First International Scientific Symposium on the River Meuse

November 27-28, 2002
Maastricht, Netherlands

PROCEEDINGS

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Foreword

The first scientific Meuse Symposium was held in Maastricht on 27 and 28 November 2002. under the auspices of the International Commission for the Protection of the Meuse (ICPM), which in the meantime has been renamed the International Meuse Commission (IMC).

The objectives of the symposium were to exchange information on various aspects of the Meuse and its catchment basin, identify existing gaps in knowledge, publicise the work of the ICPM and promote co-operation between scientists and managers from different catchment basin countries. The symposium was organised by the Netherlands and attended by 275 people, distributed as follows over the countries: 11 from France, 88 from Belgium, 21 from Germany and 155 from the Netherlands.

The Meuse Symposium was divided into four themes : "Geomorphology", "Hydrology", "Pollutants and Effects" and "Ecology". We intentionally opted to hold plenary sessions only so as to promote knowledge about all of these disciplines among the participants. This is necessary for working together in an integrated way and strengthens understanding for other concerns. The leitmotif of the symposium was elucidating the interdependencies between the various aspects. For example, the geomorphological structure of the catchment basin influences the water-retaining capacity and the development of high waters, but also defines - together with the layout of the bedding, level management and pollution by all kinds of substances - the ecosystems. Organising things this way also yields deeper insights into cause-effect relationships.

It became clear that a great deal of knowledge exists on the various aspects and throughout the catchment basin. Unfortunately, it often appears that there is little integration of the information on that level. Nevertheless, for the first time a number of lectures offered a river- or basin-wide synthesis.

Those who attended unanimously agreed that the symposium was a great success and had largely met its objectives. Thus it seemed only logical to continue this initiative and organise a scientific Meuse Symposium at regular intervals. France has already stated that it would like to organise the second symposium in 2005.

Prof. Dr. Patrick Meire
Chairman ICPM 2001-2002

PROCEEDINGS

ORAL PRESENTATIONS

Topic 1:

Geomorphology

Geomorphological structure of the (French part) of the Meuse Valley.

J. CORBONNOIS

The French part of the Meuse, 465 km long, drains a catchment basin of 10420 km². The essential characteristics of this part, which constitutes the upstream water of the river, are favourable to a rather slow movement of the water, with frequent overflowing and not very active morphodynamic evolution.
The purpose of this presentation is to identify the essential features that participate in the hydrogeomorphological functioning of the river and explain, in connection with the heritages, the current morphologies.

The current functioning of the river

The functioning of rivers is determined by factors to do with the state, the appearance of the catchment basin and the valley, the geomorphological evolution, and factors to do with dynamics: incline, flow rate, and anthropogenic actions.
For the Meuse, the combination of these factors has proved favourable in delaying the cutting of the river compared with neighbouring rivers, and a small current incision of the minor bed in the alluvial bottom, explaining the frequent overflowing.

1 – **The configuration of the catchment basin** is linked to the diversion of many tributaries that impoverished the river during the Tertiary and Quaternary. The result is a long and narrow shape (Fig. 1) that prompts a slow transfer of water from upstream to downstream.

2 – **The shape of the valley** changes little from upstream to downstream, with an incision in the plateaux of at least 80 to 100 m deep, and alternating rectilinear and sinuous sections (steep-sided meanders). The longitudinal incline is always small, 4% upstream from Bourmont, less than 1% to downstream, with a slight increase in the crossing of the Ardennes (Fig. 2). The bottom of this valley, less than 1000 m wide on average, is covered by a minor, highly sinuous bed, as well as by intermittent outflows that run through the major bed (flood channels).

3 – These characteristics are explained by the **valley's history**. Indicators allow for a paleogeographic reconstitution that leads to the current configuration of the landscapes.

- The levels of the terraces are quite well preserved downstream from the old confluence of the Moselle (Harmand, 1989). As in most valleys in the East of France, a wide corridor, a few dozen metres deep in the plateaux, was drained before the narrower incision which leads to the current shape of the valley. These fluviatile levels were connected to those identified in the Ardennes and up to Maastricht (Pissard et al 1997).
- The abandoned fluvial forms: in addition to the levels of the terraces, the dead valleys of the Moselle and the Bar at about 30 m above the Meuse, illustrate the delayed cutting But its previous force is attested by the size of the valley, and by the steep-sided meanders formed straight after structural discontinuities (Deshaies, 1994), created by a bigger river before the last diversions.
- The characteristics of the alluvial bottom: the appearance of the bottom corresponds approximately to that shaped some 300 000 years ago, but the nature of the materials has been modified. The siliceous alluvium brought by the Moselle, before the capture, have often been cleared and replaced by calcareous sediments (Harmand 1989). They are in turn concealed by 1 to 3 metres of fine materials from the Holocene (Lefebvre 1993) which line the current major bed run through by the Meuse and many intermittent channels.

4 – **The anthropogenic actions** are more discrete in comparison with other valleys. In the major bed, the land occupation is predominantly rural with a clear predominance of grassy sections, except for the many towns downstream. In the minor bed, they comprise dams that feed diversions to sawmill and old mills, or to the north branch of the East Canal which runs along the Meuse from the uphill slope of Commercy. Sixty-five (65) in all, these dams are more or less well kept. They raise the water line over several kilometres upstream, thus aggravating the risk of overflowing. Furthermore, the scraped minor bed is characterised by higher banks, delaying the overflowing and allowing for the development of crops in certain locations.

These four major factors explain the current conditions of the water flow in the alluvial bottom and fix the characteristics of the alluvial dynamics. These are expressed discretely: sapping and slow recoiling of the banks, highly localised alluvial accumulations. But it is quite active to maintain locally live forms. Frequent overflows because of the low banks and the level raised by the many dams continue to disperse energy and constitute a limit to erosion on the minor bed.

But there are local variants to this overall operating pattern that are explained by the various operating orders, according to the sectors. Thus, the nature of the subsoil, the width of the alluvial bottom, the course of the Meuse, and anthropogenic actions make it possible to identify four sectors (Fig. 2). Other heterogeneous elements appear on a larger scale, as shown by the Stenay section.

The Stenay section

A detailed cartography of the major bed and the analysis of cross sections (communicated by the department of infrastructure and facilities (known by the French acronym DDE) of the Meuse) show important morphological variations over short distances.
The alluvial bottom is crossed by a dense network of natural drains (minor bed, water level channels, old meanders) as well as artificial drains (drainage canals, the East Canal), to which should be added some gravel ponds (Fig. 3).
This network has a widely variable capacity. The sections through the minor bed reveal major differences in surface areas of wet sections (from 80 to 200 m²) and overflowing rates (76 to 375 m³/s), depending on the height of the banks and the arrangements of the bed: cleaning of the bed and artificial raising of the water line over 6 kilometres upstream from the Stenay dam, a vestige of an old navigation channel downstream from Sassey, unauthorised aggregate extraction with lowering of the banks, and over-excavation of the bed lead to erosion.
This mechanism affects the filling conditions of the major bed during overflowing periods and the current functioning of the alluvial bottom.
The channels and old meanders, the formation of which is difficult to date, are located precisely where the bed's capacity is reduced. Used during overflowing periods, they contribute to the rapid dispersion of the energy from the overflows. The grassland suffices to prevent their development. So the Meuse is virtually stable.

Finally, this section comprises a summary of the Meuse's bed configurations. It shows that anthropogenic actions have caused a slow adjustment of the river spread over many decades. But whereas punctual actions may disturb this functioning, the characteristics of the river system nonetheless help contain the effects thereof over short distances.

Conclusion

More detailed studies are needed to determine with greater precision the conditions under which the Meuse's beds are changing and to assess the speed of that change.
The river seems to be relatively stable on the scale of the entire valley, proof of a dynamic balance left relatively undisturbed by anthropogenic actions. The configuration of the setting reveals a slow development that combines the workings of the minor bed to that of the major

bed through frequent overflows. They in turn indicate a small incision of the bed and that overflows are part of the river system.
The conditions under which the valley is used, in particular the occupation of the soil, have made it possible to preserve this environment, so an effort should be made to preserve the workings thereof. But this features in the manager's current concerns.

