JCAR ATRACE

Scoping Study of the Vechte, Berkel and Oude IJssel river basins

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Zusammenfassung

Dieser Bericht stellt die Ergebnisse der Scoping-Studie für die Flussgebiete Vechte, Oude IJssel (Issel) und Berkel im Rahmen des JCAR ATRACE-Programms vor. Es handelt sich dabei um ein gemeinsames Kooperationsprogramm für angewandte wissenschaftliche Forschung zum Hochwasser- und Dürrerisikomanagement in regionalen Flusseinzugsgebieten.

Die Ziele der Scoping-Studie sind:

- Beschreibung des aktuellen Stands der Wissensbasis für das erweiterte Einzugsgebiet Vechte[1]
- Beschreibung des derzeitigen Managements von Hochwasser und Dürren im erweiterten Einzugsgebiet Vechte.
- Identifizierung von Wissenslücken, bei denen die Forschung zur Verbesserung des länderübergreifenden Managements von Hochwasser und Dürren beitragen könnte.

Der Bericht enthält eine Beschreibung des Gewässersystems aus physikalischer und institutioneller Sicht. Außerdem werden die relevanten Sektoren, die von Hochwasser und Dürren betroffen sind, behandelt. Es wird eine Bestandsaufnahme relevanter Daten und Berechnungsmodelle vorgelegt und ein Überblick über die Gesetzgebungen, Absprachen und Planungen zum Hochwasser- und Dürremanagement in beiden Ländern, Deutschland und den Niederlanden, gegeben. Die Beschreibung und die Bestandsaufnahme bilden die Ausgangspunkte für die Scoping-Studie. Die präsentierten Informationen stammen größtenteils aus bestehenden Berichten und Interviews mit relevanten und regional zuständigen Akteuren.

Es wird erwartet, dass sowohl das Hochwasser- als auch das Dürrerisiko in Zukunft aufgrund des Klimawandels und sozioökonomischer Entwicklungen wie Landnutzungsänderungen und Wirtschaftswachstum zunehmen werden. Dieser Bericht kombiniert alle verfügbaren Informationen, um den Status des Hochwasser- und Dürrerisikomanagements und die Herausforderungen des länderübergreifenden Managements zu bewerten.

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[1] In diesem Bericht bezeichnen wir die drei Flussgebiete Vechte, Oude IJssel und Berkel als das erweiterte Vechte-Einzugsgebiet.

Es gibt einige Beispiele für eine erfolgreiche länderübergreifende Zusammenarbeit beim Hochwasserrisikomanagement im Untersuchungsgebiet, wie etwa das gemeinsame Hochwasservorhersagesystem für die Vechte und die Gründung der grenzüberschreitenden Plattform für regionales Wassermanagement (GPRW). Die GPRW hat mehrere gemeinsame Projekte initiiert, wie das INTERREG-Projekt Living Vechte-Dinkel. Dieses Projekt führte zu einer grenzüberschreitenden Auenrenaturierung im Gebiet der Vechte.

Darüber hinaus betonten die deutschen Akteure in den Interviews, wie wichtig es sei, von den niederländischen Kenntnissen und Erfahrungen in Bezug auf Wasserrückhaltemaßnahmen zu lernen, wie z. B. der Wasserrückhalt auf landwirtschaftlichen Feldern mit Hilfe kleiner Wehre. Die GPRW ist ein gutes Beispiel für länderübergreifende Zusammenarbeit. Einige Teilnehmer sind jedoch der Meinung, dass die Effektivität noch gesteigert werden kann. Auf niederländischer Seite verkörpern die Waterschappen alle wichtigen Instanzen. Auf deutscher Seite nehmen die Akteure der unteren Entscheidungs- und Umsetzungsebenen teil, die höchste Ebene jedoch nicht, was zu längeren Abstimmungsprozessen führt.

Trotz der vielen guten Beispiele beschränkt sich die länderübergreifende Zusammenarbeit noch häufig auf den Austausch von Informationen, obwohl eine gemeinsame Analyse sowie Planung des Risikomanagements oder der Abwehrbereitschaft erforderlich wären. Insbesondere wurde nach den letzten Dürrejahren in der Region (2018, 2019, 2020, 2022) die Notwendigkeit einer verstärkten länderübergreifenden Zusammenarbeit im Bereich des Dürrerisikomanagements erkannt, jedoch wurde dies bisher noch nicht umgesetzt.

Ein weiteres Hindernis bei der länderübergreifenden Zusammenarbeit sind Unterschiede bei Daten und Modellen. Ein länderübergreifendes Netzwerk relevanter Stakeholder zu diesem Thema ist noch nicht etabliert, wobei die Einreichung eines gemeinsamen INTERREG-Vorschlags zur nachhaltigen Grundwasserbewirtschaftung als ein erster Schritt gesehen werden kann.

Der Bericht schließt mit der Identifizierung der wichtigsten Wissenslücken, welche in den Interviews genannt wurden. Auf der Grundlage dieser Wissenslücken wurden Aktivitäten identifiziert, die als Teil von Folgeaktivitäten von JCAR ATRACE oder in anderen Projekten in Betracht gezogen werden könnten. Die folgenden Aktivitäten, wie Kooperationen und Forschungsprojekte wurden in der untenstehenden Reihenfolge vorgeschlagenen:

1. Eine **quantitative Wassersystemanalyse** zur Bewertung der grenzüberschreitenden Interaktion unter normalen Umständen und ein länderübergreifender **Stresstest** für extreme Hochwasser- und Dürreereignisse. Sowie einschließlich einer Bewertung der Auswirkungen möglicher Interventionen. Wir sind der Meinung, dass dies eine der ersten gemeinsamen Aktivitäten sein sollte, um die weitere Vorbereitung auf extreme Klimaereignisse einzuleiten. Dies kann dazu beitragen, Prioritäten auf weitere Forschung und Planung zu setzen.

2. Es wird empfohlen, eine **umfassende Bewertung des Hochwasserereignisses 2023 / 2024** für das gesamte Einzugsgebiet vorzunehmen, einschließlich der Maßnahmen zur Vorbereitung auf das Ereignis. Die Evaluierung kann zu weiteren Erkenntnissen auf der Grundlage empirischer Daten führen und detaillierte Einblicke darüber liefern, wie die länderübergreifende Koordinierung verbessert werden kann. Wenn möglich, könnte dies ein integrierter Schritt in dem zuvor erwähnten Stresstest sein.

3. **Definitionsstudie** für die gemeinsame Entwicklung eines **zukunftssicheren Hochwasser- und Dürrevorhersagesystems**, das auch unter extremen Bedingungen verwertbare Informationen liefert. Dazu gehört auch eine Verbesserung des Überwachungsnetzes. Die Bedeutung dieser Aktivität liegt in der Integration von Hochwasser- und Dürrevorhersagen sowie in der Verbesserung der länderübergreifenden Vorhersage bei Extremereignissen.

4. Wichtig ist auch eine **Evaluierungsstudie** über die Wirkung aller Akteure für die länderübergreifende Zusammenarbeit innerhalb des derzeitigen **Governance-Rahmens**. Auch Möglichkeiten zur Anpassung dieses Rahmens für eine **längerfristig wirksamere Zusammenarbeit** müssen mitgedacht werden.

5. **Quantitative Folgenabschätzung von Maßnahmen** zur Schwammfunktion im Einzugsgebiet und anderer (naturbasierter) Lösungen sind ebenfalls notwendig. Diese Art von Maßnahmen hat das Potenzial, das Hochwasser- und Dürrerisiko zu senken. Da diese Maßnahmen am wirksamsten sind, wenn sie in den flussaufwärts gelegenen Teilen der Einzugsgebiete angewendet werden, hat diese Folgenabschätzung einen stark länderübergreifenden Charakter.

6. Die Einrichtung eines **grenzüberschreitenden Grundwasserüberwachungsnetzes** könnte ein erster Schritt zu einer umfassenden grenzüberschreitenden Strategie für das Dürremanagement sein. Grenzüberschreitende Einblicke in die (Trends der) Grundwasserverfügbarkeit sind ein wichtiges Element für eine gemeinsame Analyse und die Formulierung einer Strategie zur Bewältigung von Dürrerisiken.

Die GPRW könnte eine wirksame Plattform sein, um diese gemeinsamen Aktivitäten zu ermitteln, zu gestalten und zu lenken. Dies würde jedoch die Teilnahme weiterer staatlicher und nichtstaatlicher Akteure erfordern, sowie eine Erweiterung ihres Zeit- und Finanzbudgets für grenzübergreifende Aufgaben.

Samenvatting

Dit rapport presenteert de resultaten van de ‘scoping’ studie voor de stroomgebieden van de Vecht(e), Oude IJssel en Berkel in het kader van het JCAR ATRACE programma (Joint Cooperation programme for Applied scientific Research on flood and drought risk management in regional river basins). Dit is een samenwerkings-programma voor toegepast wetenschappelijk onderzoek naar overstromings- en droogterisicobeheer in grensoverschrijdende regionale stroomgebieden.

De doelstellingen van de ‘scoping’ studie zijn:

- Het beschrijven van de huidige status van de kennisbasis van het uitgebreide Vechtstroomgebied[2].
- Het beschrijven van het huidige beheer van overstromingen en droogtes in het uitgebreide Vechtstroomgebied.
- Het identificeren van hiaten in de kennis, waar onderzoek zou kunnen bijdragen aan het verbeteren van het grensoverschrijdend beheer van overstromingen en droogtes.

Het rapport geeft een beschrijving van het watersysteem, vanuit een fysiek en institutioneel perspectief, en van de relevante sectoren die worden beïnvloed door overstromingen en droogte. Een inventarisatie van relevante data en rekenmodellen wordt gepresenteerd en er wordt een overzicht gegeven van de instellingen, regelingen en plannen voor overstromings- en droogtebeheer voor beide landen. De beschrijving en inventarisatie vormen de uitgangspunten van de ’scoping’ studie. De gepresenteerde informatie is grotendeels afkomstig uit bestaande rapporten en interviews met relevante stakeholders.

In dit rapport wordt alle beschikbare informatie gecombineerd om de status van het overstromings- en droogterisico en de uitdagingen op het gebied van grensoverschrijdend beheer te beoordelen. Verwacht wordt dat zowel het overstromings- als het droogterisico in de toekomst zullen toenemen als gevolg van de klimaatverandering en sociaaleconomische ontwikkelingen, zoals veranderingen in landgebruik en economische groei.

[2] In dit rapport verwijzen we verder naar de drie stroomgebieden Vecht, Oude IJssel en Berkel als het *uitgebreide* Vechtstroomgebied.

Er zijn enkele voorbeelden van succesvolle grensoverschrijdende samenwerking met betrekking tot overstromingsrisicobeheer in het studiegebied, zoals het gezamenlijke overstromingsvoorspellingssysteem voor de rivier de Vecht en het Grensoverschrijdende Platform voor Regionaal Waterbeheer (GPRW). Via dit GPRW zijn verschillende gezamenlijke projecten geïnitieerd, zoals het INTERREG-project Levende Vecht-Dinkel. Dit project resulteerde in grensoverschrijdend herstel van uiterwaarden in de Vechtregio.

Duitse actoren benadrukten in de interviews het belang om te leren van de Nederlandse kennis en ervaringen op het gebied van waterretentiemaatregelen, zoals het vasthouden van water op landbouwvelden met behulp van kleine stuwen. Het GPRW is een goed voorbeeld van grensoverschrijdende samenwerking, maar sommige deelnemers vinden dat de effectiviteit verder kan worden vergroot. Aan Nederlandse zijde vertegenwoordigen de Waterschappen alle belangrijke autoriteiten. Aan de Duitse kant nemen belanghebbenden van de lagere overheden deel, maar het hoogste niveau niet, wat leidt tot langere coördinatieprocessen.

Ondanks de vele goede voorbeelden blijft de grensoverschrijdende samenwerking in het gebied vaak beperkt tot het uitwisselen van informatie; terwijl gezamenlijke analyse en planning van risicobeheer of voorbereiding op overstromingen en droogtes nodig is. Sinds de recente droogtejaren in het gebied (2018, 2019, 2020, 2022) wordt de noodzaak van meer grensoverschrijdende samenwerking ook op het gebied van droogterisicobeheer erkend, maar tot nu toe is dit nog niet tot stand gekomen.

Verschillen in gegevens en modellen worden gezien als een van de obstakels voor grensoverschrijdende samenwerking. Er is nog geen grensoverschrijdend netwerk van relevante belanghebbenden over dit onderwerp opgericht, maar de recente indiening van een gezamenlijk INTERREG-voorstel over duurzaam grondwaterbeheer kan worden gezien als een eerste stap.

Het rapport sluit af met de identificatie van de belangrijkste kennishiaten die tijdens de interviews zijn genoemd. Op basis van deze kennishiaten zijn de volgende activiteiten geïdentificeerd die kunnen worden overwogen als onderdeel van vervolgactiviteiten van JCAR ATRACE of in andere projecten, in deze voorgestelde volgorde:

1. Een **kwantitatieve watersysteemanalyse** om de grensoverschrijdende interactie onder normale omstandigheden te

bepalen en een grensoverschrijdende **stresstest** voor extreme overstromingen en droogte, inclusief een beoordeling van de effecten van mogelijke interventies. Wij denken dat dit één van de eerste gezamenlijke activiteiten zou moeten zijn, om verdere voorbereiding op extreme omstandigheden te initiëren en om verder onderzoek en planning te prioriteren.

2. Het wordt aanbevolen om een uitgebreide **evaluatie van de hoogwatergebeurtenis in 2023 / 2024** voor het hele stroomgebied uit te voeren, inclusief de governance met betrekking tot de voorbereiding op en de calamiteitenbestrijding tijdens het hoogwater. De evaluatie kan leiden tot meer inzichten op basis van empirisch bewijs en kan gedetailleerde lessen opleveren over hoe de grensoverschrijdende coördinatie kan worden verbeterd. Indien mogelijk kan dit een geïntegreerde stap zijn in de eerdergenoemde stresstest.

3. **Een definitiestudie** voor de gezamenlijke (door)ontwikkeling van een **toekomstbestendig voorspellingssysteem** voor overstromingen en droogtes dat ook onder extreme omstandigheden bruikbare informatie oplevert. Dit omvat o.m. ook een verbetering van het meetnet. Het belang van deze activiteit ligt in de integratie van de voorspelling van overstromingen en droogtes en in de verbetering van grensoverschrijdende voorspellingen tijdens extreme gebeurtenissen.

4. Een **evaluatiestudie** van de invloed van alle actoren op de grensoverschrijdende samenwerking binnen het **huidige bestuurskader** en mogelijkheden om dit kader aan te passen voor **effectievere samenwerking op de langere termijn**.

5. **Kwantitatieve effectbeoordeling** van **maatregelen** voor sponswerking en andere (natuurgebaseerde) oplossingen op stroomgebiedsschaal. Dit soort ingrepen heeft het potentieel om overstromings- en droogterisico's tot op zekere hoogte te verminderen en heeft een sterk grensoverschrijdend karakter, omdat deze maatregelen het meest effectief zijn als ze worden toegepast in de stroomopwaarts gelegen delen van stroomgebieden.

6. Het opzetten van een **grensoverschrijdend grondwatermeetnet** zou een eerste stap kunnen zijn op weg naar een alomvattende grensoverschrijdende droogtebeheerstrategie. Grensoverschrijdend inzicht in (trends in) de beschikbaarheid van grondwater is een

belangrijk element voor een gezamenlijke analyse en formulering van een strategie voor droogtebeheer.

Het GPRW zou een effectief platform kunnen zijn om deze gezamenlijke activiteiten te identificeren, vorm te geven en te begeleiden. Hiervoor zou echter de lijst van deelnemende overheden en andere belanghebbenden moeten worden uitgebreid evenals een uitbreiding van hun tijd en financiële budget voor grensoverschrijdende taken.

Summary

This report presents the results of the scoping study for the Vechte, Oude IJssel (Issel) and Berkel river basins in the framework of the JCAR ATRACE program (*Joint Cooperation programme for Applied scientific Research on flood and drought risk management in regional river basins*).

The objectives of the scoping study are:

- To describe the current status of the knowledge base of the extended Vechte Basin[3].
- To describe current management of floods and droughts in the extended Vechte Basin.
- To identify the knowledge gaps, where research could help to improve the transboundary management of floods and droughts.

The report provides a description of the water system, from a physical and an institutional perspective. The relevant sectors that are affected by floods and droughts are also covered. An inventory is presented of relevant data and computational models and an overview is given of the institutions, arrangements and planning regarding flood – and drought management for both countries. The description and inventory form the starting points of the scoping study. The presented information is mostly taken from existing reports and interviews with relevant stakeholders.

This report combines all available information to assess the status of flood and drought risk and their transboundary management challenges. Both flood and drought risk are expected to increase in the future due to climate change and socio-economic developments, such as land use change and economic growth.

There are some examples of successful transboundary cooperation in flood risk management in the study area, such as the joint flood forecasting system for the Vechte river and the establishment of the *transboundary platform for regional water management* (GPRW). Through this GPRW, several joint projects have been initiated such as INTERREG project Living Vechte-Dinkel. This project resulted in transboundary flood plain restoration in the Vechte region.

[3] In this report we further refer to the three river basins Vechte, Oude IJssel and Berkel as the *extended* Vechte basin.

Furthermore, in the interviews the German actors highlighted the importance of learning from the Dutch knowledge and experiences regarding water retention measures such as retaining water on agricultural fields using small weirs. The GPRW is a good example of transboundary cooperation, but some participants feel that the effectiveness could be further increased. On the Dutch side, the regional water authorities represent all the important authorities. On the German side, stakeholders from the lower level water authorities participate, but the highest level does not, which leads to longer coordination processes.

However, despite many good examples, cross-border cooperation in the area is often limited to the exchange of information; while joint analysis and planning of risk management or preparedness is needed. In particular, the need for increased transboundary cooperation in drought risk management was recognized after the recent drought years in the area (2018, 2019, 2020, 2022), but so far this has not been implemented.

Differences in data and models are seen as one of the obstacles in transboundary cooperation. A transboundary network of relevant stakeholders on this topic is not established yet, but the recent submission of a joint INTERREG proposal on sustainable groundwater management can be seen as a first step.

The report concludes with the identification of the most important knowledge gaps, mentioned in the interviews. Based on these knowledge gaps, the following activities have been identified that could be considered as part of follow-up JCAR ATRACE activities or in other projects, in this suggested order:

1. A quantitative **water system analysis** to assess transboundary interaction during normal circumstances and a **transboundary stress-test** for extreme flood and drought events, including an assessment of the impacts of possible interventions. We think this should be one of the first joint activities, to initiate further preparedness for extreme conditions and it could help to prioritize further research and planning.

2. It is recommended to start a **comprehensive basin-wide evaluation of the 2023 / 2024 high water event**, including governance related to preparedness. The evaluation may lead to more insights based on empirical evidence and can provide detailed lessons on how the transboundary coordination may be improved. If possible, this maybe an integrated step in the before mentioned stress-test.

3. **Definition study** for joint development of future-robust flood and drought **forecasting system**, that provides actionable information, also under extreme conditions. This includes an improvement of the monitoring network. The importance of this activity lies in the integration of flood and drought forecasting and in improvement of transboundary forecasting during extreme events.

4. An **evaluation study** of the leverage of all actors for transboundary cooperation within the **current governance framework** and possibilities to adapt this framework for **more effective cooperation** in the longer term.

5. **Quantitative impact assessment** of catchment-scale **sponge functioning** measures and **other** (nature-based) **solutions**. This kind of intervention has the potential to reduce flood and drought risk to certain limits, and has a strong transboundary character as these measures are most effective if applied in the upstream parts of catchments.

6. Establishing a **transboundary groundwater monitoring network** could be a first step towards a comprehensive transboundary drought management strategy. Transboundary insights in (trends associated with) groundwater availability is an important element of a joint analysis and formulation of a strategy to manage drought risk.

The GPRW could be an effective platform to identify, shape and guide these joint activities. However, this would require an extension of the number of participating governmental and non-governmental stakeholders as well as an expansion of their time and financial budgets for cross-border tasks.

Contents

List of Abbreviations

AGDR	Delta Rhine Working Group German: Arbeitsgruppe Deltarhein Dutch: Werkgroep Rijndelta
AMIGO	Current Model Instrument Gelderland East Dutch: Actueel Model Instrument Gelderland Oost
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection German: Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz
BauGB	(German) Building Code German: Baugesetzbuch
BOWAB	German: BOdenWAsserBilanzierung
CMIP5	Coupled Model Intercomparison Project Phase 5
CER	European Critical Entities Resilience Directive
DEM	Digital Elevation Models
DHZ	Deltaplan High Sandy Soils Dutch: Deltaplan Hoge Zandgronden
DWD	German weather service German: Deutscher Wetter Dienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EU	European Union
FEWS	Flood Early Warning System
FPA	Flood Protection Act
FRM	Flood Risk Management
FRMD	Flood Risk Management Directive
GER	Germany

GIS	Geographic Information System
GHOR	(Dutch) Medical Assistance Organization in the Region Dutch: Geneeskundige Hulpverleningsorganisatie in de Regio
GPRW	Transboundary Platform for Regional Water management German: Grenzüberschreitende Plattform für Regionale Wasserwirtschaft Dutch: Grensoverschrijdend Platform voor Regionaal Waterbeheer
GRADE	Generator of Rainfall And Discharge Extremes
HARMONIE	Hirlam Aladin Research on Mesoscale Operational Nwp In Euromed
HWVZ	Flood forecasting centre Lower Saxony German: Hochwasservorhersagezentrale (Lower Saxony)
JenV	(Dutch) Minister of Justice and Safety Dutch: Minister van Justitie en Veiligheid
INTERREG	European Territorial Cooperation
IPPC	Intergovernmental Panel on Climate Change
JCAR ATRACE	English: Joint Cooperation programme on Applied scientific Research to Accelerate Transboundary Regional Adaptation to Climate Extremes German: Gemeinsames Kooperationsprogramm für angewandte wissenschaftliche Forschung zum Hochwasser- und Dürrerisikomanagement in regionalen Flusseinzugsgebieten Dutch: Samenwerkings-programma voor toegepast wetenschappelijk onderzoek naar overstromings- en droogterisicobeheer in grensoverschrijdende regionale stroomgebieden
KliBoG	Climate impact adaptation soil and groundwater German: Klimafolgenanpassung Boden und Grundwasser
KNMI	Royal Netherlands Meteorological Institute Dutch: Koninklijk Nederlands Meteorologisch Instituut

KRITIS	Critical infrastructures German: Kritische Infrastrukturen
KWB	climatic water balance of the growing season German: Klimatische Wasserbilanz in der Vegetationsperiode
LANUV	The NRW State Agency for Nature, Environment and Consumer Protection German: Das Landesamt für Natur, Umwelt und Verbraucherschutz NRW
LAWA	Federal/State Working Group on Water German: Bund-Länder Arbeitsgemeinschaft Wasser
LBEG	Lower Saxon State Office for Mining, Energy and Geology German: Landesamt für Bergbau, Energie und Geologie
LCO	National Flood Threat Coordination Committee Dutch: Landelijke Coördinatiecomissie Overstromingsdreiging
LCW	National Water Distribution Coordination Committee Dutch: Landelijke Coördinatiecommissie Waterverdeling
LGR	National Groundwater Register Dutch: Landelijk Grondwater Register
LHM	National Hydrological Model Dutch: Landelijk Hydrologisch Model
LWG	State Water Law of NRW German: Landeswassergesetz NRW
MIPWA	Methodology Interactive Planning Water Management Dutch: Methodiek Interactieve Planning Waterbeheer
MTW	Management team on water shortages Dutch: Managementteam Watertekorten
MU	Ministry for the Environment, Energy and Climate Protection Lower Saxony German: Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz
MUNV	Ministry of the Environment, Nature Conservation and Transport NRW German: Ministerium für Umwelt, Naturschutz und verkehr des Landes Nordrhein-Westfalen

NCTV	National Coordinator for Counterterrorism and Safety Dutch: Nationaal Coördinator Terrorismebestrijding en Veiligheid
NFPP	(Dutch) National Flood Protection Programme
NGO	Non- governmental organisation
NIPV	Dutch Institute for Public Safety Dutch: Nederlands Instituut Publieke Veiligheid
NKatSG	Lower Saxon Disaster Control Act German: Niedersächsisches Katastrophenschutzgesetz
NKomVG	Lower Saxon Municipal Constitution Act German: Niedersächsisches Kommunalverfassungsgesetz
NL	Netherlands
NLWKN	Lower Saxony Water Management, Coastal and Nature Protection Agency German: Niedersächsischer Landesbetrieb für Wasserschutz, Küsten- und Naturschutz
NLPG	National Programme for Rural Areas Dutch: Nationaal Programma Landelijk Gebied
NM7Q	The annual minimum flow rate averaged over 7 days
NRW	English: North-Rhine Westphalia German: Nordrhein-Westfalen
NWG	Lower Saxon Water Law German: Niedersächsisches Wassergesetz
OGewV	(German) Surface Water Ordinance German: Oberflächengewässerverordnung
RBO	Regional Administrative Consultation Dutch: Regionaal Bestuurlijk Overleg
RDO	Regional Drought Meetings Dutch: Regionale Droogte Overleggen
ROG	(German) Regional Planning Act German: Raumordnungsgesetz
RS	Remote Sensing
RWS	(Dutch) Department of Waterways and Public Works Dutch: Rijkswaterstaat

SGDR	Delta Rhine Steering Group German: Steuerungsgruppe Deltarhein Dutch: Stuurgroep Rijndelta
SGI	Standardized Groundwater level Index
SGK /PGK	Permanent Border Water Commission German: Ständige Grenzgewässerkommission Dutch: Permanente Nederlands-Duitse Grenswaterencommissie
SOG	(German) Act on Public Safety and Order German: Gesetz über die öffentliche Sicherheit und Ordnung
THW	(German) Federal Agency for Technical Relief German: Technisches Hilfwerk
UDAG	Updating the data basis for adaptation to climate change in Germany
VR	Safety regions Dutch: Veiligheidsregio‘s
WAZ	Water and Wastewater Association Niedergrafschaft German: Wasser und Abwasser Zweckverband Niedergrafschaft
WMCN	National Water Management Centre of the Netherlands Dutch: Watermanagementcentrum Nederland
WDOD	Regional Water Authority Drents Overijsselse Delta Dutch: Waterschap Drents Overijsselse Delta
WFD	Water Framework Directive
WHG	(German) Water Act German: Wasserhaushaltsgesetz
WRIJ	Regional Water Authority Rijn and Ijssel Dutch: Waterschap Rijn en Ijssel
WRO	(Dutch) Spatial Planning Act Dutch: Wet Ruimtelijke ordening
WSV	Waterways and Shipping Administration German: Wasser- und Schifffahrtsverwaltung
ZON	East Netherlands Freshwater Supply programme Dutch: Zoetwater Oost Nederland

Glossary

Term (English)	Lan-guage	Term	Definition (by authors for the scope of this document if not specified otherwise)
Catchment, basin	German Dutch	Einzugsgebiet Stroomgebied	
District	German	Kreis, Landkreis, kreisfreie Stadt	Administrative subdivision higher than a municipality.
Governmental district	German	Bezirk, Regierungsbezirk	Regional mid-level local government units in four of Germany's federal states, including Nordrhein-Westfalia
Municipality	German Dutch	Gemeinde gemeente	Lowest level of territorial division.
upstream **downstream**	German Dutch German Dutch	oberstrom bovenstrooms unterstrom benedenstrooms	Located upwards along a water course with respect to a certain location the same water course Located downwards along a water course with respect to a certain location the same water course
Water association (Germany)	German	Wasserverband	An organization in Germany set up under public law with varying organizational structure and tasks. Typical tasks are wastewater treatment, water management, flood control and others. Members are industrial water users and municipalities representing the domestic water users.
Regional Water Authority (Netherlands)	Dutch	Waterschap	Public organization in the Netherlands responsible for the water management of a specific region. The regional water authorities have an elected management board and levy a water tax from the inhabitants living in their region.
Flood Risk Management Plan	Dutch German	Overstromingsrisicobeheerplan (ORBP) Hochwasserrisiko-managementplan	Flood risk management plans required by the European Flood Directive (2007).
European Floods Directive	Dutch German	Europese Richtlijn Overstromings-risico's (ROR) EU – Hochwasser-richtlinie	
Water Framework Directive	Dutch German	Kaderrichtlijn Water (KRW) Wasserrahmen-richtlinie (WRRL)	
Vechte	Dutch German	Vecht Vechte	
Oude IJssel	Dutch German	Oude IJssel Issel	

1 Introduction

The mission of the Joint Cooperation program on Applied scientific Research (JCAR) is to improve the cooperation on flood and drought management and research in order to Accelerate Transboundary Regional Adaptation to Climate Extremes (ATRACE). To achieve this, the ambition of JCAR ATRACE is to foster long-term international research partnerships to enhance the knowledge base and knowledge network on flood and drought risk management in transboundary regional river basins.

The first main objective is to improve preparedness for floods and droughts by facilitating regional governments in Belgium, Germany, Luxembourg and the Netherlands to improve integrated planning, development and management of regional river basins and preparations for extreme climate events. The second objective is to improve transboundary collaboration by fostering long-term partnerships between European knowledge institutes to enhance the knowledge base and inform flood and drought strategies in transboundary regional river basins. Please visit http://jcar-atrace.eu for further information on the program.

It should be noted that the JCAR ATRACE program focuses on the consequences of extreme floods and droughts in regional basins. Floods and droughts along (the main branches of) the major rivers, such as the Rhine, Meuse, Ems and Scheldt are not considered, as these are covered by their respective international river commissions.

The extended Vechte Basin, including the basins of the Vechte, Oude IJssel and Berkel (Figure 1), is the main focus of this report.

The main objectives of this scoping study are:

- To describe the current status of the knowledge base of the extended Vechte Basin.
- To describe current management of floods and droughts in the extended Vechte Basin.
- To identify the knowledge gaps, where research could help to improve the transboundary management of floods and droughts.

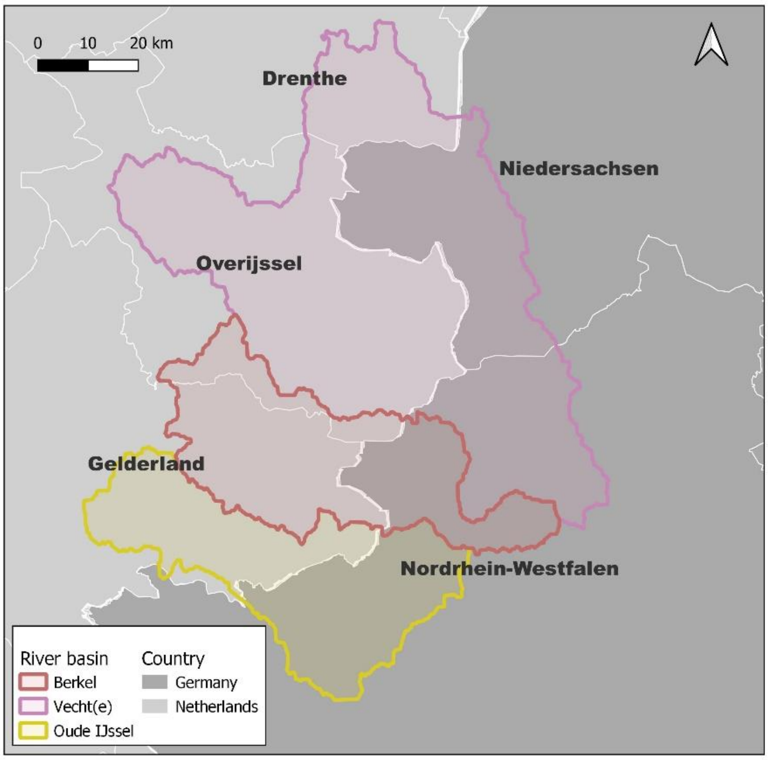


Figure 1: Study area outlining the location of the river basins.

The content of this report is based on a review of existing reports, papers, plans and other relevant documents. Furthermore, some 25 interviews have been held with relevant stakeholders. The list of interviews is presented in Annex A.

Chapter 2 of this report provides a description of the extended Vechte basin, including descriptions of the water system and the relevant sectors that are affected by floods and droughts. In chapter 3 extreme events - floods and droughts – in the study area are described. The institutions, arrangements and planning relevant for management of floods and droughts are described in Chapter 4 and the transboundary cooperation is evaluated in chapter 5.
Chapter 6 presents an overview of the relevant data and computational models for the basin and the way these are used. The report concludes in Chapter 7 with an assessment of the current flood and drought risk and their transboundary management practices, resulting in the identification of the most important knowledge gaps. Follow-up research within JCAR ATRACE (chapter 8) will focus on these knowledge gaps.

2 Description of the basin

2.1 Geography

The study area encompasses several transboundary regional rivers, which flow from north-western Germany into the north-east of the Netherlands. The area consists of three main basins (the Vechte, the Berkel and the Oude IJssel) as depicted in Figure 2. For consistency with local structures, the study area has been defined by the GPRW (Transboundary Platform for Regional Watermanagement) working area, which is synonymous to the Deltarijn-Oost / Deltarhein Ost area as defined in the Flood Risk Management Plan of the Rhine and is referred to as the extended Vechte basin in this report.

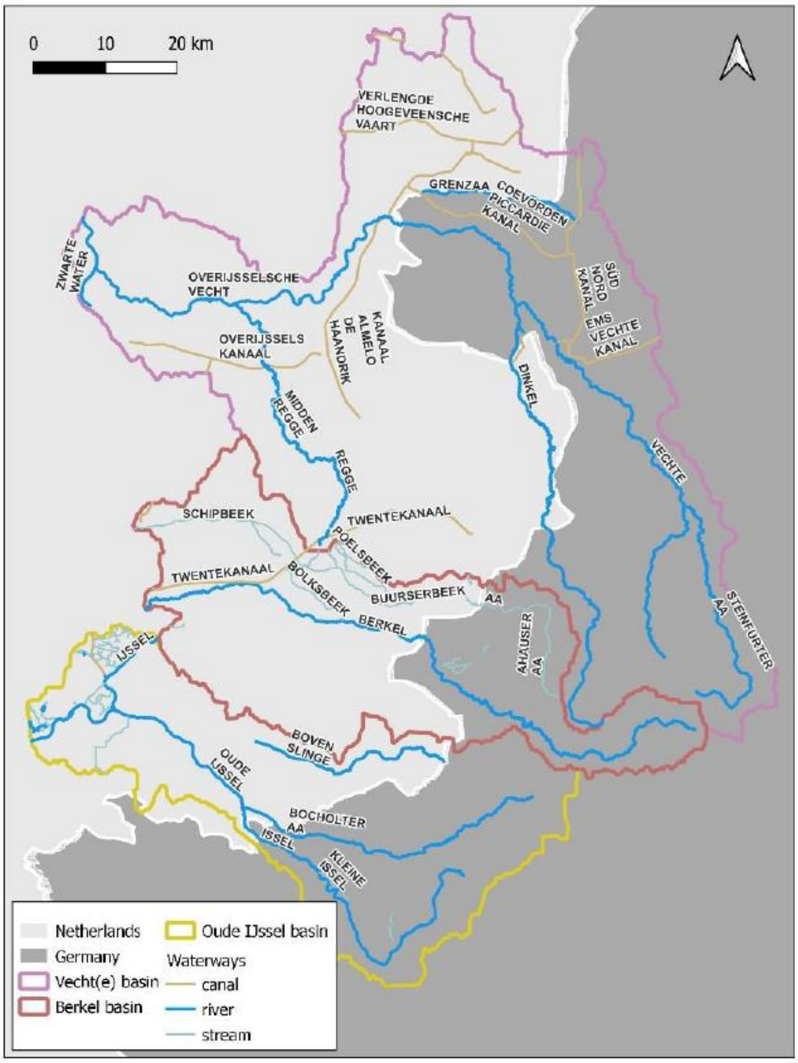


Figure 2: Study area showing the rivers and canals

The whole area has a size of 7,600 km^2 of which approximately 57% is situated in in the Netherlands (4,300 km^2) and the remaining 43% in Germany (3,300 km^2).
The area spans two federal states in Germany: Lower Saxony (1.100 km²) and North Rhine-Westphalia (NRW, 2.200 km²), as well as three provinces in the Netherlands: Drenthe, Overijssel and Gelderland.

Table 1 gives a short description of the three basins. The Vechte basin is the largest of the three basins at 4,393 km². It's 2.5 times larger than the basin of Oude IJssel (1,638 km²) and 5.5 times larger than the Berkel basin (792 km²) (see Table 1). While the Berkel river has a mean slope of 0.9‰, the Vechte river and the Oude IJssel River only have a mean slope of 0.4‰ and 0.3‰ respectively.

Table 1: Catchment characteristics (MUNV, 2005, 2022)

River Basin	Basin Size [km^2]	River Length [km]	Elevation difference [m]	Main tributaries	Land-use	
Vecht / Vechte	4,393	182	70	Steinfurter Aa, Lee, Dinkel, Regge	Meadows Forests Agriculture Urban Water	32% 18% 38% 10% 3%
Oude IJssel / Issel	1,638	178	49	Aa-Strang, Bocholter Aa	Meadows Forests Agriculture Urban Water	30% 19% 38% 11% 2%
Berkel / Berkel	792	114	103	Groen-losche Slinge	Meadows Forests Agriculture Urban Water	38% 18% 35% 7% 1%

In total, approximately 2.08 million people live in the study area, of which 1.41 million live in the Netherlands and 0.66 million in Germany. This translates to an average population density of 324 people/km² in the Netherlands and 203 people/km² in Germany.

On both sides, several cities are directly located at the rivers such as Schüttorf (GER), Nordhorn (GER), Emlichheim (GER), Coesfeld (GER), Vreden (GER), Borken (GER), Bocholt (GER), Hardenberg (NL), Ommen (NL), Zwolle (NL), Lochem (NL) and Doetinchem (NL). While all of these cities represent damage potential for a possible flood along the watercourses, only five (Nordhorn, Bocholt, Hardenberg, Zwolle, Doetinchem) have more than 50,000 inhabitants.

In the study area, agriculture (37%) is the predominant land-use, followed by grassland (33%), forests (18%) and urban areas (9%) (see Figure 3). In the Netherlands, the Vechte river winterbed (winter flood extent area) is used for regular agriculture during the rest of the year. Wetlands are mainly situated in the border region and efforts in both countries have been and are made to restore them. In general, there are neither major differences in land-use between both countries nor between the individual catchments.

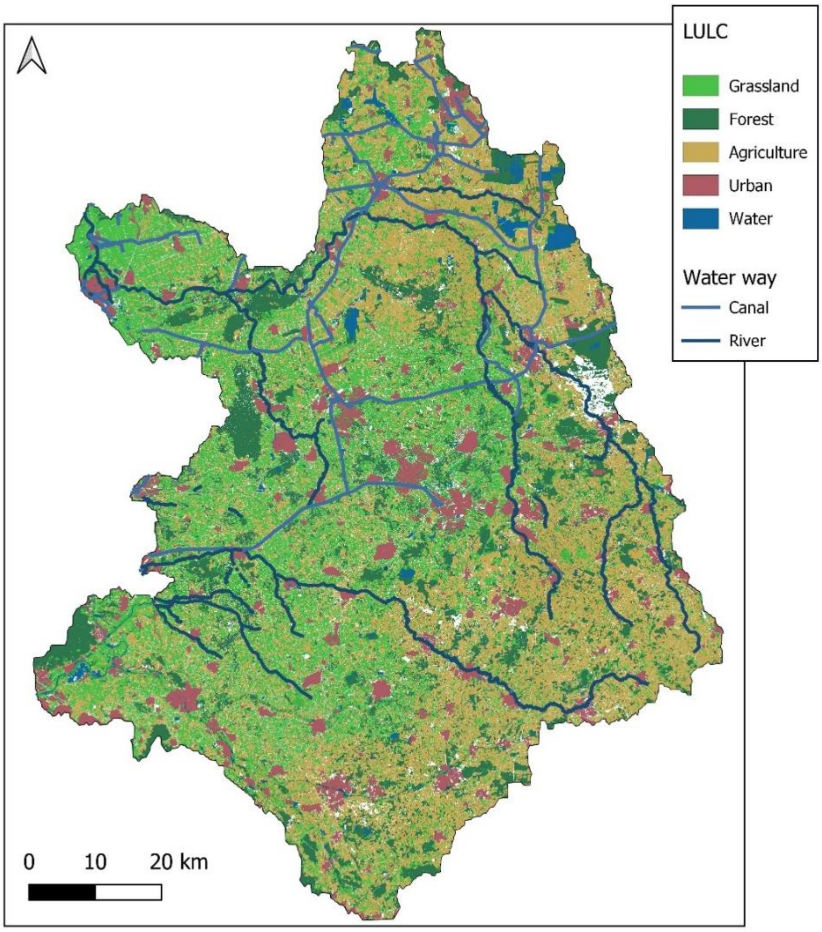


Figure 3: Land-use map (based on CLC 2018)

The Vechte basin plays a vital part in the freight transport between the Netherlands and Germany (European Commission, 2017). Both are part of the North Sea Baltic corridor (Bundesnetzagentur, n.d.). The A1 in the Netherlands from Amersfoort to Bad Bentheim which ends in the A30 in Germany towards Osnabrück is an important route for freight transport via road. The rail transport route North Sea Baltic corridor traverses the Vechte basin on its way from Amersfoort to Osnabrück (see Figure 4). There are plans to expand the freight transport via this route even more (Rijksoverheid, n.d.-b). Also, the cities of Almelo and Hengelo have core inland ports for the north sea baltic corridor (European Commission, 2017) making them logistic hotspots (Omgevingsagenda Oost-Nederland, 2020).

