Plan of approach for exceptional low water events in the Meuse basin

December 2020

English not being one of the IMC's official languages, the English version of this report is not an official translation and is only provided to make this report more widely available.

Commission Internationale de la Meuse
Internationale Maascommissie
Internationale Maaskommission
International Meuse Commission

Table of contents

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In memory of Marcel de Wit, whose book "Gouttes de pluie, flux de Meuse" was used for chapter 4 of the plan of approach to exceptional low water events.

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List of figures

List of Tables

List of Abbreviations

AMICE: Adaptation of the Meuse to the Impacts of Climate Evolutions

CERFACS: Centre Européen de Recherche et de Formation Avancée en Calcul scientifique (European Centre for Advanced Research and Training in Scientific Computing)

CHIMERE 21: research project «CHIers – Meuse: Evolution du RégimE hydrologique au 21e siècle»

CILE: Compagnie Intercommunale Liégeoise des Eaux SCRL

IMC: International Meuse Commission

ICPMS: International Commissions for the Protection of the Mosel and Saar

ICPR: International Commission for the Protection of the Rhine

WFD: Water Framework Directive

IRBD: International River Basin District

DREAL: Direction Régionale de l'environnement, de l'aménagement et du logement

FRD: Flood Risk Assessment and Management Directive

DSCLIM: open-source software that performs statistical disaggregation of climate scenarios using a method based on weather patterns and analogues

EDF: Electricité de France

GCM: Global Climate Models

IPCC: Intergovernmental Panel on Climate Change

WG: Working Group

WG H: Working Group Hydrology/Floods

KMI: Koninklijk Meteorologisch Instituut van België (Royal Belgian Météorological Institute)

KNMI: Koninklijk Nederlands Meteorologisch Instituut (Royal Dutch Météorological Institute)

LAWA: Bund/Länder-Arbeitsgemeinschaft Wasser

MaxD: maximum number of consecutive days in the year when the calculated VCN7 for each calendar day was below a given threshold

M7Q: Arithmetic mean flow rate for 7 consecutive days

PRUDENCE: Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects

RCM: Regional Climate Models

HMN: Homogeneous Measurement Network

SAFRAN: Système d'Analyse Fournissant des Renseignements Adaptés à la Nivologie (Analysis System Providing Information Adapted to Snow Conditions)

SDAGE: Schéma Directeur d’Aménagement et de Gestion des Eaux (Masterplan for Water Development and Management)

SPW: Service Public de Wallonie

SumD: total number of days in the calendar year when the calculated VCN7 for each calendar day was below a given threshold

SWDE: Société Wallonne des Eaux

VCN7: lowest average of the arithmetic flow rate averages over 7 consecutive days in a given period (year, month, week...). Here 1 year.

WATAK MLNBK: Waterakkoord Midden-Limburgse en Noord-Brabantse kanalen

1. Introduction

Low water is a natural phenomenon that can affect all rivers, including transboundary rivers such as the Meuse, Sambre, Chiers or Roer. It results from a period of prolonged absence of precipitation in the catchment area of a river. The hydrogeological conditions in the catchment area also play a key role, so that rivers that are geographically close to each other can react differently to the lack of rainfall. Human activity and/or expected climate change can/may also exacerbate the phenomenon.

At the 18th IMC's Plenary Assembly on 26 November 2010, the States and Regions, Parties to the IMC decided to endorse a Plan of Approach on low water events. The aim of this plan of approach was to anticipate as best as possible situations of extreme low water events and the resulting water shortage in the Meuse basin and thus to limit the damage caused by them as much as possible.

In application of this resolution, the IMC's "hydrology/floods" WG carried out an initial analysis of this topic from 2011 to 2012, which led to the production of a summary report on the "List of the main elements of the low-water problem in the various states and regions of the Meuse basin".

During the presentation of this summary report, the IMC plenary assembly asked the "hydrology - floods", "water framework directive" and "governance and coordination" working groups to further develop this first draft in order to answer the following three questions:

- what is an exceptional low water event in the Meuse River basin?
- what are its concrete consequences?
- How can we react in such a situation?

The submitted report summarises the current knowledge and defines what an exceptional low-water event in the Meuse basin is, based on a large amount of new data.

The first concrete consequences and the first approaches to possible reactions are also presented.

2. Legal framework

2.1 The Water Framework Directive and its guidance documents

2.1.1. Low water and good status of surface water bodies

If we look at the normative definition of good status[1] defined in Annex V of the WFD, one can see that the classification of the ecological status of surface water bodies is based primarily on biological parameters. Hydromorphological, chemical and physico-chemical parameters are considered in support of the latter. Hydrological parameters are only taken into account in the context of hydromorphological parameters in the form of the hydrological regime (quantity and dynamics of water flows, connection to groundwater bodies (cf. Figure 1).

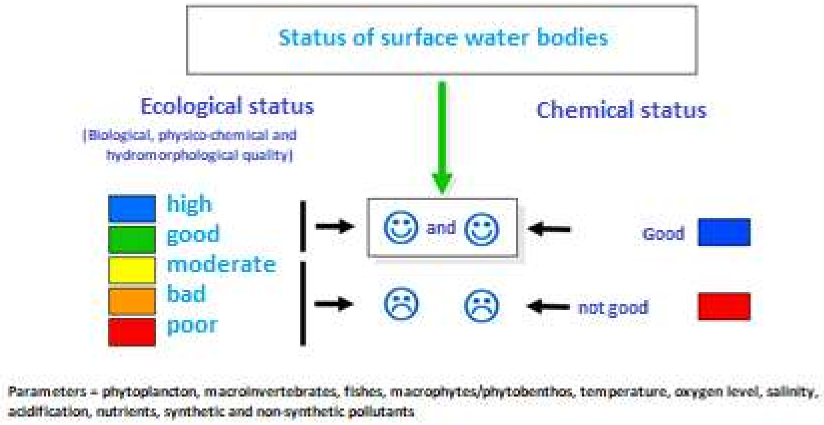


Figure 1: Assessment of the status of a surface water body according to the normative definition in Annex V of the WFD

This observation highlights the fact that when trying to assess whether a water body is in good condition or not, **hydrological conditions must be considered as a cause or explanatory factor** for any alterations/deterioration observed in the biological, physico-chemical and chemical parameters.

In other words, it means that the competent authorities of the river basin districts are required to **take measures/actions to address the hydrological conditions existing in a surface water body if these are identified as being one of the factors preventing the achievement of the good status.**

2.1.2. WFD programmes of measures and quantitative management actions

In its article 11 on the programme of measures to achieve the environmental objectives of water bodies**, the WFD provides for a (non-exhaustive) series of actions relating to the quantitative management of water bodies (see part B of annex VI of the WFD):**

- *abstraction controls,*

[1] The hydrological regime of a water body is taken into account in the same way as its morphological conditions when assessing whether or not the water body is in very good condition.

- *demand management measures, inter alia, promotion of adapted agricultural production such as low water requiring crops in areas affected by drought,*

- *efficiency and reuse measures, inter alia, promotion of water-efficient technologies in industry and water-saving irrigation techniques,*

- *desalination plants,*

- *rehabilitation projects.*

In order to determine whether such quantitative management actions are necessary, **the WFD provides for the following two analyses to be carried out when identifying the pressures that may degrade the status of surface water bodies** (see section 1.4 of Annex II of the WFD):

- *Estimation and identification of significant water abstraction for urban, industrial, agricultural and other uses, including seasonal variations and total annual demand, and of loss of water in distribution systems;*

- *Estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances.*

These analyses are carried out as part of the preparation of the analyses and reviews as provided for in Article 5 of the WFD.

The "Plan of Approach for Low Water" is a first limited approach for this purpose.

It should be kept in mind that the technical effectiveness of the implemented measures can be significantly reduced when natural conditions are unfavourable. Member States should be aware that difficult natural conditions can reduce the effectiveness of national programmes of measures under the WFD.

For this reason, the WFD provides in Article 4(6) for the possibility of temporary derogation from the environmental objectives of a water body in the case of "***circumstances of natural cause or force majeure which are exceptional*** *or could not reasonably have been foreseen, in particular extreme floods and* ***prolonged droughts [...] when all of the following conditions have been met:***

a) all practicable steps are taken to prevent further deterioration in status and in order not to compromise the achievement of the objectives of this Directive in other bodies of water not affected by those circumstances;

b) the conditions under which circumstances that are exceptional or that could not reasonably have been foreseen may be declared, including the adoption of the appropriate indicators, are stated in the river basin management plan;

c) the measures to be taken under such exceptional circumstances are included in the programme of measures and will not compromise the recovery of the quality of the body of water once the circumstances are over;

d) the effects of the circumstances that are exceptional or that could not reasonably have been foreseen are reviewed annually and, subject to the reasons set out in paragraph 4(a), all practicable measures are taken with the aim of restoring the body of water to its status prior to the effects of those circumstances as soon as reasonably practicable, and

e) *a summary of the effects of the circumstances and of such measures taken or to be taken in accordance with paragraphs (a) and (d) are included in the next update of the river basin management plan."*

According to the European Guidance Document N°20 (01) of the Common Implementation Strategy (CIS) process for the WFD, in the event of prolonged drought, priority human needs (e.g. drinking water supply) can be temporarily met at the expense of environmental needs, provided that the conditions of Article 4(6) of the WFD are met[2].

The above-mentioned guidance document states that with regard to prolonged droughts:

- *Member States will have to differentiate between the effects of prolonged droughts, which are purely natural phenomena, and the effects of human activities.*
- *It is necessary to distinguish between the drought itself and the effects of water use and management practices.*

The technical report on drought management (02), for example, clarifies the following (see Figure 2):

- In the programmes of measures provided for in Article 11 and Annex VI of the WFD, water quantity management actions are to be taken to avoid permanent or frequent quantitative deficits that prevent the environmental objectives of surface water bodies from being achieved.
- In addition, Member States wishing to benefit from the derogation provided for in Article 4(6) of the WFD in the event of a prolonged drought should draw up a low-water management plan, defining:
  - *« **the conditions under which [drought] circumstances that are exceptional [...] may be declared**, including the adoption of the appropriate indicators»,*
  - *« **the [temporary] measures to be taken under such exceptional circumstances** ».*

[2] "during a prolonged drought, (..), priority needs related to human activity (e.g. drinking water supply) can be temporarily met at the expense of the environmental needs, i.e. allowing a temporary non- achievement of the environmental objectives"

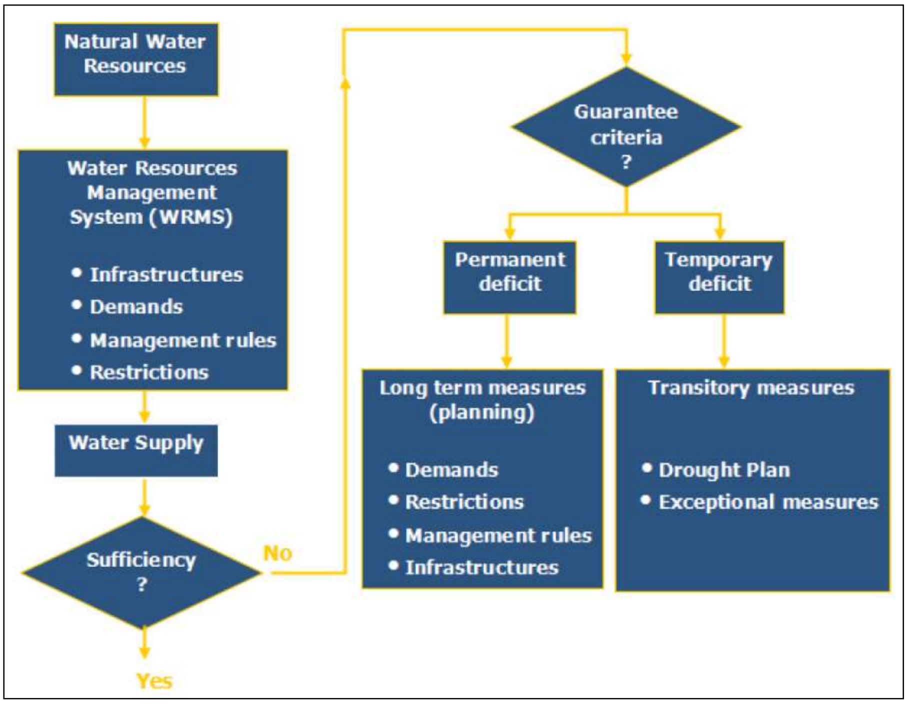


Figure 2: Measures to be taken according to the type of quantitative deficit encountered (03)

According to the technical report 2008-023[3], used here as an example, the following aspects are important for a drought management plan:

- Definition of indicators, in particular threshold values of flow (or rainfall deficit in the absence of hydrological monitoring points) associated with the different stages of drought,
- Implementation of measures according to the degree of exceedance of these values, to avoid compromising the achievement of the WFD objectives as much as possible and to limit water uses, in particular drinking water supply, as little as possible.

In practice, the setting of threshold flows for drought management faces the following material difficulties related to the provisions of the WFD:

- As with the river-specific reference values associated with very good status for the quality elements of ecological status under the WFD, **these threshold values cannot be determined independently of the size of the catchment area and the climatic and geological conditions of the water bodies**.
- **These thresholds should** not only **take into account** ecoregions and surface water body types, but also **the uses allowed by the competent authorities (pollution flows and water abstraction).**

[3] The technical report distinguishes 4 situations with corresponding measures:
Normal status: No additional measures required beyond those that contribute to achieving WFD good status through sustainable water management, e.g. controlling water demand, water storage, etc;
Pre-alert status: Implementation of the specific drought management measures (i.e. informative and control measures) in order to prevent the deterioration of water bodies, while continuing to meet water demands;
Alert status: Intensification of the pre-alert status through water saving measures or reduction of water consumption (depending on the socio-economic impact of the measures and in consultation with stakeholders) in order to avoid deterioration of water bodies status;
Emergency or extreme status: All previous prevention measures have been applied, but the drought situation reaches a critical status where no water resources are sufficient for the essential demands (even affecting and restricting public supply), additional measures might be used to minimize impacts on water bodies, ecology and drinking water supply. In this emergency until the return to normal conditions, measures should be implemented to ensure the restoration of aquatic ecosystems as soon as possible.

2.2 National regulatory frameworks

2.2.1. In France

In France, there is no permanent decision on the priorities for the different water uses in the Meuse basin, as there is sufficient water overall, both in terms of surface water and groundwater.

The SDAGE (Schéma Directeur d'Aménagement et de Gestion des Eaux) is the French management plan of the Water Framework Directive for the problem of drought management. It highlights the absence of a marked overall imbalance between water use and available resources in the Meuse district. As a result, its guidelines and provisions do not aim to manage structural imbalances but to deal with exceptional or local situations of drought and overexploitation of water resources

Crisis flows have thus been defined at Chooz (Q = 14 m^3/s) and Saint-Mihiel (Q = 1.2 m^3/s) and correspond to values below which only the needs of drinking water supply and environment can be met (cf. figure n°3).

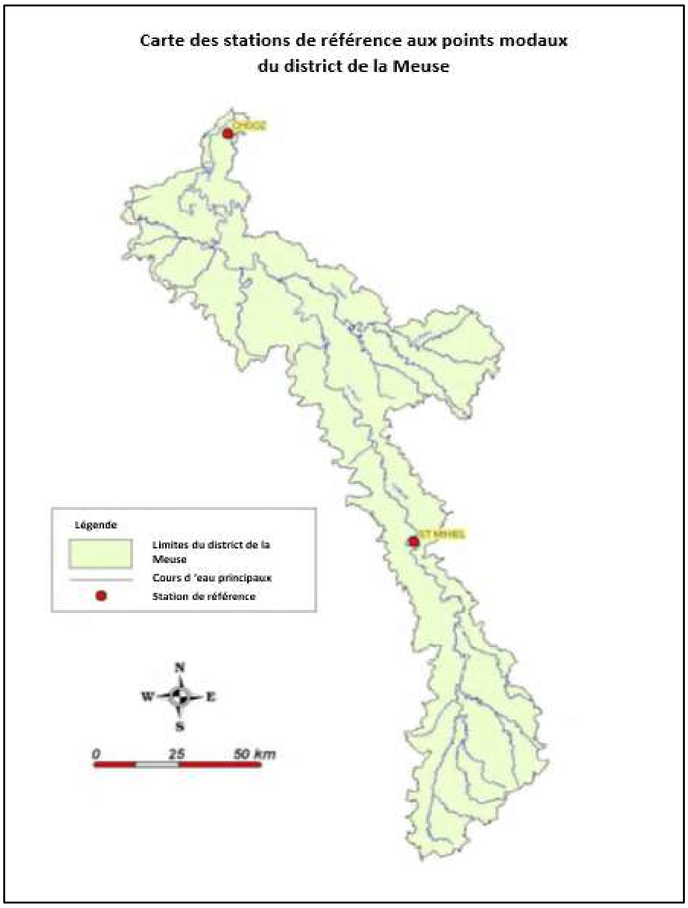


Figure 3: Map of reference stations for the quantitative management of surface water in the French part of the Meuse basin (source: SDAGE Rhin-Meuse)

These crisis flows are used as a guide for the departmental framework decrees for drought management, which take into account the tributaries of these rivers in more detail. These decrees define in particular a catalogue of measures for restricting water use which will be implemented in a progressive manner by the authorities during droughts.

2.2.2. In Wallonia

In Wallonia, for waterways, priority is given to the transport function of the waterway. Special rules exist through the operating permits of some industries which must limit or even stop their activities in certain circumstances.

The Decree on the Management of Non-Navigable Watercourses adopted on 15 December 2018 allows the suspension of some activities during droughts, such as some surface water abstractions.

A study was carried out to see how environmental and water legislation could be adapted to provide legal levers for managing drought situations.

2.2.3. In Flanders

As part of the reactive part of the water shortage and drought risk management plan, a scenario has been developed to describe the framework for information exchange between the different parties and the coordination of measures and communication in case of water shortage and drought.

In Flanders, for example, there is a provisional framework for weighting priority water uses pending a definitive framework, which is expected in spring 2021.

The Drought Commission was also set up in 2018 with the task of coordinating at Flemish level during periods of water shortage and drought and advising on appropriate measures.

With regard to the proactive water scarcity and drought policy, a Flemish water scarcity and drought risk management plan will be drawn up and included in the third generation of basin management plans.

In the Integrated Water Policy Decree, it is furthermore foreseen that objectives in terms of water quality or quantity will be established and that the good quantitative status of surface waters will be achieved.

2.2.4. In the Netherlands

In the Netherlands, the degressive set of priorities defines how available water is allocated in times of water deficit (Table 1). This series sets the priorities according to which the different categories of water users (e.g. agriculture, nature, navigation, drinking water) are supplied with water, and thus forms the basis for decisions on water allocation during periods of water deficit. This series is then broken down to a regional level for the Dutch Meuse basin. The series recognises four categories of water users. Within categories 1 and 2 there is a fixed order of priority; for categories 3 and 4 the prioritisation is based on minimising economic and societal risks. Users with the lowest priority level will be the first to be deprived of water and will have to take action themselves. However, the agreement on the flows of the Meuse (see 9.2.2) prevails over the degressive set of priorities.

The degressive set of priorities is a guide for the manager; there is still room for a more precise weighting according to the specific characteristics of the region, risks, damages and benefits.

In practice, choices will be made according to these criteria so that any difficulties are distributed as fairly as possible.

Table 1: Degression of priorities for the Dutch Meuse basin

Category 1 : **safety and prevention of irreversible damage**	**Category 2:** **Utilities**	**Category 3:** **small-scale high-risk use**	**Category 4:** **other interests**
1. Stability of water defences by means of level control 2. Protection of peatlands remains by means of level maintenance buffer zones has priority over →	1. Water supply 2. Energy supply has priority over →	• Temporary watering of high capital crops • Process water in industry • Renewal of urban water has priority over →	1. Aquatic ecology and water quality: • minimal flow in streams with high ecological value • Fight against botulism and blue-green algae because of serious risks • minimum flow in fish ladders (during fish migration) 2. Other interests: • Shipping (incl. recreational) • Agriculture (excl. grassland irrigation) • Terrestrial nature (except irreversible damage) • Cooling water for industry • Other aquatic nature

2.2.5. In Germany

Water supply in Germany is governed by general management principles. In this context, the abstraction and diversion of surface water or the storage and lowering of surface water levels are subject to authorisation under water law (permit or authorisation). During the authorisation procedure, rules are laid down within the framework of the general management principles to ensure that water is used in a way that does not cause damage. In addition to demonstrating the availability of water resources, questions concerning the consequences for 'third parties' also play a role (impact on third party abstractions as well as use and water rights, impact on nature and landscape, protected areas, specially protected species, remains/monuments etc.). In this context, the applicant is required to provide the necessary evidence.

2.2.6. In Luxembourg

In Luxembourg, all withdrawals and discharges of water into surface waters are subject to authorisation under water law. In this context, particular care is taken to ensure that the quantity withdrawn or discharged does not lead to a deterioration in water quality.

During dry and low water periods, it is generally forbidden to take water from watercourses. During these periods, all water withdrawals covered by an authorisation are therefore prohibited.

In addition, Luxembourg participates in the monitoring of low water levels in the ICPMS.

2.3 Summary

Crisis management linked to low water levels may lead to the implementation of measures such as limiting or stopping uses (water abstraction, discharges, cooling of thermal power plants, hydroelectric production, etc.) due to legal and regulatory provisions which differ from one country/region to another; this remains the sole competence of the countries and/or regions concerned even if certain uses are the subject of multilateral agreements (cf. chapter 9.2).

The management of low water situations is regulated differently from one country to another in the Meuse catchment area:

- The availability of water, the use of water and the functions of that use differ from country to country, leading to differences in national regulations;
- The critical flow thresholds depend on the use function and may therefore be different.

In addition to flows, considerations of surface water quality also play a role here.

Quantitative surface water management measures may also be necessary to achieve the environmental objectives set by the WFD for certain surface water bodies, particularly in cases where withdrawals linked to human activities are identified as being one of the factors responsible for the deterioration of the ecological status of aquatic environments.

The objective of the Meuse Agreement, as the basis for the IMC, is to ensure sustainable and integrated water management in the international Meuse River basin district. This approach includes water quality through the WFD, floods through the FRD, but also droughts and low water levels. Water use, especially during low water conditions, can have an impact on the functions of water use, such as navigation and drinking water, but of course also on the environmental objectives of the WFD. Therefore, it is important to know:

- whether the accentuation of the decrease in low water flows or the modification of the flow regime (inter alia flow fluctuations) caused by abstractions/management related to human activities is responsible for negative effects;

- whether coordination of bilateral (respectively multilateral) quantitative management actions envisaged by the competent authorities concerned is necessary or useful to remedy these negative effects (Figure 3).

This approach will be discussed in Chapter 9.1.1

Furthermore, as explained in chapter 2.1.2, the occurrence of a prolonged drought can significantly reduce the technical effectiveness of the actions implemented under the programmes of measures of the Member States and compromise the achievement of the environmental objectives for certain surface water bodies.

While the WFD has provided for the occurrence of such a case in the context of the derogation provided for in Article 4(6), recourse to this provision is conditional, inter alia, on the implementation of additional temporary measures to reduce as far as possible the negative consequences on the status of surface water bodies.

3. Previous work

As mentioned in the introduction, the IMC's "Hydrology/Flood" WG has carried out an initial analysis of extreme low-water situations and the resulting water shortages in the Meuse catchment area by producing a summary report in 2012.

Drought is understood as a period of prolonged absence of rainfall. Drought is a phenomenon that can have 3 types of consequences depending on its duration:

- In the first phase: a water deficit in the soils which may impact on agricultural activities.
- in the second phase: a reduction in the flow of water in the rivers (= low water).
- in a third phase: a decrease in groundwater resources.

The 2012 report provides an overview of the existing situation in the different parts of the basin with regard to:

- international agreements on the distribution of water in the Meuse basin,
- any priority rules set for water uses during low water periods,
- the reservoirs and their function in the event of low water,
- actions that can be taken during low water periods (e.g. abstraction bans, appropriate management of dams/impoundments)
- measures in place to monitor low water levels (e.g. flow rates, water levels, dissolved oxygen, algae, temperature),
- hydrological models used to predict the evolution of low water flows,
- an inventory of the problems encountered during low-water periods.

4. Hydrology of the Meuse

(Excerpts from Gouttes de pluies, flux de Meuse. A transnational water management in dry and wet weather by Marcel De Wit, 2008) (04)

« Water moves in an endless cycle. It evaporates from the earth's surface, is transported by the atmosphere, condenses to form clouds and finally returns to the earth's surface as precipitation, after which the cycle repeats itself. The sun provides the energy to make this **hydrological cycle** work**»** (Figure 4).

