (e.g. Vinke et al., 2022; Figure 3) and of the 2022 low discharge (e.g. Hendriks & Mens, (eds.) 2024; Figure 4), show that there is an increased number of trips needed in the corridor Rotterdam-Germany during low discharge, resulting in a sevenfold cost increase (simulated; Vinke et al., 2022). This increase in number of trips holds for dry bulk transport, not for liquid bulk and containers (Vinke et al., 2023).



(a)



(b)

Figure 3 *Reconstruction of 2018: number of trips (a) and transported volume (b) in 2018 for four vessel classes. Source: Vinke et al. (2022).*

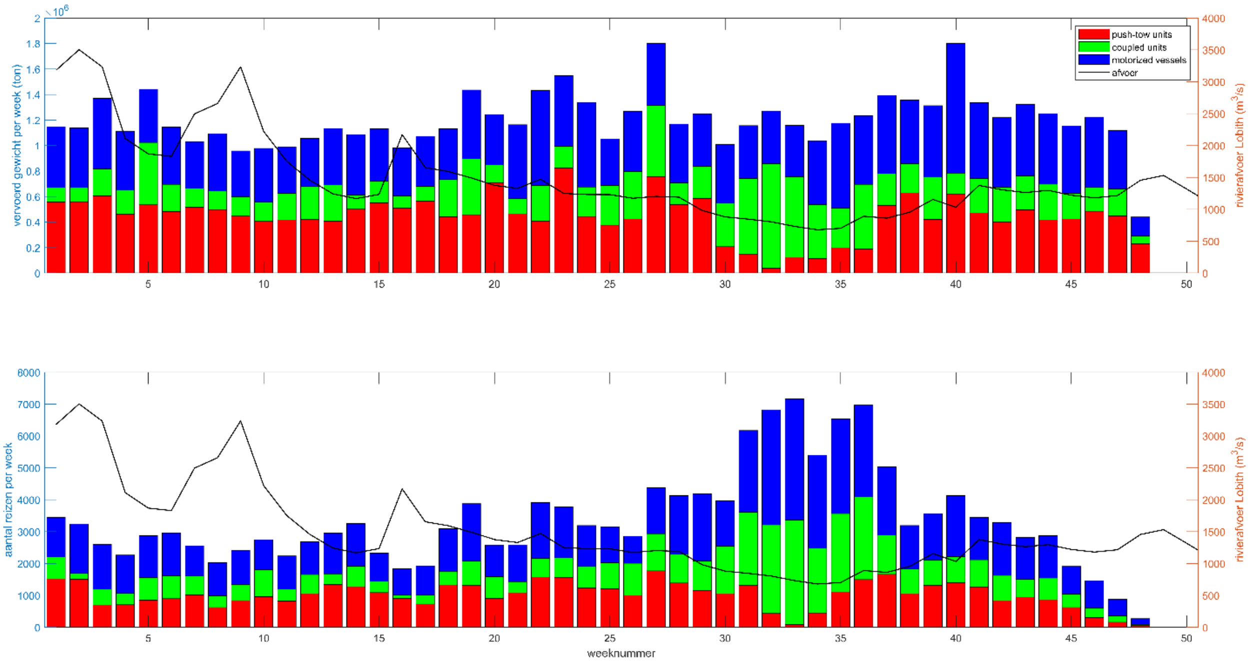


Figure 4 *Reconstruction of 2022: transported volume in tons (top) and number of trips (below) per week in 2022 for three vessel types (push-tow units, coupled units, motorized vessels). Source: Hendriks & Mens (eds.) (2024). Please note that the data from week number ~45 onwards is incomplete or missing in the figure, since the graph was created in December 2022.*

Predictable versus unpredictable

According to Stahl et al. (2022), the discharge at Lobith consists of mostly rainwater and snow (melt water). As already explained above, the components vary over the year (Figure 5). Roughly we can say that the fraction of the snow component is between 10-50% of the river discharge, and that the fraction will decrease in the future.

The actual amount of snow is quite well known, and can be accessed via ERA5. As such, the snow component of the discharge in the coming weeks can be predicted to some extent. Rainfall in the next couple of weeks is much less predictable. This means that the predictability is reasonable, however we cannot be too confident. There is a correlation, though not strong, between the snow depth and the minimum summer discharge (Figure 7). Also, the predictability decreases over the years as the snow component decreases (Figure 6).