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Fig 1: The French part of the Meuse catchment basin

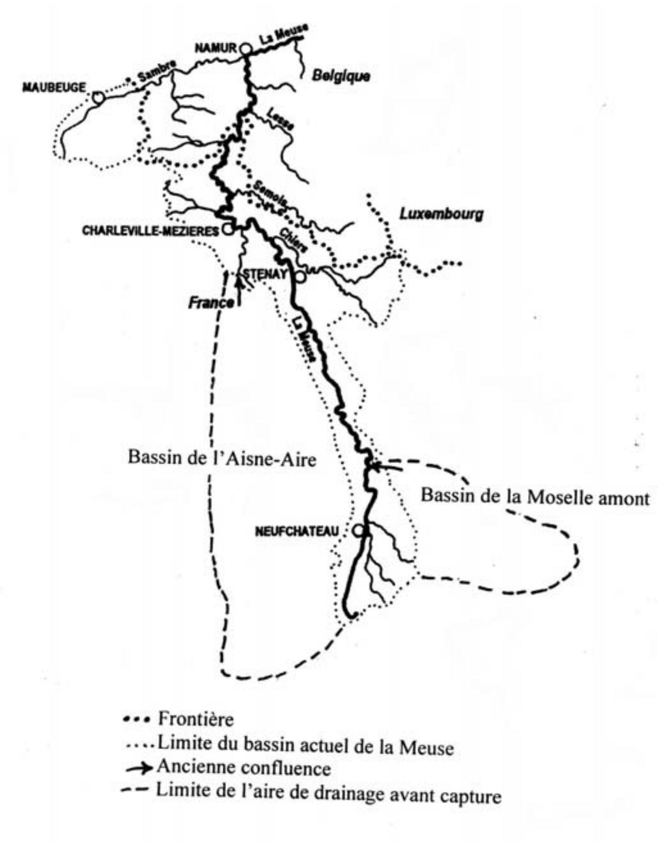
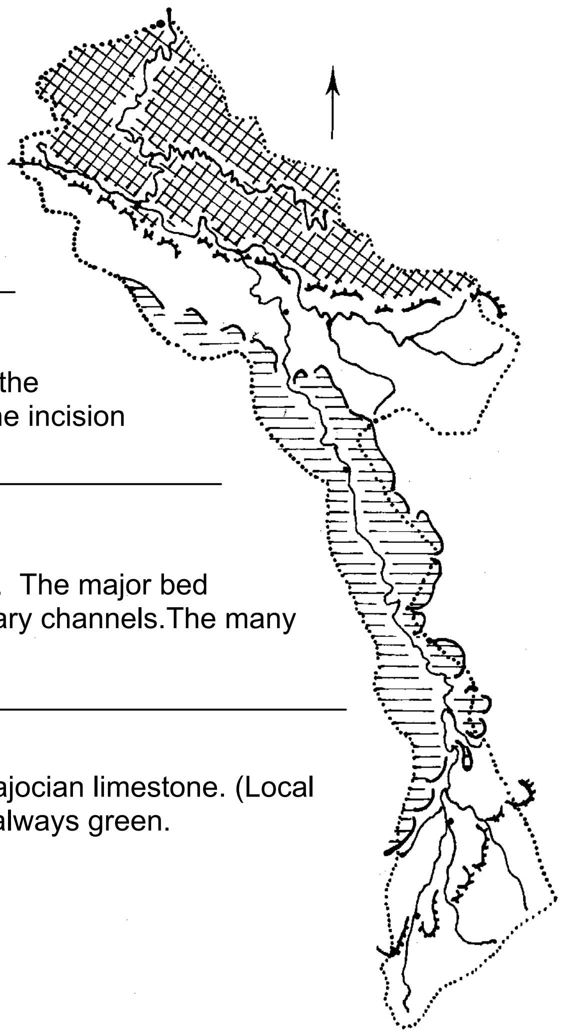


Fig 2a: The major constituent sectors of the Meuse Valley



Downstream from Charleville Mézières:
The Meuse forms steep-sided meanders in the Ardennes base. The arrangements are quite strict.

From Dun sur Meuse to Charleville Mézières:
The alternating narrow and wide sectors affect the flow of the water and create favourable conditions for the raising or the incision of the minor bed

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From Domrémy to Dun sur Meuse:
The valley is clearly overcalibrated in Oxfordian limestone. The major bed is crossed by a very winding minor bed and many secondary channels.The many dams promote frequent overflows.

Upstream from Domrémy:
The valley is rather curved except in the crossing of the Bajocian limestone. (Local draining). The soil occupation comprises sectors that are always green.

Fig 2 b: Section along the alluvial bottom of the Meuse from the spring to the border

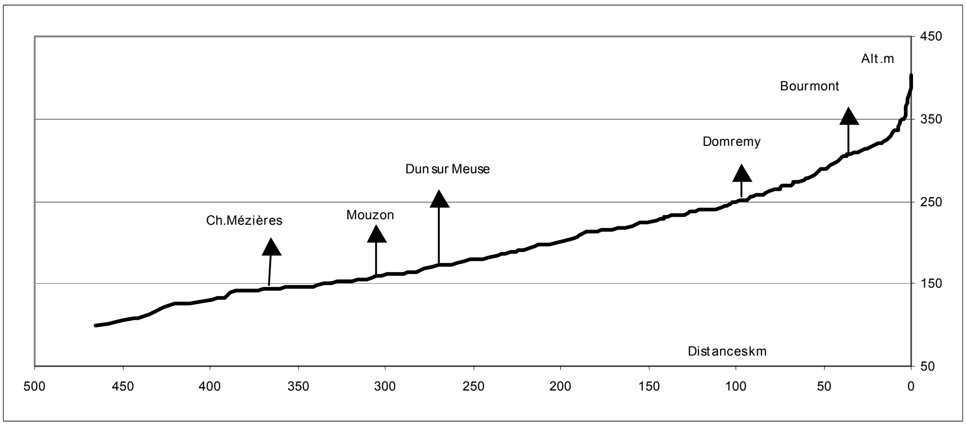


Fig 3a: The Sassey-to-Stenay section. Configuration of the alluvial bottom on a larger scale.

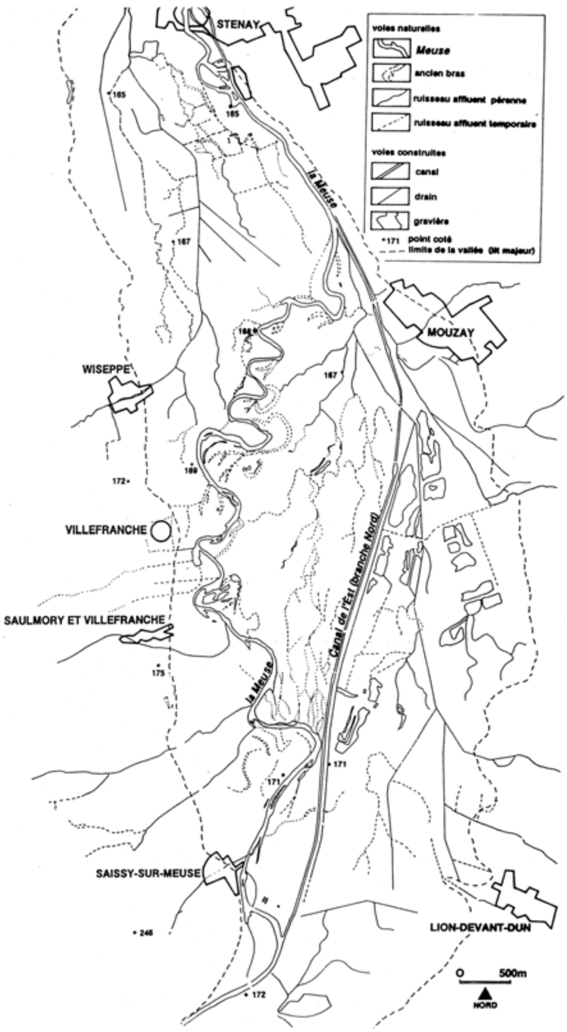


Fig 3b : *Different aspects of the alluvial*

Appearance of the major bed to the North of Verdun (Charny sur Meuse dam)

Overflowing channel near Domrémy

Appearance of the minor bed near Lacroix sur Meuse

Morphodynamics of the Meuse River and its tributaries in the Ardenne Massif

F. PETIT

The morphodynamics of the Meuse River change radically on entering the Ardenne Massif, with regard to the hydrological regime and the nature and amount of bedload carried. In Lorraine, the Meuse catchment is elongated with few tributaries, as a result of various instances of river capture as described by Pissart *et al.* (1997). When the Meuse reaches the Ardenne Massif close to Charleville, it enters an area of Palaeozoic rock that it does not leave until downstream of Liege. This area of Palaeozoic rock largely corresponds with the Walloon part of the river's course and its basin. Due to the resistant nature of the primary rock and the geomorphological heritage of the area, especially in terms of relief energy, the Meuse valley is narrow and incised. The alluvial plain here is narrow when compared to the upstream part of the course (in Lorraine) and especially when compared to what one sees downstream. As a result, the extent of the zone liable to flooding is limited and hence the amount of water that may be stored here during periods of flood is also limited. In natural conditions this also reduces possibility of riverbed shifting and the formation of free meanders.

The greatest numbers of tributaries flow into the Meuse between Monthermé and Liege. Moreover a substantial increase in catchment size is evident: at Charleville the area of the Meuse basin is 7682 km², whereas at Visé, on the border of Belgium and Holland, the basin covers 20802 km² (Vereestraeten, 1970). This indicates the importance of the rivers of the Ardenne, especially in relation to bed load supply (coarse material that makes up the riverbed), which leads to an increase in the slope of the river as it crosses the Ardenne Massif.

But the Meuse has undergone a strong anthropogenic influence (especially between Namur and Liege) in response to requirements for both navigation and flood protection. Measures in this regard mainly consist of embanking, regular dredging of sediment and enlarging of the channel, and construction of locks which create calm stretches of water (Micha & Borlée, 2000). In this way, the geomorphological action of the river has been greatly disturbed, limiting lateral erosion and resulting in the disappearance of riffles and the removal of many islands.