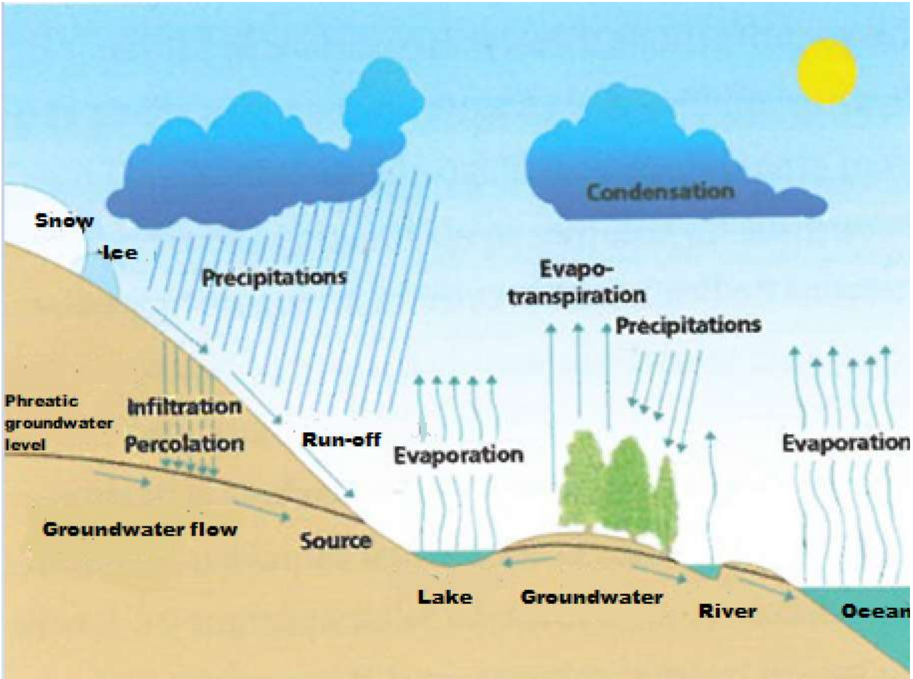


Figure 4: Hydrological cycle (04)

« On average, 30 km^3 of water falls into the Meuse catchment area each year in the form of precipitation. Of this 30 km^3, twelve reach the sea. The remaining 18 km^3 evaporate» (Figure 5).

« The total amount of water in the Meuse River basin is much higher and can only be estimated approximately. Based on the average volumes and retention times of water in the overall hydrological cycle, the total volume of water in the Maas basin is around 500 km^3 (this refers to groundwater).

Figure 6 below shows the relative contribution of the upstream Meuse and its tributaries to the discharge at the watershed outlet. It shows that part of the flow (14%) comes from the most upstream part of the catchment (French part). »

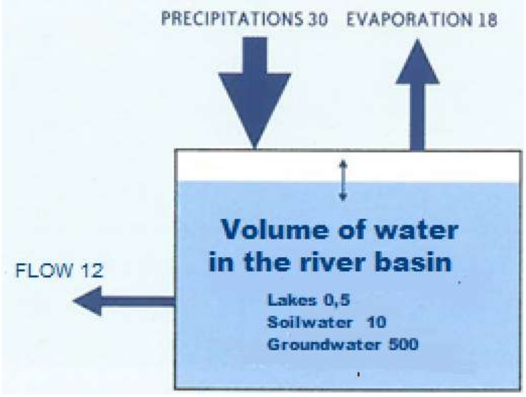


Figure 5: Approximate annual water balance of the Meuse catchment area (km^3) (04)

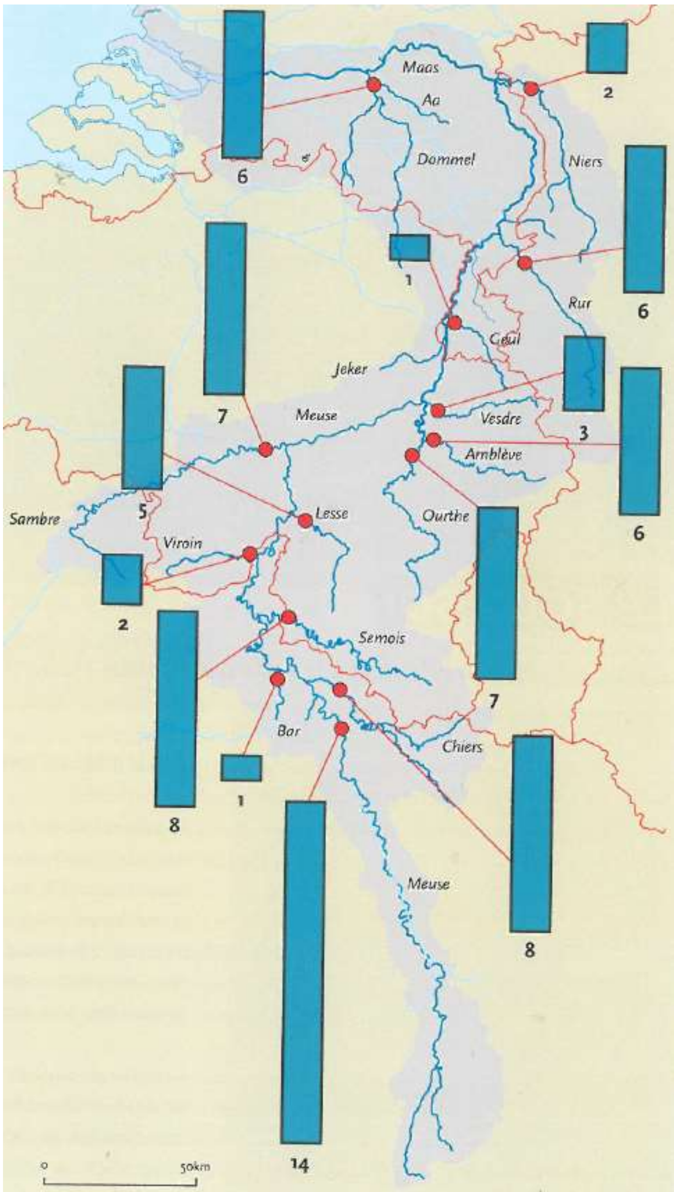


Figure 6: Relative contribution (percentage) of the upstream Meuse and its tributaries to the discharge at the watershed outlet (04)

« Imagine that the above-mentioned 12 km^3 of water flows into the Meuse in an ideal way throughout the year. Every month 1 km^3 or a thousand billion litres of water. There would then be enough water available and no water-related problems would arise. But then the Meuse would become a boring, artificial river. No river on earth is free from seasonal fluctuations in flow. These seasonal fluctuations are called the **river flow regime** (Figure 7), of which the climate is the most important factor. »

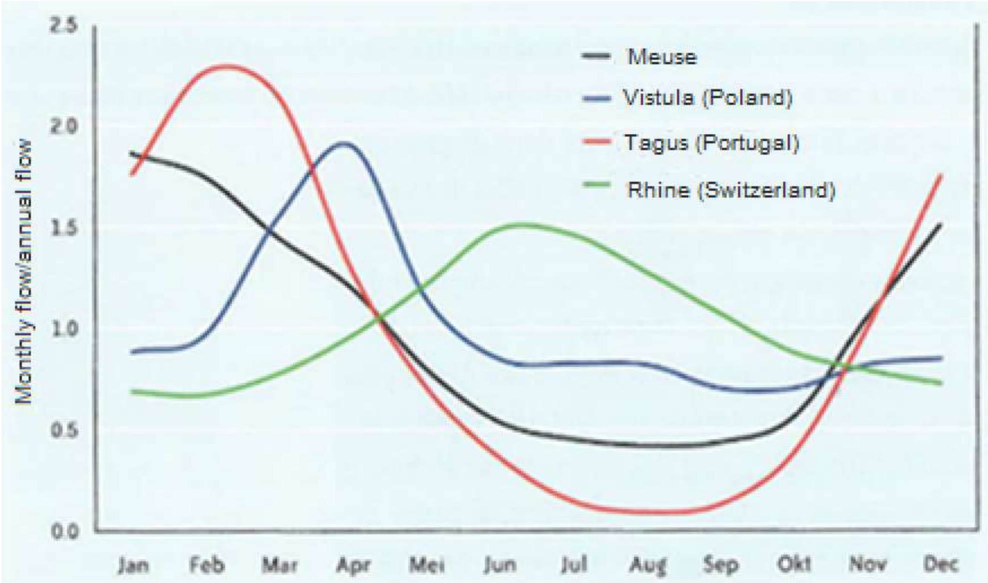


Figure 7: Hydrological regime of the Meuse and three European rivers [(04)]

«The rivers in the Meuse basin are all characterised by a **rainfall regime (a flow regime dominated by rainfall)**. Average flows peak in winter or spring and are lowest in August and September, and even October.

Precipitation in the Meuse catchment area is distributed over the seasons. However, the flow recorded in winter is higher than in summer. To explain the flow regime of the Meuse, one must consider evaporation, which is low in winter and high in summer. In the Meuse catchment area, evaporation on a hot, sunny and windy summer day can amount to seven millimetres per day. This is more or less the same amount as the average evaporation during a full January.

The consequence is that a surplus of precipitation occurs in winter and a lack of precipitation in summer. During a period of excess rainfall, the soil is saturated with water (storage). In a period of low rainfall, the plants actually suck water out of the soil.

However, water flows into the Meuse during the summer months when the amount of water evaporating is greater than the amount of precipitation. This flow is called the **base flow** of the river. It comes from the above-mentioned groundwater reservoir which contains much more water (approximately 500 km^3) than the amount of water that falls from the sky on an annual basis (30 km^3) and feeds the river, even when it does not rain. We can think of the subsoil as a buffer between the rainfall and the river flow. This buffer transmits the precipitation signal in a slowed down and attenuated way as fluctuations in this flow (Figures 8 and 9). »

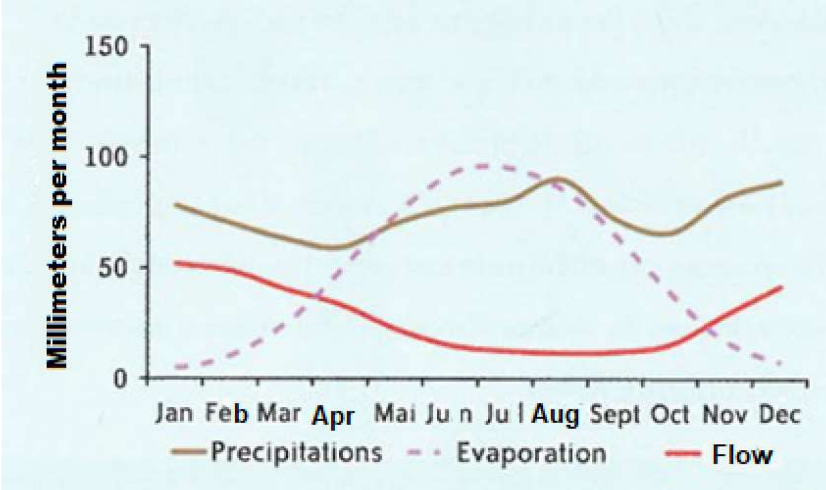


Figure 8: Amount of water that falls as precipitation, evaporates and is transported monthly in the Meuse catchment area (04)

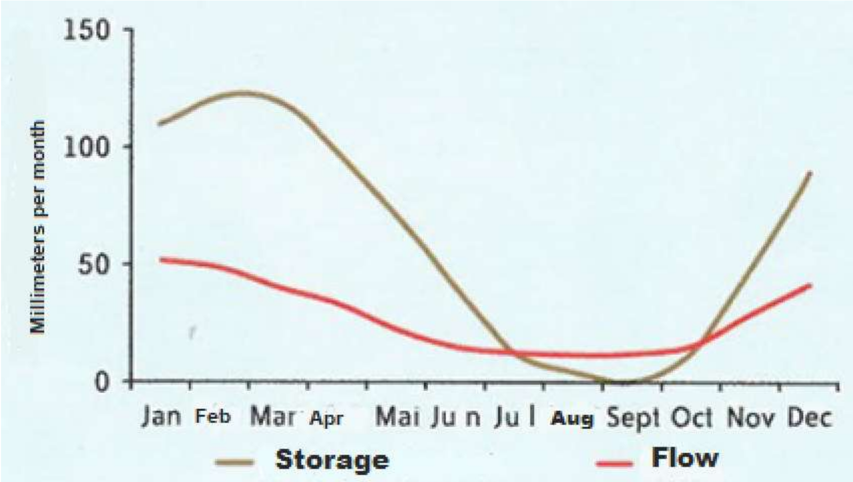


Figure 9: Amount of water (mm) that is stored in the soil (storage) compared to September (0 mm) (04)

« The influence of man on the overall water balance of the Meuse is limited. The surplus precipitation and the volume of flow in the river are mainly determined by climate. Man has no influence on the amount of precipitation and only a limited impact on evaporation through land use. The influence of water management on the flow regime of the Meuse only becomes clear when we reduce time and space. Human interventions such as drainage, irrigation, the construction of retention basins, the shifting of the course of rivers, etc. cause the water to flow to a different place and at a different speed. On an annual basis, this makes little or no difference to the total water balance in the catchment. But locally it can be the missing drop in the water balance in times of drought (Figures 10, 11, 12 and Table 2). »

Overview of the main adaptations to the Meuse, its tributaries and canals	
1808-1810	Construction of the Canal du nord
1822-1826	Construction of the Zuid-Willemsvaart
1824-1828	Canalisation of the Sambre, 22 locks (part of the Charleroi-Brussels Canal)
1826-1835	Canalisation of the French Sambre
1827-1830	Canal Voorne-Putte (unlocking Rotterdam)
1835	Construction of the canal des Ardennes
1837-1845	Water depth on the Meuse between the French border and Sedan-Verdun at 1.10 metres
1837-1853	Construction of the canal Marne - Rhine
1838	Belgian Meuse: towpaths, reinforcement of dikes and water depth of 1.50 metres
1843-1846	Expansion of Kempen canals
1853-1880	Belgian Meuse Canal: 23 locks, water depth of 2.20 metres
1863	Adjustment of water outlet to Kempen canals
1864-1884	New Merwede
1874	Canal de l'Est. Meuse partly canalised and partly parallel canal: 59 locks, water depth of 1.80 metres
1875	Construction of groynes and longitudinal dikes in the Meuse
1878	Gileppe dam. One of the oldest reservoirs in Europe opened by Leopold II
1884-1904	Construction of the Bergse Maas
1915-1929	Improvement of the Meuse in the Netherlands: Linne-Grave, water depth of 2.80 metres, 5 dams
1923-1940	Modernisation of the Belgian Meuse: water depth of 3.00 metres with 15 locks, removal of islands
1923	Construction of the canal Wilhelmina
1927	Construction of the canal Meuse-Waal
1928	Enlarging Kempen canals
1930-1935	Construction of the canal Juliana, 3 locks
1930-1945	Construction of the canal Albert
1931-1942	Canalisation of the Meuse: Grave-Heerewaarden, channel rectifications and widening of the major and minor river beds
1939	Rurtalsperre. One of the largest reservoirs in Europe
1942	Closing the Beers weir
1957-1989	Modernisation of the Belgian Meuse: water depth of 5-8 metres with 6 locks, removal of islands
1970	Construction of the Lateral canal
1980	Rectification of the river in Gennep-Boxmeer
2002	Strépy-Thieu boat lift, Canal du centre

Figure 10: Overview of the main adaptations made to the Meuse, its tributaries and canals. Based on Micha & Borlee (1989) and Berger & Mugie (1994) [(04)]

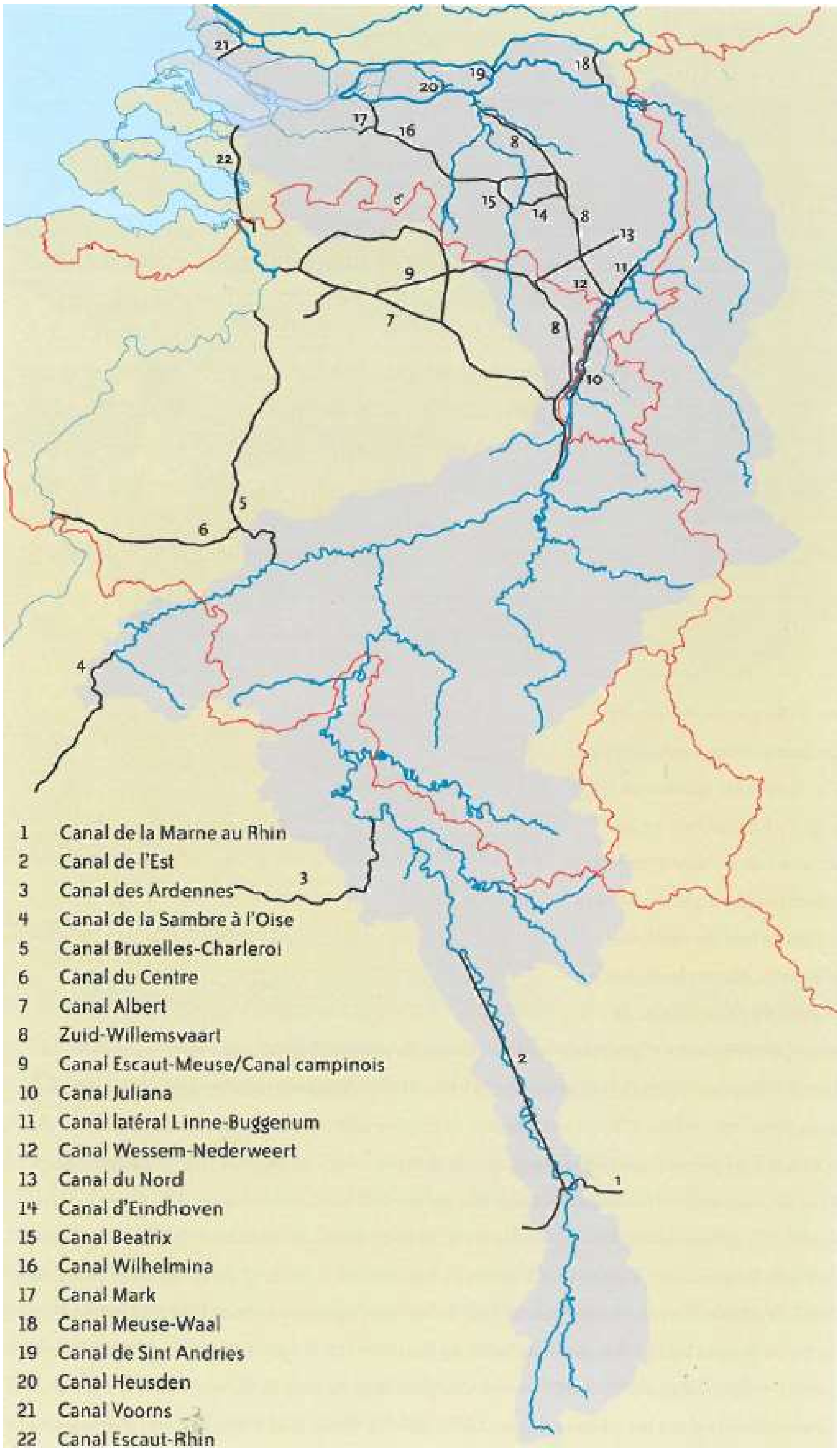


Figure 11: Canals in the Meuse basin (04)

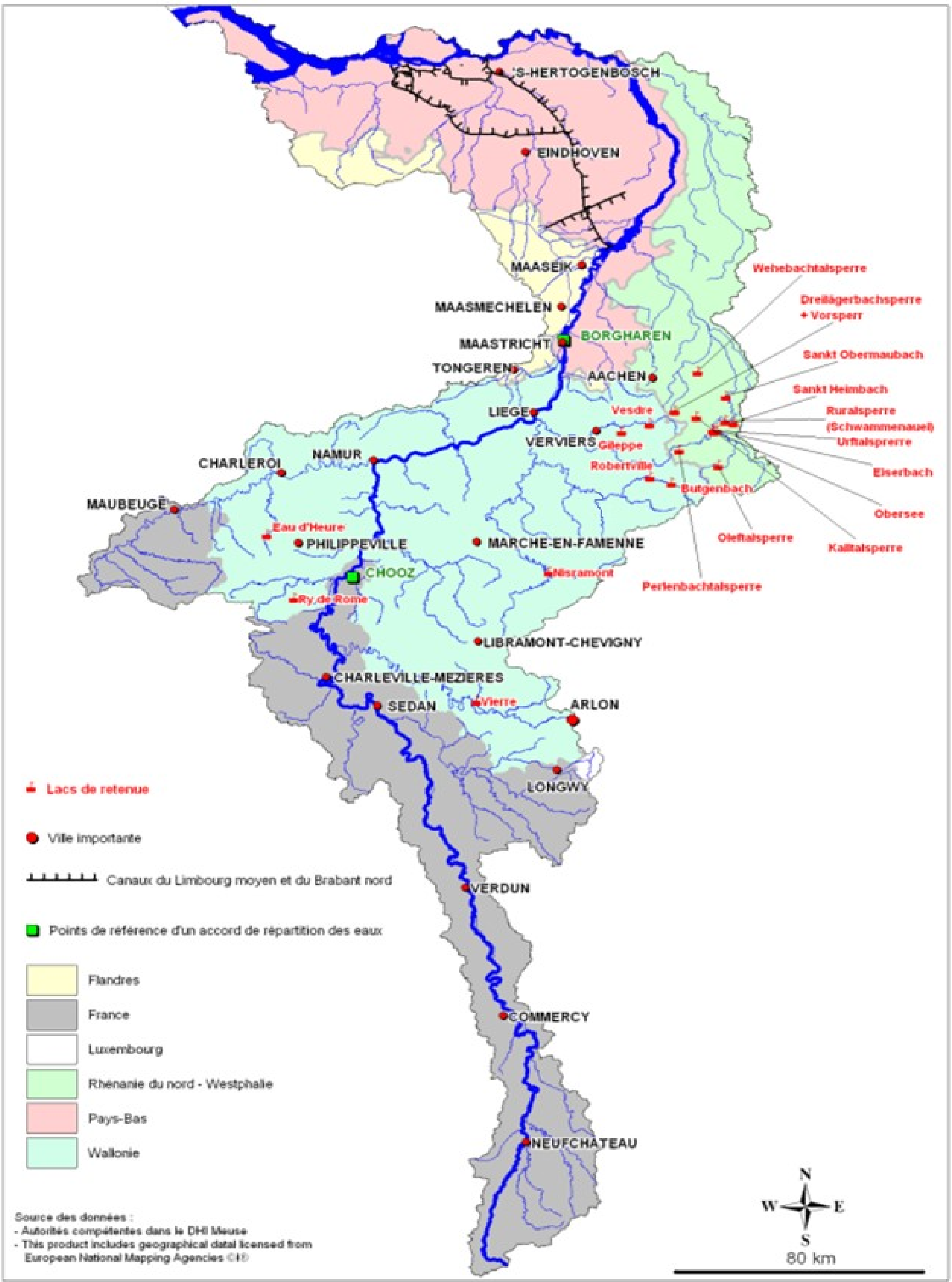


Figure 12: Main reservoir dams in the Meuse catchment area (source - IMC - summary report 2012)

Table 2: Characteristics of the main reservoir dams in the Meuse catchment area (source - IMC - summary report 2012, unpublished)

Dam	Watercourse	Storage volume (Mm^3)	Catchment area (km^2)
Dam of the Gileppe	Gileppe	26,4	54
Dam of the Vesdre	Vesdre	25	105,95
Dam of Nisramont	Ourthe	3	740
Dam of the Ry of Rome	Ry de Rome	2,2	10,1
Dam of Eau d'Heure	Eau d'Heure	14,75	79
Dam of Plate Taille	Plate Taille	67,8	7,6
Dam of Bütgenbach	Warche	11	72
Dam of Robertville	Warche	7,7	118
Dam of the Vierre	La Vierre	1,3	242
Dam of Olef	Olef	19,3	47,4
Dam of Urft	Urft	45,5	373,9
Dam of the Rur	Rur	185	666,2
with the pre-Dam Eiserbach (>100.000 m^3, > 5m)	Rur	0,3	4,2
with the pre-Dam Obersee (>100.000 m^3, > 5m)	Rur	17,8	626,2
Dam Heimbach	Rur	1,2	667,2
Dam of the Obermaubach	Rur	1,7	792,7
Dam of the Wehebach	Wehebach	25,1	43,5
Dam of the Dreilägerbach	Dreilägerbach	3,7	21,7
with the pre-Dam (>100.000 m^3, > 5m)	Dreilägerbach	0,1	14,2
Dam of the Kall	Kallbach	2,1	28,8
Dam of the Perlenbach	Perlenbach	0,8	61,2

5. Naturalization of flows

The influence of the volumes of water withdrawn or discharged on the flows of the Meuse has been quantified. The historical flows measured are converted into so-called natural flows.

Natural flow is defined as the flow that would be measured in the absence of canals, withdrawals, discharges and water storage.

A statistical analysis of the natural and measured flows of the Meuse at three selected measuring stations, namely Chooz, Liege and Lith-Megen, is then carried out in order to establish statistical threshold values.

5.1 Results at the Chooz station

This study was carried out as part of the "CHIMERE 21" project on the Evolution of the Hydrological Regime in the 21st Century.