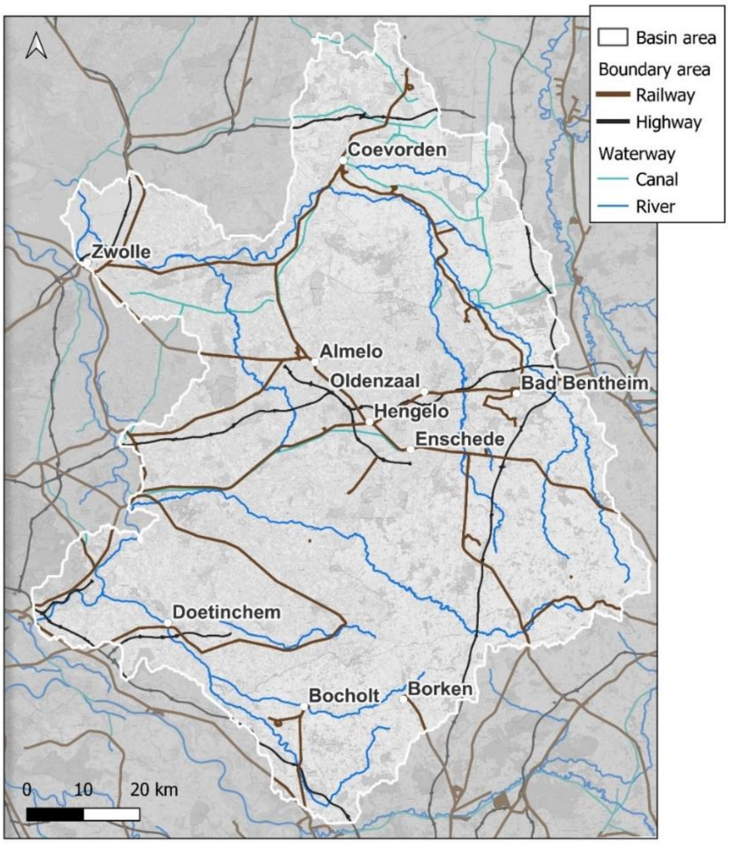


Figure 4: Railway, highway, canals and rivers in the study area based on OpenStreetMap data.

2.2 Climate

Historic data and future climate projections in Germany are provided by the German weather service (Deutscher Wetter Dienst - DWD) and in the Netherlands by the Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut - KNMI).

2.2.1 Actual Climate

The climate in the study area can be defined as temperate and marine with cold winters and warm summers. On average, the annual precipitation in the study area is approx. 835 mm, without clear seasonal patterns. Yearly evatransporation in the study area is approximately 555 mm (WRIJ, n.d.).

Groundwater replenishment exhibits a seasonal dependency, occurring during the hydrological winter half-year (November – April) through precipitation infiltrating the soil. In the summer half-year (May-October), evapotranspiration predominates causing the majority of precipitation to be lost without contributing to groundwater replenishment (NLWKN, 2022a).

The annual average groundwater replenishment in Lower Saxony was 156 mm (1981 – 2010; LBEG, 2019) and 110 mm in North-Rhine Westphalia (2001 – 2020; LANUV, n.d.). In the Dutch study area, the annual average groundwater replenishment based on the national hydrological model (LHM4.1) was about 180 mm (2011 – 2018; NHI, n.d.). In Figure 5 it can be seen that in the Lower Saxon part of the study area, the groundwater replenishment rate is mostly between 100 – 300 mm per year.

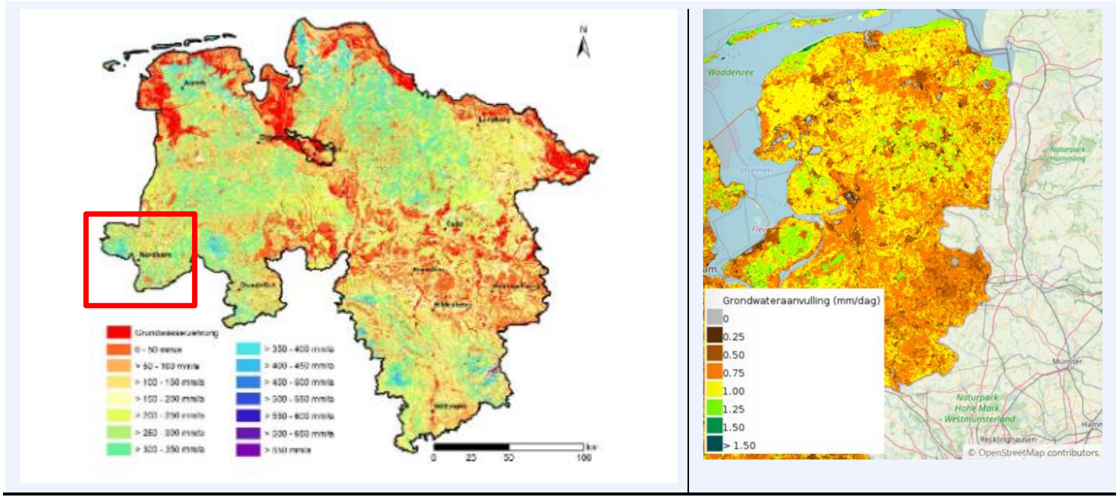


Figure 5: left: Distribution of groundwater recharge rates in Lower Saxony (calculated for the period 1981-2010, LBEG, 2019*, right: distribution of the groundwater recharge rates in East-Netherlands,* NHI, n.d.*)*

2.2.2 Climate Change

Europe, as a whole, is expected to experience an increased likelihood of heavy rainfall, leading to floods, as well as prolonged periods with high temperatures and high evapotranspiration causing droughts (Verdonschot, 2009). Higher precipitation levels will result in increased surface runoff to streams and higher river floods (Verdonschot, 2009). As global warming intensifies, both summer low-water situations and agricultural droughts are exacerbated (Samaniego et al., 2018).

The effects of climate change on the study area are already seen. Increases in the annual temperature ranging from 1.5°C to 2.3°C are reported over the last 120 years. (KNMI, 2023; Scheihing, 2019). The increase is accompanied by more warm days (>25 degrees) and more frequent heatwaves. Simultaneously, the number of frost days has decreased, and overall precipitation has increased, especially in autumn and winter (NLWKN, 2022a; Scheihing, 2019). The German Weather Service reports a precipitation increase of about 100 mm for the period 1881 to 2015 in Lower Saxony (Bender et al., 2009). In the Dutch study, precipitation in the winter months (December – February) increased by 26% since 1906 (WRIJ, n.d.).

Also, the differences between individual years are increasing. In 2023 the highest rainfall amounts for at least 100 years were measured for Lower Saxony (1070 mm), the Netherlands (1153 mm) and North-Rhine-Westphalia (1203 mm) (DWD, 2023). While 2018 was one of the driest years with 500 mm in Lower Saxony, 607 mm precipitation in the Netherlands (KNMI, 2018) and 601 mm in NRW (LANUV, n.d.-b). Variations in yearly mean precipitation of +/- 20 % are not unusual in the last decade (LANUV, 2024). Several high-intensity rain events were observed in the study area in the last 15 years, such as in August 2010, May 2012, July 2014, June 2020, December 2023; WRIJ, n.d.).

The German weather agency prepares climate projection data and provides regional climate projections for the future. The current projections are downscaled from the global climate projections of the Intergovernmental Panel on Climate Change's 5th Assessment Report (IPCC AR5) as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5). As the global climate projections have been updated and presented in the IPCC AR6 report, there is currently a project UDAG (Updating the data basis for adaptation to climate change in Germany) to update the regional climate projections for Germany based on the CMIP6 projections, the updated projections are expected to be finalized in 2026 (DWD, n.d.).

The existing regional climate model ensembles consistently indicate a significant increase in the annual average temperature for Northern Germany. The temperature increase range for Lower Saxony spans from a minimum of 0.6 °C to a maximum of 4.9 °C by the year 2100 (reference period 1971 to 2000). This projected temperature increase is associated with a reduced likelihood of frost days (minimum temperature < 0 °C), an increase in the number of warm days (maximum temperature ≥ 25 °C), hot days (maximum temperature ≥ 30 °C), and in increase in the length of the thermal vegetation period (Scheihing, 2019). They also depict a wide range of potential changes in seasonal precipitation amounts (Scheihing, 2019). Summer precipitation amounts are projected to decrease by 6%, while winter precipitation is projected to increase by 11% for the period from 2021 to 2050 compared to 1971 to 2000. Relative changes of -2 % to 10 % of yearly precipitation amount is projected for the period from 2021 to 2050 compared to 1971 to 2000. For the period from 2071 to 2100, a relative change of between -12 % and (MU, 2019). In the future, a further intensification of the low-water situation in the study area is expected compared to the reference period (1971 – 2000). A reduction of 20% of the discharge during summer low flows (NM7Q) is possible, while at the same time summer flood events are expected to become more extreme (Increase in HQ100 discharges by 50%, MU, 2019).

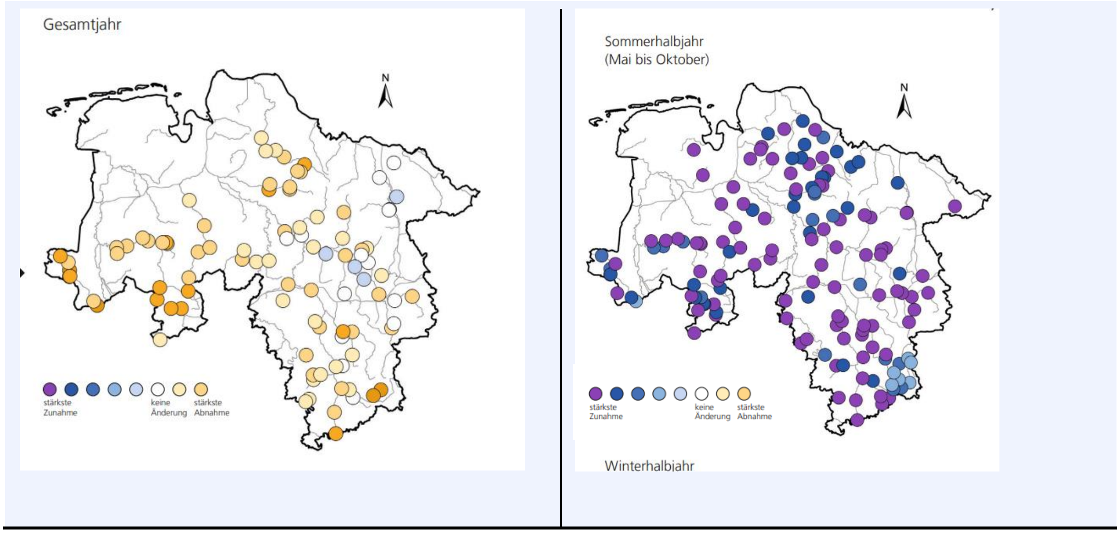


Figure 6: left: Changes in the low water discharge NM7Q at the end of the 21st century that could occur under a "business as usual", right: Changes in the peak discharge for an HQ100 at the end of the 21st century, which could occur under a "business as usual" scenario (MU, 2019).

In the Netherlands, the KNMI provides climate projections for the Netherlands. The new climate scenarios based on the IPCC CMIP6 projections were published in 2023. The scenarios can be categorized in:

- a high emissions scenario (denoted by capital 'H') in which emissions increase strongly until 2080 and then level off. The global increase in temperature around 2100 is estimated at 4.9°C.
- a low emission scenario (denoted by capital 'L') in which emissions are rapidly reduced and greenhouse gases are removed from the atmosphere to limit global warming to below 2°C. The global increase in temperature around 2100 is estimated at 1.7°C.

These two scenarios mean to represent the range of climate change outcomes. Further warming will lead to drier summers and wetter winters in the Netherlands; however, the climate models differ in the extent of this effect. To show these differences, the scenarios have been further categorized in:

- a 'wet' scenario (denoted by the letter 'n') with highly humified winters and slightly dried out summers.
- a 'dry' scenario (denoted by the letter 'd') with slightly wet winters and considerably dried out summers.

More information on the different scenarios is illustrated in Figure 7. In general, these scenarios project an increase in average temperature (higher increase in the summer than in the winter). The temperature increase will result in an increase in precipitation and an increase in high intensity summer rains. It will be wetter in the winter and drier in summer. Less rain is expected in the summer and the evaporation will increase, resulting in more and longer drought periods (KNMI, 2023).

Figure 7: Four scenarios for climate change in the Netherlands round 2100 (KNMI, 2023).

The new climate scenarios can be used to calculate the effect on different sectors. The scenarios will be used to update the Delta scenarios[4] and the National Adaptation Strategy (Deltares, 2018).

For both the German and the Dutch part of the extended Vechte Basin, an increase in frequency and severity of flood and drought events is expected.

2.3 Hydrology

The Vechte river originates in North Rhine-Westphalia and flows about 182 km through Lower Saxony into the Netherlands. It has five major tributaries that contribute to its flow dynamics. Next to the Vechte river, Berkel and Oude IJssel are the other two considerable water bodies in the IJssel basin. The Vechte, Berkel and Oude IJssel rivers all originate in Germany.
The Vechte enters the Netherlands close to Emlichheim and flows into the Zwarte Water (close to Zwolle), which flows into the Zwarte Meer, and

[4] The new Deltascenarios will be based on the combination of the of the KNMI'23 climate scenarios and PBL's socio-economic scenarios for the Netherlands (the WLO scenarios) (KNMI, 2023). The objective of the Deltascenarios is to collectively provide a coherent picture of climatic and socio-economic developments, the uncertainties therein, and their implications for water management (Deltares, 2018).

finally into the IJsselmeer (WDOD, 2021). The mean discharge at the mouth of the river is 50 m³/s, whereas it can vary between 5 m³/s in low flow conditions and 300 m³/s in high flow conditions.

From downstream to upstream, the following tributaries flow into the Vechte in Germany: Steinfurter Aa, Eilleringsbecke, Ahlder Bach, Lee, und Emlichheimer Entlastungskanal and in The Netherlands: Beneden Regge, Ommerkanaal, Mariënberg Vechte Kanaal, Radewijkerbeek and Afwateringskanaal (Holthone). The peak discharges for different return periods at several locations along the Dutch part of the Vechte almost double from the most upstream to the most downstream part (Figure 8) (Haastregt, 2023).

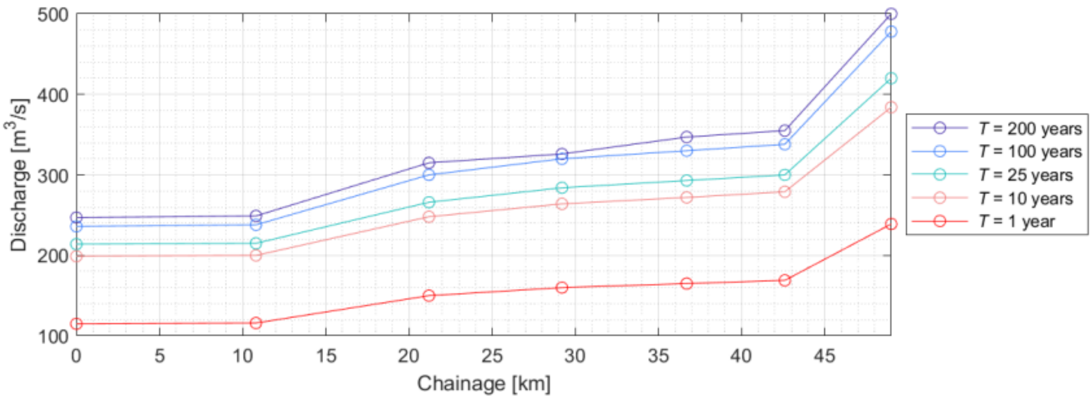


Figure 8: Peak discharges at several locations along the Dutch Vechte (T=return period of discharge) (Haastregt, 2023)

The flow dynamics of the Vechte river are strongly dependent on precipitation, and water abstraction during the summer (Koronaci, 2022). The extensive drainage activities in the Vechte valley, coupled with the Vechte's course straightening, result in a swift discharge of water (Maas & Woestenburg, 2013). This, in turn, leads to an exceptionally low base flow during extended dry spells, causing a deficiency in water supply for both natural ecosystems and agricultural needs.

Due to the flow regulation, the Vechte experiences diminished flow velocities over long periods within a year, while at the same time high flows are rapidly discharged. The intermittent rapid flow velocities contribute to the river's carving, forming a deep channel with habitats that lack diversity. Furthermore, the dam constructions induce moisture in the upper river valley and desiccation in the lower valley. Substantial portions of the natural floodplain are no longer interconnected with the river system, resulting in insufficient storage capacity (Waterschap Vechtstromen, 2021b).

In the Netherlands the area has a long history of human interventions. The natural peat was excavated since the Middle Ages and the area was drained to make it suitable for agricultural use.
The reduction of floodplain areas and retention capacity highly influences the flow regime in the Vechte area. Furthermore, the Vechte was canalized to allow for transport, further influencing its flow characteristics.

The Berkel River flows into the IJssel at Zutphen. The German part of the Berkel has a meandering character with a narrow profile (Blom & Van der Werf, 2022). The Dutch part is highly canalized with a broad and deep summer bed (Van Dongen, R., Eysink, F., Van de Weerd, 2015).

The annual maximum daily discharge of the Berkel at Rekken (close to German-Dutch border) for return periods of 1 and 100 years is 42 and 78 m^3/s, respectively (Van Dongen, R., Eysink, F., Van de Weerd, 2015).
The annual maximum daily discharge of the Oude IJssel at weir De Pol for return periods of 1 and 100 years is 54 and 126 m^3/s, respectively. (Botterhuis & Klopstra, 2004)

The two main tributaries of the Oude IJssel are the Issel and the Bocholter Aa, which join at Ulft. Downstream of weir De Pol, the Bielheimerbeek flows into the Oude IJssel (Botterhuis & Klopstra, 2004).

In De Jong (2023) a water balance has been made for a part of the Vechte. The main inflows and outflows of the system have been quantified. Also, in Luijkx (2020), a water balance has been made for some parts of the Vechte basin (Ommerkanaal, Dinkel and Sallandse Wetering).

Figure 9: Dutch part of the Vechte including locations of weirs and main lateral inflows (Haastregt, 2023)

To regulate the flow in the river at different locations, weirs have been constructed in the past (Figure 9) (Haastregt, 2023; Koronaci, 2022). To deal with the effects of climate change, nowadays the focus of the Vechte weirs is on retaining and storing water in case of water deficiencies and discharging water downstream in case of water excess. By retaining and storing water, the water stays in the system, which can later mitigate the adverse impacts of droughts (Waterschap Vechtstromen, 2021b). Retaining and storing water has been implemented by creating meandering channels around the weirs to restore the river to its original state at some locations (Koronaci, 2022). This will influence the flow and water levels in the river. Changes in waterways have been reported in documents such as “Factsheet KRW 49 waterlichamen Vechtstromen” on the site from the regional water authority Vechtstromen (https://www.vechtstromen.nl/bestuur/waterbeheerprogramma-2022-2027/) or “KRW factsheets” on the site from Drents Overijsselse Delta (https://www.wdodelta.nl/waterbeheerprogramma). As a means for climate change adaptation, the weirs will also be managed differently. They will be operated more often and faster when periods of drought or extreme precipitation are expected (Waterschap Vechtstromen, 2021b). All these measures are taken to reduce the impacts of droughts and water surplus for the water users, which for the Vechte are mostly agriculture and nature (Waterschap Vechtstromen, 2021b).

One of the first climate change impact studies for the Vechte basin has been carried out by Middelkoop et al. (2001). They applied a conceptual rainfall-runoff model to assess climate change impacts on streamflow and found an increase in annual peak flows of about 20% and a decrease in late summer flow of about 5% under the UKHI2050 scenario. Van Velzen et al. (2007) reported an expected increase in streamflow between 7 and 18% in 2050 and 11 and 31% in 2100 under the WB21 scenario. Verdonschot (2009) obtained results in line with Middelkoop et al. (2001) using a physics-based hydrological model covering part of the Vechte basin. He found that both the frequency of peak discharges and the number of drought events will increase for different Hadley Centre scenarios. Recently, KNMI climate scenarios and impacts were qualitatively translated to the Vechte basin (Waterschap Vechtstromen & WDOD, 2022). Hydrological impacts are generally consistent with previous research showing increases in drought frequency and flood probability. Hydrological climate change impacts studies for the Oude IJssel and Berkel have not been found in the scientific and professional literature.

2.4 Geohydrology

System Description

The catchments of the Vechte, Berkel and Oude IJssel are part of the Rhine River basin, and their geological characteristics are influenced by the complex geological history of the region. The catchments exhibit a diversity of soil types due to the presence of glacial deposits from past ice ages combined with ongoing fluvial processes.

The study area comprises predominantly free-draining sandy areas originating from the Pleistocene, called Hoog Nederland in the Netherlands (Hendriks et al., 2022) and Niederungen im Nord – und Mitteldeutschen Lockergesteingebiet in Germany (LBEG, 2016).

The Pleistocene sands are characterized by their unique geomorphology and dominant sand and loam deposits, originating from the Pleistocene epoch [2.6 million – 11700 years BC] (Stouthamer et al., 2020).
The variations between glacial and interglacial warm periods with alternations of erosions and depositions and progressing and retreating ice caps resulted in a landscape characterized by high ridges (moraines), fine aeolian sand deposits (cover sands) and stream valleys (Stouthamer et al., 2020), as illustrated in Figure 10.

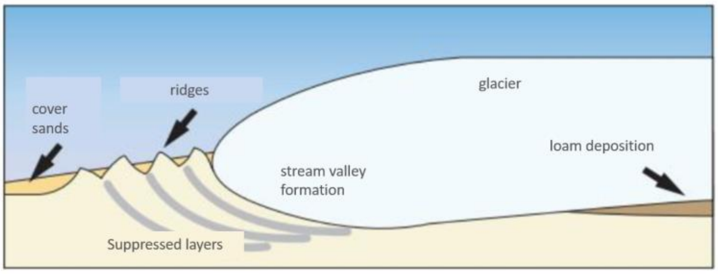


Figure 10: Forming of the landscape in the study area (translated from Provincie Overijssel, 2013)

The moraines, cover sands, and stream valleys define the current functioning of the groundwater system in the area. The hydrogeological base in the Vechte basin is on average situated at about 100 m a.m.s.l. (Waterschap Vechtstromen, 2017). On top are layers of clay and sand from different formations from the Holocene and Pleistocene period.
On the higher grounds with sand or boulder clay, rainwater and surface water infiltrate via the phreatic aquifer (mainly sands) to deeper aquifers. Below the phreatic aquifer is a relatively impermeable layer of 3 – 4-meter thickness which forms the boundary between the phreatic groundwater and the first (semi-) confined aquifer. The thickness of the first aquifer varies between 10 and 90 m (LBEG, 2016).

The higher grounds (moraines) are the main groundwater recharge areas. Due to their thick unsaturated layer, the residence time of groundwater is large and the overall dynamic in the system is low (van Doorn & Jalink, 2017).

The groundwater is flowing from the higher grounds to the loamy and peaty soils in the lower grounds, where the groundwater seeps to the surface and contributes to river discharges. In general, the Pleistocene sandy topsoil and subsurface are characterized by a high permeability and a corresponding high infiltration capacity, and hence limited residence times of water in the unsaturated zone (van Doorn & Jalink, 2017).

In principle, the groundwater follows the course of the tributaries to the main water courses. Only along the Oude IJssel the underground catchment area differs from the topography-based catchment area, as the aquifer also drains to the Rhine (MUNV, 2005).

Human Interventions

The human influence on the groundwater system is considerable. Before human interference, the groundwater flow from higher to lower areas was strongly delayed. However, intensive drainage, groundwater abstractions (e.g. for drinking water, irrigation) and changes in land use affected the groundwater flow and led to changes in groundwater levels and flows, as illustrated in Figure 11. Both in the Netherland and Germany the area has been and still is heavily drained to maximize agricultural use.

Groundwater is the dominant source for drinking water supply in the Vechte catchment, as summer river discharges are too low to be sufficient for drinking water supply (Interview Vitens, NLWKN). In Germany, the Issel aquifer is an important source for water supply, where the water is mainly extracted from the shallow aquifers (MUNV, 2005). Groundwater is also used for irrigation purposes. While in the Dutch part, water supply for a large area (Berkel, Oude IJssel and parts of the Vechte) is provided by water through a surface water supply system (Twente canals, see Section 2.7), the remaining area is solely dependent on precipitation and groundwater. Groundwater extraction increases strongly in dry years. Groundwater use for irrigation is expected to increase by 55% in 2050 in the Netherlands (Waterschap Vechtstromen, 2024) and by 100% in 2050 in NRW.

For these reasons, the groundwater level in the study area has been falling for 150 years (Hendriks et al., 2022), which has a great influence on the river discharges during summer; the period in which the rivers are fed to a considerable extent by groundwater (MUNV, 2005). Especially small brooks are often drying up during dry periods (NLWKN, 2024a).

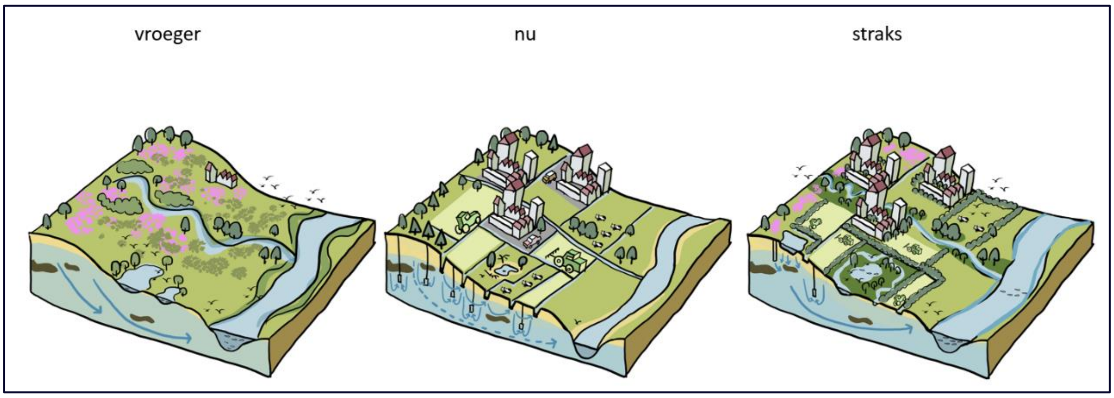


Figure 11: Changes in land use and water use in the Higher Netherlands through time and their effect on groundwater and nature. Left: natural situation (up to about 200 years ago); middle: current situation; right: possible future situation in which with a number of measures groundwater levels can be raised and seepage flows strengthened. These include the following types of measures: less drainage, less extraction, infiltration of surface water (Hendriks et al., 2022).

Due to limited surface water availability, local groundwater recharge relies mainly on precipitation and is often hampered by the effective drainage. For this reason, the groundwater system is susceptible to changes in precipitation regimes by climate change (van Doorn & Jalink, 2017).

Climate change is more likely to cause higher groundwater levels in winter and lower groundwater levels in summer resulting in larger fluctuations of the groundwater levels; which will be affecting its natural functions.

In summer, an increase in prolonged periods of drought, and as a result a rise in water demand, will increase the pressure on the groundwater aquifers (Waterschap Vechtstromen, 2024) further since nature already suffers from structurally lowered groundwater levels due to extensive land use changes and increasing groundwater withdrawals.

In recent years several projects were initiated to set the first steps towards restoring the water system such as Emslandplan 2.0, Zoetwatervoorziening Oost-Nederland (ZON) and the EU Horizon Project SpongeWorks (starting September 2024).

Recent and ongoing studies in the Berkel and Oude IJssel basins are assessing the impact of increasing the groundwater levels between 20 – 40 cm on different land-uses. An increase in groundwater levels is needed to mitigate desiccation (Province of Gelderland).
There are several types of measures to increase the groundwater levels in the sandy areas. According to Hendriks (2022), the three most effective are:

- Reduce drainage: Removal or raising of dewatering devices (watercourses, ditches, trenches, drains)

- Reduce abstraction: reduce groundwater abstraction and compensate withdrawals by additional infiltration during winter
- Infiltration of surface water in areas with deep groundwater levels

Transboundary impacts

It can be concluded from the interviews that knowledge about transboundary impacts of groundwater is limited. Especially, the Dutch authorities mentioned the transboundary impact of groundwater as one of the main knowledge gaps in the system (Province of Gelderland, Regional Water Authority Vechtstromen, Province of Overijssel). More cooperation and joint groundwater models were also mentioned by the German stakeholders (LBEG, Wasserverbandstag, WAZ).
In general, two types of transboundary groundwater impacts can be identified:

- Directly influencing cross-border groundwater levels through abstractions / recharges.
- The impact of the (upstream) groundwater level on (downstream) streamflow, e.g. drying up of streams or low base flows caused by low groundwater levels upstream.

According to Vitens, the direct transboundary impact of changes in groundwater dynamics is limited, as the groundwater aquifer thins out towards the border (Interview Vitens), which is also illustrated in Figure 12.

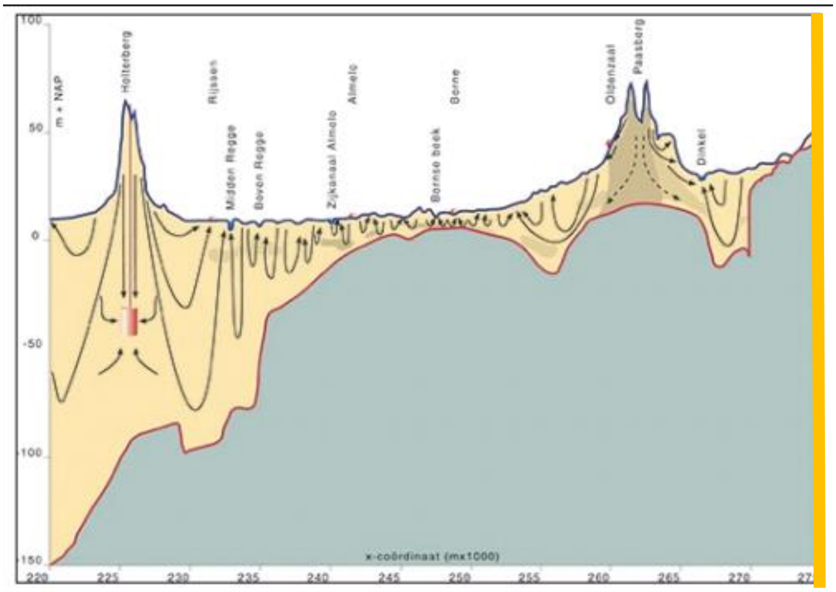


Figure 12: Conceptual model of the groundwater aquifer in the Dutch part of the study area thinning out towards Germany (The border is marked as an orange line on the right side of the x-section) (RIWM, 2014).

In the study area only one location at Manderveen is known, where Dutch and German (drinking) water abstractions have cross-border influences.

However, as there are no transboundary groundwater models on a regional scale, the direct transboundary impact has not been well assessed. According to the province of Overijssel more cooperation is needed, to avoid one stakeholder needs to limit the abstraction while the other stakeholder is increasing abstraction (Interview Province of Overijssel). Similarly, the drinking water company in Germany (WAZ) mentioned the need to collaborate transboundary on replenishing groundwater bodies (Interview WAZ).

The second type of groundwater impact is the impact of groundwater levels upstream on the baseflow downstream. The mechanisms are much better understood; however, quantification is limited. During summer, the transboundary brooks and rivers are dependent on groundwater recharge, and nature protection areas in the border region (e.g. peatlands) suffer from too little baseflow which limit their potential for ecological restoration and requires transboundary cooperation (Interview Natuurmonumenten). In this context, especially the Buurserbeek was mentioned. Hence, water retention measures in Germany, leading to higher groundwater levels, would also benefit nature protection areas in the Netherlands.

In general, as mentioned in several interviews in both countries (Province of Gelderland, GPRW) the transboundary cooperation for groundwater is much less developed than the cooperation on surface waters, which is also linked to the limited knowledge on the degree of groundwater interaction across the border.

2.5 Water use

In the extended Vechte basin groundwater extractions by the public water supply companies, serving various sectors, are dominant, but in dry years agriculture may at least use similar volumes of water. In the pilot area of the Vechte basin in Lower Saxony, the drinking water use is separated in three categories. According to the drinking and wastewater association WAZ (Wasser und Abwasser Zweckverband Niedergrafschaft, WAZ, 2024), approx. 50 % of the drinking water supply is used by private households, 30 % for agriculture and 20 % for industry. But it is to mention, some industrial companies in the area have their own water rights and use their own water in their processes. Also, many agricultural companies operate their own wells for irrigating the fields and supplying animals. This makes it complicated to assess how much water is used by whom in detail. All of the above uses require a permit for abstraction.

Within the Dutch part of the Vechte basin, extractions above 60 m^3/hour or 50,000 m^3 per month or within areas of restrictions require a permit, to be requested from the Water Authority. Extractions above 10 m^3/hour require at least a notification to the Water Authority. Permitted extractions and extractions with notification also require monitoring and registration at the LGR (National Groundwater Register), but for extractions with notification, implementation is only partly achieved in practice (Rekenkamer Oost-Nederland, 2022).

Over the period 2000 to 2015, groundwater extractions in the province of Overijssel, containing most of the Dutch part of the Vechte basin were almost constant, but extractions rose by 10% between 2015 and 2020. Industrial groundwater extractions amount to 5% of total extractions and have declined (Rekenkamer Oost-Nederland, 2022).

In case of water shortages, water in the Netherlands is allocated to users conform a policy of prioritization. Water uses are divided in four classes of highest to lowest priority:

1. Safety and prevention of irreversible damage: stability of flood defences, water level management for the prevention of settlement and of irreversible ecological damage.
2. Public utilities: supply security of drinking water and (water demands underlying) energy supply
3. Smal-scale high-value water uses (temporary irrigation capital-intensive crops, industrial process water)
4. Other uses: shipping, agriculture, nature (with no irreversible damage), industry, recreation, inland fisheries, drinking water and energy supply (not necessary for supply security) and other interests (MInW, 2020).

Industrial water use generally has a low consumptive part: most water will return to the surface water system. For its impact on water systems, water quality problems caused by pollutants in the return flow may well exceed the surface water scarcity problems caused by the water quantity consumed; for groundwater use, it may significantly impact aquifer sustainability.

Water withdrawals by agriculture is rising in dry years. As a result of climate change (see chapter 2.2), loss of yield is to be expected more frequently due to dry periods and heavy rain fall events. Agriculture will adapt to the changing precipitation which will result in a significant increase of irrigation in the summer months (Anter & Kreins, 2013).
In large parts of the Vechte basin, freshwater for agricultural use is available from local sources like private wells and regional water suppliers.

Downstream areas, e.g. in the management area of Regional Water Authority Drents Overijsselse Delta (WDOD) and in the province of Drenthe, are supplied by freshwater from the Ijssel River through canals, partly relying on pumping. In the more upstream parts of the basin in the Netherlands, in dry periods during the growing season, crops and pastures are often supplied with additional freshwater using sprinkler-irrigation. For short dry spells, freshwater stored in ditches or local ponds may be relevant, but groundwater pumped up by farmers is by far the dominant source of irrigation water.

An analysis of agricultural water use in 2018 and 2019 found that groundwater extraction for use in agriculture could even be as large as extractions by the public water supply company, but that uncertainties are large (Projectteam Droogte Zandgronden Nederland, 2021).

Estimated extractions for irrigation in 2018 for Regional Water Authority Vechtstromen were estimated with two methods at 20 million m^3 (LHM – National Hydrological Model) and 45 million m^3 (RS – Remote Sensing). Similarly, for Drents Overijsselse Delta, LHM yielded 25 million m^3 and RS yielded 51 million m^3. The main difference in the estimates emerged from the assumptions on the area irrigated. In the LHM estimate, outdated information on agricultural practices in late spring were used; in the RS estimate, remote sensing was used to diagnose irrigation application. Remote sensing indicated that 30 to 33% of the agricultural area was irrigated, LHM assumed around 10%. In both methods, significant uncertainty exists on the irrigation depth (in mm) applied.

A third estimate, based on registered water use, was not available for the two regional water authorities of the Vechte. For other regional water authorities, the estimate based on registered and reported uses was structurally below model-based estimates.

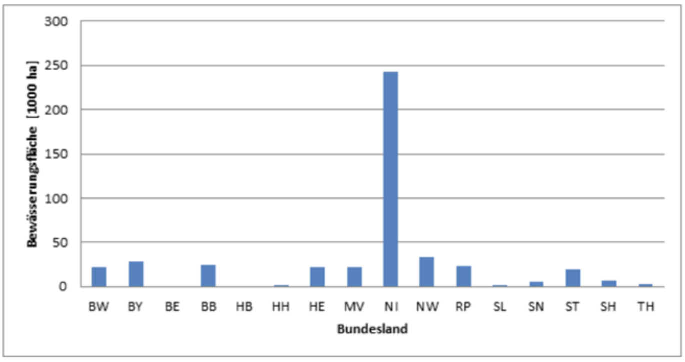
Registered extractions for irrigation in the management areas of Regional Water Authority Vechtstromen and Drents Overijsselse Delta in an average year amount to 6 million m^3 and 5 million m^3 respectively; in a typical dry year this increases to 19 million m^3 and 17 million m^3. The additional water use from small non-registered extractions is unknown for Vechtstromen and Drents Overijsselse Delta, but model-estimates in regional water authorities' areas in Noord Brabant suggest that they may be of the same magnitude of even far exceed registered extractions (UVW & IPO, 2021).

To put the agricultural water extractions in 2018 in perspective, average groundwater extractions from the public water supply company in Vechtstromen and Drents Overijsselse Delta amount to 45 million m^3 and 47 million m^3 respectively. The RS estimates indicate that agricultural water use in drought years may equal or exceed the extractions for the higher-prioritised use. Nature impacts of agricultural water use is even worsened by the location of extractions, because 29 to 33% of agricultural extractions are in nature areas and their buffer zones for Vechtstromen and Drents Overijsselse Delta (compared to 8 to 13% of other types of extractions).

Discussions in literature and policy on agricultural water use address various important recommendations:

- Registration of water use should improve, both in coverage and timely availability of water use information.
- Thresholds of registration (or reporting requirement) should be lowered. A region with scattered smaller extractions from a groundwater aquifer is a prototypical example of a common resource problem. Leaving substantial extractions without registration requirements provides to make it into a "tragedy of the commons" leading to water scarcity. Extensive international experiences with common pool resources management strongly argue for wider registration (and reporting) (Witte et al., 2020).
- Less water intensive cultures should be grown. In the current situation, grass and crop cultures grown are selected based on net economic yield, not on the water usage. As freshwater (blue water) is not perceived as scarce in regular years, cultures are chosen that even exhaust green water (rainwater, temporarily stored in the soil) in such years, and require more irrigation water in drier years (Witte et al., 2020).
- Related to that, it is recommended to explicitly consider green water in water management (Hoekstra, 2012). Reporting of water use, that traditionally focusses on blue water use and blue water balances can be extended with information on green water use and indicate where intensive green water use may feed blue water sensitivity and reduce water scarcity.

In the German Vechte basin in the area of the WAZ in Lower Saxony, 30% of the public water is used for agriculture, not including private wells.
In total, 2.7% of the agricultural area in Germany is irrigated (Federal Statistical Office, 2016). Lower Saxony is the most irrigation-intensive federal state with around 242,000 hectares of irrigated area in 2015 (see bar chart below).



Quelle: Destatis (2016).