These measures have also had an impact on transport and sedimentation of the suspended load. Samples were taken systematically in 1980 and 1983 (Close-Lecocq *et al.*, 1982; Lemin *et al.*, 1987) and have been compared to a study made a century earlier by Spring & Prost (fig. 1a). A significant difference may be seen between the sediments currently transported by the Meuse and those transported in 1883. These differences may be explained by changes made to the riverbed for navigational purposes. When the level of water is low, flow is extremely slow in the more or less horizontal stretches of water behind weirs. This allows the sedimentation of suspended elements and greatly reduces the load carried by the river. As the discharge increases the deposited sediments are remobilised and the load is greater than it would have been without human interference to the course of the river. But there is also an additional modification: the amount of total suspended load has considerably increased since 1883. This may have as much as tripled over the course of the past century.

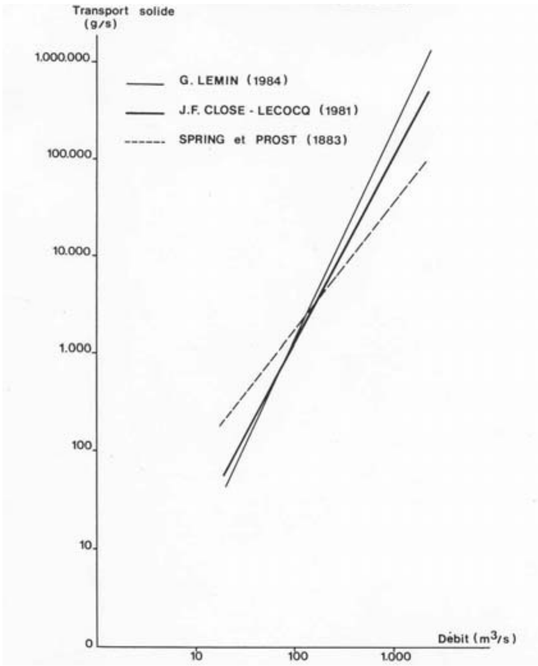
According to an early hypothesis, this increase was a result of the industrialisation of the Sambre-Meuse valley. But analysis of the industrial discharge shows that these quantities of discharge were largely counterbalanced by the dredgings carried out on the Meuse. Therefore, the increase of transported sediment is the result of another factor. Deposition of sediment on the floodplain during flooding had previously limited the increase in suspended load. Nowadays the river is almost entirely channelled and rarely floods, thus it allows the load that has been brought from upstream to be evacuated. This hypothesis was confirmed using a calculation based, on one hand, on the increase of the load during the last century and, on the

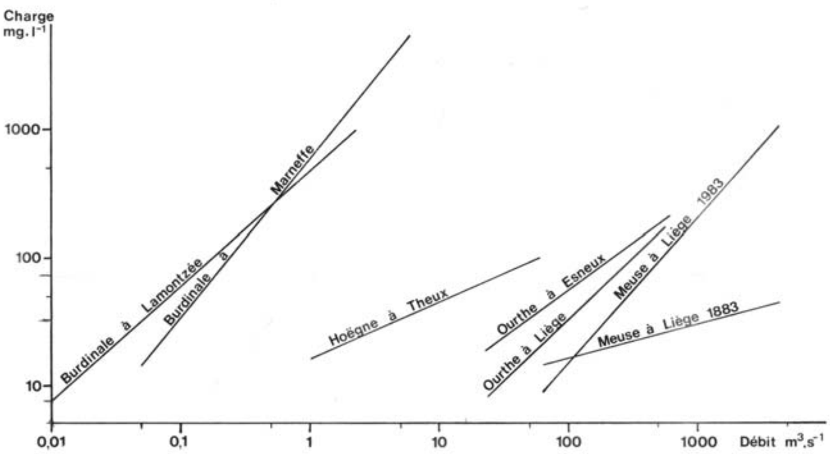
other hand, on the sedimentation rate in the floodplain. The latter was estimated using the presence of well-known ancient tracers (microslag from middle age metal working).
Figure 1b shows other relationships between the concentrations of suspended load and the discharges of the tributaries. These differences relate to land use and thickness of loess cover in the catchments (Lamalle *et al.*, 1989).

Figure 1:

A: comparison between the curves showing the relation between the logarithms of suspended transport (kg/s) and discharge (m³/s) for the Meuse river in Liège; data taken from Spring & Prost (1883), Close-Lecocq et al. (1982) and Lemin et al., (1987). ⇨

B: Lines of regression established between the suspended load (concentration in mg.l⁻¹) and the discharge of different rivers of the Meuse Basin (Lamalle et al., 1989). ⇩





Another study consisted of sampling the suspended load in different reaches of the Meuse (Vrolix & Pissart, 1989). Two illustrative examples are taken from figure 2.

- Between Andenne and Ivoz: the lines are very close and are not significantly different. This indicates that the sediment supply from tributaries such as the Mehaigne and the Hoyoux do not seem to affect the sediment load transported by the main river.
- In contrast, between Ivoz and Monsin the lines are significantly different for a large part. An estimation of the quantities passing through Ivoz and Monsin shows that, for the discharge range considered, even though the Ourthe carries a non-negligable load, the suspended load carried at Monsin is less than that at Ivoz. The discharge that flows into the Albert canal does not explain this decrease in load. These observations show that there is a zone of

sedimentation between these two stations (notably where the river widens upstream of Monsin) but this is at least partially mobilised by discharges of the order of 700 m^3s^{-1}.

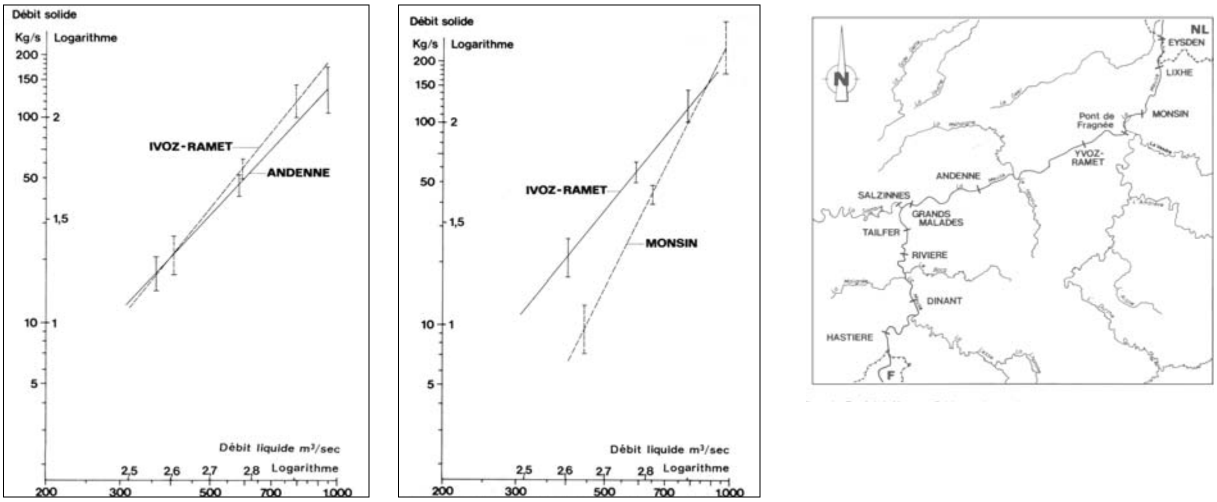


***Figure 2**: Relation between the solid discharge of suspended load and the liquid discharge between Andenne and Ivoz-Ramez (see location on the map). Vertical lines show the 95% confidence intervals of the different regressions (Vrolix & Pissart, 1989).*

Generally speaking, little is known of the quantities of coarse sediment that rivers transport. In the case of the Meuse, regular dredging and deepening of the channel (for navigation) have led to the uniformisation of certain sections (almost total disappearance of bedforms) and an impoverishment of the bedload, to such an extent that the bedrock is exposed at the bottom of the riverbed. This deficiency of coarse sediment automatically limits the amount of sediment that may be carried during flood events.
The following seems to confirm this theory: in the city of Liege, holes present into the riverbed (surveyed during the 1960's) act as veritable sediment traps. Surveys carried out by the *Service de la Meuse liegeoise* (Ministère de l'Equipement et des Transports) at the end of the 1980's show that these holes are still not filled in. This confirms that the sediment discharge of the bedload has been greatly limited.
However, some sediment transit is not out of the question. Indeed, other surveys also made in collaboration with the *Service de la Meuse liegeoise* show that there are holes full of alluvial sediment between bedrock outcrops that appear in the bed. Samples were taken in order to perform granulometric analysis. Due to its size, this material may be partly mobilised during high discharges allowing the possibility of bed reshaping and allowing the bedload to be used once again as a tool by the river.

Dynamic of the Ardenne Tributaries of the Meuse
Considering the significant influence of the Ardenne rivers on the dynamic of the Meuse, the value of understanding their geomorphology must be acknowledged. A synthesis of the main rivers of haute Belgique (the upland area of Belgium) focuses, first of all, on the identification of the bankfull discharge of about 30 rivers at more than 50 different stations. This has led to an outline of regional typology (Petit & Pauquet, 1997).
The bankfull discharge recurrence was calculated by adjusting the partial series of discharges in Gumbel's law: this recurrence is in the order of 0.4 years for small rivers of the Ardenne and is hardly greater than 1 year for rivers such as the Ourthe, Ambleve, Lesse and Semois. However, this value is significantly greater for the rivers of Famenne, Condroz, Hesbay and the Lorraine region of Belgium.
A brief synthesis of studies on bed load mobilisation and carriage has also been proposed.
The occurrence of bedload mobilisation was defined using tracers (coloured tracers, magnetic tracers and radio emitting tracers). Such experiments carried out on the Ourthe, the Lesse and many of their tributaries have shown that bedload mobilisation occurs at discharges that are

clearly less than the bankfull discharge. In this way, material is carried much more frequently than is generally accepted (Petit et al., 1996). This method also allowed the size of material transported by these rivers to be determined (D_{50} moved in the region of 50 – 70 mm).