Naturalization of flows consists in identifying water intakes and discharges with a potential influence on daily flows at the hydrological stations to be modelled (Figure 13).

The aim is to obtain uninfluenced daily flow records used to calibrate the hydrological models.

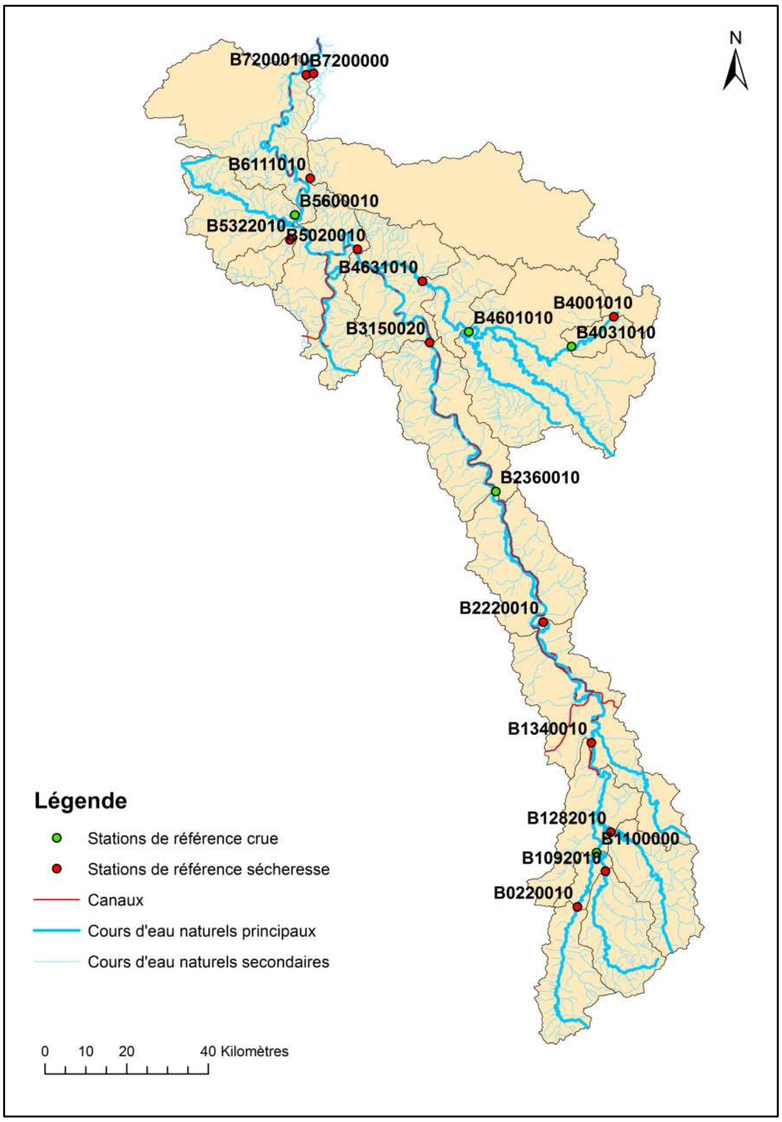


Figure 13: Map of reference stations in the French Meuse basin

• Influences of dams and reservoirs

There are no major control structures in the French part of the Meuse basin.

Some dams are located on tributaries of the Meuse:

- Dam on the Vierre, a tributary of the Semois, located in Belgium (capacity of 1.5 hm^3); management for hydroelectric production;
- the hydroelectric complex of the Revin Saint Nicolas Les Mazures power station, on the Faux (about 20 hm^3 in all).

These dams are not considered to have any significant influence on low water levels.

• Influences of canals

Presence of three canals (see figure14):

- Eastern canal (Northern branch);

- Ardennes canal;

- canal from the Marne to the Rhine.

Little river traffic = 1 to 10 boats / day (T = 350 t max)

No data available apart from the maximum volumes withdrawn:

- in the Méholle at Void-Vacon Qmax = 0.75 m^3/s (three 0.25 m^3/s pumps)
- in the Meuse at Troussey Qmax = 1 m^3/s

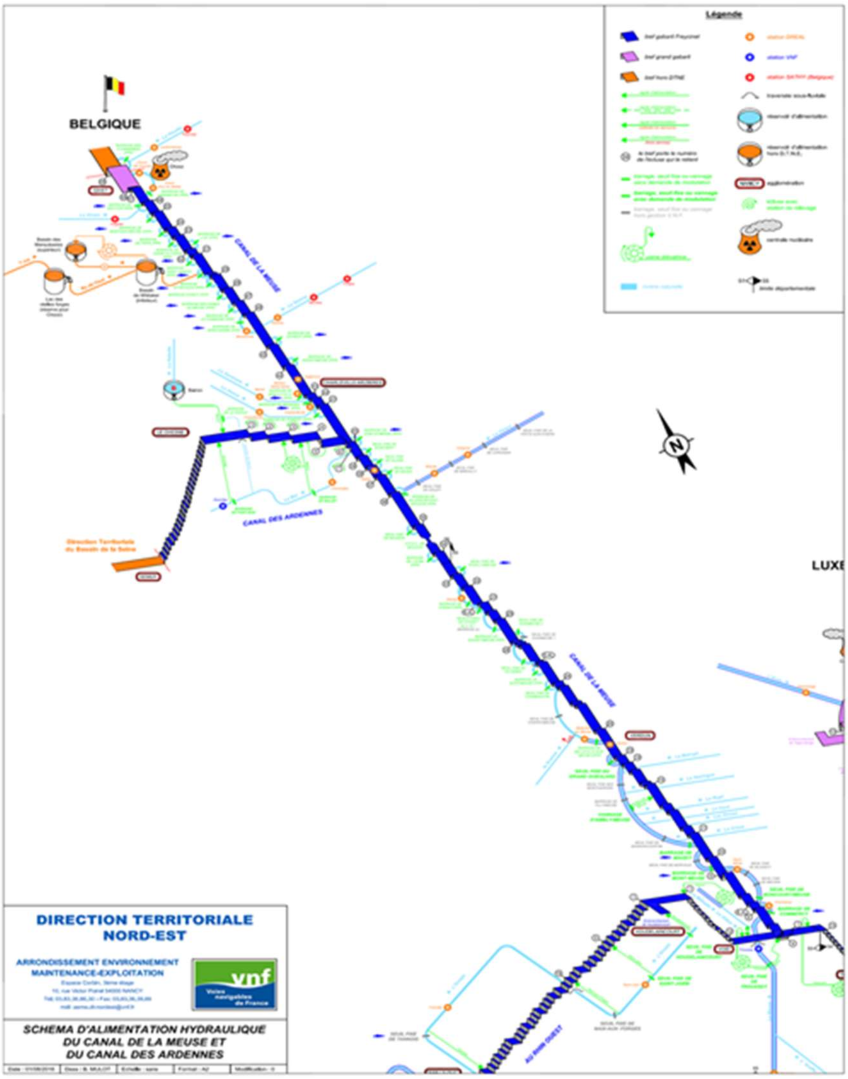


Figure 14: Hydraulic supply diagram for the Meuse and Ardennes canals

- **Influences of mining operations**

The Meuse basin was mined in the 19th and 20th centuries (Figure 15).

There was a gradual cessation of mining from the mid-1980s to the late 1990s (Figure 16).

A return to normal functioning of the aquifers, accompanied by a temporary maintenance of water levels on the Crusnes, was observed until the mid-2000s.

Average values of low-water support or discharge of minewater on three rivers: 0.1 m³/s on the Crusnes, 0.13 m³/s on the Othain, 0.2 m³/s on the Moulaine.

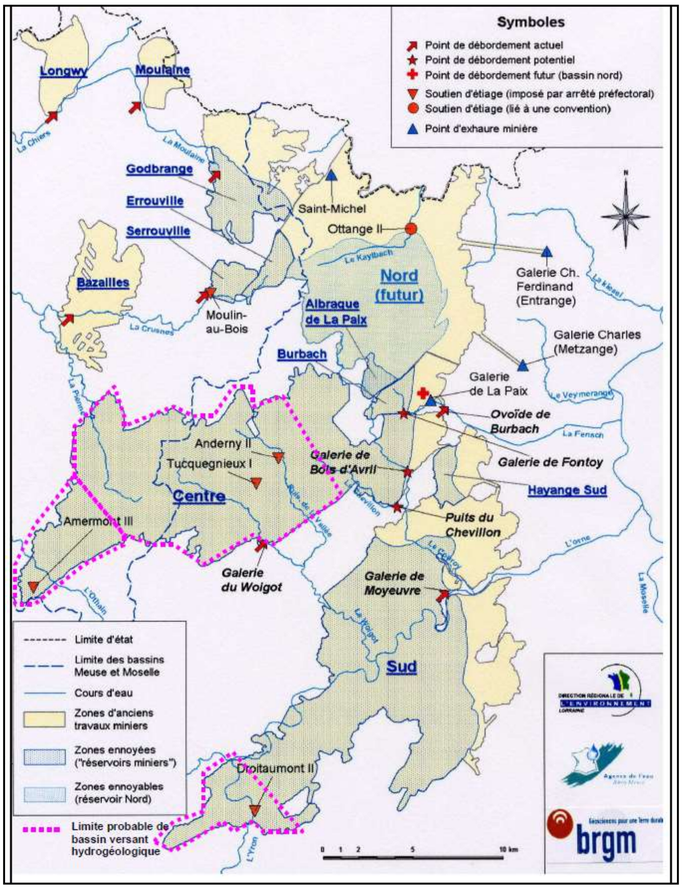


Figure 15: Map of minewater discharges in north-eastern France

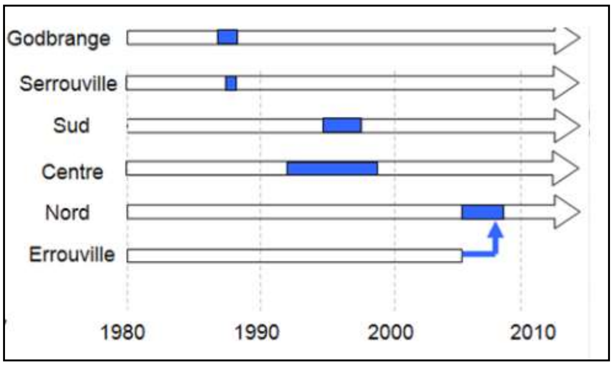


Figure 16: Periods of mine discharges (in blue) by sector (period during which minewater was pumped out and discharged into the surface water system)

- **Influences of drinking water withdrawals and municipal wastewater treatment plants (Table 3)**

Table 3: List of river abstractions in the French Meuse catchment area for drinking water

INS - Name	UGE - Name	INS - Average Flow (m3/d)	INS - Average Flow (m3/s)
PRISE D'EAU EN MEUSE	CHARLEVILLE MEZIERES	90	0.001
LA HOUILLE - PRISE D'EAU	GIVET	1200	0.014
LA PILETTE RUISSEAU PAS FAUVIN	MONTHERME	80	0.001
RUISSEAU LA FAUGEE	MONTHERME	520	0.006
PRISE D'EAU LA SORMONNE	CHARLEVILLE MEZIERES	4000	0.046
PRISE D'EAU DE MONTMEDY	C.D.C DE L'AGGLOMERATION DE LONGWY	2000	0.023
PRISE D'EAU DU VAIR	SYNDICAT VRAINE ET XAINTOIS	20	0.000

- **Influences of industries**

30 industrial sites are examined (available data = volumes withdrawn and/or discharged annually) (Table 4).

Table 4: Consumption of the main industrial sites in the French Meuse basin from 2012 to 2014

Industrial sites	Consumption 2012 (m3/s)	Consumption 2013 (m3/s)	Consumption 2014 (m3/s)
LACTO SERUM France SA	-0,03936	-0,04318	0,04155
Fromagerie de l'ermitage	-0,02432	-0,02553	-0,02527
Fromagerie Henri Hutin	-0,01409	-0,0141	-0,01355
BG	-0,01201	-0,00879	-0,01033
Nestlé Waters Supply Est (Vittel)	-0,01185	-0,01545	-0,01162
SNC CANELIA ROUVROY POUDRE	-0,00642	-0,00681	-0,0074
Ineos Enterprises France SAS	-0,00337	-0,00415	-0,00459
Fours à Chaux de Sorcy	-0,00248	-0,00089	-0,0012
Union Laitière de la Meuse (ULM)	-0,00239	-0,00275	-0,00371
Carrières et Fours à Chaux de Dugny	-0,00225	-0,00213	-0,00243
SOLEVAL France - Charny sur Meuse	-0,00201	-0,00185	-0,00234
Centre de stockage des déchets d'Eteignières	-0,00147	-0,00113	-0,00137
FVM Technologies	-0,00144	-0,0013	-0,00142
ARCELOR MITTAL Commercy	-0,00102	-0,00209	-0,00214
SCORI EST	-0,00101	0,00000	-0,00087
HANON SYSTEMS CHARLEVILLE SAS	-0,00068	-0,00086	-0,00119
Etablissement de Cliron. Dit BRENNTAG ARDENNES	-0,00025	-0,0002	0,00000
Daum	-0,0001	-0,0033	-0,00213
ARCAVI-Chalandry-Elaire	-0,00008	-0,00008	-0,00007
SAS EUROVITA	-0,00005	-0,00017	-0,00008
ACTEGA Rhenacoat SAS	-0,00002	-0,00001	-0,00001
FAURECIA	-0,00001	-0,00001	-0,00005
ARCELORMITTAL Atlantique et Lorraine MOUZON	0,00000	-0,00157	-0,00098
GESTAMP PRISMA	0,00000	0,00000	-0,00003
Total	**-0,12668**	**-0,13635**	**-0,05123**

Withdrawals for drinking water, wastewater discharges and industrial consumption in the French Meuse basin (excluding Chooz nuclear power plant) have very little influence on the flows of the Meuse.

This is due to the low population density and very limited industrial activity in the basin, which is essentially agricultural (grazing).

For the Chooz NPP (nuclear power plant), daily consumption is estimated from evaporation data, i.e. **between 0.6 and 1.8 m³/s evaporated between 2011 and 2015 (Figure 17).**

It was commissioned in 1996 (Chooz A) and 1997 (Chooz B).

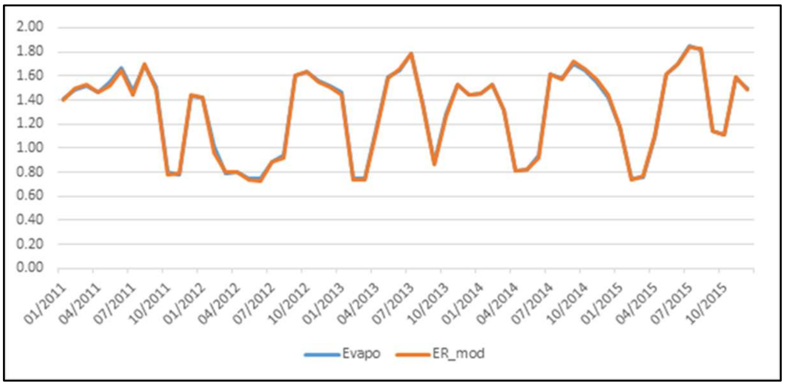


Figure 17: Average monthly evaporated flow from the Chooz power plant between 2011 and 2015 (in m³/s)

- **Location of influences and hydrological stations (Figure 18)**

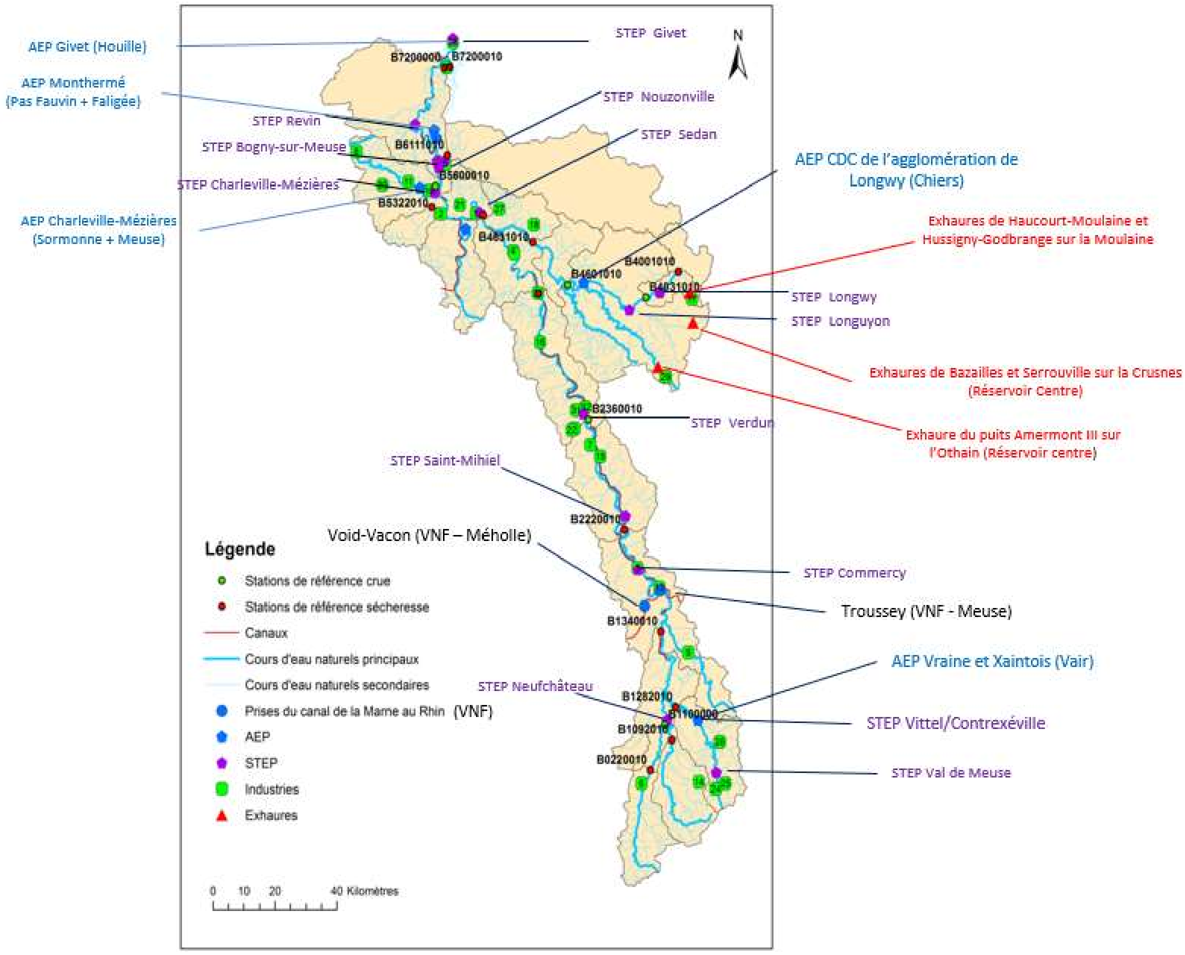


Figure 18: Map of influences and hydrological stations

- **Treatment of influences at stations (Figure 19)**

To assess the influences at the stations, assumptions are made:

- annual volumes evenly distributed;
- transfer times of less than a day;
- arithmetic sum of known influences (releases (+) and withdrawals (-));
- Drinking water abstractions from groundwater are considered as a source of water outside the basin;
- visual analysis of hydrographs.

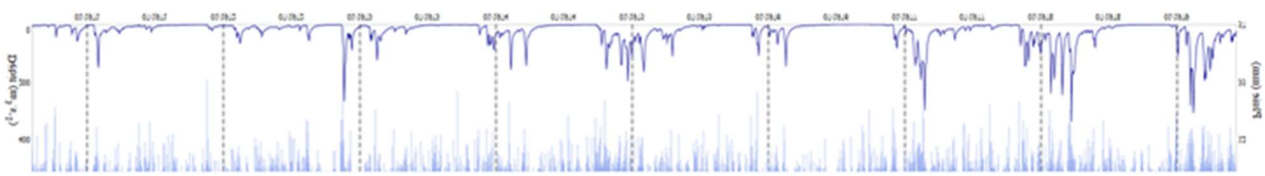


Figure 19: Flow of the Meuse at Saint-Mihiel

- **Results**

Information is limited on the influences (start date, developments, lack of detailed chronicles over the reference period).

Numerous stations with very fluctuating low-water flows (problem of low-water rating curves and/or influence of aquatic vegetation on the measured heights).

Calculations at Chooz (1958-2016) (Table 5)

Table 5: Results of the VCN7 measured and naturalized at the Chooz station

CHOOZ	Measured VCN7	Naturalized VCN7
VCN7 (T=2 years)	27.30 m^3/s	27.39 m^3/s
VCN7 (T=5 years)	17.60 m^3/s	17.10 m^3/s
VCN7 (T=10 years)	13.34 m^3/s	13.37 m^3/s
VCN7 (T=20 years)	10.89 m^3/s	10.92 m^3/s
VCN7 (T=50 years)	8.67 m^3/s	8.68 m^3/s

It should be noted that from 1956 to 2004, the flows used to calculate the naturalized flows are those of the Chooz-Ile-de-Graviat station located downstream of the Chooz nuclear power station.

After 2004, the flows used for the calculation are those of the Chooz-Trou-Du-Diable station located upstream of the power plant (Figure 20), built to make the measurements more reliable and thus before the influence of the power plant.

The impact of the power plant's withdrawals (see Figure 17) in the calculation of naturalized flows is therefore taken into account from 1996 (start-up of the power plant) to 2004 (change of measurement station), i.e. for 7 years out of a measurement record of more than 50 years, which explains the weak influences observed on naturalized VCN7.

Conclusion:

The French Meuse basin is essentially rural. It is subject to low water abstraction compared to the natural flows of the Meuse, upstream of the Chooz nuclear power plant, which explains the small differences between the flows measured at the Chooz station and those naturalized. The main withdrawal from the Meuse in France is at the Chooz nuclear power plant.

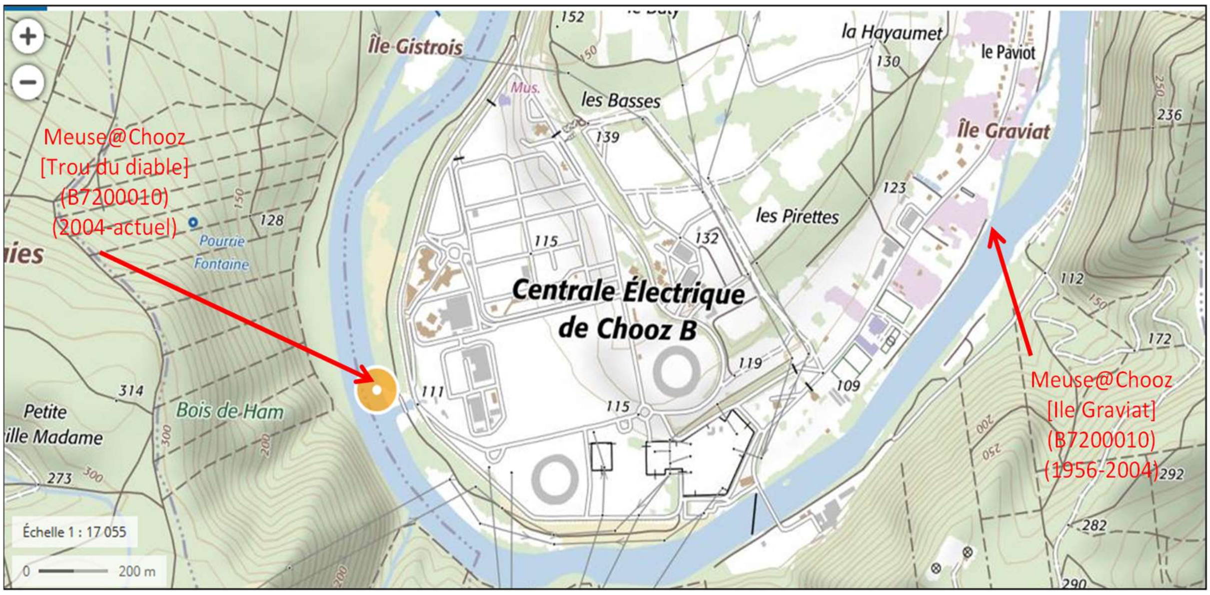


Figure 20: Location of hydrological measurement stations at Chooz

5.2 Results at the Liege station

Flow naturalization consists of identifying water intakes and discharges with a potential influence on daily flows at a given station.

The aim is to obtain an uninfluenced daily flow record used to calculate extreme low-water flows.