Figure 13: Watered agricultural land in 1000 ha in the Bundesländer of Germany in 2012 (Anter & Kreins, 2013). *Lower Saxony is abbreviated as NI, North Rhine Westphalia as NW.*

The following table from the Thünen Institute (2015) shows the water requirements for agricultural irrigation in North Rhine-Westphalia for different periods of time. For the initial situation, a water requirement of around 19 million m^3 per year is calculated for NRW. The water requirement for horticultural crops in North Rhine-Westphalia will increase by less than 50%, while for agricultural crops roughly triples until 2050. Over time, these development tendencies become stronger. By the last time period considered (2051-2080), the water requirement in North Rhine-Westphalia is expected to increase around 19 times. According to Kreins et al. (2015), this means around 350 million m^3 (Kreins et al., 2015). More than 90% of this comes from agricultural irrigation.

	1961-1990			1990-2020		
	Gesamt	Landwirtschaft	Gartenbau	Gesamt	Landwirtschaft	Gartenbau
NRW	14,1	3,4	10,7	25,1	12,6	12,4
Düsseldorf	6,2	1,9	4,4	10,9	6	4,9
Köln	3,4	0,8	2,6	7,1	4,2	3
Münster	2,9	0,6	2,3	4,9	2	2,9
Detmold	1,3	0,2	1,2	1,8	0,4	1,3
Arnsberg	0,3	–	0,3	0,4	0	0,4

	2021-2050			2051-2080		
	Gesamt	Landwirtschaft	Gartenbau	Gesamt	Landwirtschaft	Gartenbau
NRW	56,6	39,4	17,1	128,6	101,9	26,6
Düsseldorf	22,7	15,9	6,9	50,2	39,5	10,7
Köln	21,5	17,5	4	50,5	44,3	6,2
Münster	7,2	3,5	3,7	12,5	7	5,6
Detmold	4,2	2,2	2	11,2	8	3,2
Arnsberg	1	0,4	0,6	4,1	3,1	1

Quelle: Kreins et al. (2013; 2015).

Figure 14: Development of irrigation requirements in agriculture in North Rhine-Westphalia (in million m^3)(Anter et al., 2018).

Transportation by shipping as well as recreational shipping provide an additional water demand. This is mainly in the form of a minimum water level requirement, which is a form of non-consumptive use. However, the operation of sluices results in a downstream discharge, which can be seen as consumptive use for the upstream area. Transportation by shipping in the area is focused on the Twente Canal system, while recreational shipping takes place mainly on the Vechte and the Oude IJssel.

The last important function using water is nature. This refers to both aquatic nature and terrestric water-dependent nature, which mainly depends on sufficiently high groundwater levels. Quantification of these water demands for the basin is complex. For the Vechte area, within the border water commission it is currently discussed to add minimum flows as appendix to the border water treaties (see also chapter 4.3).

2.6 Managing the Vechte

The River Vechte has a long history of human interventions, which have an impact on the river morphology. The first interventions were executed in the period between the end of the 19th century and the middle of the 20th century. In the German part of the Vechte, interventions went along with the drainage of the peat areas of North-Western Germany for agricultural usage in the 1950s (Emslandplan) (DHV, 2009). In addition to drainage, water flow was regulated through ditches parallel to the Vechte river (Talgräben). Downstream of Neuenhaus, these ditches flow to the river. Due to compliance with the WFD, several weirs have been improved for continuity purposes[5]. Water levels in the river were elevated with weirs already pre-World War 2 for irrigation purposes. Since the 1960s, the lower part of the German Vechte was canalized and straightened. During these interventions, the length of the river reduced by approx. 50 km.

In the Netherlands, meanders of the free-flowing river were also removed, and the river was straightened to convey flood waves more quickly for flood prevention (Wolfert & Maas, 2007). This canalization of the river was achieved by straightening 69 meanders and reducing the river length by 25 km (Spruyt & Fujisaki, 2021; Wolfert & Maas, 2007).The immediate result of this river straightening was an increase of the river bed slope, which led to bed degradation and a decrease in flow depth (Wolfert &

[5] "River continuity refers to the possibility for water, sediments, aquatic fauna to pass freely in the upstream and downstream directions along the river [...]. Any manmade barrier in a river can disrupt this river continuity by fragmenting the river corridor and fluvial habitats. This fragmentation alters exchanges and passage within the river corridor and river connectivity on which depend ecological processes (ECRR, 2019)."

Maas, 2007). The bed degradation was counteracted by constructing bank revetments and seven tilting gate weirs to regulate the flow depth, six of which are still in use (Haastregt, 2023).

During the last 25 years, there has been an attempt to improve the ecological functions of the river by increasing the morphological activity and making the river partially natural again by implementing a series of interventions along the river. This has been documented particularly well for the Dutch Vechte part (see Annex A and Haastregt, 2023) for further information. In Germany, the dismantling of the weir in Schüttorf (NLWKN, 2021e), the creation of floodplain waters near Nordhorn (NLWKN, 2021a) and the creation of succession or initial channels close to Schüttorf (NLWKN, 2021c) are recent projects that are documented.

In the Netherlands, emergency retention areas and pools in floodplains for water abstraction during dry periods were constructed at different parts of the river by 2000. After 2000, and until recently, a series of side channel constructions and modifications has been implemented along the river. At the same time, the banks at parts of the Vechte and at some of the side channels have been restored to a more natural state by complete or partial destoning. The floodplains have been affected by the effort to renaturalize the River Vechte, either by lowering parts of them or by giving more room to the river at some parts by widening the cross section of the main channel and/or by remeandering. Finally, several other types of interventions have been implemented, such as the construction of sluices and the replacement and strengthening of dikes.

In its current situation, the River Vechte has a drop of 105 m over a total length of 182 km, with 10 m of this drop being in the Dutch part (Lamers, 2017). The median sediment diameter of the river is 0.325 mm (Lamers, 2017).

Otermann (2015) provided an overview of some recent morphological developments in the River Berkel, which is summarized in the following. The River Berkel used to be a dynamic river but has undergone many changes since the Middle Ages (Driessen et al., 2000; Pinkert, 2017). Probably, the most notable change is the large-scale straightening of the river, which reduced its length from 170 km to 110 km. The River Berkel has the biggest change in bed level elevation in the German part. The total elevation drop is around 100 meters over its whole water course, i.e., from near the town of Billerbeck from which it originates until it flows to the IJssel near Zutphen, after crossing the German-Dutch borders near Oldekott.

Before the many and large-scale changes that it went through, the River Berkel was experiencing regular flooding. In the 19th century, land cultivation was increased, which led to even more flood prone conditions due to artificial drainage of the land. The many large-scale interventions and the construction of weirs deteriorated its nature and the dynamics of the river, including the disappearance of fish species and the floodplains not getting inundated any more. However, there has been an ongoing effort since 2005 to restore some of the river functions by constructing nature-friendly riverbanks and fish passages, and by rerouting the river flow through old meanders. Moreover, water storage on the floodplains is sought by compensating farmers to allow water on their land.

In 2014, the straight part of the Berkel between Almen and Zutphen was restored to its former dynamic meandering course by reestablishing the flow through bends and former flow routes. In total, 15 bends were added, which increased the river length by 2.5 km. The river obtained a flow pattern that is typical for meandering rivers with deeper and faster flow in the outer bend and shallower and slower flow in the inner bend. In this new situation, the maximum allowed discharge at the weir at Lochem is 9 m^3/s, with the excess water being diverted to the Twente Canal.

2.7 Water-related infrastructure

The flow and water level in the main rivers in the Vechte Basin are heavily regulated by infrastructure. An inventory executed in the years 2002 – 2004 for the part of the Vechte basin in Lower Saxony shows 109 substantial riverbed structures with a water drop of more than 30cm and 9 siphons and culverts with a length of more than 100m (NLWKN, 2004). While some of these structures have been adapted or removed to improve the connectivity of different parts of the river, 90% of the catalogued infrastructure is still in place (personal communication, Vechteverband). In this section we provide an overview of the most important types of infrastructure and their impact on the water system, especially during floods and droughts. We furthermore indicate how and by whom the most important infrastructure is maintained and operated.

Embankments

Embankments for flood protection exist along the entire Vechte. Due to the dispersed responsibility for water-related infrastructure in Germany, information on dikes is not centrally available. In the Netherlands, the regional water authorities (‘Waterschappen’) are responsible for the maintenance of embankments. For the Vechte, the regional water authority Drents Overijsselse Delta manages the embankments. The only embankments in the Vechte basin that are part of the Dutch system of primary flood protection are the embankments along the Vechte downstream of Ommen (Figure 15). These embankments have a maximum allowed failure probability of 1/300 per year for the embankments on the north side of the river and 1/3000 per year for the south side as defined in the national Water Law. The difference between these two safety standards is caused by the difference in potential damage in case these embankments fail. Failure of other embankments in the basin is expected to cause less damage and therefore have less stringent safety standards. In the Netherlands, these are called 'regional embankments'. Their maximum allowed failure probability is regulated by the provinces. Management of these embankments is with the regional water authorities. In Germany, the level of protection is not regulated. Therefore, information on safety standards of embankments in Germany do not exist.

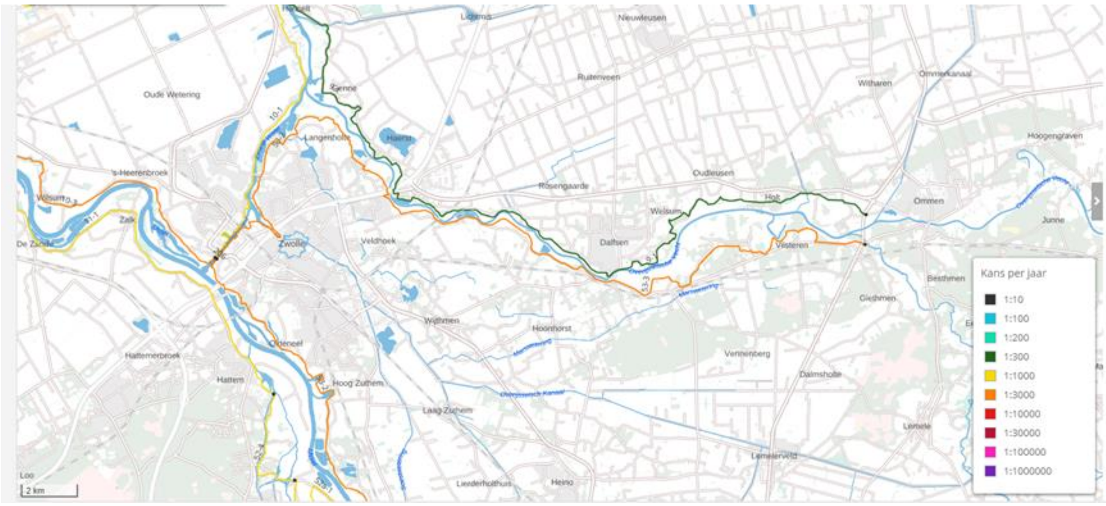


Figure 15: Map the embankments that are part of the primary flood protection in the Netherlands and their maximum failure probability (WVP, n.d.) *.*

Storage areas

Another part of the flood protection infrastructure is formed by the areas designated to store water during high water events with the aim to lower the water level and the resulting damage downstream. Parts of the riverbeds of the Regge and Dinkel have been restructured to store water. Also, along the Vechte, several nature-based retention areas have been implemented, e.g., close to Quendorf (NLWKN, 2021d). Furthermore, two storage areas (Noord – and Zuid Meene) have been designated along the Vechte between Gramsbergen and De Haandrik.

Weirs and sluices

Weirs are used to maintain the water level above minimum values to serve different purposes, such as irrigation, nature, and navigation. The latter is more important in the larger rivers and canals, while the former two are more important in the smaller streams and ditches. In the main rivers and canals, sluices are used to enable ships to move between compartments with different water levels. Fish ladders have been created next to weirs to allow passage of migrating fish (Figure 16).

Figure 16: Fish ladder (left), weir (centre) and navigation sluice (right) on the Vechte River (pictures Marnix van der Vat)

In Lower Saxony, several weirs have been adapted to enhance river continuity (see Figure 17).

Figure 17: Overview of measures to restore river continuity in the Vechte river (NLWKN, 2024)*. The figure presents the measures implemented until 2007. In the meantime, the weir in Schüttorf has been adapted as well* (NLWKN, 2021e)*.*

The sluices on the rivers are mainly used for recreational purposes. There is transport of goods by shipping using sluices in the Oude IJssel and the Twentekanaal. The sluices to enter the Twentekanaal from the IJssel are located at Eefde. The canal system extends upstream to Enschede, Almelo and Coevorden. In Germany, the Vechte is connected via the Ems-Vechte-Kanal with the Ems. The Nordhorn-Almelo-Kanal once connected the two cities Nordhorn and Almelo; however, the Dutch part of the canal has been backfilled. Sluices are situated at the Ems south of Lingen and at the Vechte in Nordhorn (NLWKN, n.d.-c).

Pumping stations

In the Dutch part of the basin, small pumps are used to divert water from the rivers, streams, and canals, mainly for irrigation purposes. During drought events the main external source of water for the Dutch part of the area is formed by the Twentekanaal system, which feeds the Vechte at De Haandrik. A large pumping station with a capacity of 22 m^3/s is located at the sluice complex in Eefde and abstracts water from the IJssel into the Twentekanaal. Due to leakage and sluice losses the effective capacity is estimated to be 16 m^3/s (Witteveen en Bos, 2016). During recent low flow events, the water level in the IJssel has decreased to a critical level below which further abstraction becomes difficult. This would result in serious impact for water supply and shipping along the Twentekanaal system. There are also about 20 pumping stations which discharge water from the surrounding areas into the Vechte.

Operation, maintenance, and management

In the Netherlands, the regional water authorities are responsible for operation of most of the water-related infrastructure. Rijkswaterstaat is responsible for the Twentekanaal and the sluice complex and pumping station at Eefde.

While the NLWKN is responsible in Lower Saxony for control, development and maintenance of the Vechte river, the Vechteverband is responsible for all smaller streams with supra-local significance. The Vechte area in North Rhine-Westphalia is managed by different maintenance associations.

3 Extreme events in the basin

3.1 Floods

The severity of a flood event depends highly on landscape characteristics. The Vechte, Berkel and Oude Ijssel flow mostly through a fairly flat to slightly hilly landscape in North Rhine-Westphalia, Lower Saxony and the Netherlands and show few topographical differences. In this type of landscape two type of flood events can be differentiated:

1. Riverine floods: Long continuous rain (moderate intensity) in combination with wet soils resulting in large areas being flooded. These events predominantly occur in the winter months.
2. Pluvial floods: Short /medium – high intensity rainfall causing local flood events. Predominantly occurring in the summer months.

Historic events and impacts

Over the last 100 years, the study area was subjected to flood events in 1960, 1998, 2010 and 2023/24. In the upcoming paragraph we will give a short summary of the last three events and their impact on the area.

In October 1998 the area experienced a major riverine flood. Excessive rain (203mm/months in Lower Saxony – 363% of the average monthly amount, 291 mm/month in Hoogeveen/Netherlands in the study area on saturated grounds) led to high river discharges causing floods in Germany and the Netherlands (KNMI, 1999; NLWKN, n.d.-a). Especially, the Dinkel overflowed its banks and caused flooding in the surrounding areas. Due to the time of the year, major agricultural losses occurred in the intensively farmed arable land in the flood plains. Other areas had just been harvested and were exposed to erosion without any protection, there was a high loss of topsoil (NLWKN, n.d.-a).

In the Netherlands, the water level in the Vechte was so high that the towns of Coevorden, Gramsbergen, Hardenberg and Ommen were threatened, embankment breaches were considered possible, and evacuations were almost initiated (Waterschap Vechtstromen, 2020).

The flood resulted in a change of perspective in Eastern Netherlands. Initiatives and projects were started to renaturalize the straightened rivers, so that the water would drain more gradually. Also, major water retention areas (Gramsbergen, Meene) were created.

In 2010, high intensity rain caused a pluvial flood in the border region of Germany and the Netherlands. In Germany, locally 180 mm rain in 24 hours was recorded in the Muensterland, in the Netherlands at Hupsel station the highest daily precipitation (130mm) measurement in the Netherlands for 30 years was recorded. The extreme rain resulted in flooded streets and basements and agricultural damage in the whole area (Ems Vechte Welle, 2022; Vreugdenhil et al., 2010). Numerous emergency services were deployed for days. In the Netherlands, the National Road N18 was flooded (WRIJ, n.d.).
In Germany Nordhorn, Epe and Gronau were threatened, as the rivers overflowed its banks in various places (Feuerwehr Gronau, 2020).

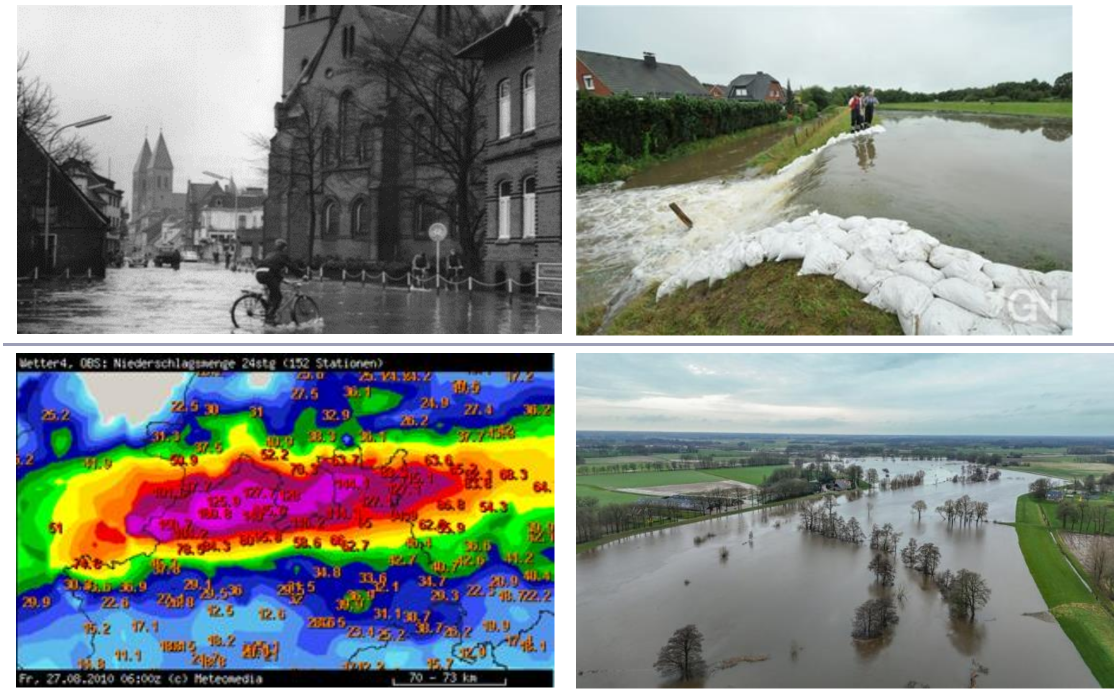


Figure 18: up left: flood in Gronau 1960 (Dinkel) (WDR, 2016); up right: flood in the district Grafschaft Bentheim in 2010 (Grafschafter Nachrichten, 2016); left: selective amounts of precipitation in 24 hours during a heavy rain event in 2010 in the Netherlands, NRW and Lower Saxony (Unwetterzentrale, 2010); below left: Extend of the Vechte during the 2023/2024 high water event (NU.nl, 2024)

The most recent flood in the study area occurred in the winter of 2023/24. Over the Christmas holidays, high water levels occurred in the study area. In Emlichheim, the Vechte water level rose above the third reporting level (NLWKN, 2024b). The flood was characterized by a great spatial extent (large parts of Lower Saxony, NRW and East Netherlands were affected) and the long duration of precipitation. Between 18.12.2023 and 3.1.2024 an accumulated precipitation between of 100 and 200 mm was recorded in the study area. This resulted in high discharges (ECDM, 2024; NLWKN, 2024b).

In Figure 19 can be seen that the water levels were high over weeks. Record water levels were registered at the Vechte in Emlichheim and Neuenhaus (See Annex B).

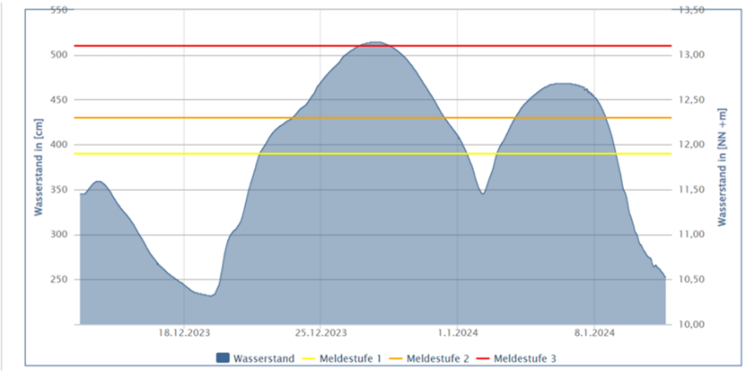


Figure 19: Vechte, Gauge station Emlichheim showing water levels from mid-December 2023 to mid-January (NLWKN, 2024b)

Building damage in the order of €23,000 was reported in the municipality of Emlichheim. Also, a school center which is intended as an emergency location in case of evacuation and a contact point in crisis situations, was flooded. Additionally, a local heat outage occurred. Moreover, many basements were flooded due to the high groundwater levels. At a regional level, recreational infrastructure and some bicycle paths and small roads were temporary blocked, some directly due to high water, others due to storm-water drainages being blocked by natural debris (Waterschap Vechtstromen, 2023). A variety of local flood nuisances were reported, including evacuation of a petting zoo in a park in Hardenberg, as well as smaller water damages in various streets (RTV Oost, 2023; RTV Vechtdal, 2023).

Embankments in the region of Laar are currently assessed for damages. The long duration of the flood led to losses of winter grain (Chamber of Agriculture of Lower Saxony, Emsland area). The flood also highlighted that current communication and alarm plans need to be made clearer and more automated (District Steinfurt).

In the Dutch study area, especially along the Vechte, many water level and discharge measurement stations stopped working as the levels were outside their measurement range. These measurement stations are critical for the operational flood forecasting systems. The flood forecasting system for the Vechte (FEWS Vechte) performed well. However, the accuracy of the forecast could be improved. Preliminary conclusions and recommendations of an ongoing evaluation are:

- The quality and reliability of the discharge measurements were not sufficient, thus an increase in robustness of the measurement network is needed.
- Hydrological model performance is low due to a mix of factors: (1) poor discharge measurements; (2) being outdated as they are calibrated on the 1998 flood event; (3) difficulty to model high sensitivity of actual run-off to seasonal changes (e.g. crop status). Next to the network, recalibration of the hydrological model ensures that recent changes in the water system are taken into account.
- The German part of the basin is insufficiently represented in the Dutch models to provide a timely forecast; thus, the model representation needs to be improved.

The long-term objective is to realize a future robust FEWS Vechte System.

Flood risk assessment and Potential Impact

The EU Floods directive requires a flood hazard assessment and flood risk management plan. In Figure 20 the flood extent of an extreme flood event (return period > 200 years) is visualized for the Vechte catchment. The map includes flood hazard data from the Netherlands, Lower Saxony and NRW. It shows that especially at the border region and downstream in the Netherlands large areas are expected to be flooded in such an extreme event.

According to the NLWKN and the province of Gelderland there are inconsistencies in flood maps between both sides of the border; attempts are made in a good cooperation to understand these differences. There is no joint methodology for the setup of the flood analysis (Interview NLWKN, province of Gelderland).

Based on the flood risk management plans also the number of people which will be affected by a flood event has been assessed. Table 2 gives an indication on the number of people affected in the study area (Vechte, Berkel and Oude IJssel catchments) for flood events with three different return periods (10 – 20 years, 100 years, 100+years) based on the flood risk management plan for the Rhine.

The numbers are not one to one comparable to each other, as in the Dutch calculation it is assumed that there will be no failure of the water infrastructure even under extreme conditions that exceed the return periods used in the design of the flood protection. In case of failure for these systems, thousand to ten thousand(s) of residents will potentially be affected.

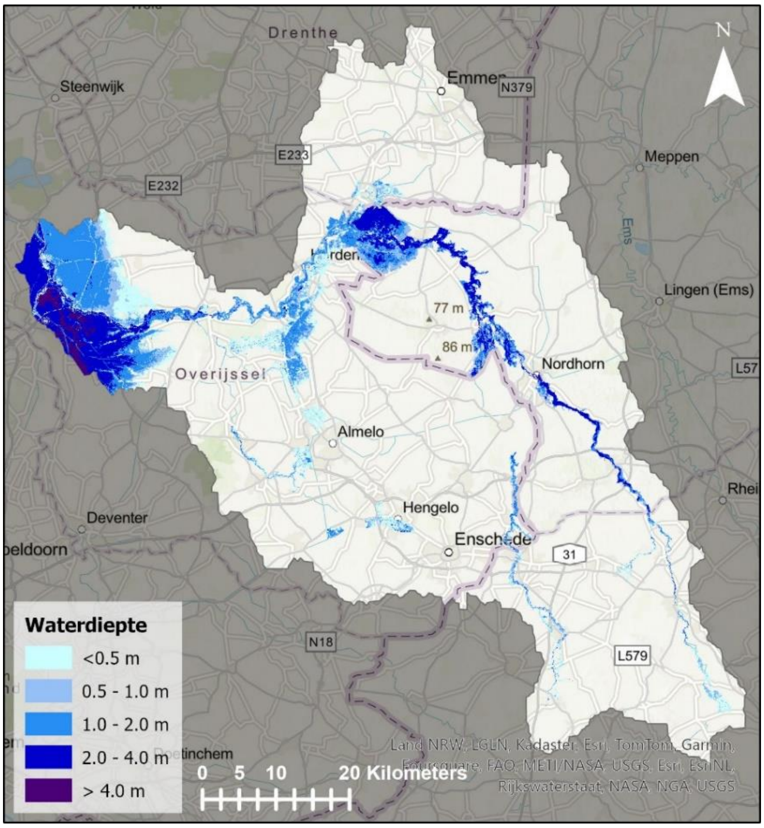


Figure 20: Flood Risk Maps of the Vechte catchment (based on open data).

Table 2: Number of affected people in the study area based on the respective flood risk management information (Deltares, 2024)

Area	HQ_{haufig} (every 10 – 20 years)	HQ_{100} (every 100 years)	HQ_{extrem} (every 100+ years)
German Study Area	3400	6300	77400*
Dutch Study Area	117	250	1988

* In this case the area around Isselburg will be flooded from the Rhine and not from the regional water system

As discussed in chapter 2.2, precipitation amounts as well as the probabilities of extreme rainfall events are increasing and are projected to further increase due to climate change (LANUV, 2018). It can be concluded from the interviews that water managers are aware that extreme floods (return periods of 100+ years) may happen, but no specific measures are taken into account to reduce the impacts of such events (e.g., Interview Borken). A modelling study in the Netherlands, in which the rainfall from the July 2021 floods in the Ardennes-Eifel was shifted into different Dutch regions, identified the study area as one of the vulnerable areas, especially the region around Zwolle, where all water concentrates and must pass the city (Deltares, 2022).

Critical Infrastructure

Whether flooding disrupts society largely depends on the impacts of the flood on critical infrastructure, as these provide vital functions for society and daily life. These functions include services such as telecommunication, transport, and electricity. Failure of one critical infrastructure system may lead to failure in other system, so-called ‘cascading effects’, which can have large consequences during and after flood events.

In anticipation of severe natural events, increased focus is placed on safeguarding critical infrastructure. After the flooding of 2021, the Dutch government issued a recommendation to define norms for critical infrastructure in relation to pluvial flooding (Beleidstafel wateroverlast en hoogwater, 2022).This is currently under research and has not yet been defined and implemented.

In Germany, infrastructure is classified under the concept of KRITIS (critical infrastructures). This connects governments, asset and network operators. KRITIS considers slightly different infrastructure functions as vital than the Netherlands (Table 3) (BSI, n.d.). By the end of 2024, the European Critical Entities Resilience Directive (CER) comes into place. This entails that critical infrastructure entities need to be resilient to a range of threats, including natural hazards, throughout the European Union (EU, 2022)

Table 3: Sectors considered as critical infrastructure in the Netherlands vs. in Germany

Netherlands critical infrastructure	**Germany critical infrastructure**
Energy	Energy
Telecom	Information technology & telecommunications
Transport	Transport & traffic
Drinking water	Food
Water	Water
Chemical	Health
Nuclear	Municipal waste disposal
Finance	Finance and insurance
Government	Strate & administration
Public order and safety	Media and culture
Military	

Open data sources have been used to locate critical infrastructure (such as power plants, transport infrastructure and hospitals) in a flood event for the study area (see Figure 21).

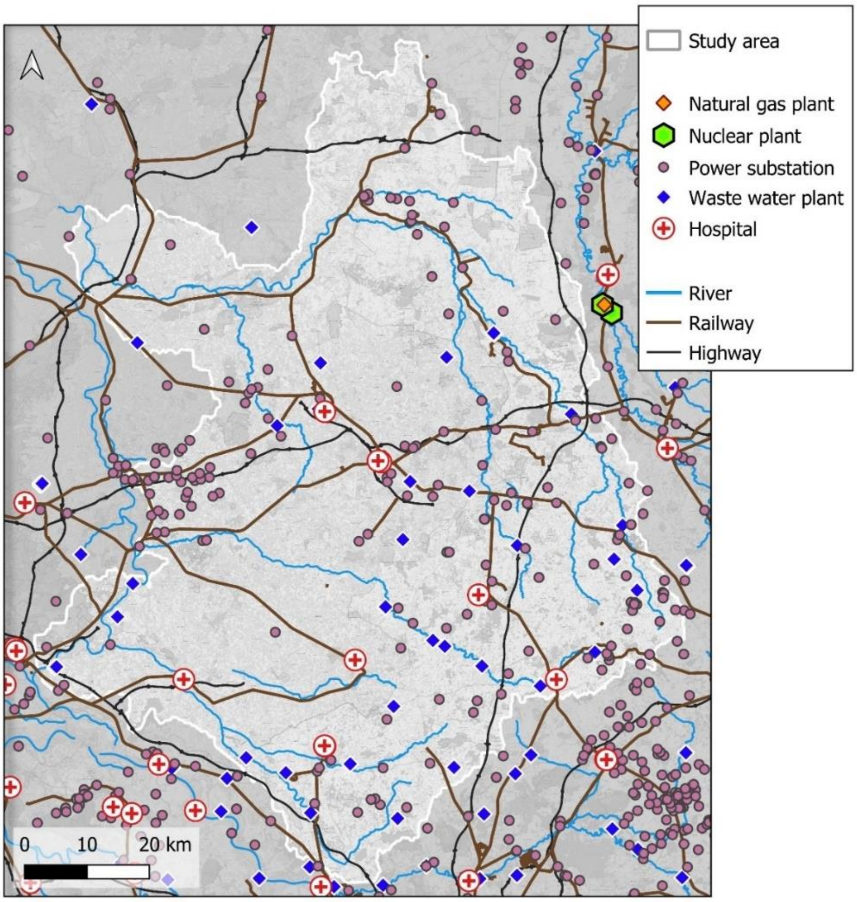


Figure 21: Critical infrastructure locations in the study area, retrieved by open-data search (OSM, 2023)

In the Netherlands, the safety regions (Veiligheidsregio's) typically possess knowledge about critical infrastructure objects during a domestic crisis. However, while consensus has been reached between Germany and the Netherlands regarding the categorization of the Lingen nuclear facility as a critical object for both countries, there remains a need for defining similar statuses for other crucial infrastructure objects that can have impacts on both countries (Safety region Twente). From several interviews it became clear that there is an important knowledge gap on this topic: it is not well-known where the critical infrastructure in neighbouring countries is located, nor how climate extremes might affect their functioning and what the impacts of this can be on the safety of a region (Safety region IJselland, district Borken, and joint municipiality of Neuenhaus).

3.2 Droughts

The region has experienced severe droughts in 1921, 1959-1960, 1976, 1996, 2003, 2018, 2019, 2020 and 2022 (Kremer Devesa, 2023; Van der Heijde, 1978). Here, we focus on the recent droughts of 2018, 2019, and

2020, for the following reasons: (1) most information is available for these periods, (2) landscape is similar to present landscape, (3) droughts were extreme, particularly in 2018.

Meteorological, soil moisture and groundwater droughts

Figure 22(a) shows the cumulative sum of the precipitation in the Dutch part of the study area for 2018, 2019, 2020, and for the climatology, i.e. the average for the period 1992-2021. On average, the annual precipitation in the Dutch study area is 835 mm, with no substantial seasonal variations. The summer droughts of 2018 and 2019 are partly caused by lowered precipitation starting in June. In 2018, the precipitation stayed low for months, causing a 200 mm lower annual sum than average. In 2019, autumn rains increased the precipitation to a near-normal sum.

In order to take the effect of evapotranspiration into account, meteorological drought is often quantified by showing the precipitation deficit, i.e. the reference evapotranspiration minus the precipitation during the growing season. The precipitation deficit for the study area is shown in Figure 22(b). The climatology shows that precipitation deficits generally increase as the growing season progresses. In winter, when precipitation exceeds evapotranspiration, precipitation deficit will be negative. Compared to average conditions, 2018, 2019 and 2020 experienced substantially higher precipitation deficits.

Similar numbers are reported for the German side. According to the LANUV, in 2018, the annual precipitation measured was just under 620 millimeters, with a precipitation deficit of 230 millimeters (LANUV, n.d.-b). This deficit persisted through 2019. Following an exceptionally rainy February 2020, a prolonged period of low precipitation extended into June, exacerbating the situation. Positive and negative precipitation anomalies of North Rhine-Westphalia as well as of Lower Saxony are shown in Figure 23. In both federal states, the precipitation anomaly of 2018 is almost down to -40%. Also, most of the following years present a negative precipitation anomaly.

The climatic water balance of the growing season (KWB), April-September for Itterbeck shows the same and is listed for the location of Itterbeck in the district Grafschaft Bentheim and the years 2018 to 2022 in Table 4. Only the year 2021 reports a positive KWB. In the year 2018, the KWB indicates the highest negative number.

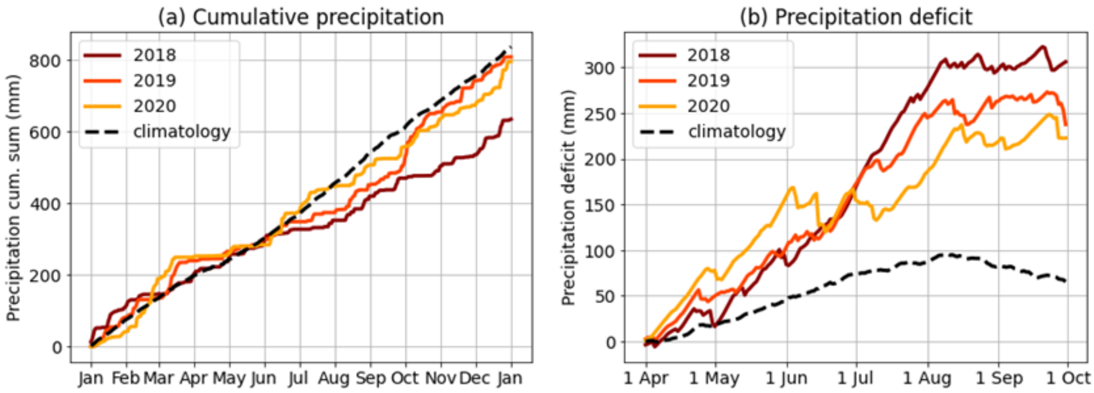


Figure 22: Meteorological data in the region with (a) cumulative precipitation for the climatology (1992-2021), and the dry years 2018, 2019 and 2020, based on KNMI data from seven stations: Almelo, Denekamp, Enschede, Hengelo, Tubbergen, Twente and Weerselo, and (b) precipitation deficit for the same periods, using reference ET data (Makkink) from the KNMI stations Heino, Hoogeveen, Hupsel and Twente.

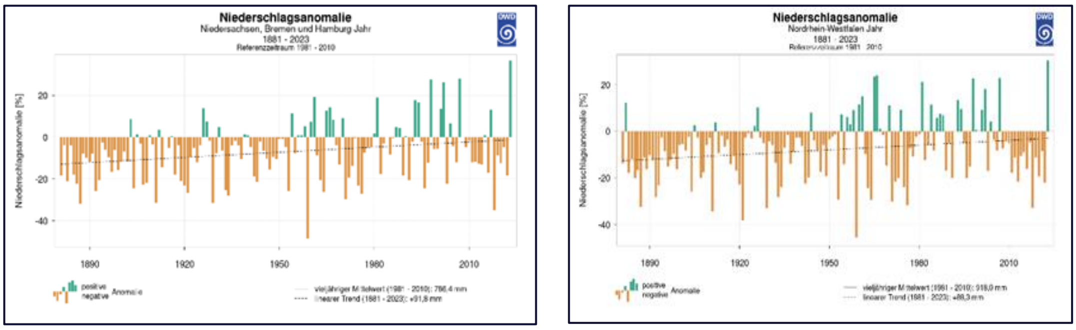


Figure 23: overview of precipitation anomalies, both positive (green) and negative (orange), from 1881 to 2023, including the average and linear trend in Lower Saxony (left) and North Rhine-Westphalia (right)

Table 4: Climatic water balance in the growing season (klimatische Wasserbilanz in der Vegetationsperiode, KWB), April-September for Itterbeck (Landwirtschaftskammer Niedersachsen)

year	**Climatic water balance in the growing season (KWB), April-September for Itterbeck**
2018	- 483 mm
2019	- 332 mm
2020	- 209 mm
2021	+ 69 mm
2022	-256 mm

The long-term average (12 years) in the Twente region shows the normal effects of the precipitation deficit and winter ‘refill’ of soil moisture. For the three selected years, soil moisture dropped to critical values, particularly in the growing season. The year 2019 started with a significant difference from normal, because winter precipitation was insufficient to nullify the precipitation deficit in the preceding growing season.

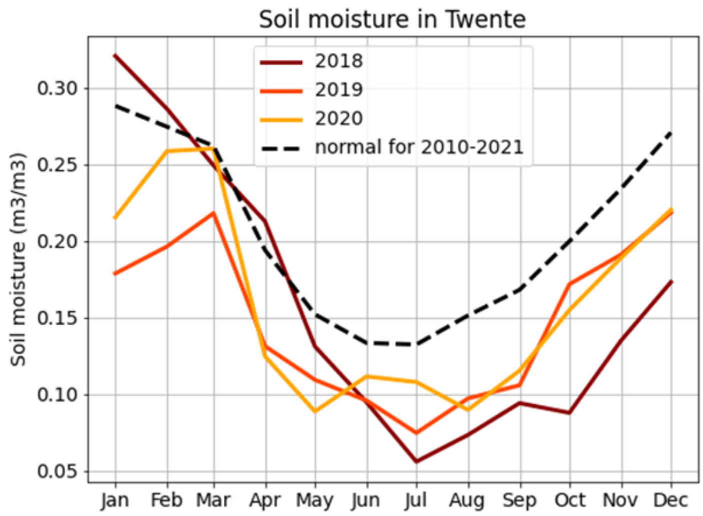


Figure 24: Moisture in the topsoil (0-10 cm) in the Twente region - averaged data from 17 stations. The dry years 2018, 2019 and 2020 are shown with the 12-year period normal. Dataset is described by Van der Velde et al. (2023).

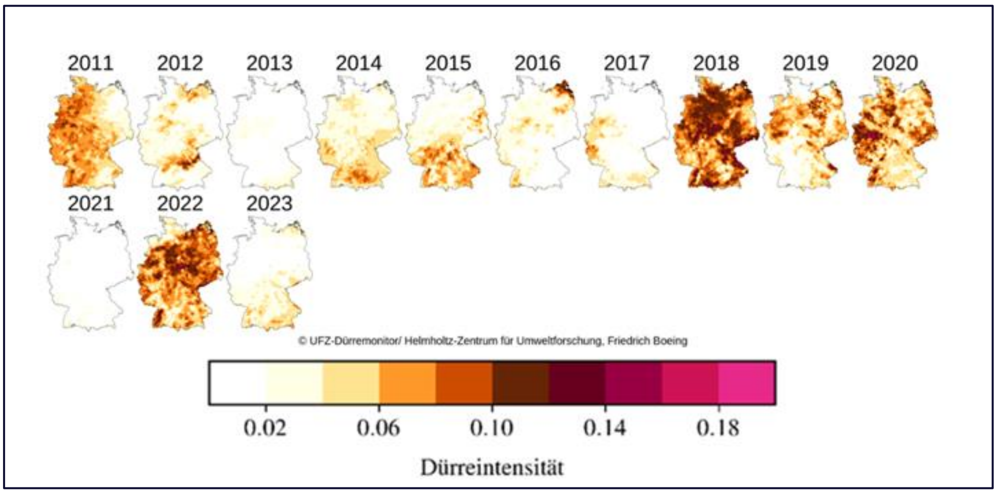


Figure 25: Drought intensity[6] of the topsoil (0-25cm) in the growing season April to October in Germany over the last years (UFZ, 2024).