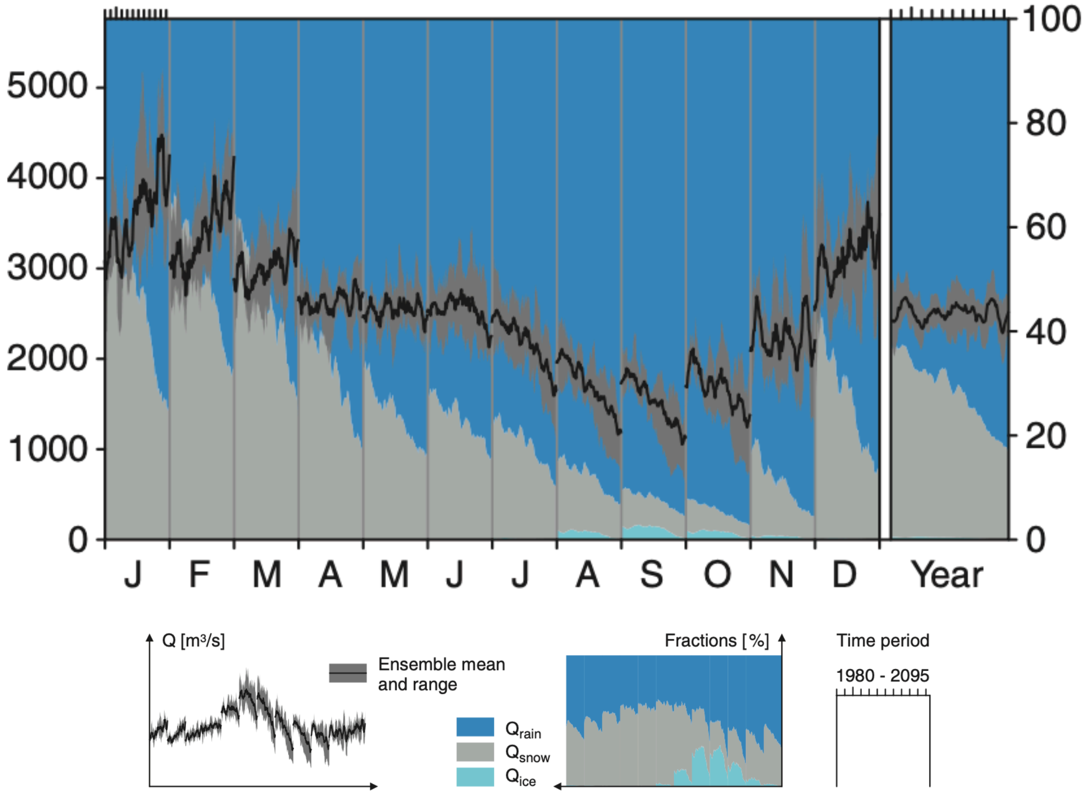


Figure 5 *Time series for Lobith of modelled river flow and the percentages of its components (rain, snow, ice) for each month and year (time period 1980-2095). Source: Stahl et al. (2022).*