Different influences have been identified on the daily flow of the Meuse at Liege:

- Groundwater, mine and quarry water and surface water catchments
- Withdrawals from nuclear power plants
- Pumping to feed the canals
- Reservoir dams

Methodology used to reconstruct the natural daily flow series of the Meuse at Liege

The starting data are the naturalized daily flows of the Meuse at Chooz over the period from 01/01/2004 to 31/07/2016 to which were added:

- the daily flows of the **tributaries** (Houille, Hermeton, Lesse, Molignée, Bocq, Burnot, Sambre, Houyoux, Samson, Mehaigne, Hoyoux and Ourthe) while applying a watershed ratio.
- the daily flows taken from the groundwater **catchments** in the Bocq, Hoyoux, Orneau and Meuse basins.
- the daily flows taken from the mine/quarry water **catchments** (Vedrin and Ligny) and from surface water (Tailfer drinking water)
- daily constants corresponding to the withdrawals from the Chooz and Tihange **nuclear power plants**

- the daily **pumping** of the Sambre which feeds the Charleroi-Brussels Canal
- the difference between the daily flows retained in the **reservoir dams** and the daily flows released: Ry de Rome, Eau d'Heure, Vesdre, Vierre*, Gileppe*, Warche* and Ourthe* (* in progress)

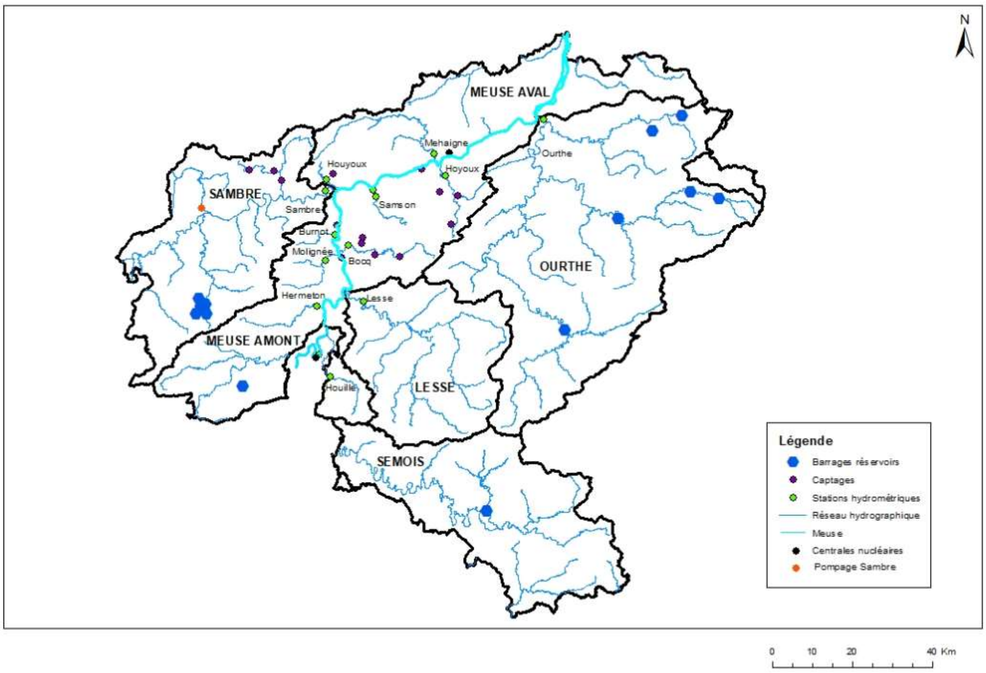


Figure 21: IRBD Meuse - Walloon part - naturalization of the Meuse flows

First results (figures 22 to 24)

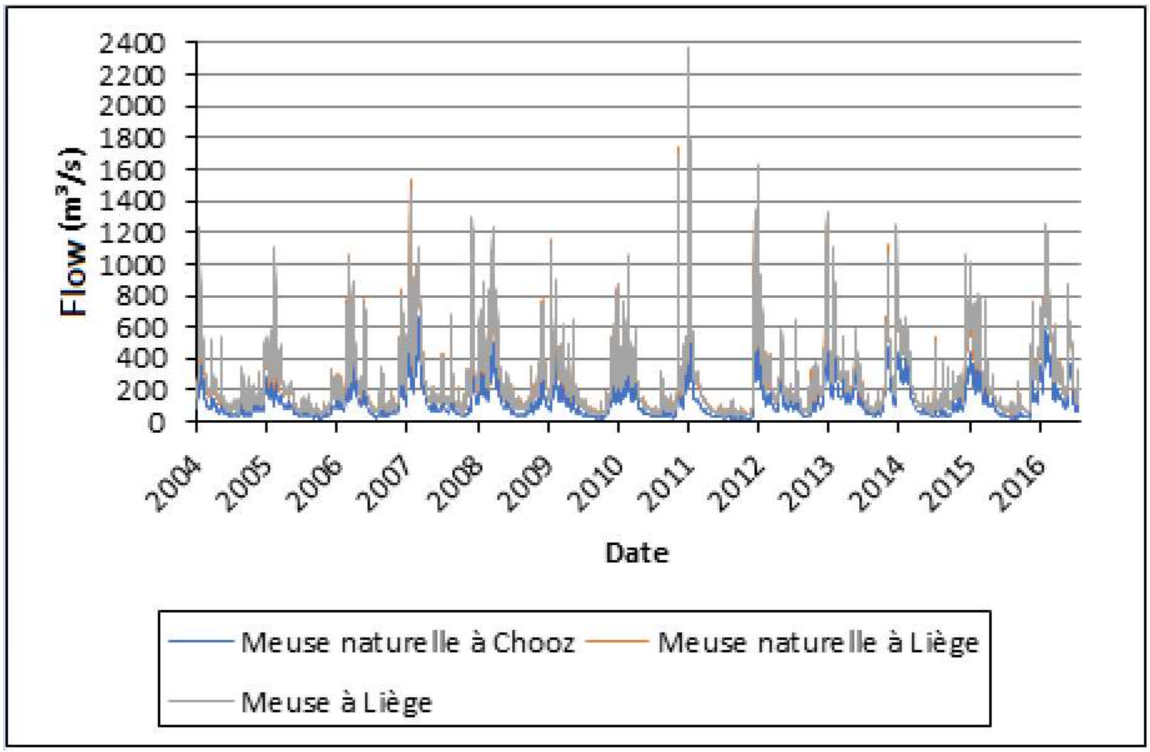


Figure 22: Daily flows of the Meuse (01/01/2004 - 31/07/2016)

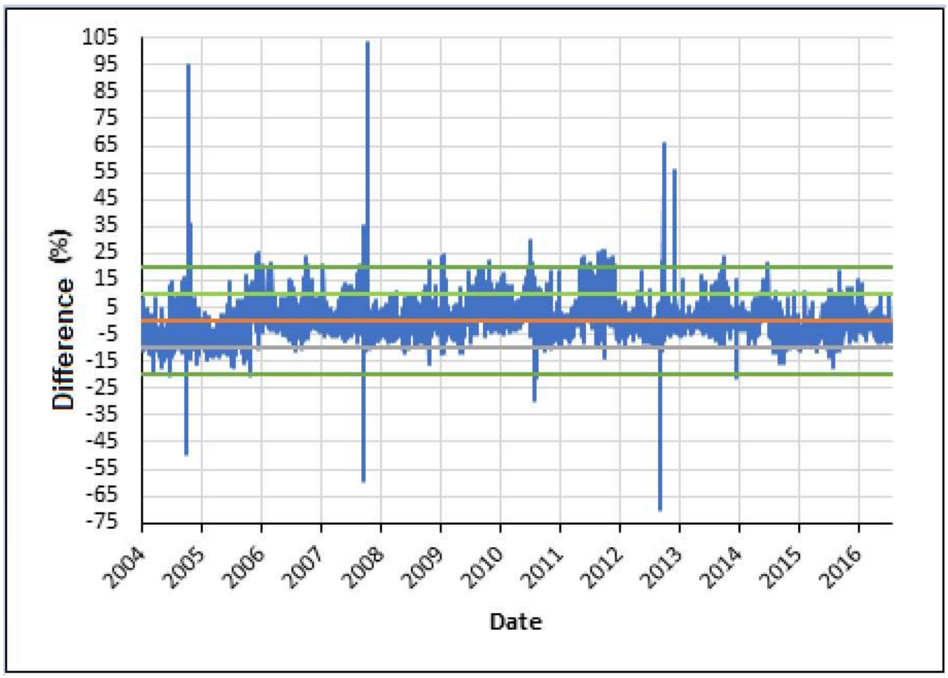


Figure 23: Difference (%) between the series of natural flows and "measured" flows in Liege (01/01/2004 - 31/07/2016)

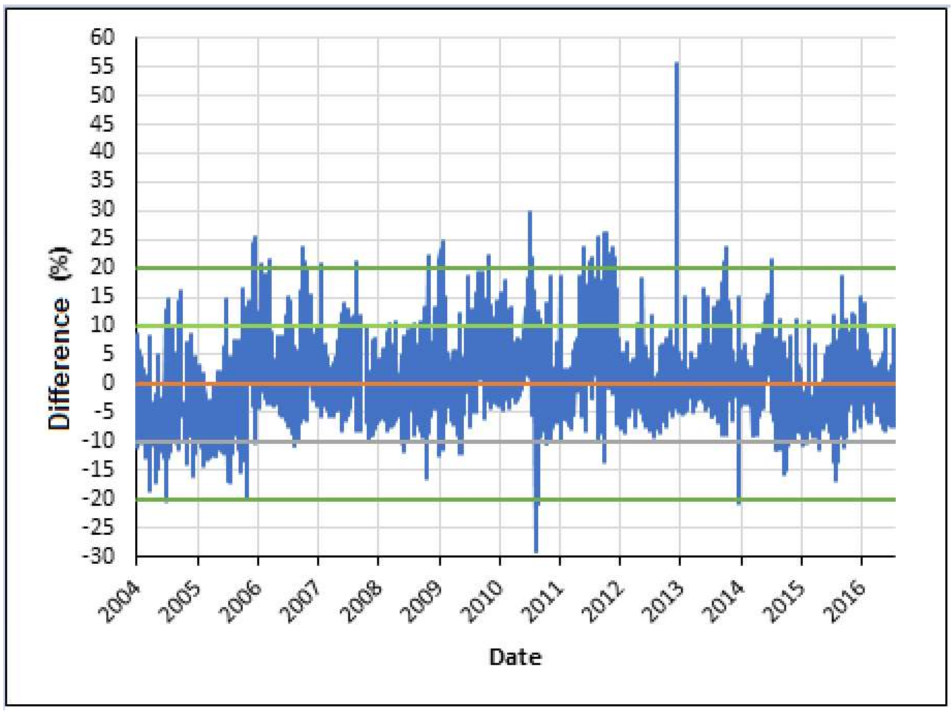


Figure 24: Difference (%) between the series of natural flows and "measured" flows in Liege (01/01/2004 - 31/07/2016) -Retracting the periods of unemployment of the Meuse

Conclusions and outlook

The reconstructed natural series is close to the measured series because it is mostly between -10 and +10%. If the difference is positive, the natural flow is higher than the measured flow and conversely, if the difference is negative, the natural flow is lower than the measured flow.

Cyclical discrepancies are observed between the 2 series. A detailed analysis must be conducted to determine the causes.

Some anomalies were detected mainly during the period of unemployment of the Meuse: 26/09/2004, 23/09/2007, 14/10/2007 and 16/09/2012.

It would be possible to improve the series of natural flows of the Meuse at Liege by taking into account the following points:

- the contribution of the intermediate catchment areas of the Meuse
- small, unmetered point intakes
- the actual water intake of the Tihange nuclear power plant
- the SWDE and CILE withdrawals upstream of Liege redistributed downstream of Liege,
- the natural flows of the Vierre, Gileppe, Warche and Ourthe rivers, taking into account their reservoirs

The areas of the unmeasured intermediate catchment areas of the Meuse represent less than 2.5% of the total area of the Meuse catchment area at Liege. These inputs can therefore be considered negligible.

Initial statistics were performed on this naturalized flow series to determine the extreme low flow rates for comparison with the observed series (Table 6). Unfortunately, the naturalized series can only be used for a very short period, from 2004 to 2015.

Table 6: Results of the measured and naturalized VCN7 at the Liege station (2004-2015)

LIEGE	Measured VCN7	Naturalized VCN7
VCN7 (T=2 years)	57.3 m^3/s	61.1 m^3/s
VCN7 (T=5 years)	50.0 m^3/s	53.5 m^3/s
VCN7 (T=10 years)	46.6 m^3/s	49.9 m^3/s
VCN7 (T=20 years)	44.0 m^3/s	47.2 m^3/s
VCN7 (T=50 years)	41.2 m^3/s	44.2 m^3/s

It is recommended not to estimate flows with a return period more than twice the length of the available history.

These results show an increase in extreme low water flows of about 7% between the observed series and the naturalized series in Liege.

5.3 Results at Lith-Megen station

The series measured at Lith forms the basis for the definition of the natural flow series at Lith. This series exists since 1911. The measured series is homogenized with respect to the current situation. Then all upstream withdrawals and discharges are added to the series.

Withdrawals/discharges upstream of Lith

1. Branches of the Meuse
2. Withdrawals/releases in the Netherlands

N.B.: withdrawals/discharges upstream of Liege are taken into account by the French and Walloon delegations.

5.3.1. Branches of the Meuse

The Meuse downstream of Liege differs from the Meuse upstream in that the water is divided between the Meuse and the Flemish and Dutch canals: the Albert Canal, the Zuid-Willemsvaart and the Juliana Canal. The distribution of water between the different branches is schematically reproduced in the figure below. The canals are connected to each other, the whole constituting a complex (Figure 25).

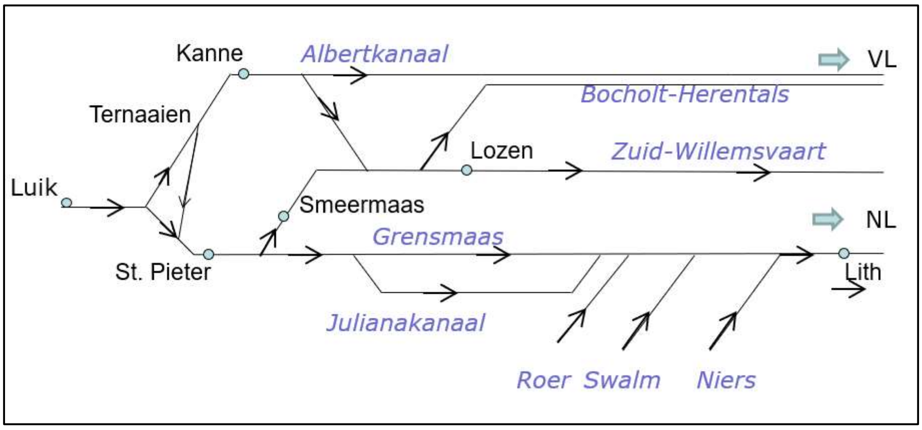


Figure 25: Diagram of the main connections and tributaries of the Meuse downstream from Liege

The following branches of the Meuse are located downstream from Liege (figure 26):

- The Albert Canal (Flanders) (since 1939)

- flows towards the Scheldt and does not join the Meuse: it is entirely in the natural series; flow measured at Kanne: maximum 19 m^3/s.

- The Zuid-Willemsvaart (since 1826)

- Partly destined for Flanders then flows towards the Scheldt, thus not joining the Meuse

- partly destined for the Netherlands, most of it returns to the Meuse, but downstream from Lith

  For this reason, the Zuid-Willemsvaart should be fully integrated into the natural series; flows measured at Smeermaas: maximum 13m^3/s.

Figure 26: Composition of the Lith natural series

5.3.2. Withdrawals and discharges within the Netherlands

In addition to the distribution of water between the Meuse and the canals, water is also withdrawn from the Meuse and the canals for drinking water production, industry, agriculture, etc. All these withdrawals and discharges must be taken into account when establishing the natural flow series. Withdrawals and discharges in the Netherlands consist of the following categories:

- Drinking water and industry (both withdrawals and discharges)

  The data are from the National Hydrological Model and have good accuracy.

  Withdrawals:

Industries:	6,4 m^3/s
Drinking water:	9,4 m^3/s
Discharge:	6,9 m^3/s

- Agricultural withdrawals

  The Nederlandse Hydrologische Instrumentarium calculates the amount of precipitation at the request of agriculture. The data are available for each model node and have sufficient accuracy.

- <u>Wastewater treatment plants</u>

  These are only discharges; the accuracy of the data is good.

- <u>Losses due to settling and leakage</u>

  These are losses to the outside of the system, e.g. the Maas-Waal Canal; losses within the system are not relevant. The decrease in sinking losses due to parsimonious lockage or pumping is taken into account. The accuracy of the data is good (Table7).

  Location Flows (m^3/s)

  Meuse – Waal Canal 2

  Wessem-Nederweert 2,5 – 0,5

- <u>Retention and infiltration</u>

  Retention/infiltration is noted in some areas:

  retention: (+) 0,1 m^3/s

  infiltration: (-) 2,9 m^3/s

  total: (-) 2,8 m^3/s

Water is used to compensate for infiltration: maintaining the water level in the Meuse and the canals is at the top of the priority list.

Table 7: Results of the measured and naturalized VCN7 at the Lith-Megen station

LITH-MEGEN	Measured VCN7	Naturalized VCN7
VCN7 (T=2 years)	60 m^3/s	82 m^3/s
VCN7 (T=5 years)	45 m^3/s	69 m^3/s
VCN7 (T=10 years)	40 m^3/s	60 m^3/s
VCN7 (T=20 years)	30 m^3/s	50 m^3/s
VCN7 (T=50 years)	25 m^3/s	38 m^3/s

Table 7 shows that for the Lith-Megen measuring station, the difference between the series of measured and reconstructed flows in low water events is about 30 %.

5.4 Summary

The difference between the naturalized and calculated VCN7 is increasing from upstream to downstream, which is consistent with an increase in water use from upstream to downstream.

For 3 stations along the Meuse, measured flow series were converted into so-called "natural" flow series. The natural flow series reflect a situation in which the anthropogenic impact (e.g. the effects of canal development, diversion of water from the Meuse to other basins, drinking water and industrial use) is compensated for. Both the natural and the measured series were statistically analysed in order to determine the frequency of low flows. The analysis of the natural flows shows that the use has increased over time. In addition, the difference in absolute terms between natural and measured flows increases downstream. The main causes of this increase are withdrawals of water that no longer returns to the Meuse, such as drinking water withdrawals for areas outside the Meuse basin and the diversion of water from the Meuse to Flanders (based on the Flow Treaty between Flanders and the Netherlands).

It is important to note that the estimation of natural flows is uncertain since past data can only be reconstructed with limited precision (evolution of withdrawals over time…).

Furthermore, with regard to the results of the statistical analysis, it should be borne in mind that the higher the return periods (e.g. T = 20 years or 50 years), the more the accuracy of the results decreases, given the reduced length of the measurement series.

6. Low flow monitoring within the IMC

6.1 Device (stations, parameter, monitoring frequency and status classification)

The current joint low water monitoring network consists of 21 flow measurement stations spread over the main course of the Meuse (10 stations) or its tributaries (11 stations) (Figure 27).

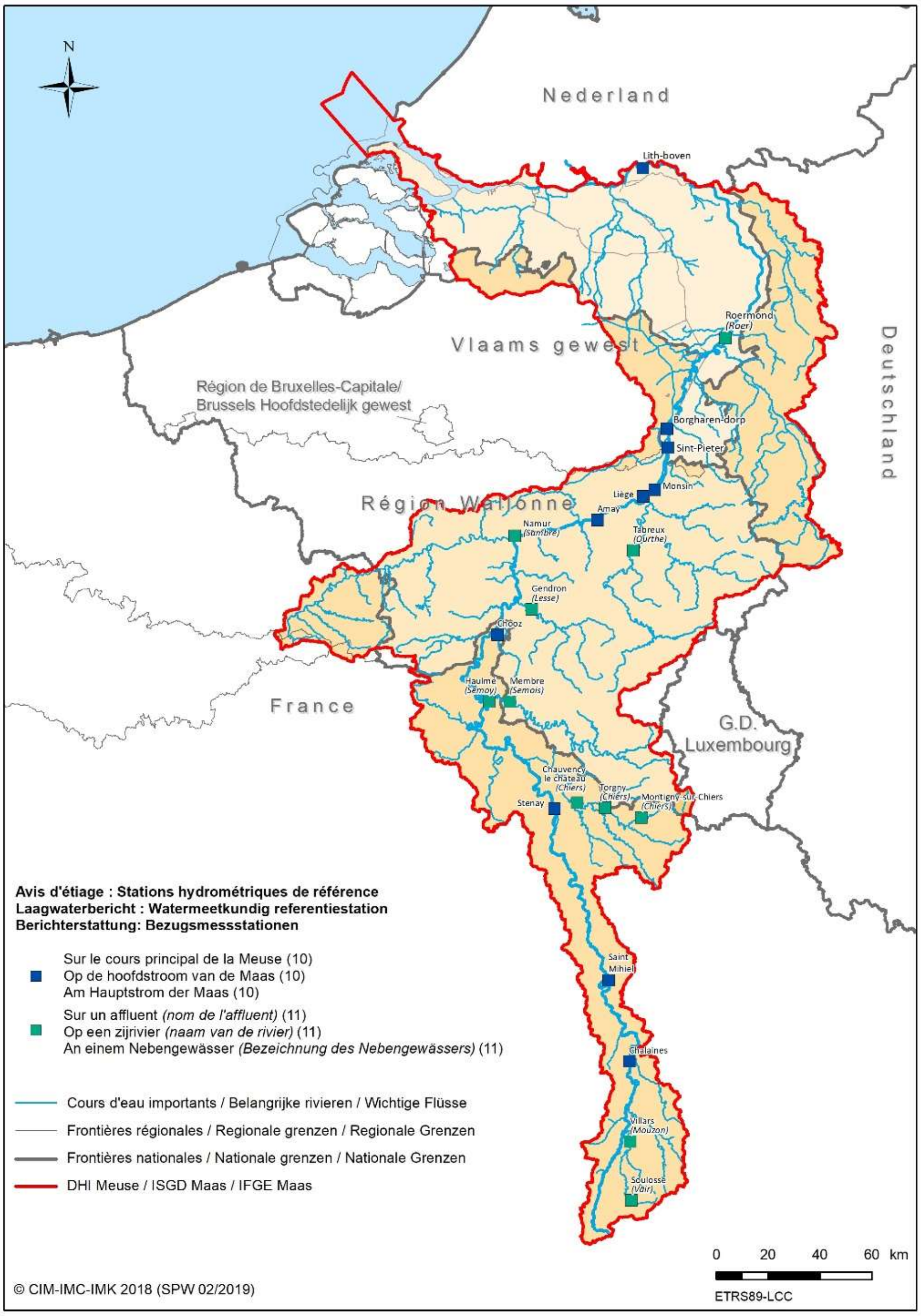


Figure 27: Map of the joint monitoring network in the Meuse basin

The follow-up of the low-water level based on the measured flows is carried out weekly from week 23 to week 43 which corresponds approximately to the period spreading from June to October. This period can be extended according to particular meteorological conditions before June or after October.

The monitoring of the low water level within the IMC is done on the basis of the average flow of the 7 days of the past week. This value makes it possible to smooth the punctual fluctuations of the flows observed on the rivers (opening or closing of gates of dam, discharges, …).

The intensity of the situation is then determined by calendar week according to a classification into five categories. As shown in Figure 28, this classification is based on the 2-, 5-, 10-, 20- and 50-year return periods of the annual VCN7. These correspond to the theoretical annual probabilities of occurrence of the phenomenon with a 50%, 20%, 10%, 5% and 2% crossing. The related flows correspond to the statistical data of the flows measured in chapter 5.