In North-Rhine Westphalia and Lower Saxony, the topsoil layers up to a depth of 25 centimeters were very dry almost everywhere in 2018, 2019, 2020 and 2022 (see Figure 25). Soil moisture droughts lead to decreased groundwater levels over time, which in turn lead to reduced recharge of ditches, streams and larger water bodies. After a meteorological drought has ended, first the soil moisture content recovers, then groundwater levels and surface water bodies (Projectteam Droogte Zandgronden Nederland, 2021). Figure 26 shows the widely used standardized

[6] Drought intensity is a dimensionless measure used to estimate the severity of a drought over a certain period of time or for a certain region. The length of the drought period and the absolute drought over time are included in the calculation (UFZ, 2024)

groundwater index (SGI) (Bloomfield & Marchant, 2013) to indicate groundwater drought on August 1 for the years 2018, 2019, 2020 and the reference year 2023. The SGI compares the current groundwater level with the average groundwater level based on historical data (usually 30 years). Negative and positive values indicate unusual dry and wet situations, respectively (Van Huijgevoort et al., 2022). This figure shows that for July, the groundwater droughts were extreme in 2018, very dry in 2019 and somewhat to moderately dry in 2020 in the study area.

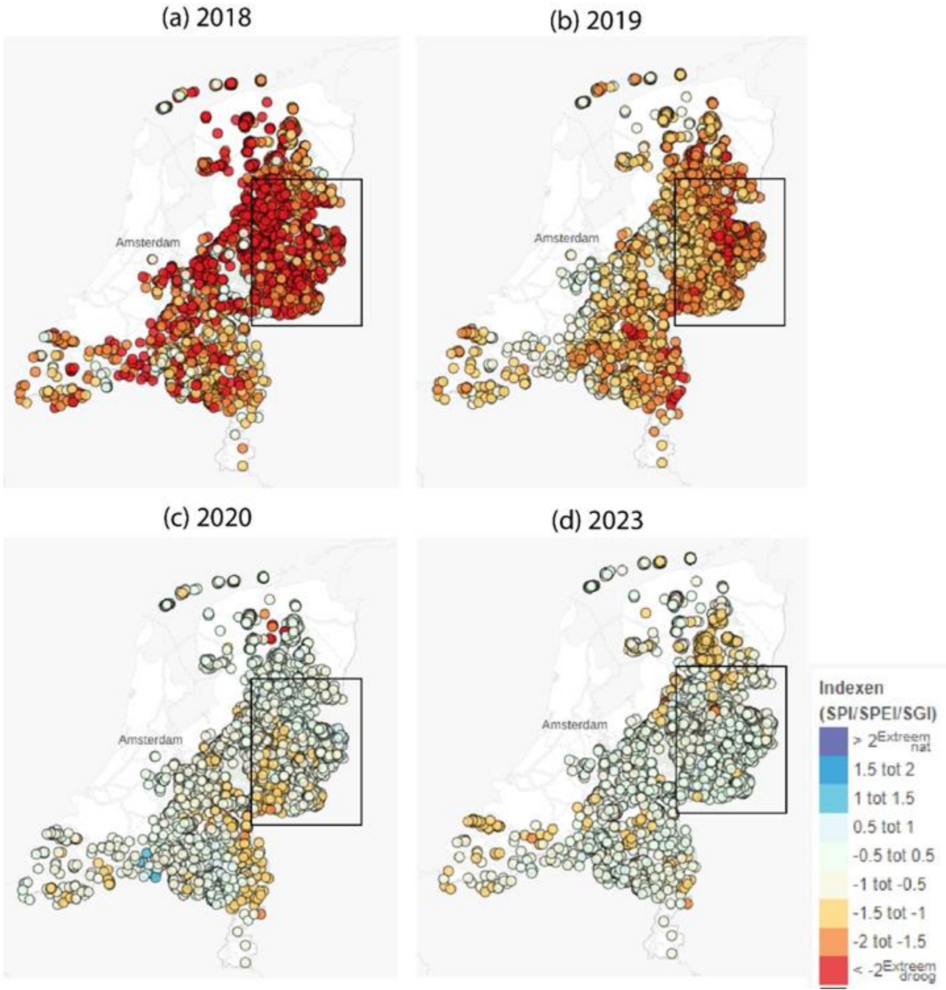


Figure 26: Standardized Groundwater Index based on a 1-month window (SGI-1) for August 1, for the Netherlands. The study area is located within the box (IPO & UVW, 2024).

Figure 27 shows the SGI-3 (3-month window) time series for the city of Enschede. Figure 27 and Figure 28 show a decreasing trend for groundwater recharge in Enschede, Netherlands as well as for Lower Saxony. The groundwater droughts of 2018, 2019, and 2020 are clearly visible. Also, the occurrence of wet conditions decreased since 2018.

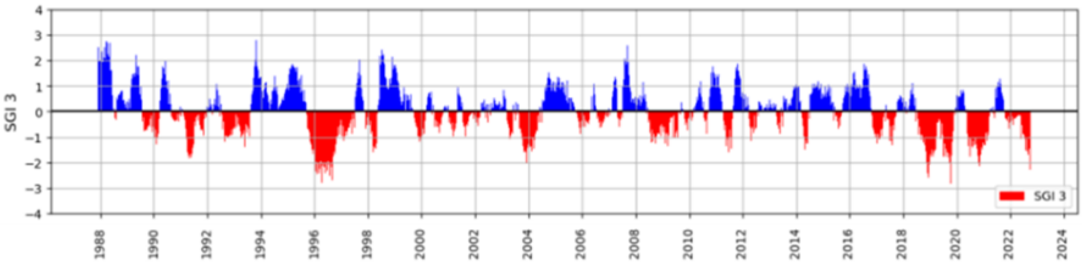


Figure 27: Standardized Groundwater Index based on 3-month window (SGI-3) time series for Enschede (Kremer Devesa, 2023).

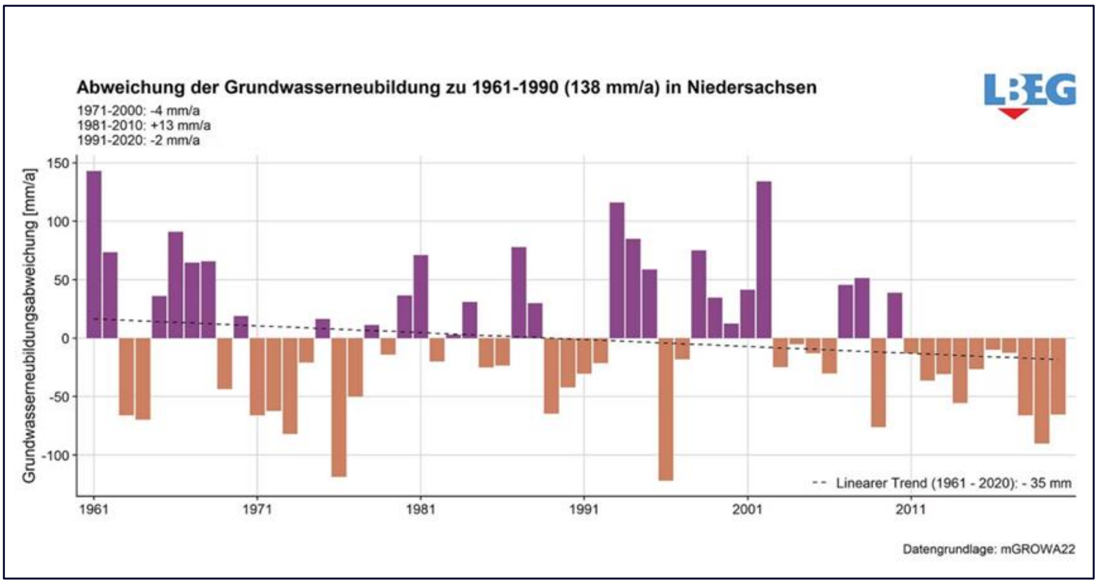


Figure 28: Deviation in groundwater recharge compared to 1961 - 1990 (138 mm/a) in Lower Saxony, Germany (LBEG, 2023)

The project team Drought (2021) calculated the local drainage (i.e. originating from local precipitation and seepage) for different Dutch regional water authorities using the 'Landelijk Hydrologisch Model (LHM)' (English: National Hydrological Model). They found that local summer drainage was lower in 2019 compared to 2018 for the regional water authorities in the study area. This means that the lag-effect of 2018 in combination with the meteorological drought in 2019 caused lower drainage in 2019. Figure 29 shows the local drainage for regional water authorities Vechtstromen and Rijn and IJssel and specifically compare the 2018 drainage with the 90th percentile bandwidth of 1988-2017. From July onwards, the 2018 drainage falls below the 90th percentile bandwidth. Although the drainage does not reach zero, local streams have dried up (Projectteam Droogte Zandgronden Nederland, 2021).

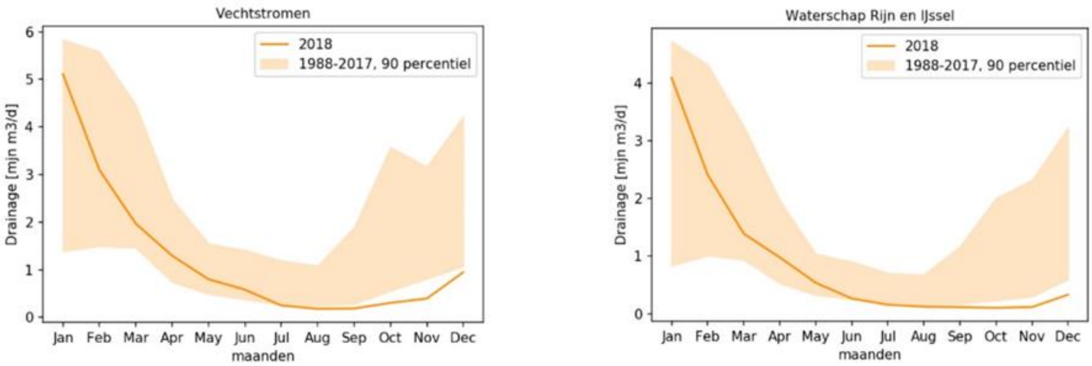


Figure 29: Local drainage from regional water authorities Vechtstromen and Rijn and Ijssel based on the LHM model, comparing 2018 with the 90% bandwidth of the climatology (Projectteam Droogte Zandgronden Nederland, 2021).

The catchments of the Vechte, Berkel and Oude IJssel largely overlap the 'oostelijk zandgebied' (Eng: eastern sand area) in Van Asseldonk et al. (2020). They studied the economic impact of the droughts of 2003, 2006, 2018 and 2019, compared to the surrounding years in the period 2001-2019. For almost all crops, there was less crop yield in the 'oostelijk zandgebied' as a result of dry weather. The two dominant crops in this area, grass and maize, yielded 14 and 18 percent less 'dry matter', respectively compared to normal years. Irrigation effects are included in these calculations. The northern part of the Vechte basin is part of the 'noordelijke zandgebieden' (Eng: northern sand areas), for which the following changes in yield were found: grass -8%, maize -8%, potato (seed) -6%, potato (starch) -13%, sugar beet -9%, barley +4%, and wheat +1% (Projectteam Droogte Zandgronden Nederland, 2021).

However, annual incomes are not only based on yield, but also on market prices, which are determined on European or global level. Extremely variable annual incomes were found for the studied dry years (see Table 5).

Table 5: Percentage changes in annual incomes for dry years compared to 'normal' years. Based on (Asseldonk et al., 2020).

	2003	2006	2018	2019	Average
Arable (eastern, central and southern sand)	11	4	50	-14	13
Arable (northern sand and peat)	-5	-1	-55	-73	-34
Dairy cattle (eastern sand)	-27	-8	-8	22	-5
Dairy cattle (northern sand)	-33	-10	9	60	6

Water use

Total agricultural water use increases as a result of droughts. The source of this water is either groundwater or surface water. In addition, in the period between 2001 and 2019, both the percentage of farms that irrigated and the irrigated area per farm have gradually increased. This is probably due to smaller farms without irrigation systems being replaced by larger companies with irrigation capacities. Total water use for the relevant areas is summarized in Table 6. Van Asseldonk et al. (2020) based their numbers on *bedrijveninformatienet* (Eng: business information network) of *Wageningen Economic research*.

Table 6: Water use in million m3 for dry years in the period 2001-2019. Based on Van Asseldonk et al. (2020).

	2003	2006	2018	2019
Arable (eastern, central and southern sand)	5	<1	19	19
Arable (northern sand and peat)	5	4	12	16
Dairy cattle (eastern sand)	10	7	18	22
Dairy cattle (northern sand)	<1	3	5	8

Impact on nature

Although little is reported about the effects that the droughts of recent years have had on the specific nature areas in the study area, we know in general that nature in the area is suffering from droughts. The types of nature that are most vulnerable to droughts – e.g. fens, high peat, heath, moist forest, rough pastures with standing water, streams (Jansen et al., 2020)- all exist in the area. These types of nature are already suffering from gradual desiccation due to human-induced falling groundwater levels for over a century, mainly in favour of agriculture (see Chapter 2.4). Many of these types of nature depend on higher groundwater levels. Droughts such as those of 2018-2020 and 2022 can lead to changing hydrological processes, changes in water and soil chemistry, loss of biodiversity and changes in the food chain (Jansen et al., 2020). Van den Eertwegh et al. (2021) acquired survey-based information on the effects of 2018-2019 droughts on nature in the high sandy areas of the Netherlands. Respondents confirmed the patterns described by Jansen et al. (2020). Damage to fauna and flora was mainly observed for nature types characteristic of wet and humid nutrient-poor locations. These are nature types that are almost or completely dependent on precipitation or seepage for their water supply. In addition, the drought would exacerbate the ecological consequences of atmospheric deposition: drought and acidification would be a toxic mix. In 2019 due to a heat period, the oxygen level in the Vechte (Nordhorn) was between 2,0 and 3,8 mg/l which can be critical for some fish populations as shown in Figure 30 (Grafschafter Nachrichten, 2019). Also, in the years 2022 and 2023 the dry periods effected the river systems causing low water levels and dry soil as shown in the pictures below. However, van den Eertwegh et al. (2021) and Witte (2022) concluded that ultimate consequences of the recent droughts can only be determined in a few years' time through a thorough analysis. The expected long-term effect is an increase in the nutrient richness of wet and humid soils due to increased decomposition of organic material and acidification of the soil, as a result of that decomposition and the disappearance of base-rich seepage. This will result in the decline of less common species, due to competition between species (Witte, 2022).

Figure 30: up left: Too low oxygen content in waters damages fish stocks (Grafschafter Nachrichten, 2019)*; up right: low water level of the Vechte (Neue Vechte) in Metelen* (Westfaelische Nachrichten, 2022)*; down: plants suffer from dry soil* (NDR, 2023)

4 Institutions, arrangements, and planning

4.1 Germany

4.1.1 Water management

In Germany, concurrent legislation exists regarding water resources governance and management between the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), located at the two ministerial sites in Berlin and Bonn, and the environmental ministries of the federal states.

In order to implement the EU WFD (Water Framework Directive) and FRMD (Flood Risk Management Directive), the federal entity passed the Water Act (Wasserhaushaltsgesetz, WHG), which came into force in 2010. The federal states subsequently needed to detail the enforcement of the WHG and the EU directives for their territories. Hence, the state of Lower Saxony adopted the new Lower Saxon Water Law (Niedersächsisches Wassergesetz, NWG) in 2012, while in North-Rhine Westphalia the State Water Law (Landeswassergesetz, LWG) was continuously amended and exists in a revised version since 1995.

Apart from the federal and state laws, the federal republic passed several ordinances which organise certain requirements of the EU directives (compare Table 7), e.g., the categorisation, typification and delineation of surface water bodies according to the requirements of the WFD is detailed in the Surface Water Ordinance (Oberflächengewässerverordnung, OGewV).

Table 7:Overview of laws, ordinances, plans and guidelines on the European, national and federate state levels relevant for water resources, flood risk and drought management in Germany. Source: own elaboration

<table>
<tr><th></th><th></th><th>Water resources management</th><th>Flood management</th><th>Drought management</th></tr>
<tr><td>EU</td><td></td><td>Water Framework Directive (WFD)</td><td>Flood Risk Management Directive (FRMD)</td><td></td></tr>
<tr><td></td><td></td><td>Groundwater Directive (GWD)</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Habitats Directive</td></tr>
<tr><td></td><td></td><td colspan="3">Birds Directive</td></tr>
<tr><td>Germany</td><td></td><td colspan="3">Water Resources Act (WHG)</td></tr>
<tr><td></td><td></td><td colspan="3">National Water Strategy</td></tr>
<tr><td></td><td></td><td colspan="2">Federal Waterways Act (WaStrG)</td><td></td></tr>
<tr><td></td><td></td><td>Surface water Ordinance (OGewV)</td><td>Flood Protection Act II (2. HochwSchG)</td><td></td></tr>
<tr><td></td><td></td><td>Groundwater Ordinance (GrwV)</td><td colspan="2">Federal Soil Protection Law (BBodSchG)</td></tr>
<tr><td></td><td></td><td colspan="3">Federal Nature Protection Law (BNatSchG)</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Ordinance on soil protection and contaminated lands (BBodSchV)</td></tr>
<tr><td></td><td></td><td>LAWA Guidelines</td><td>LAWA Guidelines</td><td></td></tr>
<tr><td>Federate states</td><td>Lower Saxony</td><td>Lower Saxony Water Law (NWG)</td><td colspan="2">Lower Saxony Soil Protection Act (NBodSchG)</td></tr>
<tr><td></td><td></td><td colspan="3">Lower Saxony Nature Protection Law (NNatSchG)</td></tr>
<tr><td></td><td></td><td>Ordinance on Responsibilities in the Field of Water Law (ZustVO-Wasser)</td><td>Lower Saxony Dike Act (NDG)</td><td></td></tr>
<tr><td></td><td></td><td>Circular on the quantitative management of groundwater</td><td>Flood Damage Waterways Ordinance (HochwasserVO NI)</td><td></td></tr>
<tr><td></td><td></td><td>Lower Saxony's contribution to the management plans and programmes of measures 2022 to 2027 for the Elbe, Weser, Ems and Rhine river basins</td><td>Circular on the designation of floodplains</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Permanent Grassland Maintenance Ordinance (DGL-ErhV NI)</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Erosion control regulation (ESchV NI)</td></tr>
<tr><td></td><td></td><td></td><td>Flood hazard maps and flood risk maps</td><td></td></tr>
<tr><td></td><td>North-Rhine Westphalia</td><td>State Water Law (LWG)</td><td>Flood risk management plan of the River Basin Community Rhine</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Flood risk management and Water Framework Directive funding guideline (FöRL HWRM/WRRL)</td></tr>
<tr><td></td><td></td><td colspan="3">State Nature Conservation Act (LNatSchG NRW)</td></tr>
<tr><td></td><td></td><td>Management plan and programmes of measures for the Rhine, Weser, Ems and Meuse river basins in NRW</td><td colspan="2">State Erosion Protection Ordinance (LESchVO NRW)</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Permanent Grassland Maintenance Ordinance (DGL-VO NRW)</td></tr>
<tr><td></td><td></td><td></td><td>Flood hazard maps and flood risk maps</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Flood risk management plans and measures for the municipalities</td><td></td></tr>
</table>

Legend: Laws and Directives | Ordinances | Plans, maps and guidelines

Water management in Germany is organized on different levels. While the federal BMUV details basic aspects through the WHG, the implementation and enforcement of legislation is the duty of the federal states. North Rhine Westphalia operates with a distribution of responsibilities on three levels, while in Lower Saxony the middle administrative level was abolished in 2005 and therefore only two levels exist (see Table 8, and Annex D explaining the responsibilities of the organizational levels).

In order to coordinate a uniform approach on joint water management and water law issues, the Federal/State Working Group on Water (Bund-Länder Arbeitsgemeinschaft Wasser, LAWA) was initiated in 1956 as a working group of the Conference of Ministers of the Environment (Umweltministerkonferenz). For example, in its responsibility in the LAWA, representatives of the federal states decided on a joint approach to review and update the preliminary risk assessment regarding the FRMD in 2017 (MU, n.d.). While in the first management cycle each federate state elaborated their own Flood Risk Management Plans, the river basin community Rhine coordinated the Flood Risk Management (FRM) Plan for the entire area. For the River Basin Management Plans, there is no coordinated planning between federate states.

Table 8: Overview of responsibilities of water authorities and technical authorities in North Rhine Westphalia and Lower Saxony (own elaboration based on BMUV, 2023, MUNV 2014, 2021, NWG 2011, ZuStVO-Wasser Lower Saxony 2014).

Federate state	**North Rhine-Westphalia**	**Lower Saxony**
Highest water authority	Ministry of the Environment, Nature Conservation and Transport	Ministry of the Environment, Energy and Climate Protection
Technical authority	State Agency for Nature Conservation, Environment and Consumer Protection (LANUV)	Lower Saxony Water Management, Coastal and Nature Protection Agency (NLWKN)
Higher water authority	Governmental district of Münster and Düsseldorf	
Lower water authority	Districts of Borken and Steinfurt	District of Grafschaft Bentheim
Municipalities	District of Münster: Aahaus, Altenberge, Billerbeck, Bocholt, Borken, Coesfeld, Gescher, Gronau (Westphalia), Heek, Isselburg, Laer, Legden, Ochtrup, Rhede, Rosendahl, Stadtlohn, Steinfurt, Südlohn, Velen, Vreden, Wettringen	Samtgemeinden Emlichheim, Uelsen, Schüttorf; Cities Neuenhaus, Nordhorn, Bad Bentheim; Municipality Wietmarschen

	District of Düsseldorf: Hamminkeln, Huenxe, Reed, Schermbeck, Wesel	
Maintenance Association	Maintenance Association lower Dinkel area	Vechteverband, smaller maintenance associations (e.g., Hardinger Becke, Rammelbecke)

During the interviews, the NLWKN pointed out that, although there are common objectives for drought risk management and WFD, in Lower Saxony currently only measures on single-topic project basis are planned or implemented, which means chances of synergy are missed. Such projects include the water retention via infrastructure (e.g.bulkheads) rather floodplain restoration (e.g. connecting oxbow lakes, remeandering), which is more space-intensive.
The possibilities to create synergies between WFD implementation, drought and flood risk management, as well as nature protection are addressed in the programme "Niedersächsische Gewässerlandschaften" (Lower Saxon water landscapes). The programme aims to overcome known implementation deficits like making sites available, as well as coordinated and harmonised use of funding measures. The programme also factors in the effects of climate change and works towards adaptation. Measures are prioritised in floodplain areas with priority status according to WFD, areas with protective status according to nature protection programmes, and areas for which action is required regarding flood risk management. Interestingly, none of the interviewees of the Lower Saxon water authorities and implementing bodies mentioned this programme, even though the head of the lower water authority responsible is at the same time the head of the nature protection department. The aims of the programme are strengthened through the Lower Saxon nature conservation strategy (MU, 2017).

In North Rhine-Westphalia, WFD implementation prioritises measures with 'Strahlwirkung' (freely translated: assumed positive effect as a result of nearby measures), implying a higher impact reach, particularly in biological aspects. These measures are critical in improving the ecological conditions of water bodies in the region. Due to urban development around Gronau and the presence of high plains, it is impossible to establish a core area (source of 'Strahlwirkung') for the WFD within Germany. However, a study by Arcadis-Keulen has demonstrated that establishing such a core area just across the border in the Netherlands could fulfil Germany's WFD obligations. This approach could be integrated into the Losser Zuid sub-project of the

Province of Overijssel/Regional Water Authority Vechtstromen, benefiting from financial contributions from various cross-border entities as part of the LIVING Vechte-Dinkel project.

According to the Ministry of the Environment, Nature Conservation and Transport NRW, achieving the goals for all water bodies within the current management cycle is not anticipated (MUNV NRW, 2023). For the majority of water bodies, deadlines have been extended to 2033 or 2045. The primary reasons for these extensions are the disproportionate efforts required regarding biological aspects or natural conditions, or a combination of both. Kooij et al. (2020) state that funding projects in North Rhine-Westphalia is not a significant issue, as the state finances 80-90% of WFD measures if the specified conditions are fulfilled. Eco-Point co-financing[7] by districts and cities, almost full funding can be achieved.

Maintenance of other watercourses, like streams, is carried out by numerous maintenance associations (29 just in the Borken district).
Maintenance associations in NRW are small and fragmented compared to counterparts like the Vechteverband in Lower Saxony or a regional water authority in the Netherlands. As they are still responsible for implementing WFD measures, enhancing their capacity and capability is vital. Since 2016, the responsibility for implementing WFD in the Dinkel catchment has been with the Münster District Government. Ongoing projects from previous periods initiated by districts continue under their management. Municipalities are responsible for implementing WFD for other water bodies. In the Borken district, this responsibility has been transferred to maintenance associations. However, due to their small size, cities and communities are also involved in WFD implementation. Flood protection responsibility primarily lies with the municipalities.

In conclusion, while funding is largely secured in NRW, the main challenges lie in organizational capacity and cross-border collaboration. Enhancing the effectiveness of small local associations and integrating them into broader initiatives is crucial for successful water management and meeting WFD obligations.

[7] Eco-Points can be acquired by restoring biotopes and are regulated with the German Nature Protection Law. They furthermore are a means to balance out negative impacts of constructions that destroy valuable habitats.

4.1.2 Flood risk and disaster management

Floods are considered only since 2010 in the German Water Act (Wasserhaushaltsgesetz, WHG) (Hartmann & Albrecht, 2014). While the WHG defines the responsibilities and administrative preparations for flood risk management generally, the water laws of the federate states outline further details. The regulation outlines particularly the reporting and planning duties. It outlines land use restrictions for flood plain areas but does not define a protection level. Each local authority must largely determine the level of flood protection in its area within the framework of municipal self-administration.

The implementation of the Flood Risk Management Directive (FRMD) in Germany initially involved a provisional risk assessment in the first cycle (2010-2015) based on available or easily derivable information. The identification of hazard areas for inland waters was carried out using the watercourse delineation for flood hazard mapping.

In March 2017, the Federal/State Working Group on Water (LAWA) adopted a unified approach for reviewing and updating this preliminary risk assessment in the second cycle. According to LAWA recommendations, the risk areas from the first cycle serve as the basis for the review and update in the second cycle. This involves examining the flood-prone watercourse network for changes since the last assessment, followed by a review of the remaining watercourse network outside the risk areas.

The Flood Protection Act II (FPA II) was passed in June 2017, informed by experiences from the 2013 European flood event, which led to severe flooding along the Elbe and Danube River. This legislation affected provisions of the Water Act (WHG), the Building Code (BauGB), the Federal Nature Conservation Act, and the Administrative Court Procedure Act. It grants states, among other things, the pre-emptive right to purchase land necessary for flood protection. The BauGB grants municipalities the pre-emptive right to purchase land in flood-prone areas and obliges them to consider flood protection issues in urban development planning.

The Regional Planning Act (ROG) and state planning laws regulate spatial planning in Germany. With the FPA II, there is now the possibility of creating a federal spatial plan for flood protection. The "Regulation on Spatial Planning at the Federal Level for Cross-State Flood Protection" came into effect on September 1, 2021, and a key goal is the preservation and restoration of natural flood retention areas within the framework of preventive flood protection spatial planning.

Lower Saxony issued the Masterplan Flood Protection (NLWKN, 2021b) and inaugurated the Competence Centre for Floods (Hochwasserkompetenzzentrum) in 2020 as a reaction to the increased occurrence and impact of floods. The Masterplan is dedicated to actors responsible for technical flood protection.

Due to the catastrophic flood in July 2021 in southern NRW, the state sped up on its flood risk management tasks. As a result, the Ministry of the Environment, Nature and Transport of the State of North Rhine-Westphalia published a 10-point work plan for flood protection in times of climate change in 2022 with the goals containing the introduction of model-based flood forecasting systems for the Dinkel, Berkel, Oude Ijssel and others (test operation in 2022) and the upgrade from hydrological to flood warning gauges. The Ordinance on the Flood Information and Reporting Service from October 2023 contains that the Ministry responsible for the Environment shall be authorised, in agreement with the Ministry of the Interior, to make regulations by statutory order on information about and reporting of floods, in particular on the obligation of persons to participate in the flood reporting service, its organisation and the reporting channels as well as on the warning of floods.

The administrative setting varies between the federate states (see Table 8). With the administrative reform in Lower Saxony in 2005, the tasks of flood (risk) management were distributed between the NLWKN and the lower water authorities. For the Rhine River basin, the 'river basin community Rhine' ('Flussgebietsgemeinschaft Rhein') elaborated a common management plan for the second period. The NLWKN participates in drafting the flood risk management plans for the river basins and organises the delineation of flood risks and hazards, while in NRW the governmental district Münster (Bezirksregierung) is in charge of these tasks. The lower water authorities establish the flood plain areas based on the plans and issue an ordinance that regulates land use in these areas. In both federate states, the municipalities are in charge of identifying measures to manage flood risks. In NRW the municipalities report uniformly on the identification of measures within the municipal fact sheets on the flood risk management plan (Flussgebiete NRW). In Lower Saxony, knowledge on the implementation of measures is decentral and often informal. Actors are asked to report the measures that they plan or implemented, but they are not required to do so (NLWKN, 2015).

Generally, flood risk management is less well coordinated in Lower Saxony than in NRW. In the interviews, actors highlighted that through the abandonment of the district government, no coordinative role for flood risk management exists. To fill the void, the MU together with the NGO Kommunale Umwelt-AktioN initiated Flood Partnerships. In such partnerships, municipalities, associations, and other stakeholders within a watershed collaborate for flood protection, which entails technical flood protection, flood prevention, natural water retention, floodplain protection, and protection against heavy rainfall. Collaboration allows for exchange and provides a platform for ongoing education. Cooperative agreements outline goals and work, often beginning with the development of a flood protection concept. Lower Saxony supports these partnerships by offering technical advice and funding opportunities according to the funding guidelines for inland flood protection. The coordinative, advisory and informative role of the lower water authorities (Districts of Steinfurt, Borken and Bad Bentheim) was repeatedly highlighted during the interviews. Their possibility to directly influence the municipalities in implementing flood risk management planning are hence limited.

During the interviews, several actors stated that flood risk management has been neglected in the past years in Lower Saxony as well as North Rhine-Westphalia. Therefore, the lower water authority the district Grafschaft Bentheim established a funding stream for flood control structures. Although not many applications have been filed yet, the interviewees anticipate an increase in due time. For NRW, funding is organized on state level with a dedicated funding guideline. However, one of the main challenges for the implementation of flood risk measures is the limited space availability. As there has been no damaging floods in the region in the near past, the willingness to cede land is low (Governmental district Duesseldorf).

Regarding dedicated dikes, responsibility typically lies with dike associations or other maintenance associations, unless the state has jurisdiction. These entities are responsible for dike maintenance and must ensure preparations for dike defence, including maintaining accessible paths, providing necessary equipment and materials, and always ensuring dike accessibility.

Disaster management

Disaster management in Germany outside of wartimes is a task of the Federal States. Hence, the approaches differ between Lower Saxony and NRW. However, the States may request additional assistance by police forces of other federal states, forces and organisations of other administrations, such as the Federal Agency for Technical Relief (THW), the Federal Police or the armed forces (BMI, n.d.).

Under the German Water Act (WHG), every individual who may be affected by floods is obligated, to the extent feasible and reasonable, to take suitable precautionary measures to protect against adverse flood effects and mitigate damages. This includes adapting land use to potential adverse consequences of floods on people, the environment, or property. Only if these measures are insufficient, flood defense becomes a community task.

Lower Saxony
Flood forecasts are issued via the Hochwasservorhersagezentrale (HWVZ) in Lower Saxony. The HWVZ operates as a statewide flood forecasting center and provides crucial flood information for local authorities, businesses, and the public through various platforms. Established in 2009, it calculates flow and water level forecasts for inland gauging stations. Its activities focus on regions prone to river floods, amongst them the Vechte. The HWVZ relies on a diverse data foundation, obtaining hydrological and hydrometeorological data from multiple sources (NLWKN, Deutscher Wetterdienst DWD, Harzwasserwerke GmbH, Wasser- und Schifffahrtsverwaltung WSV). It utilises a high-resolution hydrological model (Panta Rhei) and incorporates weather forecasts for predictions. However, uncertainties, such as sudden heavy rainfall, can affect forecast accuracy. Close collaboration with stakeholders, including flood reporting services, water management authorities, and meteorological services, is vital.
The municipalities are responsible for organizing the flood emergency response during regular floods (Act on Public Safety and Order (SOG) and the Lower Saxony Municipal Constitution Act (NKomVG), NLWKN, 2015). They rely on voluntary support services like the fire brigade or the Red Cross. Municipalities take on the alarm and deployment planning, organisation of resources (e.g. sandbag storage), exercises and the training of personnel (Flasche, 2016). An additional measure to support the emergency forces during the drought is the establishment of a 'water defense' (NWG § 132), a network of fire brigades, municipalities and dike associations. However, this is not yet applied in Lower Saxony (NDR, 2024).

Disaster control is regulated in Lower Saxony by the Disaster Control Act (NKatSG), which assigns the control responsibilities to the districts and independent cities (disaster control authorities). For the Vechte area, the disaster control authority is the district Grafschaft Bentheim.

In case the district administrator declares the state of emergency, the disaster control authorities take on responsibility. There is no fixed protocol as to what is to be considered an emergency situation. However, in the interviews actors mention that a dike breach or size of the affected area or the number of affected municipalities respectively are factors for this decision. The disaster control authorities are tasked with preparing necessary measures for disaster control in their respective areas and assessing potential disaster threats. The disaster control authority is required to establish a disaster control plan for its jurisdiction, including external emergency plans and special plans for specific hazards such as floods or storm surges, which must be continuously updated. The plan outlines the alerting process, immediate measures in case of a disaster, and the deployment of personnel and resources. The plan is submitted to the competent police directorate (as the supervisory authority) and neighbouring disaster control authorities (for more information on the responsibilities of the disaster control authorities see (NLWKN, n.d.-b).

North Rhine-Westphalia

In North Rhine-Westphalia, the State Agency for Nature, Environment and Consumer Protection (LANUV) takes over the task of determining the basic data for water management and operates the flood information service. Hydrological data are collected, stored, validated, processed and made available through the operation of watercourse or flood gauges as well as precipitation and climate measuring stations. If defined water levels (‘information values’ 1 – 3; not related to the annual flood discharge but only descriptive: value 1 = "first outburst flood", value 2 = “Danger of flooding of individual developed properties or infrastructure facilities”, value 3 = “Risk of flooding of built-up areas or infrastructural facilities on a larger scale”) are exceeded at the LANUV flood gauges in North Rhine-Westphalia, the affected municipalities as well as other responsible public agencies are notified of the level exceedance. The information is additionally published on the Internet in the form of a hydrological situation report of the LANUV as well as the Data (Hochwasserportal). If threshold values are exceeded at flood gauges on the watercourses, the responsible authorities start the active reporting service. From this point on, protection and defense measures are the responsibility of the relevant authorities, such as fire departments and on-site civil protection.

The flood disaster in 2021 in NRW has shown that efforts to protect against flooding and heavy rainfall must be increased, including the implementation of the measures in the municipal profiles. The water management administration has so far tried to promote implementation through symposia on flood risk management planning, information brochures and public relations work as well as exchanges with the municipalities during the development process for the flood risk management plan. For example, funding for the implementation of flood protection measures is to be increased and hydraulic engineering measures for flood protection are to be subsidized by up to 80 percent if public areas are affected.

It is also being examined whether a 'climate surcharge' can be applied when determining flood areas. In addition, municipal and regional heavy rainfall concepts and the implementation of measures identified in these concepts are to be examined. Irrespective of the requirements of the EC Floods Directive, the floodplains of water bodies at risk of flooding are calculated in North Rhine-Westphalia and established or provisionally secured by ordinance. The basis for the calculation is a flood event that is statistically expected to occur once every 100 years (HQ100). The designation of floodplains is one of the strategic precautionary measures in flood protection with direct effects under planning law, such as restrictions on the designation or expansion of municipal building areas. This task remains a legal obligation - irrespective of the EC Floods Directive - and is carried out by the district governments. In case of flood events that statistically occur less frequently than every 100 years (HQextreme), the municipalities situated in the regarded river basins are in charge of disaster management (i.e. Ahaus, Altenberge, Billerbeck, Bocholt, Borken, Coesfeld, Gescher, Gronau, Hamminkeln, Heek, Hünxe, Isselburg, Laer, Legden, Ochtrup, Rees, Rhede, Rosendahl, Schermbeck, Stadtlohn, Steinfurt, Südlohn, Velen, Vreden, Wesel, Wettringen).

4.1.3 Drought risk and disaster management

In Germany, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection is responsible for regulating requirements for integrated water management. The Federal Ministry of Food and Agriculture is responsible for economic instruments for subsidisation of crops resistant to heat. The Federal Ministry for Digital and Transport responsible to ensure safe and smooth navigation on federal waterways and reliably calculable transport conditions, even in the event of frequent climate change-related extreme low-water periods (Kampa & Rouillard, 2023). Several laws and measures are not specifically aimed at dealing with drought but contain sections with this focus as well as instruments to minimise drought impacts:

1. Water Resources Act (WHG): The Water Resources Act is the central law in Germany that regulates water management. It contains provisions on sustainable water use, protection against water shortages and ensuring an adequate water supply. In times of drought, the lower water authorities are authorised to take measures for ensuring a fair distribution of water resources.
2. State water laws: The federal states implement the WHG in state water laws (Lower Saxon Water Law (NWG) and State Water Law

NRW (LWG)). These laws contain specific regulations for the management of water resources at the state level. During dry periods, special regulations and restrictions can be imposed to protect water reserves.

Table 7 provides a detailed overview of laws and guidelines at the various state levels. Laws and ordinances that focus on the maintenance of the water retention capacity of the soil are not specifically addressed to droughts, but support a sustainable water balance (i.e., soil protection laws/ordinances, ordinances to maintain grassland, nature protection laws). Furthermore, rural development programmes and agri-environmental measures therein as well can support the maintenance of a natural water balance by encouraging farmers to implement sustainable practices that help address drought (e.g., moor-conserving damming, permanent conversion of arable land to grassland, creation of riparian buffer strips).

Until a few years ago, the drought risk and the probability of negative impacts arising from droughts, did not get much attention in Germany and compared to floods, the effects of drought are still difficult to quantify (Blauhut & Stahl, 2018). In the recently published National Water Strategy (BMUV, 2023), water scarcity is acknowledged amongst the occurring and future challenges, especially after the drought years of 2018, 2019, 2020 and 2022. Due to the current framework conditions, such as the consequences of the climate crisis, it will be necessary in the future to develop solutions to prevent competition for use and conflicting goals over water resources, as in the national water strategy. For example, the strategy envisages implementing a uniform definition of core variables for low water and water shortages, including droughts, in the short term (BMUV, 2023, p. 85). The issue of drought is mentioned in some other actions in the national water strategy as well.

The German Working Group on Water Issues of the Federal States and the Federal Government (LAWA) is the central platform for the coordination of all related activities. The Working Groups of the LAWA have elaborated numerous strategic documents relating to drought and water scarcity, for example "Impacts of Climate Change on Water Management" (LAWA, 2020) or "Dealing with conflicting goals when adapting water management to climate change" (LAWA, 2022). These guidelines aim to support decision and policymaking in the federal states, they are not binding.

As of today, there are no concrete approaches to drought management mentioned by the National Water Strategy or LAWA. One reason for this may be that the direct effects of droughts are less visible than those of floods, and do not threaten the existence of the German population yet

(Blauhut & Stahl, 2018). Although there is widespread awareness of a future increase in drought risk after the extreme drought years of 2018 and 2019 in Europe, drought is often not yet considered a risk in Central, Northern and Eastern Europe (Blauhut et al., 2022). During the interviews carried out in this study, it became clear that the need for a transboundary drought risk management is still largely unmet.

Administrative structures tend to talk about low water levels and dry periods not droughts (e.g., interviews within this project as well as the National Water Strategy apply this framing). Structures within authorities dealing with droughts are just being developed. So far there is no regulation in Germany that comprehensively and explicitly deals with the drought issue (compare Table 8). Existing regulations (national and state water resource laws) address dryness and drought via the integrated water management perspective (Kampa & Rouillard, 2023).