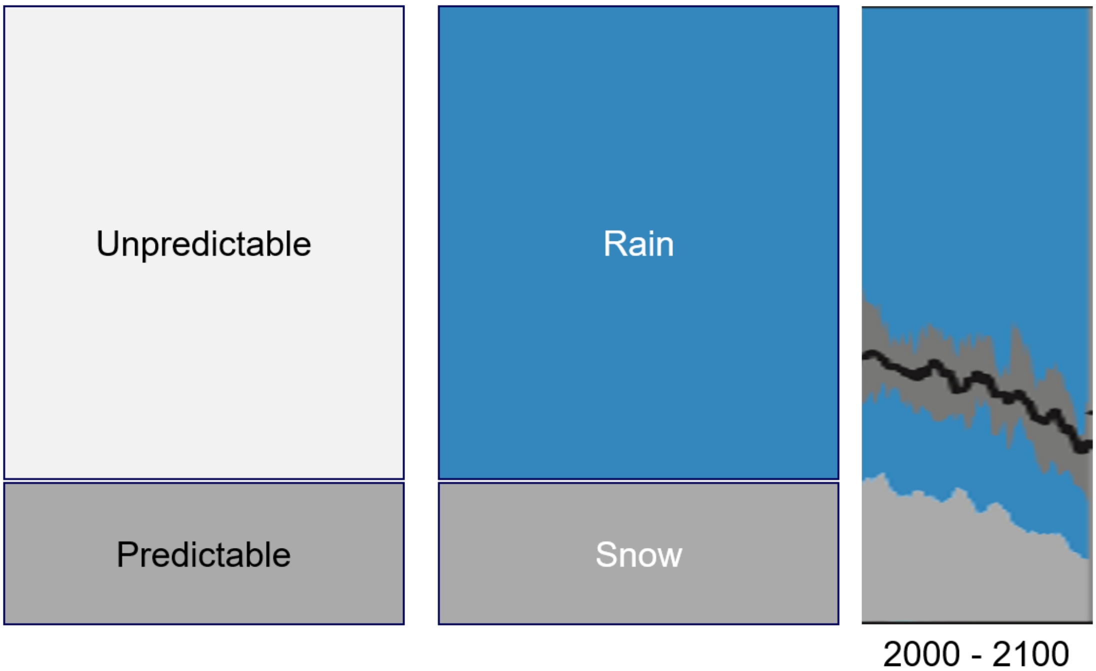


Figure 6 *Predictability of the river discharge.*

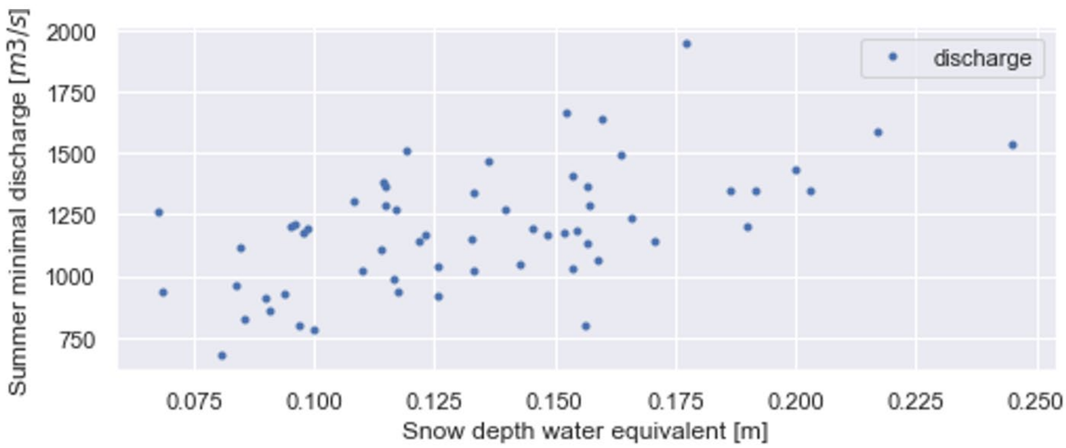
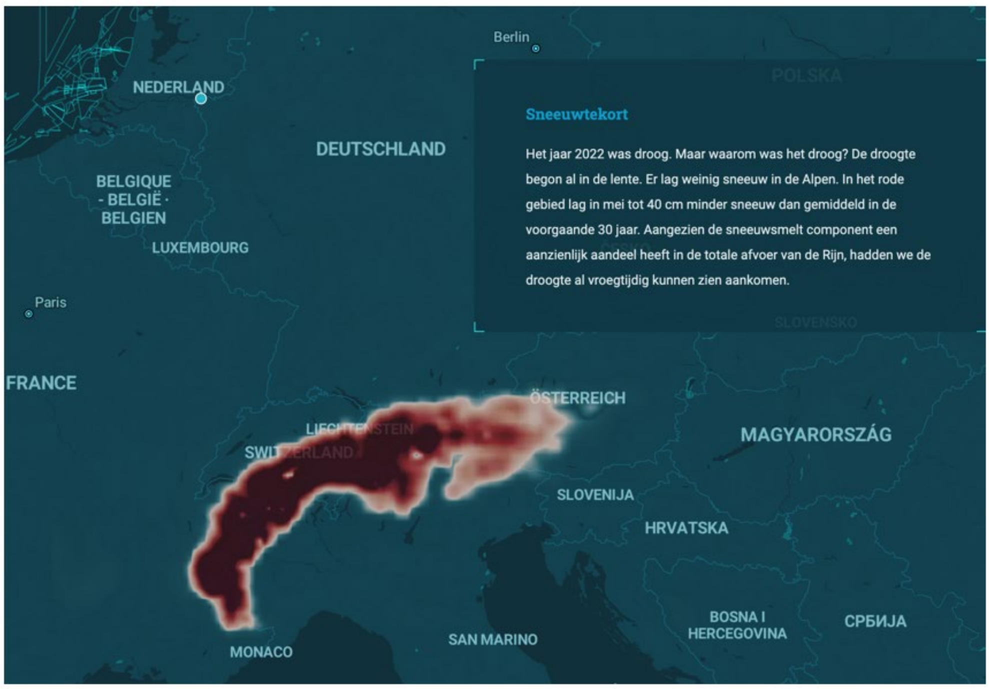


Figure 7 *Correlation between minimum summer discharge and the snow depth in the Alps.*

In May 2022, the snow pack in the Alps was up to 40 cm less thick compared to the previous years (Figure 8). As this component contributes for about 25% to the river discharge (in July), we might have been able to forecast the drought of that year. In the next section we make a discharge forecast for spring / summer based on amongst other the available snow in spring 2023.



2022

Figure 8 *Snow deficiency in spring of 2022. In the red area there was up to 40 cm less snow than averaged over the previous 30 years.*

New seasonal outlook

In order to make a discharge outlook for the coming months, we make use of the WFLOW hydrological model. An hydrological (sometimes called rainfall-runoff) model calculates the amount of water that a river discharges in the near future. Nowadays it is possible to use a spatially distributed (raster) model with high resolution, because of the availability of more and more spatial data like meteorological forcing (rainfall, temperature), land use, vegetation or soil characteristics (see e.g. Imhoff et al., 2020). As an illustration, Figure 9 shows the important variables and processes that are simulated in the “wflow_sbm” hydrological model.

The hydrological wflow_sbm model, developed by Deltares, is a model in which multiple underground layers can be defined. The bottom is divided in a saturated and unsaturated zone per layer. The model simulates evaporation and interception processes, and ice growth and melt processes in glaciers are accounted for. See the literature for a more detailed description of the model.

The model is fed with spatial initial conditions (the current state in snow depth, soil moisture and ground water) and temporal boundary conditions (rainfall over time). That leads, as an output, to river discharge forecast over time (Figure 10).

For the temporal boundary conditions, we make use of historical realisations of the weather, occurred in the past 30 years. This is comparable to the ESP-forecast of the German BfG[1]. An alternative could be to use realisations of forecasted weather, also applied by the BfG. The BfG makes a forecast for 6 weeks ahead, whereas we made an outlook for 12 weeks ahead, starting on May 1st 2023.

