Stress Test Rur

Report phase 1 - Scoping and System Understanding

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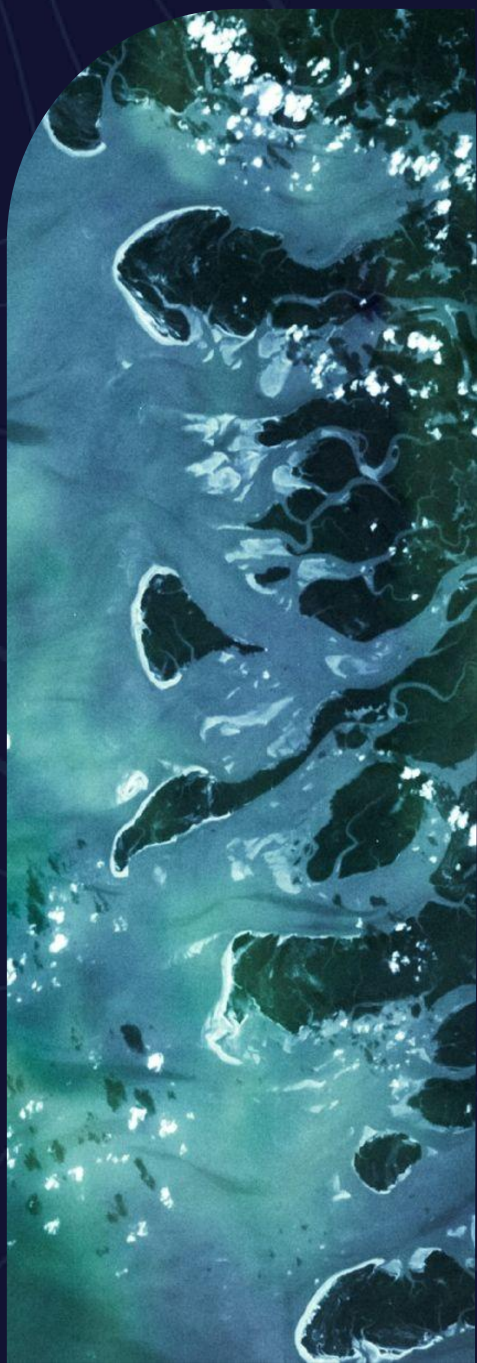
JCAR ATRACE



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Scoping and system understanding

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JCAR ATRACE

Summary

ENGLISH

The goal of a stress-test in the sense of the Joint Cooperation programme on Applied scientific Research (JCAR) to Accelerate Transboundary Regional Adaptation to Climate Extremes (ATRACE) (JCAR ATRACE, www.jcar-atrace.eu) is to investigate how a water system reacts under extreme conditions or under which conditions the system fails. A stress test provides a better understanding of worst-case conditions and consequences of extreme scenarios and options to respond to unfavourable consequences.

The approach for a JCAR ATRACE stress-test comprises the following elements:

- System description
- Hydrological conditions
- Consequences for functions and objects
- Explore possible measures.

This document is the system description of the Rur sub-catchment. The Rur catchment is an international catchment with its major part in Germany and small parts in Belgium and the Netherlands.

Beside catchment characteristics, water infrastructure and its usage and a stakeholder overview, a key outcome of this system description is a comprehensive inventory of water-related models that are available in the Rur catchment. To the best knowledge of the authors such an inventory has not been compiled before. Along with the system description a glossary of technical terms in multiple languages (German, Dutch, French) is provided.

DEUTSCH

Ziel eines Stresstests im Sinne des Kooperationsprogramms „Joint Cooperation programme on Applied scientific Research (JCAR) to Accelerate Transboundary Regional Adaptation to Climate Extremes (ATRACE)“ (JCAR ATRACE, www.jcar-atrace.eu) ist es, zu untersuchen, wie ein Wassersystem auf extremen Bedingungen reagiert bzw. unter welchen Bedingungen das System versagt. Ein Stresstest trägt dazu bei, ein besseres Verständnis für Worst-Case-Szenarien und Folgen von Extremszenarien zu entwickeln. Darüber hinaus zeigt ein Stress-Test mögliche Schutzmaßnahmen auf.

Der Ansatz für einen JCAR ATRACE-Stresstest umfasst die folgenden Elemente:

- Systembeschreibung
- Hydrologische Bedingungen
- Konsequenzen für Gewässerfunktionen und relevante Objekte
- Erkundung möglicher Maßnahmen

Das vorliegende Dokument enthält die Systembeschreibung des Teileinzugsgebietes Rur. Das Rur-Einzugsgebiet ist ein internationales Einzugsgebiet mit einem großen Teil in Deutschland und kleinen Teilen in Belgien und den Niederlanden.

Neben der Beschreibung des Einzugsgebiets selbst, der Gewässerinfrastruktur und der Gewässernutzung sowie einem Überblick über die Interessengruppen ist ein wesentliches Ergebnis dieser Systembeschreibung eine umfassende Bestandsaufnahme der wasserbezogenen Modelle, die im Rur-Einzugsgebiet verfügbar sind. Nach bestem Wissen der Autoren ist eine solche Inventur bisher nicht erstellt worden. Zusammen mit der Systembeschreibung wird ein Glossar mit Fachbegriffen in mehreren Sprachen (Deutsch, Niederländisch, Französisch) bereitgestellt.

NEDERLANDS

Het doel van een stresstest in de zin van het Joint Cooperation programme on Applied scientific Research (JCAR) to Accelerate Transboundary Regional Adaptation to Climate Extremes (ATRACE) (JCAR ATRACE, www.jcar-atrace.eu) is om te onderzoeken hoe een watersysteem reageert onder extreme omstandigheden of onder welke omstandigheden het systeem faalt. Een stresstest geeft een beter inzicht in de worst-case-omstandigheden, gevolgen van extreme scenario’s en schetst mogelijkheden om op nadelige gevolgen te reageren.

De aanpak voor een JCAR ATRACE-stresstest bestaat uit de volgende elementen:

- Beschrijving van het systeem
- Hydrologische omstandigheden
- Gevolgen voor gebruiksfuncties van het watersysteem en relevante objecten
- Verkennen van mogelijke maatregelen.

Dit document bevat de systeembeschrijving van het deelstroomgebied Roer. Het Roer-stroomgebied is een internationaal stroomgebied met het grootste deel in Duitsland en kleine delen in België en Nederland.

Naast kenmerken van het stroomgebied, waterinfrastructuur en het gebruik ervan en een overzicht van de stakeholders, is een belangrijk onderdeel van deze systeembeschrijving een uitgebreide inventarisatie van water-gerelateerde modellen die beschikbaar zijn in het Roer-stroomgebied. Voor zover de auteurs weten is een dergelijke inventarisatie niet eerder gemaakt.

Samen met de systeembeschrijving is een verklarende woordenlijst van technische termen in meerdere talen (Duits, Nederlands, Frans) bijgevoegd.

Français

L'objectif d'un test de résistance au sens du programme de coopération conjoint pour la recherche scientifique appliquée sur la gestion des risques d'inondation et de sécheresse dans les bassins fluviaux régionaux (JCAR ATRACE, www.jcart-atrace.eu) est d'étudier comment un système d'eau réagit dans des conditions extrêmes ou dans quelles conditions le système est défaillant. Un test de résistance permet de mieux comprendre les conditions les plus défavorables ainsi que les conséquences des scénarios extrêmes et les options pour répondre aux conséquences défavourables.

L'approche d'un test de résistance JCAR ATRACE comprend les éléments suivants :

- Description du système
- Conditions hydrologiques
- Conséquences pour les fonctions d'utilisation du système d'eau et les objets pertinents
- Exploration des mesures possibles.

Ce document est la description du système du sous-bassin versant de la Rour. Le bassin versant de la Rour est un bassin international dont la majeure partie se trouve en Allemagne et de petites parties en Belgique et aux Pays-Bas.

Outre les caractéristiques du bassin versant, l'infrastructure de l'eau et son utilisation, ainsi qu'une vue d'ensemble des parties prenantes, l'un des principaux résultats de cette description du système est un inventaire complet des modèles liés à l'eau qui sont disponibles dans le bassin versant de la Rour. À la connaissance des auteurs, un tel inventaire n'a jamais été compilé auparavant. La description du système est accompagnée d'un glossaire des termes techniques en plusieurs langues (allemand, néerlandais, français).

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1 Introduction

Originally, a stress test is a medical test of the human heart under physical exercise. In the context of the Joint Cooperation programme for Applied scientific Research on flood and drought risk management in regional river basins (JCAR ATRACE) we investigate how a system reacts under extreme conditions or under which conditions the system fails. Goal of a stress test is to gain a better understanding of worst-case conditions and consequences of extreme scenarios.

The “stress test Rur” aims to gain a better understanding on how the Rur catchment reacts to worst-case conditions of extreme scenarios, learn what consequences are and to identify possible measures to mitigate unfavorable consequences. So the system failure here is the failure of the water system. Inundations are typical system failures, but other failures are also thinkable, for example water scarcity or destructed hydraulic structures. Consequences of system failure addresses consequences for the people living in the catchment area. Examples for consequences are flood damage to houses and critical infrastructure, limited accessibility of locations during a certain period or interruptions in supply with drinking water and electricity, or evacuations of inhabitants.

By carrying out this stress-test we will further develop the stress test approach such that the stress test Rur can become a guideline for other stress tests on the same catchment or other catchments in the cross-border area between the Netherlands and North Rhine-Westfalia.

The approach of the stress test Rur follows the method for an inter-regional stress test as outlined in Figure 1. The global method consists of three phases:

1. The starting points phase comprises scoping and system understanding.
2. The analysis is the stress test itself. Here scenarios are evaluated for system failure
3. Screening (of measures)

This document contains the first element, the scoping and the system understanding. Parts 2, analysis and screening, are described in a separate report.

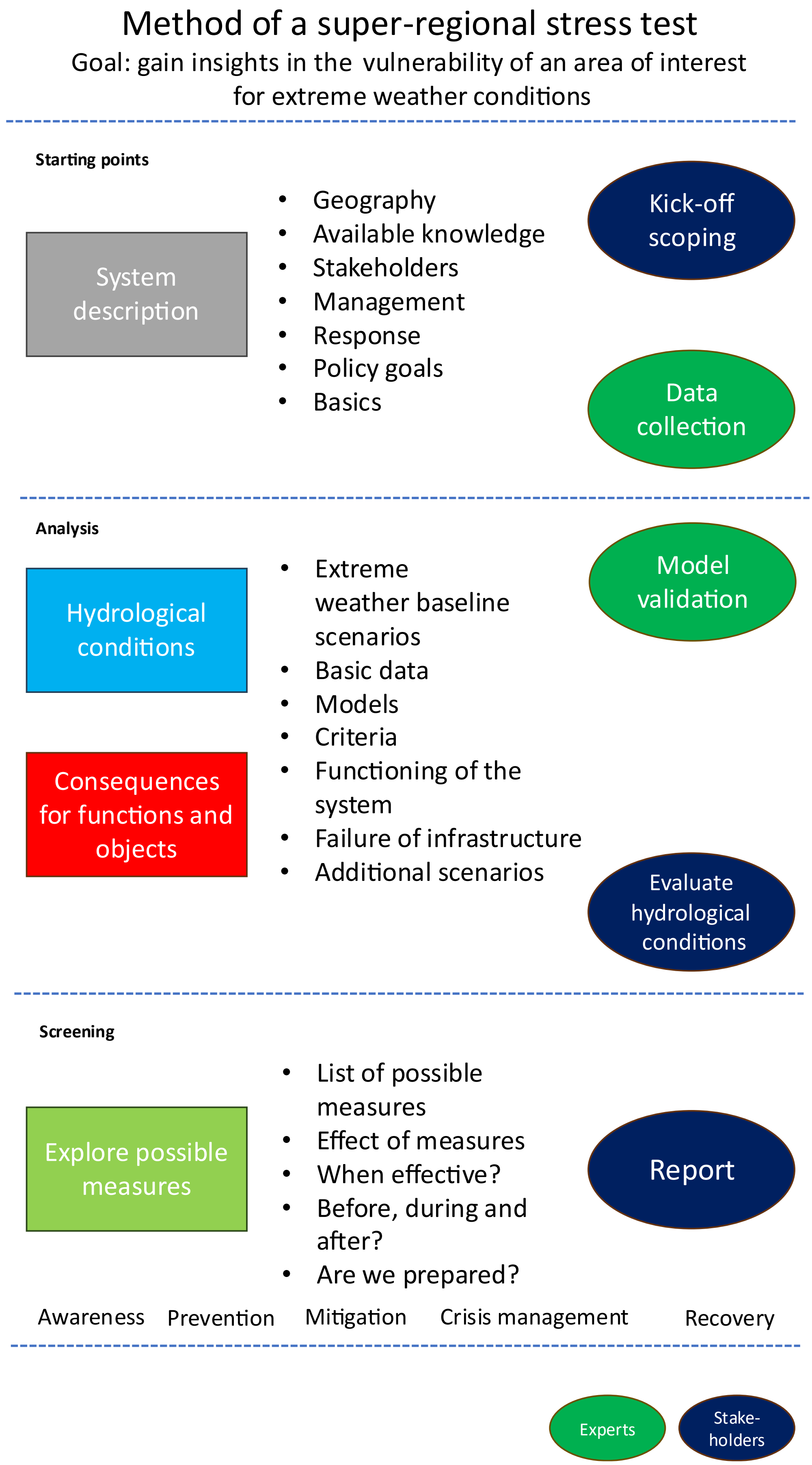


Figure 1 Approach stress test

2 System description of the Rur

2.1 Catchment characteristics

2.1.1 Geography

The Rur River is a mid-European low mountain to lowland river within the climatic zone of the westerly wind drift. The Rur River's catchment extends from the mid-mountainous area of the northern Eifel Mountains in its upper reach to the lowlands of the Lower Rhine Embayment in its lower reach (Kufeld et al. 2010). The Rur River is 165 km long, and the catchment size is 2.338 km² (vom Kothen & Pütz 2005) Its source is located in the in the raised bog area of the High Fens in Belgium at an altitude of 660 m above sea level.

About 6.7 % of the Rur River's catchment is in Belgium, approximately 4.6 % is situated within Dutch territory, and almost 90 % of the catchment is in Germany (Bogena et al. 2005). The catchment area of the Rur River makes up 7 % of the Meuse catchment area. Beside the Sambre tributary, it is one of the few tributaries in the catchment that is significantly regulated by dams (Kufeld et al. 2010).

In its upper reach, the Rur River flows through Belgium for approximately 10 km, before flowing through the Eifel, a low mountain range in Germany (MKULNV NRW 2014).

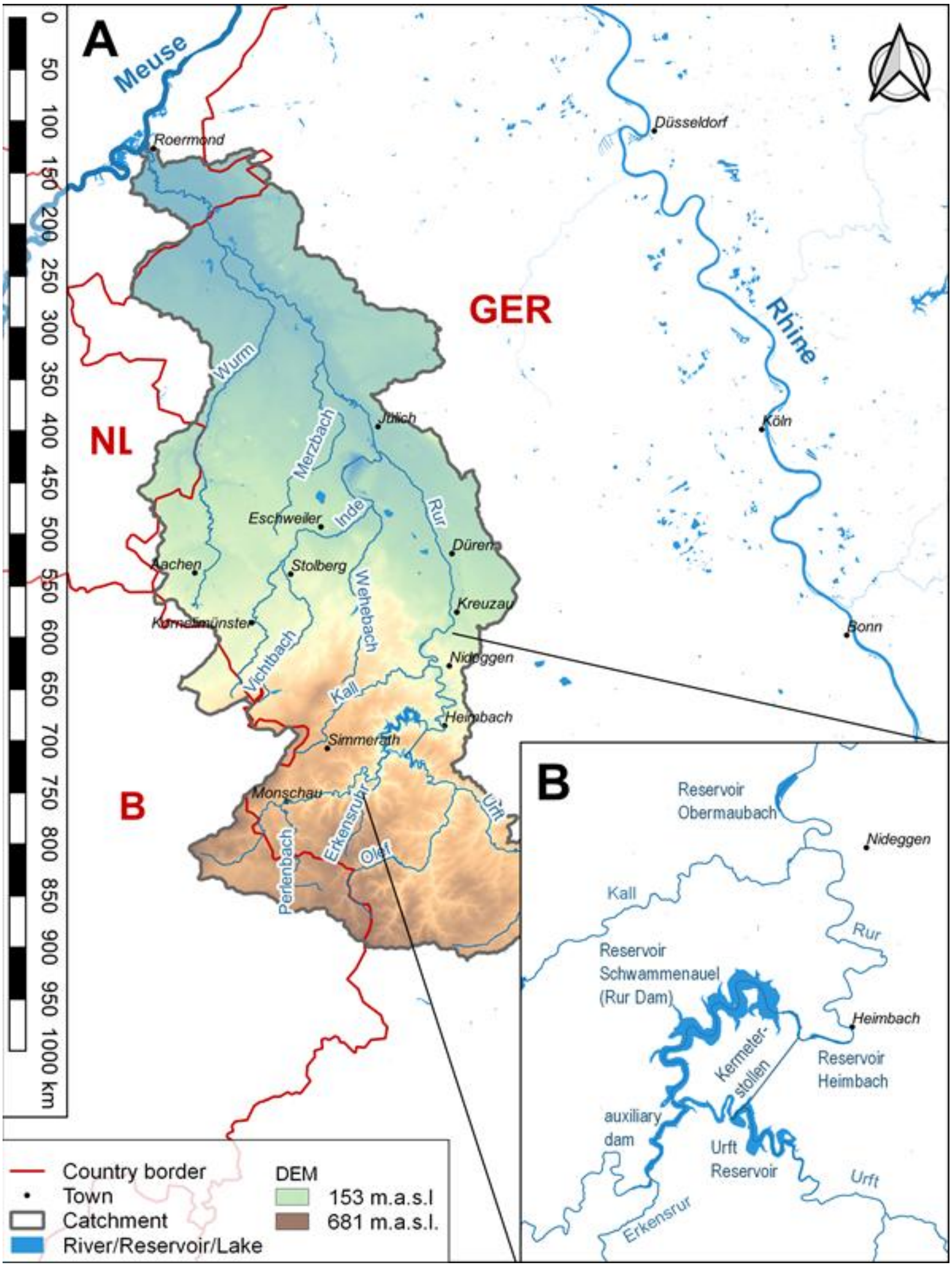


Figure 2 A: Rur River catchment and main tributaries. B: Overview of the Urft Reservoir and Rur Dam. Source: Wolf 2023

2.1.2 Hydrography

The Rur river is a tributary of the Meuse river. Its contribution to the Meuse can be significant, especially during low flow when its average contribution can grow to up to 12-16 % (Kramer 2021, RIWA-Maas 2021), with peaks up to 20-25 % (Pyka et al. 2016, Demny et al. 2018). This can be attributed to the presence of the Rur reservoir system which is described in further detail in Section 2.2.1.

Figure 3 shows the longitudinal profile of the Rur and its tributaries. The Rur can be divided into three hydrographic regions. First, there is the Upper Rur, located in the Eifel, where also the largest reservoirs are located. The main tributaries in this region are the Urft river, which has the Olef river as its tributary, and the Kall river. Upstream of the reservoirs, the discharge shows a typical pluvio-nival variation over the hydrological year (Figure 5).

In the Middle Rur, the main tributary is the Inde river, with the Vichtbach and Wehebach as its tributaries. The Lower Rur has the Wurm river as its most important tributary, and splits into the Rur and the Hambeek before entering the Meuse in Roermond. In the lower reach the Rur can be considered a gravel-rich lowland river.

The Rur River has a naturally varying discharge (Künster 1967). Rainfall is distributed relatively evenly throughout the year, the differences being due to evaporation (Künster 1967). Additionally, the High Fens regulate the run-off by holding precipitation water, serving as water source for the flat northern agricultural and industrial prone parts (Künster 1967).

The river systems of the Eifel mountains—, including the Upper Rur, Urft, and Olef Rivers, experience mean yearly rainfall ranging from 850 to 1100 mm (Gallusser 1964). Evaporation is very high towards the lowlands, exceeding 500 mm annually (LfU 2019). Near Düren, nearly 90 % of precipitation evaporates (Künster 1967). The Rur River exhibits a significant bed slope, with 1.4 % in the uplands and 0.1 % in the lowlands, with impermeable shale bedrock.

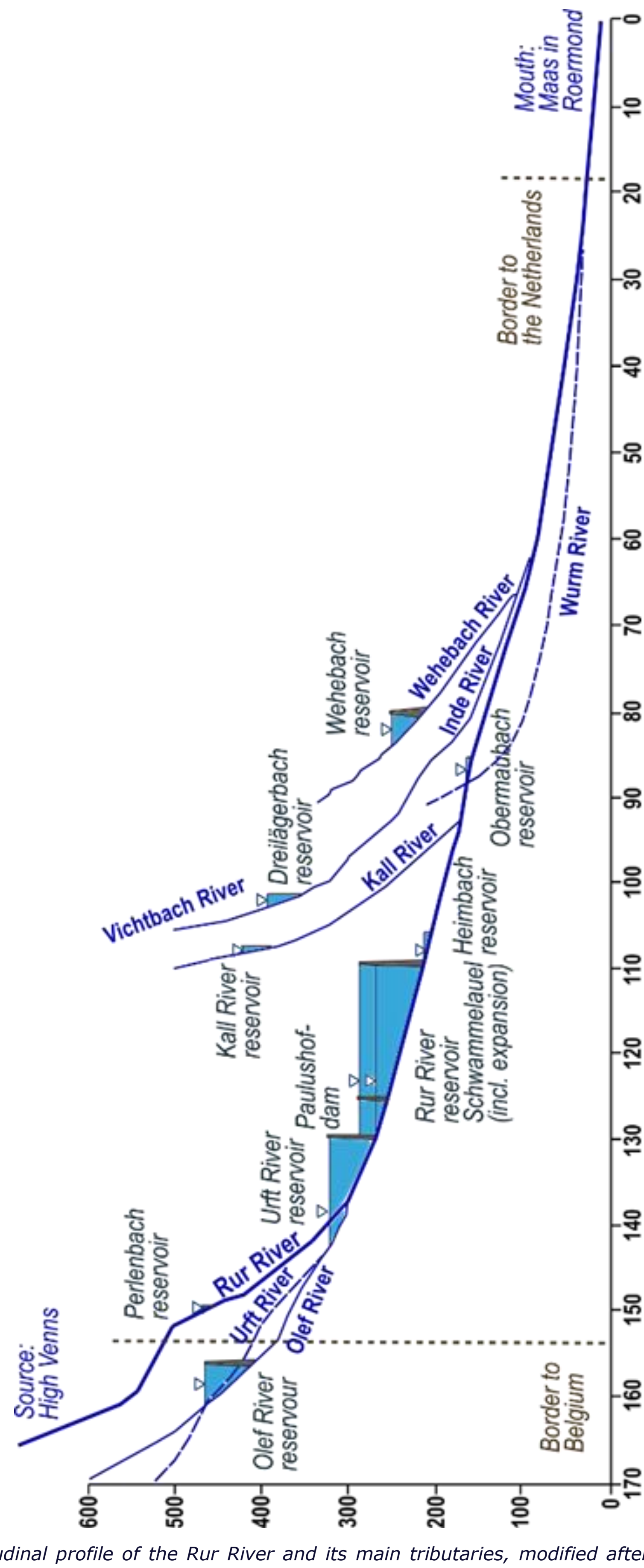


Figure 3 Longitudinal profile of the Rur River and its main tributaries, modified after 'WVER, Steuer-ordnung' in Kufeld et al. 2010. Source: Wolf 2023

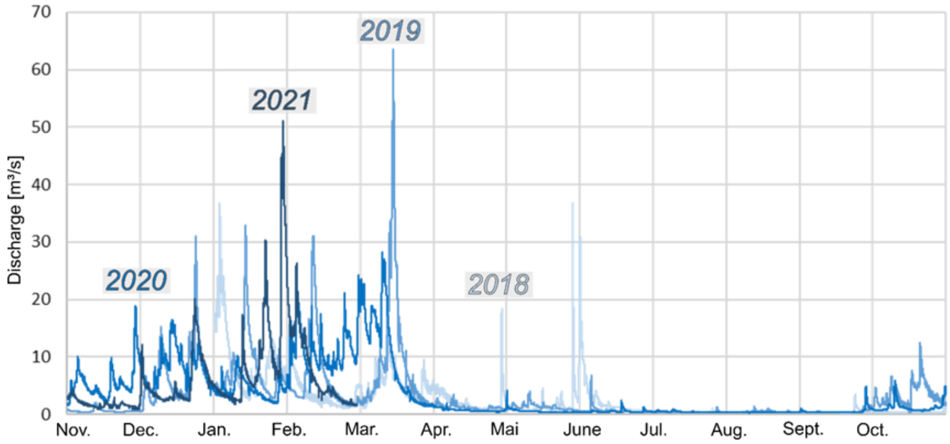


Figure 4 Measured discharge at the gauging station Monschau during the project timeframe divided into circles of the hydrological year. In Monschau, in the low mountain region, the Rur River's discharge is not influenced by large dams. Hence, the typical yearly pattern of a pluvio-nival discharge regime can be observed. Source: Wolf 2023

2.1.3 Land use

Studies have highlighted the significant impact of land use changes on run-off patterns within the catchment. Deforestation, for instance, can lead to runoff increases ranging from 4 % to 43 % (Shukla et al. 2020). The Rur River catchment is characterized by dynamic landscape with distinct land uses along its course. In the upper Rur catchment, forests dominate, while the lower reaches are characterized by agriculture, industry, and urban areas (Figure 5). Over the past two centuries, the northern Eifel region has undergone significant transformations, including urbanization, reforestation efforts, and changes in agricultural practices (Figure 6, Nilson 2006). Industry plays a significant role in water usage within the catchment. The anthropogenic alteration of the catchment is evident, with forest cover prevailing in the uplands and grassland and farmland occupying the plateaus (Kufeld et al. 2010).

Today, the Rur River's dynamics are heavily influenced by human activities, with private companies, particularly in the paper industry, remaining large water consumers in the region (Bressers et al. 2016; Wagner et al. 2013). The upper catchment is characterized by large dams (Figure 2).