So far, little attention has been paid to water retention measures that would affect the drought risk long-term. The WFD speaks of near-natural waters, for example in order to mitigate droughts. So far, droughts have been dealt with by, for example, limiting water withdrawal during dry periods. In fact, there is no water prioritisation in general during a drought. Such a prioritization is currently widely discussed and is mentioned in the National Water Strategy. Water limitations happen during agricultural and social droughts at local level. For example, in Lower Saxony, water withdrawal for farmers, gardeners and pool owners was regulated throughout the day by imposing temporary bans during the last dry periods. This initially occurs as a recommendation from water suppliers, and, in the case of acute problems, a restriction is issued by the lower water authorities. However, this is only a selective solution to the problem and does not address the cause. As a long-term solution, water sensitive landscape management including the increase of water retention in the landscape is envisioned by the National Water Strategy. During the interviews, such projects were already mentioned by stakeholders (e.g., DIWA, water retention in agricultural ditches by Vechteverband).

During the interviews, actors pointed out that the number of applications for irrigation allowances increased in the past years due to the drought situation. This trend could further intensify during periods of prolonged drought and heat. It is very likely that in the future there will be greater use in the summer months of the groundwater reserves formed in the winter months and longer periods with low groundwater levels (LAWA, 2020). Also, groundwater monitoring of water levels and water quality is necessary. Measures to increase the groundwater supply and to promote groundwater recharge must be put in place. An economical and careful use of groundwater as a resource is necessary. In accordance with the management objectives of the WFD, the WHG and the Groundwater Ordinance, groundwater abstractions may not exceed groundwater recharge.

First steps to drought management are taken. Lower Saxony developed a water supply concept (NLWKN, 2022b). To overcome future drought periods, the concept highlights the necessity for cooperation of actors and therewith for integrated water resource planning. An underlying goal is to strengthen the sensitivity and knowledge of groundwater stakeholders regarding the increasing drought risk for agriculture and groundwater-dependent ecosystems due to climate change and to further raise awareness of how to deal with limited water resources.

On this note, the State Office for Mining, Energy and Geology (Landesamt für Bergbau, Energie und Geologie, LBEG) of Lower Saxony has started a project in 2022 to adapt to climate change. The project is called KliBoG - Climate impact adaptation soil and groundwater (Klimafolgenanpassung Boden und Grundwasser) - and is composed of three parts. All three sub-projects are part of the program of measures of the Lower Saxony strategy for adapting to the consequences of climate change. In subproject 1, water balance models are being further developed to, among other things, be able to better estimate drought situations today and in the future with the help of soil moisture and seepage water formation. Data and models are updated for this purpose. Subproject 2 consists of improving water retention in the area through unsealing and adapted land use, including climate-resistant ecosystems, as a contribution to adaptation to climate impacts. Subproject 3 consists of climate-adapted groundwater management and 3D modelling in the Lüneburg area.

In North Rhine-Westphalia, the State Office for Nature, Environment and Consumer Protection (Landesamt für Natur, Umwelt und Verbraucherschutz, LANUV) also has a specialist climate change information system with reference to drought. The country is therefore also aware of the climatic changes caused by climate change and increasing droughts. On the website of the municipal advisory service for climate impact adaptation, those affected can find information on advice, support and networking opportunities (LANUV, n.d.-c).

Drought risk management is only starting in Germany. Lower Saxony and North Rhine-Westphalia still have a long way to go to manage increasing drought risk. The National Water Strategy addresses water scarcity in many important points. It is crucial that the strategy will now be implement within regulations and project in order to become reality. First steps are made, for example with KliBoG strengthening monitoring, landscape management and improving water retention. In addition to the federal states, the regions such as individual municipalities or districts are aware that water must be stored in areas for the dry periods in the long term in order to protect groundwater and surface water. This can happen through renaturation, peat protection, conscious irrigation, but also through private individuals with cysts in their garden.

4.2 The Netherlands

4.2.1 Water management

The Waterwet ("Water Act'') in the Netherlands allocates responsibilities in water resource management over several administrative levels and organizations. The Water Act has been in force since end of 2009 and is based on integrated management of the entire water system. The Water act integrated eight specific water laws into one piece of legislation: Water Management Act, Flood Defence Act, Groundwater Act, Surface Water Pollution Act, Sea Water Pollution Act, Reclamation and Embankments Act, Water Resources Act and legislation on infrastructure and pollution of underwater beds (a former paragraph in the Soil Protection Act). The autonomous jurisdictions are now framed in the Water act in terms of close cooperation. Historically, especially the 1916 and 1953 flood disasters were influential in the quest of improved coordination across levels and scales as well as for merging the large number of regional water authorities into fewer and larger organizations (Kuks, 2009).

The Water Act regulates the management of surface water and groundwater, and also improves the coherence between water policy and spatial planning. It touches upon water quality and water quantity alike. At the same time as the Water act, the renewed system of 'water ordinances' of the provinces and the regional water authorities came into force. These also had to be adapted to the new integral law and are based on state constitutional laws upon provinces and regional water authorities as well as upon the Water Act. The resulting division of responsibilities is schematized in the table below. Management of the regional water systems is the responsibility of the regional water authorities, while RWS is responsible for the management of the main water system consisting of the main rivers and canals.

Table 9: Division of responsibilities as laid down in the Water act (adapted from IPLO, 2023; Ministry of General Affairs, 2023)

Government layer	Responsible for:
Central government (Ministry & Rijkswaterstaat)	✓ National policy and national measures ✓ Flood protection standards pertaining to the primary flood defence systems[8], like dykes and dunes that protect the country against water from the sea and the major rivers. ✓ Management of the main water system (the main rivers and canals)
Provinces	✓ Translation of national water policy into regional measures ✓ Development of the regional water programs ✓ Operational duties with respect to some water management issues, such as groundwater abstractions licenses and groundwater monitoring ✓ Management of groundwater quality (Soil Protection Act). ✓ Supervision of the management of the regional water systems ✓ Coordination of regional input for the national Flood Risk Management Plans and Programmes under the European Flood Risk Directive
Regional water authorities	✓ Management of plans regarding the water quality within their district ✓ Management of regional flood defence systems, that protect the country against, e.g., water from the canals. ✓ Management of the regional water system (Determination and implementation of measures) ✓ Urban wastewater treatment
Municipalities	✓ Storm – and groundwater in urban areas ✓ Drainage of wastewater and excess rainwater through the sewer systems (Water Act and the Environmental Management Act).

Developments over time, including the new Environmental Law

The discourse on fragmentation and integration in the Netherlands, dating back to the 1960s, is crucial in understanding contemporary challenges. Kuks (2009) identifies the lack of integration during this period as

[8] The primary flood defences provide protection against flooding from the North Sea, the Wadden Sea, the major rivers Rhine, Maas and Westerschelde, the Oosterschelde, IJsselmeer, Volkerak-Zoommeer, Grevelingenmeer and the tidal part of the Hollandsche IJssel and the Veluwerandmeren.

detrimental to current agendas, particularly regarding climate change vulnerability and reduced resilience.

The Spatial Planning Act of 1962 played a key role by enabling the expropriation of land for water drainage, leading to landscape and economic sector restructuring. This legislative move increased drainage capacity and resulted in the canalization of water courses. Simultaneously, land reconstruction and agricultural land subdivision aimed at boosting productivity intensified drainage efforts.

The division between generic democracy and functional democracy hindered coordination between water policy and land use policy. Until the late 1980s, regional water authorities were predominantly farmer-dominated, but administrative mergers reduced their number from over 2500 in 1950 to 21 by 2009. This consolidation brought about increased capacity, expertise, and the introduction of elections for the general and daily board of the 21 regional water authorities.

The regulation of groundwater in the 1980s through the Ground Water Act laid the groundwork for integration. Early '90s amendments provided a common ground for addressing depletion, environmental, and ecological considerations. Despite these efforts, integrating sector ambitions in water, environment, nature, and land use faced challenges due to complexity and fragmented authorities. A constitutional change in 1992 granted regional water authorities primacy over regional water management, transferring operational tasks from provinces and municipalities to regional water authorities.

Despite these efforts, dissatisfaction with fragmentation persisted across water, nature, environmental, and spatial planning domains. This dissatisfaction prompted the development of an integrative Environmental Law (in Dutch: Omgevingswet). Since January 1, 2024 (IPLO, n.d.), this law consolidates over 20 existing laws, including the Water Act, Spatial Planning Act, Nature Conservation Act, Expropriation Act, Excavation Act, Environmental Management Act, and Soil Protection Act.

The Environmental Law aims to enhance integration at the decentralized level, with decentral actors such as provinces, municipalities, and regional water authorities taking the lead in realizing sectoral integration. Two trajectories are envisioned at the decentralized level (Lulofs, 2020): the derivation of rules regarding the living environment and the preparation and implementation of programs and projects aligned with established norms and goals.

While EU and national legislation provide the context, coordination occurs through instruction rules across levels and policy programs. Examples include the National Flood Protection Programme and the Freshwater policy program. Despite ongoing integration efforts, the relationship between the national government, provinces, and municipalities remains fundamentally unchanged, especially in water management. However, the Environmental Law anticipates greater integration between water, nature, environment, and land use at the decentralized level.

The law broadens the scope for issuing cross-level instruction rules, facilitating practical integration, synergistic policy programs, and measures. A policy cycle is envisaged, wherein sectoral agendas, including water, are consolidated through consultation. Subsequent reviews of environmental quality standards and the creation of programs with necessary projects and activities follow, with evaluation leading to a new cycle.

The national water plan, evolving from a four-year sequence to a six-year sequence and now known as the National Delta Plan, aligns with the six-year planning regarding EU water directives. The Delta plan encompasses lenses such as flood risk management, fresh water supply, and spatial adaptation. The latter underscores efforts to intertwine water management and land use planning further.

Plans

The water plans of the national government and provinces reflect respectively national and regional (strategic) water policy. For the government this is the National water plan and for the provinces these are the regional water plans. The National Water Plan also contains a summary of the four river basin management plans (Rhine, Meuse, Scheldt and Ems) and the program of measures that have been elaborated in the plans of provinces, regional water authorities and municipalities.

The water management plans are operational in nature and are drawn up by Rijkswaterstaat and the regional water authorities. These plans establish the conditions for achieving the strategic objectives of water management and describe concrete measures. Management also includes the management of flood defenses.

The plans must consider and elaborate on the objectives of the Water Act (Article 2.1 Water Act), which are related to flood risk management, drought and water scarcity management, chemical and ecological quality of water systems, and social functions. This leads to the designation of (parts of) water systems for certain functions (see also: function allocation) and a program of measures to achieve the goals. The plans also elaborate on the objectives of the WFD and those of the Flood Risk Directive.

Article 4.8 of the Water Act stipulates that the plans, in accordance with the WFD plan cycle, are revised once every six years. Interim revision is also possible.

The Water Act also stands for greater coherence between water policy and spatial planning. With regard to spatial aspects of water policy, the water plans of the national government and provinces are also structural visions based on the Spatial Planning Act (‘Wet Ruimtelijke ordening’ - Wro). This means, for example, that where space has been created in the plans for water, this space (reserved surface area for, for example, a water storage area) is, as it were, seen as part of the structural vision as established by both government bodies. It is therefore important that the water plan, as a structural vision, also contains statements that lay the political basis for the use of Wro instruments, such as instructions, general rules and government integration plans.

With regard to municipalities there is no municipal water plan figure prescribed for the municipality. The manner in which the municipality fulfils its duties of care in the field of urban wastewater, rainwater and groundwater is included in the municipal sewerage plan. Spatial aspects of municipal water policy are reflected in structural visions and zoning plans of municipalities based on the Spatial Planning Act.

Additional to the described planning and coordination structure, cities tend to have a more holistic and integral approach and often have an ‘urban water plan’, including the municipal sewage planning and for instance efforts upon climate resilience (as stipulated in the Delta Plan for Spatial Adaptation). And in much broader perspective, over the years all kinds of cross linkages are made, crossing borders to other sectors than just water, in water goals and water rules and even more in water programs and water measures (van Leussen & Lulofs, 2009). This prepared the floor for new institutional reforms.

4.2.2 Flood risk and disaster management

Flood risk management in the Netherlands has long been characterized by a strong reliance on structural defences, such as dykes, dunes and dams. Following multiple near-flood events in the 1990s, this approach has been changing with the concept of multi-layered safety being introduced in Dutch water law in 2009. Multi-layered safety basically refers to the idea that FRM should – where possible – consider and combine three types of measures: 1) prevention; 2) land use planning; and 3) emergency-response management (Bosoni et al., 2023).

Since a revision of the Water Act in 2017, safety standards in the Netherlands are risk-based and calculated on the basis of flooding probabilities instead of water level exceedance probabilities. This implies that the number of people protected by the flood defences are taken into account in defining the safety standard (a maximum allowed failure probability of the flood defence). So, areas with a large number of potential flood casualties are awarded more stringent safety standards compared to areas with limited numbers of potential flood casualties. To assess whether flood defences comply to the safety standards, several potential failure mechanisms of flood defences (e.g., internal erosion, slope instability or damaged revetment) are taken into account (Jonkman et al., 2011). The first assessment of flood defences according to this new approach was finalized in 2023 and it was concluded that a substantial percentage of flood defences in the Netherlands do not meet these new safety standards. This was foreseen to some extent, which is why it was decided to reserve a period of 30 years to get the flood defences up to the new standard (in 2050). To ensure that all primary defences meet the new standards by 2050, the Netherlands has a National Flood Protection Programme (NFPP, part of the overarching Delta Programme, Nationaal Deltaprogramma, n.d.). The NFPP is a collaboration between all 21 regional water authorities and the national Directorate-General for Public Works and Water Management (Rijkswaterstaat).

The NFPP provides subsidy to projects that aim to improve the safety of dyke trajectories that do not meet the safety standards. Such projects typically consist of three phases that last circa three years each: exploration, elaboration, and realization. When the scope of a project is unclear, the exploration is preceded by a broader investigation phase. The NFPP also subsidizes exploration studies in which innovative solutions to more general challenges are developed in more detail.

The NFPP aims to improve defences in the most efficient and effective manner. Along rivers, this generally involves that existing dykes are heightened and/or strengthened. Especially in the larger Zwolle region, a wide range of NFPP projects are currently in the exploration, plan development or realization phase (see Figure next page). A particularly large ongoing NFPP projects is “Veilige Vecht” (Safe Vechte, number 9 in the figure), for which a preferred alternative for strengthening the various parts of the dike trajectory between Dalfsen and Zwolle has just been proposed (WDOD, 2023).

Projects are not limited to the Vechte river. For example, plans are currently prepared for dike reinforcement near an industrial area in Doetinchem along the Oude IJssel (number 50 in the figure). The NFPP also finances innovation projects. Examples of ongoing innovation projects in Zwolle region are Dijken & Natuur (focusing on developing furthering the implementation of flood risk mitigating measures in protected nature areas; number 3 in the figure) and flood resilient landscapes (focusing on the further development of a method, including narratives, solutions, assessment methods, to better integrate future flood risk measures into changing landscapes; not in the figure). Both projects are led by water authority Drents-Overijsselse Delta and include the University of Twente and Deltares as partners.

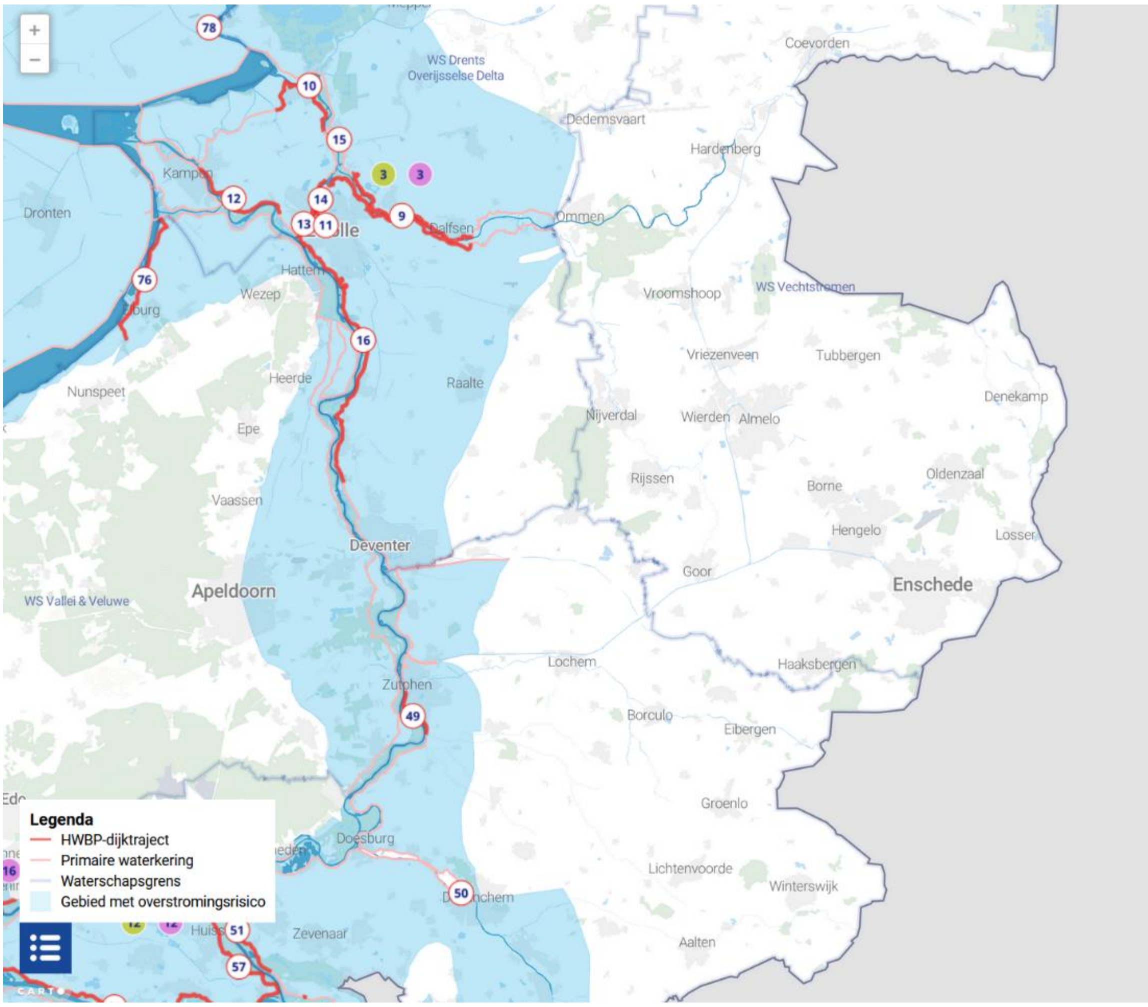


Figure 31: Overview of ongoing NFPP projects in the extended Vechte basin (HWBP, 2024)

A completed NFPP project that is relevant for the larger Vechte river basin, is the exploration study for the Vechte river (in Dutch: POV Vecht). The project was initiated by Regional Water Authority Vechtstromen and Drents-Overijsselse Delta, and the province of Overijssel (WDOD, n.d.-b). The aim was to explore whether more diversified FRM measures could contribute to lowering the costs of dyke reinforcement. The project was initiated in 2017 since the majority of the dykes along the downstream part of the river do not meet the new standards. The question was whether other measures, upstream or downstream in the river basin, could have a positive impact on the dyke reinforcement challenge and perhaps also contribute to solving other societal challenges, such as drought and water scarcity in the upstream part of the basin (WDOD, n.d.-a). To assess the feasibility and effectiveness of alternative measures, the project combined technical studies with stakeholder activities (Vinke-de Kruif & de Weerd, 2019). The project included two information exchange sessions with German stakeholders who were responsible for water management in the most upstream part of the basin. The results are now informing new projects and programmes.

Throughout the exploration study, there were many exchanges and interactions with organizations involved in 'Space for the Vechte' (in Dutch: 'Ruimte voor de Vecht', n.d.). This network organization was established in 2007 and is a collaboration between thirteen organizations (water authorities, province, municipalities, and organizations for nature, landowners, marketing, agriculture and businesses) active in the Dutch part of the Vechte basin. Collaboration occurs both administratively (collaboration between civil servants) as well as politically (in Dutch: breed bestuurlijk overleg). In the most recent collaboration agreement for 2023-2026, all partners committed to continuing their collaboration, development of a masterplan and vision for 2050, and further development of regional plans that are demanded by the National Programme for Rural Areas (NPLG in Dutch). The scope of the activities includes climate adaptation and safety, nature and biodiversity, sustainable agriculture and socio-economic development, attractive living environment.

Over the past years, a wide range of measures has been initiated within the context of the Space for the Vechte program. For example, in the context of the WFD and the first National Flood Protection program, efforts have been made in the past planning period(s) to, among other things, de-stoning banks. And passing of weirs by naturally designed side channels. A special point of attention here is the water level of the Vechte. The Regional Water Authority Vechtstromen has opted for a fixed level option for the longer term, also no longer higher levels in summer, lower levels in winter. To this end, consultations are being held with the Regional Water Authority Drents Overijsselse Delta (WDOD). A fixed water level is thought of as being

more favourable for the ecological development of the bank compared to the current unnatural levels, with a high-water level in summer and a low level in winter. The drought resilience consequences seem not to be taken deeply into this discussion yet (Knol et al., 2020). There is however in general a strong relation between drought policies and measures (see below) and the implementation of the WFD. Measures upstream are often aiming for more natural blue veins; such brings benefits to both water quality as well as droughts and vulnerability to droughts. Such projects are often financed from nature restoration funds and are therefore Natura 2000 related. For river restoration measures and blue vein restauration measures the projects are also often managed by regional water authorities though (co-)financed by the province, related to nature funds. Where restructuring projects take place, in addition to regional water authorities, municipalities and interest groups are also involved (Helder et al., 2017). Regional project scan also be co-financed by one of the national Delta sub-plans.
Regional water authorities are the organizations that flesh out the details working from goals to programs, projects and measures. Over the past decades most of the attention was upon flood risks and upcoming WFD requirements regarding water quality and ecological quality of water bodies. And only very recently the agenda of droughts is added.

Disaster management

In the Netherlands, flood- and drought-related disaster management are closely connected and involve the responsibility of water and drought risk managers such as the regional water authorities and the department of waterways and public works (Rijkswaterstaat- RWS). These parties are part of the regular water management chain. During events considered crises or disasters, management and mandate shifts to crisis management structures led by regional authorities, safety regions (Veiligheidsregio's), and local or regional emergency workers. These crisis control parties are part of a general crisis chain (Rijksoverheid, n.d.-a; RWS VWL, 2021).

Governance bodies within the general crisis chain are responsible for public order and safety. This chain of organizations consists of the ministry of Justice and Safety, the provinces, safety regions and the municipalities (Waterschap Vechtstromen, 2021a). On a national level, the minister of Justice and Safety (JenV) is primarily responsible for crisis control, the functioning of crisis control policy as well as the crisis control structures and organizations (Rijksoverheid, n.d.-a). Additionally, every ministry has a crisis control center for crises related to their domains (NCTV, 2022). The ministry of Infrastructure and Water works is responsible for the policy regarding flood- and drought- protection (IenW, n.d.).

Most of the crisis coordination and management at the regional level is in the hands of the safety regions. The Dutch safety regions oversee and are responsible for the public safety of a region during any type of event (not only floods and droughts). There are 25 safety regions in the Netherlands (Figure 33). Safety regions perform crisis coordination and control. They are also in charge of the oversight of emergency workers such as fire fighters, police and ambulances (Rijksoverheid, n.d.-c). Generally, when an event is large enough and spans multiple (safety) regions, the national crisis chain structures will be activated as well.

In the Netherlands, the water management chain manages both flood and drought risk. Parties within this chain usually have a specific area of expertise. In this chain, we find the Ministry of Infrastructure and Water Works and Rijkswaterstaat on a national level and the regional water authorities on a regional and local level. The regional water authorities are in close contact with the National Water Management Centre of the Netherlands (WMCN), who continuously monitor flood and drought risks for the whole of the Netherlands. The WMCN has a commission on floods (Landelijke Coördinatiecomissie Overstromingsdreiging – LCO) and droughts (Landelijke Coördinatiecommissie Waterverdeling – LCW) (Waterschap Vechtstromen, 2021). During a larger-scale flood or drought event, water- and drought-related parties (such as the WMCN, KNMI, Rijkswaterstaat, regional water authorities) and the crisis management chain (safety regions and provinces) but also stakeholders of vital processes such as drinking water parties (Landelijk draaiboek hoogwater en overstromingsdreiging, 2023) collaborate closely (see Figure 32 for more detail on stakeholders). The roles of relevant authorities during national floods and droughts are extensively reported in crisis plans and handbooks for floods and droughts (e.g., National Crisis Plan High water and flooding, National handbook high water and flood threats, National handbook water distribution and drought).

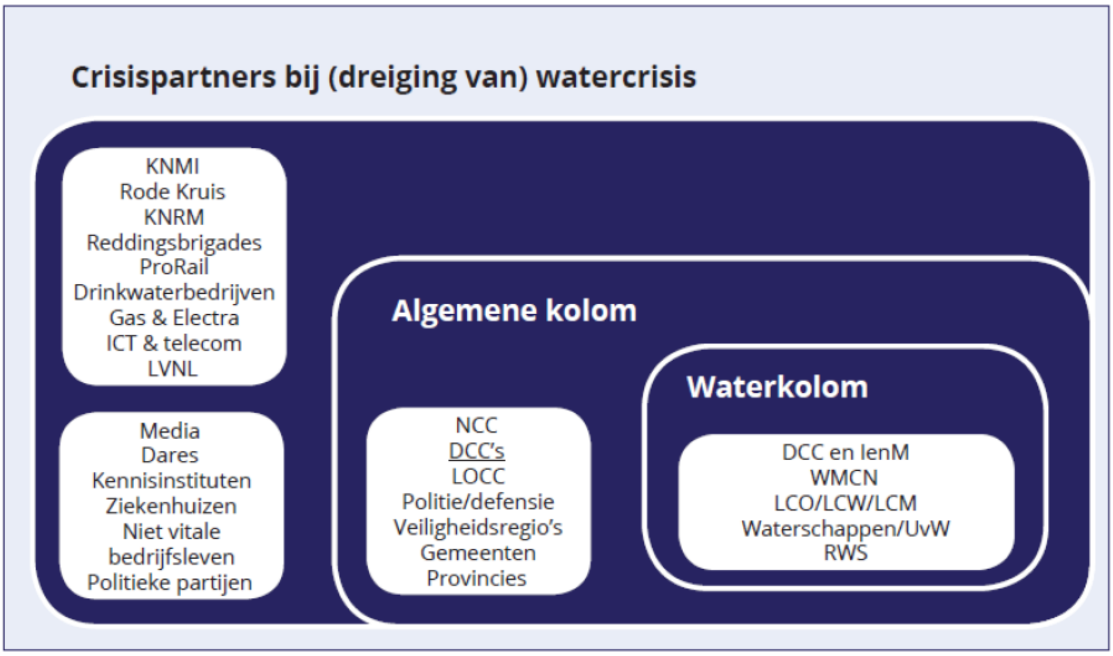


Figure 32: Crisis partners during the (threat of) a water-related crisis (van der Klei, 2017). From: (NIPV, 2023)

Provinces, safety regions and regional water authorities in the study area

Within the Dutch part of the study area, there are three relevant provinces (Overijssel, Gelderland en Drenthe) four safety regions (Twente, IJsselland, Drenthe and Noord- en Oost- Gelderland) and three regional water authorities (Vechtstromen, Rijn and Ijssel, Drents Overijsselse Delta).

The safety regions (VRs) play a vital role in crisis management. They are an extension of the municipalities and are governed by a board consisting of all the mayors of the municipalities in that safety region. The board chair is usually the mayor from the largest municipality. VRs are not only responsible for floods and droughts but for any kind of threat to public safety. If a threat covers multiple municipalities simultaneously, the chairman of the safety region becomes responsible (Rijksoverheid, n.d.-a). The board and safety regions are responsible for establishing and maintaining the fire brigade, the GHOR (Medical Assistance Organization in the Region), preparing for fires and organizing disaster response and crisis management (Rijksoverheid, n.d.-a). The core tasks are regulated in the law for safety regions (Wet Veiligheidsregios). The responsibilities are:

a. The inventory of risks associated with fires, disasters, and crises and creating a risk profile;
b. Advising the competent authority on risks related to fires, disasters, and crises as designated by or pursuant to the law, as well as in cases determined in the policy plan;
c. Advising the Mayor and decision-makers

d. Preparing for the suppression of fires and organizing disaster response and crisis management;
e. Establishing and maintaining a fire brigade;
f. Establishing and maintaining a Public Health Service (GHOR);
g. Providing the emergency call center function;
h. Purchasing and managing common equipment;
i. Setting up and maintaining information provision within the services of the safety region and between these services and other services and organizations involved in the tasks mentioned under d, e, f, and g.

As mentioned before, VRs do not operate alone. For water-related crises including droughts, there is a strong coupling with the regional water authorities, provinces and municipalities. Usually, safety regions rely on the information that regional water authorities provide. They also work together formally as decided in the crisisplan, risk plan and decision-making plan. Both safety regions IJsselland and Twente declared in the interviews that this cooperation is quite smooth.

VRs also have an informative role in which they communicate with stakeholders about different scenarios that might occur and how to prepare for these. For example, VRs try to assess how to be climate resilient. Despite the fact that thinking about and preparing for climate-related scenarios is a relatively new development, VRs Twente and IJselland, located in the extended Vechte basin, already engage in this for some time. VR Twente focusses rather on drought-related impact scenarios than on high-water and flooding. VR Ijsselland is also preparing for water-related scenarios. However, they indicated that they were insufficiently prepared for the high-water event of 2023/2024, with the combination of all the factors that occurred.

At the same time, the NIPV (2023) reports that even though safety regions usually consider climate factors such as floods and droughts in their risk profiles, it is a relatively new topic of which the effects on crisis management and response are not well-known yet. As a result, the risks of climate threats are not always embedded in crisis response plans and in the knowledge of emergency workers. Especially events that span multiple safety regions may prove challenging in crisis response, as every safety region is organized differently and there is limited experience with such events (NIPV, 2023).
12 out of the 25 safety regions in the Netherlands share a border with Germany or Belgium. These 12 regions need to coordinate their crisis-plans with the cross-border counterpart. This may for example lead to Dutch fire-fighters coming into action during a fire in Germany and vice versa (Rijksoverheid, n.d.-a). Usually, this operational side (firefighters / police)

is well-coordinated, also across the border. During the interviews it became clear that cooperation and exchange of information on other elements (mostly preventive) is more limited. There is always at least one person who will represent the Netherlands when there is a transboundary crisis. But there is not always systematic or regular cooperation or exchange of information across the border. During the interviews with VRs IJsselland and Twente, interviewees highlighted the importance of timely information exchange with Germany. In the past, activating all relevant crisis structures timely has proven to be challenging due to differences in communication and timing of informing. In times of flooding, the safety regions have to trust that the information will be shared timely by German counterparts to the regional water authorities and that the regional water authorities will inform the safety regions in time to be able to perform adequate crisis management.

What happens during floods and droughts?

There are different stages relevant to **flood crisis management**: from business as usual to extreme events/disaster. The different stages are detailed below and are adapted from a national framework (Landelijk Crisisplan Hoogwater en Overstromingen, 2020). During business as usual, the Dutch regional water authorities carry out the day-to-day activities regarding water/flood management in close collaboration with Rijkswaterstaat and the provinces. Their responsibilities remain in place in first instance during heightened threats of extreme rainfall, high water or a flood event. They will additionally collaborate more closely with other water management partners like Rijkswaterstaat and with the provinces and municipalities (Waterschap Vechtstromen, 2021a). The regional water authorities have crisis plans, as they are obliged by law (Waterwet, artikel 5.29). If there is an event happening that cannot be handled under business as usual, the regional water authorities will have dedicated crisis teams in the field on a tactical and strategic level. The scale, threat and financial consequences of an event determine the type of crisis mode and the level to which the regional water authorities will inform other parties and the region (Waterschap Vechstromen, 2021). In this crisis mode, the regional water authorities make use of volunteers in the field.

As the threat increases, they might seek additional support from flood-crisis parties such as the Water Management Centre or the general crisis parties such as the safety region. If a flood event starts to threaten public safety, the responsibility transitions to organizations in the crisis chain, usually the safety region.

Table 10 demonstrates the different stages that can be distinguished, from business as usual (code green) to a crisis at the responsibility of the crisis management parties (code red) (WMCN, 2023). If there is a disaster or crisis that expands beyond a specific location, responsibility is transferred to the safety regions who will then have full mandate, also over the regional water authorities and their activities (Wet Veiligheidsregio's, section 39).

Table 10: Color codes for flood events adapted from Landelijk Draaiboek Hoogwater en Overstromingsdreiging (WMCN, 2023)

Code green	Business as usual
Code yellow	Some high water, water authorities take precautionary measures, some activities might be restricted. WMCN and crisis parties may be informed.
Code orange	High water threat increases or is predicted to increase. Water authorities take additional measures, large-scale measures are being prepared, some damage may occur. Water authorities will inform crisis authorities and collaborate with them.
Code red	Extreme situation (predicted). Large-scale measures are being prepared. Damage may occur. Safety may be endangered. This is where responsibility transitions fully to crisis structures, usually on a national level but the execution will be done by safety regions.

Figure 33: Safety regions in the Netherlands. From: CBS areas 2016-2024 (CBS, 2024).

4.2.3 Drought risk and disaster management

What has been shared in sections 4.2.1 and 4.2.2 applies also to drought risks in water resource management. Institutions, arrangements and planning are mostly identically organized.

In the event of drought, fresh water from the major rivers and lakes is allocated as best as possible among all water users in various regions.

Guiding water towards high sandy soil landscapes in the east of the Netherlands is mostly done via the Twentekanaal. In this way, water from the River IJssel can be brought to Enschede as well as to the Vechte at De Haandrik (South of Coevorden) (See Figure 40, Annex E). The water supply through the Twentekanaal is managed through a water agreement (Waterakkoord) between Rijkwaterstaat, the provinces of Overijssel and Drenthe and the regional water authorities of Rijn and IJssel and Vechtstromen. The agreement formalizes the water supply of parts of Overijssel, Gelderland and Drenthe as well as the water discharge to the Twentekanaal by the freely draining areas of Overijssel and Gelderland. However, the network does not deliver water to the whole area, considerable parts are therefore dependent upon precipitation for water supply.

The Delta program is the leading national water plan on flood risk, drought risk and climate adaptation. The Dutch cabinet and parliament agreed recently to have water and soil as the guiding principles in land use planning. With this decision, far reaching on-land reconstruction efforts are announced. This is done for example to increase the sponge capacity of soils of various use, and to slow down and control irrigation. This could also be referred to as “restoring landscapes to increase climate robustness and resilience to mitigate Anthropocene impacts on land-water systems”. A century of land development led to increased speed of irrigation of agricultural land and build up areas. Now, the objective is changing towards local collection of rainwater, storage of water and slow infiltration and irrigation. The provinces play an important role in this as they are managing the strategic groundwater resources as well as the spatial planning of the rural areas.

With regard to responsibilities and tasks upon droughts, the situation in the Netherlands was intensely discussed for some years in several studies (Freriks et al., 2016; Lulofs, 2018). Essentially, actual responsibilities with regard to preventing loss of sponge capacity and restoring sponge capacity on land are not allocated properly in institutions. After ample discussion about the importance of establishing such responsibilities, under the new Environmental Law the responsibility and authority of regional governments in the generic democracy is broadened from implementing the national chemical quality standards alone (the known soil pollution topic) to the biological and physical quality of the soil. This refers to land development and land use that aligns to principles of “sponge landscapes” and “sponge cities’”. Hence, regional governments become responsible for acting upon this, for example by adjusting spatial planning. This empowers the province to act upon this and to support water-land related climate adaptation action, if needed using authority, while doing too little might even make authorities vulnerable to court decisions upon neglect (Lulofs, 2020). This might read as a small adjustment though this opens the opportunity to regulate landowners and land users upon creating sponge capacity on their parcels, by issuing standards upon soil quality. High standards of biological and physical quality can only be reached by some reconstruction efforts and specific (agricultural) use.

Whether there will be political support remains to be seen, and implementation of the new law will be spread over time. However, the institutional base is created for taking action towards implementation of policy strategies and plans with other instruments than just incentives. The responsibility for this and the legal duty to take care of this is now allocated to the provinces and the municipalities. Regional water authorities have to coordinate with them and offer expertise and guidance upon the land-water system in the policy cycle.

Meanwhile, setting the legal perspective upon tasks, responsibilities and accountancy aside, there are ongoing drought adaptation policies (for more information on drought and drought policy in East Netherlands, (Bressers et al., 2016). Since circa a decade, projects and measures are prepared and taken in the East Netherlands Freshwater Supply programme (in Dutch: ZON – Zoetwater Oost Nederland, ZON, n.d.). This is the regional equivalent of the national Delta plan freshwater (in Dutch: Deltaplan zoetwatervoorziening), emphasizing the multi-level character of Dutch policies upon floods (Room for the River, NFPP 1 and 2) and droughts. In the East and South of the Netherlands, the Rhine-East Regional Administrative Consultation (RBO) and the Delta Plan Steering Group on High Sandy Soils (DHZ) are developing a joint program for a future-proof water supply on high sandy soils. The regional freshwater program for East Netherlands is part of the national Delta Plan and as such aims for coordination between national, supra-regional and regional water systems. In these plans, the WFD goals and drought ambitions get interlinked. In the regional main water system, the government finances regional projects, 75% regional, 25% national (Werkgroep zon, 2020). As explained in 4.2.1, the Delta plan itself is renewed every six years.

Drought crisis management is similar to flood crisis management in the sense that the responsible parties are firstly the day-to-day parties. When a crisis hits public safety, the crisis management structures are activated. When water shortages are starting to occur, the collaboration and advice from crisis management parties increases. Parties will collaborate in Regional Drought Meetings (RDO) where they exchange information and coordinate communication. This can be advice from drought-crisis parties such as the Water Management Centre in relation to droughts (LCW). When the situation worsens and transitions towards public safety and / or civil unrest, the main responsibility is in the hands of the general crisis parties and the safety region will take the main role, while the drought parties take on an advisory role. Extreme events usually entail a combination of regional and national level. It may be that the national structure takes over in the management team on water shortages (MTW). But the regional execution of public safety will remain in the hands of the safety region (RWS VWL, 2021).

To manage droughts adequately, the Netherlands also applies a ranking system to prioritize activities that can still use water during (extreme) droughts, the 'Verdringingsreeks' (displacement series, see Section 2.6). Some regions have defined the categories more specifically. For example, for the region Twentekanalen – Overijsselse Vecht category 4 activities also include irrigation of grass and maize (Handleiding verdringingsreeks, 2020). Table 11 provides an overview of the meaning of the different national disaster color codes with respect to droughts, similar to Table 10 with respect to floods.

Table 11: Color codes for droughts. Adapted from the national color codes to illustrate different stages in drought crisis management (RWS VWL, 2021).

Code green	Business as usual
Code yellow	Some water shortages threaten to occur. Water authorities and Rijkswaterstaat are leading but seek collaboration with drought-crisis structures (e.g. WMCN-LCW). There is regional collaboration to exchange information and be uniform in communication.
Code orange	Actual water shortages. The regional water authorities, Rijkswaterstaat and the provinces are still leading but let themselves be additionally advised by drought-crisis organizations (such as the WMCN-LCW) and public crisis organizations (e.g. safety regions and/or national management team water shortages (MTW). There is regional collaboration to exchange information and ensure uniform communication. The displacement series will need to be used (nationally categories 3 and 4 may be threatened, and regionally categories 1 and 2).
Code red	Extreme situation (predicted). The crisis structure (safety regiono, emergency services, crisis centers of the ministries, etc.) become leading, while the drought-parties advice. There will be societal consequences.

Rijkswaterstaat as well as regional water authorities have operational roles during low water periods, guiding with their infrastructure water more strategically nationally and regionally in order to offer accurate water supply as much as possible. In times of drought crises, Rijkswaterstaat organizes a team to provide regional crisis teams with information, outlooks and support. There is a continuous national water allocation committee

(Landelijke Coördinatiecommissie Waterverdeling) active that addresses water allocation including drought risks, there are always other related interests such as fresh water supply, salination control and services like shipping, agriculture and nature too. On a regional level, there are regional drought consultation bodies active (Regionale Droogte Overleggen - RDO). Two relevant examples in the context of this report are the Regional Drought Consultation Twente Kanalen and Overijsselsche Vecht and the RDO Gelderland respectively. Given all interests and concerns touched upon there are water agreements developed in Regional Coordination Bodies, which basically overlap with the RDOs, also in the case of the mentioned RDOs. Also, there is term of operations and roadmaps agreed upon at forehand. Updating of water agreements and roadmaps is based, among other things, on the experiences of drought and low-water distribution issues. There is a roadmap developed as a guidance tool (RWS VWL, 2021). The chairpersons of the RDOs participate in the LCW at times of upscaling due to low water and drought.