The result is a number of realisations in future discharges (“spaghetti plot”) as presented in Figure 11. The way of visualisation should be tailored to the user’s needs. The output can, for example, be presented as boxplots, bar plots and a plume with confidence bands (some examples in Figure 12).

---

[1] Dashboard: https://6wochenvorhersage.bafg.de/
6-weeks forecast for Kaub (discharge and water level):
https://vorhersage.bafg.de/6-Wochen-Vorhersage/Rhein-Kaub_6Wochen_Abfluss.pdf
https://vorhersage.bafg.de/6-Wochen-Vorhersage/Rhein-Kaub_6Wochen_Wasserstand.pdf

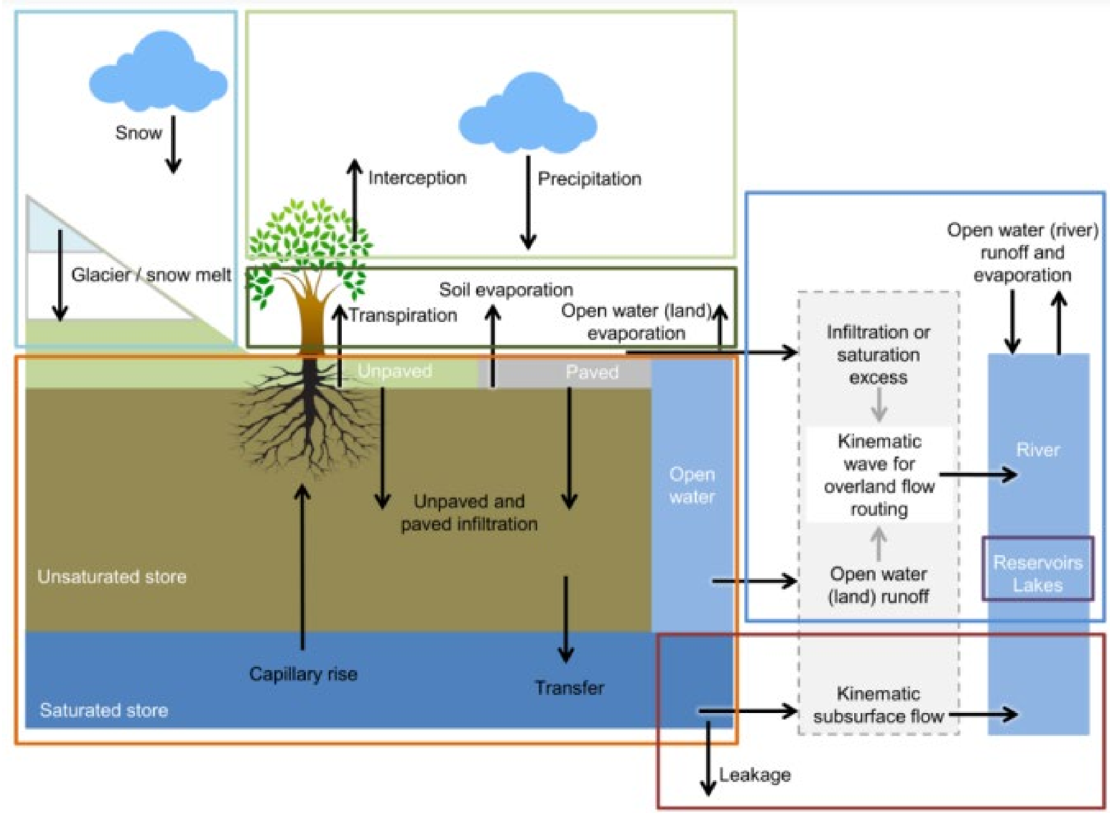


Figure 9 *Sketch of the different processes and fluxes in the wflow_sbm hydrological model. Source: Verseveld et al. (2022).*