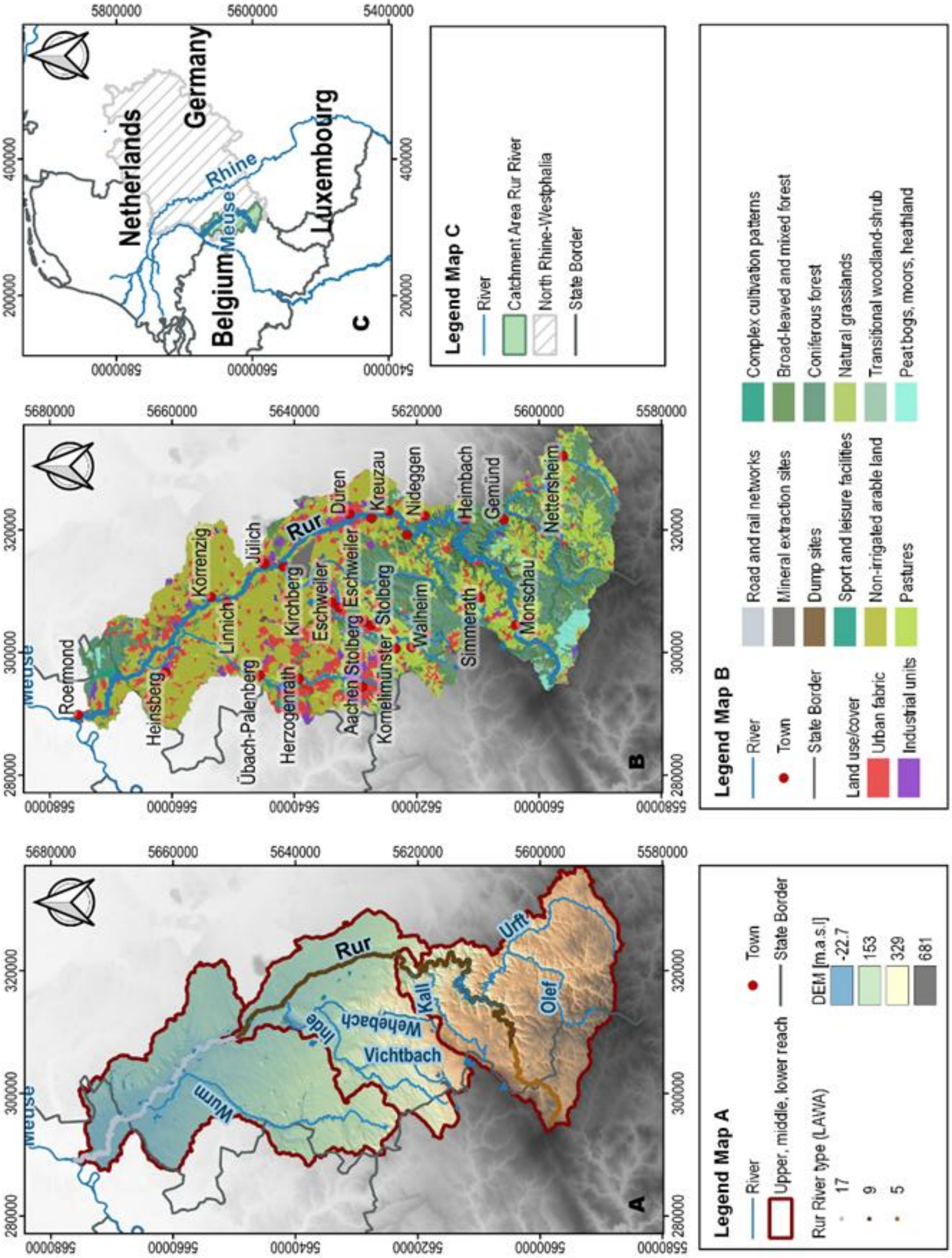


Figure 5 *Catchment of the Rur River. Map A shows elevations, based on Bezirksregierung Köln 2021, and the main rivers with the typology of the Rur River according to Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025a, the so-called LAWA-types. LAWA river type 17 describes coarse material-rich, siliceous low mountain range streams, LAWA river type 9 describes silicate, fine to coarse material-rich low mountain streams, and LAWA river type 5 describes gravel-rich lowland rivers. Map B shows land use and land cover based on EEA 2016). Map C gives an overview of the location of the catchment of the Rur River.*

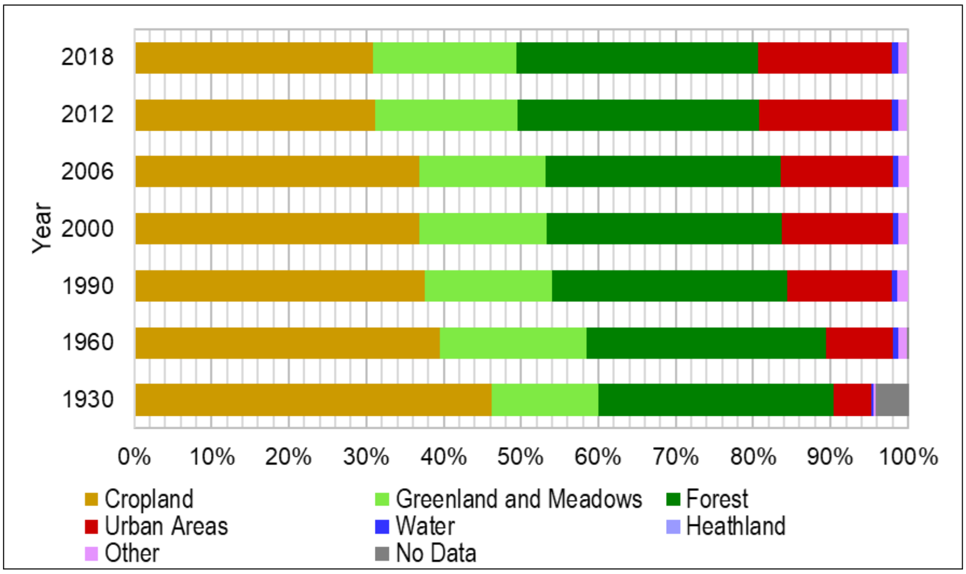


Figure 6 Land Use in the Rur Catchment based on data from Nilson 2006) and EEA 2016).

The Rur River catchment has a long history of human influence. Romans mined minerals in the Inde River catchment for weapon production (Schmidt-Wygasch et al. 2010), established water mills on the Rur River (Droste 2003), and implemented urban drainage systems. Urbanization began centuries ago, with Aachen already piping small spring streams during Napoleonic times (Lehmkuhl 2011). Deforestation in the Urft River catchment during Roman times left a lasting impact (dos Santos Mendes 2016). However, the most significant changes occurred in the last two centuries, altering land use and shaping today's river morphology (Nilson 2006). Urbanization intensified in the past century, significantly impacting the landscape (Figure 6).

Post-World War II, industrialization shifted to agriculture in the Rur catchment, leading to increased river pollution from wastewater (Paul 1994). Structural changes in the Monschau region in the 1950s transitioned from small-scale agriculture to settlement expansion (Dussart & Claude 1971). River management focused on reclaiming floodplains for agriculture and expanding settlements from the war era to the early 1980s (Lehmkuhl 2011). Technological advancements post-war saw the abandonment of water mills in favor of electricity (Brykała & Podgórski 2020). Large-scale groundwater pumping and river course relocations facilitated open-cast lignite mining (Lehmkuhl 2011), with river management limited to vegetation clearance (Paul 1994)

2.1.4 Cities and populations

The largest cities in the Rur River's catchment are Aachen, Düren, Stolberg, Eschweiler and Heinsberg in Germany and Roermond in the Netherlands. All cities are located in the middle and lower reaches of the Rur River.

Table 1 Number of inhabitants of municipalities in the Rur catchment (CBS 2023, GV-ISys 2023).

City	Number of inhabitants	Kreis (D) or Province (NL)	River
Roermond (NL)	60.000	Limburg	Rur
Kerkrade (NL)	46.000	Limburg	Wurm
Aachen (GE)	252.000	Aachen	Wurm
Düren (GE)	93.000	Düren	Rur
Jülich (GE)	33.000	Düren	Rur
Eschweiler (GE)	56.000	Aachen	Inde
Herzogenrath (GE)	47.000	Aachen	Wurm

2.1.5 Hydrogeology

In terms of resources, three types of maps are often used when addressing the geohydrology of the catchment: soil maps addressing the upper layer, geological maps describing the deeper layers and geohydrological maps, addressing the characteristics of groundwater and surface water. These types of maps are available for the Rur catchment for the Dutch and the German region. The Dutch data can be accessed on a national level via the NHI (Nederlands Hydrologisch Instrumentarium) and Dinoloket, and the German data on state level via the Geologischer Dienst NRW.

Table 2 Overview of maps related to hydrogeology of the Rur catchment.

	Dutch	German (NRW)	EU / global
Soil map	NHI Catalogue (Geo-Network 2024)	Bodenkarte von Nord-rhein-Westfalen BK50 (Geologischer Dienst NRW 2014)	Harmonized World Soil Data-base v 1.2 (FAO 2009; Fischer et al. 2008)
Geological map	Geologische Kaart van het Koninkrijk der Nederlanden (TNO 2023)	Geologische Karte von Nordrhein-Westfalen GK50 (Geologischer Dienst NRW 2020)	
Geohydrological map	NHI Catalogue (Geo-Network 2024)	Hydrogeologische Karte von Nordrhein-Westfalen HÜK250 (Geologischer Dienst NRW 2019)	

Several authors (Bogena et al. 2005 Bogena et al. 2018) give a general description of the hydrogeology of the Rur catchment. Again, the distinction can be made between the rocky highlands in the Eifel and the flat low-lands downstream of the reservoirs.

The upland area is defined by solid rock layers with low permeability and minimal groundwater recharge. As a result, water resources in this part of the Rur catchment are managed through reservoirs used for drinking water, energy production, and flood control. This region experiences strong sea-sonal variations, with significant runoff after rainfall events, while the lower Rur catchment’s runoff is heavily regulated by water management practices.

In contrast, the northern flatland region has abundant loose rock aquifers with high groundwater recharge rates, leading to intensive groundwater extraction for drinking and service water. The hydrogeology here is also influenced by the need to manage water levels in deep open-cast lignite mines

The Rur catchment can be divided into two main soil-landscape units (Bogena et al. 2005, Bogena et al. 2018). The southern part features soils like Fluvisols, Gleysols, Eutric Cambisols, and Stagnic Gleysols with a silt loam texture. The northern part has Cumulic Anthrosols near drainage lines and Haplic Luvisols, both with silt loam textures. Additionally, loamy sand soils like Fimic Anthrosols and Dystric Cambisols are found in the northernmost loess plain. The northern soils in the low-lands are highly productive, with an average field capacity of over 200 mm, whereas the upland southern soils have lower field capacities, ranging from 50 to 150 mm, and can drop below 30 mm in some areas.

2.1.6 Morphology

Due to geological variations and the transition from the low mountain area to the lowlands, the catchment exhibits diverse river types (Table 2). The steep uplands are predominantly composed of silt and clay, while the transitional zone features sand and gravel, and the lowlands are primarily sand-based. In the uplands, the Rur River and its tributaries are characterized as coarse material-rich, siliceous low mountain streams, gradually transitioning to gravel-rich lowland rivers as they approach the lowlands.

Figure 7 Example of the Rur River in its upper, middle, and lower reach. A shows large boulder in the coarse material-rich riverbed in the uplands (07.07.2019), B shows gravel deposits in the riverbed in the middle reaches (27.04.2021), and C shows the straightened and wide riverbed towards the lowlands (22.07.2021). Source: Wolf 2023

Table 3 Overview of the typology of the Rur River and its main tributaries according to MULNV NRW 2020, LAWA 2013. Source: Wolf 2023

River or river section		River Type, according to UBA, 2014	Explanation
Rur River	Source to downstream of Monschau	LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
	Upper and middle reach	LAWA Type 9	Silicate, fine to coarse material-rich low mountain streams
	Lower reach	LAWA Type 17	Gravel-rich lowland rivers
Urft River	Source to Nettersheim	LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
	Nettersheim to Kall	LAWA Type 7	Coarse material-rich, carbonate low mountain streams
	Downstream of Kall	LAWA Type 9	Silicate, fine to coarse material-rich low mountain streams
Olef River	Source to Hellenthal	LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
	Downstream of Hellenthal	LAWA Type 9	Silicate, fine to coarse material-rich low mountain streams
Kall River		LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
Vichtbach River		LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
Wehebach River		LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
Inde River	Source to Walheim	LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
	Walheim to Vichtbach confluence	LAWA Type 7	Coarse material-rich, carbonate low mountain streams
	Vichtbach confluence to Eschweiler Patternhof	LAWA Type 9	Silicate, fine to coarse material-rich low mountain streams
	Downstream of Eschweiler Patternhof	LAWA Type 17	Gravel-rich lowland rivers
Wurm River	Source to Übach-Palenberg	LAWA Type 5	Coarse material-rich, siliceous low mountain range streams
	Downstream of Übach-Palenberg	LAWA Type 17	Gravel-rich lowland rivers

Before large dams were constructed, the Rur River's sidearms regularly changed after flood events (Künster 1967). Widespread forest destruction from the early Middle Ages to the 19th century significantly increased sediment input into the Eifel river systems (Lehmkuhl et al. 2010; Dussart & Claude 1971; Vandenberghe et al. 2012).

Since the late 19th century, heathland has been converted to coniferous forests, accompanied by the construction of drainage ditches, leading to heightened soil erosion and sedimentation in the Rur River (Dussart & Claude 1971). Intense agricultural and forestry practices in the early 19th century amplified surface runoff, flood dynamics, and sediment inflow into the river. In the lowlands, charcoal production for ore smelting led to extensive deforestation in the Early Modern Period (Schmidt-Wygasch et al. 2010).

In the early 19th century, the Aachen government deemed the Rur River too unpredictable yet too dry in summer (WVER 1999). Plans for large-scale streambed straightening emerged as early as 1792 due to severe bank erosion during floods. However, lack of community participation in funding and residents attributing the issue to heavy deforestation hindered these plans. Instead, local river works in 1807 and 1808 included meander cutting and embankments near Körrenzig (Hansen 1992). Increased flood risk prompted emergency measures such as vegetation clearance from floodplains and riverbeds (Paul 1994). Between 1817 and 1821, the Rur River was relocated near Körrenzig following another meander formation during a flood event (Hansen 1992).

The 'Rurwasserverband' founded in 1955 began river straightening between Düren and the German-Dutch border (Hansen 1992), continuing in 1960 near 'Merkener Rurbrücke' and downstream of Düren in the 1960s (Schiller 1992; Nilson 2006. Today, the middle reach of the Rur river is regulated with weirs to prevent incision (Künster 1967), with the first restoration occurring in 1996 near Jülich (Goedeking 2012). Local communities mostly regulated river adjustments (Künster 1967), often lacking documentation. Overall, river regulations and mine water drainage led to groundwater level decline around the lignite mine (Künster 1967).

2.1.7 Climate

North Rhine-Westphalia has a relatively humid and cool climate due to its proximity to the Atlantic Ocean (Bressers et al. 2016; Kufeld et al. 2010). As already mentioned in chapter 2.1.2., precipitation in the upper catchment is significantly higher than that in the northern lowlands (Kufeld et al. 2010). Here, the Rur River is prone by its pluvio-nival discharge regime due to the Eifel mountains (Lehmkuhl 2011). Thus, the highest discharge is experienced in winter months and followed by long periods of dry weather runoff in summer (Figure 4). Flood events mainly occur in spring and winter due to prolonged rainfall or snowmelt, and in summer due to convective heavy rainfall. Due to its discharge regulation, runoff peaks are smaller downstream of the dammed river sections (Esser 2020; Lehmkuhl 2011). Figure 8 shows average precipitation and air temperature for observation point Roetgen which is close to Aachen.

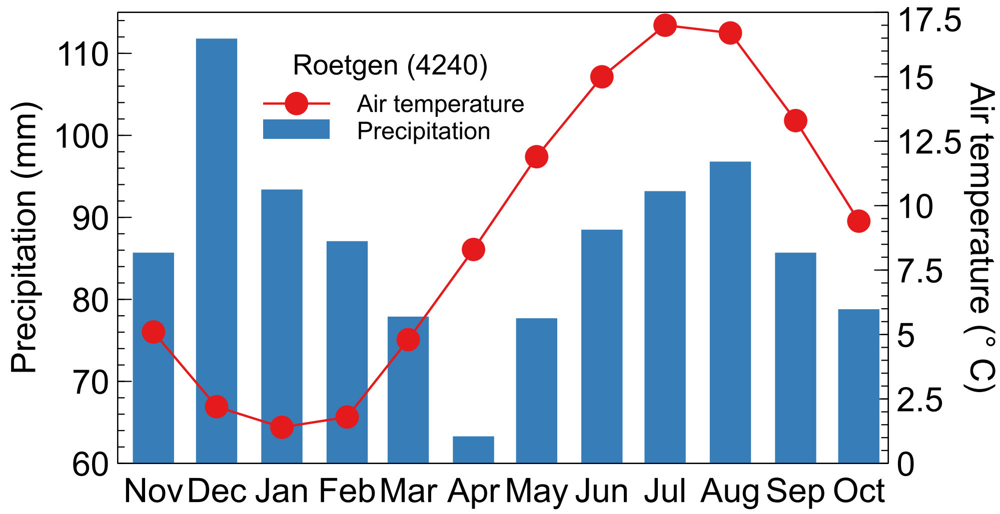


Figure 8 Average precipitation and air temperature for each month in the hydrological year for the period from 1991 to 2020 for observation point Roetgen (station number 4240, data source: Deutscher Wetterdienst 2025)

2.1.8 Discharge, floods and low flow conditions

The Rur gauge in Monschau was installed in 1954, followed by the gauge in Stah in 1960 and Jülich Stadion in 1971. Consequently, none of the water level records predates the construction of the dams. Discharge values for gauge Stah is given in Table 4.

Table 4 Discharge values for Stah gauging station in m³/s (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025b)

Parameter	Abbreviation (German)	Value
Lowest low flow	NQ	6.34
Average low flow	MNQ	11.22
Average discharge	MQ	21.43
Average flood discharge	MHQ	86.24
Flood discharge	HQ	129.35

The most significant floods before the flood event of mid-July 2021 recorded up to 2010 occurred in 1983 and 1998, with water levels reaching up to 2.8 meters in Jülich (see Table 5).

Table 5 Auswertung öffentlich zugänglicher Gewässerkundlicher Jahrbuchseiten von Pegeln der (Eifel-)Rur, Quelle: (LANUV NRW 2014c, 2014b, 2014a)

Pegel	HHQ (Extremwert 1)	Extremwert 2
Monschau	15.09.1998, 110 m³/s, 183 cm	22.12.1991, 98,7 m³/s, 182 cm
Jülich-Stadion	27.05.1983, 164 m³/s, 279 cm	18.03.1988, 152 m³/s, 114 cm
Stah	27.05.1983, 129 m³/s, 277 cm	12.12.1966, 129 m³/s, 281 cm

The Rur has faced floods since the early Middle Ages, with reports of regular bridge damage at Nideggen-Brück due to spring floods (Tichelbäcker 2007). In 1890, a flood raised water levels over 2 meters in the middle course (Weyrich 1938). Two consecutive floods in December 1902 and January 1903 reached up to 1.82 meters due to heavy rainfall and snowmelt runoff from the Eifel mountains (Weyrich 1938). In June 1905, heavy rainfall in the Eifel mountains led to the next flood, and the newly constructed Urft dam was unable to hold everything back (Weyrich 1938). The next record flood in February 1906 is said to have led to water levels not seen since 1797 (Weyrich 1938).

In the Inde catchment, floods have been monitored since 1966, with the highest recorded in July 2014 and September 2007, reaching 385 cm in water level and 89.5 m³/s in discharge (LANUV NRW 2021a). The Mulartshütte gauge recorded the highest floods in July 1985 and twice in 2007 (LANUV NRW 2021b).

Historical records highlight floods dating back to the 18th century, with devastating impacts on towns like Stolberg and Eschweiler (Ritter 1889; Müller 2022). Floods in 1897 and 1906 submerged large areas, causing extensive damage to infrastructure and claiming lives (Bote an der Inde 1897, 1906). Subsequent floods until 1966 caused moderate damage, but in 1966, floods inflicted significant harm to Eschweiler's urban and industrial areas, resulting in around DM 3,000,000 in damages (Oberer Indeverband 1966). Since the 1970s, floods have caused localized damage, mainly affecting cellars (Müller 2014; Velten 2007; Bote an der Inde 1991). Flash floods from heavy rainfall have also become increasingly frequent since the turn of the millennium, causing cellar floods in 2006, 2014, and 2018 (Müller 2022, Figure 9).

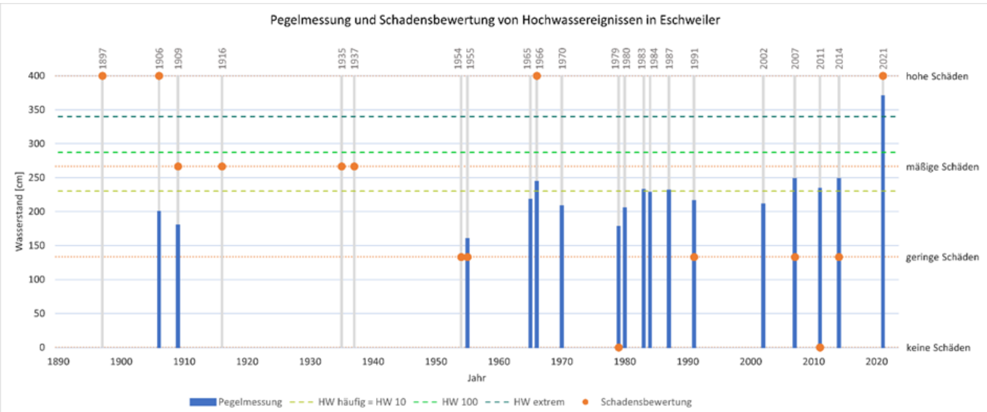


Figure 9 Rechercheergebnisse zu historischen Hochwassern im Einzugsgebiet der Inde, Quelle: Müller 2022.

In most floods, water levels range from 2 m to 2.5 m, corresponding to discharge rates of approximately 60 m³/s to 90 m²/s. Over the period analyzed, frequent 10-year events exceeded this level 7 times, with an HQ100 event not occurring until 2021. July 2021 saw a discharge peak leading to a water level of about 370 cm, significantly surpassing an HQ100, also qualifying as an HQextreme. Among 25 flood events with known dates, 18 occurred in winter, while the three highest floods (2007, 2014, and 2021) happened in the last 15 years during summer. Heavy rainfall was the primary cause of 9 floods, with snowfall and snowmelt contributing to others (Müller 2022). Technical control errors, like the Dreilägerbach dam overflow in 1966, were cited in some cases (von Laufenberg 2020). Flood duration varied from hours to a day, often surprising locals (Bote an der Inde 1897, 1906, 1955).

Historical records show no significant protective measures until the 20th century, with sporadic actions like cellar clearing after disasters (Bote an der Inde 1906; Koch 1882). Improved public awareness post-1906 flood led to private precautions, possibly reducing damage. Central protection measures began in the 19th century, including bank reinforcements and gradual river regulation (Bosselmann 2008; Eschweiler Geschichtsverein e.V. 2008). Current development levels correspond to an HQ200 (Müller 2022).

The reservoirs in the Rur catchment are operated to stabilize the discharge (see also Section 2.2.1). Consequently, the Rur has not seen extreme low flow conditions in recent history. Due to the water supply from the reservoirs, the Rur river is able to contribute significantly to the discharge of the Meuse during low flow conditions (RIWA-Maas 2022; Kramer 2021). This can be beneficial for maintaining a minimum-flow in the Meuse river, but also for maintaining water quality during low floods, e.g. the effects of water temperature (Pyka et al. 2016).

2.1.9 Future climate change

Climate change is projected to cause longer summer droughts in the Rur–Meuse region (van der Hurk et al. 2014). Due to its significant contribution and the role of reservoir management, the Rur river can play an important role in the future of water management in the Meuse catchment under such a changing climate. The reservoirs can safeguard a minimum flow during dry periods, which have a positive effect on low-flow conditions upstream of the Rur-Meuse confluence (RIWA-Maas 2022).

At the same time, climate change may pose challenges with respect to flood protection in the future as local climate change projections show wetter conditions for the Rur catchment, leading to an increase of peak discharge during floods (Demny et al. 2018).

2.2 Water infrastructure

2.2.1 Reservoirs

The Rur basin contains 10 reservoirs, of which six are managed by WVER, three by water supply companies. The Cranenweyer, the only conventional reservoir in the Netherlands, has its origin in the aftermath of hard coal mining and has primarily a recreational purpose. Table 6 lists the dams. Note that the name of the dam and the reservoir lake behind in practice are sometimes used synonymously. Where applicable, the name of the lake is mentioned, too.

Table 6 Dams and reservoirs in the Rur catchment

Country	Name of the dam and the lake where applicable	Impounded water	Volume of the reservoir lake (Mio m³)	Surface area (ha)
Germany	Dreilägerbachtalsperre	Dreilägerbach, Vicht	4.280	40.0
Germany	Kalltalsperre	Kall	2.100	18.0
Germany	Oleftalsperre	Olef	20.300	110.0
Germany	Perlenbachtalsperre	Perlenbach	0.900	15.0
Germany	Paulushofdamm; divides the Rursee into the Ober-see (forebay) and the Hauptsee (main lake)	Rur		
Germany	Rurtalsperre Schwammenauel with and reservoir lake Rursee	Rur	202.600	783.0
Germany	Stauanlage Heimbach Staubecken Heimbach	Rur	1.430	34.6
Germany	Stauanlage Ober-maubach	Rur	1.650	55.4
Germany	Ufttalsperre	Urft	47.750	216.0
Germany	Wehebachtalsperre	Wehebach	25.060	162.0
Netherlands	Cranenweyer	Anstelerbeek		20.0

There is not much public information available about the reservoirs managed by the water supply companies, and they do not fulfill a role in drought measures and flood retention capacity. The reservoirs managed by WVER do have these functions. Their response to floods and droughts is described in detail in their operation plans and the accompanying volume-release plans.

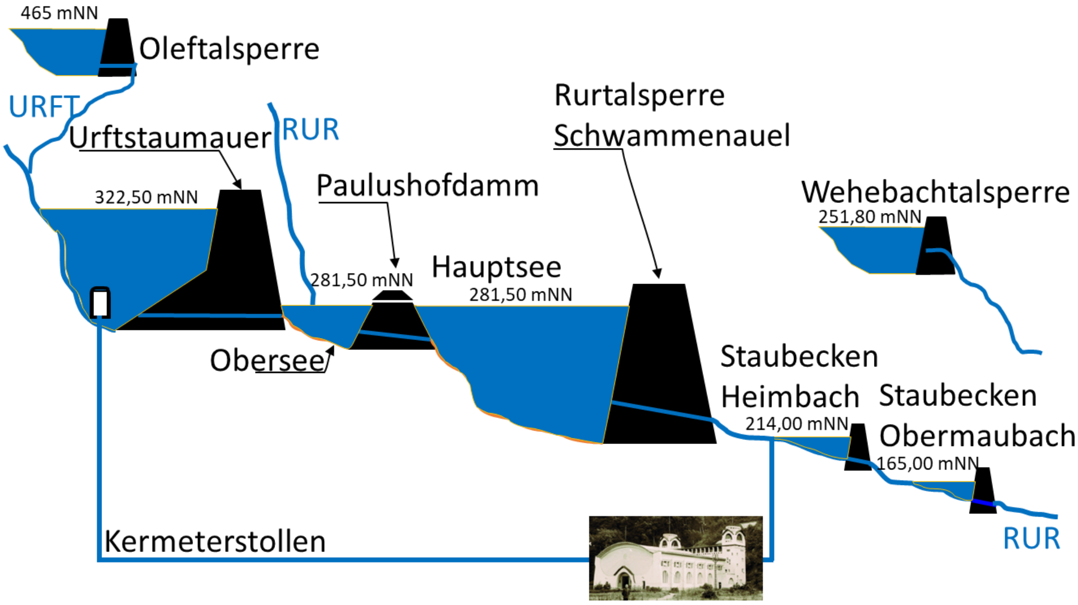


Figure 10 Reservoir system (source: Wasserverband Eifel-Rur, Reichert et al. 2024)

Dam construction aimed to meet Düren's industrial water demand, generate hydropower, and mitigate floods (Künster 1967; Franzius & Proetel 1927; Intze 1906). Francis turbines, highly efficient, rivalled steam energy (Meurer 2000). Initially, the Urft reservoir provided 9 m³/s for 360 days, a significant increase from the previous 130 days (Künster 1967), yet fell short of the industries' 12 m³/s needs (Künster 1967). Subsequent droughts and floods spurred further reservoir construction (Franzius & Proetel 1927). World War I halted industrial progress (Franzius & Proetel 1927). Schwammenauel and Heimbach reservoirs were built from 1934 to 1938, expanded from 1955 to 1959 (Meurer, 2000), alongside other dams: Dreilägerbachtalsperre (1909-1911), Kalltalsperre (1934/1935), Perlenbachtalsperre (1953-1955), Wehebachtalsperre (1977-1983), and Oleftalsperre (1955-1959) (Meurer 2000). Dam construction altered the Rur River's sediment transport, affecting bedload and flow continuity for over a century. The dams, with a total volume of 300 million m³, allocate 70 million m³ for flood prevention and utilize 80 million m³ annually for water supply (Polczyk 1999).