Having discussed how it is organized there are also some bottom-up crisis management observations from the severe droughts in 2006 and 2018 to present. Regional water authorities report that droughts in 2006 and 2018 were acted upon mostly based upon expertise and maybe even intuition of employees in an ad hoc manner, while guidelines, checklists and factsheets on the work floor level hardly exist (Braak et al., 2019). It appears that the calamity plan of the four regional water authorities in WFD area Rhine East and their experience are dominated by flood risks. Experiences with droughts in the extreme dry summers of 2006 and 2018 were evaluated in regional water authorities, for instance Regional Water Authority Vechtstromen. Bans were issued in 2018 upon extraction from ponds and surface water. There was also a ban upon the extraction from groundwater. Regional water authorities have this option based upon their "Keur", the decentral water ordinance of the regional water authority. The scope of authority to issue rules upon use of water resources and upon landowners is restricted to their primary tasks. During the drought, mowing, damming and pumping station management was intensified. Additional water supply from the IJssel and the IJsselmeer was sent to the Eastern high sandy soils, and coordination between water managers and water users was more intensive. This does not prevent damage by definition, as a significant part of Dutch GPRW area, circa 60%, the border area, is dependent upon precipitation alone. There are also areas with vulnerable nature where no extraction is allowed.

To prepare for the future crises the evaluation report suggests organizing regular exchange of data upon the border crossing water ways as Vechte, Dinkel and Berkel envisioned to optimize in extreme situations. The emergency preparation for drought crisis management is in need of further development (Braak et al., 2019).

5 Transboundary cooperation

The foundation for cross-border cooperation was laid in 1958 with EUREGIO (EUREGIO n.d.). **EUREGIO**, a special-purpose association under public law linking Münsterland, Osnabrückerland and the neighbouring Dutch municipalities. It was founded to strengthen economic development through project funding in the border region. EUREGIO is seen as a pioneer of the European INTERREG programme. Since 2016, regional water authorities have been able to join EUREGIO. While this seems interesting for the Dutch stakeholders (Waterschap Vechtstromen, 2020), this possibility of cooperation was not mentioned in discussions with the German stakeholders.

The origin of cross-border cooperation in water management are the border treaties dating back to 1816 and 1824 that were overridden by the Border Treaty of 1960 and the agreements for individual border waters (for more information on the border treaties, see Mostert & Lukat, 2021, for more information on transboundary cooperation until 2010, see Renner et al., 2017). Most of the interviewed stakeholders are content regarding the existing institutional framework that addresses transboundary issues. In their current form, the border treaties tackle the maintenance of the water bodies with the effect of managing a determined water level. The contract on the Vechte acknowledges that in times of low water flow, all parties need to withdraw water with care (section 5). The contract on the Dinkel regulates that the water level for different parts of the river may not fall below certain values (sections 4 and 5). Still, the interviewed stakeholders consider these regulations insufficient. Within the border water commission (Grenzgewässerkommission), it is discussed to amend the border water treaties by adding low flow water levels and discharges.

Generally, the actors agree with each other that no additional formal institutions are needed. However, some actors, particularly those that are involved in practical water management (Vechteverband, Regional Water Authority Rijn and Ijssel), suggest setting up informal agreements regarding water retention measures to avoid conflicts. Currently, Germany retains much less water than the Netherlands. Several planned and ongoing projects focus on increasing water retention in Germany, which will have an impact on the extended Vechte basin (e.g., within the DIWA project, water retention in agricultural ditches in the Bentheim area). One example for such an informal agreement is the agreement on the Radewieke. The agreement exists between Dutch and German organisations for situations of low water flow. In these cases, water is pumped back from the IJsselmeer into the Radewieke on the German side.

The Permanent Border Water Commission (SGK) was established on the basis of the border water treaty of 1960. This commission is the formal body for coordinating cross-border water management issues. The stakeholders in the SGK and in subcommittees meet yearly to discuss water management issues that affect the contracting parties. In the early years, the exchange focused primarily on water quality and flooding (Waterschap Vechtstromen, 2020). The culture of the SGK is described by many stakeholders as very formal. The management of the respective subcommittees sets the agenda, which in case of the Vechte is the NLWKN and the Province of Overijssel, while the participants simply report back to the management. In addition to the agreements on the individual border waters from the 1970s and 1980s, the Vechte Management Plan (1997) and the Dinkel Plan (2002), which aimed at the ecological restoration of the entire Dinkel were milestones in the cooperation (Waterschap Vechtstromen, 2020).

Based on the border water agreements, water body inspections also take place every six months. These are inspections of the watercourse sections in question in which Dutch and German stakeholders participate (mostly the German water associations, Regional Water Authority Vechtstromen and the German lower water authorities). These inspections are the basis for an informal exchange between the operational stakeholders.

Within the framework of the European WFD and FRMD, the **Delta Rhine Working Group** (AGDR) and **the Delta Rhine Steering Group** (SGDR) were created in 2005 to fulfil the legally required coordination between member states in river basins larger than 2500 km². According to some stakeholders, these coordination bodies have revitalised cross-border cooperation by bringing together the right stakeholders and working together in technical working groups (AGDR) on specific topics (Waterschap Vechtstromen, 2020). A joint approach to implementing the water directives is discussed within these bodies. They exchange information on water quality monitoring, fish migration, groundwater management and flood protection and report their activities to the EU Commission. In an evaluation of transboundary cooperation since the 1950s, Renner et al. (2017) mention that the success of these platforms in tackling complex environmental problems like diffuse pollution or river restoration is limited.

The cross-border Vechte Valley Strategy containing a transboundary vision was published in 2009. It was a joint cooperation between the water authorities in Germany and the Netherlands. A participation structure for the development of the region was set up, the Vechte and Vechte Valley cross-border steering group and the cross-border programme team, which is responsible for the development and implementation of certain topics. The aim of the Vechte Valley Strategy is to develop the Vechte into a near-natural lowland river by 2050, taking flood protection into account (OHV & NWP Planungsgesellschaft mbH, 2009).

Triggered by the moderate success of WFD implementation (Renner et al., 2017) and following the flood event in 2010, which was characterized by a lack of communication and uncoordinated disaster response, the **Cross-border Platform for Regional Water Management** (GPRW) was founded at the end of 2011 (Waterschap Vechtstromen, 2020) to strengthen cooperation in the region. The members are the regional water authorities of Vechtstromen and Rijn and IJssel, the districts Grafschaft Bentheim, Emsland, Borken and Steinfurt and the governmental district of Munster. The GPRW deals with a wide range of topics relating to water management such as flooding, water quality, fish migration, dealing with nutrias and muskrats, urban water and climate impact adaptation, including the topic of drought. The platform has also organised a cross-border data exchange. The GPRW is described by many stakeholders on both sides of the border as a driving force for joint projects. While several platforms for transboundary cooperation exist, most actors understand the GPRW as the most practice oriented and effective platform. On the one hand, this is attributed to the high degree of organisation (e.g., an organising office, continuous exchange due to frequent meetings). On the other hand, stakeholders mention the more informal character of the platform, which facilitates a lively exchange between the partners.

A flagship project of the GPRW was the INTERREG project Living Vechte-Dinkel (2017-2021), which focused on the objectives of the Vechte Valley Strategy of 2009 and strengthened the near-natural development of water bodies, the economic strengthening of the region by emphasizing regional identity and tourism as well as cross-border cooperation in 15 sub-projects. The Living Vechte-Dinkel project is seen as a transition from cross-border dialogue to cross-border cooperation (Pergens, 2018 interviews). However, the interviewed stakeholders agree that more transboundary action is needed.

In March 2021 and with the experience of the drought years, the Declaration of Intent on Cross-Border Climate Adaptation was drawn up in which the GPRW stakeholders committed to the topic of climate impact adaptation. This can be seen as a start for more practical action, which has already led to the joint INTERREG proposal for the DIWA project. This project focusses on drought strategies in water management. Next to the implementation of specific measures (water retention) and the evaluation of their impact on the entire system, new strategies and tools will be developed and applied. It builds on the former Living Vechte-Dinkel project (INTERREG financed) that ended in 2021. Despite DIWA still being in the proposal phase, several stakeholders see this as a fruitful basis for further cooperation.

While stakeholders on both sides of the border seem equally enthusiastic about the arising cooperation opportunity in the DIWA project, it seems that some Dutch actors perceive the willingness of German actors for cross-border cooperation with the Dutch partners as limited. From the interviews, two explanations seem possible. On the one hand, the German actors, particularly those in Lower Saxony, have a high workload due to the administrative reform in 2005, where one water management level was abandoned. Project work that is not part of the regular duties is additional effort, which needs to be handled by the existing personnel. Therefore, their capacities for additional transboundary collaboration are limited. On the other hand, the German water management administration is decentralised. Therefore, in some situations, e.g., within the GPRW, not all relevant actors are present, and decision-making takes more time, which might facilitate the impression of lower priorities for transboundary cooperation on the German side. In addition, the degree of dependency of the Netherlands from Germany for information and effective flood and drought measures is higher than vice versa, and hence, the need for closer cooperation is naturally higher.
It is therefore important to make cross-border cooperation fit in with the daily work of German partners in terms of timing and content as much as possible as well as to base projects on previous joint activities (Interview GPRW).

Drinking water supply in the border region is abstracted from a transboundary aquifer (see Section 2.3). The drinking water companies Vitens and Wasser- und Abwasser-Zweckverband Niedergrafschaft (Water and wastewater association, WAZ) are in close contact with each other as they have shared water rights for this aquifer. However, in the event of a drought, there are doubts as to whether the measures in place will be sufficient. On the one hand, a drought is likely to be experienced on both sides of the border as well as neighbouring water sources to which support agreements exist, which makes additional supply in a severe drought situation difficult. On the other hand, the regulation in case of drought is not sufficiently clear. Here, more cross-border coordination is needed (Province of Overijssel, districts Grafschaft Bentheim and Steinfurt).

From a nature protection point of view, the peatlands and the natural streams in the Borken area are of high value to nature protection and water management in the Netherlands (Natuurmonumenten). The Borken district does not value these natural assets much, as they are relatively small, and agriculture is an important economic factor in the region. However, particularly in time of drought, the drained peatlands cannot store the water which then causes the drying up of natural streams with effects on the Achterhoek area. There are several projects dealing with this area and the effects of drought and flood focusing on the rivers Berkel and Oude IJssel (Vitens, Watershap Rijn and Ijssel). For this, we recommend strengthening the transboundary cooperation to raise awareness at the Borken district for the transboundary value of its natural assets.

In the extended Vechte basin as well, soils are drained with the effect of a decreased groundwater replenishment and drying up of streams in the summer periods. WFD targets can only be reached if water retention is formulated as an objective in the German part of the river basin. The functioning of the integrated water system particularly in the border region, hence the interplay between ground and surface water bodies, was highlighted as a knowledge gap during the interviews (GPRW, Grafschaft Bentheim). However, there are several projects planned to increase the systemic understanding for water retention and the interplay between surface and ground water (e.g., DIWA, SpongeWorks, water quantity management of the district Grafschaft Bentheim, water resources study by GPRW, tackling drought in the Achterhoek by Regional Water authority Rijn and Ijssel, water safety landscapes by Regional Water Authority Drents Overijsselse Delta and Province of Overijssel). These projects can support the understanding of transboundary effects of water management measures and should be used to support the transboundary cooperation.

While water retention aspects are often mentioned regarding drought prevention, flood related projects with transboundary character were not mentioned in the interviews. As the GPRW was founded on the lessons learnt during the flood 2010, flood risk management and flood defence are important topics for the partnership. In 2012, a flood alarm plan was issued, based on which two flood defence exercises have been carried out in 2016 and 2021. The evaluation of the latter exercise showed that improvements can be made particularly in the areas of communication (who is in charge and how can this person be reached?) and information exchange (analysis of the existing and necessary information exchange and implementation in the alarm plan) (van der Klei, 2021). During the winter flood 2023/24, the need for clearer and automated communication was highlighted, as the existing flood alarm plan in the Netherlands contains ambiguous responsibilities and tasks (District Steinfurt).

Table 12 presents issues that actors identified to hinder transboundary cooperation. Particularly for tackling drought management, several actors stress the need for more transboundary cooperation (Vechteverband, Vitens, Regional Water Authority Rijn and Ijssel, province of Gelderland, province of Overijssel, Natuurmonumenten, district Steinfurt, GPRW). On the one hand, the information exchange on drought relevant measures should be enhanced (Vitens, Vechteverband). On the other hand, cooperation between particular actors (i.e., maintenance associations, lower water authority and Vechtstromen) and other actors than the water authorities (i.e., municipalities and other non-water actors) should be strengthened.

As pointed out by Renner et al. (2017) and as became clear during our interviews (i.e., GPRW), the effectiveness of transboundary cooperation and its implementation success is limited due to the nature of the river basin as a regional river basin that includes only small shares of the federate states Lower Saxony and NRW. Due to the centralised decision-making structure of water governance in Lower Saxony, not all the actors needed for decision-making are regularly present in cooperation meetings. Furthermore, their leverage to change policies to harmonise Dutch and German water policy is marginal.

During the interviews it was emphasized that transboundary collaboration often depends on individuals on both sides of the border who act as knowledge carriers. However, this system is very vulnerable. When these ‘connectors’ leave the system, they often lead a void and knowledge is lost. For this reason, it is crucial that capacity is dedicated to transboundary collaboration and that it is well embedded in the organizations.

Since 2019, an annual Border Region Conference has been held as part of cross-border cooperation between the Netherlands and NRW. This conference acts as a network involving various levels of politics. In the interviews within this scoping study, none of the stakeholders mentioned this platform to be relevant for transboundary water management. However, at the 2021 conference, the leadership group decided to explore the inclusion of water and nitrogen as new themes for enhanced cooperation. The relevance of the topics was assessed in an explorative study (Lieshout & Werven, 2022). Its findings highlight similar issues as addressed by the stakeholders in our interviews. Other than the results of interviews and literature research within this study, van Lieshout & van Werven (2022) address the need for adaptation of the border water treaties to the current conditions and political frameworks (i.e., water body structure). While the uptake of low water flows in the border water treaties are currently discussed, the majority of the interviewed stakeholders does not see the need for extensive changes. Also, a study by Mostert & Lukat (Mostert & Lukat, 2021) highlights that stakeholders have working routines beyond the border treaties. An adaptation of the legal basis is not required for a successful transboundary coordination. Different than van Lieshout & van Werven (2022), we find the GPRW by far more promising than the SGK as coordination body for water related questions. Stakeholders uniformly agree that only within this platform actual cooperation has taken place.

Table 12: Overview of issues mentioned by stakeholders during the interviews that hinder transboundary cooperation. We distinguish between national and international aspects. However, all issues mentioned are understood to affect transboundary cooperation. (The table only includes actors that have mentioned barriers to coordination.)

Issue identified	**NLWKN**	**District Grafschaft Bentheim**	**Vechteverband**	**Emlichheim**	**Wasserverbandstag**	**WAZ**	**Governmental district Duesseldorf**	**District Borken**	**District Steinfurt**	**Province of Overijssel**	**Province of Gelderland**	**Natuurmonumenten**	**Regional Water Authority Rijn and IJssel**	**Safety region Twente**	**GPRW**
On national level															
Centralised and fragmented water governance system in Germany leads to less effective decision making in transboundary cooperation (i.e., GPRW)		x	x				x						x		x
Lack of capacities for transboundary cooperation	x		x						x	x				x	x
Inner-German coordination and cooperation in addition to transboundary coordination and cooperation binds capacities					x						x				
On international level															
Conflict of use: in the Netherlands the focus is on nature conservation and business, in Lower Saxony and NRW on agriculture					x				x			x			
Language	x		x			x			x						x
Data exchange	x				x			x	x						
Differing specifications in legislations for management tools (flood risk maps, modelling, drought management plans)	x				x	x					x				
Transboundary transparency on responsibilities and contact persons			x								x				
Cultural differences (bureaucratic culture, communication)	x			x			x		X					x	x
Little exchange between municipalities and other relevant actors of other sectors				x						x					x

6 Data and Models

The information presented in this chapter has been gathered through interviews as well as a brief literature review. A complete overview cannot be guaranteed, but a brief summary is given, and several important aspects are addressed. Tables with overviews of data and models are presented in Annex C.

6.1 Data

Data Overview and International Exchange

A table is presented in Annex C with a complete overview of the relevant data available for flood and drought management in the Netherlands and Germany regarding the extended Vechte river basin. It highlights the comprehensive framework for surface water, groundwater, meteorology, and land use data collection. Discharge is measured through a network of gauging stations in the study area. The network is maintained by the NLWKN in Lower Saxony, LANUV in NRW and by the regional water authorities in the Netherlands. In the Netherlands the coverage of the gauge network is good, but the recent winter highwater showed that the quality and reliability of the gauges under high discharge conditions needs to be improved.

For the Vechte basin, data from the German discharge stations is fed into the FEWS Vechte System.

Groundwater monitoring in both nations is ensured by well-based measurements, offering publicly accessible insights with varying temporal resolutions. The meteorological data collection involves a blend of local weather stations, ground radar and satellite provided by the national meteorological institutes.

Geographical, geomorphological, and land use data are obtained from publicly accessible land use and soil maps, with detailed elevation data characterizing the catchment area. In NRW much geo-data is available online (LANUV) such as Digital Elevation Models (DEM), aerial photos, watercourses, topography, location of structures. The same applies for the Dutch regional water authorities. However, important data such as the dimensions of water-related infrastructure and watercourses are not publicly available (Interview WRIJ). In Lower Saxony DEM data is not publicly available.

Challenges in Data Exchange

Despite the availability of comprehensive data, challenges persist in the (inter-)national exchange of data, which is crucial for effective monitoring and modelling. Initially, Dutch and German authorities regularly engaged in data exchange during the early implementation of the WFD, a practice that has ceased over time. Interviews reveal that international data exchange could be significantly improved, citing issues with missing data, accessibility and applicability across borders. See Annex C for a table with a list of unavailable data.

(Hydro)geological nomenclature differs between the countries, resulting in (hydro)geological maps which do not match at the border. Translation tables exists but are considered insufficient.

Furthermore, flood risk maps differ and do not match up at the border due to the fact that the underlying statistics differ between the countries. (The river discharge related to a flood with a return period of 100 years differs between the countries, and hence the flood extent and hazard also differs.)

An example of missing data and accessibility issues is the measurement data such as water levels and flow rates. Data from the LANUV can be easily downloaded, however, the districts in Germany also measure these data at many locations, but this information is not publicly available (Interview WRIJ).

Another example is the (lack of) availability of transboundary information in official maps. Official German base maps only show sections from Germany and not from the Netherlands (and the other way around). This makes planning in the border area more difficult. There are also no official aerial photographs from Germany and the Netherlands combined. To solve the problem, unofficial aerial photographs from google earth are used (WaBo untere Dinkel).

Examples of successful transboundary data exchange include precipitation data, where hybrids of Dutch and German radar-based estimates are utilized in the model HARMONIE (Hirlam Aladin Research on Mesoscale Operational Nwp In Euromed) and the ECMWF (European Centre for Medium-Range Weather Forecasts) forecast, and discharge data, facilitated by a data-sharing agreement to support the FEWS-Vechte model. Soil data presents a challenge, with detailed data available in the Netherlands through DinoLoket, while German parts of the catchment rely on site-data and extrapolations for model schematizations (WaBO untere Dinkel).

The international data exchange is also enhanced by the current development of an interactive infiltration map. It will be used to assess infiltration capabilities and is going to be accessible on the GPRW website. Also, efforts are made to merge existing groundwater data sources to improve the groundwater level understanding (district Steinfurt, WaBo Untere Dinkel).

Conclusion
The extensive array of data collection and monitoring efforts across the Netherlands and Germany underscores the critical need for cross-border cooperation in environmental conservation and catchment management to enhance the effectiveness of flood and drought management practices. Addressing the challenges in data exchange and emphasizing the strengths of the existing data collection frameworks are essential steps toward sustainable management of the extended Vechte basin.

6.2 Models

A large variety of models is used for the extended Vechte basin. The available models with their purpose, the geographic scope of the model, owner/designer/initiator of the model, and year of construction and last update are given for Germany and the Netherlands in Annex C. The table represents an overview of models, a full representation of all models available in the Vechte catchment is not guaranteed. The main models are presented below.

6.2.1 Runoff Modelling

HBV
The HBV model is a continuous, spatially lumped, conceptual hydrological model where components of the water cycle are estimated using a combination of physical-based and empirical approaches. The resulting river flow is routed using a 1D routing scheme. The combined system is able to simulate hydrology, hydraulics and predict event dynamics driven by rainfall.
The HBV model, which is set up for the whole Vechte catchment, consists of 14 sub-catchments and is also used in the FEWS Vechte forecasting system.

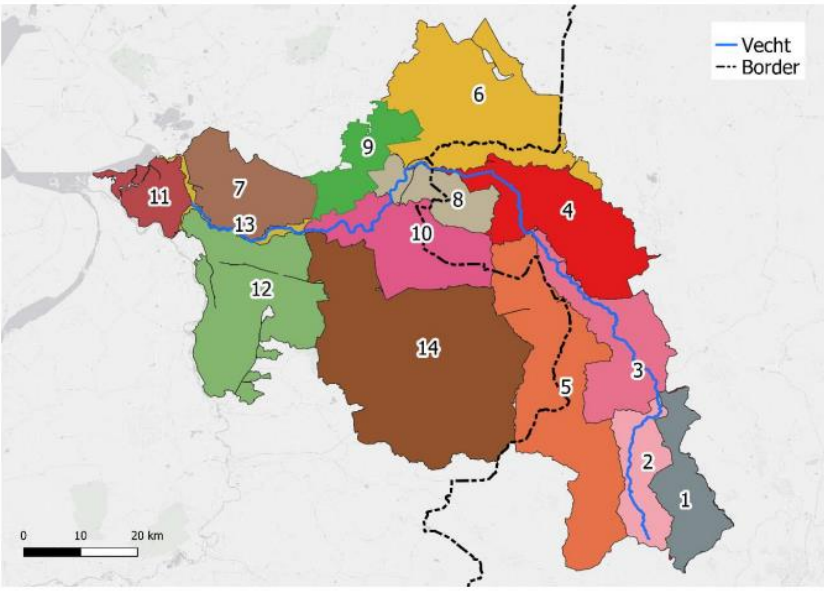


Figure 34: The hydrological units used in the HBV model (Luijkx et al., 2020)

GRADE – Vechte

GRADE is a system for stochastic rainfall generation that can be used to assess intensity-frequency curves, with spatial coverage, under current climate context or alternative climate scenarios. This system has long been used for the Rhine system, and recent developments have set up the model for the Vechte as well. HKV lijn in water and Deltares are collaborating on implementing a link between GRADE-Vechte and FEWS-Vechte in order to carry out the intensity-frequency work for the Vechte catchment.

6.2.2 Inundation Modelling

National flood model Netherlands

At the national scale in the Netherlands, Rijkswaterstaat maintains a series of nation-covering models that are used in national flood hazard assessment and simulations. These models combine many of the standardized national datasets and were developed to simulate large-scale floods from major rivers, lakes and the sea. They provide a starting point for activities in providing more detailed flood simulations for specific regions. The collection of these model schematizations is called Baseline-NL (IPLO, 2024) which can be used by hydraulic models like SOBEK, WAQUA and DELFT3D. The figure below provides an example of a model result for the Dutch part of study area.

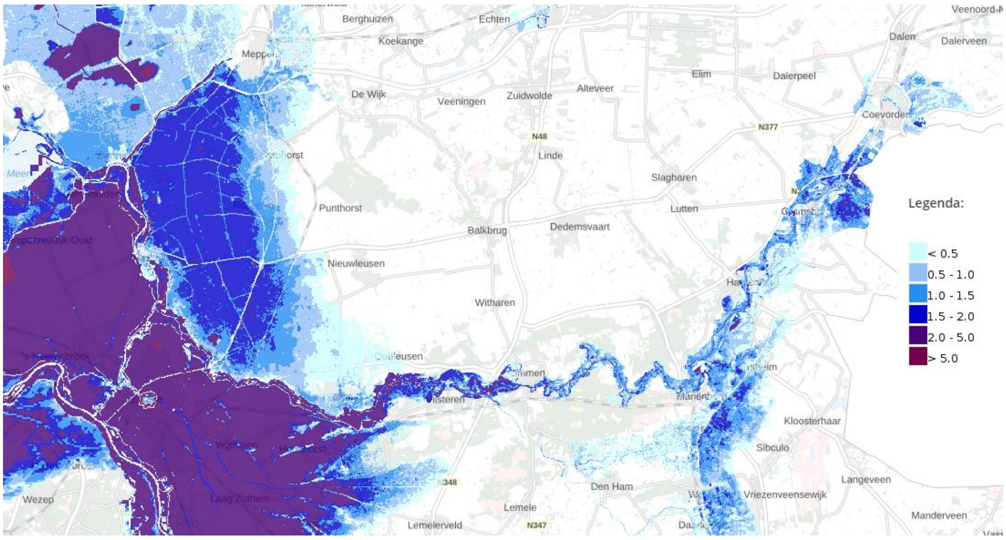


Figure 35: An example of the results of the Dutch national flood model, in this case the maximum flood depth after embankments breach. The maps are available at Atlas Leefomgeving (IPLO, 2024).

Tygron water module

The Tygron flood simulation tool (based on 2D Saint-Venant equations) was set up for local flood hazard assessment (TYGRON, 2020). The study looked in particular at the use of the rapid simulation platform and 3D visualization tools in the assessment of structural water infrastructure failure. The Tygron model (2D) results were compared with SOBEK (1D) modelling results in a master's research river study by van Renswoude (2020) (Figure 35). The results showed typical differences between the 1D and 2D approaches including a generally higher resolution of the Tygron model. On the other hand, the Tygron model results showed inaccuracies especially at low discharges due to incorrectly implemented weirs.

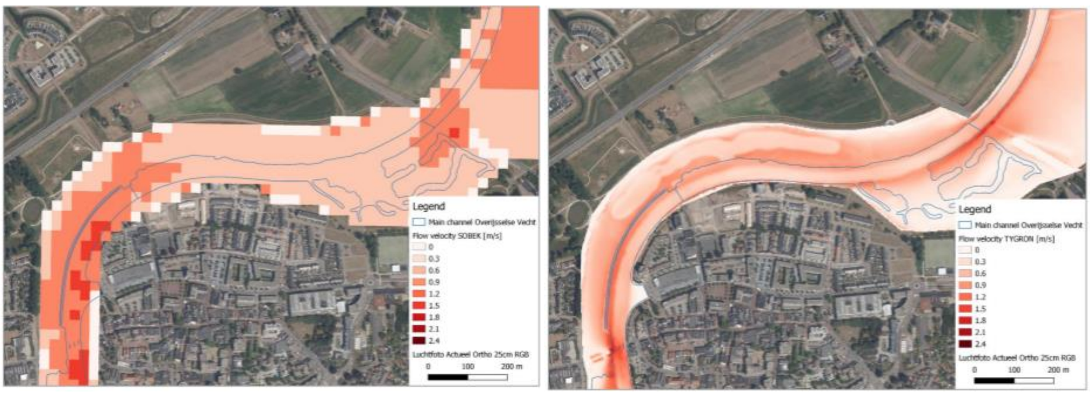


Figure 36: A comparison between SOBEK modelling results at lower resolution (Left panel) and higher resolution results using Tygron (Right panel) for the Vechte River near Hardenberg (van Renswoude, 2020)

Jabron

The program Jabron by Hydrotec enables 1D water level calculation for stead/y-state uniform and non-uniform flow conditions and can be connected to GIS applications. It is used for watercourse planning and the development of flood protection concepts. During the Vechte valley cross-border strategy project from 2007 to 2009 it has been applied to assess improvements of the flood protection and ecological state of the Vechte. During the project a 1D-model for the Lower Saxony's stretches of the Vecht and its tributary the Dinkel has been generated (Hydrotec, 2013).

6.2.3 Flood Forecasting

FEWS – Vechte

The Regional Water Authority Vechtstromen maintains and operates a Flood Early Warning System (FEWS)-Vechte model covering both the Dutch and German part of the Vechte River, but with less detail in terms of gauging stations and representation of the river network in the German part (Interview Deltares). This early warning system was developed initially as part of a collaborative framework, between 2010 and 2013, that was led by Regional Water Authority Vechtstromen, and included German partners such as the districts Grafschaft Bentheim, Borken and Steinfurt, and the Regional Water Authority Drents Overijsselse Delta. Since its initial development, a series of analyses, improvements and research activities have been published surrounding the ongoing development of the FEWS-Vechte model.

In the Dutch Vechte basins, the forecasts from the system are used to issue warnings and disseminate them to the response teams.

Additionally, there is an ongoing effort to merge components of the FEWS-Vechte model and the German PANTA RHEI system. This initiative is part of the Living Vechte collaborative framework between Dutch and German water authorities and is still ongoing.

FEWS – Berkel and Oude IJssel

There is also an operational transboundary flood forecasting system for the Berkel and Oude Ijssel River, which produces an hourly forecast for 7 days ahead. The schematization in the Netherlands is more detailed than in Germany, however the Regional Water Authority Rijn and Ijssel (WRIJ) measured the main watercourses in Germany (cross-sections) and use them in the model. Main points for improvement are adjustments to the hydrological models and the expansion of measurements points in Germany. Furthermore, there is an interest to investigate if the current system could be adapted to be used for drought forecasting as well.

PANTA RHEI

The PANTA RHEI model is a flood early warning system hosted and maintained by the German water authorities. Panta Rhei is a semi-

distributed water-balance model. The Vechte model was set up in 2016 and covers the whole German part of the Vechte basin. The system forecasts the discharges along the river up to 7 days in advance. During a flood event, forecasts are updated every 3 – 6 hours and are published on the NLWKN website Pegelonline.
In case of a flood event, the calculated model discharges for Emlichheim (most downstream point of the Panta Rhei model) are shared with Dutch authorities via the FEWS – Vechte system.

FEWS – NRW
In NRW, flood forecasting systems are currently let set up under the lead of the LANUV for all regional rivers in the federal state. This initiative is part of the 10-point action plan for flood protection (issued in reaction to the 2021 flood event in the Ardennes and Eiffel) in which the set-up of model-based flood forecasting systems for regional rivers is recommended. The system is set up in the DELFT-FEWS platform using the LARSIM model for forecasting.

6.2.4 Groundwater Modelling

NHI
In the Netherlands, as part of the NHI (national hydrologisch instrumentarium) several regional groundwater models (ModFlow-MetaSwap/iMOD) exists, with a resolution of 25 m x 25 m. There are two models which are present in the study area – AMIGO and MIPWA.
AMIGO (Actueel Model Instrument Gelderland Oost) covers the area which is managed by the regional water authority Rijn and IJssel and was jointly commissioned by the regional water authority Rijn and IJssel, province of Gelderland and drinking water company Vitens. MIPWA (Methodiek Interactieve Planning Waterbeheer) is the regional groundwater model for North – Netherlands and covers four provinces: Groningen, Friesland, Drenthe and Overijssel.

BOWAB and mGROWA
In Lower Saxony, the LBEG (Lower Saxon State Office for Mining, Energy and Geology) currently uses two models for groundwater management: BOWAB (BOdenWAsserBilanzierung) and mGROWA. BOWAB is a water balance model that was developed at LBEG. The soil water balance of agricultural land can be calculated on a daily basis and used to make statements on irrigation control and information on the displacement of dissolved substances. It is publicly available on LBEG website (LBEG, n.d.).

The mGROWA model was developed by LBEG in collaboration with Forschungszentrum Jülich and gives information on the monthly groundwater balance on a large scale. It calculates groundwater recharge rates (Ertl et al., 2019). A state-wide groundwater model is planned to be developed starting in 2024.

In NRW, the mGROWA model for day-to-day and long-term ground water level prediction has been implemented region wide as well (Herrmann et al., 2019). It has the same functionalities as in Lower Saxony and is publicly available at the GeoPortal NRW (NRW, 2020). On the local level within the municipalities and the regional water authorities, a more detailed and sophisticated groundwater model is considered beneficial. If a groundwater model on a local scale was implemented, the respective stakeholders could benefit from more realistic data and better access and compatibility of the model results.

6.2.5 Previous initiatives for model collaboration

There are various ongoing initiatives for stronger collaboration between Dutch and German water authorities in flood and drought modelling. The list below names some of these that include plans to further combine and improve modelling methods between the organizations.

- Veilige Vecht: https://veiligevecht.wdodelta.nl/default.aspx
    - Scoping Report: https://veiligevecht.wdodelta.nl/bibliotheek/default.aspx#folder=2583417
- De Vecht POV: https://devecht.eu/pov/
- Vecht Visie: https://devecht.eu/vechtvisie/
    - https://devecht.eu/publish/pages/29934/nl_vechtvisie_internet_1.pdf
    - https://devecht.eu/publish/pages/29934/themakaart_water_090527_1.pdf
- The Interreg proposal DIWA, which includes a work package on transboundary groundwater modelling and data analysis and exchange.

6.2.6 Conclusion

As the overview of models used within the extended Vechte basin shows, there is a great variety in models used. This ranges from hydrological models to hydraulic models as well as groundwater models. While each model approach has its values and raison d’être, it complicates uniform usage of model results by the different stakeholders.

The model landscape in the extended Vechte basin is diverse and covers several model approaches and purposes. Local models have the advantage of generally being well adapted and validated for their study areas. Furthermore, the users usually have detailed local knowledge and are able to identify inconsistencies within model results easily. However, these local models lack the capability of showing connections within the whole catchment. That way, potential in collaboration and knowledge exchange is lost which could be valuable in case of an approaching flood or drought event.

There have been demonstrable initiatives to collaborate and combine Dutch and German models, but in practice it has proven challenging to lead to internationally useful products. Taking the FEWS Vechte as an example, the system was collaboratively developed between 2010 – 2013. However, as discussed in chapters 2.8 and 3.2.1, there are still considerable improvements needed in order to achieve a robust and reliable flood forecasting system.

7 Conclusions

7.1 Floods

The extreme floods in Western Europe in 2021 resulted in an increased focus on flood risk management in regional river basins.

In NRW, the 10-point work plan for flood protection in times of climate change was published in 2022. In the Netherlands, the policy council on flooding made 21 proposals to adapt flood and high-water level policies to be better prepared for a period of extreme precipitation. According to the interviewees, in Lower Saxony no specific actions have been taken after the flood of 2021.

In NRW, one of the recommendations was the implementation of flood warning systems in regional river catchments. As a result, model-based flood forecasting systems for the Dinkel, Berkel and Oude Ijssel are in development. Unlike in many other transboundary basins, there already exists a transboundary flood forecasting system for the Vechte catchment (FEWS Vechte). The system was developed jointly after the floods in 1998. It is regularly updated on the Dutch side of the border; however, updates of the German area are much less frequent.

One of the recommendations from the policy council in the Netherlands is that every region should perform a regional stress test of their water system as well as performing transboundary stress tests. These stress tests include a 'water system assessment' (waterbeeld) as well as an impact assessment. The Dutch actors emphasized in their interviews that there is much interest to perform such an assessment of the extended Vechte basin to better understand the transboundary water-system itself and to evaluate the potential (transboundary) impacts of extreme floods on the study area.

The extended Vechte basin is frequently subjected to floods, e.g. the high water situation during the Christmas break in 2023/2024. This winter flood event led in general to limited damage; however more extreme floods events are expected in the future.

Actors in the study area on both sides of the border mentioned that the potential impacts of an extreme flood are not well understood, especially impacts on critical and sensitive infrastructure and cascading-effects have not been looked at.

Actors on both sides of the border are aware that climate change will increase the probability and intensity of extreme floods. However, at the same time there is no common approach to / guideline on how to incorporate the effect of climate change in flood probabilities. Flood probabilities are usually based on historical flood events, not taking into account future changes in climate.

Different flood probabilities and model approaches also cause inconsistencies in the flood risk and flood hazards maps along the border. So far, cooperation among the actors is effective for communicating the differences; however, there are no plans yet for creating these maps jointly. A first step could be to add the flood risk and flood hazards maps of the extended Vechte basin to the Rhine atlas which provides a standardized representation of the flood risk along the whole river.

While in the Netherlands the approach to flood risk management is uniform throughout the country, actors in Lower Saxony emphasized the challenges of a missing state-wide approach to flood risk management. As a result, the level of flood protection differs greatly between municipalities.

7.2 Droughts

In recent years the study area was affected by several major drought events. Especially, the Dutch actors emphasized that they are much more concerned about drought-related impacts (such as drinking water supply, desiccation and subsidence) than flood-related impacts.

The water system on the Dutch side is much more regulated than the German study area. In Germany, the rivers are to a greater extent freely flowing and the possibility to manage water is much smaller. In the Netherlands, the infrastructure makes it possible to abstract water from the Ijssel to supply a part of the extended Vechte basin with imported water (through the Twente canal system), and there are more possibilities to retain water in the system (through weirs etc.). Historically, the water infrastructure in the Dutch part of the study area was mainly used to drain and discharge the water as quickly as possible to avoid water logging and flooding. However, as the area suffered much from desiccation, in the last years a paradigm shift took place and there is a much higher focus now on water retention. Many drought risk management projects have been executed to retain more water in the systems and to increase the groundwater levels in the area. Drought management and thereby water retention is one of the focus areas of the local regional water authorities.

In Germany, actors both in NRW and Lower Saxony emphasized the importance of a state-wide drought management concepts and plans, as well as personnel, which is dedicated for drought management. Such a state-wide strategy is required to be able to implement water retention measures structurally on a large-scale and use aquifer recharge as a means of increasing the groundwater levels strategically. The actors also highlighted the importance of learning from the Dutch knowledge and experiences in regard to water retention, such as retaining water in agricultural areas using small weirs.

Historically, agriculture was mainly rain-fed in the study area. However, the recent dry springs and summers required irrigation in order to limit crop damage. As a result, the potentially irrigated area is increasing, and it is foreseen to increase further in the future. In Lower Saxony, there are plans to use processed water for irrigation. Currently, this water is discharged back to the river and contributes to the river flow to the Netherlands.

Compared to the transboundary impacts of floods, the transboundary interactions of droughts are much less understood. Retaining more water in Germany, will impact the river discharges in the Netherlands. However, the transboundary impact and especially the extent of the impact on groundwater levels across the border is much less understood.

Nature areas in the Netherlands located at the border suffer from brooks falling dry in the summer as groundwater levels on the German sides are too low to sustain them. On both sides of the border, the overview of (small) groundwater extractions is limited, so that there is no good understanding about how much water exactly is withdrawn from the aquifers. On both sides of the border, activities are ongoing to get a better picture of the groundwater extractions. A common transboundary groundwater study / model might be a mean to enhance the cross-border collaboration as well as the cross-border understanding on groundwater.

7.3 Transboundary cooperation

Unanimously, the GPRW cooperation is regarded positively on both sides of the border. On the other hand, platforms such as the (permanent) border commission are mainly seen and used for information exchange. The GPRW is recognized as a vehicle for actively cooperating and jointly executing projects such as the Interreg DIWA (proposal) or the EU-Horizon SpongeWorks project starting this year. Stakeholders uniformly agree that only within this platform actual cooperation has taken place.

On both sides of the border, it was emphasized that for successful cooperation and projects it is paramount that across the border the right people with the right mandate are involved, so that decisions can be made at location. Currently, the lack of participation of the NLWKN in GPRW requires additional coordination causing longer decision-making processes. For this reason, a stronger involvement of the NLWKN is strongly desired by the local water authorities in Lower Saxony. On the Dutch side the provinces, which play a crucial role in drought issues, are not part of the GPRW.

Differences in data and models are seen as one of the obstacles in transboundary cooperation. Due to the use of different statistics and models the flood risk maps differ between Germany and the Netherlands. These differences have been discussed, however there is not yet a project / initiative initiated to commonly evaluate the flood risk of the basin. Regarding models, the interviewed actors see most necessities in common transboundary groundwater and climate adaptation models. Also, a common flood forecasting model for the Berkel and Oude IJssel were mentioned.