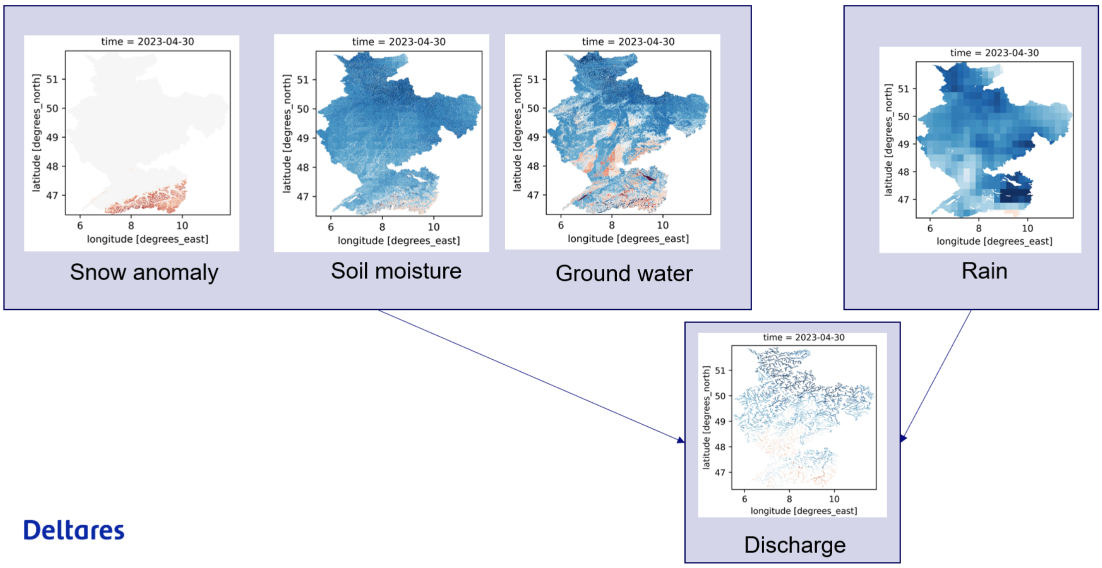


Figure 10 *Available snow, soil moisture and groundwater are the variables that can help predict the discharge more than a few days ahead.*

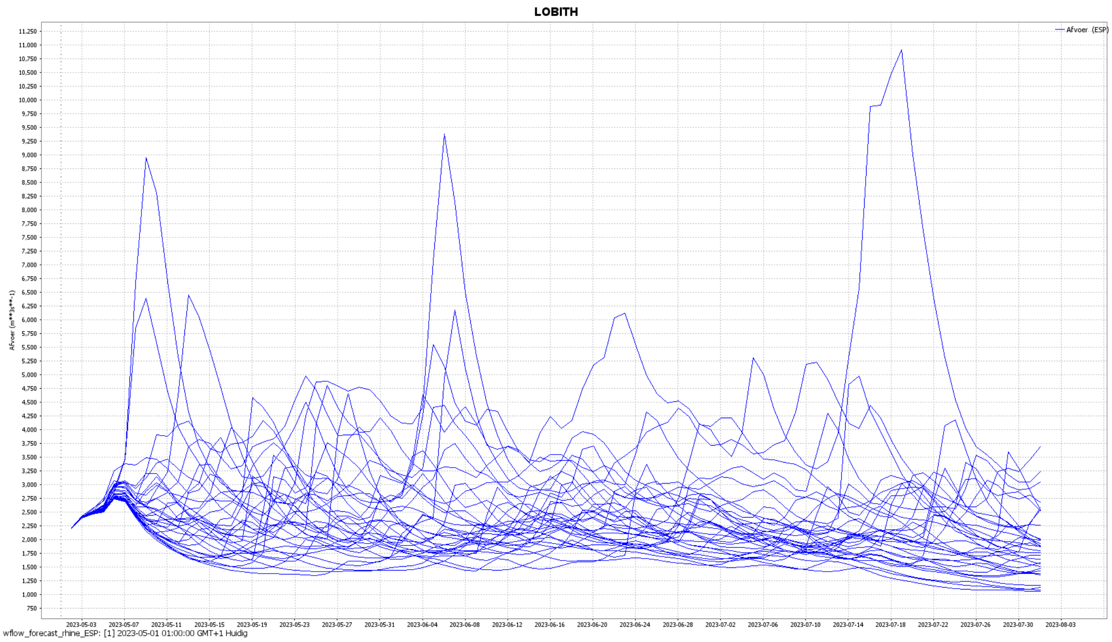


Figure 11 *New seasonal discharge outlook for Lobith, a forecast for 12 weeks ahead that was created 1st of May 2023.*

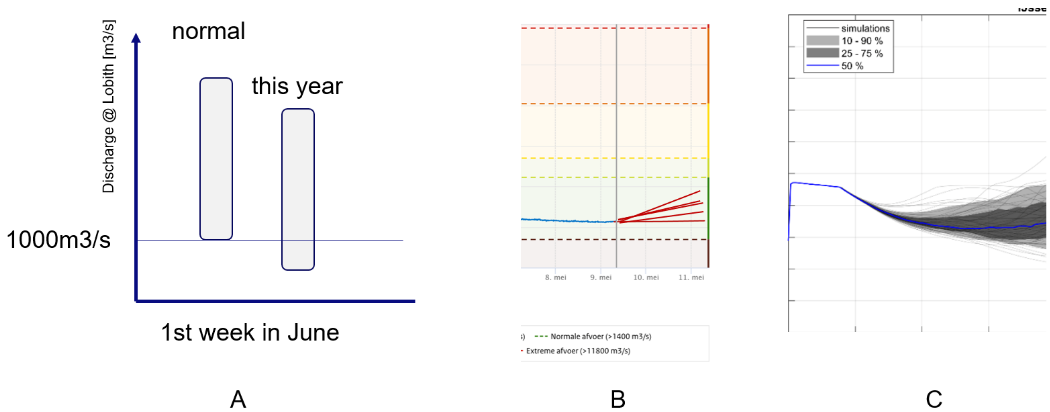


Figure 12 *Alternative forms of visualisation / presentation.*

Added value and additional sources and information

In contrast to short-term predictions, seasonal forecasts are not yet or hardly used within the inland shipping sector, while it is regularly stated that this information can be of added value. If a dry period might be expected for the future, this can be anticipated on by organizing additional vessels, arranging other modality, replenishing stocks preventively.