It was also possible to gain an idea of the quantities carried by these rivers on the basis of the records of quantities of sediment regularly removed from the bed. Dredging is carried out systematically in the same locations and these sites end up playing a role similar to that of a sediment trap. Also, control profiles are made for each dredging in order to ensure that the riverbed returns to its initial elevation. These values, expressed in specific bedload discharge in order to allow comparisons between basins of different sizes, vary from 0.5 $t.km^{-2}.an^{-1}$ for rivers such as the Ourthe and Ambleve to 1.2 $t.km^{-2}.an^{-1}$ for the Semois, and exceed 2 $t.km^{-2}.an^{-1}$ for smaller rivers of the northern Ardenne (Petit *et al*., 1996; Gob *et al*., 2003).

Finally, the speed of bedload propagation (sedimentary wave) was estimated for relatively long time intervals thanks to the presence of semi-natural tracers (Sluse & Petit, 1998; Houbrechts & Petit, 2001). These tracers consist of slag left over from metalworking that was carried out in the valleys of the Ardenne region during the middle ages. This slag was disposed of in the rivers and acted (and still acts) in the same way as the bedload. Lastly, it can be stated that this bedload propagation is relatively slow (between 1.8 km and 3.3 km per century) yet corresponds well with the rare values proposed in the literature.

ACKNOWLEDGMENT

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PROCEEDINGS

ORAL PRESENTATIONS

Topic 2:

Hydrology

A hydrological description of the Meuse basin

M. DE WIT, F. POITEVIN, P. DEWIL, AND F. DE SMEDT

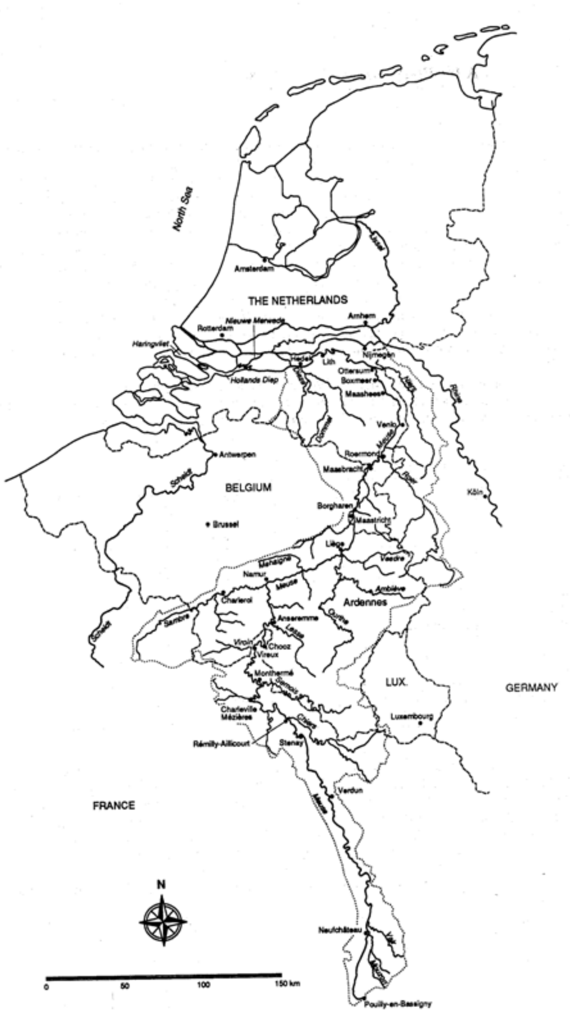
Introduction

The Meuse is used for the supply of water for domestic, industrial, and agricultural use. The Meuse is also used for navigation, and fulfils ecological and recreational functions. Moreover, the floodplains of the Meuse offer many favourable conditions for human settlement. Floods and low flows are natural phenomena that may hamper the above mentioned functions of the Meuse. This implies that the benefits of the use of the Meuse and its floodplains have to be balanced against the risks associated with the use of the Meuse and its floodplains. A good understanding of the hydrology of the Meuse is needed to make up this balance.

River basin

The Meuse basin (Figure 1) covers an area of approximately 30,000 square kilometres, including parts of France, Luxembourg, Belgium, Germany, and the Netherlands. The Meuse basin has a temperate climate, with rivers that are dominated by a rainfall-evaporation regime, which produces low flows during summer and high flows during winter. The Meuse basin can be subdivided into three major geological zones: i) the Lotharingian Meuse (upstream of Charleville-Mézières). This part of the Meuse basin mainly consists of consolidated sedimentary Mesozoic rocks, ii) the Ardennes Meuse (between Charleville-Mézières and Liège). Here the river transects the Paleozoic rock of the Ardennes Massif, and iii) the lower reaches of the Meuse (downstream of Liège). The Dutch and Flemish lowlands are formed by Cenozoic unconsolidated sedimentary rocks. The hydrological conditions of the Meuse basin are to a large extent a reflection of the geology of the Meuse basin. The average annual precipitation amounts 800 to 900 mm·year^{-1} in the southern part of the basin, around 700 to 800 mm·year^{-1} in the northern part of the basin and more than 1000 mm·year^{-1} in the Ardennes. The average discharge of the Meuse at the outlet (Hollands Diep) is approximately 350 m^3·s^{-1}. This corresponds to a precipitation surplus of almost 400 mm·year^{-1}.

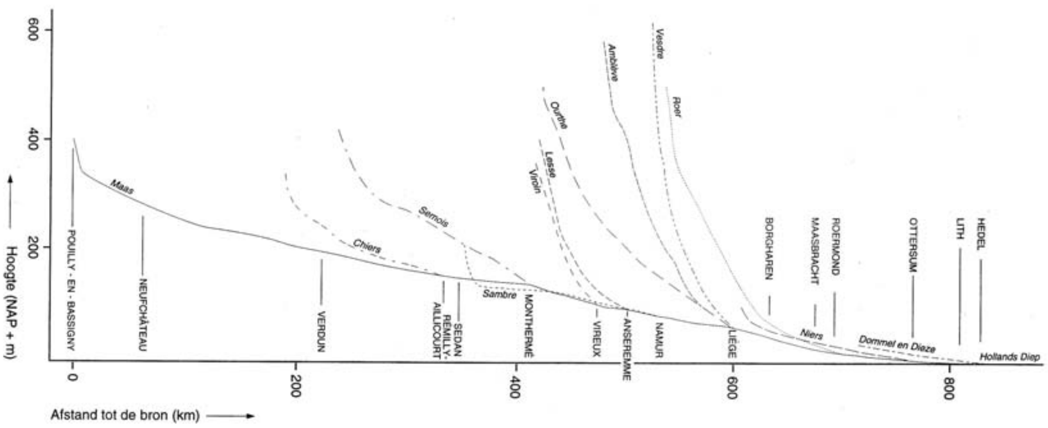
Figure 1. Location of the Meuse basin



River network

The gradients of the Meuse and its main tributaries are shown in Figure 2. The largest gradients, up to 5 m·km^{-1}, are found in the tributaries that spring in the Ardennes/Eifel Massif (Semois, Viroin, Lesse, Ourthe, Amblève, Vesdre, and the upper reaches of the Rur). From Neufchateau to Maasbracht the Meuse has a rather constant gradient of on average about 0.5 m·km^{-1}. However, the floodplain of the Meuse changes moving from south to north. In the southern part of the basin the Meuse flows through a hilly landscape with wide floodplains. Here the Meuse is partly regulated by weirs and partly flanked by a lateral canal. Even during an average flood, a wide floodplain gets inundated (see Figure 3). These inundations cause a weakening of the flood. This explains why flooding events in the southern part of the Meuse basin often don't cause serious problems in the central and northern part of the Meuse basin. In the central part of the Meuse basin between Charleville-Mézières and Liège the Meuse is captured by the Ardennes Massif. In this stretch the Meuse is completely regulated with weirs and it flows through a narrow steep valley where flood waves are hardly weakened. The width of the floodplain (winterbed) in the northern part of the Meuse basin generally varies between 200 meters and two kilometres. Between Borgharen and Maasbracht there are no weirs and the river is flanked by a lateral canal. Further north the Meuse is regulated with weirs and becomes a typical lowland river with a small gradient. Downstream of Boxmeer the river is embanked.