The reservoir system of Urfttalsperre, Oleftalsperre, Rurtalsperre Schwammenaul, Staubecken Heimbach and Staubecken Obermaubach serves multiple purposes. As mentioned above, the primary objective of the dams was and is the supply of water for industries. The reservoir operations aim to ensure a minimum flow that meets the demands from downstream water users and ecology. Another purpose is flood control. These two objectives are conflicting with each other. Operations follow a volume-release plan that prescribes the reservoir release in dependence of the day in the year (the season) and the current filling level (the volume of water in the reservoir). Figure 10 shows the volume-release plan. The reservoir volume is divided into zones, and each zone a reservoir release is assigned to. The supply level (Stauziel) and the full supply level (Vollstau) change with the season; during the wet season the plan provides more flood storage volume than during the dry period. Consequently, the volume-release plan foresees higher reservoir release during the flood season for the same storage volume. According to the operational plan the reservoir release is always between 5 and 60 m³/s. There is a dynamic area (white color) with a dynamic average filling line (Dynamische Mittellinie) where the actual reservoir release is decided upon by the operators.

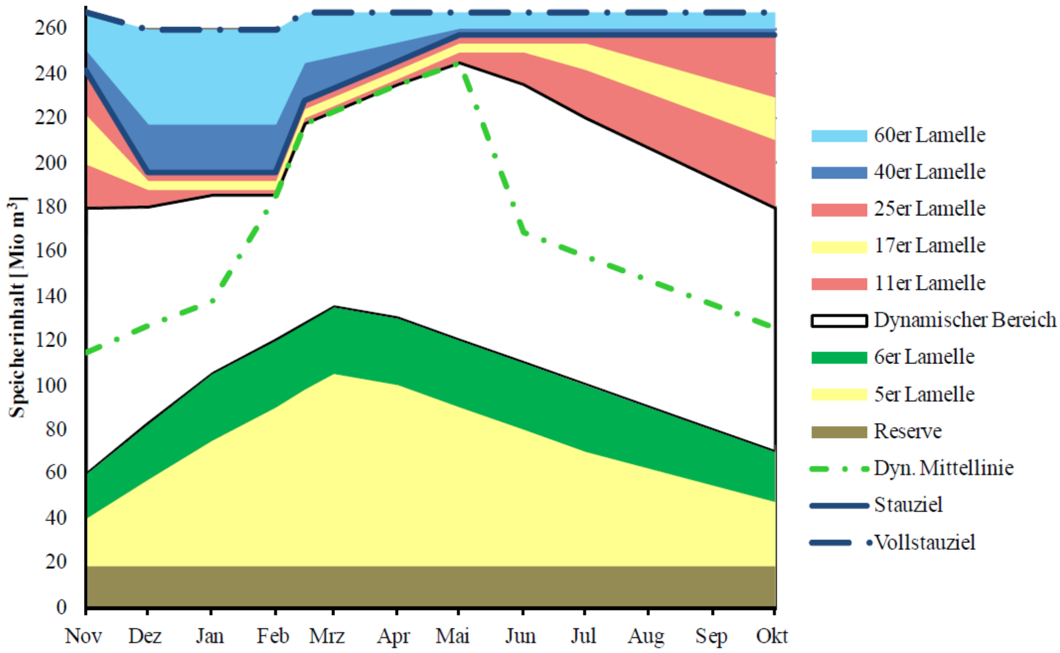


Figure 11 *Volume-release plan of the Rur reservoir system (Kufeld 2013a)*

Under extreme flood conditions, an operational emergency headquarter is set up and the dam operators coordinate with the supervising authority (Bezirksregierung Köln) on measures. Pass inflow operations where the reservoir release equals the inflow is an option if the reservoir is already filled to the full supply level. If this is not the case, operations aim to make best use of the flood storage volume in order to prevent flood damage downstream as good as possible. The operational protocol does not foresee a pre-release to drawdown the reservoir level in order to create more flood storage volume. A pre-release creates an artificial flood wave, this will in most cases coincide with flood peaks from the unregulated catchments of Untere Rur, Wurm and Inde downstream of the reservoirs and increase the flood damage. Consequently, the dam is operated to store as much of the inflowing water and increase the release not before the flood waves from the downstream sub-catchments are declining.

Wasserverband Eifel-Rur is developing a specific operational plan for drought management. This development addresses dry spring seasons where the hydrological conditions do not provide sufficient water to fill the reservoirs (Homann 2017).

2.2.2 Wastewater treatment plants

In 1934, wastewater treatment in the Rur catchment began (Schiller 1992), followed by large-scale canalization planning in 1967 (Künster 1967). Although water pollution decreased, river course structural quality remained poor (Lehmkuhl 2011). Impact loading from wastewater plants post-heavy rainfall and industrial water warming kept water quality low (Lehmkuhl 2011). Visible pollution caused fish deaths, but had limited consequences (Paul 1994). The establishment of Abwasserverband Rur (Rur Wastewater Association) in 1968 improved water management (Paul 1994, 1999), with the modernization of the treatment plant from 1958 to 1964 (Schiller 1992).

In 1993, the 'Wasserverband Eifel-Rur' (WVER) took over water management in the Rur catchment, including wastewater treatment and large dams, established legally in 1990 by NRW (WVER 2018).

2.2.3 Dikes and detention basins

Given the characteristic as a lowland river (Section 2.1.2), dikes are present along the Lower Rur (Figure 12) and the Inde and Vichtbach. The dikes protect buildings and build-up area, so there is no continuous dike along Vichtbach, Inde and Rur.

Lateral detention basins along the Lower Rur are not present yet, but along with dike relocation considered as potential flood protection measures in the flood protection concept.

The tributaries and Middle and Upper Rur are mid-mountainous water courses with steep valley slopes. Consequently, there are no dikes present in this area.

Wasserverband Eifel-Rur operates around 40 detention basins (Hochwasserrückhaltebecken), most of them are in and around the city of Aachen and Herzogenrath. The installation of additional detention basins is planned as part of the flood protection concept (Section 2.1.2).

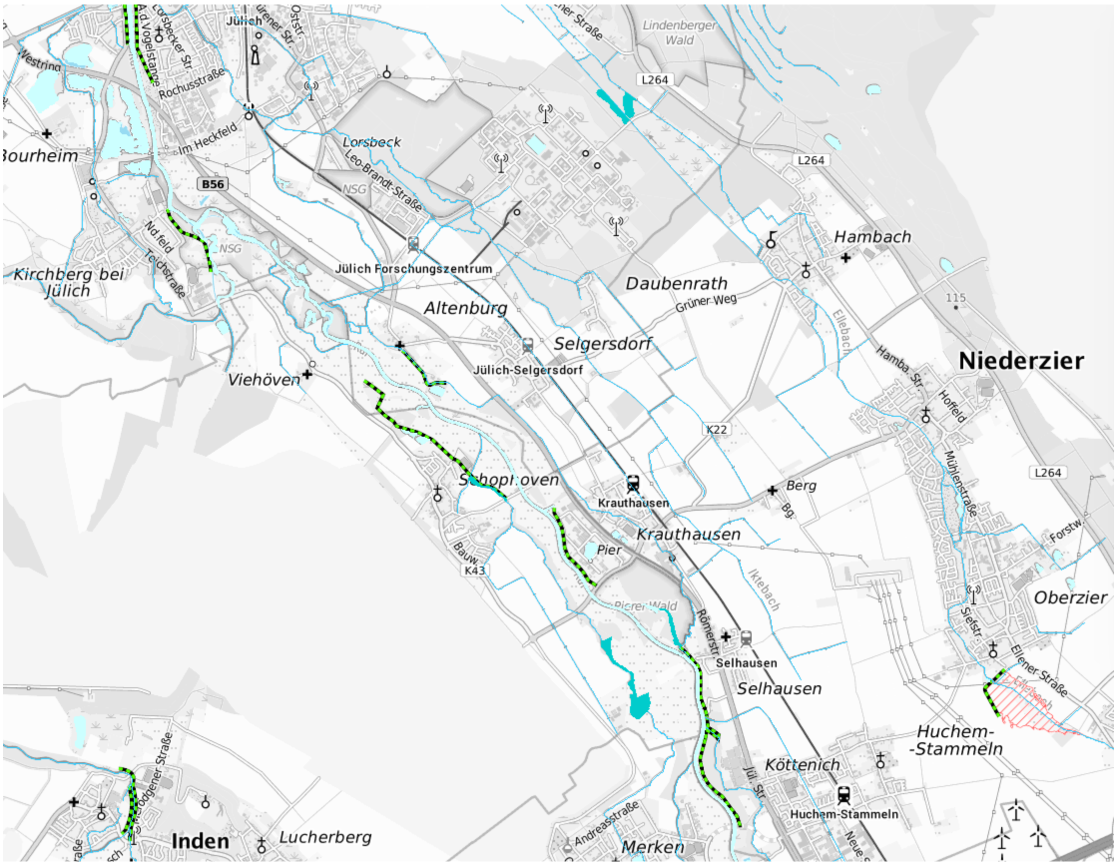


Figure 12 Map screenshot of the Rur river section between Düren and Jülich with dikes (dotted line green-black) and "Hochwasserrückhaltebecken Oberzier". The Rur passes the two open-pit mines Hambach (to the East) and Inden (to the West). Source: Geschäftsstelle des IMA GDI Northrein-Westfalen 2025

Figure 13 Small detention basin for buffering rainfall water in Herzogenrath-Bierstraß (photo: B. Becker)

A list of larger detention basins to retain stream flow and rainfall water is given with Table 7. These basins are due to their size subject to supervision of the district council (Bezirksregierung Köln).

Table 7 Detention basins with crest height of 5 m or higher in the Rur catchment (Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen 2003)

Name	Year of construction	Crest heigth	Storage volume	Water
Euchen	1984	18.00 m	0.863 hm³	
Rahe	1988	5.00 m	0.090 hm³	Wildbach
Herzogenrath	1989	5.00 m	0.097 hm³	

Smaller detention basins are listed in Table 8.

Table 8 Detention basins with crest height of less than 5 m in the Rur catchment (Geschäftsstelle des IMA GDI Northrein-Westfalen 2025). HRB: Hochwasserrückhaltebecken (German)

Name	Location	Water
HRB Kahlgracht	Aachen Hüls	Haarbach
HRB Debyestraße	Aachen Schönforst	Haarbach
HRB Echtz	Echtz	Schlichbach
HRB Merode	Merode	Schlichbach
HRB Konzendorf	Konzendorf	Derichsweiler Bach
HRB Eifelstraße	Bohl	Omerbach
HRB Gressenich	Gressenich	Omerbach
HRB Gey	Birgel	
HRB Oberzier	Oberzier	Ellebach

2.2.4 Hydraulic structures

South of Roermond centre, the Hambeek bifurcates from the Rur's main course. The Northern Control Lock and the Southern Control Lock (Figure 14, a and b) have been installed to prevent inundations in the centre of Roermond via the Rur due to backwater effects from high water level in the Meuse. The Southern Control Lock guides water from the Rur through the Groene Rivier and the Hambeek. This happens when a water level of 19 m+NAP is reached on the Meuse (Geertsema & Asselman 2022).

In addition to the Hambeek, there is an emergency option to divert high water to the Meuse via the so-called "Green River" or Roer overflow. This overflow area is normally dry but can be activated during high water threats. To use it, soil and road surfaces must be excavated at three specific locations, which is a major and costly intervention. The inflow point is just upstream of the southern floodgate (Geertsema & Asselman 2022).

Furthermore, Roermond has the so-called ECI-stuw, a weir to feed the ECI hydropower plant (ECI: Electro Chemische Industrie, today the buildings host an event location) with water from the Roer, and two structures to control the water level in the Rur: gate "Groot Hellegat" and the Hoge Bat, an inflatable rubber dam.

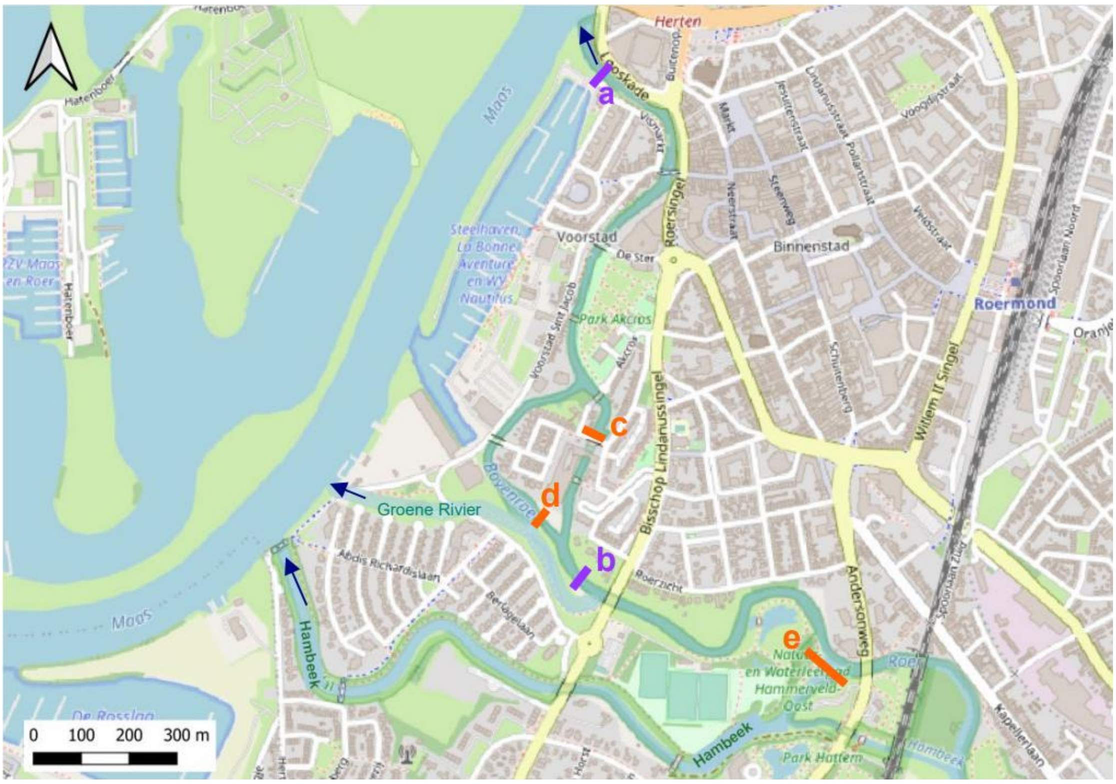


Figure 14 Map of the Rur mouth in the Meuse with the hydraulic structures "noordelijke keersluis" (control lock, a), "zuidelijke keersluis (control lock, b)", het "ECI-stuw" (weir to feed the ECI hydropower station, c), Groot Hellegat (d) and Hoge Bat (inflatable rubber dam, e). Picture source: Asselman & van Heeringen 2023

2.3 Water use functions

2.3.1 Drinking water

Reservoirs supply the majority of drinking water for the region, groundwater supplies a much smaller share of the drinking water (Schweda 2022).

To ensure that the water has a good quality, water is withdrawn from different layers in the reservoir and also composed from different reservoirs.

During the summer period the Rur supplies a significant share of the Meuse discharge. The Meuse is a source of drinking water for approximate 7 Million people in the lower Meuse region (Netherlands and Flanders).

2.3.2 Hydropower

RWE Power operates hydropower station Heimbach at Rurtalsperre dam. Power plant Heimbach is fed via the Kermeterstollen from the Urfttalsperre. The dam operator WVER grants a daily volume of water, and RWE Power allocates this during the day. Staubecken Obermaubach damps hydro peaks from the power generation and stabilizes the flow.

2.3.3 Industry

Side arms on the floodplains served as mill ditches for centuries, with their exact age now indeterminable (Künster 1967). In the early Middle Ages, the demand for hydropower, especially for grain mills, led to numerous mill ditch constructions on the Rur River (Vandenberghe et al. 2012; Droste 2003). The 'Lendersdorfer Mühlenteich' dates back to 1342, likely a merge of older ditches (Künster 1967). Most mill ditches between Obermaubach and the Inde tributary were likely built by the 10th century (Künster 1967).

Industrialization began with the cloth industry in the uplands, peaking in the northern Eifel in the late 18th century (Knotter 2018; Barkhausen 1960). Lignite extraction for heavy industry started in the 1820s between the Rur and Inde Rivers (Coenen & Schüler 2004), causing water pollution, especially in the Inde River from ore mining (Esser 2020; Paul 1994). Iron smelting demanded lignite, coal, and hydroelectric power, leading to watercourse straightening and dam construction (Schwind 1984).

Pre-industrial water management faced discharge fluctuations due to mills, floods, and pollution (Bernhardt & Hüesker 2013). The Industrial Era prioritized water for industry over agriculture, sparking conflicts (Paul 1994). Mill ditches were used for paper manufacturing in Düren in the mid-19th century (Paul 1994; Zorn & Warm 1967), and at the location of Düren two-thirds of the Rur River's water was directed into mill ditches in dry periods (WVER 1999). Sugar cane and paper industries settled along rivers in Aachen, Jülich, and Düren (Lehmkuhl 2011; Paul 1994). In 1957, the 'Kreuzau-Niederauer Teich' joined with the 'Dürener Graben,' diverting 3.1 m^3/s from the Rur (Künster 1967).

Water authorities balanced flood protection with industrial water needs, resulting in river regulations, dam construction, and lowered groundwater levels (Lehmkuhl 2011). Residents attempted flood protection with dams and meander cuttings, albeit unsuccessfully (Paul 1994). The government proposed Rur River regulations in 1907 (WVER 1999), leading to dam construction from 1900, notably the Urft River reservoir (Intze 1906).

In current times, water from the Rur river is still relied on for industrial use. The paper industry belongs to the main water users (see also Section 3.2.3.7).

Similarly, water from the Rur river is used as cooling water for the Weisweiler power plant's lignite-based energy production (Bogena et al. 2005). Water is pumped from the Rur at Schophoven and stored in Lake Lucherberg before being sent to the power plant. The topic of lignite mining in the Rur catchment is explored in more detail in the following section 2.3.4.

2.3.4 Lignite mining

Mining activities in the heavily industrialized Nordrhein-Westfalen region encompass the Rur and Inde rivers (Bogena et al. 2005). This area, known as the 'Rurscholle,' is characterized by its geological features and the impacts of open-pit mining (Becker et al. 2008). The Rurscholle, bordered by fault lines and the Maas River, contains multiple lignite layers with permeable surface soil, allowing groundwater pumping effects to spread throughout the region. Consequently, the Rurscholle is significantly impacted by mining activities.

In the Rur catchment, several mining-related consequences are evident. For instance, the Inde River was partially relocated in 2005 to accommodate open-pit lignite mining and is influenced by groundwater pumping and discharge near Lamersdorf and Kirchberg, averaging 1.0 m^3/s and 0.5 m^3/s, respectively (MULNV NRW 2020; LANUV 2002, MUNVL 2018). The Inde mine pumps over 200 million m^3 of water annually, causing local groundwater table drops of up to 100 meters (Bachmann et al. 2007). Such extractions influence the water balance in the catchment and are therefore included in water allocation (RIWA-Maas 2022) and hydrological models (Hartgring 2023) of the Rur.

Similarly, the Hambach mine, with an annual pumping volume of 310 million m^3, releases water into the Erft River. Although these mines are outside the Rurscholle, groundwater exchange occurs through the permeable upper aquifer, affecting neighbouring regions.

Due to the energy transition, mining in Inde will cease, and there are plans to divert water from the Rur in Jülich to fill the remaining pit, creating an artificial lake (Pyka et al. 2016). This diversion is scheduled to begin after mining ends in 2030 and be completed by 2070 (Drogue et al. 2010).

2.3.5 Recreation and boating

The Rur and tributaries are non-navigable rivers. Canoeing events take place annually, and the dam operations support this with additional release to ensure a sufficient water depth if necessary.

Lake Rursee is popular destination for recreational boating (sailing, rowing) and bathing.

2.3.6 Nature and ecology

Reservoir operations account for water demand for nature and ecology with a minimum release in the operation plans.

2.3.7 Agriculture

Agriculture in the Rur area is basically rain-fed. Between Linnich and the Dutch-German border, water extractions for irrigation are present. The amount of extracted water is very uncertain, because farmers usually do not report the extracted amount, and unlicensed (illegal) extractions may take place also (van der Krogt et al. 2022). Structural water extraction for agriculture via irrigation canals or irrigation pipes are not present.

2.4 Flood risk

2.4.1 Germany

The state of Nordrhein-Westfalen publishes flood related maps (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025c):

- Flood hazard maps (German: Hochwassergefahrenkarten, HWGK) show potential inundations, water depth and velocity for different scenarios.
- Flood risk maps show where inhabitants, protected areas, cultural objects are potentially endangered and show industrial sites with hazard potential.
- Heavy rainfall information maps.

The maps can also be downloaded for usage in geographical information systems from the geoportal.NRW (Geschäftsstelle des IMA GDI Northrein-Westfalen 2025).

Flood maps have been prepared for different scenarios (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025c):

- High probability ($HQ_{häufig}$): return interval between 10 and 20 years.
- Medium probability (HQ_{100}): return interval of 100 years.
- Low probability (HQ_{extrem}): return interval more than 100 years.

For the low probability scenario the exact return interval is not specified exactly. The scenario is meant to be understood in the sense of a "1000 year flood" ("Jahrtausendhochwasser"), but the connotation "extreme" does not mean that the scenario is the most extreme scenario thinkable in the sense of a worst-case scenario or a probable maximum flood.

Figure 15 shows a screenshot taken from the interactive flood hazard map of the state Nordrhein-Westfalen (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025d). Towns and villages with flood-prone area due to fluvial flooding according to the flood hazard map are Kornelimünster, Stolberg and Eschweiler along the Inde and Kreuzau, Düren and Jülich along the Lower Rur. Along Olef and Urft, flood-prone populated areas are Schleiden, Kall and Nettersheim.

Figure 15 Flood hazard map for the low probability scenario (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025d). For a legend see Figure 18.

Flood risk maps are shown in Figure 16 and Figure 17 for the area downstream and upstream of the Rur reservoirs, respectively. Yellow dots on this map indicate so-called IED sites. These are sites with special environmental obligations related to industrial emissions.

The colour code indicates that for the above mentioned towns inundations affect residential buildings, functional buildings and commercial areas, and agricultural areas.

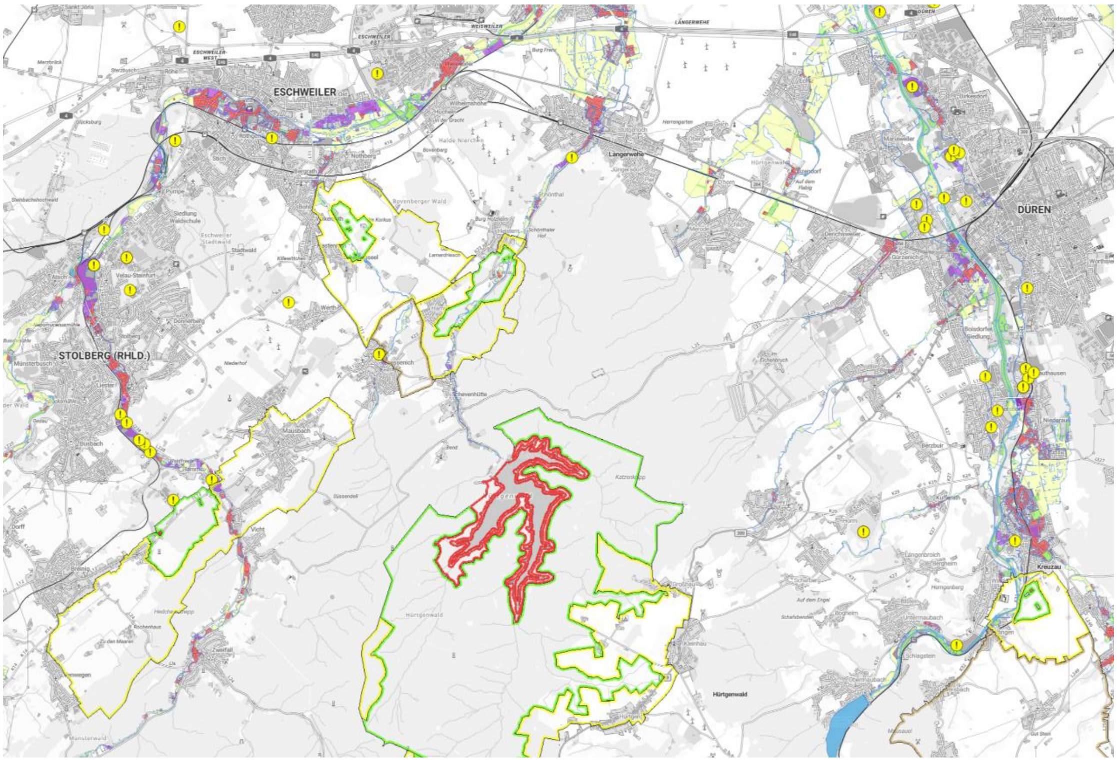


Figure 16 Flood risk map of the area downstream of the Rur reservoirs for the low probability scenario (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025d). For a legend see Figure 18

Figure 17 Flood risk map of the area upstream of the Rur reservoirs for the low probability scenario (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025d). For a legend see Figure 18

Figure 18 Legend to Figure 15 and Figure 16

The heavy rainfall information map (Figure 19) shows a concentration of hazard along the rivers and streams for the southern part – this is due to the hillslope characteristics with steep slopes in this area. In the North the potential for inundations due to heavy rainfall is more widespread and not limited to the vicinity of the streams, because the land surface is flatter here, such that rainfall water concentrates less fast in rivers and streams.

Figure 19 Heavy rainfall information map (Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen 2025d)

2.4.2 The Netherlands

An inundation map for the Dutch part of the Rur is shown in Figure 20. The inundation depth corresponds to an extreme low probability of once in 100 000 years or less. The inundation area covers only small parts of the built-up area.

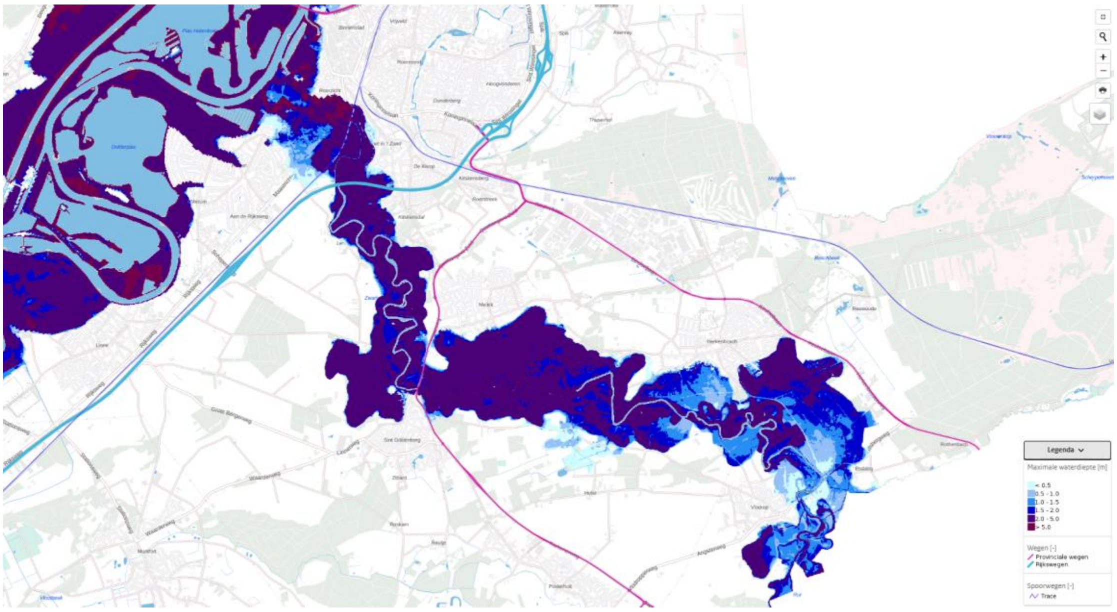


Figure 20 Maximum inundation depth with extreme low probability for the Dutch part of the Rur (Rijkswaterstaat 2025)

Due to backwater effects, the water level in the Meuse plays an important role for the flood risk in the Dutch part of the Rur catchment, in particular for the city of Roermond. Hydraulic structures (Section 2.2.4) have been installed to prevent inundations of Roermond's city centre from the Meuse via the Roer.