There appears to be more attention for transboundary flood risk management than for transboundary drought risk management. While actors working in flood-related topics knew their counterparts across the border well, the Dutch actors in drought management emphasized the difficulties of finding their counterpart in Lower Saxony / NRW. Furthermore, different stakeholders need to be involved in drought management than in flood management. Drinking water companies, farmer’s associations and nature conservation organizations need to be involved closely.

To avoid future conflicts, actors on both sides of the border suggested to make agreements on retention areas as well as minimum required flows from Germany to the Netherlands.

7.4 Knowledge gaps

In total more than 80 knowledge gaps have been collected in more than 25 interviews (see Annex E). The majority of the knowledge questions falls into the bio-physical category. Knowledge gaps by the Dutch authorities focus strongly on:

1. a better system-understanding to be able to quantify transboundary interactions of hydrological processes during floods and droughts using transboundary models
2. the need for integrated catchment-wide stress tests
3. a better understanding of the potentials and limitations of the sponge functioning of the landscape

These knowledge gaps are also touched upon in chapter 2.4 (geohydrology), 3.1 (floods) and 6 (data and models), while the information and data exchange is established, joint methodology and analysis, which will enhance the system-understanding are limited. In

Knowledge questions from the German stakeholders are strongly related to:

1. the need for state-wide comprehensive drought management concepts and strategies (Lower Saxony and NRW)
2. the need for flood management concepts and plans (Lower Saxony)
3. the interest to learn from the Dutch approach to drought management

These knowledge questions are linking to the state of the drought management in Germany as described in chapter 4.1.3 (Drought risk and disaster management). While a National Water Strategy was published in 2023, no concrete approaches to drought management are mentioned yet. The need for comprehensive flood management concepts is also discussed in chapter 4.1.2 (Flood risk and disaster management).

On both sides, the need of better monitoring (especially groundwater) is mentioned as well as the need for data harmonization (especially hydrogeological data). The need of developing adequate models (e.g. a transboundary groundwater model, a dynamic groundwater model for Lower Saxony, transboundary flood forecasting models for Berkel and Oude IJssel) was stressed in several interviews by a wide range of different actors and is also emphasized in chapter 6.2 about the models.

The stakeholders involved in the crisis management (safety regions in the Netherlands and municipalities in Germany) emphasized that the impacts of extreme floods and droughts are not well understood yet in the study

region, especially the impacts and cascading effects related to critical and sensitive infrastructure. Furthermore, the impact of extreme events (e.g. above HQ100) is often not considered at all.
Critical infrastructure as well as the understanding of the flood and drought impacts are discussed in chapter 3.1 (Floods) and 3.2 (Droughts).

Especially on the Dutch side there is great interest in the potential and limits of catchment-scale sponge functioning measures on extreme floods and droughts such as:

- how to find the right balance between too wet and too dry
- the effect of flood / drought measures on the opposite extreme (in regard to future measures, but also the need to quantify the effect of already implemented measures
- the possible role of restored transboundary peatlands / areas with large unsaturated zones for the mitigation of floods and drought impacts as well as their importance for nature conservation. Many (transboundary) small brooks dry up in the summer and therefore currently the possibilities to restore the ecologically in these brooks is limited.

The chapters on climate (2.2), floods (3.1) and droughts (3.2) emphasize that flood and drought events are both expected to increase in frequency and intensity, which also increases the need for measures which ideally can mitigate floods and droughts.

Based on the interviews Dutch actors had no overview of the planned flood and drought mitigation measures in the German part of the extended Vechte basin. There is also a knowledge gap about the impact of these measures on the flood and drought risk in the Netherlands and which type of measures would lead to a changed situation.

On both sides of the border, also knowledge questions related to governance were mentioned in the interviews. In the Netherlands, the questions focus on possibilities to further improve the transboundary cooperation and ways to overcome the difficulties due to the different water management structures in the countries / states. In Germany, the knowledge questions focus on the lack of plans, strategies and concepts as well as the conflicting goals of the Water framework Directive (free flowing water) with drought management strategies (retaining water). This conflict hinders the implementation of highly needed drought mitigation measures in the system.

These knowledge gaps are linked to the transboundary cooperation and its identified challenges as described in chapter 5.

An overview of all knowledge gaps identified during the Vechte Scoping Study can be found in Annex E.

8 Scoping for JCAR ATRACE

Based on the identified knowledge gaps and the results of the literature study, the following activities could be considered in the follow-up of JCAR ATRACE or in other projects:

The need for a **transboundary water system analysis** and a **transboundary stress-test** was strongly emphasized in the interviews. The common understanding of the risk of extreme floods and droughts can be seen as the foundation to facilitate jointly addressing these risks. Impact assessments will allow analyzing the (transboundary) effects on critical and vital infrastructure. In the study area, the current understanding is limited which will strongly hamper crisis management in case of an extreme event.

Comprehensive evaluation of the highwater 2023 / 2024 for the whole catchment. The event is currently evaluated locally by the different regional water authorities and in Germany the NLWKN is evaluating the flood events in Lower Saxony. Bringing these assessments together will enable a catchment–wide analysis of the things that went well and the things which need to be worked on. As part of the stress-test implementation plan the assessments may be synthesized and evaluated.

Forecasting Systems - The FEWS Vechte system faced difficulties forecasting the recent high-water event, resulting in a loss of confidence of the local regional water authorities in the system. There are several challenges. First of all, the underlying monitoring system in the study area needs to be improved. The recent highwater showed that the measurement range of many measurement points is too limited (e.g. at the Regge), resulting in the absence of reliable measurement points, which are required to feed the forecasting system. Furthermore, the hydrological and hydrodynamical models in the FEWS Vechte require recalibration and further development, as they are not sufficiently able to simulate the hydrological and hydraulic processes in the catchment under extreme conditions. Within the JCAR ATRACE programme an analysis of the FEWS-Vechte system is being set up to outline the top-3 actions required to come to a climate-resilient FEWS -Vechte for the whole catchment.

There is a transboundary FEWS system for the Berkel and Oude IJssel which is operated by the Dutch regional water authorities and at the same time there is a FEWS system developed for all regional rivers in NRW. The knowledge and expertise on both sides of the borders could be combined into a joint forecasting system.

Investigate possibilities to **further improve transboundary cooperation** and ways to overcome the difficulties due to the different water management structures including a review of the December 2023 high water from a governance perspective. Such as an evaluation of the leverage of all actors for transboundary cooperation within the current governance framework and possibilities to adapt this framework for more effective cooperation to tackle future climate extremes.

Catchment-scale sponge functioning measures are seen as an opportunity to increase the resilience of the basins against floods and droughts. However, there are still many uncertainties in their mitigation effect for extreme events as well as their impact on both extremes. As part of an EU-Horizon project called SpongeWorks several sponge functioning measures will be implemented in the Vechte catchment, and their effects will be quantified.

The need of a **comprehensive drought management strategy** was mentioned in several interviews. However, the cooperation on drought risk management is limited and a transboundary network does not exist yet. Also, the understanding of the (transboundary) groundwater interaction and therewith the need for transboundary cooperation is not known. The establishment of **a transboundary groundwater monitoring network** can not only improve the understanding of the transboundary interactions but can also be a starting point for transboundary cooperation on this subject.

The floods in 2021 increased the focus on flood risk management in smaller basins. In the study area, a plethora of projects is starting up to focus on different aspects of flood risk management.
In 2009, a joint vision on the Vechte was developed which outlined the necessary steps to transform the Vechte into a half-natural river with clean water, healthy nature and an economically thriving environment. **Reassessing the vision** and evaluating the progress, successes and challenges could provide valuable lessons for the projects and initiatives currently starting up.

Ideally, ongoing and upstarting projects (e.g. DIWA, SpongeWorks, JCAR ATRACE) will align their activities to create synergies and maximize the benefits for the study area.

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Annexes

Annex A: Overview of performed interviews

Table 13: Overview of interviews in the Netherlands

Stakeholder	Description	Date	Interview	Type
Rijkswaterstaat	National authority for infrastructure and water works	15.01.2024 08.02.2024	Deltares	online
Provincie Overijssel	Regional State Authority	05.12.2023	Deltares	online
Provincie Gelderland	Regional State Authority	26.09.2023	Deltares	@location
Waterschap Vechtstromen	Local Water Authority	23.01.2023	Deltares	@location
Waterschap Drents Overijsselse Delta	Local Water Authority	06.11.2023	Deltares	online
Waterschap Rijn en Ijssel	Local Water Authority	16.11.2023	Deltares	@location
Veiligheidsregio Twente	Crisis Management	12.12.2023	Deltares	online
Veiligheidsregio IJsselland	Crisis Management	15.01.2024	Deltares	online
Vitens	Drinking Water Company	13.12.2023	Deltares	online
Natuurmonumenten	Nature organisation	07.12.2023	Deltares	online

GPRW	Coordination office	23.01.2023	Deltares	online

Table 14: Overview interviews in Lower Saxony

Stakeholder	Description	Date	Interview	Type
Ministerium für Umwelt, Energie und Klimaschutz	Highest Surface Water Authority	21.11.2023	UOs, Deltares	online
NLWKN	State Authority	21.11.2023	UOs, Deltares	online
LBEG	State Authority for mining, energy and geology incl. groundwater	30.11.2023	UOs, Deltares	online
Grafschaft Bentheim	Lower Water Authority	22.10.2023	UOs	online
Vechtverband	Maintenance and landscape conservation association	14.11.2023	UOs	online
Wasser – und Abwasser Zweckverband	Drinking Water Company	14.12.2023	UOs	online
Samtgemeinde Neuenhaus	Municipality (Crisis Management)	12.12.2023	UOs	online
Samtgemeinde Emlichheim	Municipality (Crisis Management)	04.01.2024	UOs	online
Amt für regionale Landesentwicklung	Regional State Development including peatland renaturation	18.12.2023	UOs	online
Wasserverbandstag e.V.	Umbrella organization of water associations	17.11.2023	UOs	online

Table 15: Overview interviews in NRW

Stakeholder	Description	Date	Interview	Type
MULNV	Highest Water Authority		RWTH Aachen, Deltares	
LANUV	State Authority	05.04.2023	RWTH Aachen, Deltares	online
Bezirksregierung Muenster	Upper Water Authority			
Bezirksregierung Duesseldorf	Upper Water Authority	19.03.2023	RWTH Aachen	online
Kreis Borken	Lower Water Authority	14.12.2023	RWTH Aachen	online
Kreis Steinfurt	Lower Water Authority	22.01.2024	RWTH Aachen	online
Wasser- und Bodenverband ‘Unteres Dinkelgebied’		04.12.2023	RWTH Aachen, UOs	online

Annex B: Description of the Basin

Geography:

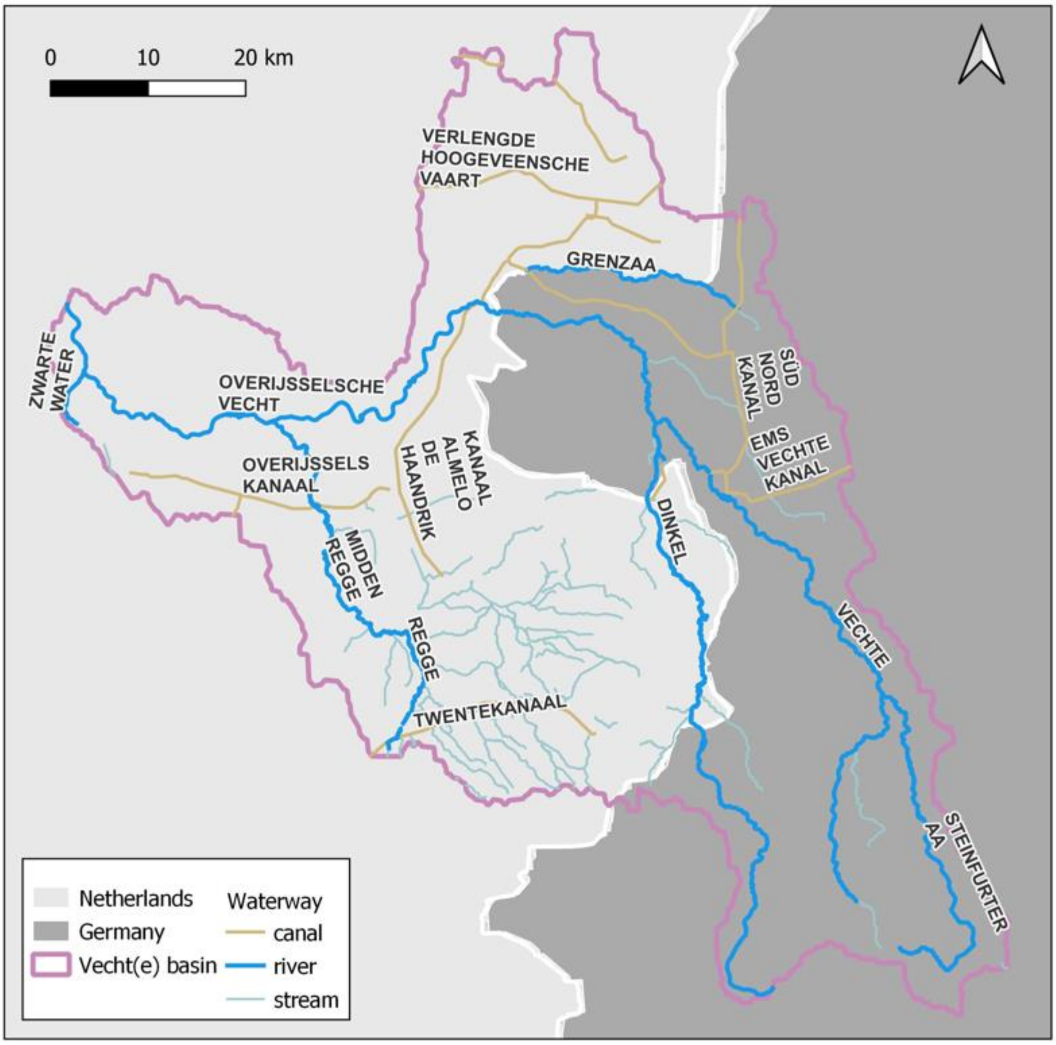


Figure 37: Vechte catchment

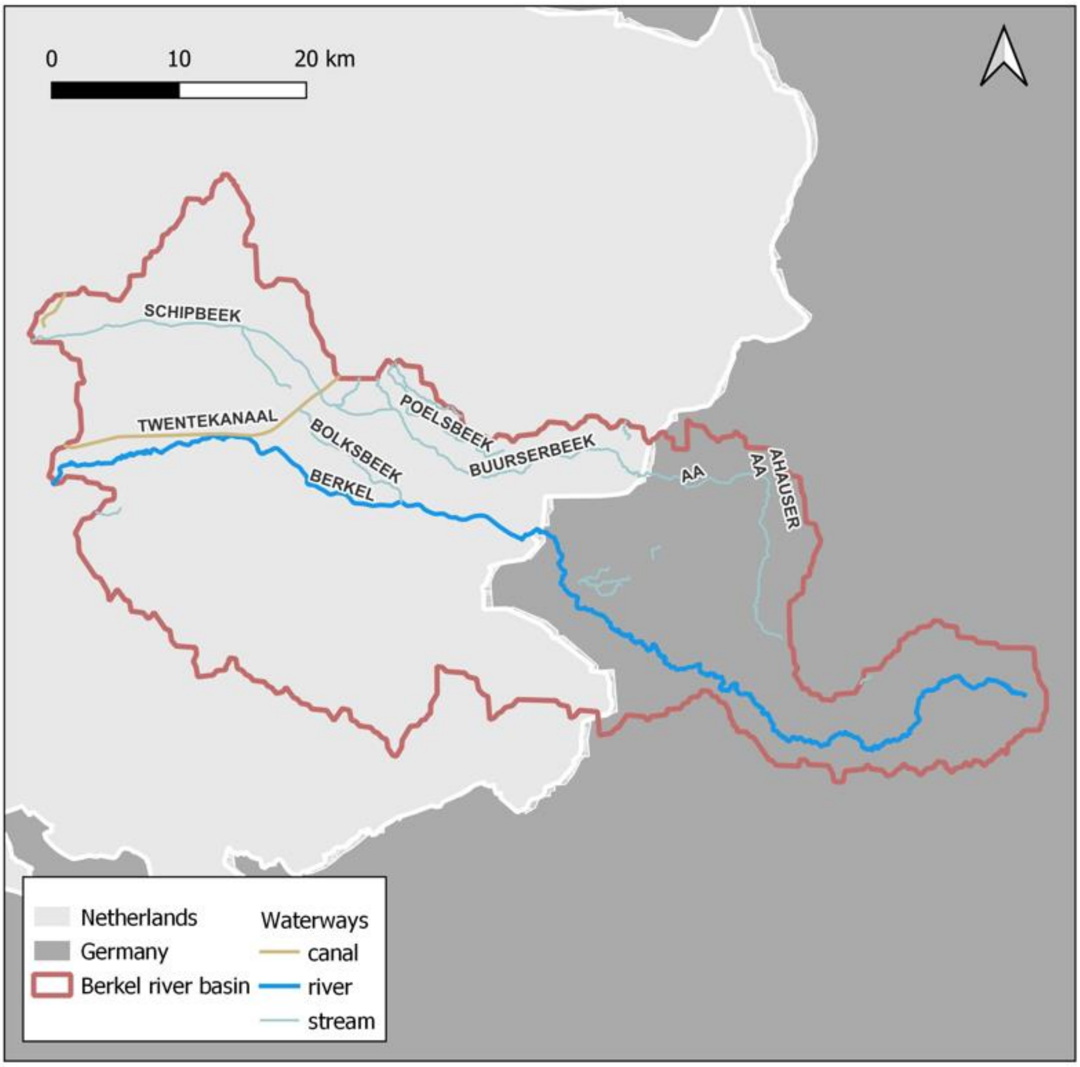


Figure 38: Berkel Catchment

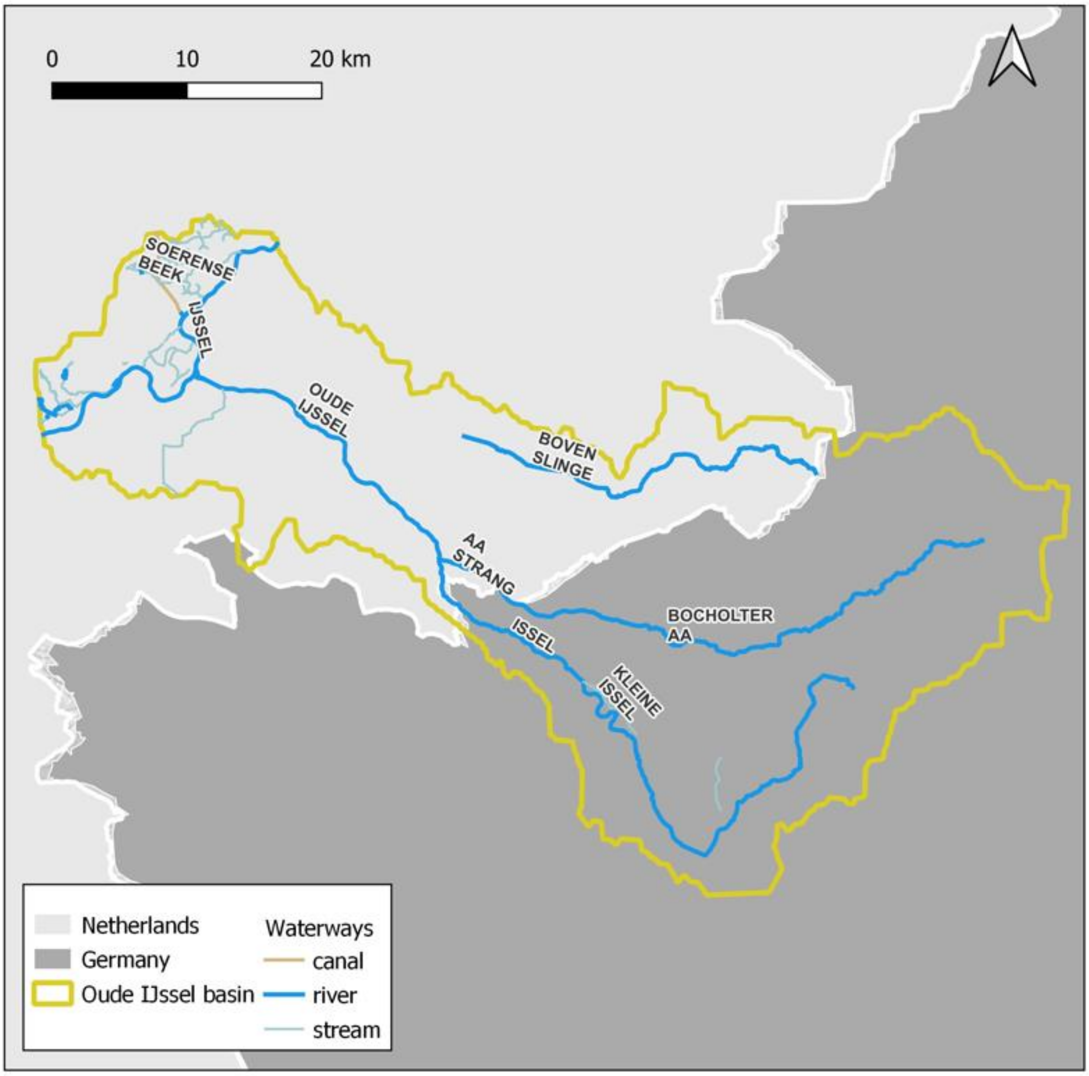


Figure 39: Oude IJssel catchment

Morphology:

Table 16: Projects along the Dutch Vechte executed since 1998 in the area managed by regional water authority Vechtstromen (adapted from van Haastregt, 2023).

Finished	Project (translated)	Description of project
1999/2000	Construction Noord- & Zuid-Meene	Emergency retention area
2004	Uilenkamp	Digging side channel
2008	Molnmarsch	Digging weir passing side channel next to weir Mariënberg
2008	Brucht	Widened shallow meandering river, 2 bumps
2009	Loozensche Linie	Digging side channel

2010/2017	Vechte parks Hardenberg	Lowering ground level, destoning, canoe ditch, construction fish ladder
2012	Side channel Junne phase 1	Digging weir passing side channel next to weir Junne
2012	Barrier Vechte	Barriers near Ommen South, Stekkenkamp and the Laar brought to higher level
2013	Sluice Hardenberg	Construction sluice around weir
2014/2016	Grensmeander	Side channel, destoning, shallowing, dike replacement
2016	Vechte bank North	Widening northern banks (urban side) and widening beneath the bridge Ommen
2017	Barrier Vechte	Regional barrier brought to higher level
2018	Vechte bank South	Side channel has been realised near camping Koeksebelt
2019	Sluice Junne	Construction sluice around weir
2019	Sluice Mariënberg	Construction sluice around weir
2022	Baalder floodplain	Digging graben, removing sand resisting bank
2022	Elongating side channel Junne	Side channel- has been elongated on upstream side
2022	Karshoek-Stegeren	Elongating side channel, meander, nature friendly banks, destoning
2022	Rhezermaten	Meanders, nature friendly banks, design dimensions Vechte, destoning
2023 (in progress at the time)	Gramsbergen	Digging side channel De Haandrik, removing sand resisting bank, nature friendly banks, destoning
Unknown	De Haandrik - Vechte	Widening cross section of the crossing with channel Almelo de Haandrik until inlet Zuid-Meene

Table 17: Projects along the Dutch Vechte executed since 1998 in the area managed by WDOD (adapted from van Haastregt, 2023).

Finished	Project (translated)	Description of project
2000	Water supply plan Dalfsen (Emmertochtsloot)	Construction of pools in floodplain from which water can be abstracted in dry periods
2002	Construction settling pool Vilsteren	Construction settling pool at the south side of the Vechte
2006	Destoning river bank Vechterweerd	Destoning southern river bank of summer bed
2007	Construction floodplain Berkum	Construction graben in floodplain and small design measures
2010	Construction natural buffer Agnietenberg	-
2010	Construction side channel Den Doorn	Construction of shallow side channel at Huis Den Doorn
2012	Destoning Varse	Destoning side channel Varse (northern side)
2012	Destoning river banks Vechte	Destoning (complete and partial) of a part of the river banks on this trajectory
2014	Nature friendly river bank Vilsteren-Dalfsen	Destoning of river bank, breaching summer banks, construction of bumps in summer bed
2014	Construction Vechte park Dalfsen	Construction Vechte park with heightening/deepening in floodplain Vechte
2014	Construction waterfront Dalfsen	Dike strengthening at the urban area Dalfsen (northern side Vechte)
2014	Construction Vechtecorridor	-
2015	Construction side channel Vilsteren	Construction blue side channel with inlet
2015	Dike strengthening Hessum	A very small part of the barrier was heightened (until T1250)
2015	Construction green ditch Vechterweerd	Construction of green ditch in southern floodplain weir Vechterweerd

2015	Construction access bridge weir Vechterweerd	The accessway with culvert to the weir complex was replaced by a bridge (flow width ±90 m)
2016	Area development Varse	Digging northern floodplain of the Vechte

Floods:

The following table provides an overview of water peaks at specific water level measuring points. The values are between 1964 and 2017 and include various measuring points on the Vechte and Dinkel. Yet, the data from the flood winter 2023/24 was not included. The data was added manually through the time range diagram (30 days) in January 2024. For the German Neuenhaus und Emlichheim the flood 2023/24 shows the highest extrem value of river water level. As shown in the table, for Ohne at river Vechte and Pegel I at river Dinkel other floods were even higher.

Table 18: Extreme values of river water levels (Vechte and Dinkel) at different level measuring points (1964-2017). Source: Pegelonline, NLWKN

**2023 winter/christmas flood manually added*

River	Level measuring point	Extreme values (1964 – 2017*)	
Vechte	Ohne, Germany	12.12.1965	328 cm / NN + 36,94 m
		15.01.1968	336 cm / NN + 37,02 m
		27.08.2010	355 cm / NN + 37,21 m
		27.12.2023	302 cm / NN + 36,68 m
	Neuenhaus, Germany	01.01.1987	512 cm / NN + 16,12 m
		29.10.1998	510 cm / NN + 16,1 m
		30.08.2010	512 cm / NN + 16,12 m
		27.12.2023	515 cm / NN + 16,15 m
	Emlichheim, Germany	14.03.1981	485 cm / NN + 12,85 m
		02.01.1987	498 cm / NN + 12,98 m
		31.10.1998	508 cm / NN + 13,08 m
		27.12.2023	514 cm / NN + 13,14 m
Dinkel	Lage I, Germany	09.02.1966	334 cm / NN + 18,34 m
		01.01.1968	339 cm / NN + 18,39 m
		23.02.1970	333 cm / NN + 18,33 m
		26.12.2023	316 cm / NN + 18,16 m

Annex C: Data and Models

Table 19: Available Data for the Study area for Netherlands (NL) and Germany (G)

Surface Water – Water Levels and Discharge	

NL	**Water Level**
	- Measured with: Weirs
	    - Temporal resolution: Various
	    - Availability: mostly regional water authoroties/provinces own data, (partly) publicly available
	    - Unit: mm above NAP
	
	Discharge
	- Measured with: Measuring stations*, Mostly using cross section combined with flow speed
	    - Temporal resolution: Mostly hourly measured at specific locations
	    - Availability: mostly regional water authorities/provinces own data, (partly) publicly available
	    - https://waterinfo.rws.nl/#/publiek/waterhoogte
	    - Unit: m^3/s
	
	- Based on: Water levels (based on Q-h relations)
	    - Temporal resolution: Various
	    - Availability: mostly regional water authoritiess/provinces own data, (partly) publicly available
	    - Unit: m^3/s

G	**Water Level and Discharge**
	- Gauge of the NLWKN Meppen (4 gauges in the Vechte river basin)
	    - Temporal resolution: 15 min,
	    - Availability: 15 min values of the last 30 days can be viewed at https://www.pegelonline.nlwkn.niedersachsen.de,
	    - Unit: m & cm/NN
	
	- Gauge of the LANUV NRW (2 gauges in the Vechte river basin)
	    - Temporal resolution: Continous measurements
	    - Availability: Values for the last year can be viewed at https://hochwasserportal.nrw
	    - Unit: cm
	
	Additional information:
	- In addition to the gauges and data provided by the state of North Rhine-Westphalia, regional gauging networks are also intended to inform the population. Some of the information is also passed on to NL. (Interview with district Borken)

	- The Borken district has a flood service with an on-call service that acts independently of the state of NRW to report rising water levels at an early stage (internal agreement) (Interview district Borken)
Groundwater – Groundwater Level	

NL	- Wells (give point measurements)
	Can be transformed into spatial data by using Artificial Neural Networks (Beltman, 2020)
	  - Temporal resolution: Depends on the station.
	  - Availability: Freely available from the Dinoloket website (responsible institute is TNO – all subsurface data from the Netherland is documented in the Basic Subsurface Registration System (Basisregistratie Ondergrond -BRO)). Or collected for regional water authorities by external companies like for example Wareco.
	  - https://www.grondwatertools.nl/gwsinbeeld/
	  - Unit: mm relative to MSL (mean sea level)

G	- NLWKN Meppen measuring stations (4+3 in the Vechte river basin with data available online, further gauges existent)
	  - Temporal resolution: Daily measured
	  - Availability: Values can be viewed at https://www.grundwasserstandonline.nlwkn.niedersachsen.de/Messwerte,
	  - Unit: m above sea level and m below ground level
	
	- Wells (point measurements)
	  - Temporal resolution: monthly
	  - Availability: freely available on https://www.elwasweb.nrw.de
	  - Unit: m above NHN (standard elevation zero)

Meteorology - Precipitation	

NL	- (Local) KNMI weather stations: 3 in the Dutch part: Twente, Heino and Hupsel (on the edge), since 1951, 1991, and 1981, respectively.
	  - Temporal resolution: Hourly, two times a day processed
	  - Spatial resolution: Point
	  - Availability: Collected by KNMI, Publicly available
	  - https://www.knmi.nl/producten-en-diensten/
	  - Unit: mm
	
	- Ground radar data (gridded), corrected using rain gauges [KNMI, 2023a,b]
	  - Temporal resolution: 5 min, hourly
	  - Availability: Collected by KNMI, dataset can be downloaded via the Open Data API.

	- Unit: mm
	
	- The Global Precipitation Measurement (GPM) satellite constellation [West et al. (2019)].
	  - Temporal resolution: Every 1-2h, operational since 2014
	  - Spatial resolution: 0.1° – 0.25°
	  - Availability: Publicly available
	  - Unit: mm
	
	- E-OBS gridded ensemble
	  - Temporal resolution: Daily sum, since 1950.
	  - Spatial resolution = 0.1° – 0.25°
	  - Availability: Publicly available [Cornes et al. (2018)].
	  - Unit: mm
	
	- ERA5 re-analysis from the Copernicus Climate Change Service (C3S) at ECMWF (European Centre for Medium-range Weather Forecasts)
	  - Temporal resolution: Hourly, since 1950.
	  - Spatial resolution: 0.25° - 0.5°.
	  - Availability: Publicly available [Vicente-Serrano et al. (2023)].
	  - Unit: mm

G	- DWD data
	  - Temporal resolution: 10-minutes; hourly; daily and monthly data
	  - Availability: publicly available on https://www.dwd.de
	  - Unit: mm
	  - Additional information on air pressure, temperature, cloud cover, vapor pressure, relative humidity, ground conditions, wind and visibility available

Geography/ Geomorphology/ Land Use	
Soil moisture content	

NL	- In situ stations (Twente network), managed by UT-ITC (root zone soil moisture) [Van der Velde et al. (2023)].
	  - Temporal resolution: Every 15 min
	  - Spatial resolution: Point
	  - Availability: Publicly available through dans-easy or International Soil Moisture Network, ISMN (2009-2022]. New data downloaded twice per year. Contact: Paul Vermunt (UT-ITC).
	  - https://ismn.earth/en/dataviewer/
	  - Unit: m3/m3
	
	- Satellites (only top layer is measured)
	  - Temporal resolution: depends on satellite (see table 4 below)

	- Spatial resolution: depends on satellite (see table 4 below) - Availability: Mostly publicly available (or companies like for example Planet) - Unit: m3/m3 (Luijkx, 2020) Additional Information: Besides, there are algorithms [e.g. Bauer-Marschallinger et al. (2018)] from which soil moisture can be calculated from the radar satellite of choice. In 2024, NISAR [Kellogg et al. (2020)] and BIOMASS [Quegan et al. (2019)] synthetic aperture radars (SAR) will be launched, which have high potential for soil moisture estimation with spatial resolutions of <200m.

G	- DWD-data (Calculated with the AMBAV model of the ZAMF in Brunswick)
	  - Temporal resolution: daily
	  - Spatial resolution: point data, which is then interpolated
	  - Availability: publicly available on https://www.dwd.de
	  - Unit: %nFK (field capacity)
	- Soil moisture
	  - Few measuring stations in Germany (and Netherlands)
	  - https://ismn.earth/en/dataviewer/
	- Measurements by the GD NRW, LANUV NRW and chamber of agriculture NRW
	  - Temporal resolution: daily
	  - Spatial resolution: point data
	  - Availability: publicly available on https://www.gd.nrw.de
	  - Unit: pF (potency of free energy of the water)
	  - Additional information on temperature, precipitation and potential evapotranspiration available

Land use Maps (including location of rivers)	

NL	- Land use maps
	  - Details: Maps from 2010 and 2015. Formats = .shp, WMS, WFS. Responsible institute = Statistics Netherlands.
	  - Availability: Publicly available through pdok website (PDOK, 2023a).
	
	- Crop parcel registry (Basisregistratie gewaspercelen)
	  - Details: Annually updated crop type map. Formats = .gdb, WMS, WFS, WMTS.
	  - Availability: Publicly available through governmental website (MEACP, 2023). for the years 2009 – 2020 downloads are available at the tab ‘Databronnen’ and under ‘INSPIRE Atom’ and from 2016 also view services are available.

G	- Land survey register

	○ Details: Updated quarterly. Formats = NAS, GML. Responsible institute = Geobasis NRW. ○ Availability: Publicly available on https://www.geoportal.nrw
Soil maps	
NL	- Soil texture, soil physical parameterizations ○ Details: Responsible institute: Wageningen Environmental Research. Available formats = .shp, .gdp. ○ Availability: Publicly available (BOFEK, 2020; Heinen et al., 2021).
G	- Soil type, physical parameterization ○ Details: Latest update 08.2023. Responsible institute: Geological Service NRW. Available formats = .shp, geodatabase ○ Availability: Publicly available on https://geoportal.nrw
Elevation, Bed level	
NL	**Elevation** - Actueel Hoogtebestand Nederland. ○ Details: Responsible institutes: RWAs, provinces, Directorate-General for Public Works and Water Management. Available formats = GeoTIFF, WMS, WFS, WMTS, WCS. ○ Availability: Publicly available through pdok website (PDOK, 2023b). **Bed Level** Collected from: - Field measurements (several instruments can be used) ○ temporal resolution: Mostly measured for research, so no constant measurements ○ Availability: unclear ○ Unit: unclear - Satellite measurements (for floodplains) In the Netherlands combined in Algemeen Hoogtebestand Nederland (AHN) ○ Temporal resolution: based on passing speed of satellite, mostly once per day ○ Availability: Publicly available ○ Unit: m
G	**Elevation** ○ Details: Responsible institute: Geobasis NRW. Available formats: WMS, PNG, JPEG, TIFF. ○ Availability: publicly available on https://geoportal.nrw
Potential evapotranspiration	
NL	Based on data (temperature, wind and sun) from: - Local KNMI weather stations: 3 in the Dutch part: Twenthe, Heino and Hupsel

	○ Temporal resolution: Hourly, two times a day processed ○ Spatial resolution: Point ○ Availability: Collected by KNMI, Publicly available ○ Unit: mm - E-OBS gridded ensembles of temperature, pressure, wind speed and radiation, from which potential ET can be calculated. ○ Temporal resolution: Daily mean, since 1950. ○ Spatial resolution = 0.1° – 0.25° ○ Availability: Publicly available [Cornes et al. (2018)]. ○ Unit: mm - ERA5 re-analysis from the Copernicus Climate Change Service (C3S) at ECMWF (European Centre for Medium-range Weather Forecasts) includes potential ET based on the surface energy balance. ○ Temporal resolution: Hourly, since 1950. ○ Spatial resolution: 0.25° - 0.5°. ○ Availability: Publicly available [Vicente-Serrano et al. (2023)]. ○ Unit: mm - Satellite data-driven algorithms such as GLEAM [Miralles et al. (2011)], SEBAL [Bastiaanssen et al. (1998)], and METRIC [Allen et al. (2007)]. ○ Temporal resolution: GLEAM: daily, since 1980; SEBAL & METRIC: 5-10 days ○ Spatial resolution: GLEAM: 0.25°; SEBAL & METRIC: high, e.g. 20m. ○ Availability: Satellite data and algorithms publicly available.
G	- DWD-data ○ Temporal resolution: daily ○ availability: Publicly available on https://www.dwd.de ○ Unit: mm - Mesoanalysis ○ Temporal resolution: hourly, since 2019 ○ availability: Publicly available on https://www.kachelmannwetter.de ○ Unit: mm
Vegetation drought indices	
NL	Based on measurements from: - Passive multispectral sensors (e.g. Landsat, Sentinel-2/-3) ○ Temporal resolution: 5-10 days ○ Spatial resolution: 20 m ○ Availability: Satellite data publicly available. ○ Unit: unitless (index)

	o Examples of indices based on passive multispectral sensors are:NDVI, NDWI, VHI, WUE - Microwave sensors (e.g. Sentinel-1 or AMSR-E). o Temporal resolution: 2-6 days o Spatial resolution: 14-62 km (AMSR2), or 100m (Sentinel-1) o Availability: Satellite data publicly available. AMSR2 ready VOD product. Sentinel-1 product needs to be made (not straightforward). o Unit: unitless (index) o Example of microwave index is:VOD (AMSR2 (ready VOD product), or Sentinel-1)
G	- DWD Drought Index: o Temporal resolution: monthly o Spatial resolution: Europe o Availability: publicly available on https://www.dwd.de o Unit: DWD-SPI (Standardized Precipitation Index) - Passive multispectral sensor Sentinel-3: o can be used to calculate the NDVI o Temporal resolution: since July 2020 o Spatial resolution: Global, 300 m o Availability: satellite data available from the Copernicus Global Land service o Unit: unitless
Management	
NL	- Richtlijn Overstromingsrisico's o Availability: Publicly available
G	- Floodplain areas NRW o based on: statistical determination of a 100-year flood o updates: continous, most recent publication in May o availability: State government NRW, open data in the form of shapefiles - Risk and hazard maps NRW & Heavy rainfall maps o availability: Accessible via https://www.flussgebiete.nrw.de

Lacking, unavailable or not matching data

In Table 20 the data that is lacking, unavailable or not matching is given based on the interviews and tables above.