FREQUENT LOW WATER	LESS FREQUENT LOW WATER	SELDOM LOW WATER	VERY SELDOM LOW WATER	EXTREMELY SELDOM LOW WATER
VCN7 T = 2 years	VCN7 T = 5 years	VCN7 T = 10 years	VCN7 T = 20 years	VCN7 T = 50 years

Figure 28: Flow threshold values used to qualify the intensity of low water

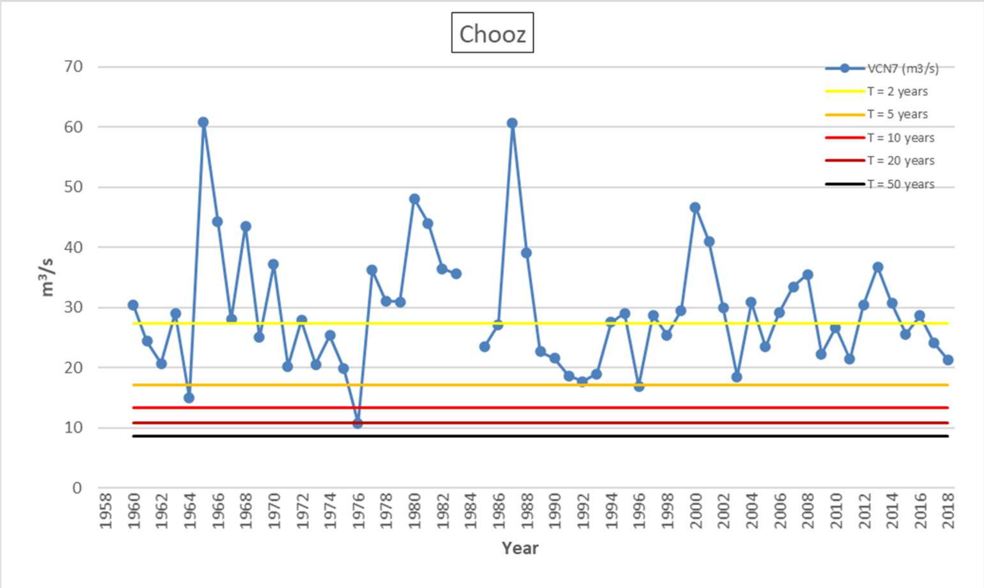
6.2 Results available at the main monitoring stations

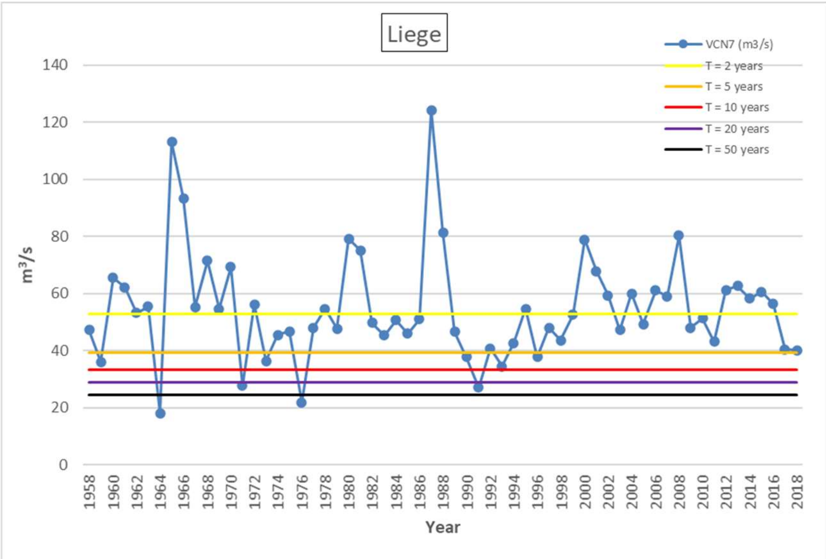
In this paragraph, the analyses of the flows of the Meuse encountered in the past at the three following hydrological stations are presented:

- Chooz,
- Liege,
- Lith-Megen.

The choice of these stations makes it possible to account for the spatial evolution of low water along the course of the Meuse over the same period of time and to see, where applicable, the effects of the bilateral water allocation agreements existing in the basin (cf. chapter 9.2).

The first analysis of the low water levels that occurred on the Meuse consists in graphically representing the VCN7 calculated for each calendar year over the entire available flow record and comparing them to the return periods of 2, 5, 10, 20 and 50 years (cf. figures 29 and 30).





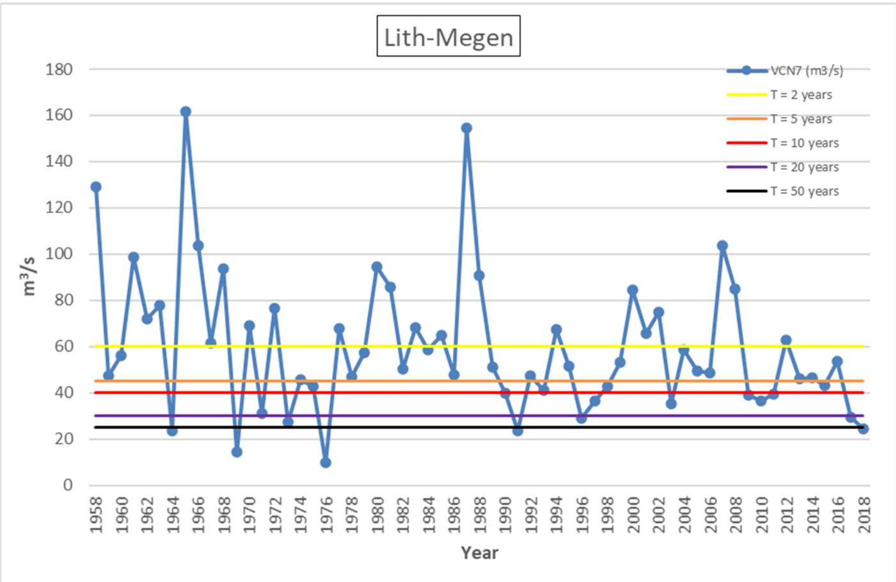


Figure 29: Comparison of the annual VCN7 at return times of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen (1958-2018)

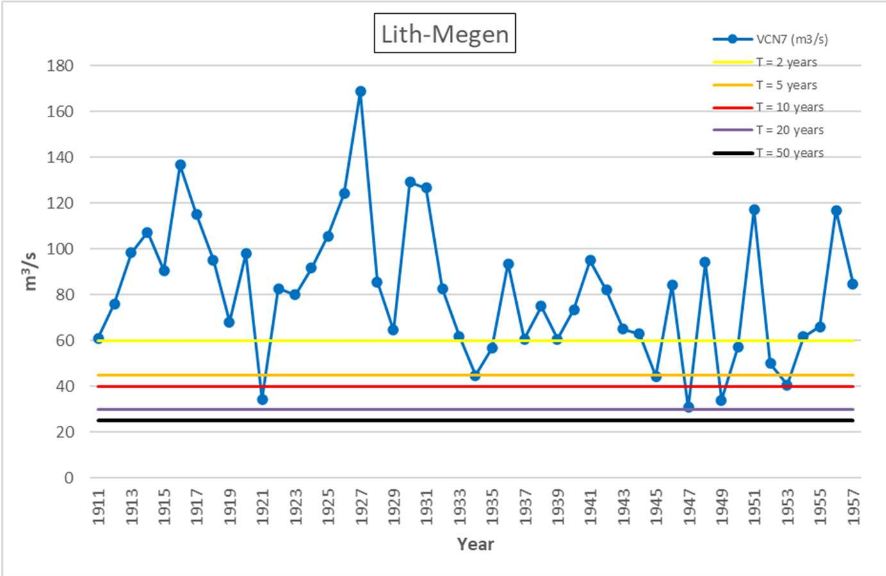


Figure 30: Comparison of annual VCN7 at 2, 5-, 10-, 20- and 50-year return times for the Lith-Megen station (1911-1957)

However, this first analysis is not sufficient to characterize the severity of a low water level and its potential negative consequences on aquatic ecosystems and uses.

If we assume that for a given threshold value, the longer the duration of the low-water period, the greater the potential negative consequences of the low-water period, it is then necessary to characterize (figure 31):

- the total number of days in the calendar year when the calculated M7Q for each calendar day was below a given threshold (parameter SumD),
- the maximum number of consecutive days in the year when the M7Q calculated for each calendar day was below a given threshold (parameter MaxD).

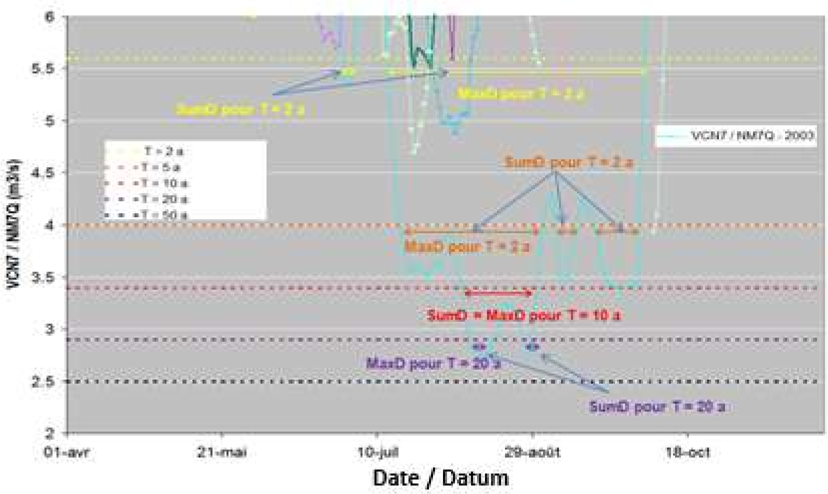


Figure 31: Example of calculation for a given hydrological station and for the low-water year of 2003 of the SumD and MaxD parameters associated with the crossing of the values of the annual VCN7 for the return periods of 2, 5, 10, 20 years

The SumD and MaxD parameters are represented in the form of annual histograms showing each of the five low-flow categories defined in Chapter 6.1. (Figures 32 et 33).

Figure 32: Total number of days when the calculated M7Q for each calendar day was below a given threshold (parameter SumD) for the return times of 2, 5, 10, 20 and 50 years – stations of Chooz, Liege and Lith-Megen (1958-2018)

Figure 33: Maximum number of consecutive days in the year when the M7Q calculated for each calendar day was below a given threshold (MaxD parameter) for the return times of 2, 5, 10, 20 and 50 years - stations of Chooz, Liege and Lith-Megen (1958-2018)

In order to have a global vision on the scale of the Meuse basin, the results obtained for the 3 stations are grouped together in a single graph by 20-year periods. For each year, the histograms for each station are represented side by side from upstream to downstream using hatching or dots inside the blocks of colour associated with each low-water category so as to be able to distinguish each of the flow measurement points (figures 34 to 39).

the following graphs, the histograms may exceed the number of calendar days, i.e. 365 days for a given year, because the Sum(D) values are accumulated by return period.

Example: In 1976 (figure 34), the number of days when the VCN7 was lower than the threshold corresponding to a return period of 20 years (= Sum(D) for T = 20 years in purple on the graph) is also included in the calculation of Sum(D) for T = 10 years (in red) but also in that of Sum(D) for T = 5 years (in orange) and Sum(D) for T = 2 years (in yellow).

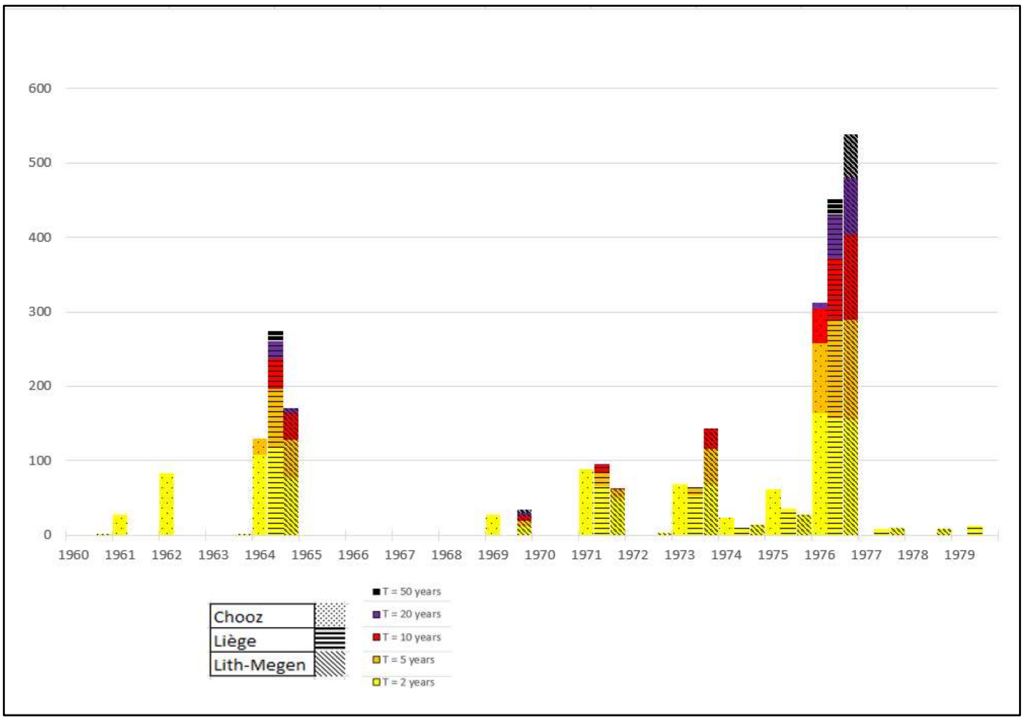


Figure 34: Total number of days when the calculated M7Q for each calendar day was below a given threshold (SumD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 1960 to 1979

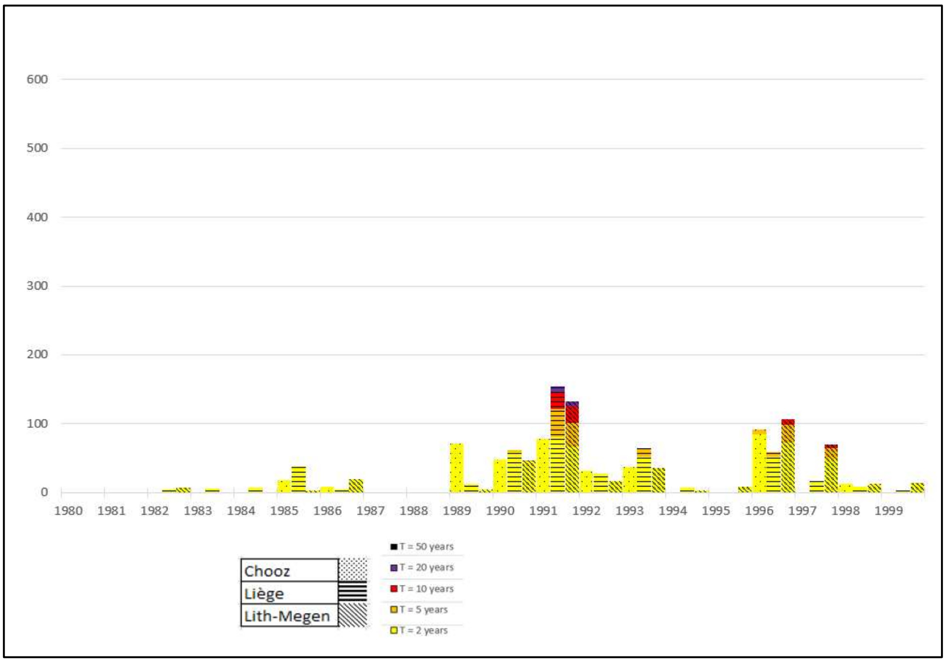


Figure 35: Total number of days when the calculated M7Q for each calendar day was below a given threshold (SumD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 1980 to 1999

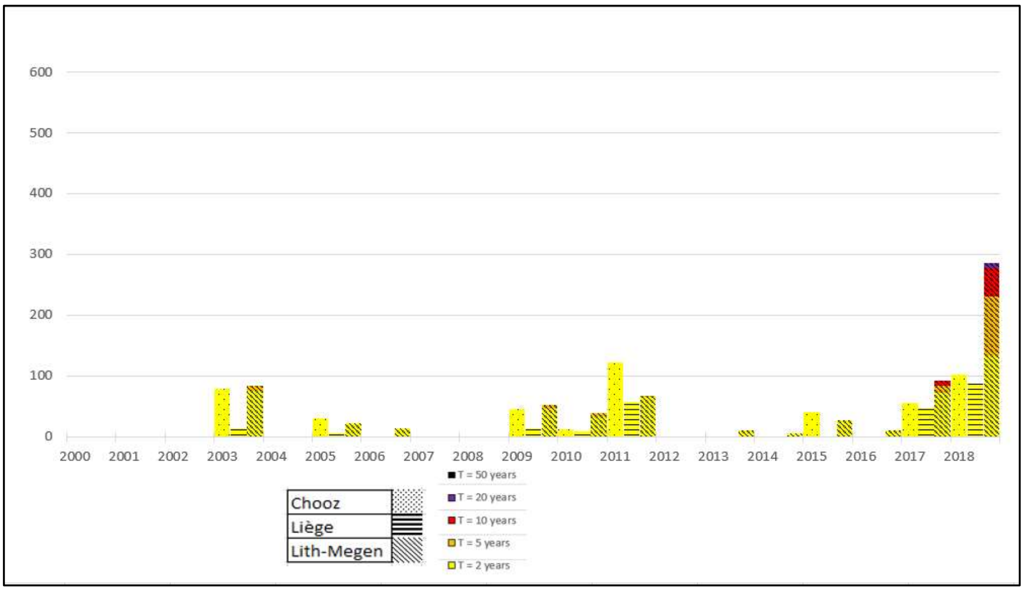


Figure 36: Total number of days when the calculated M7Q for each calendar day was below a given threshold (SumD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 2000 to 2018

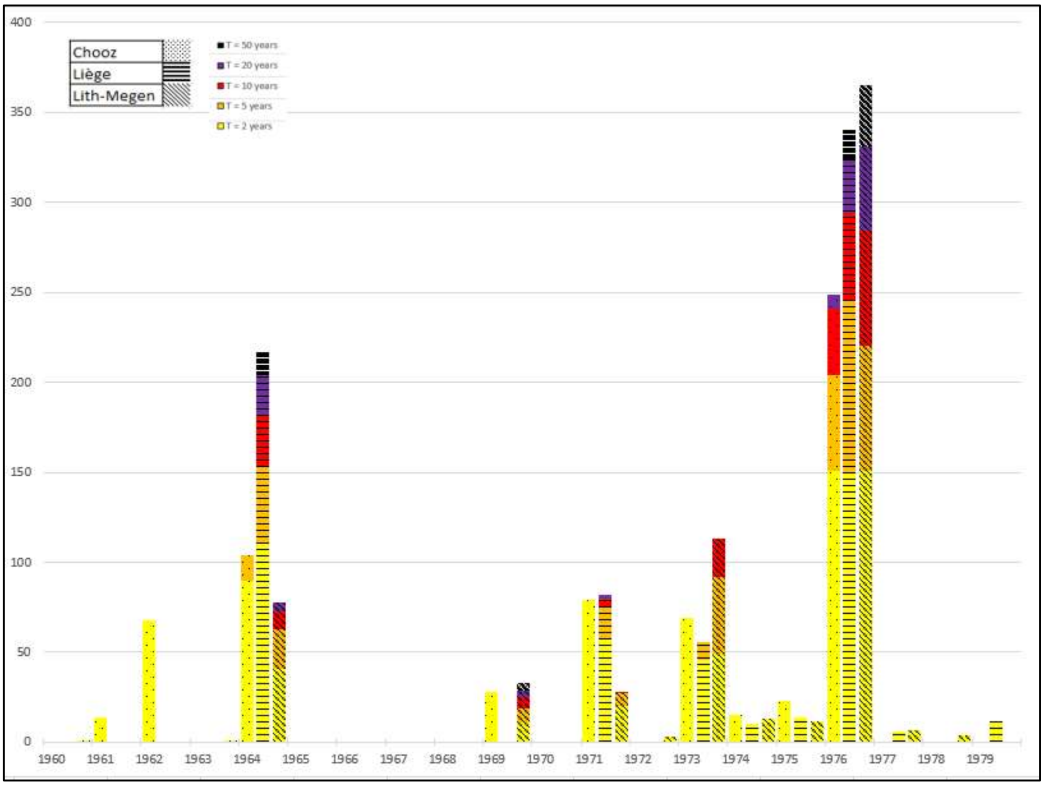


Figure 37: Maximum number of consecutive days in the year when the M7Q calculated for each calendar day was lower than a given threshold (MaxD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 1960 to 1979

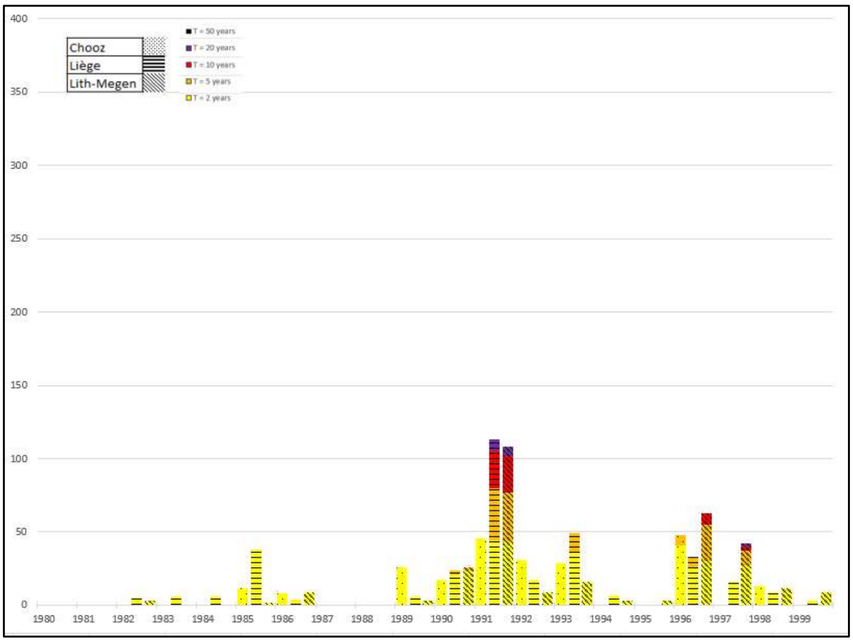


Figure 38: Maximum number of consecutive days in the year when the M7Q calculated for each calendar day was lower than a given threshold (MaxD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 1980 to 1999

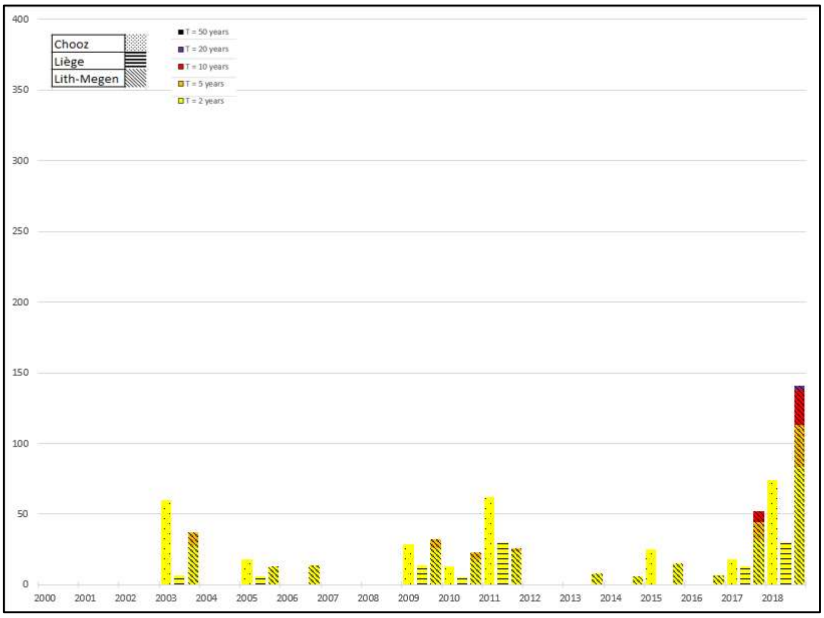


Figure 39: Maximum number of consecutive days in the year when the M7Q calculated for each calendar day was lower than a given threshold (MaxD parameter) for return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen from 2000 to 2018

An attempt has been made to present the longest possible measurement series. Unfortunately, the series available for the three stations do not all cover the same period. The series starts in 1911 for the Lith-Megen measurement site, in 1958 for the Liege site and in 1960 for the Chooz site. The common period therefore starts in 1960. The results obtained can be compared with the monitoring results of the physico-chemical and biological parameters available at the stations of the homogeneous measurement network of the IMC described in chapter 7. A comparison with the results of the monitoring of the chemical and ecological status of surface waters within the framework of the WFD is possible for the period 2000 to 2018.

6.3 Summary

In order to have a synthetic vision of the low water levels encountered in the past, the following tables are produced for the selected stations:

- table summarizing the average annual VCN7 over several years for the entire record as well as the values of the annual VCN7 associated with the 2-, 5-, 10-, 20- and 50-year return periods (see Table 8),
- table summarizing the values of the SumD and MaxD parameters for the 5 most important low-water periods (cf. tables from 9 to 11).