The July 2021 flood event prompted a Dutch report by de Jong et al. 2022, which analysed system functioning of the Meuse and flood safety. The Rur was included in this research as one of the important tributaries of the Meuse. Figure 21 (red) shows that the backwater effects from the Meuse significantly decrease starting about 8 km upstream from the confluence of the Roer and the Meuse, as the red lines grow closer to each other. Additionally, Figure 21 (blue) shows that close to the mouth the water level on the Rur is dominated by the water level on the Meuse as we see little variation between the blue lines, and that the discharge of the Rur itself becomes more important in upstream direction where the blue lines start to spread.

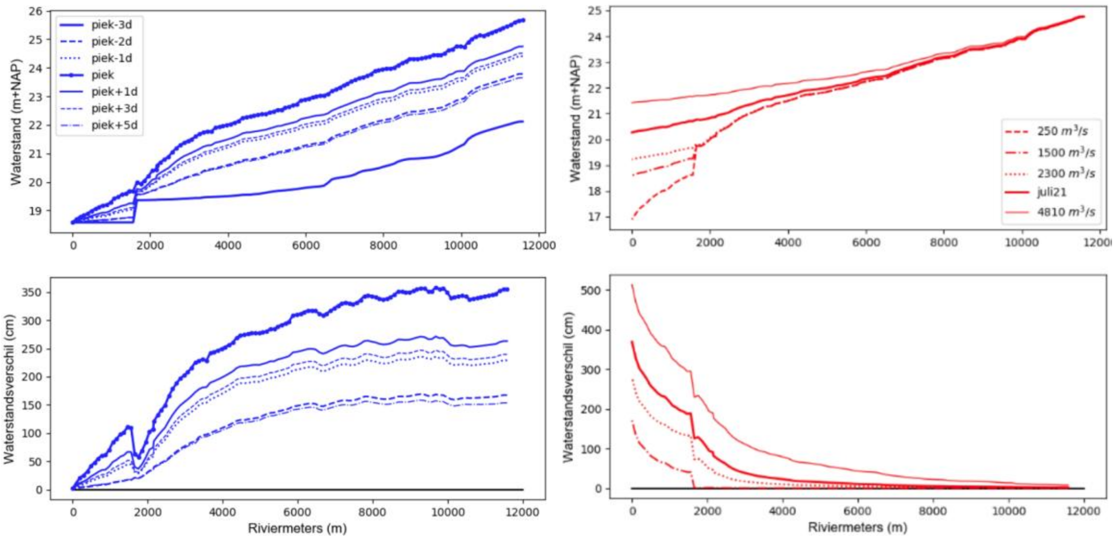


Figure 21 Water levels on the Roer for different Roer discharges (blue) and Meuse discharges (red). Lower panels show water level differences relative to the lowest gradient. Left panels: water level gradient at 1500 m³/s at St. Pieter (≈2-year return) combined with the July 2021 Roer flood wave (various days around the peak). Right panels: water levels at 140 m³/s at Stah (≈20–50-year return) with Meuse levels for July 2021 and discharges of 250, 1500, 2300 and 4810 m³/s (≈mean, 1/2-year, 1/10-year, 1/50,000-year). A weir is located on the Roer at x=1474 m. For Meuse discharges <2300 m³/s, no effect occurs upstream of the weir. Source: de Jong et al. 2022

Furthermore, a statistical analysis in the same report has shown that high flows on the Rur often occur within a period of 25 hours before or after the peak flow on the Meuse. This means that it is valid to assume that a high flow on the Rur will often occur simultaneously with peak flow on the Meuse itself.

2.5 Critical infrastructure

Critical infrastructure (CI) such as roads, bridges, and utility networks is vital for the functioning of society, but its vulnerability to flooding is not always well understood. In general, the floods of July 2021 had a major impact on CI in Germany and Belgium, while the Netherlands was affected to a lesser extent (Koks et al. 2022). Roads, bridges and railways were severely damaged, with some links still under repair years later. Power and gas supplies failed for large numbers of households, in some places for months. Drinking water and wastewater systems were destroyed or polluted, creating long-term problems for communities. Waste volumes were enormous, and debris management became a challenge in itself. Mobile networks and broadband were also disrupted until energy and access networks were restored. Hospitals, schools and care facilities were damaged or closed, forcing evacuations and temporary facilities.

The July 2021 floods showed that damage to infrastructure can greatly increase the overall impact of an event. While large-scale risk assessments provide useful national or European overviews, they often miss the severe local effects seen in catchments like the Rur (Koks et al. 2022). Furthermore, CI analyses can be challenging in a transboundary catchment due to different uses of definitions and differences in data availability (Meijer & Juch 2024). Open-data sources such as OpenStreetMaps can be used as a first start for a CI analysis, as demonstrated in Figure 22 for the Rur. The rest of this section provides an initial overview of known CI assets in the Rur catchment.

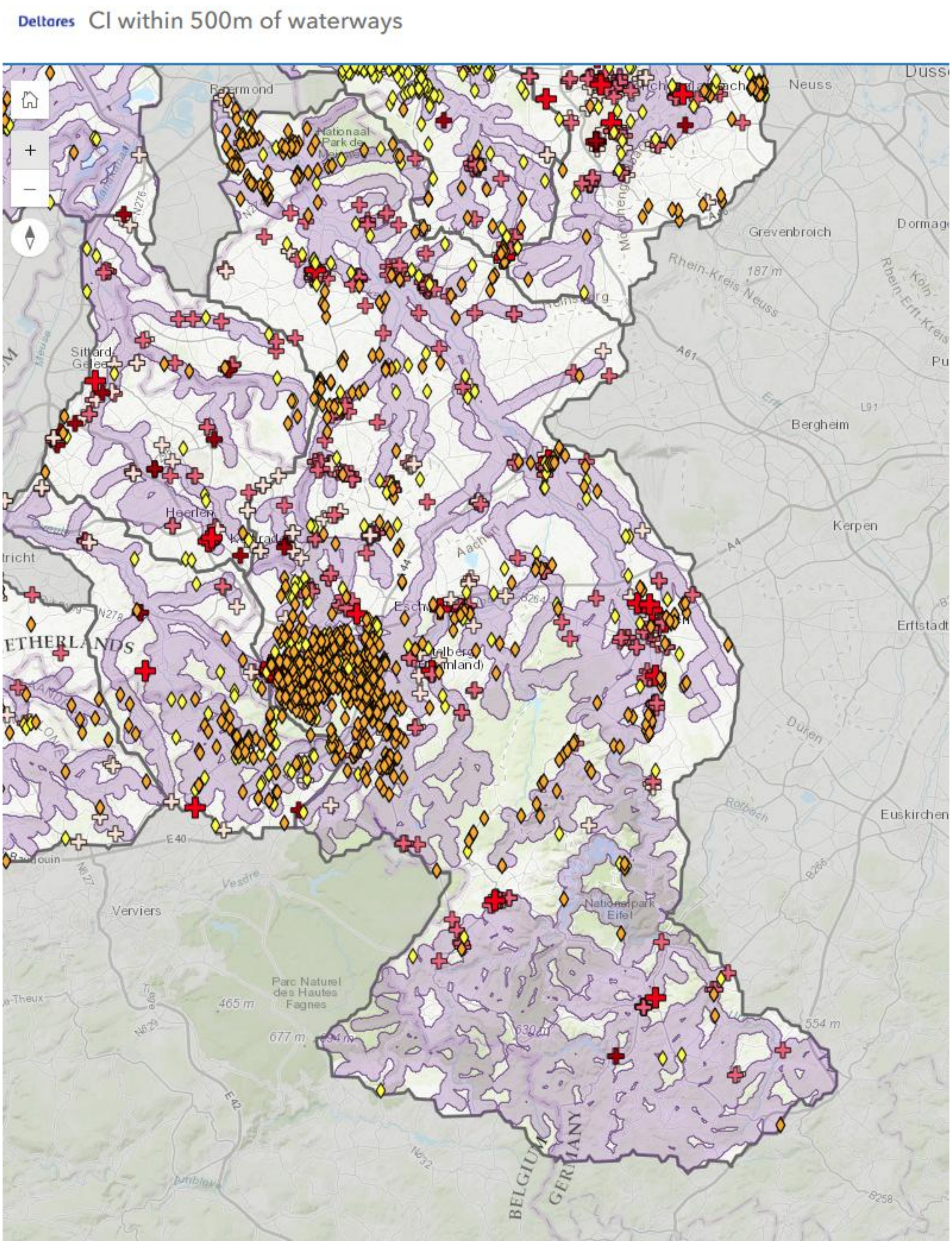


Figure 22 Critical Infrastructure assets in the Rur catchment using OpenStreetMaps data. The crosses indicate healthcare assets, diamonds indicate electricity assets, and the purple areas indicate regions within 500 meters of waterways. Source: Meijer & Juch 2024

2.5.1 Railway lines

Railway lines in the Rur catchment are, in the order of importance:

- Railway line from Aachen to Colone, connecting Paris, Liège and Cologne
- Railway line from Roermond to via Sittard to Heerlen and Maastricht

- Railway line from Aachen via Geilenkirchen to Mönchengladbach
- Railway line from Eschweiler via Stolberg to Walheim
- Railway line from Düren to Heimbach
- Railway line from Linnich to Düren
- Railway line from Heinsberg to Lindern

The major railway line from Aachen to Cologne passes Eschweiler and Düren and is, according to the flood risk map Nordhrein-Westfalen (Figure 16), not exposed to flood risk.

The railway line from Roermond to Sittard crosses the inundation area indicated on the inundation map (Figure 20).

Railway line Aachen to Mönchengladbach crosses an inundation area. The railway embankment elevates the railway above the inundation water level.

The minor railway line from Eschweiler via Stolberg to Walheim forms the border of the inundation area in Stolberg. Railway lines from Linnich to Düren and from Düren to Heimbach route along the Rur and pass the flood risk areas in some cases, in particular in Düren and Kreuzau. Minor railway line from Heinsberg to Lindern passes an inundation area.

2.5.2 Motor highways

Motor highways in the Rur catchment area are

- A4 (Germany) / E40 from Aachen to Cologne
- A44 (Germany) from Aachen towards Düsseldorf
- A46 (Germany) from Heinsberg towards Düsseldorf
- Motorway A73 (Netherlands) from Venlo to A2 (Netherlands) towards Maastricht.

Motor highway A4 / E40 from Aachen to Cologne passes inundation areas, but the highway itself is not inundated because its elevated position. A44 and A46 cross the Rur near Jülich and Heinsberg, respectively. The highway is elevated above the flood risk area.

Dutch motor highway A73 crosses the inundated area shown in Figure 20, but the highway is in a tunnel in this area.

2.5.3 Water reserves

The flood risk map of Nordhrein-Westfalen shows water reserves (Wasserschutzgebiete) as polygons with green, yellow and red colour frame (Figure 16, not included in the legend). Most water reserves are not located in the vicinity of the rivers and thus are not directly at risk of fluvial flooding. An exception is a water reserve between Kreuzau and Üdingen.

2.5.4 Industry

Power plant Weisweiler is fed with fuel from lignite mine Inden. Inden mine is located between Inde and Rur, and Inde has been relocated to make mine operations possible. In particular the relocation of the Inde is a point of attention in a flood situation: the July 2021 flood exceeded the design discharge of the Inde's new route, so the flood water found its way along the old river bed and discharged into the mine. This was a severe issue by itself, but the fuel supply for the power plant is not affected, because the operating company holds large fuel reserves.

Production stops of the paper industry along the Rur can become critical for the supply chain of goods; the pulp-and-paper products are needed for food packaging, among other purposes.

2.5.5 Objects

Sobolewski et al. 2023 list "objects at hazard" due to flooding in the Wurm-sub-catchment. Wastewater treatment plants (20), electric transmission stations (17) are the most frequent category. Hospitals (6), schools (12), educational buildings (3), kindergardens (12), home for the elderly (5) are buildings to be potentially evacuated during flood events. This study only covers a sub-catchment of the area of interest, but gives an indication on the type of objects and number that might be affected by flooding.

3 Stakeholders

3.1 Introduction

In water management, the understanding of the term stakeholder is crucial, especially for sustainable management and protection of the resource. The stakeholder theory was coined by Edward Freeman in the 1980s. Stakeholders are individuals or groups who have an interest in mostly economic activities and are directly or indirectly affected by the results of decisions made (Freeman & McVea 2001). As water is a vital resource for people, stakeholders include not only authorities, administrations, water associations or local companies, but also local residents, environmental organizations or research and educational institutes.

Especially in the international catchment area of the Rur, it is crucial to consider the different perspectives and needs of all stakeholders. By proactively involving all interest groups, greater acceptance of measures can be achieved, potential conflicts minimised and sustainable solutions found (Wei 2024; Freeman & McVea 2001).

To provide a better overview of the stakeholders that need to be involved in measures such as dyke construction or relocation, but also in situations such as flooding or drought, these are explained in more detail below in a kind of profile.

3.2 Institutional framework

3.2.1 Governmental authorities

The institutional framework reflects organizations and authorities. The Rur is not a national waterway, neither in Germany nor in the Netherlands or Belgium. National level is included in the table below though, because the Rur is a tributary in national water in the Netherlands, the Meuse.

Table 9 summarizes levels of the institutional framework in general for the different countries, Table 10 the responsibilities for water management.

Table 9 Institutional framework of different countries

Level	Germany	Netherlands	Belgium
Transnational	European Commission		
National Government (executive)	Bundesregierung	Rijksoverheid	Gouvernement fédéral de Belgique
Regional government			Gouvernement wallonne
State	Land Nordrhein-Westfalen		
Province		Province of Limburg	Province of Liège
Governmental district	Bezirksregierung Köln		
District	Kreis (various)		Ville de Liège
Municipality	Gemeinde, Stadt (various)	Gemeente (various)	

Note that “regional” has different meanings: Belgium has three regions (Wallonia, Flanders and Brussels), while in the Netherlands “de regio” is often referred to as the local waterboards.

Table 10 Institutional framework water management for the Rur

Level	Germany	Netherlands	Belgium
Transnational	International Meuse Commission		
National Government	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz Bundesministerium für Digiales und Verkehr	Ministerie voor Infrastructuur en Waterstaat	Ministère de l'Environnement, de la nature, de la forêt, de la ruralité et du bien-être animal
National water management	Wasserstraßen- und Schifffahrtsverwaltung des Bundes (WSV)	Rijkswaterstaat	
Fachbehörde (Scientific/technical agencies)	Bundesanstalt für Gewässerkunde (BfG) Bundesanstalt für Wasserbau (BAW)	Deltares	
Regional water management			Service Public de Wallonie
Fachbehörde			Service public de Wallonie, Direction des Recherches hydrauliques, Châtelet Institut royal météorologique de Belgique
State	Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen		
Fachbehörde	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen		
Province		Province of Limburg	Province de Liège
Governmental district	Bezirksregierung Köln		
Water authority	Wasserverband Eifel-Rur Niersverband	Waterschap Limburg	
Observations (Pegelwesen)	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen	Rijkswaterstaat	Service public de Wallonie, Direction des Recherches hydrauliques, Châtelet Institut royal météorologique de Belgique

3.2.2 International committees and panels

3.2.2.1 The International Meuse Commission

The International Meuse Commission (IMC, CIM 2025) was established in 2002 with the signing of the International Meuse Agreement (Ghent

Agreement). The objective of the Agreement is to achieve sustainable and integrated management of the water of the Meuse River Basin District. The Agreement was signed by the Walloon Region, the Netherlands, France, Germany, the Flemish Region, the Brussels-Capital Region, Belgium and Luxembourg and came into force on 1 December 2006.
The main tasks of the IMC are

- to coordinate the obligations of the European Water Framework Directive,
- to coordinate the obligations of the European Directive on the assessment and management of flood risks and
- to provide advice and recommendations to the Parties for the prevention and control of accidental pollution (warning and alert system).

The Commission has an action programme and meets once a year. The IMC has five permanent working groups and various temporary project groups for its preparation.

The IMC makes recommendations and adopts decisions unanimously, has a rotating presidency and meets in the three working languages (French, Dutch and German).

3.2.2.2 Ständige Grenzgewässerkommission, sub-commission A (Maas-Roer)

The sub-commission "Meuse – Rur" of the border waters commission, established on the grounds of the border contract between Germany and the Netherlands (BGBl. 1963-II-18), meets once a year and addresses issues related to

- Cross-border waters and groundwater bodies
- Flood risk management Directive 2007/60/EG
- Framework Directive 2000/60/EG
- Directive 91/271/EEC on urban waste-water treatment.

Commission members inform each other about activities and initiatives, this can also involve the use of models and tools.

3.2.3 Selected organizations in Germany

3.2.3.1 Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen

Actor's Name	**Ministerium für Umwelt, Naturschutz und Verkehr des Landes Nordrhein-Westfalen (MUNLV)**
Type and structure	Ministery on state level
Responsibility and purpose	Flood risk management Operational flood management Issuing of flood warnings
Region of responsibility	State of Nordrhein-Westfalen
Interest, task, roles, mandate	Water authority (Obere Wasserbehörde)

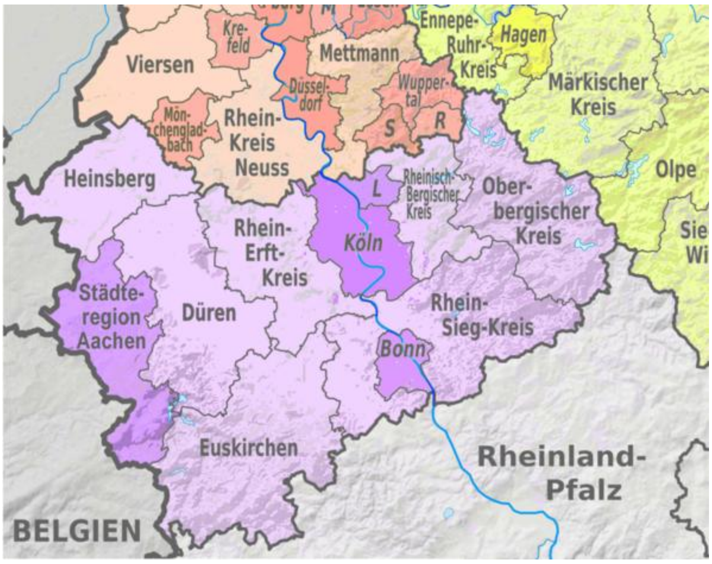
3.2.3.2 Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen

Actor's Name	**3.2.3.2 Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen**
Type and structure	Ministery on state level
Responsibility and purpose	Spatial planning
Region of responsibility	State of Nordrhein-Westfalen
Interest, task, roles, mandate	Planning authority on state level

3.2.3.3 Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen

Actor's Name	**Landesamt für Natur, Umwelt und Klima Nordrhein-Westfalen LANUK (formerly Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen LANUV)**
Type and structure	Scientific authority (Fachbehörde)
Responsibility and purpose	Operational flood forecasting, operation and maintenance of gauging stations. Flood monitoring and reporting (Hochwassermeldedienst, hydrologische Lageberichte)
Region of responsibility	State Nordrhein-Westfalen

3.2.3.4 Bezirksregierung Köln

Actor's Name	**Bezirksregierung Köln**
Type and structure	District council of the regional mid-level local government units between municipality and state, the so-called "Bezirk", governmental district.
Responsibility and purpose	Approving authority for water management. Approval and supervision of dike construction and dike maintenance. Supervision of municipalities with responsibility of flood protection. Supervision of dam operations and dam safety. Organizational structure of flood reporting procedures (Erlass von Hochwasser-Meldeordnungen) Flood reporting service (Hochwassermeldedienst) for Rur river (among other water courses) after corresponding flood levels have been exceeded. Spatial planning on regional level.
Region of responsibility	 (source: Wikipedia 2025)

3.2.3.5 Wasserverband Eifel-Rur (WVER)

<table>
<tr><th>Actor's Name</th><th>Wasserverband Eifel-Rur
https://wver.de/</th></tr>
<tr><td>Type and structure</td><td>Water authorithy by law (Sondergesetzlicher Wasserverband) according to the Eifel-Rur-Verbandsgesetz; Members are municipalities, districts, industry, drinking water supply companies (WVER 2023)</td></tr>
<tr><td>Responsibility and purpose</td><td>Water management (including dam operations)
Wastewater treatment
Maintenance of water courses
Flood protection in the whole area of responsibility, except some municipalities in the Obere Rur.
Flood reporting service (Hochwassermeldedienst) for Rur river and tributaries until corresponding flood levels have been exceeded.</td></tr>
<tr><td>Region of responsibility</td><td>Rur catchment

</td></tr>
</table>

3.2.3.6 Districts and Municipalities

Table 11 lists districts and municipalities in the German part of the Rur catchment. The municipalities are responsible for emergency response. Municipalities are in principle responsible for technical measures of flood protection if this task is not assigned to a different organization. This responsibility includes the construction, maintenance and operation of flood protection assets like dikes and retention basins.

In the Rur area, however, the responsibility for flood protection is assigned to the Wasserverband Eifel-Rur (Section 3.2.3.5) in most cases, with the exception of a few municipalities in the Obere Rur catchment.

Table 11 Districts and Municipalities in the German part of the Rur catchment

Federal state	Governmental district	Administrative district	Municipalities	
			large part of catchment area	small part of catchment area
North Rhine-Westphalia	Cologne	Euskirchen	Hellenthal	Dahlem
			Nettersheim	Blankenheim
			Kall	Mechernich
			Schleiden	
		Städteregion Aachen	Monschau	
			Simmerath	
			Roetgen	
			Aachen	
			Stolberg	
			Eschweiler	
			Würselen	
			Herzogenrath	
			Alsdorf	
			Baesweiler	
		Düren	Heimbach	Vettweiß
			Nideggen	Nörvenich
			Hürtgenwald	Merzenich
			Kreuzau	Titz
			Langerwehe	
			Düren	
			Inden	
			Niederzier	
			Aldenhoven	
			Jülich	
		Heinsberg	Übach-Palenberg	Selfkant
			Geilenkirchen	Gangelt
			Heinsberg	Erkelenz
			Waldfeucht	Wegberg
			Hückelhoven	
			Wassenberg	
	Düsseldorf	Viersen		Niederkrüchten

3.2.3.7 Private organizations

A Selection of commercial companies sorted from upstream to downstream is given with the following list (WVER 2023):

- Metsä Tissue GmbH; Metsä Greaseproof Papers GmbH
- Papierfabrik Niederauer Mühle GmbH (paper production, supply canal, see Figure 23)
- Industriepark Niederau: SCHOELLERSHAMMER GmbH
- KANZAN Spezialpapiere GmbH

- Siep Kieswerk GmbH & Co. KG
- VEOLIA Industriepark Deutschland GmbH
- J. u. W. Stollenwerk oHG

Water supply companies (public utility) are given in the following list with their major assets:

- STAWAG; WAG Nordeifel mbH
    - Operate Dreilägerbachtalsperre and Kalltalsperre
    - Water supply network connected to the Rurtalsperre
- Stadtwerke Düren GmbH
    - Participates in water works (Wasserwerk) of WAG at Wehebachtalsperre
    - SWD-Wassergewinnungsanlage Dr.-Overhues-Allee
    - SWD-Wasserwerk Ellen
    - Wasserleitungszweckverband Langerwehe
    - Wasserwerk Concordia Kreuzau
    - Reserve system for emergency supply: SWD-Wasserwerk Obermaubach

Energy supply companies:

RWE AG; RWE Generation Hydro GmbH
- Operates powerhouse at Rurtalsperre
- Lignite power plant Weisweiler (Figure 24)

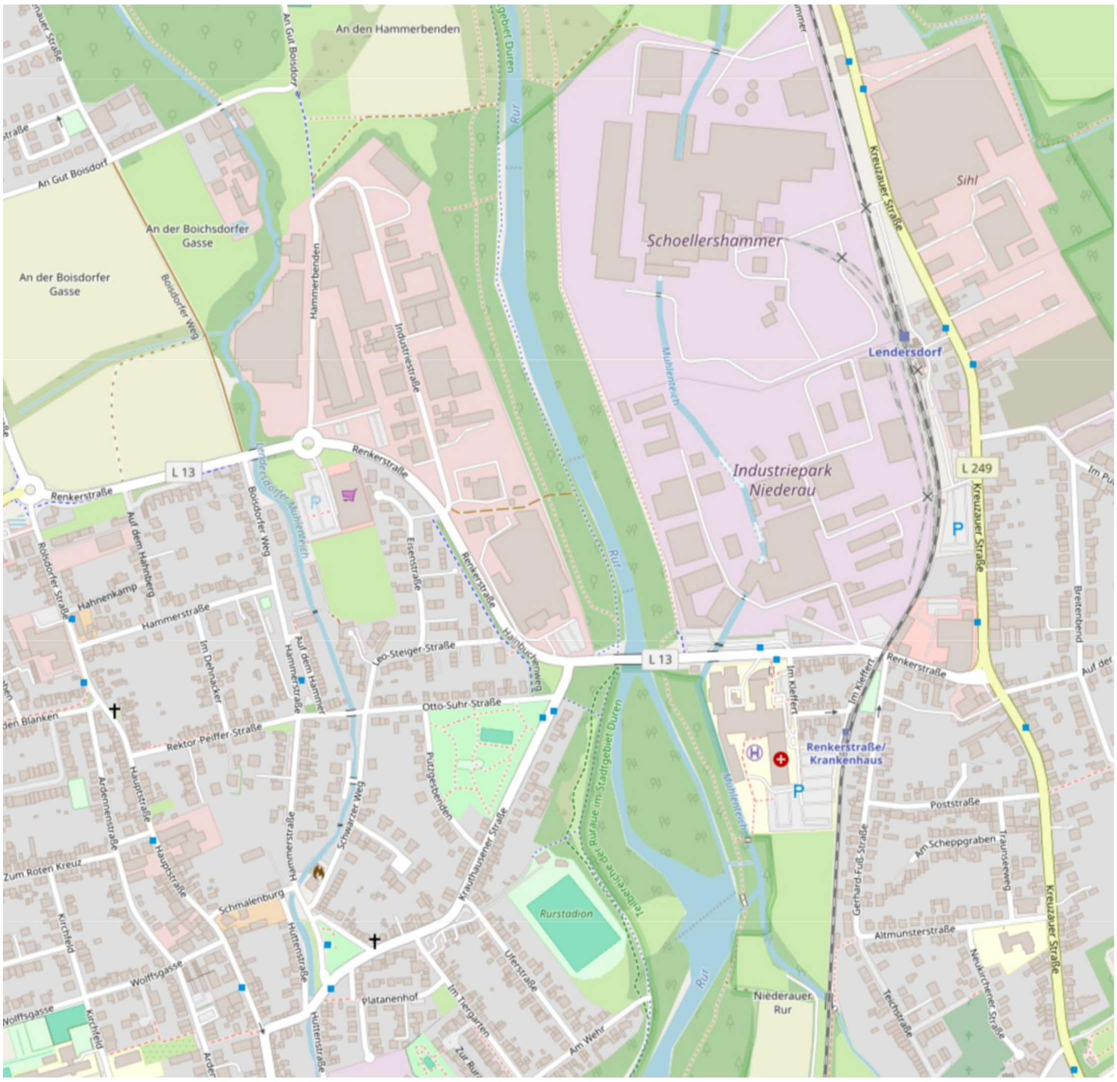


Figure 23 *Map showing the supply canal to the paper factory Niederauer Mühle*

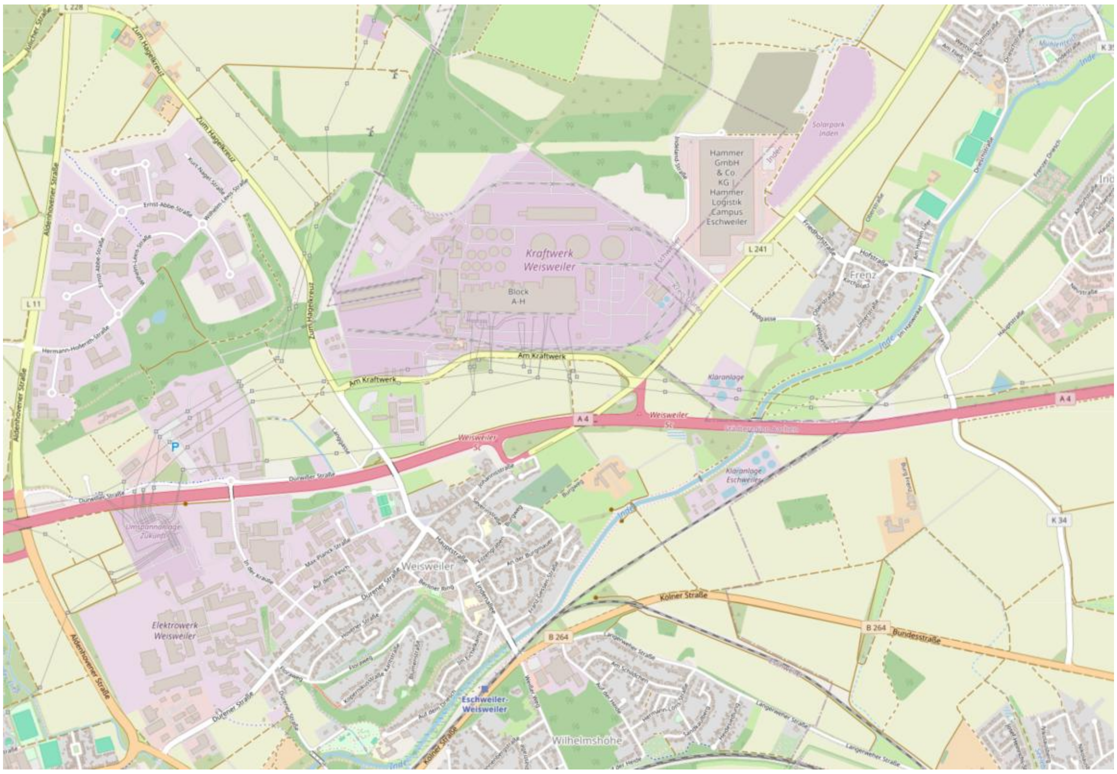


Figure 24 Kraftwerk Weisweiler, Inde

3.2.4 Selected organizations in the Netherlands

3.2.4.1 Dutch Ministry of Infrastructure and Water Management Directory-General Water and Soil

Actor's Name	**Ministry of Infrastructure and Water Management Directory-General Water and Soil (IenW DGWB)**
Type and structure	Dutch Ministry on Water policy
Responsibility and purpose	National policy, coordination and law-making on flood risk management National policy coordination on droughts
Region of responsibility	The Netherlands
Interest, task, roles, mandate	The ministry has a system responsibility on all waterways in Netherlands. Partner with (regional) partners in implementing (national) flood and drought risk strategies. The Rur is of specific interest, as part of international coordination and its contribution to national waterways.