Figure 2. River gradients of the Meuse and its tributaries
source: Berger (1992)



Human impact

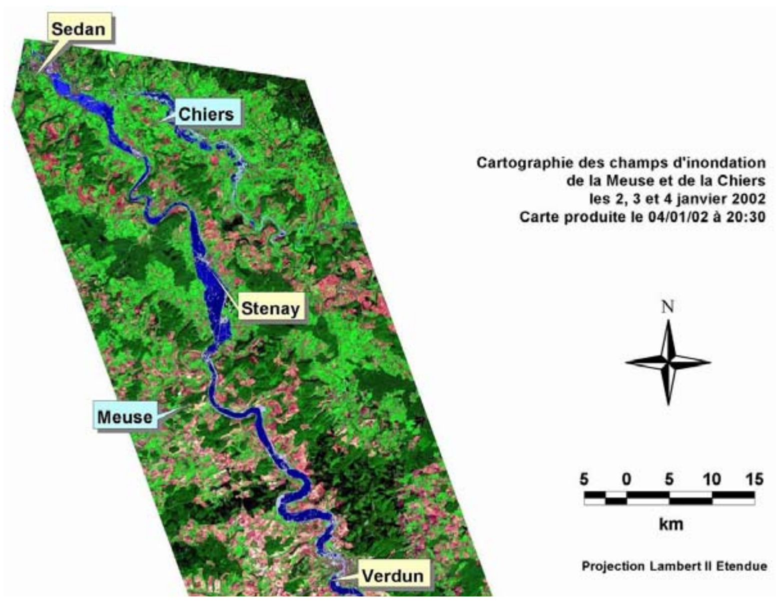
Ever since the first human settlement, human activities have effected the regime of the river Meuse. Agriculture, forestry and urbanisation have changed hydrological processes that relate to soil conditions and land cover, such as infiltration and evapotranspiration. However, the overall effect of these changes on the regime of the Meuse is not unequivocal and hard to quantify. Far more pronounced are the human impacts on the river network. Over large stretches the Meuse has been regulated, deepened, and canalised. Weirs, locks, canals and reservoirs have been constructed all over the Meuse basin. All these river works have been motivated by the need to use the river as a reliable source for water supply, electricity production and navigation. During low flows these river works have a strong impact on the discharge regime of the Meuse. A number of canals are fed by water of the Meuse. These canals are not only used for navigation but also play a crucial role in the water supply of Flanders and the southern part of the Netherlands. Together these canals discharge almost 50 $m^3 \cdot s^{-1}$, partly to areas that are located outside the Meuse basin. Reservoirs are found in the upper branches of the Rur, Viroin, Semois, Sambre, Amblève, Ourthe, and Vesdre. The volume and upstream area of the largest reservoirs are presented in table 1. These reservoirs are mainly used for electricity production, drinking water supply and (low) flow regulation. The total area located upstream of the reservoirs is relatively small and therefore the reservoirs have only a limited potential to be used for flood reduction in the river Meuse.

TABLE 1. LARGEST RESERVOIRS IN THE MEUSE BASIN

Reservoir	Sub-basin	River	Upstream area (km^2)	Volume (10^6 m^3)
Reservoirs system Eau d'Heure	Sambre	Eau d'Heure	80	85
Barrages de la Vesdre/Gileppe	Vesdre	Vesdre/Gileppe	160	51
Bütgenbach/ Robertville	Amblève	Warche	110	19
Rurtalsperre/Urftalsperre/Oleftalsparre	Rur	Rur/Urft	667	267
Wehebachtalsperre	Rur	Wehebach	44	25
Total			1061	447

Figure 3. Inundated floodplains between Verdun and Sedan

Source: Imagerie SPOT - Copyright CNES 2002 - réalisation SERTIT dans le cadre de la Charte internationale Espace et Catastrophes naturelles.

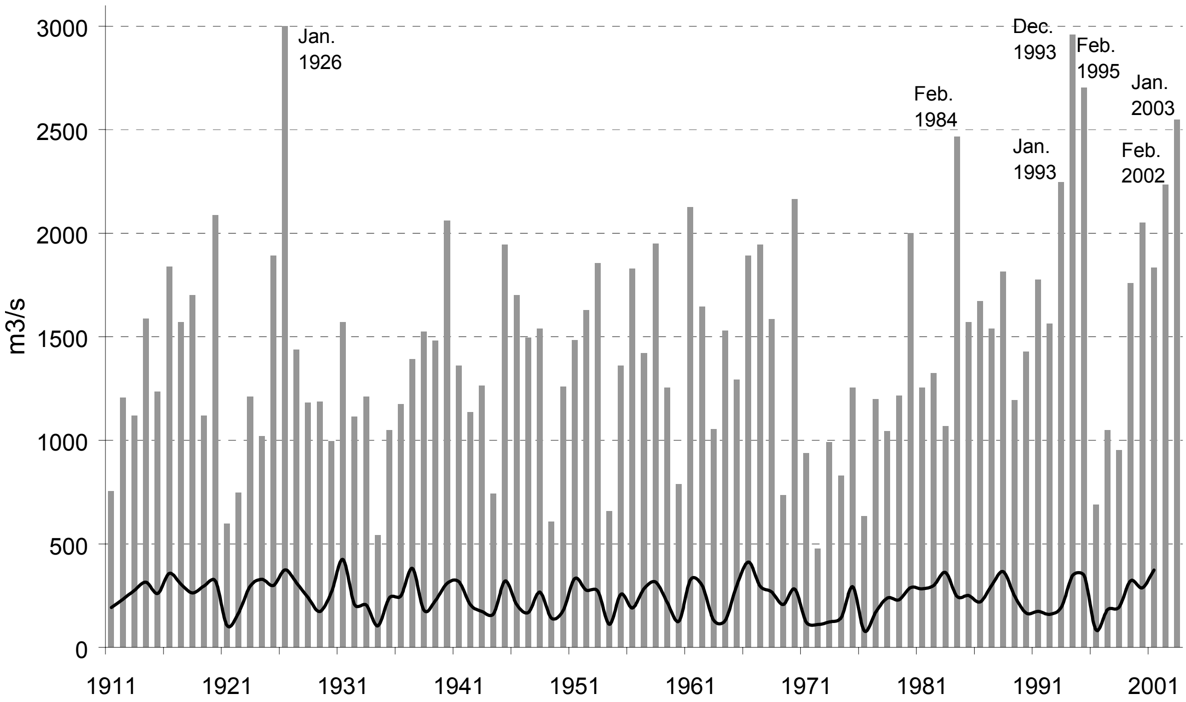


Measured discharge

The discharge of the Meuse has been measured at Borgharen (near Maastricht) since 1911. This record offers the opportunity to analyse whether the discharge regime of the Meuse has been changed over the last 90 years. The years in the graph (Figure 4) are hydrological years (from October to September). From this record it can be observed that the average annual discharge of the Meuse strongly varies. During a dry summer the discharge can be twenty times lower than the average discharge. During the floods of 1926, 1993, 1995, and 2003 the peak discharge was about ten times larger than the annual average discharge. Also the variation between different years is large. For example, the average discharge of the year 1966 was about five times larger than the average discharge of the year 1976. However, the long term variation in the annual average discharge of the Meuse appears to be small. It is striking that six of the seven maximum discharges at Borgharen in the 1911-2003 record occurred during the past twenty winter seasons. The Borgharen record is too short to conclude whether this is coincidence or a sign of climate change.

Figure 4. The maximum (bars) and annual average (line) daily discharge at Borgharen ($m^3 \cdot s^{-1}$)

Source: Rijkswaterstaat, The Netherlands



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Berger, H.E.J. (1992). Flow forecasting for the river Meuse. PhD Thesis Technical University Delft, The Netherlands.

Low water flow rates and inter-annual module of the Meuse in France

M. AUER

Presentation

(Slide: 1 overall location map)

My presentation will be geared to the methodology that has made it possible to calculate, with high precision, certain characteristic low water level values and average flow rates. I will not broach the quantitative aspect of low water levels, which continue to entail very small outflows, their spatial variability notwithstanding. This approach has led to a document called "low water flow rate and module catalogue"

The purpose of this document is to meet the requirements of the water act and the fisheries act relative to knowing the monthly low water flow rates (QMNA5) and the inter-annual module at every point of the hydrographic network.

Location

(Slide: 1 map of the hydrographic network with indication of the hydrographic stations)

The River Meuse originates in Pouilly en Bassigny, in the "Department" of the Haute Marne, heads North and, after running 490 km in France, crosses the Belgo-French border at Givet. Its hydrological catchment basin at this point is 10,430 km², only 7,800 km² of which is administratively situated in France.

The geological aspect can be defined in 4 major figures:

Slide: 1 geological map

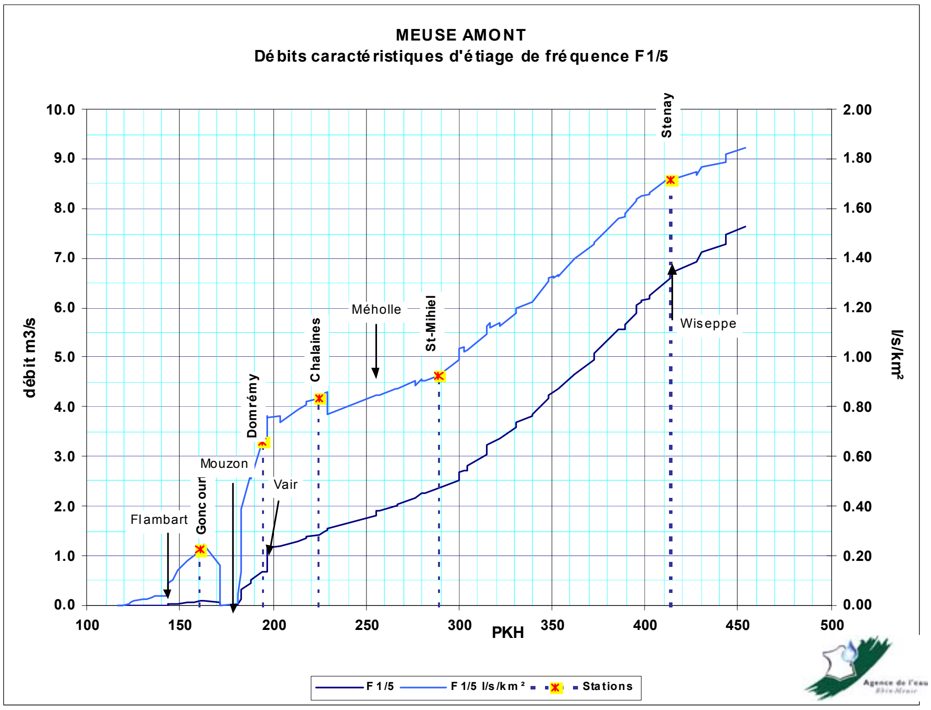
- The upstream, with its marls and clays, and some outcropping Rhetian sandstones: very slight support for low water levels. The upstream sector of Neufchâteau, with extensive faults and entirely installed in the Dogger limestones: sizeable, even total losses.
- The middle course of the Meuse, tightened between its inclines, then very narrow for 150 km from Neufchâteau to Stenay, with its limestone formation on either side: important local support for low water levels by the draining of its aquifers.
- From Stenay to Charleville Mézières with its main and important tributary, the Chiers: a transitory geological formation with:
  - The clays, marls and limestone of the Dogger, and very slight support for low water levels on the one part;
  - The aquifer of the Ardennes-Luxembourg sandstones on the right bank of the Chiers and the Meuse downstream from the confluence: high support for low water levels.

➢ The Meuse downstream which runs through the primary lands of the Ardennes massif: sound support for low water levels.

Calculation of the low water flow-rate characteristics:
(Slide: 1 map of the hydrographic network with indication of the hydrometric stations and table of the results)
These are known only to the hydrometric stations, i.e. a 30-point network over the entire basin in France. A methodology had to be developed to estimate a flow rate on a number of far denser points.

The stations:

The calculation is carried out on a homogenous series of 20 years (1971-1990): This choice was made after a preliminary specific study to obtain the complete chronicles over a representative period. A common statistical distribution law for all stations was applied to avoid distorting the results. An adjustment of this law made it possible to define 3 frequencies of monthly low water flow rates with a return period of 2.5 and 10 years.



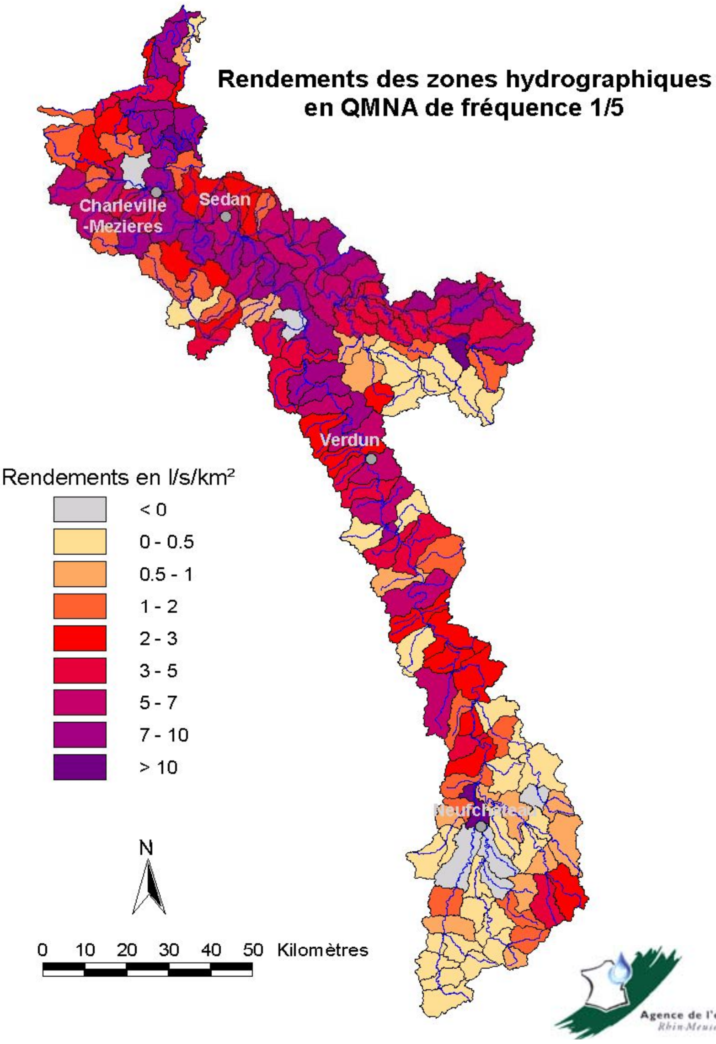
The profiles:
(slide: 1 hydrological profile of the Meuse in PK)

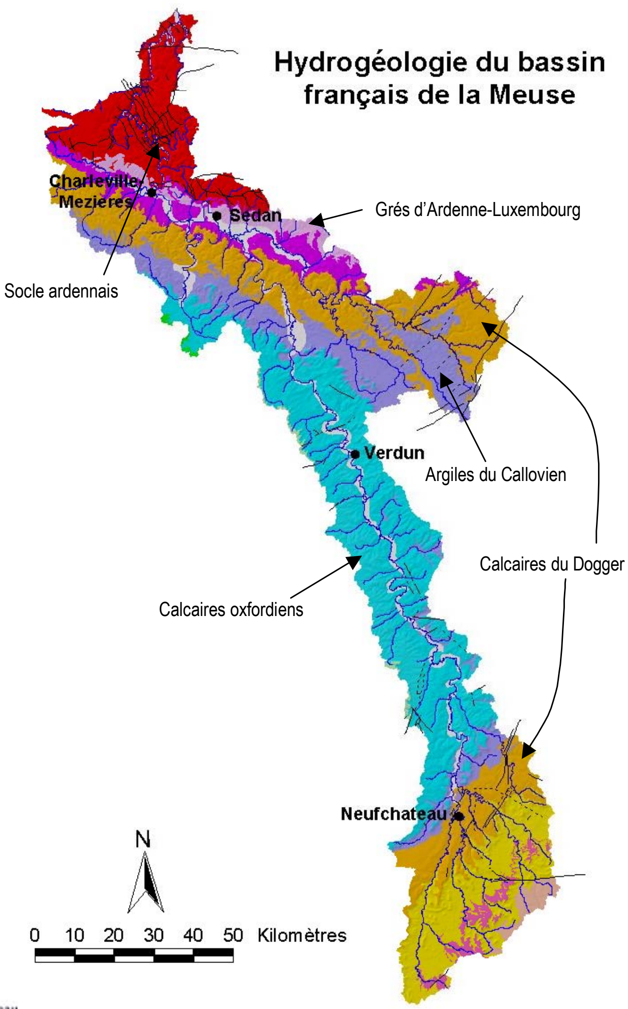
The method is based on several flow-rate measuring campaigns during low water periods on the river itself and on a sizeable number of its tributaries. At least 3 flow rate measuring campaigns over one or more years were carried out with monitoring points (> 3) at predefined strategic nodes. The purpose of this approach was to chart a standard hydrological profile per measured water flows; this same profile was then based on the characteristic flow rates calculated at the hydrometric stations.

The results:

This method yielded results on more than 700 points in the 94 water courses studied in the Meuse basin. They now refer to all uses (administrative authorities and water supply boards), and the density seems to be insufficient, because demands are also at intermediate points and at water courses not yet studied.

Related results





QMNA yield map:

These operations provide interesting information that can be used to calculate data on the intermediary points, such as the map of specific flow rates attributed to each hydrographic section. The attributed value naturally corresponds only to the main water course that defines the area and is calculated on its outlet.

Calculation of the inter-annual modules

(Slide: 1 rain map)

The method is different from that used to calculate the low water flow rates. It is based on annual precipitation. A specific study was conducted using an MNT on a grid of points at 1 km intervals for which an annual precipitation rate was calculated. This approach led to a rain map of reference based on the same period as the low water flow rates. The next step will be to define the flow deficits by correlation between the water that has flowed at the catalogue's reference hydrometric station with the precipitation rates calculated above. The calculation of the inter-annual module is based on the results at the hydrometric stations.

River management and low flows in the river Meuse in the Netherlands

M. Sc. A. Jaskula-Joustra

Characteristics of the Meuse

The Meuse takes its rise in France at the Langres plateau and flows further through Belgium, the west of the Ardennes. In Eijsden (south of Maastricht) it reaches the Netherlands and it flows to the Hollandsch Diep. The river can be divided in three parts:
The upper course (from the source to the mouth of Chiers; that is almost the whole French part of the river)
The catchment area is here long and narrow, but the flood plains are wide and the ground is porous. This area can store much water and the discharge pattern is rather calm: the peak discharge during floods is relatively small and in dry periods the discharge is relatively high.
The middle course (from the mouth of Chiers to the Dutch border)
The flood plains are here rather narrow. The number of tributaries is high and they are situated in hilly areas with a low infiltration capacity. It causes a fast runoff of the water resulting in high flood peak discharges and low flows during rainless periods.
The lower course (formed by the Dutch part of the river)
Between Maastricht and Maasbracht the Meuse forms the border between the Netherlands and Flanders. There are no barrages here, no navigation, many bends are present and the bottom consists of gravel. All this is unique for the Netherlands and Flanders and that is why nature values are here cherished.