Table 8: Interannual mean of the VCN7 for the whole chronicle and values of the annual VCN7 associated with return periods of 2, 5, 10, 20 and 50 years for the stations of Chooz, Liege and Lith-Megen

Measuring station	Interannual mean of VCN7	Period	VCN7 T = 2 y.	VCN7 T = 5 y.	VCN7 T = 10 y.	VCN7 T = 20 y.	VCN7 T = 50 y.
Chooz	29,47 m^3/s	1960-2018	27,30 m^3/s	17,06 m^3/s	13,34 m^3/s	10,89 m^3/s	8,67 m^3/s
Liege	54,6 m^3/s	1958-2018	52,9 m^3/s	39,4 m^3/s	33,3 m^3/s	28,9 m^3/s	24,4 m^3/s
Lith-Megen	69,2 m^3/s	1911-2018	60 m^3/s	45 m^3/s	40 m^3/s	30 m^3/s	25 m^3/s

Table 9: Duration of exceedance of annual VCN7 values associated with return periods of 2, 5, 10 and 20 years for the Chooz station

	VCN7	T = 2 y.		T = 5 y.		T = 10 y.		T = 20 y.		T = 50 y.	
Year	m^3/s	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)
1964	14,96	108	90	22	14	0	0	0	0	0	0
1976	10,80	164	151	94	53	46	37	8	8	0	0
1992	17,73	31	31	0	0	0	0	0	0	0	0
1996	16,90	85	41	7	7	0	0	0	0	0	0
2003	18,47	79	60	0	0	0	0	0	0	0	0

Table 10: Duration of exceedance of annual VCN7 values associated with return periods of 2, 5, 10 and 20 years for the Liege station

	VCN7	T = 2 y.		T = 5 y.		T = 10 y.		T = 20 y.		T = 50 y.	
Year	m^3/s	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)
1964	18,1	118	110	78	43	41	29	24	22	13	13
1971	27,6	66	57	18	18	10	5	2	2	0	0
1976	21,8	157	149	132	97	83	48	58	30	21	16
1991	27,0	81	44	40	36	25	25	8	8	0	0
1993	34,5	52	36	13	13	0	0	0	0	0	0

Table 11: Duration of exceedance of annual VCN7 values associated with return periods of 2, 5, 10 and 20 years for the Lith-Megen station

	VCN7	T = 2 y.		T = 5 y.		T = 10 y.		T = 20 y.		T = 50 y.	
Year	m^3/s	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)
1964	23,4	76	41	52	22	36	10	6	5	0	0
1969	14,3	12	11	8	8	6	6	4	4	4	4
1976	10,0	155	151	134	69	115	64	76	47	58	34
1991	23,7	67	43	34	34	25	25	7	6	0	0
2018	24,7	134	83	96	30	48	25	7	3	0	0

Table 12: Summary table of the two most important low water levels common to the stations of Chooz, Liege and Lith-Megen

		T = 2 years		T = 5 years		T = 10 years		T = 20 years		T = 50 years	
1964	VCN7 (m^3/s)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)	SumD (d)	MaxD (d)
Chooz	15,0	108	90	22	14	0	0	0	0	0	0
Liege	18,1	118	110	78	43	41	29	24	22	13	13
Lith Megen	23,4	76	41	52	22	36	10	6	5	0	0
1976											
Chooz	10,8	164	151	94	53	46	37	8	8	0	0
Liege	21,8	157	149	132	97	83	48	58	30	21	16
Lith Megen	10,0	155	151	134	69	115	64	76	47	58	34

Over the period 1960-2018, the analysis for the 3 stations of Chooz, Liege and Lith-Megen reveals that the highest low water levels in the Meuse basin as a whole occurred in 1964 and 1976[4]. However, an increase in the frequency of low water has been observed in recent years.

[4] For the Lith-Megen station, 2018 was also an important low water situation.

7. Impact of low water on the status of surface water bodies at the borders

Low water is a usual period in the natural hydrological cycle of rivers (see chapter 4). Biological functioning and ecological balances have been built around this constraint. Aquatic organisms have developed adaptation strategies to resist these periods of stress. Thus, not only fish, but also macroinvertebrates migrate to the mouths of tributaries. Fish take advantage of favourable hydrological conditions to migrate and wait for the end of unfavourable phases.

Nevertheless, the pressures exerted by human activities can accentuate this stress and jeopardize natural balances (see figure 40):

- By reducing available flows in rivers or lengthening the duration of low water levels, either directly (withdrawals) or indirectly (long-term climate change),
- Through discharges whose impacts can be increased during low water periods,
- Man-made channels stabilize the water level and slow down the flow velocity, thus affecting the impact of low-water periods.

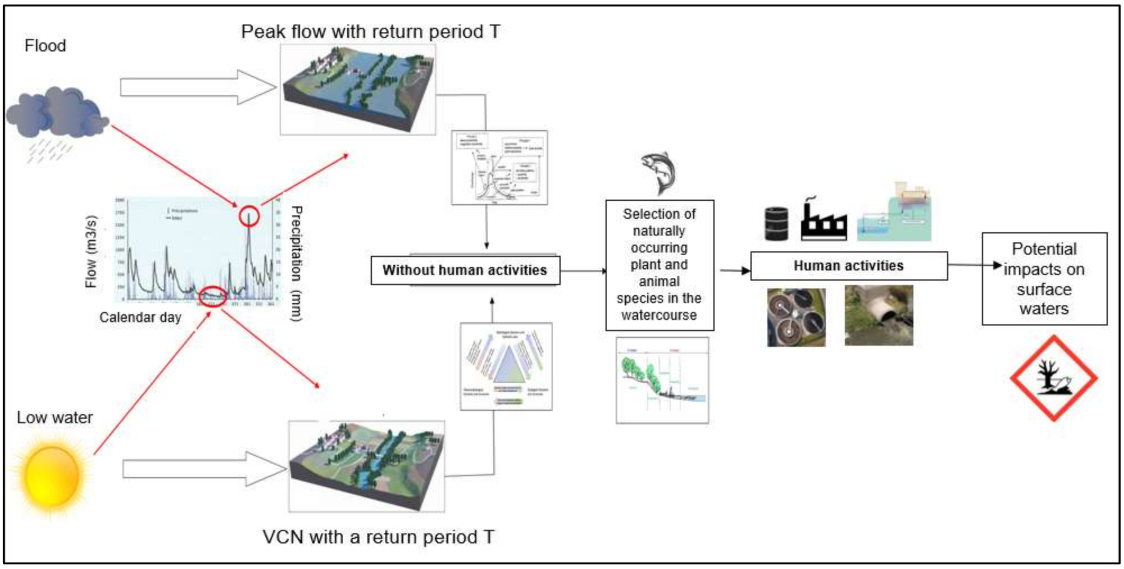


Figure 40: Links between low water (respectively high water) and surface water status

Biological communities can then undergo more or less marked alterations, namely:

- The disruption of ecological continuity, when water levels become insufficient to allow organisms to access certain withdrawal areas and tributaries; these effects are accentuated when dry periods occur,
- The increase in the concentration of certain pollutants whose discharge flows are practically constant throughout the year, due to less dilution (this is the case, for example, of pharmaceutical substances used for long-term illnesses such as cardiovascular diseases),
- The sudden influx of pollution in the event of heavy rainfall following a prolonged drought can lead to high concentrations of pollutants and a significant consumption of oxygen,

- The diversion and slowing down of the flow, with an impact on the oxygen balance and the quality of the habitats and thus on the rheophilic species,
- Stratification of the water column in heavily modified rivers, with negative impact on the oxygen balance,
- The warming of the water, with negative consequences on the availability of oxygen, particularly for fish populations, and increased risks of plant proliferation (phytoplankton and/or macrophytes).

However, the relationship between flow and pollutant concentration cannot be explained by a simple dilution rule. Indeed, during low-water periods, flows strongly linked to precipitation are greatly reduced (urban runoff, diffuse agricultural pollution, etc.). Moreover, under the effect of the temperature, often high during low-water periods, the biological processes of self-purification for easily biodegradable organic pollution are intensified, in wastewater treatment plants, but also directly in the watercourses.

The cause-and-effect relationship between low water and water quality is therefore governed by numerous, complex and often antagonistic mechanisms. The result depends largely on the specific characteristics of each watercourse.

Considering the location of the stations of the homogeneous measurement network (HMR) of the Meuse basin (cf. figure 41) and that of the joint low-water monitoring network described in chapter 6.1 (cf. figure 27), it should theoretically be possible to make a comparative analysis between the reduction of flows during low-water periods and the state of the water observed.

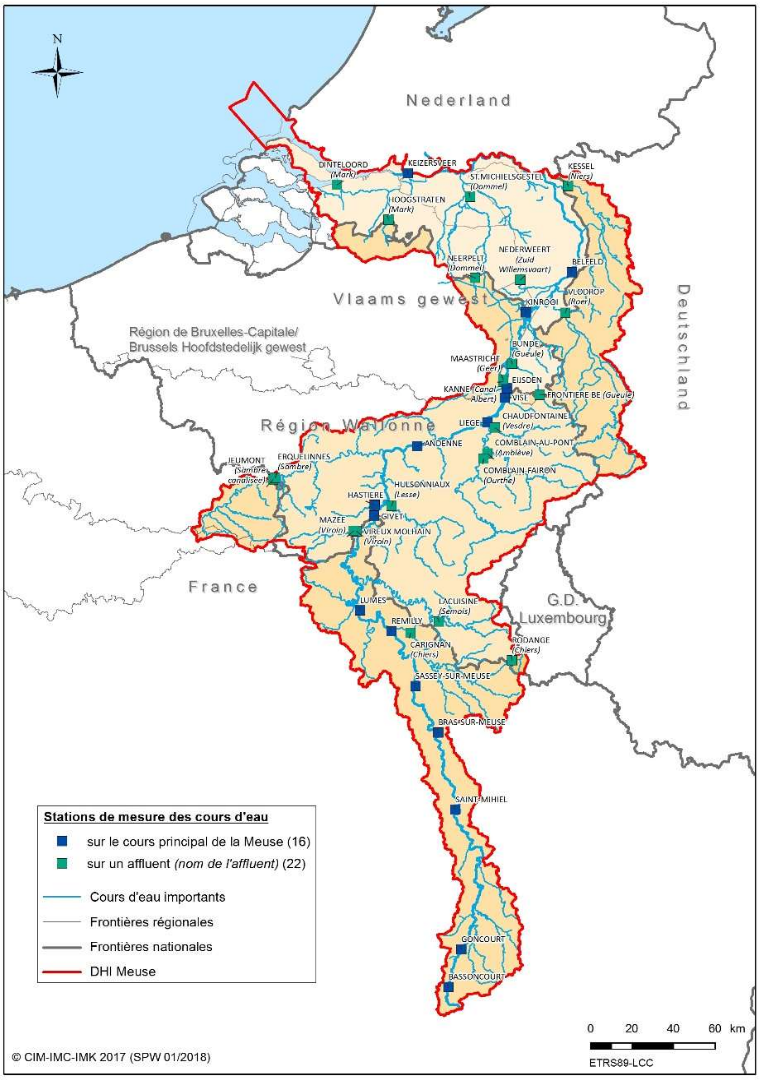


Figure 41: Location of the monitoring sites making up the Meuse Homogeneous Measurement Network (HMR)

But in practice, this is not the case for the following reasons:

- Even for the 21 hydrological stations of the joint low-water monitoring network of the IMC (cf. chapter 6.1), for which flow records of several decades are available, it is not always possible to compare monitoring results for all the physico-chemical and biological quality elements associated with the status of a water body within the meaning of the WFD. Indeed, the biological parameters are not always available every year. Moreover, they are representative of more or less long periods (according to the biological groups) which do not necessarily cover the low-water periods.

- Nevertheless, it is possible to show that water quality (general physico-chemical parameters in the sense of the WFD) can be good and stable even with marked hydrological episodes. In particular, the chronicle of annual VCN7 and the histograms of the SumD and MaxD parameters observed on the Meuse at Chooz, Liege and Lith-Megen (see chapter 6.1) can be compared with the minimum concentrations of dissolved oxygen on the one hand and the minimum concentrations of nitrates for the stations at Saint-Mihiel, Visé and Keizersveer on the other (figures 11, 42 and 43). It can be seen, for example, that the low water event in 2003 had no visible effect on these two parameters.

- Significant progress has been made and observed for the Meuse since the 1990s in the reduction of pollution thanks in particular to the successful implementation of the Urban Wastewater Directive 91/271/CEE.

This positive development is revealed through the physico-chemical parameters and is added to a possible impact of low flows during low-water periods. A causal link can therefore hardly be established between water quality and low-water events, at least not with the available data.

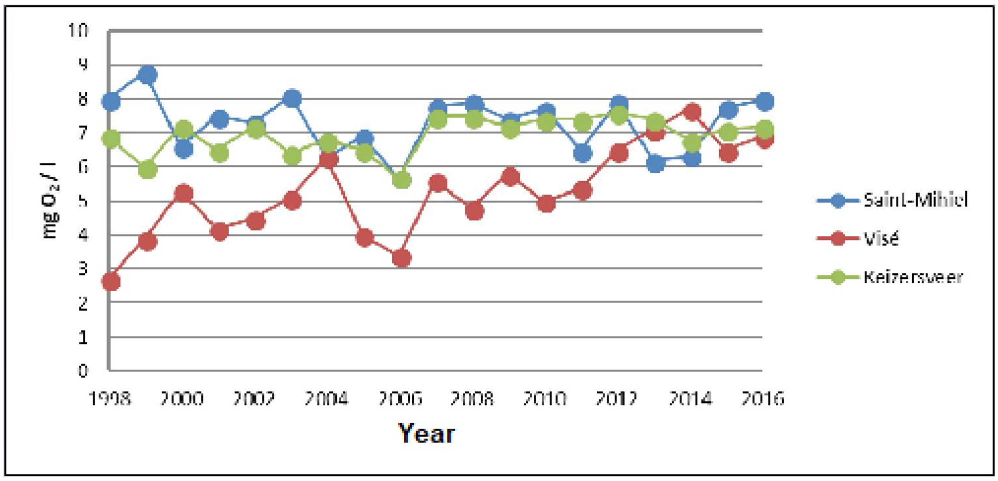


Figure 42: Changes in the minimum annual dissolved oxygen concentration measured at three water quality monitoring sites on the main course of the Meuse

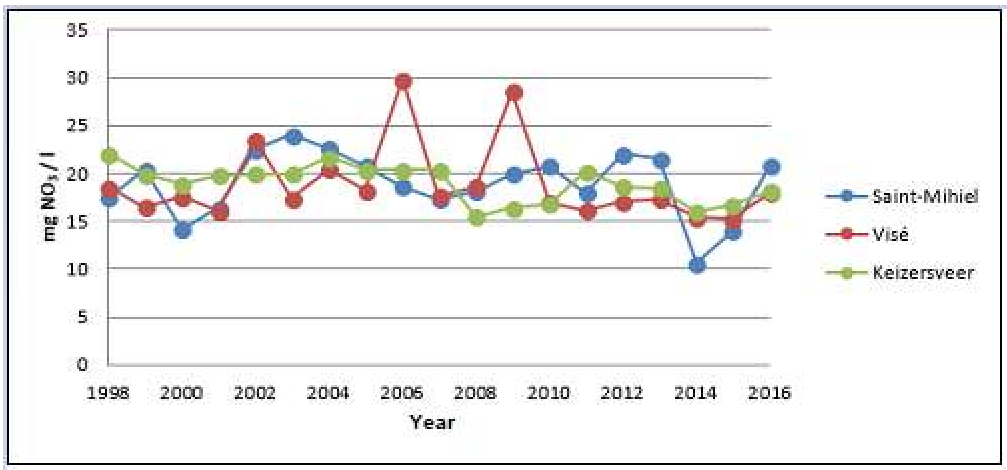


Figure 43: Changes in the maximum annual nitrate concentration at three water quality monitoring sites on the main Meuse River

8. Impact of low water on the various uses of surface water

The rivers in the Meuse basin are all characterised by a rainwater regime. Average flows peak in winter or spring and are lowest in August and September due to the summer decrease in precipitation in normal times and the increase in evaporation intensity due to temperature and plant growth.

However, difficulties for human activities may arise when the duration and/or severity of the low-flow phenomenon exceeds(s) the flow reductions usually encountered:

- The reduction in the quantity of water available may affect industrial withdrawals (particularly those linked to energy production), agricultural withdrawals, navigation (increase in waiting times by lockage, limitation of the degree of loading following the drop in the water level in extreme situations such as in 1976) as well as the resource exploitable for drinking water production.
- Recreational activities require sufficient water levels (e.g. lakes) or sufficient bacteriological quality. These activities are sometimes affected during periods of severe low water or when there is a sudden influx of bacteriological pollution via the sewage system following intense rainfall events that occur after a prolonged low water episode.
- Potentially negative impacts on surface water quality can compromise the production of drinking water from surface water - particularly in the Flemish and Dutch parts of the Meuse catchment (compliance with standards and regulations). More generally, prolonged droughts can have repercussions on both the quantity and quality of water and therefore on the uses. These impacts will be studied in a subsequent phase of updating this plan of approach.
- The stability of flood protection structures can be affected by low water levels over a prolonged period.

Although naturally adapted to periods of low water, the fauna and flora of the watercourses can be impacted by an exceptional duration and/or severity of the phenomenon.

Finally, prolonged periods of low water can also make the protection of wetlands such as peat bogs more difficult.

Figure 44 below illustrates the quantitative and qualitative impacts of reducing low-flow rates.

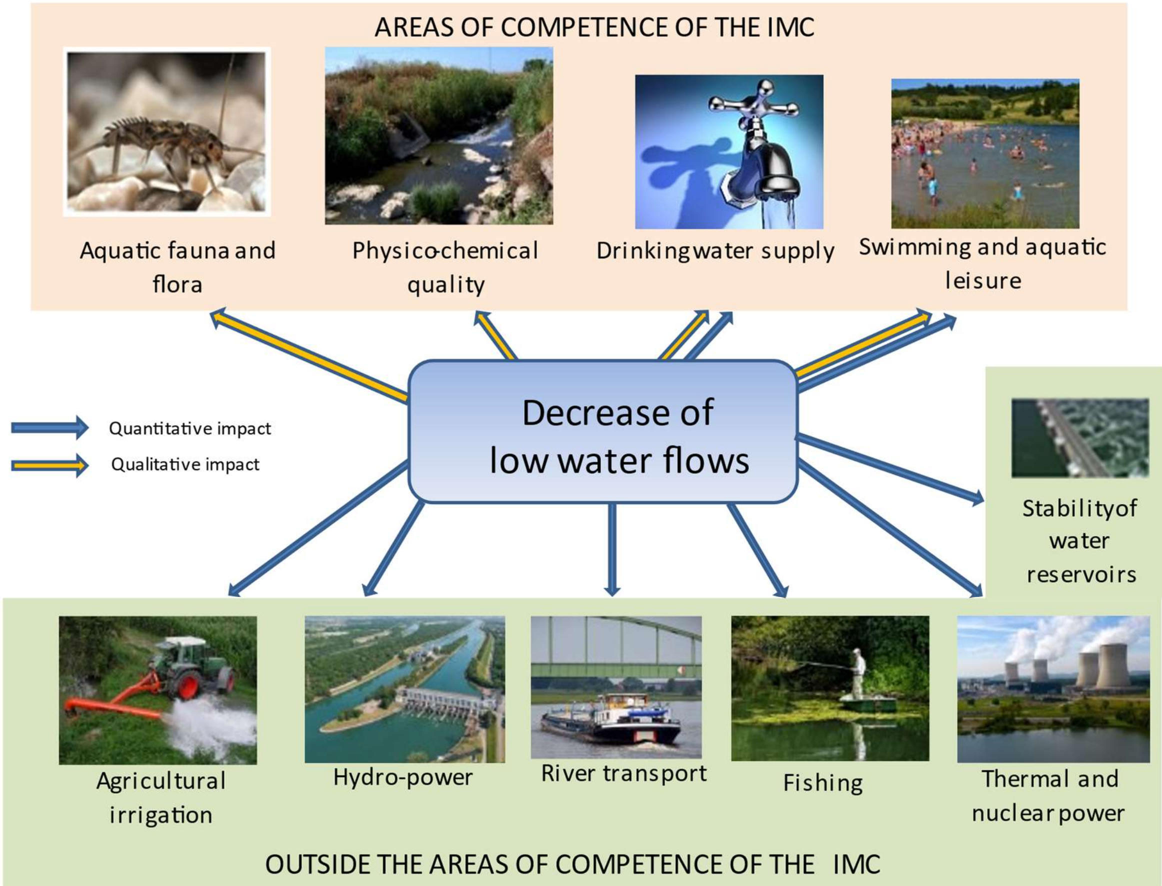


Figure 44: Schematic diagram of the impacts of low water on water status and uses

9. Reduction of the negative effects of low water on the status of surface water bodies

9.1 Measures (actions) foreseen in the management plans and the programme of measures of the Water Framework Directive

Important water quantity requirements in the Meuse IRBD arise in the areas of power plant cooling, drinking water supply in Belgium and the Netherlands and navigation on the Meuse, as stated in chapter 7.2.4 of the roof report of the Meuse IRBD management plan of the 2nd WFD cycle.

As we have seen in chapter 2.2, measures for quantitative management of surface water resources such as limiting or stopping uses (water abstractions, discharges, hydroelectric production, etc.) remain the sole competence of the States in application of the legal and regulatory provisions in force, which differ from one country to another.

However, the dimensions of environmental protection and sustainable development of the quantitative water resource must be taken into account in the different quantitative water uses (energy production, river transport, agricultural production, tourism, etc.) as also stated in recital 16 of the WFD[5].

Moreover, a policy for low water level management should not only be based on the satisfaction of quantitative needs for water uses but should also take into account environmental interests. The 1st recital of the WFD indeed reminds that « water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such».

The diagram below illustrates the difficulties and conflicts that result from a low-water management policy based on meeting the quantitative needs of water uses (Figure 45).

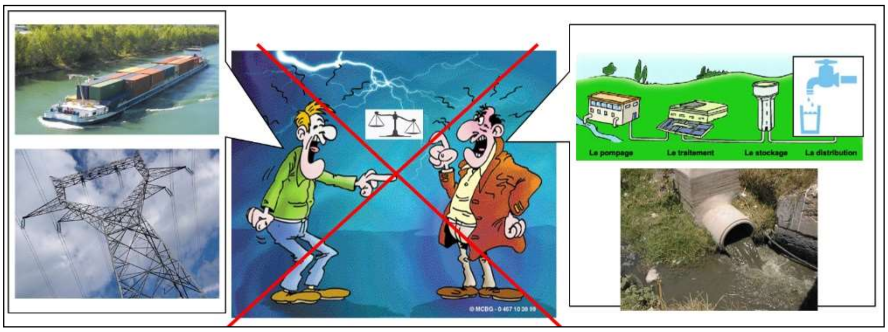


Figure 45: Potential conflicts between water users during low-water periods

[5] “Further integration of protection and sustainable management of water into other Community policy areas such as energy, transport, agriculture, fisheries, regional policy and tourism is necessary. This Directive should provide a basis for a continued dialogue and for the development of strategies towards a further integration of policy areas.”

In this context, it appears necessary:

- To analyse the current and future needs for co-ordination of the States, Länder and regions of the Meuse River Basin as regards quantitative management within the WFD implementation (see chapter 9.1.1),
- To analyse the current and future needs for coordination of the States, Länder and regions of the Meuse basin as regards low water crisis management (see chapter 9.1.2).

9.1.1 Coordination of quantitative management actions of national programmes of measures

The analysis of the current and future needs for coordination of the States, Länder and regions of the Meuse basin with regard to quantitative management within the framework of the implementation of the WFD was carried out on the basis of the following decision-making flow chart (cf. figure 46).

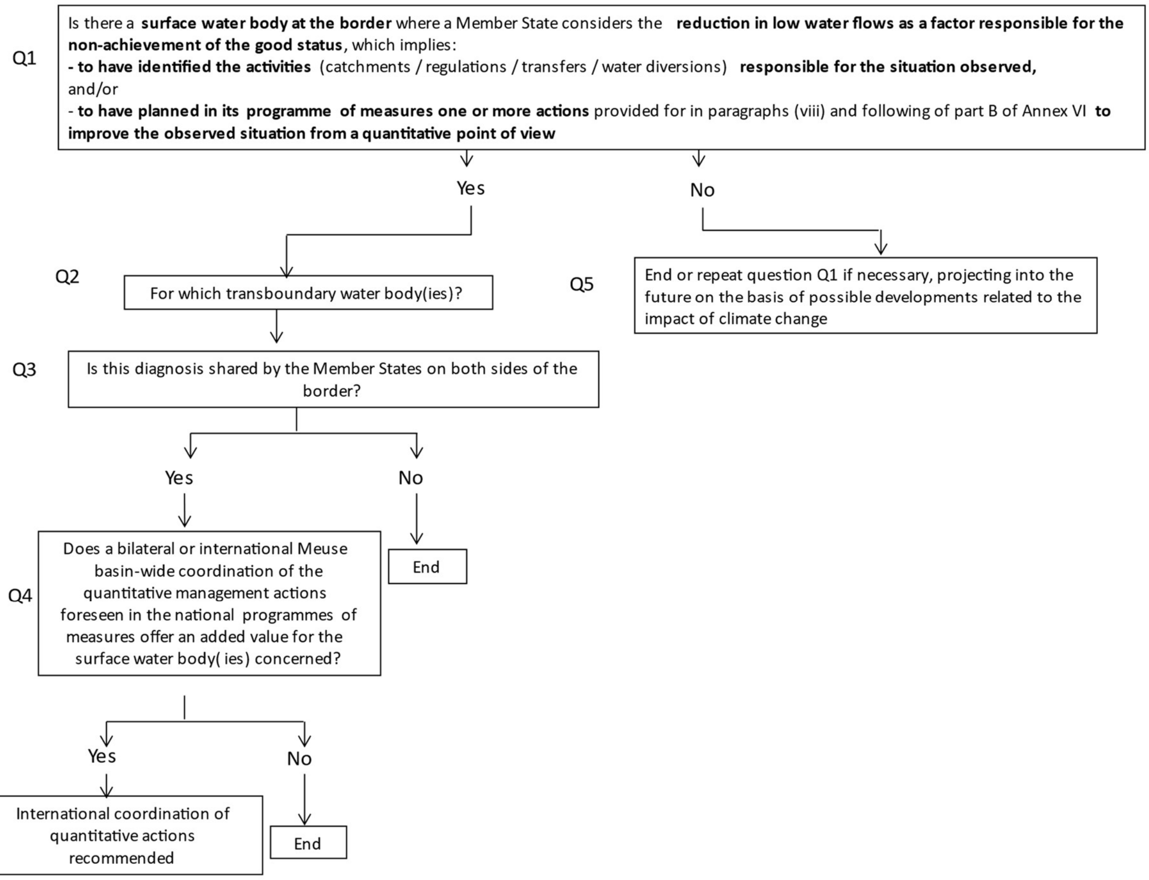


Figure 46: Decision-making flowchart on the need for international coordination of quantitative management actions

A first analysis of the surface water bodies located at the borders, based on the decision tree in figure 46, showed that low water levels would be considered as a factor responsible for the non-achievement of good status/potential for a part of these water bodies.