3.2.4.2 Rijkswaterstaat

Actor's Name	**Rijkswatertaat (RWS)**
Type and structure	National water authority
Responsibility and purpose	Executing agency of the Dutch Ministry of Infrastructure and Water Management Maintenance and development of national navigable water courses Flood protection Flood forecasting
Region of responsibility	The Netherlands
Interest, task, roles, mandate	Rijkswaterstaat is not primarily responsible for the Rur. Given the discharge contribution to the Meuse during low flow conditions for water quality and water quantity and the relation to flood risk in Roermond, the Rur is of interest for Rijkswaterstaat though. Within the frame of National water supply and navigability, general knowledge on hydrological and hydraulic processes and water use on the catchment level (here: Meuse catchment) is relevant for Rijkswaterstaat.

3.2.4.3 Provincie Limburg

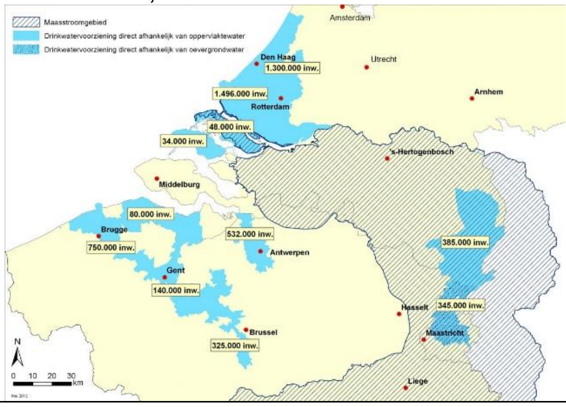
Actor's Name	**Provincie Limburg**
Type and structure	Province of the Netherlands
Responsibility and purpose	Supervision of waterboards Flood hazard and flood risk mapping Spatial planning on regional level Responsibility for groundwater bodies and thus responsibility for groundwater extractions
Region of responsibility	Province of Limburg, the Netherlands
Interest, task, roles, mandate	Low flow situations when groundwater extractions increase due to decreased water availability

3.2.4.4 Waterschap Limburg

Actor's Name	**Waterschap Limburg**
Type and structure	Water association
Responsibility and purpose	Maintenance of dikes along the Meuse and other rivers, maintenance of surface waters. Grants for water rights from shallow groundwater. Warning and monitoring within the area of responsibility. Wastewater treatment and wastewater transport. Technical advisory related to spatial planning to Province and national level.
Region of responsibility	Province of Limburg, the Netherlands  (Google Maps)

3.2.4.5 RIWA Maas

<table>
<tr><td>Actor’s Name</td><td>RIWA Maas
www.riwa-maas.org</td></tr>
<tr><td>Type and structure</td><td>Association of four water supply companies</td></tr>
<tr><td>Responsibility and purpose</td><td>RIWA Maas represents water supply companies.</td></tr>
<tr><td>Region of responsibility</td><td>Netherlands, Flanders



</td></tr>
<tr><td>Interest, task, roles, mandate</td><td>RIWA Maas is interested in a sound understanding of the water system, relevant processes and developments to early identify problems and take actions for solutions.</td></tr>
</table>

3.2.4.6 Districts and municipalities

Four municipalities can be found within the Dutch part of the Rur, namely Kerkrade, Landgraaf, Roerdalen and Roermond. The mayors of these municipalities can, together with the safety region (NL: "Veiligheidsregio") decide to commence evacuations. When the situation escalated to a certain safety level (GRIP-4), then the chair of the safety region can decide to start evacuations. The municipalities of Roerdalen and Roermond have experienced high water levels in the past due to their location close to the Rur and Meuse, but 2021 was an exceptional event. Actions were taken before and during the flood event to warn and evacuate people (Veiligheidsregio Limburg-Noord 2022).

3.2.5 Selected organizations in Belgium

3.2.5.1 Province de Liège

Actor's Name	**Province de Liège**
Type and structure	Province of the Kingdom of Belgium
Responsibility and purpose	Conservation of environment and water courses and sustainable development Technical maintenance of 2nd order water courses and technical advice on 3rd order water courses. https://www.provincedeliege.be/fr/node/169
Region of responsibility	 https://fr.wikipedia.org/wiki/Provinces_de_Belgique#/media/Fichier:Province_of_Liege_(Belgium)_location.svg

3.2.5.2 La gestion des ressources en eau, SPW

Actor's Name	**La gestion hydrologique** **Service Public de Wallonie (SPW)** https://www.wallonie.be/fr/acteurs-et-institutions/wallonie/departement-expertises-hydraulique-et-environnement/direction-de-la-gestion-hydrologique
Type and structure	Public authority, sub-division of the department of technical expertise on hydrology and environment.
Responsibility and purpose	Measurement and observations; operational flood forecasting, modelling, emergency response; control of hydraulic structures; climate change adaptation
Region of responsibility	Walloon region of Belgium

3.2.5.3 La direction des Cours d'eau non navigables, SPW

Actor's Name	**La direction des Cours d'eau non navigables** **Service Public de Wallonie (SPW)** https://spw.wallonie.be/administrations/departement-du-developpement-de-la-ruralite-et-des-cours-deau-et-du-bien-etre-animal/direction-des-cours-deau-non-navigables
Type and structure	Public authority, sub-division of the department of agriculture, natural resources and environment
Responsibility and purpose	Integrated, balanced and sustainable management of non-navigable water courses
Region of responsibility	Walloon region of Belgium

3.2.5.4 Département des Voies hydrauliques de Liège et des Barrages-réservoirs, SPW

Actor's Name	**Département des Voies hydrauliques de Liège et des Barrages-réservoirs** **Service Public de Wallonie (SPW)** https://www.wallonie.be/fr/acteurs-et-institutions/wallonie/spw-mobilite-et-infrastructures/departement-des-voies-hydrauliques-de-liege-et-des-barrages-reservoirs
Type and structure	Public authority, Department SPW Mobilité et Infrastructures
Responsibility and purpose	Infrastructure for water transport, water ways (voies hydrauliques) and storage; reservoir maintenance and operations
Region of responsibility	Province of Liège

3.2.5.5 Société Wallonne des Eaux (SWDE)

Actor's Name	Société Wallonne des Eaux (SWDE)
Type and structure	Autonomous public company, incorporated as a cooperative society
Responsibility and purpose	Drinking water supply; operation of water treatment plant and hydropower plant at four reservoirs
Region of responsibility	Walloon region of Belgium, reservoirs Ry de Rome (Couvin), Nisramont (Houffalize), Stembert (Verviers) and Lac d'Eupen

3.2.5.6 Société Publique de Gestion de l'Eau (SPGE)

Actor's Name	Société Publique de Gestion de l'Eau (SPGE)
Type and structure	Public limited company owned by the Walloon Region.
Responsibility and purpose	Coordination and financing of the water sector in Wallonia; wastewater sanitation and catchment protection
Region of responsibility	Walloon region of Belgium

3.3 Research and academic education

A list with universities and research organisations related to the Rur region is given with the following list. Note that an organization that does research on the Rur catchment not necessarily is located in the Rur region.

Germany

- RWTH Aachen University
  - Institute of Hydraulic Engineering and Water Resources Management (IWW)
  - Research Department Engineering Hydrology (LFI)
- FH Aachen University of Applied Science
- Forschungszentrum Jülich

- Hochschule Köln
- GFZ Potsdam

Netherlands

- Technische Universiteit Delft (TU Delft)
- Wageningen University and Research
- Unesco-IHE (Delft)
- Deltares

Belgium

- Université de Liège
- Katholieke Universiteit Leuven (KU Leuven)
- Université catholique de Louvain (UCLouvain), Louvain-la-Neuve

3.4 EU directives and national laws

Member states of the European Union are obliged to implement the Directives of the European Union (EU) into national law. Relevant directives for water management are

- Directive 2007/60/EG, known as the EU Flood Directive.
- Directive 2000/60/EG, known as the EU Water Framework Directive

Germany, the Netherlands and Belgium are EU member states, consequently the national laws of all riparian countries of the Rur have adopted the two above mentioned directives.

In Germany, water legislation was fundamentally reorganised in 2009. In this context, the Water Framework Directives, the contents of which were previously anchored partly in federal laws, so-called framework laws (Rahmengesetzte), and partly in state laws (Landesgesetze), were bundled in the Water Resources Act (Wasserhaushaltsgesetz, WHG). This replaced all previous federal framework laws in the area of water management. As many of the requirements of European law are very extensive, detailed questions about the regulations are shifted to the level of ordinances (Verordnung). One example of this is the Surface Waters Ordinance (Verordnung zum Schutz der Oberflächengewässer). The laws and ordinances are adopted by the governments of the federal states in state water legislation and can be adapted to the specific needs of each state (BMUV 2011).

According to Wasserhaushaltsgesetz (WHG) the government is responsible to assess flood risk and to identify flood prone areas, to publish flood hazard maps, to prepare flood risk management plans, to identify flood plains and to edict building regulations for flood plains. The WHG does not specify a certain flood protection level.

The Omgevingswet (Environment Act) came into force in the Netherlands at the beginning of 2024. It integrates many existing environmental laws, including the Waterwet (Water Act), which was previously regarded as the central set of regulations for water resource management, flood protection and water quality. The Omgevingswet, now the central law for the implementation of the Water Framework Directive and Floods directive, is intended to integrate water and environmental objectives into spatial planning by facilitating coordination between the authorities. With the minimisation of the effects of flood events as an overriding objective of the Water Framework Directive, the Omgevingswet also sets national standards for primary flood protection facilities and discuss regional flood protection as well (Kok et al. 20172016; Informatiepunt Leefomgeving 2024).

In Belgium, according to the constitution, the respective regions of Flanders, Wallonia and Brussels are each independently responsible for the areas of water policy for spatial planning, nature conservation, public works and transport on their territory. For the Meuse catchment area, the Walloon Region is therefore responsible for the implementation of the Water Framework Directive and the assessment and management of flood risks. The Surface Water Directorate of the Walloon Public Service, Agriculture, Natural Resources and Environment organises and coordinates the implementation of the Water Framework Directive at regional level. Other institutions involved are the Ministries of Environment, Nature, Forestry, Rural Affairs and Animal Welfare and the Public Company for Water Management (AUW - ÖDW Umwelt).

3.5 Networks and initiatives

3.5.1.1 MICCA – Mosan Initiative on Climate Change Action

MICCA is an initiative promoted by EPAMA since the end of 2019 (Fournier 2022), its goal is about defining and implementing measures and actions for preparing the international Meuse watershed to the impacts of climate change but also to mitigate these impacts.

Representatives from the WVER and Waterschap Limburg, both active in the Rur catchment, are member of the MICCA initiative.

Currently, the activities ceased after two proposals for funding from the European Union have been prepared without being honored. There are ideas to continue with this network under rotating chairmanship.

3.5.1.2 International Meuse Symposium

The International Meuse Symposium (Becker 2025) is a symposium series organized with the objective of sharing and exchanging knowledge on water-related modelling and processes (in the widest sense) of the Meuse catchment on a scientific basis. Target audience are all scientists, water managers and stakeholders that feel connected to the Meuse basin. The symposium series has been initiated in the course of the AMICE project in 2013 and is organized by research institutions and universities from the riparian countries of the Meuse. The symposium is organized by Deltares, the University of Liège and the Schone Maaswaterketen.

The sub-catchment of the Rur has always been a subject of talks presented at the International Meuse Symposium.

3.6 Selected current and past activities in the Rur catchment

There are various activities related to flood management in the Rur catchment by the WVER, some of which are summarized below:

- Dike renewal and flood protection concept Untere Rur. Most dikes along the Untere Rur performed well during the severe flood event from July 2021, but in general Dikes along the Untere Rur are not in good condition. Wasserverband Eifel-Rur is working on a "Deichererneuerungs- und Hochwasserschutzkonzept".
- Master Plan Inde and Vicht by WVER (WVER 2025a; Kaleß et al. 2022)
    - Location of measures from the master plan are presented on an interactive map (WVER 2025b), here also project ideas for Urft and Wurm are shown.

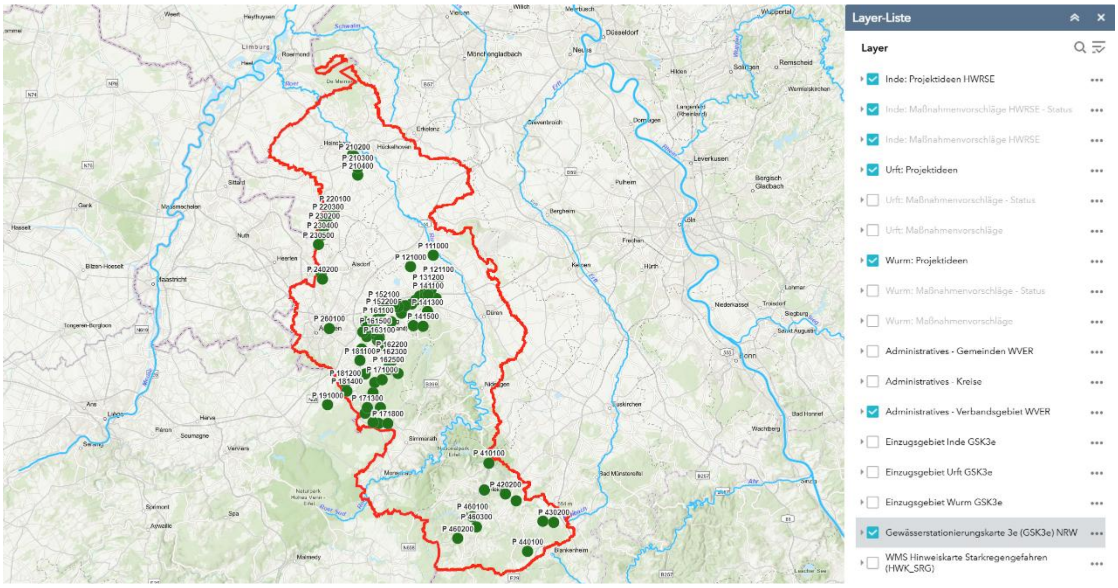


Figure 25 Interactive map viewer with the locations of planned measures within the master plans Inde & Vicht, Wurm and Urft (https://wver.maps.arcgis.com/apps/webappviewer/index.html?id=d6a48324194c4002981183bbda2a0368, last viewed on 09.09.2025)

- Academic studies on the effect of relocating dikes or the installation of lateral detention basins (Flutpolder) under flood conditions
    - Deich-Potenzialstudie und Ableitung von Ansätzen zur Flutpolderbewirtschaftung am Beispiel der Unteren Rur (Schweim 2024)
    - Optimization of Detention Basin Operation at the Lower Rur River in Germany (Urbach 2024)

Similarly, Waterschap Limburg lists several activities in an overview of past, current and future activities (https://www.waterschaplimburg.nl/uwbuurt/artikel/overzicht-0/):

- Rur
    - Rur Dredging Project – Roermond (Completed 2023). In 2023, Waterschap Limburg dredged a section of the Rur between the Bisschop Lindanussingel and the ECI power station. The removal of accumulated silt restored the operational function of the ECI power station and improved water flow. The works involved temporarily draining the section, closing upstream sluice gates, and relocating fish. The project was completed by the end of 2023.
    - Rurdelta Dike Reinforcement – Roermond (Planning 2024–2025). At the confluence of the Rur and the Meuse, flood defenses no longer meet future safety standards. Waterschap Limburg and the municipality of Roermond are jointly developing a reinforcement plan that integrates flood protection with urban redevelopment, including housing and a new city park. In August 2024, a preferred alternative was selected: a predominantly green dike integrated into the park design. Detailed design and a formal project decision are expected in 2025.
    - Willem Alexanderhaven Dike Reinforcement – Roermond (Construction 2025–2026). The primary dike at Willem Alexanderhaven does not currently meet legal flood safety requirements. Under the national Flood Protection Programme (HWBP), Waterschap Limburg will raise and strengthen the dike to protect Roermond, including parts of the Designer Outlet, from high water levels. This will not affect the discharge capacity of the Rur, but is aimed to mitigate flooding from the Meuse. Construction is planned for 2025–2026. In parallel, an integrated plan is being developed with local stakeholders to

extend protection beyond the primary dike, with secured EU funding for both the study and implementation phases.

- Wurm
  - Wurm Restoration – Rimburg (Design phase, from late 2023). The Wurm, a tributary of the Rur, was canalised in the 1970s, which reduced its ecological value. Waterschap Limburg is now working on restoration between the NATO depot and the Rimburg wastewater treatment plant. The preferred alternative, presented in late 2023, involves re-establishing a more natural stream profile. The project has received Interreg EMFloodResilience funding and has now entered the design phase.
- Bosbeek
  - Bosbeek Redesign – Herkenbosch (Concept Phase 2025). A redesign of the Bosbeek is being explored to meet natural stream standards. The full course from source to mouth is included. Findings indicate potential reconnection of the upper course to nearby wetlands, limited ecological value in the dry middle course, and suitability of the lower course as a marsh stream. A conceptual design is being drafted with input from local stakeholders. The project is part of the Roerdal–Meinweg 2022–2027 program but focuses solely on the Bosbeek which is located in the valley of the Rur.

In the Programme "WRL - waterveiligheid en ruimte Limburg" (water security and regional environment, Gouvernement aan de Maas 2025) the Limburg Water Board, the Province of Limburg, all Limburg municipalities and the National government collaborate with the aim of better protecting and preparing Limburg residents for extreme flooding in the future. The programme was launched after the extreme precipitation events of summer 2021.

The Oleftalsperre has been connected with the Riveris-Talsperre via a pipeline (WDR 2024). This reservoir is outside the catchment, located near Trier (Germany). This pipeline makes it possible to distribute water during phases of extreme drought between different regions from different sources (inter-basin transfer).

Within the KAHR project (Klima Anpassung Hochwasser Resilienz, Schüttrumpf 2025) various scientific studies have been carried out. The KAHR project was funded by the German federal ministry for education and research as a consequence of the 2021 flood event (FKZ 01LR2102H) and supported municipalities and administration during the rebuilding phase with scientific expertise.

The DryRivers (FKZ 02WEE1628B) project (Winkels 2022) addresses drought management in the Rur catchment. It focuses on interaction and consequences of meteorological drought events on groundwater, ecology and economy.

Proposals for international projects funded by various EU funds have been carried out and are being carried out.

- The AMICE project ("Adaptation of the Meuse to the Impacts of Climate Evolutions") was an INTERREG IVB North West Europe Project (number 074C) completed in 2012; in this project the Rur as one of the major tributaries had significant focus. Two EU proposals intended as follow-up of the AMICE project, both developed under the MICCA initiative (Section 3.5.1.1), were not honoured for funding by the EU.
- The Interreg V-A Euregio MeuseRhine project EMfloodResilience (EMR 228) has been carried out successfully after the flood event 2021 between 11 partners from Belgium, the Netherlands and Germany. It focused on becoming better prepared for the next extreme flood event and thereby prevent future loss of life and socio-economic damage.
- Other Interreg projects currently active are the FlashFloodBreaker project (Interreg North West Europe, NWE0200167). Its study area in Germany is the Emscher river but interesting projects results e.g. on the stress test approach there can be transferred to the Rur River as well.
- Finally, the FloodWisdom project (Interreg Meuse-Rhine, IMR6-00070) is a direct successor project of EMfloodResilience. The FloodWisdom project focuses specifically on improving the prediction of transnational flooding and reducing its negative effects.

3.7 Concluding remarks

Many international stakeholder interactions related to water management in the Rur catchment take place between the Netherlands and Germany. Even though part of the Rur catchment lies in Belgium, this area lies upstream in the Rur catchment with a limited number of inhabitants, infrastructure and measures of water management. As a result, international interactions between all three nations remain limited, and typically take place within the context of the Meuse river.

The interactions between German and Dutch organizations often take place on a bilateral level (one-to-one). This can be attributed to the fact that the Netherland and Nordrhein Westphalia show similarities in terms of geographical size, organization and population. As a result, most of the NRW stakeholders have a Dutch counterpart, and vice-versa. For example, the equivalent of the local water authority Wasserverband Eifel-Rur is the Waterschap Limburg. On a higher level, the Dutch ministry (Ministerie van Infrastructuur en Waterstaat) collaborates with the ministry of NRW (MUNLV). In terms of infrastructural maintenance and monitoring, the equivalent of LANUV is to some extent RWS. There are few interactions on the smallest local level (city, municipality or "Kreis"), and on the highest level between the Dutch and German government with respect to water management in the Rur catchment.

4 Model inventory

4.1 Weather generators

The Rur stress-test will focus on using (a combination of) available models to investigate the catchment response in extreme situations. These situations can be defined using historical events, either measured or reconstructed, or using synthetic events. A possible way to create synthetic events is using a weather generator. Typically, a weather generator simulates long sequences of weather data based on historical records, where precipitation is the parameter of main interest. It helps predict flood risks by creating realistic weather scenarios for hydrological and hydrodynamic models, especially for high return periods. Section 7.1 describes two weather generators that cover the Rur area: the GRADE instrument and the GFZ weather generator.

4.2 Hydrological models

Hydrological models are computer models that model the processes from rainfall to runoff. The primary input is rainfall, typically given in mm, and the primary output is a discharge at the catchment outlet. Hydrological models are also referred to as rainfall-runoff models. Hydrological models range from conceptual to physics-based models with a lumped, semi-distributed or fully distributed modelling concept.

Several hydrological models exist related to the Rur catchment. Fact sheets of these models are given in Section 7.2. Most of the models are either semi-distributed models on a region (subbasin) level in Germany, or large-scale distributed models containing the Rur catchment, such as the models for NRW, the Meuse and Germany.

Semi-distributed models consist of concentrated elements with uniform parametrization. The structure of these elements contains spatial information and describes how routing between the elements take place. Examples within the Rur catchment are HBV (Lindström et al. 1997), NASIM (Hydrotec GmbH 2015a), and BlueM (BlueM 2024). Distributed models are fully gridded models for which routing takes place between the grid cells. Examples of such models for the Rur catchment are LARSIM (LARSIM 2024), Wflow (Deltares 2022a) and mHM (mHM 2024).

4.3 Hydraulic models

Hydraulic models compute a numerical solution of hydrodynamic flow equations. The geometry of a hydraulic model is defined by its cross-sections and bed elevation, and the primary input is typically a discharge boundary condition on the upstream end, lateral inflows along the river course, and a downstream boundary condition, typically a water level time series or a rating curve. Mass and momentum balance equations are solved, and its primary output is discharge and water levels along the river course.

The simplest hydraulic models are defined in one horizontal dimension (1D), the longitudinal direction of the river, and described by cross-sections of the river along its profile. The flow equations (Saint-Venant) are solved along this dimension and averaged over the water depth. A network of rivers and tributaries can be defined by connecting several 1D branches. The network schematization allows to account for hydraulic structures like weirs, culverts and pumps, and bridges and detention basins. The full flow equations are difficult to solve, there are different numerical approaches; numerical stability, numerical dispersion and switch between supercritical flow and subcritical flow require special attention. ProMaIDes (ProMaIDes 2024), SOBEK and the 1D part of D-HYDRO and Delft3D-FM 1D/2D (Deltares 2024) are examples for software solutions for 1D hydraulic modelling. These software solutions solve the full flow equations. To reduce numerical complexity and computational effort the flow equations can be reduced. A summary of common reductions is given Table 12 with the corresponding limitations and application range.

Similarly, river models can also be defined in two horizontal dimensions (2D). In the case of a fully 2D model, the river and its surroundings is described by a 2D grid and the shallow water equations are solved. River cross-sections are then not defined alongside the dimension, but are contained within the grid. As a result, fully 2D models often operate at a high resolution in order to capture the river profile correctly. HydroAS2D (Hydrotec GmbH 2015b) is an example for a software package for fully 2D modelling, the 2D part of D-HYDRO and Delft3D-FM 1D/2D (Deltares 2024) supports full 2D modelling.