The management area of the Limburg Directorate of Rijkswaterstaat is formed by the Meuse from the border up to Den Bosch and some canals: Julianakanaal and Lateraalkanaal (parallel to the river) and the so called Middle Limburg Canals.

The Meuse is a rain river; it has no water reservoirs in the form of glaciers. The discharge pattern is very changeable. The largest discharges are approximately 150 times bigger than the smallest ones. The main discharge in Maastricht is 230 m^3/s; during dry summers discharges of 15 to 20 m^3/s can here occur.

Meuse Discharge Treaty

In 1995 the Netherlands and Flanders have signed a Meuse Discharge Treaty. The starting points are the equal sharing of water by both partners and a common responsibility for the Border Meuse. Very low discharges might be bad for the ecosystem here (slow flow, great areas of the minor bed that come above the water level, low content of oxygen) and that is why much effort is done to prevent that the minimum discharge falls beneath 10 m^3/s. How big this minimum acceptable discharge actually should be, is not well known. For 10 m^3/s is at that time chosen in order to dissolve the disposal of the DSM chemist plant, but the quality of its effluent is nowadays considerably improved. There is an investigation going on aimed to determine this value. It would also be desirable to know which damage on nature values caused by low-flows are irreversible.

Discharge [m³/s]	Days a year	Border Meuse [m³/s]	Flanders/Netherlands
115	113	55	30
100	92	50	25
90	66	40	25
80	53	30	25
70	41	20	25
60	33	10	25
50	20	10	20
40	9	10	15
30	2	10	10
20	0	6,7	6,7

Table 1: Meuse Discharge Treaty: water distribution

Table 1 shows the distribution of water between the Border Meuse and the use of Flanders and the Netherlands according to the Treaty. For different discharges is given the quantity of water to go to the Border Meuse and the quantity that Flanders and the Netherlands can utilize. The values mentioned here are the day average. In practise it is difficult to refer to them because of the great fluctuations of the discharge caused by a lack of synchronisation between the management of water levels for navigation and the management of hydroelectric plants upstream of the Netherlands. It is worth mentioning that the Walloon authorities are carrying out a study about the ways of decreasing these fluctuations. Wallonia is not a party of the Treaty, although this seems desirable.
In the table can be seen, that in dry periods as well the Dutch as the Flemish use has to be drastically reduced. What actually means 'the Dutch use'?

The demand and availability of water

In the Netherlands functions are ascribed to surface water. The most important functions of the Meuse and the canals managed by the Limburg Directorate regarding the division of water are: navigation, industry, agriculture, horticulture, drinking-water, water for hydroelectric plants, cooling and nature. Most problems with water shortages occur upstream of Roermond, being the mouth of the Roer. In the catchment area of this river there is a couple of barrages with storage reservoirs present which assure that the discharge of the Roer does not fall beneath 10 m^3/s. Thanks to this discharge there are practically no problems with scarcity of water downstream of the mouth of the Roer. The total use of water upstream of Roermond slightly exceeds 30 m^3/s. This is only 'the Dutch use', that is without the Border Meuse. Neither the function cooling water nor water for hydroelectric plants are mentioned here, because they need so much water, that they are cut long before low-flows really begin.

By comparing this quantity with the quantity available for the Dutch use according to the Meuse Discharge Treaty it can be seen, that an average approximately three months a year there is a shortage of water: the demand exceeds the availability.

It should be mentioned, that some of these functions consume water (water is withdrawn and it doesn't come back to the system, at least not directly). This is the case with f.i. industry or agriculture. Nature and shipping, which are the greatest users of water, don't actually consume it, they just need a certain discharge. Navigation needs water in two ways. First of all a certain depth has to be realised; to achieve this barrages are used. However they cause differences in water levels and to overcome them locks are applied. In the process of locking through the volume of water that fills a lock chamber goes downstream and can't be used again in the same lock. This is the second way that shipping needs water: it is called a *lock-loss*. This is quite a large quantity; for the Juliana Canal, where two locks are present, a discharge of 16 m^3/s is needed. Unfortunately it's not possible to combine this with the water needed for nature, because the last is required in the Border Meuse and for the navigation in the Juliana Canal and they run parallel.

Measures

So during a couple of months a year there is not enough water to comply with the demand of all functions. How can this problem be solved? Can measures be taken so that one can go on with all activities?

First of all to avoid conflicts a national system of prioritising functions is developed. The Limburg Directorate applies an altered system. A list of the functions together with the priorities they have concerning water supply in dry periods according to both systems is given in table 2. When there is not enough water the supply of water for the function with the lowest priority (third) has to be reduced. If there is nevertheless still not enough water, then the functions with the second priority have to be cut down. Actually it does not happen often that the water supply for the functions with the second priority has to be cut. Anyway the role of Rijkswaterstaat is to divide the water.

Priority	National system	Limburg Directorate system
1st	Preventing irreversible damage Stability of water-retaining structures	Nature (irreversible damage)
2nd	Drinking-water supply Industry Horticulture	Drinking-water supply Industry Horticulture
3rd	Navigation Agriculture Cooling water Maintaining low salt concentration	Navigation Agriculture Cooling water Hydroelectric plants

Table 2: Priorities of functions concerning water supply in dry periods

The users themselves have to take measures in order to be able to go on with less water. One of the possibilities is to stop the activity. This is the case with water-power stations: if there is not enough water they just stop to produce electricity. Another possibility is to apply alternative solutions. F.i. to use cooling towers instead of cooling with water. A buffer can also be created: a reservoir with a large quantity of water that can be used if one is not allowed to take the Meuse water. These measures are often taken by drinking-water companies, by industry or by horticulture. By horticulture the rainwater that falls on the roofs of greenhouses can be stored and used in dry periods. Also agriculture can create a buffer, in the ground. For many decades farmers in the Netherlands tried to keep their land dry: the rainwater was quickly brought away by middle of drainage and ditches. When it got a bit dry, they often brought water to their land from somewhere else. In this way they were dependent on water supply. Nowadays one tries to store water in the ground by limiting the quick artificial runoff. A very durable measure is to decrease permanently the use of water, f.i. by changing technologies, by using rainwater for toilets, by applying equipment to make it possible to use less water for showers or toilets, or just to be economical with water.

Rijkswaterstaat takes different measures for the sake of shipping, namely:

- Pumping water back from the low section of a lock to the high one

In the Juliana Canal there are two locks with a total difference of water levels of 23 m. By each lock pumps are installed. An average approximately three month a year up to a maximum of 12 m^3/s has to be pumped constantly day and night. This is very expensive. It also causes pollution and diminishes the natural energy resources.

- Decreasing the use of water during the process of locking through
  This can be realised by installation of reservoirs where some of the water from a lock chamber can be stored instead of being discharged at the lower section of the canal, or by siphoning lockage (water is exchanged between two parallel locks). These measures are rather expensive: it costs money to install the necessary equipment and locking through takes more time than normal, which is inconvenient for ships.
- Changing the frequency of locking
  Instead of locking every ship that arrives waiting until the chamber is full. This is very inconvenient for ships.

The Limburg Directorate takes all these measures. It is done to stimulate the transport by water instead of by road; this is better for the environment. On the other hand pumping is not good for the environment (emissions). Water shortage is therefore both a financial and environmental problem.

Although water shortages cause much loss to many users of water this item is not high at the political agenda. The reason for this is that the passed decades there was not an acute drought, although statistically they occur every 15 years. However people's memory is short and few remember still the disastrous drought of 1976. The attention to floods has as a matter of fact risen not until those of 1993 en 1995. Also the problems caused in the Netherlands by water shortages are not very spectacular. The amount of the loss caused by water shortages is not well known. Different authorities dealing with water management in the Dutch catchment area of the Meuse intend to start a research aimed on estimating this loss at present and in the future and on developing as well a short-term protocols to be implemented during water shortages as a long term policy to cope with this matter.

Measures at the source

The question can be put if there is any other possibility, more durable to decrease the problem of the water shortage. Not just by pumping or by cutting the water supply, but by taking measures at the source of the problem, f.i. the restoration of the sponge working of the ground in the catchment area. The increasing of the water keeping capacity might have a double benefit: during a rain period water would less quickly come to runoff (decreasing of the flood risk) so that during dry-weather it might better supply the Meuse. The Dutch water boards already take water-preserving measures. Also Wallonia has a policy at least not to decrease the infiltration by means of:

- no new drainage on a bigger scale,
- replacing fir-woods with deciduous trees,
- infiltration of rainwater in villages.

The stimulating of infiltration seams to be a very durable measure. But the question is if it is at all possible to take this measure in the catchment area of the Meuse due to its character. And also which effect it would have both on the decreasing of the peak discharge during floods as on the increasing of the low flows in dry periods. It would be desirable to study this matter together in different parts of the catchment area.

Future developments

For the future two aspects are relevant:

- development in the demand for water and
- development in the discharge of water in the Meuse.

A significant increase of the demand for water is forecasted. As far as the greatest user of water, navigation, the following trends are expected:

- increase of the quantity of transported goods,
- increase of the gabarits of ships (it would be more difficult to fill well the lock chamber),
- switching from transport of bulk goods to transport of containers, which means that more ship passages would be required).