It appears that further work remains to be done by the delegations on this subject.

This was started at the time of writing this report and will have to be extended in the future for the water bodies located at the borders that would require it.

9.1.2 Coordination of crisis management during low-water situations

In order to meet the present and future need for coordination of the States, Länder and regions of the Meuse basin for low-water crisis management, the following decision-making flowchart is used (cf. figure 47).

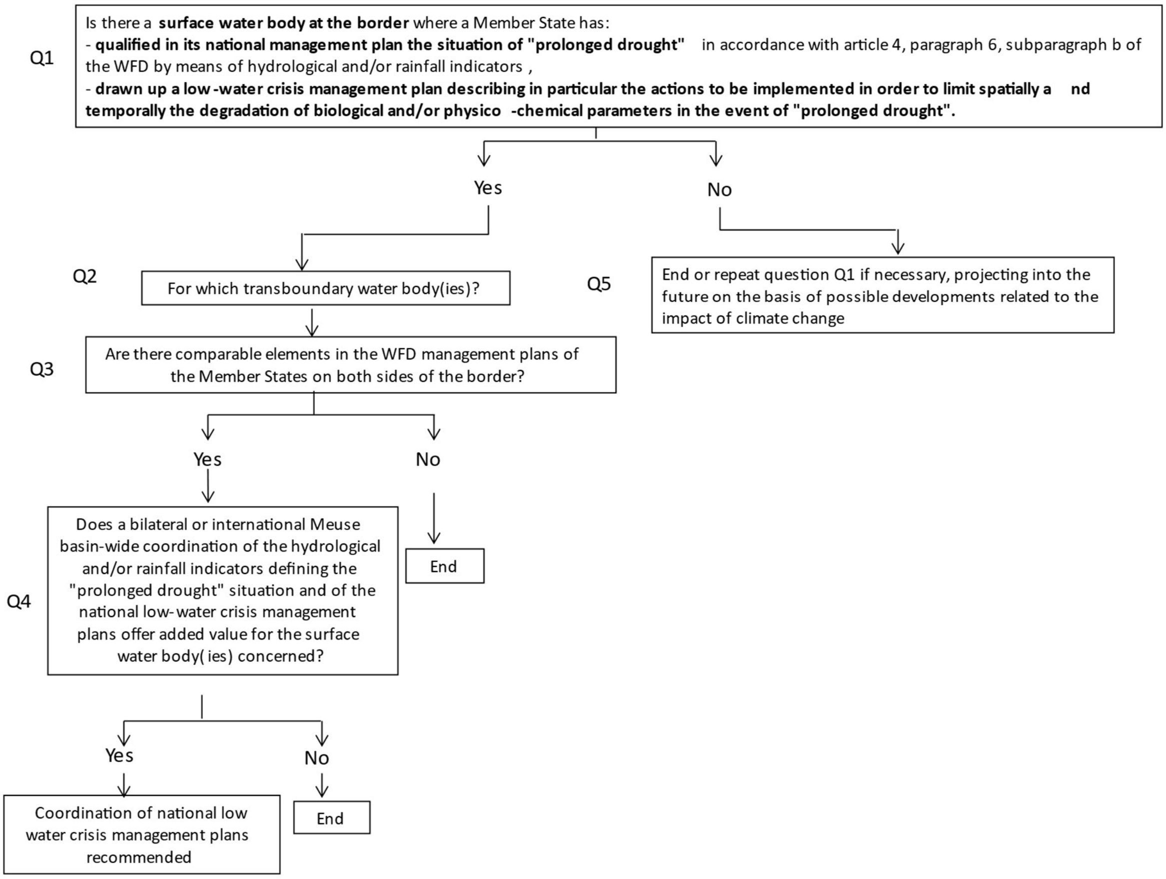


Figure 47: Decision-making flow chart addressing the need for international coordination for low-water crisis management

Further work is required to answer the questions in this flowchart.

9.2 International agreements on the allocation of flows in the Meuse River basin

9.2.1 International agreement on the CHOOZ nuclear power plant

The agreement between the Government of the French Republic and the Government of the Kingdom of Belgium relating to the Chooz nuclear power plant signed in Brussels on 8 September 1998 and transcribed into French law by Decree No. 98-1004 of 30 October 1998 provides for:

- the installation of a flow measurement station named "Chooz - Trou-du-Diable" and located upstream of the water intake and discharge structures of the nuclear power plant,
- the remote transmission of water level data ("Chooz - Trou-du-Diable" station) and rainfall data ("Chooz - Ile Graviat" station) to the Walloon hydrological services (SPW),
- the coordinated realization between EDF, the DREAL Grand Est and the SPW of a minimum of 12 gauging per year, half of which in period of low water with the obligation for EDF to ensure at least 1 additional gauging per month in period of critical low water in order to be able to calculate the flows of the Meuse,
- the implementation of the first safeguard measures when the average daily flow calculated over 12 consecutive days reaches 22 m^3/s,
- no worsening of the hydrological situation when the average daily flow calculated over 12 consecutive days reaches 20 m^3/s.

The practical details of how the provisions of this agreement are to be taken into account are set out in the order of November 17, 2009 renewing authorizations for the withdrawal and consumption of water and the release of liquid and gaseous effluents into the environment.

The volumes withdrawn from the Meuse do not exceed the following maximum values:

Annual volume	**Daily volume**	**Maximum instantaneous flow**
150 million m^3	544 000 m^3	7 m^3/s

The flow from the water intake in the Meuse is returned to the environment, except for the evaporated fraction.

The maximum quantity of water evaporated, whatever the time of year, by the two cooling towers at Chooz B is limited to 2.1 m^3/s as a daily average. The following additional restrictions apply:

- if the average daily flow of the Meuse, assessed downstream of the site over 12 consecutive days, is between 20 and 22 m^3/s, the flow evaporated during the 13th day is limited to 5% of the average daily flow of the 12th day;
- if the average daily flow of the Meuse, assessed downstream of the site over 12 consecutive days, is less than 20 m^3/s, the flow evaporated during the 13th day is zero;

- Unless exceptional circumstances are duly justified, the evaporated flow will be zero when the average daily flow of the Meuse downstream of the site is less than or equal to 14 m^3/s.

A withdrawal of 1.6 m^3/s, which is essential for cooling the reactors during production shutdowns, can take place, with full restitution, regardless of the river flow.

9.2.2 Agreement between the Flemish Region and the Kingdom of the Netherlands on the drainage of the Meuse

In the event of low flows (< 130 m^3/s), the water of the Meuse is divided between the Netherlands and Flanders in accordance with the terms of the agreement between the Flemish Region and the Kingdom of the Netherlands on the drainage of the Meuse, signed in Antwerp on 17 January 1995.

The principle of this agreement consists of an equal distribution of the waters of the Meuse between the two signatories and a common responsibility for the adjoining Meuse.

1. In the event of a flow on the Meuse of between 130 m^3/s and 60 m^3/s (start-up phase), Dutch and Flemish consumption is limited to 25-35 m^3/s each.
2. In the event of a flow in the Meuse of between 60 m^3/s and 30 m^3/s (alarm phase), the Parties guarantee a minimum flow of 10 m^3/s at the Borgharen dam. In this phase, the Parties make savings on the Dutch and Flemish consumption referred to in point 1.
3. In the event of a flow on the Meuse of 30 m^3/s or less (crisis phase), the Parties shall distribute this flow equally among Dutch consumption, Flemish consumption and the adjoining Meuse by means of further savings.

For the purpose of implementing the provisions of the Agreement, the Parties have set up a Dutch-Flemish working group for the Meuse drainage system. Although not a Party to this Agreement, Wallonia is an observer of the working group.

9.2.3 Water agreement for the Limburg (Midden-Limburgse kanalen) and North Brabant canals (WATAK MLNBK)

The WATAK (1994) is an agreement between the regional canal managers concerning the transfer of a flow of 16.5 m^3/s to these canals in normal conditions and concerning the water deficit in the event of low water. This agreement is currently being updated.

10. Potential effects of climate change on the evolution of low water flows

10.1 AMICE [05]

The purpose of this sub-chapter is to summarise the method and results presented in the report "Analysis of climate change, high-flows and low-flows scenarios on the Meuse basin" of 30 June 2010 of Action 3 of Work Package 1 of the AMICE project [05].

Carried out between 2009 and 2010 within the framework of the European Union's Interreg IVB programme, the aim of this action was to identify possible impacts of climate change on the hydrological regime of rivers in the Meuse basin in the near future (2021-2050) and in the distant future (2071-2100) [05].

10.1.1 Hydrological models used and calculation points

Flow calculations were carried out for 10 hydrological stations in the international Meuse basin (see Figure 48 and Table n°14).

Figure 48: Map of the hydrological calculation points retained in the framework of the AMICE project [05]

Each partner carried out the hydrological calculations for the stations located on its territory of competence from the hydrological models presented in table n°13.

10.1.2 Climate scenarios used for hydrological projections

The possible impacts of climate change on the hydrological regime of the rivers in the Meuse basin were estimated by comparing the flows calculated with the hydrological models for the periods 1961-1990 or 1971-2000, representing the "present time", with the flows calculated for the periods 2021-2050 (near future) and 2071-2100 (distant future).

Flows for the present time periods were calculated using meteorological data from the E-OBS 2.0 climatological database provided by the European Climate Assessment & Dataset project [(06)], which contains daily precipitation and air temperature data (2 meters) from 1950 to 2008 for Europe.

Flows for future time periods were calculated using meteorological data from the E-OBS 2.0 climatological database transformed using the “delta change method”.

From national climate models, the AMICE project partners have deduced temperature and precipitation transformation factors for each country for a wet and a dry scenario.

They also calculated transnational transformation factors for temperature and precipitation by weighting the national transformation factors by the proportion of the watershed (Table 13).

Table 13: Weighting applied to national transformation factors to arrive at a transnational scenario [(05)]

	Drainage area (km²)	Weighting coefficient
France	10.120	0,31
Walloon	10.880	0,33
Flanders & Netherlands	8.662	0,26
Germany	3.338	0,10
Transnational Meuse	**33.000**	**1,0**

10.1.3 Results

The identification of possible impacts of climate change on the hydrological regime of rivers at low water in the Meuse basin within the framework of the AMICE project was carried out on the basis of the VCN7 obtained from the daily flow data from April to September calculated by the national hydrological models:

- for the periods 1961-1990 or 1971-2000 representing "present time" using weather data from E-OBS 2.0,
- for the periods 2021-2050 (near future) and 2071-2100 (far future) by applying to the data from E-OBS 2.0 the national and transnational transformation factors for the dry and wet scenarios.

Table 14 provides the worst-case results for the ratio of future to present VCN7 for the wet (blue values) and dry (orange values) scenarios.

Table 14: Maximum change in VCN7 between April and September calculated in the AMICE project [(05)]

	Meuse St-Mihiel	Meuse Stenay	Meuse Montcy	Meuse Chooz	Meuse Sint Pieter	Lesse Gendron	Vesdre Chaud-fontaine	Rur Stah	Niers Goch
2021-2050	0.79 0.61	0.73 0.64	0.88 0.75	0.88 0.74	0.82 0.65	1.00 0.83	1.17 0.93	0.68 0.56	0.84 0.63
2071-2100	0.60 0.43	0.50 0.47	0.71 0.52	0.65 0.52	0.60 0.33	0.96 0.57	1.10 0.67	0.71 0.36	0.60 0.27

10.2 New knowledge available since AMICE

10.2.1 Netherlands [(07)]

On the basis of the new forecasts published by the Intergovernmental Panel on Climate Change (IPCC), the Royal Netherlands Meteorological Institute (KMNI) has drawn up four new climate scenarios for the Netherlands, known as KNMI'14 [(07)], for the time frames 2050 and 2085 (see figures 49 and 50), which take into account both temperature changes (scenarios G and W) and changes in air circulation (indices H and L).

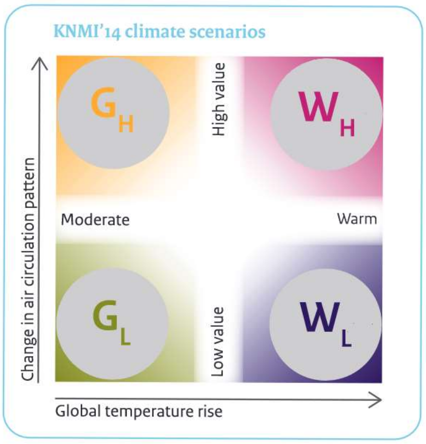


Figure 49: KNMI'14 scenarios (G stands for gematigd, i.e. moderate in Dutch; W stands for warm - H stands for high and L for low) [(07)]

The increase in global average temperature is the first classification criterion that distinguishes the scenarios. In the G scenarios, the increase in global average temperature is 1°C in 2050 and 1.5°C in 2085 compared to 1981-2010; in the W scenarios, it is 2°C in 2050 and 3.5°C in 2085 compared to 1981-2010 (see Figure 4). G stands for gematigd in Dutch, i.e. moderate; W stands for warm.

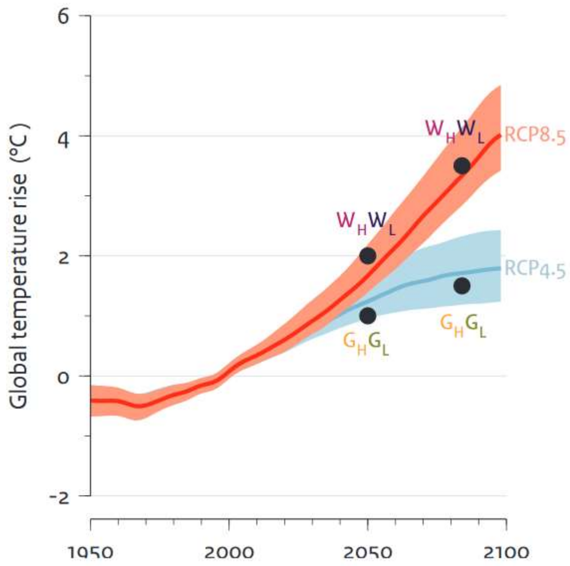


Figure 50: Temperature increase in 2050 and 2085 compared to the period 1981-2010 in the KNMI'14 scenarios (07)

In the H scenarios, westerly winds are more frequent in winter. This results in milder and wetter weather than in the L scenarios. In summer, high-pressure systems have a greater influence on the weather in the H scenarios. Compared to the L scenarios, these high-pressure systems cause more easterly winds, which means warmer and drier weather for the Netherlands. They give the change towards 2050 and 2085 compared to the climate of the period 1981-2010.

A 5th meteorological scenario $W_{H,dry}$ was developed to identify possible impacts of climate change on the hydrological regime of the Meuse River in 2050 and 2085 in the case of an extremely dry summer.

Flows for the present and future time periods were calculated using the HBV hydrological model.

Figures 51 and 52 from the KMNI report (08) show the calculated evolution at the Borgharen station of the mean monthly flows and the VCN7 with the 5 scenarios from KNMI'14 in comparison with:

- the results obtained from the previous KNMI weather scenarios,
- AMICE results,
- the results obtained from the latest IPCC weather scenarios (5th Coupled Model Intercomparison Project - CMIP 5).

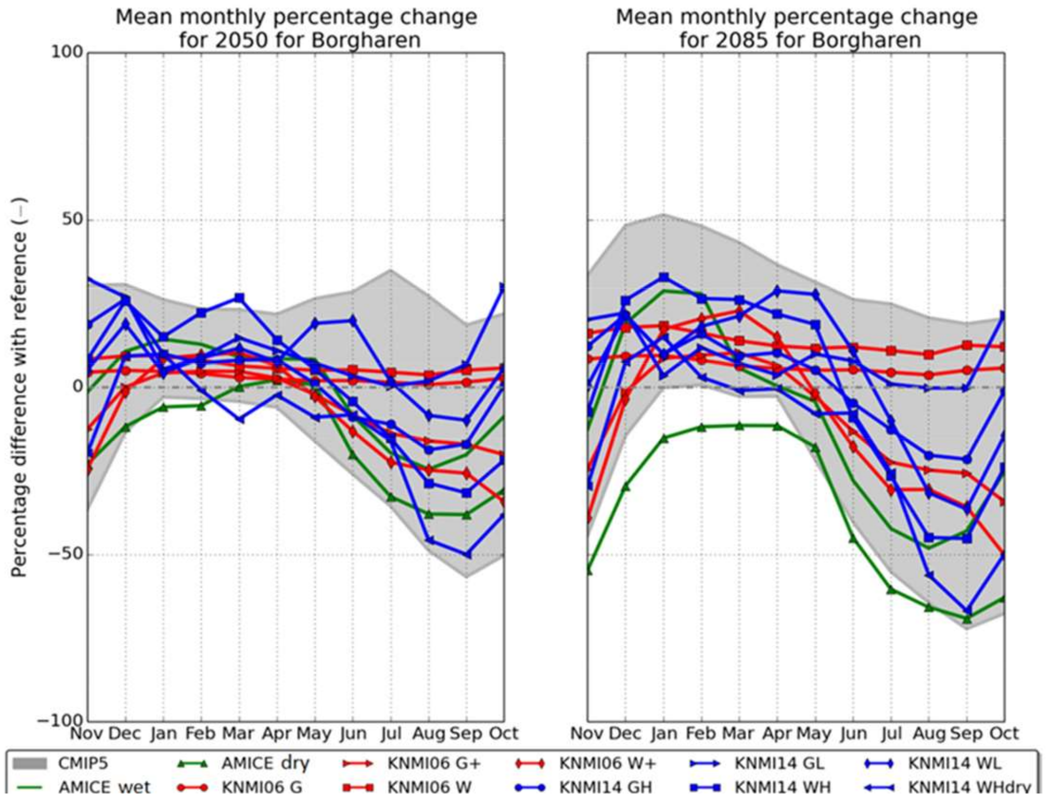


Figure 51: Calculated evolution of the monthly average flows at the Borgharen station

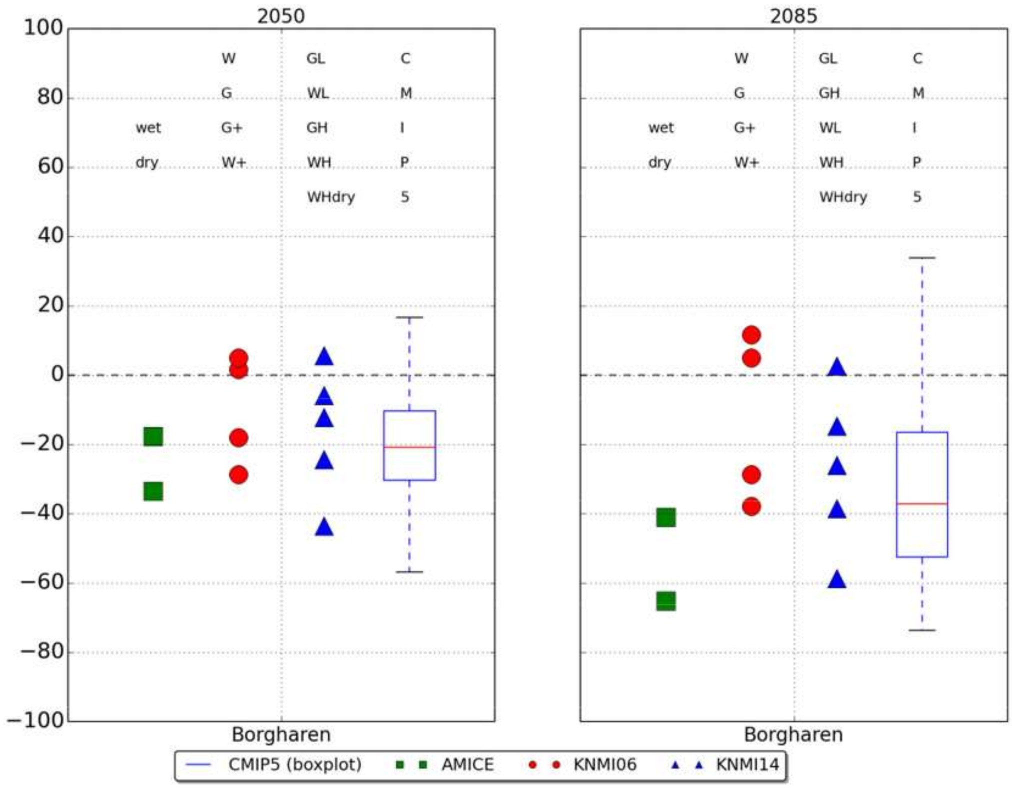


Figure 52: Calculated evolution of annual VCN7 at Borgharen station

10.2.2 France

A study project called "Explore 2070 [09] » funded by the Ministry of Ecology was conducted from June 2010 to October 2012 to assess the potential impacts of climate change on surface water resources over the future time period 2046-2065 compared to the present time reference period 1961-1990 based on the A1B scenario of the IPCC 4th Assessment Report.

To answer this question, a calculation chain involving two hydrological models (GR4 J and Isba-Modcou) was set up for 1522 catchments in mainland France [09] and 35 catchments in the overseas departments (Guadeloupe, French Guiana, Martinique and Reunion).

Seven climate models were used to project flows using the two hydrological models to 2050-2070 for the present time period 1961-1990 and the future time period 2046-2065.

To this end, a statistical downscaling method was used to move from the climatological model grid to an 8 km x 8 km grid compatible with the hydrological models used.

Results:

Figures 53 and 54 show the evolution calculated at the Chooz - Ile Graviat station of the mean monthly flows and of the VCN10, VCN30, and QMNA (minimum monthly flow) for the return periods 2 years, 5 years and 10 years.

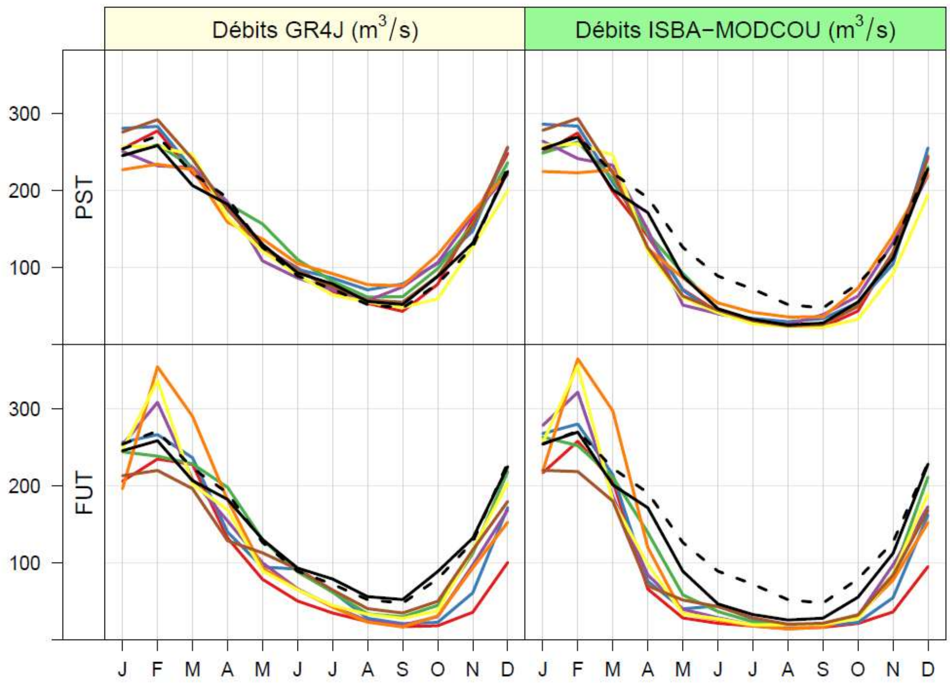


Figure 53: Monthly interannual flows calculated with the GR4J and ISBA-MODCOU hydrological models for the periods 1961-1990 (PST) and 2046-2065 (FUT) at Chooz with the 7 climate models of the EXPLORE 2070 project [09] (coloured lines) – Observed flows are dotted in black.