A more simple approach for 2D modelling is to formulate the one-dimensional flow equations (Saint-Venant) in two directions. The inundation module of SOBEK follows this approach.

A coupled 1D2D-model combines 1D modelling and 2D modelling. A 1D model represents the river course, and a lateral 2D grid represents the potential inundation area. Interactions between the river and the inundation area and its surroundings occur when the water level inside the 1D cross-section exceeds its limit, resulting in flow to the 2D grid. This coupled 1D/2D modelling is supported by SOBEK, D-HYDRO and Delft3D-FM 1D/2D (Deltares 2024).

In a reduced form, 2D models are also available for faster computation of inundation area and water levels. A typical modelling approach for such a reduced approach is the formulation of the diffusive wave equations in two directions. This equation is much easier to solve from a numerical perspective and can be parallelized easier. Rim2D uses the diffusive wave equations, and the diffusive wave modelling is also used in wflow. The friction term dominates (Table 12), so this approach is commonly used to model surface runoff. Supercritical flow during surface runoff as shown in Figure 29 cannot be modelled with this approach. The SFINCS software, which is designed for fast modelling of flooding, uses the inertial model (Leijnse et al. 2021).

A three dimensional model (3D) is similar to a 2D model, but also discretized in the vertical dimension. As a result, the depth-averaged flow equations are replaced by transport equations in both horizontal and vertical directions. Such models can be used to model complex flow situations with return currents, turbulence and transport of sediment and pollutants in vertical direction.

Table 12 Levels of reductions of the 1D flow equations (modified and extended following Rötz & Theobald 2019; Alvarado Montero et al. 2013)

Equations, approximation	Assumptions	Application range	Limitations
Saint-Venant equations	Full 1D flow equations	Dynamic waves, highly transient flow, backwater effects, varying channel width	One-dimensional flow
Inertial model	Advection neglected	Dynamic waves in uniform channels with backwater effects	Local changes in velocity (varying cross sections) not accounted for
Diffusive wave approximation	Advection and local acceleration neglected	Friction dominates; moderate transient flow, moderate flow velocities, moderately controlled, small water depth, surface runoff	Limited to subcritical flow, backwater effects accounted for to limited extent
Kinematic wave approximation	Advection and inertia neglected, water level gradient equal to bottom slope	Rivers with large slope, fairly uniform channel width	Limited to uniform flow, no backwater effects, unique relation between water level and discharge, not applicable for lowland channels, changes in flow direction cannot be modelled
Water balance	Mass conservation only	Water resources planning	No hydraulics

4.4 Reservoir models and water allocation models

Reservoir models represent the water balance in a reservoir and the human operations of reservoirs. In the context of reservoir modelling, a reservoir can be a lake behind a large dam (e. g. the Rursee), a groundwater reservoir, a natural lake, retention basins, detention basins or an artificial tank. Typically, the most important equation is the storage equation that relates the change of water volume in a reservoir to inflow and outflow. Primary input of a reservoir model is inflow to the reservoir; the primary output is the water stored in the reservoir and the outflow. Often a key element of a reservoir models are the operations, given as rules or operational objectives, or physical equations that describe the interplay between storage and release under given inflow conditions.

Simulation models aim to represent the operational decisions with if-then-else logic, often by incorporating operational rules, or, if the rules are unknown, with other logic that mimics the unknown operational rules.

Optimization models use mathematical optimization techniques to determine the best reservoir management under given constraints and operational goals. Reservoir optimization models can be used for water resources planning, operational reservoir management or the determination of operational protocols.

The primary purpose of a water allocation model is to balance inflow and outflow in a water system, where inflow is typically given by hydrological processes, but also as inter-basin transfers or industrial and domestic discharge of water into the system, and the outflow is given by human usage and other use functions. Water allocation models may contain reservoirs, too; then the reservoirs often provide a source of water beside the hydrological inflow that can be used to meet water demand.

4.5 Sediment transport models

Sediment models simulate the transport of sediments in the river. They usually need a flow pattern from a hydraulic model as input. Flow velocity and the morphology of the river bed determine the shear stress, which governs the erosion and sedimentation processes. Fact sheets of the sediment transport models in the Rur area are presented in Section 7.5.

4.6 Machine learning models

Machine learning models here summarize all models that use techniques from the field of Data Mining, Artificial Intelligence and Machine Learning in a closer sense. Different to the models described in previous sections, the machine learning models are not physics-based; in principle the models connect input and output data in a smart way. Key element of a machine learning model is the training data. Machine learning models are of interest for operational flood management, because they are much faster than physics-based computer models. One drawback are that their application range is limited by the training data: a flood event that is more extreme than the events covered in the training data cannot be modelled. Typically, training data originates from physics-based models and is prepared beforehand. Machine learning models are often limited to several points in space, while physics-based models represent the whole area of interest.

Because they are data driven, machine learning models cannot be used for design studies or to evaluate measures, because this type of modelling involves a system change.

Machine learning models that represent sites in the Rur area are presented as fact sheets in Section 7.6.

4.7 Groundwater models

Groundwater models simulate the saturated flow in porous media (the groundwater flow). The flow equations are differential equations that primarily comprise Darcy's law and mass balance. Section 7.7 contains fact sheets of groundwater models for the Rur area.

4.8 Forecasting systems

Forecasting systems are decision support systems that collect data (rainfall forecast, observed water level), process this data and feed it to models or a chain of different models to support decisions related to operational flood management. These decisions can be about issuing warnings or the control of hydraulic structures (pump discharge, reservoir release) or just for technical information. Section 7.8 contains fact sheets of forecasting systems for the Rur catchment.

4.9 Synthesis

This model inventory shows that various models of different type are available. A full coverage of the area of interest with available models is not achieved yet, as Figure 26 shows: For the Urft, only hydrological models are available, the Rur upstream of the reservoir system and the Kall river have not been modelled yet, while for parts of the Untere Rur multiple hydraulic models are present. Each model has its own modelling area, typically a subregion inside the Rur catchment, and has its specific modelling purpose, i.e. to answer hydrologic or hydrodynamic questions or questions related to water allocation, sediment transport, or reservoir operations.

For a catchment-wide stress test the challenge lies in combining and extending the different models to a larger transboundary coverage that does not stop at the Dutch-German border, and extending the models to catchment-scale.

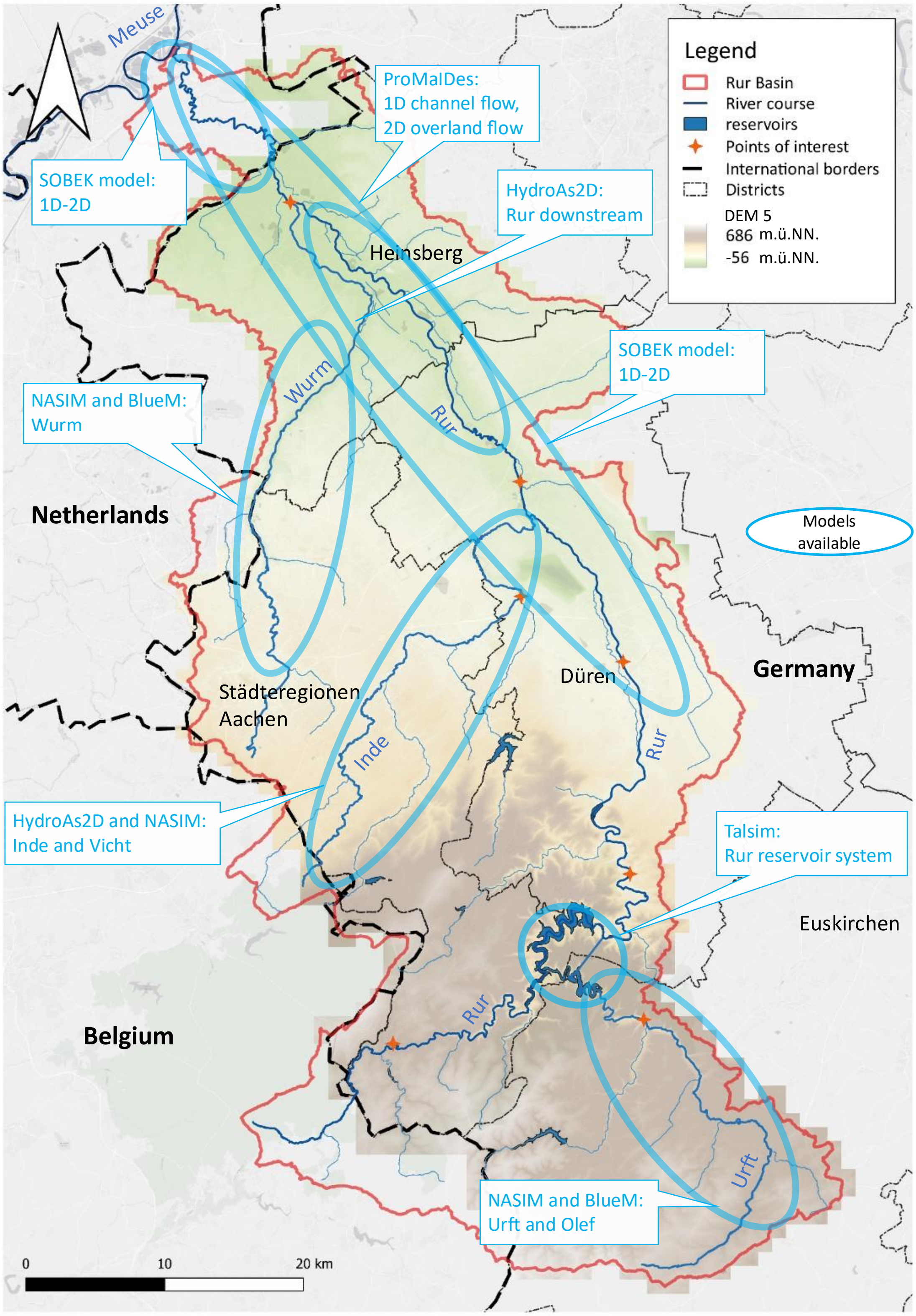


Figure 26 Selected models of different type in the Rur area

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6 Technical terms

6.1 On the definition flooding and high river stage in the context of Directive 2007/60/EC

The terms that are used for flooding and high river stage in different languages are shown in Table 13. The Flood Risk Management directive of the European Commission (Directive 2007/60/EC) defines “flood” in the sense of an inundation. Consequently, most languages use the term that corresponds to inundation in the translation of title and definition of this directive.

The German translation related to Directive 2007/60/EC is an exception: the German translation uses the term “Hochwasser” and not “Überflutung” or “Überschwemmung”. “Hochwasser” is defined in the German standardization code DIN 4049-3 1994 as a state in a surface water where a certain threshold is reached or exceeded. So technically, the term “Hochwasser” rather refers to a certain river state in a hydrological sense, which not necessarily comes with inundations. In addition, DIN 4049-3 1994 defines also “Überschwemmungsgebiete” as areas that are covered with water due to flooding of the banks (German: “ausufern”).

In colloquial German, the word “Hochwasser” is used for high water level and also to describe inundations without strictly separating between inundation and a certain state a surface water is in.

Table 13 Translation of terms related to flooding and high river stage according to Directive 2007/60/EC

	English	German	Dutch	French	Spanish
Non-technical usage	high river stage, (high water)	Hochwasser	hoogwater	crue	avenida, crecida
	flood, flooding, inundation	Überflutung, Überschwemmung, Hochwasser	overstroming	Inondation	inundación
Titel of Directive 2007/60/EC	Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks	Richtlinie 2007/60/EG des Europäischen Parlaments und des Rates vom 23. Oktober 2007 über die Bewertung und das Management von Hochwasserrisiken	Richtlijn 2007/60/EG van het Europees Parlement en de Raad van 23 oktober 2007 over beoordeling en beheer van overstromingsrisico's	Directive 2007/60/CE du Parlement Européen et du Conseil du 23 octobre 2007 relative à l'évaluation et à la gestion des risques d'inondation	Directiva 2007/60/CE del Parlamento Europeo y del Consejo, de 23 de octubre de 2007, relativa a la evaluación y gestión de los riesgos de inundación
Definition in Directive 2007/60/EC	'flood' means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems;	„Hochwasser": zeitlich beschränkte Überflutung von Land, das normalerweise nicht mit Wasser bedeckt ist. Diese umfasst Überflutungen durch Flüsse, Gebirgsbäche, zeitweise ausgesetzte Wasserströme im Mittelmeerraum sowie durch in Küstengebiete eindringendes Meerwasser; Überflutungen aus Abwassersystemen können ausgenommen werden.	„overstroming": het tijdelijk onder water staan van land dat normaliter niet onder water staat. Deze term bestrijkt overstromingen door rivieren, bergstromen, efemere waterlopen in het Middellandse-Zeegebied, en overstromingen door de zee in kustgebieden, met mogelijke uitsluiting van overstromingen door rioolstelsels.	« inondation » : submersion temporaire par l'eau de terres qui ne sont pas submergées en temps normal. Cette notion recouvre les inondations dues aux crues des rivières, des torrents de montagne et des cours d'eau intermittents méditerranéens ainsi que les inondations dues à la mer dans les zones côtières et elle peut exclure les inondations dues aux réseaux d'égouts.	«inundación»: anegamiento temporal de terrenos que no están normalmente cubiertos por agua. Incluye las inundaciones ocasionadas por ríos, torrentes de montaña, corrientes de agua intermitentes del Mediterráneo y las inundaciones causadas por el mar en las zonas costeras, y puede excluir las inundaciones de las redes de alcantarillado.

While it is often not necessary to make this distinction in colloquial conversation, it can make sense to make this conceptual distinction in a technical context. The river stretch shown in Figure 27 has a flood plain on the right side, while on the left bank it is bounded by a quay wall. If the water level reaches the top edge of the quay wall, the river carries “Hochwasser” in a hydrological sense, regardless of the location under consideration. According to the German translation of Directive 2007/60/EC, however, there would only be “Hochwasser” (here in the sense of flooding) on the left side and not on the right side of the river, because only on the left side there is land impounded that is normally not covered by water, namely the forebay.

Figure 27 Elbe in Dresden (Germany) during low flow conditions. In the foreground the right bank with floodplain, on the opposite side the river has a quai wall. (Photo: Bernhard Becker)

The river section shown in Figure 28 is bounded on both sides by a quay wall. If the water level rises to the top of the quay wall, then no ‘temporary flooding of land not normally covered by water’ would have occurred at this point, i.e. no “Hochwasser” according to the German translation of Directive 2007/60/EC. However, it is easy to imagine that at such a water level, the bridge's clearance height becomes so low that shipping must be restricted due to “Hochwasser” (then to be understood in the hydrological sense as high discharge that corresponds to high river stage), regardless of whether flooding occurs at this point or not. However, measures to protect against flooding are not yet necessary for this condition.

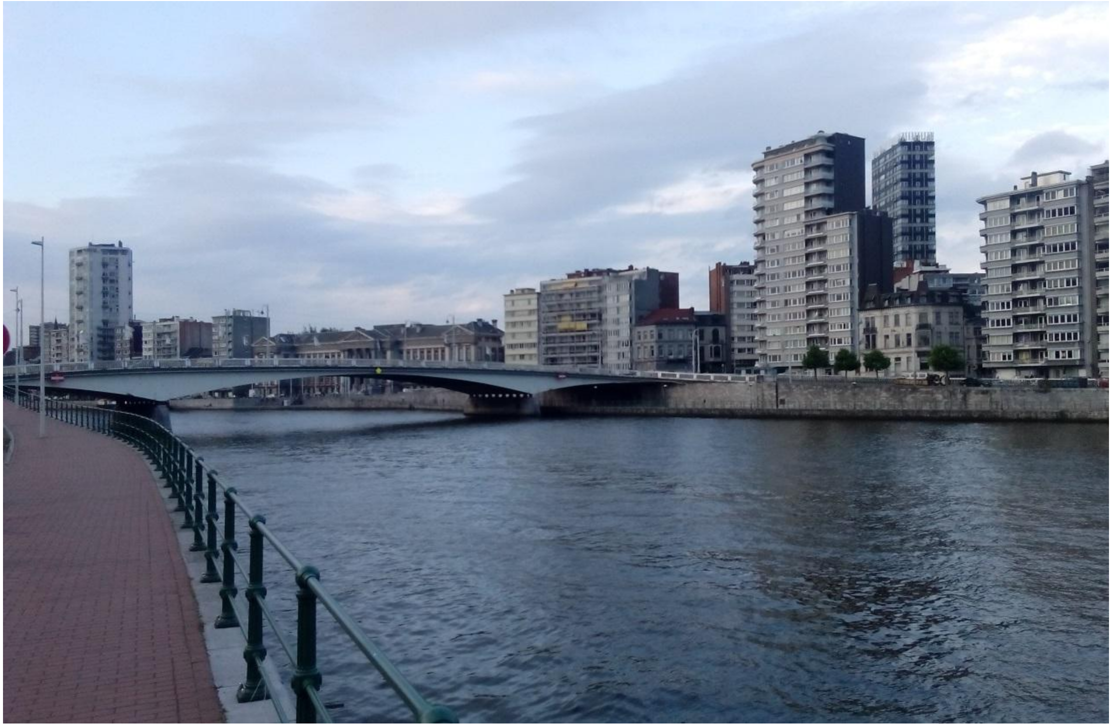


Figure 28 *The Meuse in Liège (Belgium) at normal flow conditions (photo: Bernhard Becker)*

Figure 29 shows water on the road during a heavy rainfall event. This is no "Hochwasser" in the hydrological sense according to DIN 4049-3 1994, because this water originates from rainfall (surface runoff, pluvial flooding) and does not yet belong to a surface water. But this phenomenon can certainly be considered as flooding according to Directive 2007/60/EC, because the road is normally not covered with water. But in colloquial German, this would probably be called "Überflutung" (inundation, flooding) rather than "Hochwasser".

Figure 29 Water on the road near Faweux (Belgium) May 2024 due to heavy rainfall (photo: Anke Becker)

Dictionaries often translate the German word "Hochwasser" to English as "flood". Also DIN 4049-3 1994 translates the hydrological "Hochwasser" with "flood". However, both in colloquial and technical language, the English term flood implies inundation: the traffic sign shown in Figure 30 warns with the word "flood" for water on the road, it is not meant to inform vehicle drivers about the hydrological state of a surface water close-by. Consequently, a more accurate translation of "Hochwasser" in its technical or hydrological sense to English would be "flood stage" or "highwater discharge".

Note that the term "high water" and its corresponding term in other language have a different meaning in the context sea water and tide.

Figure 30 Traffic sign with worded warning „Flood" on a road in England. The flood (inundation) is given here by a creek that exceeds its bed, not visible on the picture

6.2 Glossary

Table 14 contains a collection of technical terms in English, German, Dutch and French. To support multiple languages, the English term has been chosen as the linking element between all languages (English as *lingua franca*). Definitions are given in English language.

The terms and definitions have been collected in the course of the project by the authors. The list is not exhaustive and not sorted. Translation, definition and usage of terms is limited to the scope of this document. Terms might be used differently in a different context, and some translations and definitions might be not precise enough or even be wrong. Note that definitions are different in different languages, because different common practice and different standardisations apply. A unique translation is not always possible. To give an example: the barrage de Namur is the weir in the Meuse near the city of Namur, but the term "barrage" is not only used for weirs, but also used for large dams in French, for example "barrage de la Gileppe". Another example is the term "polder": This work is used both in Dutch and in German for catchments that have no natural drainage by gravity flow – but in German a Polder can also refer to a lateral detention basin.

Table 14 Technical terms in different languages

Term in English	Translation to language	Term in language	Definition (by authors for the scope of this document if not specified otherwise)
catchment, basin	German	Einzugsgebiet	
	Dutch	stroomgebied	
	French	bassin versant	
dam (large dam)	German	Talsperre	A barrier that stops or restrict the flow in a surface water course. A dam closes the whole valley.
	Dutch	stuwdam	
	French	(grand) barrage	
weir	German	Wehr	A barrier that stops or restricts the flow in a surface water course. A weir impounds the river bed and divides the water course in sections. Weirs can be fixed or movable.
	Dutch	stuw	
	French	barrage (petit), seuil	
detention basin (rain)	German	Regenrückhaltebecken	A basin to store rainfall water temporarily. Often the outlet is uncontrolled. Under normal condition the detention basin is empty.
	Dutch	regenwaterbuffer	
detention basin (stream)	German	Hochwasserrückhaltebecken	A basin to control the discharge of a stream under flood conditions. Under normal conditions the basin is empty. It can be installed laterally to the stream, then often an excavated area or flood plain enclosed with dikes, or longitudinally, then often realised with a single-purpose dam. A longitutinal detention basin can be designed with either controllable or uncontrollable outlet. A lateral detention basin has a structure for inflow and outflow.
	German	Polder, Flutpolder (lateral detention basin)	
district	German	Kreis, Landkreis, kreisfreie Stadt	Administrative subdivision higher than a municipality.
emergency response	German	Katastrophenschutz	Activities of emergency response on district level
	German	Gefahrenabwehr	Activities of emergency response on regional level
governmental district	German	Bezirk, Regierungsbezirk	Regional mid-level local government units in four of Germany's federal states, including Nordrhein-Westfalia
run off potential (natural or artificial)	German	Vorflut	The potential for water to run off by gravity flow (natural, “natürliche Vorflut”) or artificial drainage (“künstliche Vorflut).
minimum release	German	Mindestabgabe	The operational minimum release from a reservoir that the operations should aim to maintain according to the operational protocol
	Dutch	Minimale afvoer	
municipality	German	Gemeinde	Lowest level of territorial division.
	Dutch	gemeente	
upstream	German	oberstrom	Located upwards along a water course with respect to a certain location the same water course
	Dutch	bovenstrooms	
	French	amont	

down-stream	German	unterstrom	Located downwards along a water course with respect to a certain location the same water course
	Dutch	benedenstrooms	
	French	aval	
upstream riparian	German	Oberlieger	An organization, settlement, municipality or country that is located upstream with respect to another along a water course.
	Dutch		
down-stream riparian	German	Unterlieger	An organization, settlement, municipality or country that is located downstream with respect to another along a water course.
polder	German	Polder	A catchment that has no natural drainage by gravity flow. Polders are typically drained with the help of pumps. Note that the German term "Polder" is used also for detention basins lateral to a river or stream.
	Dutch	polder	
reservoir (general)	German	Speicher	Any water body that can store water.
retention (water)	German	Rückhalt	The process of retaining water, i. e. preventing the water to flow downstream. Retention is a form of storage, but typcially limited in capacity and time due to physical processes; it does not involve control.
	Dutch	vast houden	
storage (water)	German	Speicherung	The physical process of storing water in a general sense. Storage can be realized with the help of control.
	Dutch	berging, opslag	
	French	stockage d'eau	
reservoir (lake)	German	Stausee (also: Talsperre, then in a wider sense)	A lake created by a (large) dam, usually built to store fresh water. Multi purpose reservoirs suppress floods and provide water for human consumption, irrigation, industrial use, recreation, hydropower generation or ecological functions.
	Dutch	stuwmeer	
	French	reservoir, lac	
reservoir release	German	Talsperrenabgabe	The release from a reservoir to the downstream river section.
spillway	German	Hochwasserentlastungsanlage	A structure to provide the controlled release of water from a dam or levee under flood conditions. The capacity of one or multiple spillways in combination with other outlet means (bottom outlet and turbines) should be sufficient to handle the discharge associated to the probable maximum flood.
	Dutch	overlaat, noodoverlaat	
full supply level	German	Stauziel	Water level that corresponds to the maximum volume in a reservoir under normal conditions, the upper bound of the normal operation range.
surcharge level	German	Höchstes Stauziel, Vollstau	The water level in a reservoir that corresponds to the upper bound of the flood storage volume or flood control volume. Above this level flood surcharge begins. The surcharge level is the maximum operating level. Operations above the flood surcharge level include regular operation of the spillway.
Maximum water level	German	Hochwasserstauziel	The water level that corresponds to the upper bound of the flood surcharge zone. It is the maximum water level that is foreseen for the reservoir under flood conditions.

volume-release plan	German	Lamellenplan	An operational protocol for a reservoir that specifies the reservoir release in dependence of the time in the year and the current volume of water in the reservoir. Central elements are multiple zones, each zone a release is assigned to.
receiving water	German	Vorfluter	The water body that enables run off potential; typically a water course, but can also be groundwater or a lake.
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.
water board (Netherlands)	Dutch	Waterschap	Public organization in the Netherlands responsible for the water management of a specific region. Water boards have an elected management board and levy a water board tax from the inhabitants living in their region. Often referred to as "de regio".
Flood Risk Management Plan	Dutch German	Overstromingsrisicobeheerplan (ORBP) Hochwasserrisikomanagementplan	Flood risk management plans required by the European Flood Directive (2007).
acceptable flood risk	Dutch	Maximaal toelaatbare overstromingskans	
European Floods Directive	German Dutch French	Hochwasserrisikomanagement-Richtlinie Europese Richtlijn Overstromings-risico's (ROR) Directive inondation	Directive 2007/60/EC
Water Framework Directive	German Dutch French	Wasserrahmenrichtlinie (EU-WRRL) Kaderrichtlijn Water (KRW) directive-cadre sur l'eau (DCE)	Directive 2000/60/EC
Upper Rur	Dutch German	Boven-Roer Obere Rur	Upper region of the Rur river, reaching from its origin to Obermaubach
Middle Rur	Dutch German	Midden-Roer Mittlere Rur	Middle region of the Rur river, reaching from Obermaubach to Linnich
Lower Rur	Dutch	Beneden-Roer Untere Rur	Lower region of the Rur river, reaching from Linnich to Roermond
water quality	German Dutch	Gewässergüte waterkwaliteit	
responsibility of flood protection	German	Hochwasserschutzpflicht	The obligation a governmental organization has by law to protect inhabitants against floods. This responsibility is limited to a certain level. In Germany, this responsibility is usually assigned to the municipalities.

responsibility of maintenance (of a water)	German	Gewässerunterhaltungspflicht	The obligation an organization has to maintain a water (a water course, a lake or other). In Germany the owner of a water is responsible for its maintenance, but the owner can delegate this responsibility to others or the responsibility can be a legal obligation to others.
Flood protection concept	German	Hochwasserschutzkonzept	A strategic plan for flood protection measures. A key element is a design discharge (e. g. HQ 100).
zone (operational water management)	German	Lamelle, Speicherlamelle	A reservoir volume is divided into multiple layered zones for different purposes (flood storage zone, surcharge zone).
	Dutch	schijf	
Ordinance	German	Verordnung	
Regulation	German	Verordnung	
Framework directive	German	Rahmenrichtline	
	Dutch	kaderrichtlijn	
	French	directive-cadre	
Act (legislative act)	German	Gesetz	
	Dutch	wet	

7 Fact sheets of site-specific models

7.1 Weather generators

7.1.1 GRADE

The Generator of Rainfall And Discharge Extremes (GRADE) methodology has been developed by RWS, KNMI and Deltares. The basis is formed by a weather generator which generates long synthetic simultaneous records of daily rainfall and temperature. These long timeseries are then used in chain of hydrological and hydraulic models to generate discharge records which form the basis to determine the design discharge line, the shape of the hydrograph and the hydrograph of the waterlevels for the primary flood defences in the Netherlands managed by Rijkswaterstaat. GRADE is developed for the Meuse, the Rhine and the Vecht rivers.