The Rhine discharge outlook was discussed with the TRANS2 consortium. The partners indicated that in practice such information is not used. This outlook for the next 3 months (until August) has been created once. Before further automation/operationalization, it is necessary to take a closer look at the added value of the information. Mentioned also by one of the partners, a possible follow-up could be to look at a “value of risk approach” (e.g. what is the probability that the depth somewhere becomes lower than x).

It is known that BASF is developing procedures for internal risk-based decisions based on the BfG 6-weeks forecasts (see for example the decision tree in CCNR's Act now!). This is a nice example of how the information can be of added value in decision support.

After the discharge outlook was created, Deltares conducted an assignment with the Topsector Logistiek on the value of longer-term forecasts for the inland shipping sector (Van der Mark & Smoorenburg, 2024). In this report, an overview of initiatives and available operational forecasts is presented, together with a simplified example how a forecast could be applied in practise. Earlier an assignment was done for Rijkswaterstaat (Van der Mark & den Toom, 2019) to investigate whether it is possible to create a water depth forecast for a couple of weeks ahead based on existing data sources (and which information is missing to make such a forecast).

The reports can be downloaded here:
- Report Topsector: https://topsectorlogistiek.nl/wp-content/uploads/2024/05/TSL51.00.090-11209791-002-ZWS-0003_v1.0-Waarde-van-middellange-termijn-verwachtingen-voor-de-binnenvaart.pdf
- Two-pager Topsector: https://topsectorlogistiek.nl/wp-content/uploads/2024/07/20240620_TSL_2Pager-Deltares-2024.pdf
- Water depth: https://www.deltares.nl/expertise/publicaties/verwachting-waterdiepte-rijntakken

Conclusions and recommendations

Based on the performed sprint in TRANS2, we come to the following conclusions and recommendations:
- We have generated a Rhine discharge outlook for Lobith on May 1st 2023 for the next 12 weeks. The forecast consists of a number of possible realizations for the upcoming three months, based on the actual hydrological status and historical weather realisations. More work would be needed to provide this information as an automated service.
- Seasonal forecasts are not or hardly used by the sector. We do think that the field of "forecast-informed decision making" may be relevant to players in the inland shipping sector and should be further explored.
- Longer term forecasts may be difficult to interpret. Therefore, Van der Mark & Smoorenburg (2024) present a simplified example on how a forecast could be applied in practise. Training may be needed to interpret the value of uncertain information.
- For the operational planners, the longer forecast may not be helpful, tactical decisions with respect to modality and fleet may be taken by others. We did not yet get the right persons attached.
- It should be investigated which form of presentation fits the needs of the user.
- When future research is being defined on this topic, apart from this memo also consider the additional reports, listed in the previous section.

References

Buitink, J., Tsiokanos, A., Geertsema, T., ten Velden, C., Bouaziz, L., & Sperna Weiland, F. (2023). Implications of the KNMI'23 climate scenarios for the discharge of the Rhine and Meuse. Deltares rapport 11209265-002-ZWS-0003, 7 December 2023.

Hendriks, D. & Mens, M. (eds.) (2024). De droogte van 2022: een brede analyse van de ernst en maatschappelijke gevolgen, Achtergrondrapport. Deltares, KWR, WUR, WER, KnowH2O. September 2023. https://publications.deltares.nl/11210273_001_0001.pdf

Imhoff, R., W. van Verseveld, B. van Osnabrugge & A. Weerts (2020). Ruimtelijk schaalbare hydrologische modelparameters uit open-source omgevingsdata: een voorbeeld voor de Rijn. Stromingen 2020 (26), nr 3.

Mark, R. van der & M. Smoorenburg (2024). Waarde van middellange-termijn verwachtingen voor de binnenvaart 11209791-002-ZWS-0003, 20 februari 2024. https://publications.deltares.nl/11209791_002_0003.pdf

Mark, R. van der, M. den Toom, R. van der Wijk & K. Sloff (2020). Verwachting waterdiepte Rijntakken. Deltares-rapport 11205272-006-ZWS-0008, dd. 18 december 2020. https://publications.deltares.nl/11205272_006.pdf