LOW WATER		VCN10		VCN30		QMNA	
2 years	Qobs POD (m^3/s)	31,1		34,5		37	
	Qsim (climat obs) POD (m^3/s)	28,2	14,3	31,8	17	34,7	18,9
	Δ min (%)	−61	−13	−64	−28	−65	−31
	Δ med (%)	−55	−9	−56	−19	−57	−23
	Δ max (%)	−28	−3	−31	−8	−32	−14
5 dry years	Qobs POD (m^3/s)	22,1		24,8		26,1	
	Qsim (climat obs) POD (m^3/s)	18	12,6	19,9	13,8	21,3	15,1
	Δ min (%)	−60	−13	−62	−19	−61	−23
	Δ med (%)	−53	−9	−55	−11	−55	−16
	Δ max (%)	−34	−3	−36	−8	−36	−11
10 dry years	Qobs POD (m^3/s)	18,5		20,8		21,8	
	Qsim (climat obs) POD (m^3/s)	14,2	11,8	15,6	12,4	16,5	13,4
	Δ min (%)	−59	−10	−61	−15	−60	−19
	Δ med (%)	−50	−0	−53	−6	−53	−12
	Δ max (%)	−37	+8	−38	−1	−38	−8

Figure 54: Median, minimum and maximum values at Chooz of the relative changes between the periods 1961-1990 and 2046-2065 of the Bibliography/References VCN10, VCN30 and QMNA calculated with the GR4J model (yellow) and the Modcou model (green) with the 7 climate models of the EXPLORE 2070 project (09)

10.2.3 Wallonia

No new studies have been conducted to assess the potential impacts of climate change on low water flows in rivers.

The Walloon Region has carried out a study on adapting to climate change [10] in seven areas: agriculture, water, infrastructure/land use, health, energy, biodiversity and forests. An extensive consultation of experts has made it possible to identify the main measures to be implemented in order to adapt the Walloon Region to climate change [10]. This study [10] starts with an assessment of the situation at European level, the choice of scenarios to define Wallonia's vulnerability and how to adapt with the help of an action plan.

10.2.4 Germany

Since 2011, North Rhine-Westphalia has been operating a climate impact monitoring system with a total of 30 indicators from 7 environmental sectors.

In order to be able to describe the possible effects of climate change on the water balance, data are regularly collected, in particular on precipitation, water temperature, evapotranspiration, groundwater levels and recharge, the climatic water balance (the difference between precipitation and evapotranspiration) and average river flow.

At the end of 2019, the following trends were observed in this context:

- Winter precipitation increases, average and maximum water temperatures increase, average annual streamflow decreases, groundwater levels (annual average, as well as summer and winter) decrease, groundwater recharge decreases and evapotranspiration (annual average) increases.

The specialized information system can be consulted at the following address:

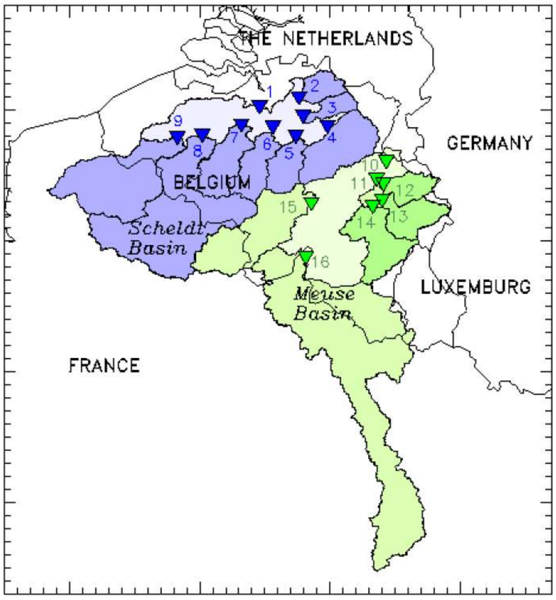
https://www.lanuv.nrw.de/kfm-indikatoren/index.php?mode=liste&aufzu=0,

The report for the year 2016 [11] is available at:
https://www.lanuv.nrw.de/fileadmin/lanuvpubl/3_fachberichte/fabe74.pdf

10.2.5 Flanders

The report on "Updating and refining the climate scenarios for Flanders up to 2100" [12] which is available at www.milieurapport.be, brings together and interprets the available knowledge on climate change with the aim of ensuring the widest possible dissemination in Flanders.

In chapter 4, it summarises the main conclusions of the various studies available on the potential impact of climate change on the hydrological regime of watercourses and refers, as far as the Meuse basin is concerned, to the results obtained within the framework of the "CCIHYDR" research project carried out by the Catholic University of Leuven and the Royal Meteorological Institute of Belgium (cf. figure No. 55 from the article "Climate change and hydrological extremes in Belgian catchments" [13]).



	Watershed	Outlet	Area (km^2)
			Scheldt Basin
1	Scheldt	Antwerp	18801
2	Kleine Nete	Grobbendonk	590
3	Grote Nete	Hulshout	468
4	Demer	Diest	1908
5	Dijle	Wilsele	896
6	Zenne	Eppegem	1096
7	Dender	Confluence	1389
8	Bovenschelde	Asper	5810
9	Leie	St Baafs	3506
			Meuse Basin
10	Meuse	Visé	20588
11	Ourthe	Angleur	3627
12	Vesdre	Confluence	708
13	Amblève	Martinrive	1068
14	Ourthe	Tabreux	1616
15	Sambre	Namur	1964
16	Meuse	Chooz	10120

Figure 55: stations calculated in the framework of the CCI-HYDR project [13]

The hydrological simulations carried out for the purpose of this study are based on the SCHEldt-MEuse model, which is the distributed version of the IRM hydrological model (Bultot and Dupriez, 1976). This model has been successfully used for different catchments ranging from about 100 to 1600 km² and representing different hydrological conditions in Belgium (Gellens and Roulin, 1998).

The structure of the SCHEME model includes 9 land cover types with a snow accumulation and melting module for each type. Evapotranspiration is calculated based on the water intercepted by vegetation and the water content of two soil layers, as well as potential evapotranspiration (PET) according to the Penman formula. Surface water is simulated with a unit hydrograph and groundwater is represented by two reservoirs. The flow produced on each cell of the network is routed to the outlet with a 1-D sub-model taking into account the river network (see figure n°56 (13)).

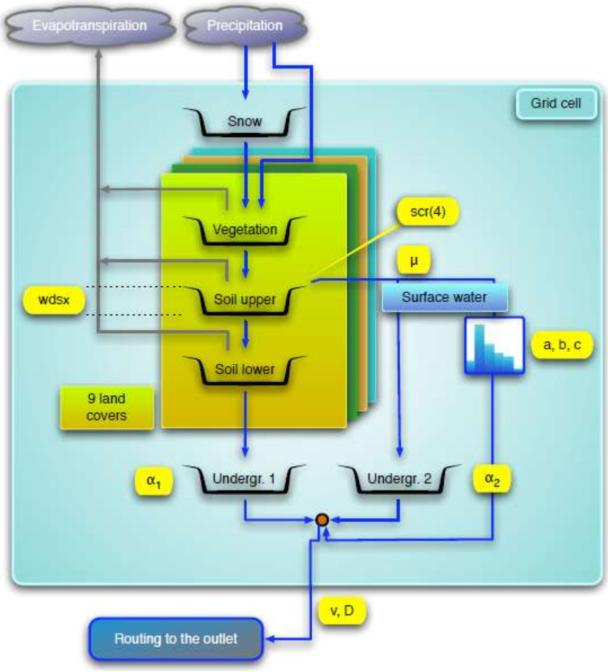


Figure 56: Diagram of the mechanisms of the SCHEME model (13)

The climatic data used in the CCI-HYDR project were obtained by transforming the observed meteorological data on the basis of a variant of the delta change method (see figure n°57 (13)).

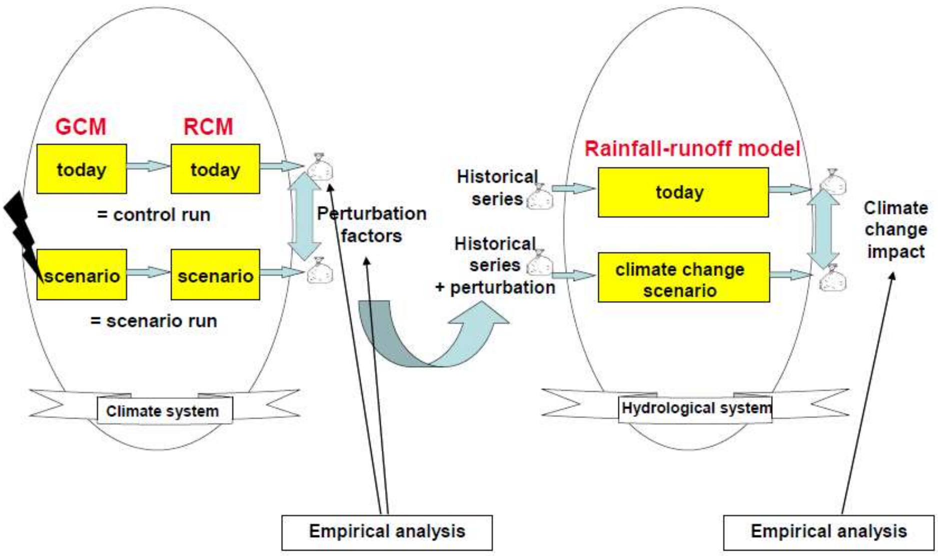


Figure 57: Principle of production of climate data used for calculations with SCHEME (13)

The transformation factors applied to the observed meteorological data were obtained from the results of the European PRUDENCE project [14] where 11 RCMs were used to dynamically downscale the climate data produced by 4 different GCMs according to the A2 and B2 greenhouse gas emission scenarios (cf. table n°15 [13]).

Table 15: climatic data used for hydrological calculations with SCHEME [13]

MEMBER	SCENARIO	RESOLUTION (Km)	SCENARIO	GCM	RCM
SMHI	SMHI-MPI-A2	49	A2	ECHAM4/OPYC	RCAO
	SMHI-MPI-B2	49	B2	ECHAM4/OPYC	
	SMHI-HC-22	24	A2	HadAM3H	
	SMHI-A2	49	A2	HadAM3H	
	SMHI-B2	49	B2	HadAM3H	
KNMI	KNMI	47	A2	HadAM3H	RACMO
METNO	METNO-A2	53	A2	HadAM3H	HIRHAM
	METNO-B2	53	B2	HadAM3H	
DMI	DMI-S25	25	A2	HadAM3H	HIRHAM
	DMI-ecsc-A2	50	A2	ECHAM4/OPYC	
	DMI-ecsc-B2	50	B2	ECHAM4/OPYC	
	DMI-HS1	50	A2	HadAM3H	
	DMI-HS2	50	A2	HadAM3H	
	DMI-HS3	50	A2	HadAM3H	
ETH	ETH	55	A2	HadAM3H	CHRM
HC	HC-adhfa	50	A2	HadAM3P	HadRM3P
	HC-adhfe	50	A2	HadAM3P	
	HC-adhff	50	A2	HadAM3P	
	HC-adhfd-B2	50	B2	HadAM3P	
MPI	MPI-3005	55	A2	HadAM3H	REMO
	MPI-3006	55	A2	HadAM3H	
CNRM	CNRM-DC9	59	A2	ARPEGE	ARPEGE
	CNRM-DE5	59	A2	ARPEGE	
	CNRM-DE6	59	A2	ARPEGE	
	CNRM-DE7	59	A2	ARPEGE	
GKSS	GKSS-SN	55	A2	HadAM3H	CLM
	GKSS	55	A2	HadAM3H	CLM
ICTP	ICTP-A2	52	A2	HadAM3H	RegCM
	ICTP-B2	52	B2	HadAM3H	RegCM
UCM	UCM-A2	52	A2	HadAM3H	PROMES
	UCM-A2	52	B2	HadAM3H	

Figures 58 and 59 show the evolution calculated for the stations of Angleur (Ourthe) and Chooz (Meuse) of the number of days for which the daily flow is lower than the 0.05 percentile. Table n°16 summarizes these results for all the stations of the CCH-HYDR project.

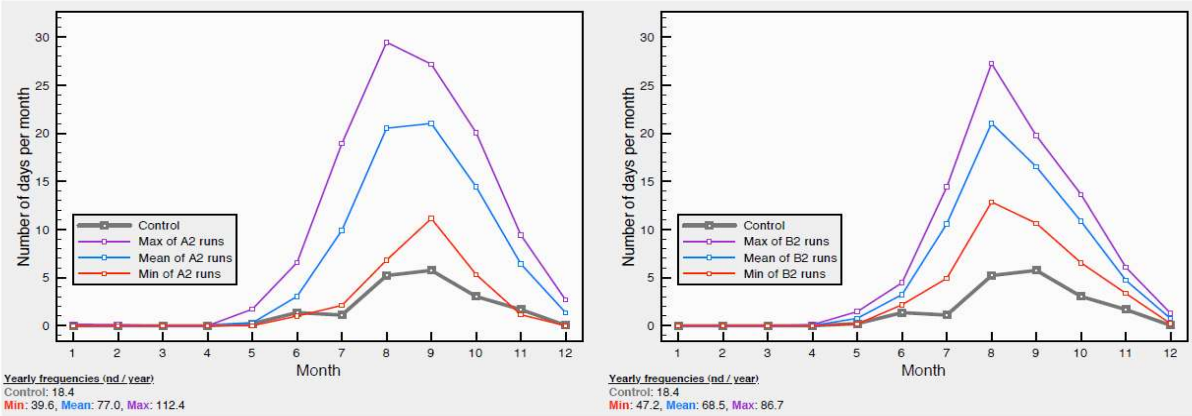


Figure 58: evolution of the number of days for which the daily flow is lower than the 0.05 percentile for the Ourthe at Angleur A2 scenario on the left and B2 on the right (13)

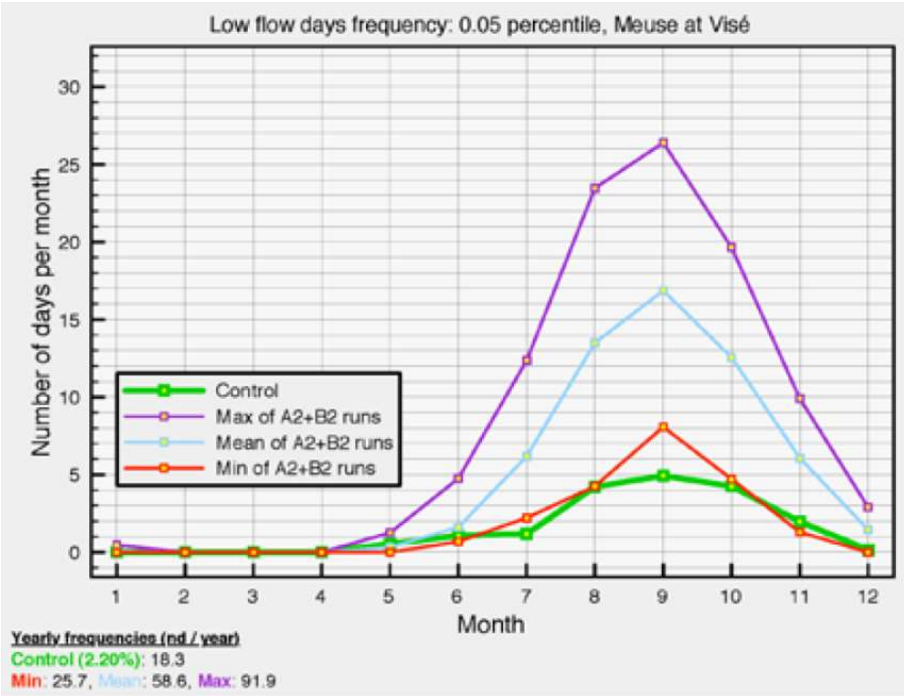


Figure 59: Evolution of the number of days for which the daily flow is lower than the 0.05 percentile for the Meuse at Chooz for all scenarios A2 and B2 on the right (13)

Table 16: Evolution of the number of days for which the daily flow is lower than the 0.05 percentile for the CCH-HYDR project stations and all the A2 and B2 scenarios on the right (13)

		Control	Scenario			Change (%)
			Minimum	Mean	Maximum	
Scheldt	Scheldt at Antwerp	18.5	26.6	60.3	95.1	225.9
	Scheldt at Asper	18.4	24.9	54.5	90.2	196.2
	Demer at Diest	18.3	31.0	60.8	94.7	232.2
	Dendre	18.6	29.8	60.3	89.4	224.2
	Dijle at Wilsele	18.4	19.5	93.8	156.5	409.8
	Grote Nete at Hulshout	18.3	28.1	55.6	84.1	203.8
	Kleine Nete at Grobbendonk	18.3	24.5	53.2	81.3	190.7
	Leie at St Baafs	18.5	15.8	42.8	73.6	131.4
	Zenne at Eppegem	18.4	28.1	73.1	113.8	297.3
Meuse	Ambleve at Martinrive	18.4	43.0	88.0	130.8	378.3
	Meuse at Chooz	18.5	20.9	48.4	77.5	161.6
	Ourthe at Angleur	18.4	39.6	74.9	112.4	307.1
	Ourthe at Tabreux	18.3	35.2	71.2	105.4	289.1
	Sambre at Namur	18.4	29.8	56.7	86.0	208.2
	Vesdre	18.6	30.4	58.7	92.4	215.6
	Meuse at Visé	18.3	25.7	58.6	91.9	220.2

11. Conclusions and recommendations

11.1 Flows

Low flows - like floods - are natural hydrological events that occur at irregular intervals with varying intensities.

The rivers of the Meuse basin as a whole are characterised by a rainfall regime. This means that the amount of water in the Meuse and its tributaries depends mainly on precipitation. Average flows peak in winter or spring and are lowest in autumn due to the summer decrease in precipitation and the increase in evaporation intensity due to temperature and plant growth.

There have been and will continue to be periods of low water in the rivers of the Meuse basin - for example the extremely dry years of 1964 and 1976.

The States and regions in the Meuse catchment area (Germany, France, Luxembourg, Flanders, Wallonia and the Netherlands) have until now used different hydrological parameters to observe and monitor low water levels. However, an international cooperation work needs to be able to agree on a common parameter and threshold values to characterize the low-water phenomenon. After having compared the hydrological parameters most frequently used, the members of the "hydrology-flooding" working group agreed on the use of the mean flow over the last 7 days (M7Q) for low water monitoring).

The States and regions in the Meuse catchment area have also agreed on a 5-category classification for representing the intensity of low water, which is also used by the two international river commissions on the Rhine (ICPR) and Moselle-Saar (ICPMS), with threshold values being set on the basis of statistical data for the parameter VCN7. VCN7 is the lowest arithmetic mean calculated over the seven consecutive days of a given period, in this case over a calendar year (Figure 60).

FREQUENT LOW WATER	LESS FREQUENT LOW WATER	SELDOM LOW WATER	VERY SELDOM LOW WATER	EXTREMELY SELDOM LOW WATER
VCN7 T = 2 years	VCN7 T = 5 years	VCN7 T = 10 years	VCN7 T = 20 years	VCN7 T = 50 years

Figure 60: Flow threshold values used to qualify the intensity of low water

The occurrence of low water is a natural process caused mainly by rainfall deficit, which is likely to occur more often in the future due to climate change. The analysis shows that, in addition to rainfall deficits, the use of surface water for human activities (withdrawals and diversions) also has an effect on the magnitude of low flows.

In the basin, use increases with population density and economic activity according to a South-North gradient, leading to an accentuation of the reduction of flows at low water.

Recommendations:

a) The results of the weekly low-water monitoring carried out within the IMC have so far been disseminated only to the specialists designated in the States and regions in the Meuse catchment area. Wider dissemination of these results to the general public via the IMC website in a way that has yet to be defined would seem to be useful in raising awareness of the importance of this phenomenon among local residents.

b) While for the joint monitoring of low water levels carried out weekly at the level of the IMC, the Meuse has hydrological stations spread over its entire course, which make it possible to see the evolution of flows in the various States and regions it crosses, this is not yet the case for its border/transboundary tributaries, which have either not yet been integrated into this monitoring or only have monitoring on part of their length. An extension of the joint low water monitoring network to the Meuse's (trans)border tributaries could be useful in developing knowledge in this area.

11.2 Impact of low water on the chemical and ecological status of surface water bodies at the borders

Low water is a usual period in the natural hydrological cycle of rivers. Biological functioning and ecological balances have been built around this constraint and organisms have developed adaptation strategies to resist these periods of stress. Alterations occur as a result of disturbances caused by human activities - such as water withdrawals, discharges or water impoundments. These alterations can exacerbate the stress caused by low water and jeopardize natural balances. Possible consequences are the disruption of ecological continuity or a significant drop in the oxygen content of the water, additional warming of the water, slowing of the flow or stratification of the water column. The concentration of some pollutants in streams may increase, but a direct link to lower flows does not always exist. Indeed, during low water periods, flows strongly linked to precipitation are strongly reduced (urban runoff, diffuse agricultural pollution, etc.). On the other hand, in the event of heavy rainfall following a prolonged drought, a sudden contribution of pollution is possible.

The data from the 38 stations of the homogeneous measurement network (HMR) of the Meuse basin (sampling frequency: monthly, annually, every three years) cannot currently be compared in all cases with the results of the weekly low water monitoring of the IMC. Nevertheless, some measuring stations show that the general physico-chemical parameters, among others the oxygen content of the water, can be good and stable even with marked hydrological episodes. It is not possible at present to predict, a priori, the quality of water in a low-water situation because the notions of quantity and quality of water are not necessarily linked.

<u>Recommendations:</u>

c) Within the framework of the preparation of the 3rd management plan under the WFD, the IMC States and Regions should intensify their exchanges on the surface water bodies located in the border regions whose reduced flows are considered as a factor responsible for not achieving good status, as well as on the measures planned to initiate a quantitative improvement. At this level, additional work should be carried out in the future within the IMC.

d) It would also be necessary to further examine the current and future needs for bi- or multilateral coordination in the field of crisis management in exceptional low water situations.

e) It seems necessary to take into account the results of the analysis concerning the link between low water levels and the status of the surface water bodies at the border for the updating of the roof management plan of the international Meuse

River basin district and to renew this work at each cycle of implementation of the Water Framework Directive.

f) It should be checked whether the networks are able to answer the questions raised here concerning low water levels. It is also advisable to carry out a more detailed analysis based on time series, if possible more complete and, if necessary, for more parameters. Continuous measurement series lend themselves perfectly to this exercise.

g) In order to be able to compare the results of quality monitoring in the Meuse basin with the hydrological situation of the watercourses, it is recommended that any extension of the current joint low water monitoring network of the IMC be coordinated with the location of the stations of the homogeneous measurement network (HMR) of the Meuse basin.

11.3 Impact of low water on the various uses of surface water

The water of the Meuse is used for a certain number of purposes (drinking water supply, navigation, industry, agriculture) for which the needs increase from upstream to downstream as the natural flows increase due to the growth of its catchment area and the contributions of its tributaries.

The difference between natural flows and the lowest measured flows (VCN7) increases downstream, which corresponds to an increase in water consumption in that direction.

These human activities can also suffer from low water levels, for example when drinking water or industrial water withdrawals, navigation or leisure activities must be limited.

Water abstractions or diversions that may have a transboundary impact on the low water flows of the Meuse are already the subject of international agreements. In addition, the States and regions in the Meuse catchment area also take measures for the routine management of water uses on their territory in order to cope with low water situations.

Surface water storage, abstraction or diversion projects that may significantly reduce upstream or downstream low water flows in other countries or regions of the basin are coordinated within the framework of impact assessments under the European Directive on the assessment of the impacts of certain public and private projects[6] to ensure a consensus between the parties concerned.

Recommendations:

h) The IMC States and Regions should inform each other in good time of major national projects involving foreseeable transboundary effects on the flows of the Meuse and/or its tributaries, even when these are coordinated within the framework of bilateral agreements and the implementation of the Directive on the assessment of the effects of certain public and private projects.

[6] Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment

11.4 Potential effects of climate change on the evolution of low-water flows

The studies carried out on the potential impact of climate change on the regime of the rivers in the Meuse basin do not always provide information on the evolution of the VCN7 parameter currently used as a reference within the IMC or do not always allow the uncertainties of the hydro-climatic modelling chains used to be assessed in comparison with the observed results or with regard to the evolution of flows over time.

However, all these studies carried out independently, with different hydrological and climatic models, show that **a reduction in low water flows is to be expected in the future even with the most optimistic greenhouse gas emission reduction scenarios**.

In order to face these changes, the States and regions of the Meuse River Basin have all committed themselves to the development and/or implementation of plans for adaptation to climate change in their jurisdiction.

<u>Recommendations:</u>

i) In order to better assess the current situation on the one hand and the modifications of the ecosystems and uses resulting from the increase in temperature and the probable reduction of the watercourse flows on the other hand, it is advisable to develop devices for continuous monitoring of the temperature of the surface water bodies bordering the Meuse basin.

j) It is also recommended to continue, within the IMC working group on "hydrology/floods", the regular exchanges of information and experience on the study projects concerning the potential impact of climate change initiated on future or current projects (CHIMERE 21 for example).

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