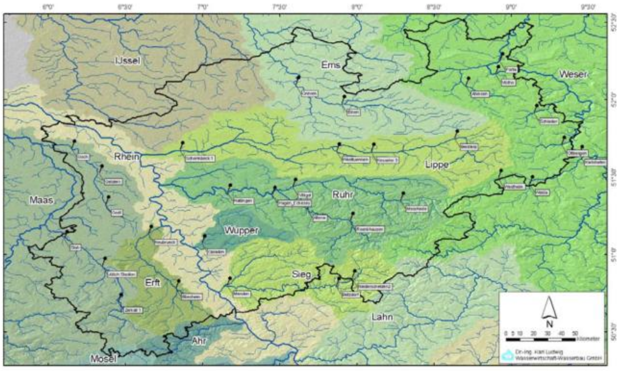
The current iteration of GRADE (Hegnauer et al. 2023) works with a stochastic multivariate weather generator that transforms a 60-70 years historic timeseries into a synthetic timeseries of 50.000 years for precipitation and temperature. The hydrological model consists of several HBV models, and the hydraulic model is a SOBEK3-1D2D model. The new iteration of GRADE (currently developed) used a single wflow_sbm for the hydrogical model of each catchment (Meuse, Rhine, Vecht) instead of multiple HBV models, and therefore requires gridded meteorological data from the weather generator. However, the overall methodology for the weather generator remains the same.

7.1.2 Non-stationary regional weather generator by GFZ (nsRWG)

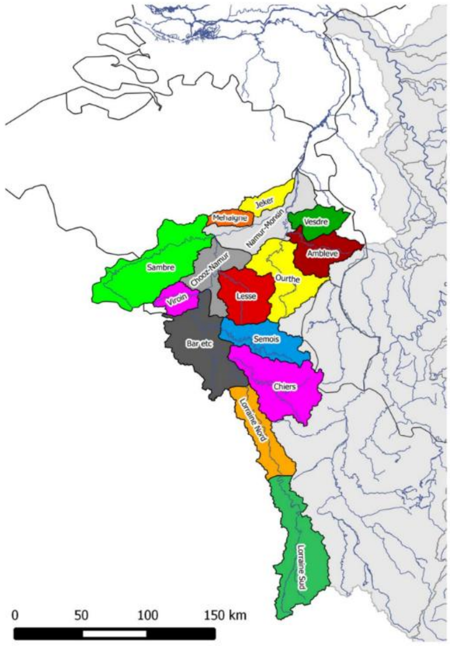
The non-stationary regional weather generator (nsRWG, Nguyen et al. 2024) provides "long-term […] consistent synthetic weather data" (thousands of years) and has been applied for Germany. Input data is large-scale circulation pattern from ERA5 reanalysis mean sea level pressure fields (large scale) and regional daily mean temperature. This input data is processed by the nsRWG to regional precipitation. This output can then be fed into hydrological models.

7.2 Hydrological models

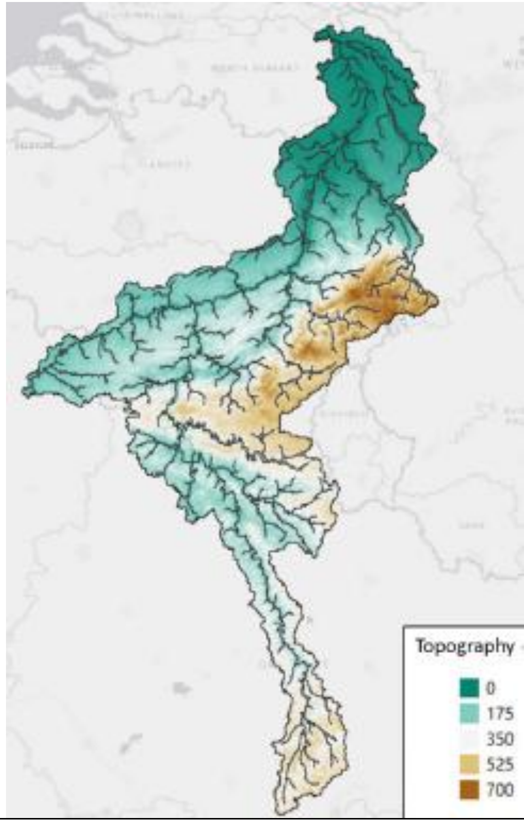
7.2.1 LARSIM models by LANUV

Model name	Operational hydrological models LARSIM
Software	LARSIM (Large Area Runoff Simulation Model, LARSIM 2024)
Category	Hydrological model
Purpose of the model	Operational flood forecasting
Model owner	LANUV
Model developed by	Dr. Karl Ludwig (Consulting Engineer)
Modelling area	All sub-catchments within the area of Nordrhine-Westfalia 
Model resolution	Time: hours Space: 10 km
Reference	Richter et al. 2009
Usage and state of maintenance	Models have been built in 2009 for climate change studies. Multiple LARSIM models have been integrated in a flood forecasting system, this is being made operational (Feb. 2024)

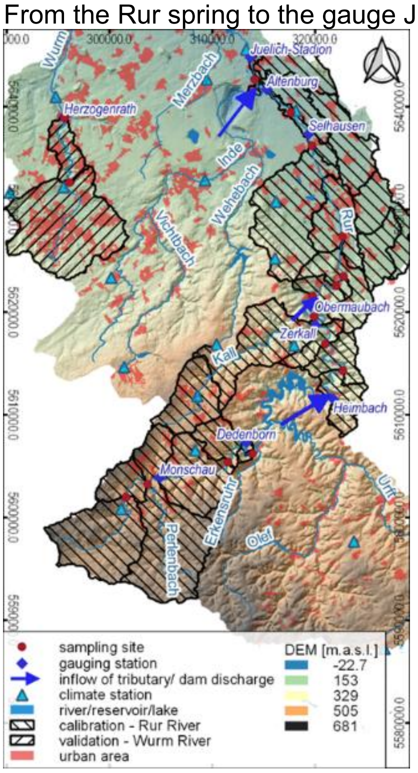
7.2.2 HBV model of the Meuse catchment by Rijkswaterstaat

Model name	**HBV model Meuse**
Software	HBV-96 (Lindström et al. 1997)
Category	Semi-distributed hydrological model
Purpose of the model	Operational flood forecasting, operational low flow forecasting, climate change studies
Model owner	Rijkswaterstaat
Model developed by	Deltares
Modelling area	The Meuse catchment until Borgharen 
Model resolution	Time: days, hours Space: spatially lumped Subbasins: 15
Reference	Hegnauer 2023
Usage and state of maintenance	Models are continuously updated for operational low flow and flood forecasting and climate change studies.

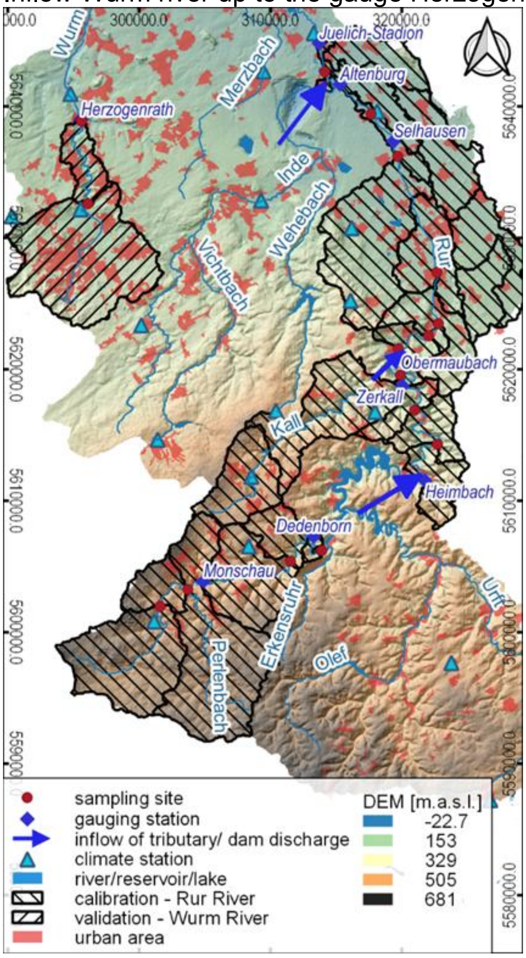
7.2.3 Wflow model of the Meuse catchment by Rijkswaterstaat

Model name	**Wflow model Meuse**
Software	wflow (Deltares 2022a)
Category	Distributed hydrological model
Purpose of the model	Operational flood forecasting, operational low flow forecasting, climate change studies
Model owner	Rijkswaterstaat
Model developed by	Deltares
Modelling area	The Meuse catchment until Mook 
Model resolution	Time: days Space: 1 km
Reference	van der Krogt et al. 2022; Bouaziz 2020
Usage and state of maintenance	Models are continuously updated for operational low flow and flood forecasting and climate change studies.

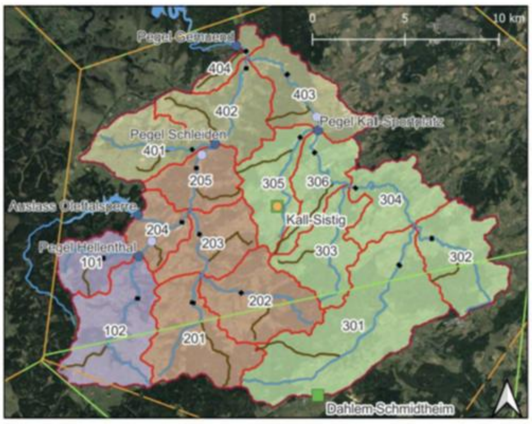
7.2.4 BlueM Rainfall-runoff model from the spring to the gauge Jülich-Stadion

Model name	Rainfall-runoff model Rur river
Software	BlueM (SCS-method, BlueM 2024)
Category	Hydrological model, lumped
Purpose of the model	Rainfall-runoff modelling
Model owner	IWW, RWTH Aachen University
Model developed by	Stefanie Wolf, Felix Steudtner
Modelling area	From the Rur spring to the gauge Jülich-Stadion  Source: Wolf et al.
Model resolution	Time: 6th October 2019 to 1st February 2021, 15 min resolution Space: subcatchments: 224-6600 ha
Reference	Master thesis Felix Steudtner and land use study of student assistant Annika Lambert Wolf, S., Stenger, D., Steudtner, F. et al. Modeling anthropogenic affected sediment transport in a mid-sized European river catchment–extension of the sediment rating curve equation. Model. Earth Syst. Environ. 9, 3815–3835 (2023). https://doi.org/10.1007/s40808-023-01703-8
Usage and state of maintenance	Operation 2019-2021 Inflows were fed in as time series

7.2.5 BlueM Rainfall-runoff model Wurm river up to the gauge Herzogenrath

Model name	Rainfall-runoff model Wurm river
Software	BlueM (SCS-method, BlueM 2024)
Category	Hydrological model, lumped
Purpose of the model	Rainfall-runoff modelling
Model owner	IWW, RWTH Aachen University
Model developed by	Stefanie Wolf
Modelling area	Inflow Wurm river up to the gauge Herzogenrath  *Source: Wolf et al.*
Model resolution	Time: September 30th, 2019 to June 29th, 2021, 15 min resolution Space: 197-2667 ha
Reference	Wolf, S., Stenger, D., Steudtner, F. et al. Modeling anthropogenic affected sediment transport in a mid-sized European river catchment–extension of the sediment rating curve equation. Model. Earth Syst. Environ. 9, 3815–3835 (2023). https://doi.org/10.1007/s40808-023-01703-8
Usage and state of maintenance	Operation 2019-2021

7.2.6 BlueM Rainfall-runoff model of the Urft and Olef rivers

Model name	Rainfall-runoff model Urft and Olef rivers
Software	BlueM (SCS-method, BlueM 2024)
Category	Hydrological model, lumped
Purpose of the model	Reconstruction of the July flood 2021
Model owner	IWW, RWTH Aachen University
Model developed by	Judith Schüring
Modelling area	Catchment areas of the Urft and Olef rivers 
Model resolution	Time: 01.11.2018 00:00 – 31.07.2021 23:45 Space: 413 – 4693 ha
Reference	Bachelor thesis Judith Schüring 2023
Usage and state of maintenance	Reconstruction failed due to too few climate stations and too low spatial precipitation resolution

7.2.7 NAsim-Modelle Urft und Olef

Model name	NASim-models for Obere Rur, Urft and Olef rivers
Software	NASim (Hydrotec GmbH 2015a), Jabron (Hydrotec GmbH 2015c)
Category	Hydrological model, lumped, with hydraulic routing
Purpose of the model	Flood hazard maps within the frame of the EU flood risk management directive EG-RL 2007/60/EG
Model owner	Bezirksregierung Köln (Auftraggeber)
Model developed by	FISCHER TEAMPLAN
Modelling area	Urft and Olef
Model resolution	
Reference	Franz Fischer Ingenieurbüro GmbH 2018
Usage and state of maintenance	Models were developed in 2018.

7.2.8 NAsim-Model Inde und Vichtbach

Model name	NASim-models Inde and Vichtbach
Software	NASim (Hydrotec GmbH 2015a), Jabron (Hydrotec GmbH 2015c)
Category	Lumped hydrological model hydraulic model
Purpose of the model	Analyses within the flood protection concept (Hochwasserschutzkonzept), 9 retention basins Inde, 12 basins Vichtbach
Model owner	WVER
Model developed by	Roman Düren within a MSc thesis
Modelling area	Inde und Vichtbach
Model resolution	
Reference	Rose 2024; Düren 2023
Usage and state of maintenance	Updated in 2017 and recently used for the above mentioned study, regular maintenance Christina Tibelius, MSc. thesis

7.2.9 NAsim-model of the Wurm

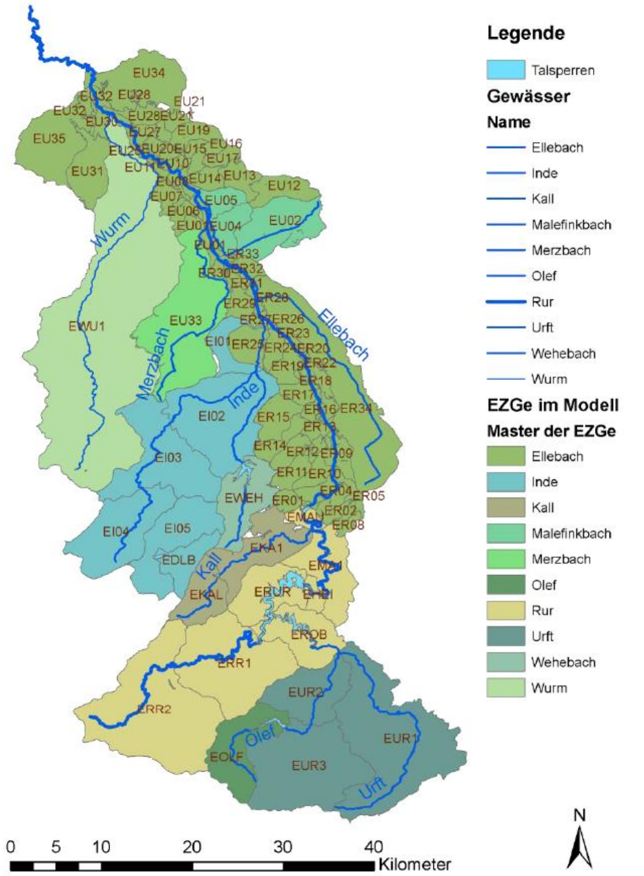
Model name	NASim-model Wurm
Software	NASim (Hydrotec GmbH 2015a), Jabron (Hydrotec GmbH 2015c)
Category	Lumped hydrological model, hydraulic model
Purpose of the model	Analyses within the flood protection concept (Hochwasserschutzkonzept)
Model owner	WVER
Model developed by	
Modelling area	Wurm
Model resolution	
Reference	Rose 2024
Usage and state of maintenance	Updated in 2017, regular maintenance

7.2.10 mHM model of the Rur catchment

Model name	mHM-model of the Rur catchment
Software	mHM, Samaniego et al. 2010
Category	Hydrological model, distributed
Purpose of the model	Flood event analysis.
Model owner	GFZ Potsdam
Model developed by	GFZ Potsdam
Modelling area	Rur catchment
Model resolution	
Reference	Merz et al. 2024
Usage and state of maintenance	Model has been developed recently. Model is cali-brated, but inundation modelling and damage model-ling not yet implemented.

7.2.11 Hochwassermerkmalsimulation of the Rur

<table>
<tr><td>Model name</td><td>Talsim-Model of the Rur</td></tr>
<tr><td>Software</td><td>NASim (Hydrotec GmbH 2015a), Jabron (Hydrotec GmbH 2015c)</td></tr>
<tr><td>Category</td><td>Hydrological model, flood routing. Wave propagation is described with the help of parameters (“Hochwassermerkmale”), the flood wave characteristic is described with the help of parameters for translation and retention. The parameters are derived from statistical analysis of historic data.</td></tr>
<tr><td>Purpose of the model</td><td>Climate change analysis for floods</td></tr>
<tr><td>Model owner</td><td>WVER</td></tr>
<tr><td>Model developed by</td><td>SydroConsult GmbH</td></tr>
<tr><td>Modelling area</td><td>Rur catchment until the Dutch-German Border



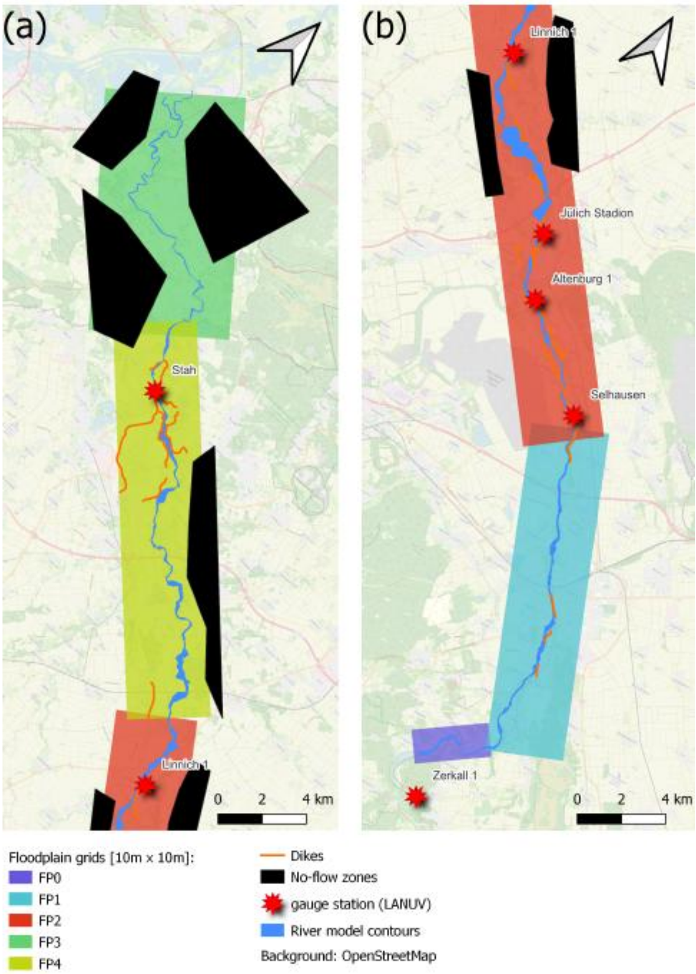
(Demny & Lohr 2014)</td></tr>
<tr><td>Model resolution</td><td>86 sub-catchments</td></tr>
<tr><td>Reference</td><td>Demny & Lohr 2014</td></tr>
<tr><td>Usage and state of maintenance</td><td>Model has been developed within a climate change study</td></tr>
</table>

7.3 Hydraulic models

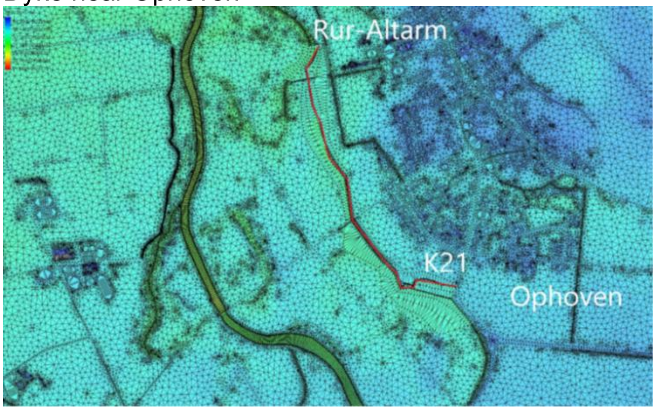
7.3.1 Rim2D model of the Rur catchment

Model name	Rim2D-model of the Rur catchment
Software	Rim2D (GFZ Potsdam)
Category	2D inundation model with diffusive wave approximation, 1D urban drainage
Purpose of the model	Urban pluvial flood event analysis. The software has also been applied for a catchment-wide analysis of the Ahr valley with the July flood 2021 scenario.
Model owner	GFZ Potsdam
Model developed by	GFZ Potsdam
Modelling area	Rur catchment
Model resolution	To be determined
Reference	Apel et al. 2022, 2024
Usage and state of maintenance	Possible development as addition to the mHM model of the Rur catchment (Section 7.2.10).

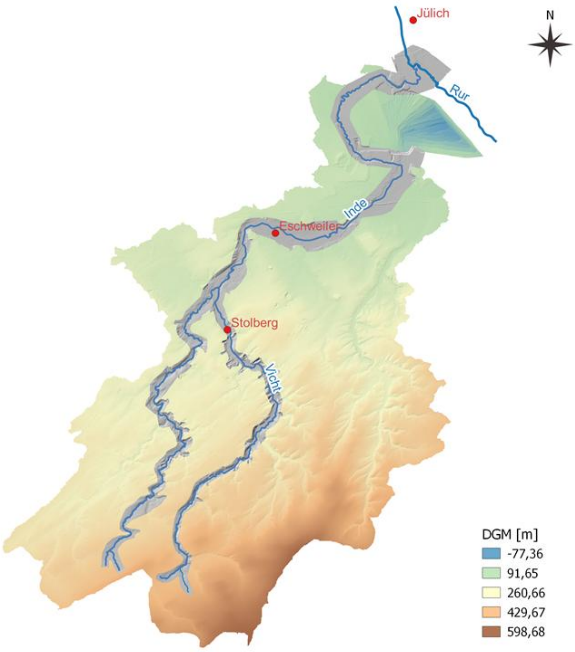
7.3.2 Promaides model of the Rur

Model name	**Promaides model of the Rur**
Software	Promaides (RWTH Aachen University, Hochschule Magdeburg-Stendal)
Category	Combined unsteady 1D channel flow (diffusive wave approximation) and 2D overland flow (diffusive wave approximation)
Purpose of the model	Flood modelling, risk assessment, damage calculation
Model owner	RWTH Aachen University
Model developed by	RWTH Aachen University
Modelling area	Obermaubach to the mouth of the Rur in the Meuse, lateral inflows from Inde, Ellebach, Merzbach and Wurm.  (Hartgring 2023)
Model resolution	Spatial resolution: 1D: one cross-sectional profile each 100 m or less; 2D: 10 m by 10 m cells
Reference	Hartgring 2023; Kufeld 2013b; Dewals et al. 2012; Detrembleur et al. 2011
Usage and state of maintenance	A first version of the model has been developed within the AMICE-project

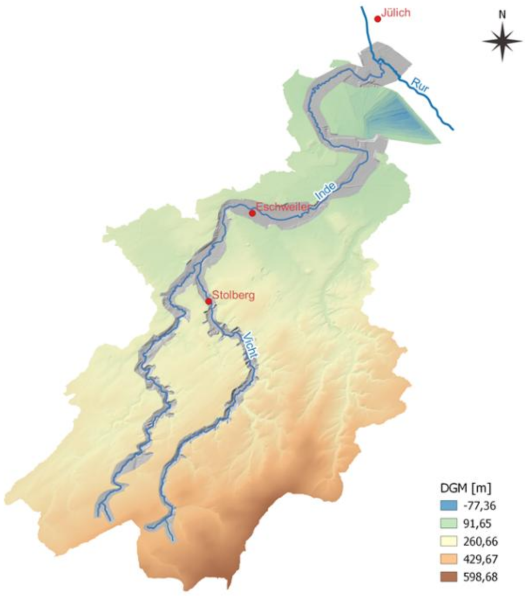
7.3.3 HydroAs2D model Untere Rur

Model name	HydroAs2D model Untere Rur
Software	HydroAs2D (Hydrotec GmbH 2015b)
Category	Hydrodynamic numerical model
Purpose of the model	2D flood modelling, polder study
Model owner	WVER
Model developed by	WVER
Modelling area	Dyke near Ophoven 
Model resolution	Time: Space: ~ 105 km² Resolution: ~ 150 m²
Reference	
Usage and state of maintenance	Master thesis Nico Schmitz in collaboration with the WVER Heleen Urbach, MSc. Thesis

7.3.4 HydroAs2D-model Inde river

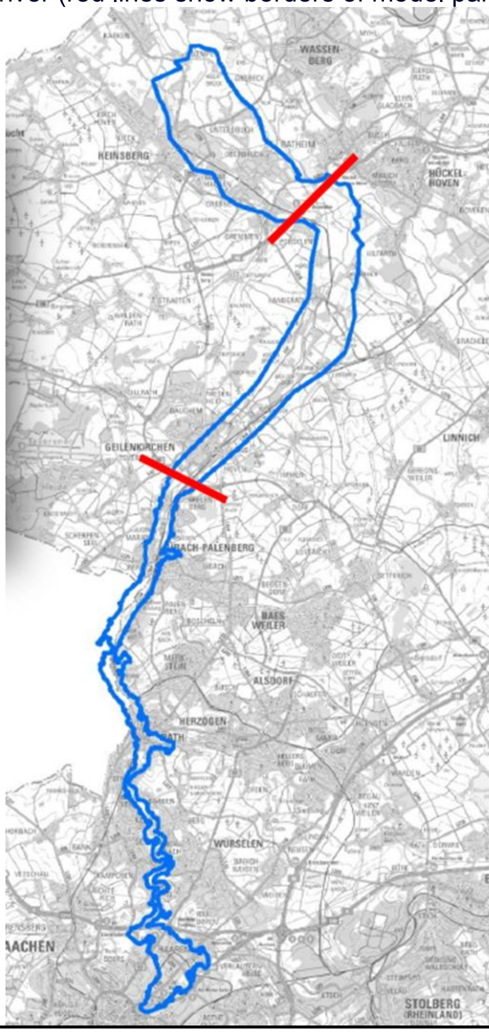
Model name	HydroAs2D-Model Inde river
Software	HydroAs2D (Hydrotec GmbH 2015b)
Category	Hydrodynamic numerical model
Purpose of the model	Comparison of the current status and the planning status due to the measure
Model owner	RWTH Aachen University, IWW
Model developed by	Felix Steudtner
Modelling area	Inde river from headwaters (missing part to spring region) to confluence into the Rur river 
Model resolution	Upper Inde (from the source to Stolberg): Time: 400 000 s Space: 5.62 km²/ 562.42 ha resolution: ~7.4 m² (whereby the river channel has a much higher resolution than the surrounding area) lower Inde (from Stolberg to mouth): is being finalized, according to the schedule completion will be at the end of August
Reference	KAHR project
Usage and state of maintenance	Model still in development. The river tube is completed and the river surrounding area almost completed. The gauge models as partial models are commissioned externally and not completed yet. For the potential analysis there will be updates.

7.3.5 HydroAs2D-model Vicht river

Model name	HydroAs2D-Model Vicht river
Software	HydroAs2D (Hydrotec GmbH 2015b)
Category	Hydrodynamic numerical model
Purpose of the model	Comparison of the current status and the planning status due to the measure
Model owner	IWW
Model developed by	Felix Steudtner (RWTH Aachen University)
Modelling area	Vicht river from Grölisbach to confluence into the Inde river 
Model resolution	Time: 450 000s /125h Space: 12.26 km² / 1 226.36 ha resolution: ~8.5 m² (whereby the river channel has a much higher resolution than the surrounding area)
Reference	KAHR project
Usage and state of maintenance	Model completed at the end of 2023 and since then in operation. It is used for potential analysis of the flood protection measurement from the WVER Mas-terplan. Later the model will be used to reconstruct the discharge values of the flood event 2021 and to create new flood hazard maps. The model is also used in the research program HüPros. The initial model is at the status of 2023. Only for the potential analysis changes are made based on the initial model. After the official recognition of the cali-bration curve by the LANUV and the district govern-ment no further updates are planned.