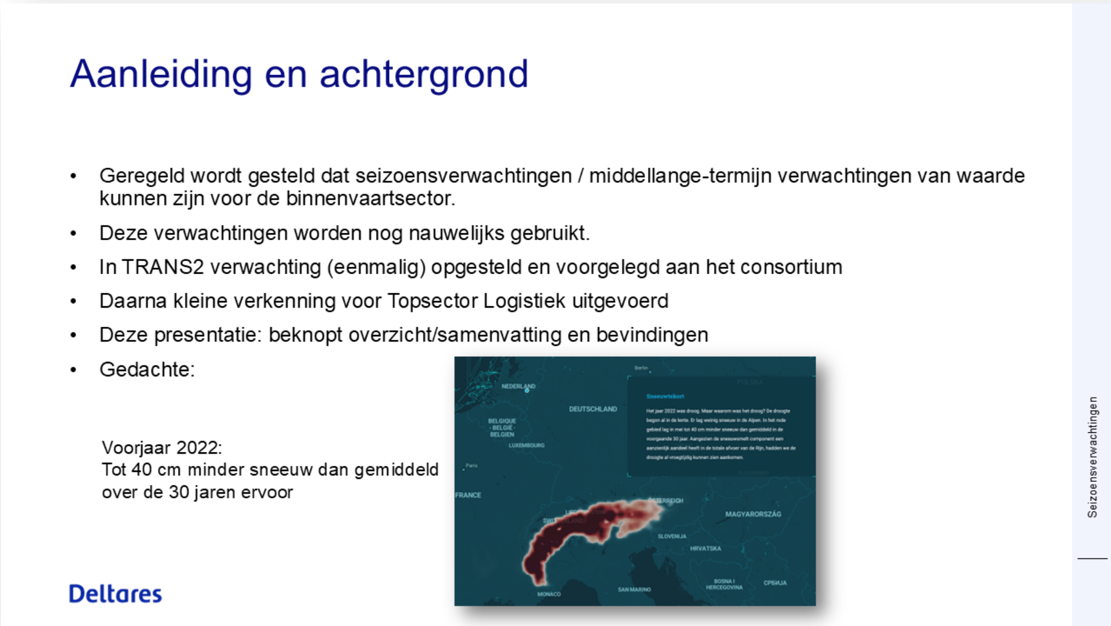
Stahl, K., M. Weiler, M. van Tiel, I. Kohn, A. Hänsler, D. Freudiger, J. Seibert, K. Gerlinger & G. Moretti (2022). Impact of climate change on the rain, snow and glacier melt components of streamflow of the river Rhine and its tributaries. Synthesis report. CHR report no. I 28. International Commission for the Hydrology of the Rhine basin (CHR), Lelystad.

Verseveld, W.J. van, A.H. Weerts, M. Visser, J. Buitink, R.O. Imhoff, H. Boisgontier, L. Bouaziz, D. Eilander, M. Hegnauer, C. ten Velden, & B. Russell (2022). Wflow_sbm v0.6.1, a spatially distributed hydrologic model: from global data to local applications, Geosci. Model Dev. Discuss. [preprint]; DOI: 10.5194/gmd-2022-182.

Vinke, F.R.S., M. van Koningsveld, C. van Dorsser, F. Baart, P.H.A.J.M. van Gelder & T. Vellinga (2022). Cascading effects of sustained low water on inland shipping. *Climate Risk Management*, *35*, Article 100400. https://doi.org/10.1016/j.crm.2022.100400

Vinke, F., B. Turpijn, P. van Gelder, & M. van Koningsveld (2023). Inland shipping response to discharge extremes: A 10 years case study of the Rhine. *Climate Risk Management*, *43*, Article 100578. https://doi.org/10.1016/j.crm.2023.100578

Appendix: slides PowerPoint-presentation final meeting TRANS2 (24 January 2025)



Middellange-termijn verwachtingen

- Waar hebben we het dan over?

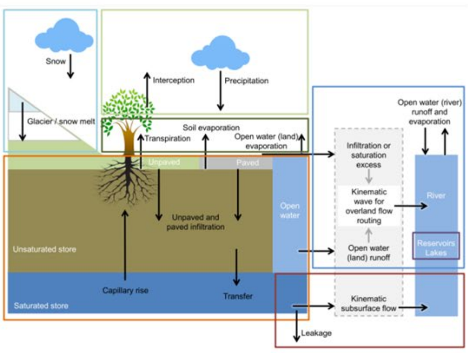
Tijdschaal	Zichttijd verwachting	Typische vragen	
Korte termijn	Dagen	Hoeveel lading aan boord? Wat is de verwachte aankomsttijd (ETA)? Waar moet ik baggeren? Welke vaarwegmarkering is nodig? …	Operationeel
Middellange (seizoen) termijn	Weken - Maanden	Extra schepen / andere schepen inzetten? Andere modaliteiten nodig? Voorraadbeheer aanpassen? Extra opslagcapaciteit? Tussenstops inplannen? …	Tactisch
Lange termijn	Jaren - Decennia	Welke scheeps- en vloot investeringen? Welke infrastructurele aanpassingen aan de vaarweg? Verplaatsen industrie? …	Strategisch

Deltares

Seizoensverwachtingen

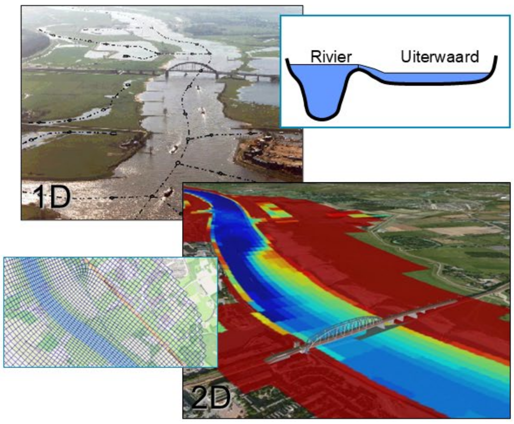
Middellange-termijn verwachtingen: totstandkoming

1. Hydrologische modellering: afvoer



Bron: Verseveld et al. (2022)

2. Hydrodynamische modellering: waterstand

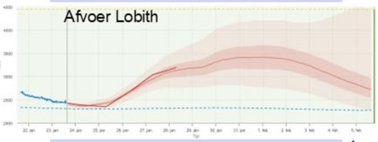


Deltares

Seizoensverwachtingen

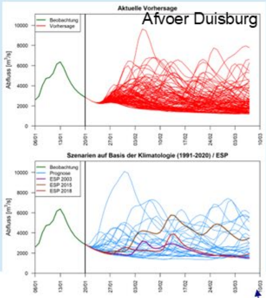
Wat is er zoal beschikbaar?