Table 20: Unavailable, lacking or not matching data for the Vechte Catchment

Surface Water – Water Levels and Discharge	
NL	Partly unavailable: - Information gained by the districts is not publicly available (Interview Regional Water Authority Rijn and IJssel, 2023)
Meteorology - Precipitation	
NL	Unavailable and lacking: - Real time data is hardly available and quality is not always guaranteed (Interview Regional Water Authority Rijn and IJssel, 2023) Additional information: By placing personal weather stations in the border area (in Germany) more data can be easily collected (Interview Regional Water Authority Rijn and IJssel, 2023)
Geography/ Geomorphology/ Land Use	
Waterworks	
NL	Lacking: - Dimensions/heights of waterworks (Interview Regional Water Authority Rijn and IJssel, 2023)
GER	Annual digital recording of (agricultural) abstractions and a standardised digital water book should be improved as a matter of priority (Interview with NIKO)
Maps	
GER	comprehensive mapping of drainage ditches and drainage systems is necessary, as both have a significant impact on the landscape water balance and are essential information for modelling (Interview with NIKO)
Land Use	
	Dutch and German maps do not always match (Interview province of Gelderland, 2023)
Geology and Hydrogeological Data	
	Dutch and German geology and hydrogeological data is not matching and translation table are needed to align the data.
Management	
NL	Not matching: - (Interview province of Gelderland, 2023) Richtlijn Overstromingsrisico's

	- Dutch and German maps do not match (Interview province of Gelderland, 2023)

Table 21: Overview of Models in the study area Catchment (Germany and Netherlands)

Model	Purpose	Geographic scope / Catchment	Developer /Owner/Initiator	Year of construction	Year of last update	Additional comments	Source/ Reference
3Di	Hydraulic model (used for understanding of floods and measures to prevent and mitigate flood impacts)	?	Nelen en Schuurmans	?	?		
AMIGO	Model groundwater	Regional (Oost-Gelderland)	Commissioned by: Regional Water Authority Rijn and IJssel, de province of Gelderland and Vitens	?	?	Models are partly including Germany, but data is limited	https://www.flussgebiete.nrw.de/system/files/media/document/file/top6_mgrowa_fzj.pdf
BOWAB	Soil water balance model for area-specific determination of the soil water balance. mGROWA is based on BOWAB.						
Delft FEWS, Larsim	Flood forecasting	14 bodies of water in North Rhine-Westphalia: Berkel, Dinkel, Emmer, Ems, Erft, Inde, Issel, Lenne, Lippe, Nethe, Ruhr, Rur, Sieg and Werre	Hydrotec based on Deltares	2022			https://www.hydrotec.de/hochwasservorhersage-nrw-mit-delft-fews/?highlight=%22hochwassergefahrenkarte%20nrw%22

Delft3D FM	2D dynamic flow simulation or 3D water flow modelling		Deltares		2023		https://www.deltares.nl/en/software-and-data/products/delft3d-flexible-mesh-suite https://www.flussgebiete.nrw.de/system/files/media/document/file/bericht_hwgk_hwrk.pdf
Delft-FEWS	Flood forecasting and early warning	National and international (also international exchange of knowledge)	Deltares	2002/ 2003	?		https://www.deltares.nl/software-en-data/producten/delft-fews-zicht-op-verwachtingen
D-Hydro	Floods, storm surges, hurricanes, waves, flooding due to heavy precipitation, sediment transport, morphology, water quality and ecology		Deltares	2015			
Dufl ow	simulating one-dimensional unsteady flow in open-channel systems. The program is designed for simple networks of channels with simple structures.			1989		all funcionalities are included in SOBEK	https://www.sciencedirect.com/science/article/abs/pii/027312239600193X
FEWS Vechte	Flood prediction model	Vechte	Vechtstromen	2014			https://gprw.eu/images/pdf/Artikel_Land_Water_FEWS_Vecht_June_2012_komp.pdf
flood hazard map	The flood hazard maps provide information on which areas are flooded during floods and what water depths and flow velocities can be expected.	NRW	Hydrotec and INFRASTRUKTUR & UMWELT comissioned by MKULNV	2014		not a model, but based on modelations	https://www.flussgebiete.nrw.de/hochwassergefahrenkarten-und-hochwasserrisikokarten

G3D	Groundwater models (G3D) are created on the basis of the loose rock models. These are used primarily for forecasting, planning and calculating water management measures. In this way, the hydrogeological and hydraulic conditions of the groundwater bodies can be examined and analyzed in detail.	Belgium, Denmark, Germany (Lower Saxony, Bremen), Netherlands, United Kingdom	The model was created as part of the EU Interreg project Topsoil and is based on the evaluation of aeroelectromagnetic data.	inbetween 2015 and 2022		Applied by LBEG[3]	
Glofas	flood early warning system; combined information from satellites, models and in-situ measurements	global at a resolution of 20 km	Copernicus	2018	2023	limited use for the Vechte catchment due to low resolution	https://www.globalfloods.eu
GREAT-ER	Environmental risk assessment and management of chemicals in river basins	Regional	Initiative of: Environmental Risk Assessment Steering Committee	1999	2014	There is already looked into transbounary implementation in the paper of Lämmchen et al. (2021)	https://www.usf.uni-osnabrueck.de/en/forschung/applied_systems_science/great_er_project https://cefic-lri.org/toolbox/great-er/
HBV	Model rainfall runoff	Catchment (input parameters characterise the area)	-	-	-		
HydroAs	2D simulation of watercourses and surface runoff from precipitation		Hydrotec		2023		https://www.hydrotec.de/software/hydroas/
Hydro-As-2D	Calculation of floodplain areas		Hydrotec			Applied at NLWKN	
Jabron	1D water level calculations which can be connected with GIS	Vechte and its tributary the Dinkel in Lower Saxony	Hydrotec comissioned by NLWKN	2004	2018		https://www.hydrotec.de/vechte-und-dinkel-2013-oekologische-verbesserung-und-

							hochwasserschutz/
Larsim	flood forecasting, water balance modelling	has been used by NRW, Bavaria, Baden-Württemberg and Rhineland-Palatinate	Albert-Ludwigs-University Freiburg	2000			https://geoportal.bafg.de/dokumente/kliwas/modelle/factsheets/factSheet_LARSIM_de.pdf
mGROWA	In order to determine groundwater recharge, hydrogeologists develop complex water balance models, for example mGROWA, and calibrate them to discharge data. Hydrogeologists used mGROWA to calculate groundwater recharge for the various areas of Lower Saxony. The model is partly based on BOWAB. The water balance variables of real evaporation, total runoff and groundwater recharge were quantified for NRW	Lower Saxony, North Rhine Westphalia	FZ Jülich	2003	2023	Applied at LBEG[1] and LANUV[2]	https://www.flussgebiete.nrw.de/system/files/atoms/files/4_fzj_mgrowa_growanrw2021.pdf

MIPWA	Model groundwater	Regional (Overijssel, Drenthe en Groningen)	commissioned by: Provinces of Overijssel, Drenthe and Friesland, Regional Water Authorities of Hunze en Aa's, Friesland, Noorderzijlvest, Vechtstromen and Drents Overijsselse Delta, drinking water company of Groningen, Vitens	2007	2022	Bonilla (2021) looked into combining the MIPWA model with the SOBEK and Walrus model and concluded that merging these models can provide further insight into a water system's operation and responsiveness to interventions.	https://www.mipwa.nl/
NASIM	The precipitation-runoff model maps the hydrological processes of natural and urban catchment areas		Hydrotec		2023	can be combined with Delft-FEWS for flood forcasting	
NASIM (N-A-Modell)	NASIM is used to create flood protection concepts, to estimate the effect of runoff-reducing measures, to determine groundwater recharge or to support the real-time control of a flood protection system.					Applied at NLWKN	

PANTA RHEI	Operational flood prediction model Groundwater model for the irrigation association Itter Water quantity management model groundwater model coupled with surface waters to understand their interplay, including all withdrawal quantities	Lower Saxony Ground water body Itter (Lower Saxony and the Netherlands) District Grafschaft Bentheim	Hydrology, Water Management and Water Protection Department of the Leichtweiß-Institute for Hydraulic Engineering at the TU Braunschweig, Institute for Water Management IfW GmbH, used at NLWKN Vechteverband, owner and developer is a Hydrologist in service of Vechteverband Lower water authority at district Grafschaft Bentheim	~ 2022, in development	?	The model will be used for the planned county wide model of the lower water authority at district Grafschaft Bentheim The model is intended to be a shared resource for all stakeholders. The project also involves assessing the current state and planning for the future, considering different climate scenarios for the years 2030 and 2050.	(chapter 7, NLWKN 2021; https://www.nlwkn.niedersachsen.de/klimawandelkompakt/klimafolgenmodellierung/impactmodellierung-186636.html)
PCR-GlobWB	large scale hydrological model for global and regional studies	global at a resolution of 5 km	Utrecht University	2011	2018	limited use for the Vechte catchment due to low resolution	https://globalhydrology.nl/research/models/pcr-globwb-1-0/
SOBEK	Predict floods, Optimalisation drainage systems, Control of irrigation systems, Design of sewer overflows, River morphology, Salt intrusion, Surface water quality, 1D/2D model, Flood forecast, Wave runoff	Weser (flood forecast, wave runoff) parts of Vechte modeled in 'Rivierengebied' and 'Ijsselmeergebied' (without upstream parts of the catchments, only the	Deltares			Smaller ditches can be added to the model, this has been done in Applied at NLWKN	(Hehenkamp, 2019) https://www.deltares.nl/software-en-data/producten/sobek-suite

		major rivers and channels)					
Tygron Water module	local flood hazard assessment based on 2D Saint-Levant equations	Vechte and other river catchments	Tygron	2019			https://www.tygron.com/water-safety/
Walrus, SOBEK, FEWS, Panta Rhei	Flood forecasting model for the entire Vechte catchment area in both Germany and the Netherlands	catchment area of the vechte and dinkel	Regional Water Authority Vechtstromen	2020		all part of the living vechte dinkel project as a cooperation between Germany and the Netherlands	https://devecht.eu/de/living-vechte-dinkel/massnahmen-0/massnahme-04a/
WALRUS - model	Model rainfall runoff		Wageningen University	2014	?		
WAQUA	Model waterlevels, flows and concentrations of dissolved substances in surface waters						https://iplo.nl/thema/water/applicaties-modellen/watermanagement modellen/waqua/
Water Evaluation And Planning (WEAP) model	Waterbalance model for agriculture and urban systems (used to determine wateruse)	Regional, but can be used on transboundary catchments (Terink, van Deijl, & van den Eertwegh, 2022)	?	1988	?		

Waterwijzer Agriculture (WWL)	Evaluate effect of changes in hydrological conditions on crops yield	National & regional (using the WWL-table) Regional (using WWL-regional) Plot/specific location (using WWL-maatwerk)	STOWA (commissioned by: Ministerie van I&M/Deltaprogramma Zoetwater, Planbureau voor de Leefomgeving (PBL), provinces of Gelderland, Noord-Brabant, Limburg en Utrecht, STOWA en the regional water authorities of Vechtstromen and Aa and Maas and drinking water companies Vitens en Brabant Water, Staatsbosbeheer en Natuurmonumenten)	2018	2023 (validation) Newest version 2021	Transboundary: Already applied in Belgium	https://waterwijzerlandbouw.wur.nl/ https://waterwijzer.nl/publicaties https://waterwijzer.nl/achtergronden/de-waterwijzer-landbouw https://edepot.wur.nl/554082
Waterwijzer Nature	Evaluate effect water availability/management on vegetation goals (mostly connected to drought)	Regional	STOWA (commissioned by: Ministerie van I&M/Deltaprogramma Zoetwater, Planbureau voor de Leefomgeving (PBL), provinces of Gelderland, Noord-Brabant, Limburg and Utrecht, STOWA and the regional water authorities Vechtstromen en Aa en Maas en de drinking water companies Vitens en Brabant Water, Staatsbosbe	2018	2023 (further development)		https://waterwijzer.nl/publicaties https://waterwijzer.nl/achtergronden/de-waterwijzer-natuur

			heer en Natuurmonumenten)				
Wflow_sbm	Hydrological Model	Upstream Vechte catchment	Deltares (PhD)	2023	2024		
	Flood Forecasting	covers WRIJ's main cross-border watercourses (i.e. also the Ahauser Aa, Berkel, Schlinge, Bocholter Aa and IJssel)	WRIJ	?	?	produces hourly forecasts 7 days ahead	
	1D2D D-Hydro flood model	cross-border dyke ring 48 (from Wesel to Doesburg)	WRIJ	?	?	currently building a cross-border 1D2D D-Hydro model of the Schipbeek and Berkel rivers (other river basins will follow later). Germany is part of this model but somewhat coarser than NL due to lack of German data (we miss many	

						profiles and artwork dimensions)	

Additional Model descriptions:

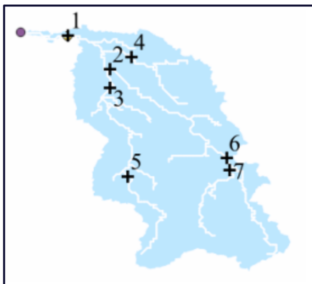
1) Delft3D FM

Similar to the use of Baseline NL with Sobek the dataset can also be used to feed the Deflt3D FM modelling suite. The primary differences here pertain to how the physics are approximated within the model and how the landscape is discretized spatially. Delft3D FM allows a full 2D dynamic flow simulation with a flexible triangular mesh, or 3D water flow modelling with regular or curvilinear grid, with potential to include sediment processes.

2) WFLOW

In a 2022 work by Koronaci et al., the usage of the WFLOW model was explored for the Vechte catchment (Koronaci, 2022). This hydrological model can be used to calculate rainfall-runoff relations.

The study focused on improving estimates of extreme events by adapted data-assimilation methods. The model combined local and global datasets (DWD for precipitation, ERA5 for Evapotranspiration) to carry out a water-balance calculation based on empirical modelling with 1D kinematic routing. The model includes various tools for automated data collection and model setup and works using a regular square grid.



Map ID	1	2	3	4	5	6	7
Station Name	Emlichheim	Wehr-Neuenhaus	Lage I	Osterwald	Gronau	Ohne	Bilk

Figure 7 The discharge stations used to calibrate the wflow model setup for the Vechte catchment (Koronaci, 2022).

Global models and datasets

3) Glofas and PCR-GlobWB

The glofas modelling system is an operational flood early warning system developed by the Joint Research Centre, and hosted and operated by Copernicus. The program gathers national and local data to auto-calibrate and assimilate data for the hydrology and hydraulic routing carried out within the model. The method is fully open-source, runs daily at global scale, and all results are published through the Copernicus data portal. Simulations and routing are carried out at low resolution (approx. 20 km), to facilitate efficiency. A similar model, PCR-GLOBWB is developed at Utrecht University at higher resolution (5 km gridcells). Because of the low resolution, these types of models have limited use in the context of the Vechte Catchment. However, many European regions rely on this platform for flood early warning actively.

4) Various commercial global products

Besides all the products mentioned above, another category of flood products exists that cover the Vechte catchment. A variety of commercial organizations have produced global flood hazard maps. Examples are the Aquaduct analyzer, WorldBank Global flood hazard maps, and the global flood tools by Nelen&Schuurmans. Despite their spatial coverage, these products provide little effective use in the Dutch-German context for a variety of reasons. Firstly, better models exist and due to the low resolution and course assumptions of these models their quality suffers. Secondly, for the Netherlands in particular, these products often suffer because the low resolution does not support the effects of embankments on the simulations. Effectively, the results show the Netherlands as if there would be virtually no embankments, and large overestimations of flood impact occur even at low probabilities.

Annex D: Institutions, arrangements and planning

Institutions:

Table 22: Overview of responsibilities of water authorities and technical authorities in North Rhine Westphalia and Lower Saxony (own elaboration based on BMUV 2023 , MULNV NRW 2021 , MKLNUV NRW 2014 ,ZuStVO-Wasser Lower Saxony (2014), NWG (2011)).

Federate state	North Rhine-Westphalia	Lower Saxony
Highest water authority	**Ministry of the Environment, Nature Conservation and Transport** Control of water management and higher-level administrative procedures. Decisions on the RBMPs and Programmes of Measures Legal and technical supervision as well as coordination of tasks with regard to the water management authorities. Coordination of the flood risks assessment and related activities to flood risk management planning	**Ministry of the Environment, Energy and Climate Protection** Supervision of water bodies as well as the enforcement of the regulations of the European Community concerning management of waters and the federal or Land legislation enacted for this purpose Decisions on Programmes of Measures and RBMPs, FRMPs Technical supervision as well as coordination of tasks with regard to the water management authorities
Technical authority	**State Agency for Nature Conservation, Environment and Consumer Protection (LANUV)** Monitoring of water bodies Assessment of flood risks and activities related to flood risk management planning	**Lower Saxony Water Management, Coastal and Nature Protection Agency (NLWKN)** Decisions on water uses Supervision, maintenance of water bodies of 1st and specific water bodies of 2nd order (e.g., Vechte) Decisions on the development of water bodies Implementation of specific tasks related to the WFD Assessment of flood risks and activities related to flood risk management planning (e.g., suggestion of flood-plain zones), Drafting FRMPs
Higher water authority	**District of Münster and Düsseldorf** Regional water management planning, significant water law procedures, administrative procedures regarding water uses.	

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	Supervision, maintenance and development of water bodies of 1st order, supervision of water bodies of 2nd order Implementation of the FRMD: Assessment of flood risks and activities related to flood risk management planning, coordination and supervision of measures Supervision of flood protection measures on water bodies of 1st and 2nd order	
Lower water authority	**Districts of Borken and Steinfurt** Water law procedures Monitoring, maintenance and development of water bodies of other order than 1st and 2nd official decisions, for example on wastewater discharges Regulation of land uses in flood-plain areas	**District of Grafschaft Bentheim** Water law procedures Inspection of the implementation of the duties by maintenance associations Official decisions, for example on wastewater discharges. Regulation of land uses in flood-plain areas
Municipalities	**District of Münster: Aahaus, Altenberge, Billerbeck, Bocholt, Borken, Coesfeld, Gescher, Gronau (Westphalia), Heek, Isselburg, Laer, Legden, Ochtrup, Rhede, Rosendahl, Stadtlohn, Steinfurt, Südlohn, Velen, Vreden, Wettringen** **District of Düsseldorf: Hamminkeln, Huenxe, Reed, Schermbeck, Wesel** Implementation and maintenance of flood risk protection measures in their area Disaster response	**Samtgemeinden Emlichheim, Uelsen, Schüttorf; Cities Neuenhaus, Nordhorn, Bad Bentheim; Municipality Wietmarschen** Implementation and maintenance of flood risk protection measures in their area Disaster response
Maintenance Associations	**Maintenance Association lower Dinkel area** Development and maintenance of water bodies, Construction and maintenance of facilities in and around water bodies, Protection of properties against storm surge and floods, Improvement of agricultural and other land, including the regulation of soil water and soil air balance, Production, procurement, operation, maintenance and removal of sprinkler systems as	**Vechteverband, smaller maintenance associations (e.g., Hardinger Becke, Rammelbecke)** Monitoring & maintenance of water bodies of 2nd order, if the responsibility is not with the state[2] All other aspects as stated for NRW.

well as irrigation and drainage systems, Technical measures for the management of groundwater and surface waters, Procurement and provision of water, Preparation, preservation and maintenance of areas, facilities and water bodies for the protection of the natural ecosystem, the soil and for landscape conservation, Promotion of cooperation between agriculture and water management and further development of water, soil and nature conservation, Promotion and monitoring of the above tasks.[1]

[1] "Wasserverbandsgesetz vom 12. Februar 1991 (BGBl. I S. 405), das durch Artikel 1 des Gesetzes vom 15. Mai 2002 (BGBl. I S. 1578) geändert worden ist"

[2] Niedersächsisches Wassergesetz (NWG) vom 19. Februar 2010 (Nds. GVBl. S. 64), Zuletzt geändert durch Art. 5 G zur Änd. des G über den Nationalpark „Niedersächsisches Wattenmeer" und des AusführungsG zum BundesnaturschutzG sowie zur Änd. weiterer Gesetze vom 22.9.2022 (Nds. GVBl. S. 578)

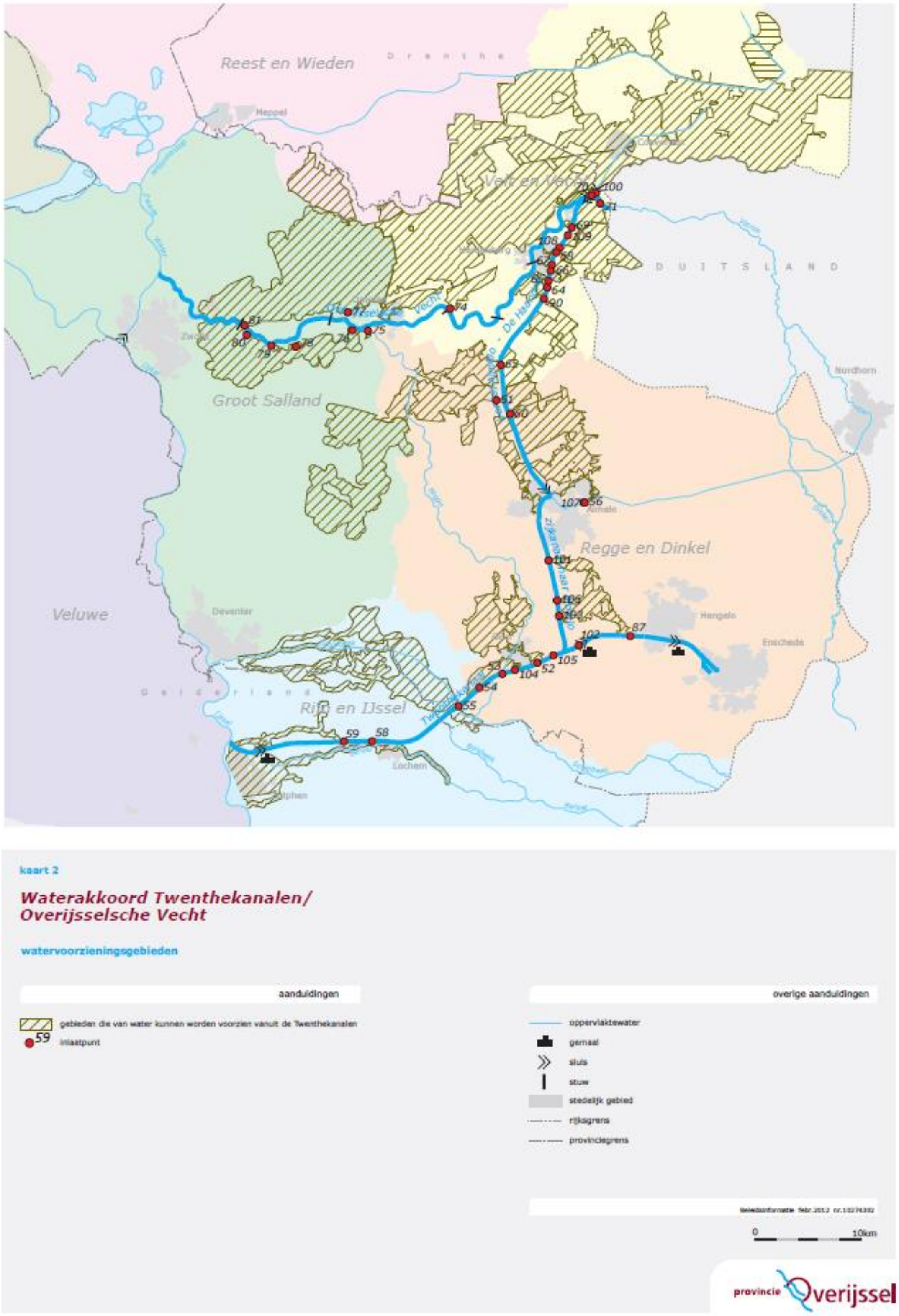

Figure 40: Map of the water supply network - Twenthekanalen

Overview of projects and plans:

These tables give an overview of the plans and initiatives, which were mentioned in the interviews.

It can be seen that many projects and initiatives are taking place at the moment in the study area which are focusing on flood- and drought management and climate adaptation. There are also a few transboundary projects foreseen in the next years, such as the INTEREG proposal

Table 23: Overview of flood and drought management related projects in the Netherlands

Project	Project Lead	Topic	Partners	Duration
Klimaatrobuste Vechtstromen	Vechtstromen	Drought Management		
GRADE Vechte	RWS	Model Development	Vechstromen, Deltares	2024
HWBP Vechte	WDOD	Flood Infrastructure	Vechstromen	2020-2023
Zoetwatervoorziening Oost Nederland (ZON) Fase 2		Water supply	Provincies, municipalities, regional water authorities	2022 – 2027
Haarvaten op Peil (HOP) – ZON onderdeel	Vechtstromen	Drought Management		
Slim Watermanagement	RWS	Drought / Flood Management	regional water authorities	2022 – 2027
Panorama Waterland	Vitens	Spatial Planning		2020 -
Klimaatadaptatie in de Praktijk KLIMAP	KLIMAP consortium	Climate-adaption	23 different organisations	2020 -2024
Aanpak Droogte in de Achterhoek	Province of Gelderland	Drought Management	19 different partners	2020 – current
Bovenregionale Stresstesten Oude Ijssel and Berkel	WRIJ	Flood Risk Management		Ongoing
Berkel en Oude Ijssel Highwater Forecasting	WRIJ	Flood Forecasting		ongoing

Verkennende studie robuuste wateraanvoer Twentekanalen-Overijsselse Vecht	RWS	Water Supply		2020 – current
Quickscan Droogte IJsselvallei	HKV	Water Supply		2023
FEWS Vechte Update	WDOD	Forecasting	Vechtstromen, Deltares	ongoing
Waterveiligheidslandschappen	WRIJ	Climate – adaptation	13 partners	2023 -
Adaptatieve Strategie Drinkwater Voorziening	Province of Overijssel	Water Supply	WDOD, Vechtstromen Vitens	

Table 24: Overview of flood and drought management related projects in Lower Saxony

Project	**Project Lead**	**Topic**	**Partners**	**Duration**
KliWaKo (Klima- Wasser – Kooperation)	district Emsland	Water supply, Drought Management	Among others: Trink-und Abwasserverband Bad Bentheim, Vechteverband	2019 - 2022
Emslandplan 2.0 - Nachhaltiges Wassermengenmanagemen	District Emsland	Drought Management	Among others: District Grafschaft Bad Bentheim, NLWKN, LBEG	2020-2021
Wasserversorgungskonzept Niedersachsen	MU	Water Supply Concept		2017 – current
Projekt KliBoG – Klimafolgenanpassung Boden und Grundwasser	LBEG	Model Development, Drought Management		2022 – 2027
NBank Hydrogeological Modelling	District Grafschaft Bentheim	Model Development	Vechteverband	

NBank Climate Change Adaptation	Vechteverband	Drought Management	TAV (Trink und ABwasserverband Schuettdorf, Maintenance Associations	
Klimafolgenanpassung Wasserwirtschaft	MU	Climate Adaptation Funding Guideline		Ongoing
Projekt kommunale Starkregenvorsorge in Niedersachsen	UAN	Pluvial Flooding		2023 – 2025
KliBiW (Globaler Klimawandel – Wasserwirtschaftliche Folgenabschätzung für das Binnenland)	MU	Climate impact assessment for inland waters	Among others: NLWKN, LBEG	2008 - 2023
Programm Niedersächsische Moorlandschaften	MU	Peatland protection program		ongoing

Table 25: Overview of flood and drought management related projects in NRW

Project	Project Lead	Topic	Partners	Duration
Hochwasserschutzkonzept (HWSK) Bocholter Aa	District Borken	Flood Risk Management	Municipialities along the river	2017 - 2022
10-Punkte Arbeitsplan Hochwasserschutz in Zeiten des Klimawandels	MUNV	Flood Risk Management		ongoing

Table 26: Overview of transboundary flood and drought management related projects

Project	Project Lead	Topic	Partners	Duration
Interreg DIWA: Drought Strategies in Water Management	Regional Water Authority Vechstromen	Drought Management	Among others: District Grafschaft Bad Bentheim, Province of Gelderland	Proposed
SpongeWorks	LU Hannover	Flood – and Drought-management	Among others: District Grafschaft Bad Bentheim, Vechteverband, Regional Water Authority Vechtstromen, Gemeente Hardenberg	Sep 2024 – Sep 2028
CrisisManagement Saxion Project	GPRW	Crisis Management	Regional Water Authority Vechstromen	ongoing
Interreg Living-Vechte Dinkel	Regional Water Authority Vechtstromen	Climate- adaptation	Regional Water Authority DOD, Province of Overijssel, district Borken, district Steinfurt, district Grafschaft Bentheim, NLWKN etc.	2017 – 2021
Irrigation Association Itter / Reutumer Ringen		Transboundary groundwater management	WAZ, Vitens	

Annex E: Identified Knowledge Gaps

ID	(Research) topic	Knowledge client	Cat.
1	What is the impact of waterquality on nature related to water storage (e.g. river valley inundation, water intake from other areas)? And in which situations does that play an important role (wet soils absorb less water than drier soils)	Natuur-monumenten	WQ
2	True integration of groundwater - surface water models to be able to simulate processes better (e.g. reinfiltration)	Natuurmonumenten	MOD
3	Development of joint transboundary models could help to improve transboundary cooperation as their is a joint knowledge base	Natuurmonumenten	MOD
4	Should we just accept that cross-border cooperation is complicated or are there ways to improve it?	Province of Gelderland	GOV
5	Cross-border water system analysis required to outline cross-border interactions (1. Identification of cross-border hotspots, 2. identification of further gaps, 3. Better understanding of groundwater interaction)	Province of Gelderland	USDS
6	Transboundary Stress Tests (uniform methodology, evaluate transboundary effect of measures, link stress test with risk dialogue)	Province of Gelderland	ST
7	What is needed in terms of joint monitoring? To also quantify the impact of measures on neighbouring countries	Province of Gelderland	MON
8	Coincidence of flood waves caused by implementing flood mitigation measures in one part of the catchment / tributary ?	Province of Overijssel	SU
9	Impact on spatial planning (Can measures upstream also take over a task downstream, so that less dyke reinforcement/measures are needed downstream,	Province of Overijssel	USDS

	what does too much and too little water mean for the other functions to be served)		
10	Sponge functioning strategy: How effective are measures to improve spongefunctioning? Which effect have measures taking in Germany on the discharges in the Netherlands?	Province of Overijssel	USDS
11	What role can cross-border wetlands play in this region? (e.g. Bourtanger Moor) Can these also contribute to water functions.	Province of Overijssel	SF
12	Research on sponge effect: Balance between too dry and too wet (why exactly does it work, sponge can only used once), What is the effect of drought measures on flooding and vice versa?).	Rijn and Ijssel	SF
13	Transboundary Stress Tests: How far will the peak be reduced in Germany / System understanding of the whole system	Rijn and Ijssel	ST SF
14	What happens if more flood or drought measures are taken on the German side. What does retaining water upstream (in Germany) mean for downstream discharge of cross-border rivers and brooks?	Rijn and Ijssel	USDS
15	What is the Cost-benefit tipping point for upstream measures?	Rijn and Ijssel	USDS
16	Tipping point for retention: indicators for operational management: when do we have to lower weirs.	Rijn and Ijssel	DM
17	Can you do something with early warning? Transboundary? - Jointly define thressholds and scenarios to increase transboundary components.	Rijn and Ijssel	FF
18	Improve forecasting Drought forecasting --> also transboundary. Is it possible to derive stream run-off at the border from using German monitoring data?	Rijn and Ijssel	MON
19	Mode of regulation and governments is very different on different sides of the border. How to arrange that better?	Rijn and Ijssel	GOV

20	Mapping of drought impacts (Do we have the right models to predict drought events? How effective are measures to reduce drought impacts? How do droght mitigation measures infleunce the landscape? Subsidence effects? Sufficient water for firefighting?	Veiligheidsregio Twente	IMP
21	Water-bodem sturend: What is the impact if more upstream measures are taken (e.g. to retain water)? What is the impact on your flood risk if applying groundwater measures to reduce drought risks?	Drentse Overijsselse Delta	SU
22	(Transboundary) Stresstests and waterbomb studies: The impact from Germany as well as the downstream imact from the Ijsselmeer is unknown. What is the worst-case scenario?	Drentse Overijsselse Delta	ST SU
23	Reliable forecasts for extreme events: FEWS? What can AI do in it?	Drentse Overijsselse Delta	FF
24	Risk communication: How do you interpretate and communicate the risks from all the different studies going on (hydraulic loads from inspections, NBW tests, groundwater simulations, above standard stress tests in urban areas)	Drentse Overijsselse Delta	RC
25	Also in the context of the Sponge Strategy: how do you make it a good story? Historically, flooding occurs further and further downstream, but now you actually want to spread it more across the area again. How do you communicate that in a good way?	Drentse Overijsselse Delta	SF
26	Quality of measurement data is a major problem and acts as a hindrance in many projects.	Drentse Overijsselse Delta	MON
27	Development of a guideline for how to deal with droughts (currently only adhoc measures are executed)	Vechteverband	DM
28	Knowledgemanagement: How to facilitate knowledge sharing and understanding since younger generations are less familiar with the old plans and structures (e.g. in approval processes the baseline conditions have to be defined, however there are different baseline definitions --> finding a common ground would improve collaboration)	Vechteverband	KM

29	Need for research in the area of proportionality or appropriateness of ecological assessments (e.g. ecological assessments for water bodies which have been dry many years). They propose creating guidelines or a framework that distinguishes between different water bodies, such as flowing streams or stagnant ditches, and suggests that simplified procedures could be applied to water bodies that are known to dry up periodically. Research focusing on understanding the ecosystems of periodically dry water bodies, aiming to provide scientific support to balance ecological considerations with regulatory requirements.	Vechteverband	GOV DM EA
30	The need for a comprehensive flood protection concept covering all municipalities - also addressing heavy rain and drought. High level concept required to guide indivicual municipalities	Grafschaft Bentheim	FM
31	Absence of drought-specific concepts is noted. Importance of cross-border, well-coordinated concepts for better preparedness and a more robust knowledge base.	Grafschaft Bentheim	DM
32	Establishment of a drought monitor (currently information on groundwater trends is only upon request)	Grafschaft Bentheim	MON
33	Establishment of exchange rounds at different levels (e.g. via a newsletter)	LBEG	TC
34	Joint groundwater management: uniform or harmonised assessment criteria	LBEG	TC
35	The effect of upstream (drought) measures on downstream discharges.	Vitens	USDS
36	What is the effect of RWZIs becoming cleaner (European legislation requiring a 4. treatment step in future for large RWZIs) on water quality during droughts?	Vitens	WQ
37	Can infiltration water/water used for groundwater recharge be better protected. A lot of treatment is currently required because infiltration water / surface water is of poor quality. What happens in case of a calamity?	Vitens	WQ

38	Model necessaryties: entire groundwater model in Germany (NDS), transboundary groundwater model and models for climate adaption	Wasserverbandstag	MOD
39	How to raise wareness about water use and water consumption?	Wasserverbandstag	PA
40	More data is needing	Samtgemeinde Neuenhaus	MON
41	How to handle critical infrastructure with incoming floods and droughts?	Samtgemeinde Neuenhaus	CI
42	Rethinking and cooperation (including with nature conservation) must work, especially in order to accommodate long-term dry periods: the groundwater bodies must be replenished	WAZ	DM TC
43	Monitoring data for floods and droughts	ArL	MON
44	What is an extreme event? How high will be the future flood to count as an extreme? What weather forecast do we need to work with in future?	Samtgemeinde Emlichheim	FM MON
45	What can we do now to counteract future droughts in a solution-oriented manner?	Samtgemeinde Emlichheim	DM
46	The development of precipitation and its potential impact on fluvial or pluvial flooding events. The need for a paradigm shift from retrospectively analyzing statistical rainfall data to future-oriented forecasts is highlighted.	MU & NLWKN	FM
47	Understanding the behavior of watercourses during low-water periods, particularly in regions like the Elbe. Knowledge gaps extend to low-water conditions, hydromorphology, groundwater, and water security and quality.	MU & NLWKN	DM
48	The need for more detailed models capable of predicting both low-water and flood conditions accurately is highlighted.	MU & NLWKN	MOD

49	The functioning of the integrated water system in the border region (the whole cycle: surface-groundwater connection, what do the groundwater bodies in the border regions look like): How is everything interconnected? What are the exchanges? What are important sub-areas we should focus on? Where will you implement measures? Where is the best place to retain water?	GPRW	SU
50	Water system evaluation with quantitative stress test also for drought.	Deltares - Dimmie Hendriks	SU ST
51	Opportunities to restore large-scale areas near the border / retain water in the subsoil (peatladns, areas with thick unsaturated zone à hillsides); so that both countries benefit.	Deltares - Dimmie Hendriks	SF
52	Flood assessment: Analysis of groundwater levels: How fast did groundwater levels fall again? What places did that happen very quick or slow? Are there parts of the area where current high groundwater levels could limit the effect of an upcoming period of drought on groundwater? How can we hold a future that excess water from a wet winter?	Deltares - Dimmie Hendriks	MON
53	Opportunities for a cross-border groundwater measurement system and monitoring (expanding Drought Portal and Duerre Monitor)	Deltares - Dimmie Hendriks	MON
54	Set up FEWS environment (or similar) to bring different models and monitoring together.	Deltares - Dimmie Hendriks	MOD
55	One desire is to have more knowledge of the recovery capacity of the groundwater system East Netherlands. What is an acceptable decline in a dry year and can recover in a (hydrologically) average winter. This could be of great value in discussions about infiltrating river water in e.g. De Veluwe (water battery).	RWS	DM

56	Impact of soil erosion on water levels, groundwater and water distribution (Waal receives more and more water, and IJssel less).	RWS	WA
57	Opportunities for relationship with nature and WFD targets (side channels, riparian channels, longitudinal dams).	RWS	WQ
58	Can we develop systems where we can prepare drinking water from surface water from the river in combination with nature?	RWS	WA
59	In order to be able to make better statements about the future landscape water balance, precipitation projections need to be further developed using global and regional climate models. While these can already project the temperature well, the projections of precipitation are still associated with large uncertainties. Different weather conditions such as the Vb weather conditions cannot yet be easily projected. However, these statements are necessary in order to plan adaptation measures in a targeted manner.	NIKO	MOD
60	Large data gaps in the area mapping of drainage ditches and drainages. Both have a significant impact on the landscape water balance and information is necessary for modeling	NIKO	MON
61	An annual digital recording of (agricultural) withdrawals and a uniformly maintained digital water book should be improved as a priority. In general, monitoring, e.g. B. also of levels, and the collection of measurement data is important in order to be able to better project future conditions.	NIKO	MON
62	Better planning for critical infrastructure and vital functions before a crisis	VR Ijsselland	CI
63	Understanding where problems arise (hotspots)	VR Ijsselland	CM
64	How can the Safety Region (Veiligheidsregio) fulfil their own role on how to climate-adapt a city/country so that you stay ahead of problems. How can it be ensured that you are not directly affected by either too much or too little water?	VR Ijsselland	CM

65	From an information management perpective: how could you predict a bit more what is going to happen? And how do you easily translate that into crisis management. Collaborating and interpreting information is very tricky.	VR Ijsselland	CM
66	What do you do if things do go wrong and what solutions are there then? What are the cosenquences and how do you communicate them? Thinking about major consequences is not commonly done by the regional water authorities	VR Ijsselland	CM
67	Spatial planning in the long term: No longer thinking about how we organise it for 10 years, but what will it look like in 100 years? How do you make it robust? And what about sea level rise?	VR Ijsselland	SP
68	1. What happens downstream if drought and/or flood control measures are taken in Germany: a. consequence of large-scale use of mobile dykes in Germany on downstream drains? What are the possible consequences of the failure of a mobile dike? b. consequence of structural investments in water safety in Germany? c. consequence of groundwater management in Germany on the surface runoff of transboundary streams? d. consequence of groundwater management on groundwater in NL?	Waterschap Vechtstromen	SU
69	What do new climate scenarios mean for the Vecht? Which scenarios are used in Germany? What are the differences?	Waterschap Vechtstromen	CS
70	What can be considered extreme drought? What happens during such an event?	Waterschap Vechtstromen	DM
71	Lack of a cross-border groundwater model for understanding groundwater flow dependency	Waterschap Vechtstromen	DM
72	Opportunities for exchange with the Netherlands on **digitally controlled dams**: How does it work? How does water use and management in Germany change the waters in the Netherlands? Would cooperation on the digital control of dams be possible? How can this system be established in Germany (NDS)? Would an	Landwirtschaftskammer Niedersachsen	TC

	excursion to the locations in the Netherlands be possible?		
73	improve comunication: from research to advicing instititutions like the chamber of agriculture	Landwirtschaftskammer Niedersachsen	KE
74	Regulations and guidelines for drought management, as in the Netherlands, are considered useful and are lacking in Germany.	Kreis Borken	DM
75	Extreme situations above the applicable HQ100 and HQextreme scenarios are not considered.	Kreis Borken	FM
76	Understanding of the impacts on critical infrastructure during extreme flood and drought events is vital.	Kreis Steinfurt	CI
77	Discussion on implementing EU directives affecting water management, balancing diverse needs and requirements, and handling policy conflicts.	Kreis Steinfurt	DM
78	Comprehensive (german) Drought strategy and management required (similar to the Dutch drought management strategy)	Bezirksregierung Duesseldorf	DM
79	Nowcasting system for regional rivers	LANUV	MOD
80	How do I communicate uncertainties to citizens and organisations? How to motivate people to make decisions in the face of uncertainty	LANUV	RC
81	Definition of standardised national terminology: What is information / warning / measures	LANUV	RC
82	How can I make models faster? E.g. dynamic flood maps? To what extent can I use AI for this?	LANUV	MOD

Categories: WQ = Water Quality, MOD = Modeling, GOV = Governance, USDS = upstream-downstream dependencies, ST = Stresstest, MON = Monitoring, SU = System Understanding, SF = Sponge functioning, DM = Drought management, FF = Flood forecasting, IMP = Impact, RC = Risk Communication, KM = Knowledge management, EA = Ecological assessment, FM = Flood management, TC = Transboundary cooperation, PA = Public Awareness, CI = Critical infrastructure, WA = Water Availability, CM = Crisis Management, SP = Spatial Planning, CS = Climate scenarios