7.3.6 HydroAS2D model Wurm

Model name	HydroAs2D-Model Wurm river
Software	HydroAs2D (Hydrotec GmbH 2015b)
Category	Hydrodynamic numerical model

Purpose of the model	Comparison of the current status and the planning status due to the measure
Model owner	Bezirksregierung Köln (Cologne)
Model developed by	ProAqua Ingenieurgesellschaft mbH
Modelling area	Wurm river from Aachen to confluence into the Rur river (red lines show borders of model parts) 
Model resolution	Model upper course: Time: 108,000s /30h Space: 12.8 km² / 1,277.56 ha resolution: ~9.2 m² (whereby the river channel has a much higher resolution than the surrounding area) Model middle course: Time: 108,000s /30h Space: 21.8 km² / 2,180.5 ha resolution: ~14.4 m² (whereby the river channel has a much higher resolution than the surrounding area) Model lower course: Time: 108,000s /30h Space: 18.6 km² / 1,864.7 ha

	resolution: ~16.5 m² (whereby the river channel has a much higher resolution than the surrounding area)
Reference	Flood Hazard Map (FHM) 2019
Usage and state of maintenance	Model completed in May 2019 and since then in operation. It was used for FHM in 2019. Later the model was used for analysis of the flood protection measurement from the WVER Masterplan in 2022 and since then for follow-up calculations of the Masterplan.

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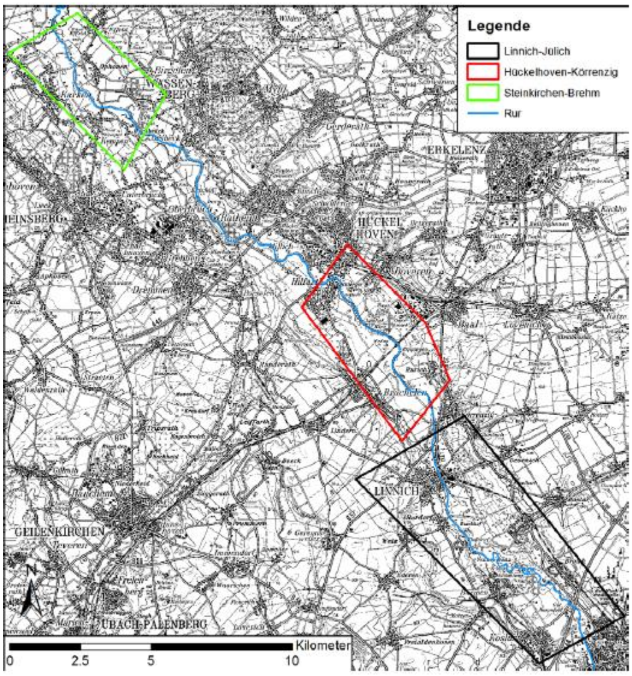
7.3.7 HWAP-Models

Model name	HWAP models (HWAP is an abbreviation for “Hoch-wasseraktionsplan” (engl.: flood action plan))
Software	ProVos, WSPWin (ProAqua Ingenieurgesellschaft für Wasser- und Umwelttechnik mbH)
Category	Hydrodynamic numerical model
Purpose of the model	The model development was carried out by ProAqua on behalf of Bezirksregierung Köln for the “Hochwas-seraktionsplan”
Model owner	Bezirksregierung Köln
Model developed by	ProAqua Ingenieurgesellschaft für Wasser- und Um-welttechnik mbH
Modelling area	Kall, Rur from Obermaubach to the Dutch border, Wurm
Model resolution	
Reference	
Usage and state of maintenance	Models have been developed ca. 15 years ago (from 2024), WVER has imported the cross sections of the Rur model to JABRON, the JABRON model is not yet complete.

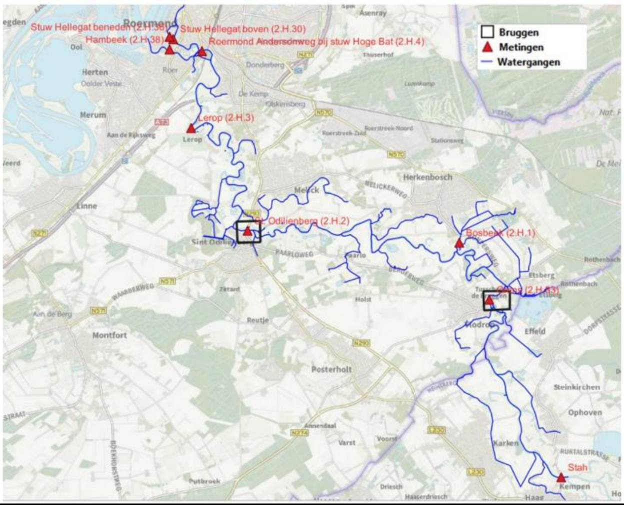
7.3.8 SOBEK model of Waterschap Limburg

Model name	SOBEK model of Waterschap Limburg
Software	SOBEK 2 (Deltares) with 1D-2D coupling for flood-plains
Category	Hydrodynamic numerical model
Purpose of the model	Various hydraulic studies
Model owner	Waterschap Limburg
Model developed by	Waterschap Limburg with different contractors
Modelling area	Dutch part of the Rur
Model resolution	10-50 m
Reference	
Usage and state of maintenance	The model is regularly updated

7.3.9 SOBEK validation model for AMICE

Model name	SOBEK model of the Untere Rur AMICE
Software	SOBEK 2 (Deltares) with 1D-2D coupling for flood-plains
Category	Hydrodynamic numerical model
Purpose of the model	Validation of the Promaides model of the Rur (Section 7.3.2) within the frame of the AMICE project
Model owner	RWTH Aachen University, IWW
Model developed by	RWTH Aachen University, IWW
Modelling area	Untere Rur from Obermaubach to the mouth in the Meuse  Detail of the modelling area with floodplains mod-elled in 2D (Kufeld 2013b)
Model resolution	10-50 m
Reference	Kufeld 2013b
Usage and state of maintenance	The model has in 2013 and has not been used any-more since then.

7.3.10 D-HYDRO model of Waterschap Limburg

Model name	1D2D D-HYDRO model of the Dutch Rur
Software	D-HYDRO (Deltares) with 1D-2D coupling for flood-plains
Category	Hydrodynamic numerical model
Purpose of the model	Forecasting, analysis
Model owner	Waterschap Limburg
Model developed by	Deltares, HKV
Modelling area	
Model resolution	Flexible mesh
Reference	
Usage and state of maintenance	Updated after 2021 floods

7.4 Reservoir models and water allocation models

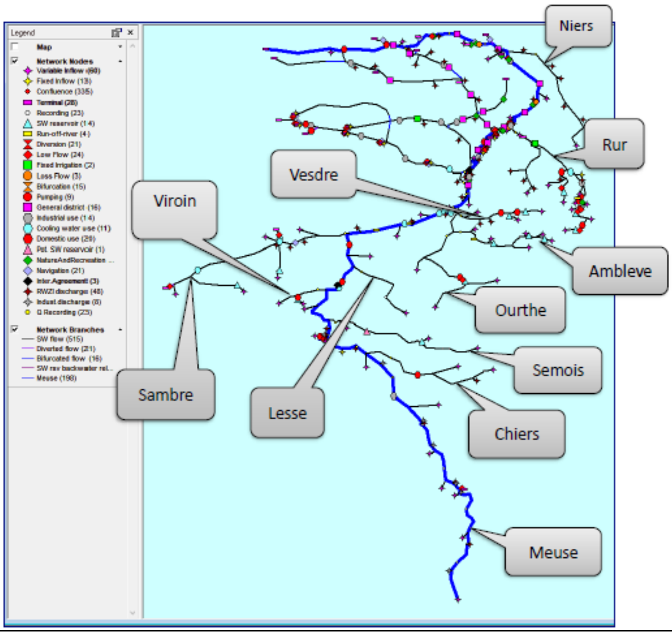
7.4.1 Talsim model of the Rur reservoir system

Model name	**Talsim-model of the Rur reservoir system**
Software	Talsim (SydroConsult GmbH 2023)
Category	Reservoir simulation model, reservoir optimization model
Purpose of the model	Support of reservoir management
Model owner	Wasserverband Eifel-Rur
Model developed by	SydroConsult
Modelling area	Rur reservoirs
Model resolution	
Reference	Kufeld 2013a
Usage and state of maintenance	Model is regularly used by WVER for short-term and long-term planning studies

7.4.2 RTC-Tools model of the Rur reservoir compound

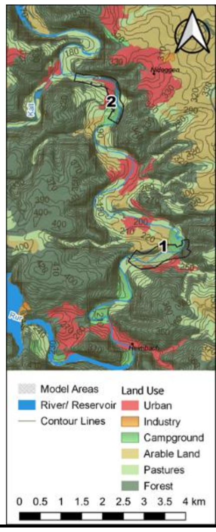
Model name	**RTC-Tools model of the Rur reservoir compound**
Software	RTC-Tools (Deltares 2022b)
Category	Reservoir optimization model, reservoir simulation model
Purpose of the model	Water resources planning under optimal reservoir operations
Model owner	Gregor Johnen (University of Duisburg-Essen)
Model developed by	Gregor Johnen
Modelling area	Reservoir compound of the Rur reservoirs
Model resolution	Time: days Space: One reservoir node
Reference	Johnen et al. 2021
Usage and state of maintenance	Model completed November 2020 within the frame of an MSc project at University of Duisburg-Essen in collaboration with Deltares

7.4.3 The RIBASIM model of the Meuse

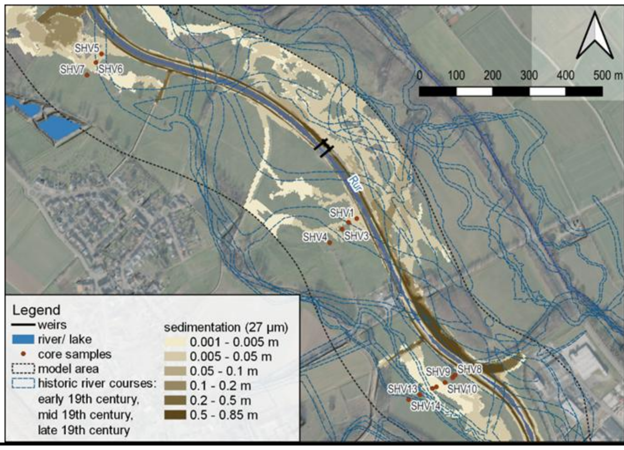
Model name	**RIBASIM model of the Meuse**
Software	RIBASIM (Deltares)
Category	Water balance model
Purpose of the model	Bottle neck analysis for low flow conditions in the Meuse
Model owner	RIWA Maas
Model developed by	Deltares
Modelling area	The Meuse and its major tributaries and reservoirs. 
Model resolution	Time: 10 days Space: network model
Reference	van der Krogt et al. 2022
Usage and state of maintenance	Model completed in 2022, update with the latest climate change scenario is planned for 2024. The model is meant to become a shared model for stakeholders in the Meuse catchment.

7.5 Sediment transport models

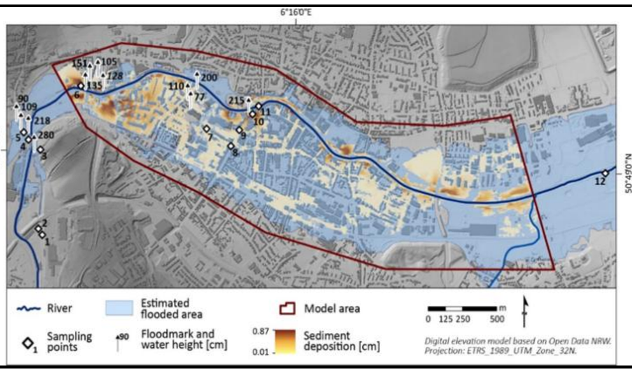
7.5.1 Delft3D-Model between Rur dam and Obermaubach

Model name	Delft3D-Model from Rur dam to Obermau-bach
Software	Delft3D
Category	Sediment model
Purpose of the model	Investigation of the effects of the dam on the sediment balance
Model owner	IWW
Model developed by	Stefanie Wolf
Modelling area	Between Rur dam and Obermaubach 
Model resolution	Time: 2010–2020, 3 months representative data is upscaled to 200 years Space: model 1: 0.26 km² (without the riv-erbed itself) ,4106 cells, width of 220 m model 2: 0.39 km² (without the riverbed it-self), 9150 cells, width of about 300 m resolution: 2.5–18.5 m
Reference	Wolf, S., Esser, V., Lehmkuhl, F. et al. Long-time impact of a large dam on its down-stream river's morphology: determined by sediment characteristics, pollutants as a marker, and numerical modelling. J. Sedi-ment. Environ. 7, 403–424 (2022). https://doi.org/10.1007/s43217-022-00103-9
Usage and state of maintenance	not yet realised in the model. Realisation planned

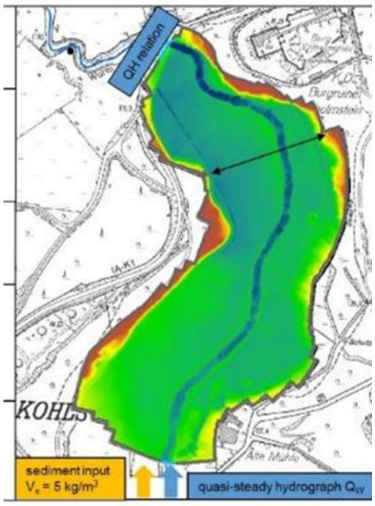
7.5.2 Delft3D-Model: Floodplains near Schophoven

Model name	Delft3D-Model: Floodplains near Schophoven
Software	Delft3D
Category	Sediment model
Purpose of the model	Floodplain modelling near Schophoven
Model owner	IWW
Model developed by	Stefanie Wolf
Modelling area	Schophoven, behind wastewater treatment plant Düren 
Model resolution	Time: December 1965 to March 2019 Space: 1079844 m², 1.3 – 43.8 m² cell size, mean cell size: 10.2 m²
Reference	-
Usage and state of maintenance	Last project maintenance: July 2023; project continuing is undecided, model is not in use at the moment

7.5.3 Delft3D-Model in Eschweiler (Flexible Mesh)

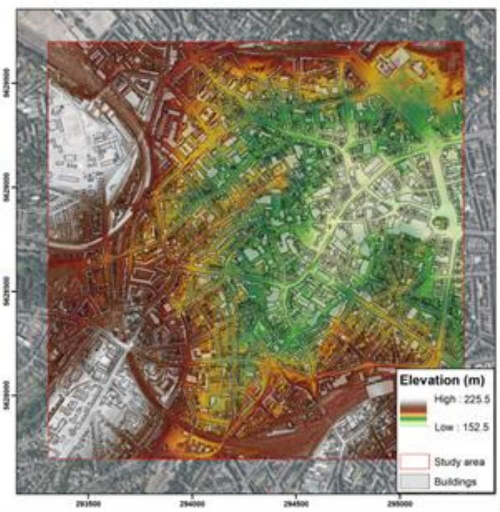
Model name	Delft3D-Model in Eschweiler
Software	Delft3D (Flexible Mesh)
Category	Sediment model
Purpose of the model	Simulation of the July flood 2021
Model owner	IWW
Model developed by	Leonie Märker-Neuhauss
Modelling area	
Model resolution	Time: An equivalent maximum flood wave discharge of 270 m3/s over 6 h represents the peak of the flood wave from July 15th 2021, at 03:30 am to 09:30 am Space: 3.62 km², grid has a grid width of 3.25 m to 28.2 m, and consists of a total of 44,468 cells, average size of the cells is 72.24 m², with 9.86 - 312.63 m².
Reference	Weber, A., Wolf, S., Becker, N. et al. The risk may not be limited to flooding: polluted flood sediments pose a human health threat to the unaware public. Environ Sci Eur 35, 58 (2023). https://doi.org/10.1186/s12302-023-00765-w
Usage and state of maintenance	Anna-Lisa Maaß

7.5.4 Delft3D-Model Wurm river

Model name	Delft3D-Model Wurm river
Software	Delft3D
Category	Numerical model
Purpose of the model	Study of long-term morphologic impacts
Model owner	IWW
Model developed by	Anna-Lisa Maaß
Modelling area	
Model resolution	Time: Data from 1969 – 2016, data extended to 200 years Space: 1 km of the Wurm River, 18,383 grid cells, with 1513 grid cells in the main channel, average cell size: 8.3 m²
Reference	Anna-Lisa Maaß, Holger Schüttrumpf, Long-term effects of mining-induced subsidence on the trapping efficiency of floodplains, Anthropocene, Volume 24, 2018, Pages 1-13, ISSN 2213-3054, https://doi.org/10.1016/j.ancene.2018.10.001. Buchty-Lemke, M., Hagemann, L., Maaß, AL. et al. Floodplain chronology and sedimentation rates for the past 200 years derived from trace element gradients, organic compounds, and numerical modeling. Environ Earth Sci 78, 445 (2019). https://doi.org/10.1007/s12665-019-8428-4
Usage and state of maintenance	Model not in use at the moment

7.6 Machine learning models

7.6.1 floodGAN

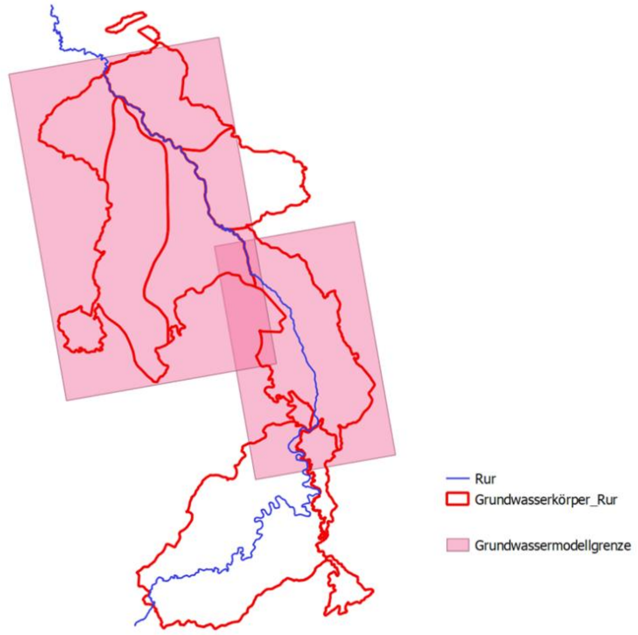
Model name	floodGAN
Software	Python 3.8; TensorFlow 2.1; C++; QT 4.13
Category	Machine learning model
Purpose of the model	pluvial flood prediction limitation: 1h events static hazard maps
Model owner	Julian Hofmann
Model developed by	Julian Hofmann
Modelling area	2 × 2 km² of the city center Aachen, Germany 
Model resolution	Time: 5 min. Space: 1 m² resolution in rainfall intensity was selected with 1mm/h, while the precipitation fields had a spatial range of 200–1000 m
Reference	Hofmann & Schüttrumpf 2021
Usage and state of maintenance	Output of a PhD thesis

7.6.2 Deep Waive

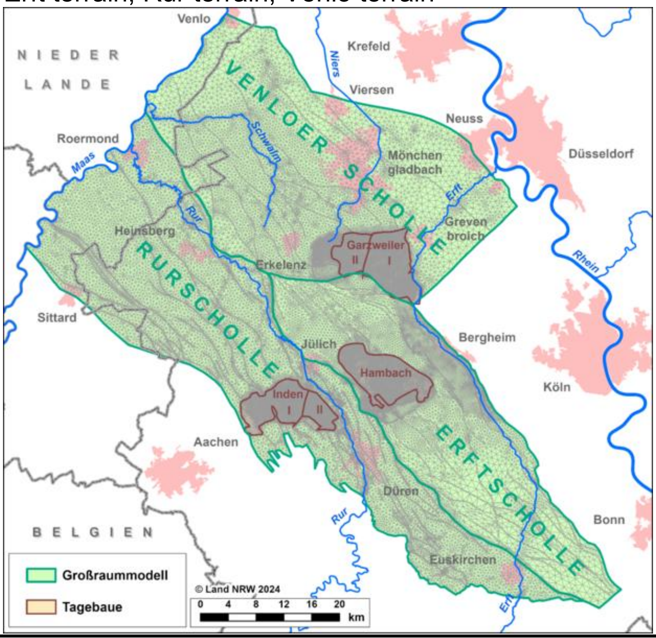
Model name	DeepWaive
Software	Custom FloodWaive deep learning libraries and architectures / Python
Category	Deep Learning Model / Hybrid-Transformer Model
Purpose of the model	Pluvial and fluvial flood prediction
Model owner	FloodWaive Predictive Intelligence GmbH
Model developed by	FloodWaive Predictive Intelligence GmbH
Modelling area	Max. cell count: Generalized-Model (DeepWaive 3.0) = 10.000.000.000 (10^10) cells -> 10000 km²
Model resolution	Space: 1m x 1m Time: 1 min – 5 min Coverage of simulation time: 15 min – 72 h events
Reference	Hofmann & Holt 2024
Usage and state of maintenance	Actively used in operational flood forecasting and risk assessment. Regularly updated and maintained by FloodWaive's development team to ensure optimal performance and accuracy. Version updates are released quarterly, with ongoing validation against real-world flood events.

7.7 Groundwater models

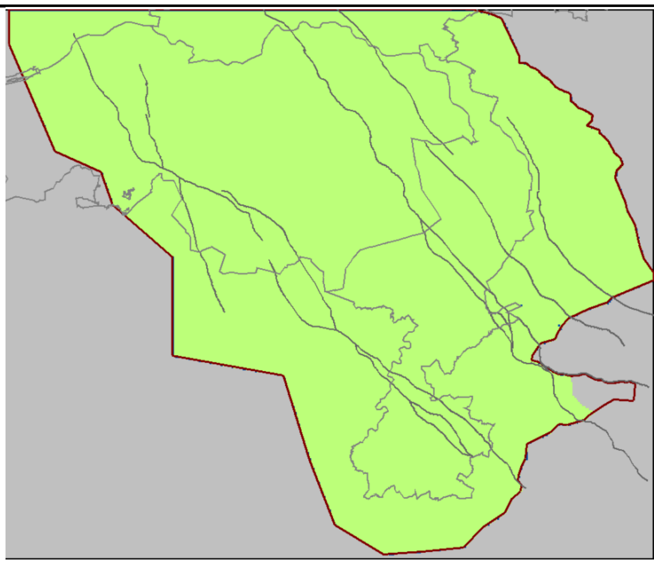
7.7.1 DryRivers groundwater model

Model name	Groundwater model Rur river
Software	LofloDes (on basis of ProMalDes)
Category	Groundwater model
Purpose of the model	For modelling only the 1st groundwater level is taken into account. The result refers to the global water level. Later the coupling of the groundwater and the Rur river will be considered for modelling. The model will be later used for consequence analysis of low water.
Model owner	RWTH Aachen University, IWW
Model developed by	You Wu
Modelling area	Between Obermaubach and Dutch border 
Model resolution	Time: 01/2002-01/2005 Space: 2.5 km X 2.5 km
Reference	AP 4.1 from DryRivers project
Usage and state of maintenance	LofloDes is in the development stage and calibration status. The model will not be published. (Status: 02/2024)

7.7.2 Large-scale groundwater model of the Rhenish lignite mining area

<table>
<tr><td>Model name</td><td>Grundwassergroßraummodell Rheinisches Revier</td></tr>
<tr><td>Software</td><td>FEFLOW (DHI Wasy GmbH)</td></tr>
<tr><td>Category</td><td>Groundwater model</td></tr>
<tr><td>Purpose of the model</td><td>Scientific support to groundwater-related questions that arise from lignite mining in the Rhenish lignite mining area</td></tr>
<tr><td>Model owner</td><td>Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen</td></tr>
<tr><td>Model developed by</td><td>GCI GmbH (RWTH Aachen University, IWW)</td></tr>
<tr><td>Modelling area</td><td>Erft terrain, Rur terrain, Venlo terrain

</td></tr>
<tr><td>Model resolution</td><td>Space: 10-1500 m, time: quarters of a year (three months)</td></tr>
<tr><td>Reference</td><td>LANUV 2024, Becker et al. 2008; Bachmann et al. 2007</td></tr>
<tr><td>Usage and state of maintenance</td><td>The model accompanies the governmental supervision of the mine drainage planning and operation, it is regularly updated.</td></tr>
</table>

7.7.3 IBRAHYM

Model name	IBRAHYM (Integraal Beheergebiedsdekkend Regionaal Hydrologisch Modelinstrumentarium)
Software	iMOD 5, MetaSWAP, MODFLOW-2005, MODFLOW 6
Category	Groundwater model
Purpose of the model	Analysis of low and deep groundwater aquifers and human impacts on these.
Model owner	Waterschap Limburg, Provincie Limburg, Waterleidingmaatschappij Limburg
Model developed by	Deltares, Alterra, SWECO, Royal Haskoning
Modelling area	 Province of Limburg, parts of the Rur terrain
Model resolution	Space: quadratic cells of 100 m
Reference	Swierstra et al. 2023; Vermeulen et al. 2007
Usage and state of maintenance	The model is regularly updated and supports practically all groundwater-related questions in the Province of Limburg.

7.8 Forecasting Systems

7.8.1 FEWS Waterschap Limburg

Forecasting system name	**FEWS Waterschap Limburg**
Purpose of the system	Flood forecasting
System owner	Waterschap Limburg
Maintenance	Support and maintenance contract with consultants
Software platform	Delft-FEWS (Deltares)
Operational area	Roer from Stah to Roermond
Models included	SOBEK model Roer (1D)
Data sources	
Usage and state of mainte-nance	Operational, used during daily duty

7.8.2 RWsOS

Forecasting system name	**RWsOS**
Purpose of the system	Flood forecasting, drought forecasting,
System owner	Rijkswaterstaat
Maintenance	Deltares
Software platform	RWsOS
Operational area	Meuse basin
Models included	2 HBV models, 1 for the upper Rur (1 element), 1 for the lower Rur (5 elements), connected with RTC-model of the Rur reservoir system. These are used to simulate Rur in-flow into the Meuse (SOBEK 3 model)
Data sources	Need to check
Usage and state of mainte-nance	Need to check

7.8.3 FEWS LANUV

Forecasting system name	**FEWS LANUV**
Purpose of the system	Flood forecasting
System owner	LANUV NRW
Software platform	Delft-FEWS (Deltares)
Maintenance aspects	Support and maintenance contract in place, contractor is currently Hydrotec
Operational area	Nordrhine-Westfalia
Models included	LARSIM models (Section 7.2.1)
Data sources	Obserwation network LANUV
Usage and state of mainte-nance	Standalone application, operationalization in progress (2024)

7.8.4 FEWS WVER

Forecasting system name	**FEWS WVER**
Purpose of the system	Flood forecasting, drought forecasting envisaged
System owner	WVER
Software platform	Delft-FEWS (Deltares)
Maintenance aspects	
Operational area	Rur catchment, WVER operational area
Models included	TALSIM models (Section 7.4.1) LARSIM model (Section 7.2.1)
Data sources	Rain radar and forecast data provided by German Weather Service. Blend of real-time data of rain radars, nowcasts from rain radar and forecast models (ICON-EU-EPS) as input for hydrological models
Usage and state of maintenance	Standalone application, pilot stage, provides a forecast every hour
Reference	Fuchs et al. 2023