+14 dagen
- Rijkswaterstaat
- BfG



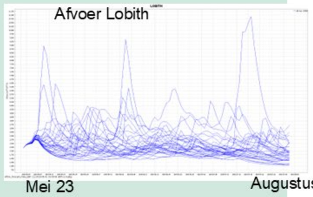
5 febr

+6 weken
- BfG



10 maart

+12 weken
- Pilot in TRANS2



Deltares

Seizoensverwachtingen

6-weken verwachting BfG: zeer gedegen product

- Waterstand + afvoer voor enkele pegels in de Rijn: Maxau, Worms, Kaub, Keulen, Duisburg
- Meerdere visualisaties: grafieken, boxplots, taartdiagrammen, tabellen
- Interactieve webapplicatie (zelf grenswaarden kiezen)
- 3 presentaties, verwachting rivierafvoer op basis van:
  - weersverwachting van ECMWF (European Centre for Medium-Range Weather Forecasts)
  - Opgetreden weer (1991-2020)
  - Historisch opgetreden afvoer

Deltares

Seizoensverwachtingen

Voorbeeld BASF

(bron van informatie: presentatie internationaal BfG colloquium)

- 6-weken verwachtingen voor logistieke planning inmiddels onmisbaar, zeker bij dreigende droogte
  - Multimodale overwegingen
  - Strategisch voorraden inrichten
  - Anticiperen op tekorten van bepaalde grondstoffen (weinig ruimte voor opslag)
- Verwachtingen zelf zijn inmiddels in verschillende planningstools geïntegreerd
- Planners en andere beslissingnemers krijgen regelmatig training, inclusief begrip en werken met verwachtingen

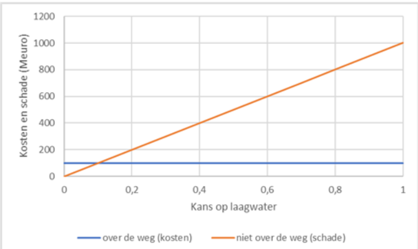
Bron: BASF, opgenomen in 'Act Now' van CCR

Deltares

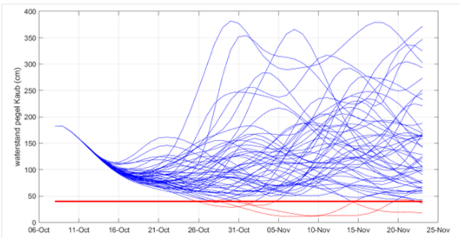
Seizoensverwachtingen

Gesimplificeerd fictief voorbeeld: hoe te gebruiken

- Essentie risicoafweging:
  - keuze drempelwaarde voor kans op laagwater (schade)
  - afweging tussen kosten van mitigerende maatregel versus schade bij laagwater



- Doorvaren:
  - Lading te laat op bestemming: schade € 1M per dag
- Alternatief transport:
  - Via weg: kosten bedragen € 100.000 per dag
- Kosten-schade ratio van 10%



- Inschatting kans op laagwater bij drempelwaarde: 8%
- Kiezen voor doorvaren (lagere kosten)

Seizoensverwachtingen

Bevindingen

- Breed-gedragen gevoel dat middellange-termijn verwachtingen meerwaarde kunnen hebben (getuige ook initiatieven van HbR, RWS/droogtetafel, BfG/BASF, topsector logistiek).
- Middellange-termijn verwachtingen worden in NL niet/nauwelijks bekeken of gebruikt.
- De tactisch beslisser is nog niet goed aangehaakt (de operationeel planner heeft niet zo veel aan de langere zichttijd).
- Niet iedere onderneming is er mee geholpen?
- Verwachtingen vragen om andere (probabilistische) benadering:
  - De dimensies ‘kans’ en ‘risico’ zijn complex om mee te werken, pluim geeft geen houvast
  - Begrip en training nodig
- Generieke tool lastig te maken, omdat elke sector of organisatie eigen specifieke risico-afwegingen of tactische beslissingen kent
- Vooral de industrie in Duitsland met transport over de Rijn die baat kan hebben bij verder vooruit kijken, zij zijn al met de Duitse BfG met dit soort zaken bezig. Hoe belangrijk is het voor NL transport / NL industrie?

Deltares

Seizoensverwachtingen

Bedankt

www.deltares.nl
rolien.vandermark@deltares.nl
@deltares
@deltares
linkedin.com/in/rolienvandermark/
facebook.com/deltaresNL

Gegenereerd met Bing AI Brain; Microsoft Copilot