So in the future much more water will be necessary for shipping. The increase of the demand for water can also be expected for other functions, among others because of the policy aimed to save groundwater by switching to the use of surface water.

The other development is the expected climate change. However the scientists are not quite sure which impact it would have on the discharge of the Meuse during low-flows. It would become warmer, the evapotranspiration would probably increase, in the summer it would rain less but with a bigger intensity. As a result of this the low-flow periods could last longer and the discharges could decrease. On the other hand the precipitation in winter would increase so that the ground might being better filled with water and thus it could later better supply the Meuse. It is not quite sure which one of these opposite tendencies would be stronger, but knowing the characteristics of the catchment area of the Meuse it can rather be expected, that in the future less water would be available during dry summers. It would be very desirable to know which medium discharges one can expect in the future in summer and, even more important, which would be the minimum discharges and what would be the probability they would occur.

Conclusions

- Low flows in the Meuse are a problem for the users of water (financial) and for the aquatic ecosystems.
- Because of the increase of the economic activities and the change of climate the problem of water shortages is going to increase in the future.
- This problem can be solved with technical measures, but this is very expensive and bad for the environment.
- Measures at the source would be very desirable to decrease the problem.
- A couple of studies should be realised in order to cope better with water shortages.

Monitoring Garzweiler II based on the Water Frame Directive – Quantitative Condition of the Groundwater in the Partial Catchment Area of the Niers

DR. H.G. MEINERS

Introduction

This paper shall show the approach to the description and assessment of the quantitative condition in the inventory control of the Water Frame Directive for the Niers catchment area. First deliberations will be introduced as to how to deal with the lowering sinking of the groundwater caused by the brown coal mine Garzweiler II within the context of the Water Frame Directive (WFD).

The Niers in the Maas basin

The Maas Basin encompasses several states: France, Belgium (Wallonia, Flanders), the Netherlands and Germany. The tributaries of the Niers, (Eifel-) Rur and Schwalm are mostly in Germany but flow into the Maas in the Netherlands. Of the countries bordering on the Maas Basin, Germany, has with approx. 3,700 km² the smallest surface area. However, the significance of the German area for the water management of the Maas should not be disregarded: Of the 7.7. million population in the Maas Basin area 23% (1.8 million) live in Germany (NL: 39 %, Belgian provinces 31 %, and France 7 %) (VOLZ, KETELAARS, WAGENVOORT 2002).

The catchment area of the Maas tributary, the Niers is almost entirely in Germany. It covers approx. 1,350 km² (Fig. 1). One should note the relatively high rate of population in the Niers catchment area (715,000) and, with this, the high-level requirement of drinking and processing water from the groundwater (approx. 65 million. m³/a) and also the large quantity of treated sewage (87 million m³/a). A major characteristic of the southern Niers catchment area is the brown coal mine, Garzweiler II, 10 km south of Mönchengladbach and 15 km east of the Dutch-German border by Roermond. The Niers catchment area is also home to the "Natura 2000" and the bird sanctuary with bordering forest land "Schwalm-Nette-Platte" which are of international importance.

The State Environment Office in Krefeld is in charge of the inventory control in line with the WFD for the partial catchment area of the Niers. The Niers Water Authority is the responsible water authority; in the southern part of the catchment area it is also the Erft Water Authority concerning questions of brown coal mining.

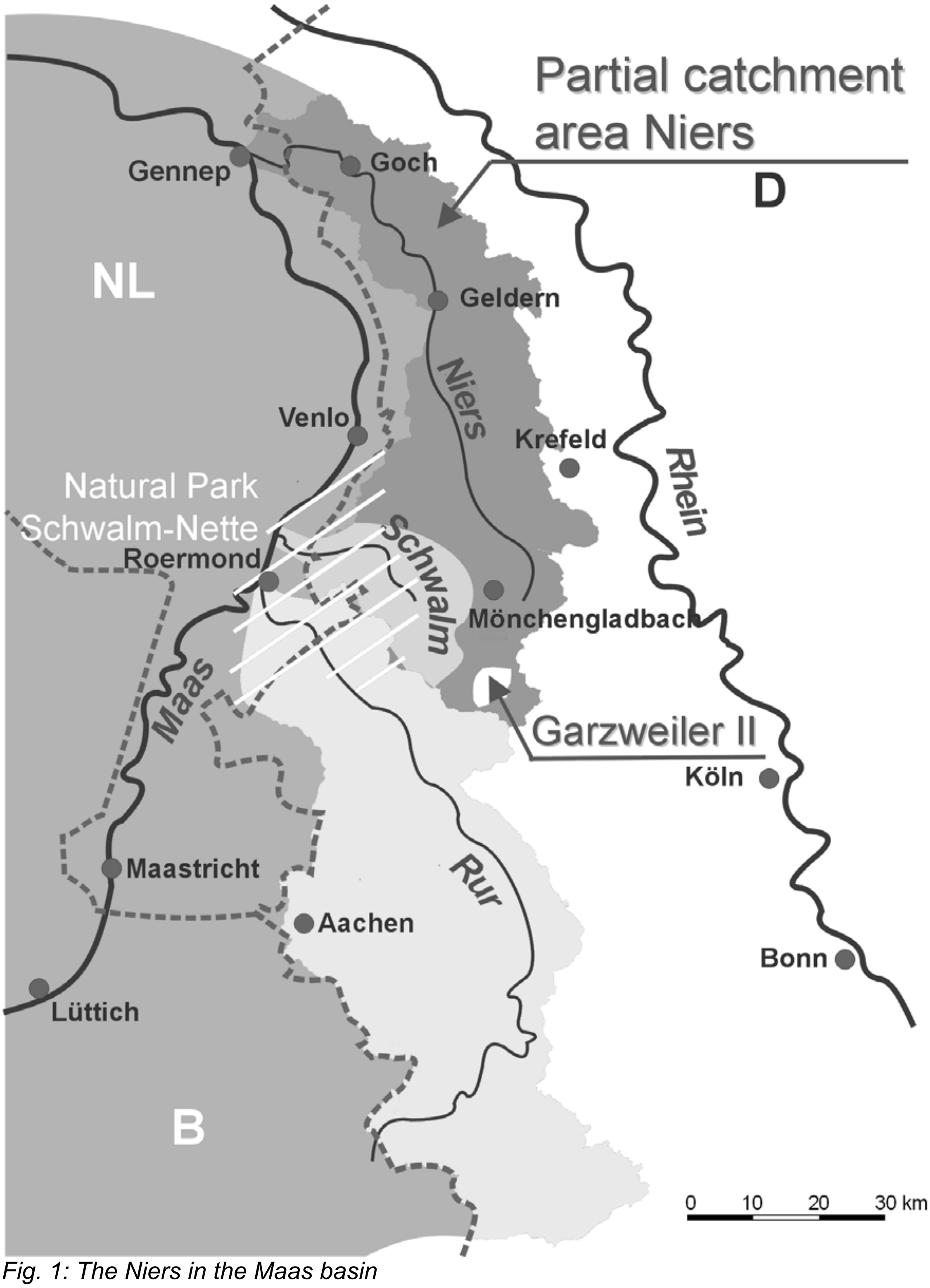


Fig. 1: The Niers in the Maas basin

Method for assessment of quantitative condition

The basic principles on groundwater body identification and inventory control of groundwater in line with the WFD are in North Rhine Westphalia very detailed and documented in a guide-line (MUNLV 2002). In the initial description the following proceeding stages should be differentiated in an overview:

(1) State-wide identification of groundwater bodies. This is effected in porous aquifers with particular consideration of the groundwater flowing conditions.
(2) Description of the hydrogeology and covering layers according to data available from state-wide maps (Scale: 1: 50,000 - 1: 100.000).
(3) Designation of the potential hazard for the chemical condition (to date substantiated for diffuse matters based on utilisation data, agricultural data and groundwater analyses).
(4) Quantitative condition: trend analysis and areal balance.

A trend calculation per control point is carried out. (Control period 1971 – 2000, no gaps in control > 400 d, control measurements at least every six months, clear allocation to the uppermost aquifer); a negative trend of > 1 cm/a is considered significant.

The control points have a scope of 50 km²: If only < 50 % of the groundwater is covered by the scope, the data pool is not sufficient enough for a trend analysis of the entire groundwater. In such a case the groundwater (with the appropriate significance for the water supply) is considered as potentially jeopardised.

Finally an areal balance is carried out using the scope of control points with a clearly negative trend: > 33 % negative trend: the groundwater is potentially jeopardised; 20 - 33 % negative trend: a special inspection order is given to the various agencies.

Groundwater in the Niers catchment area

The result of the identification of groundwater bodies for the Niers catchment area is shown in Fig. 2. Eight groundwater bodies are differentiated and the hydrogeological, water management and any special characteristics compiled in a catalogue. It is important for the processing that all examinations and analyses refer to one respective body of groundwater.

Resulting from the trend analysis and the areal balance (see above) there are two groundwater bodies in the Niers catchment area with a negative trend (identified in Fig. 2, and supplemented by a further jeopardised groundwater body in the Schwalm catchment area). These groundwater bodies are possibly quantitatively jeopardised, i.e. there is the risk of the WFD quantitative objectives (Art. 4 Annex V) not being met. The reason for the negative trend of the groundwater development is the lowering of the groundwater as a consequence of the brown coal mining (sumping).

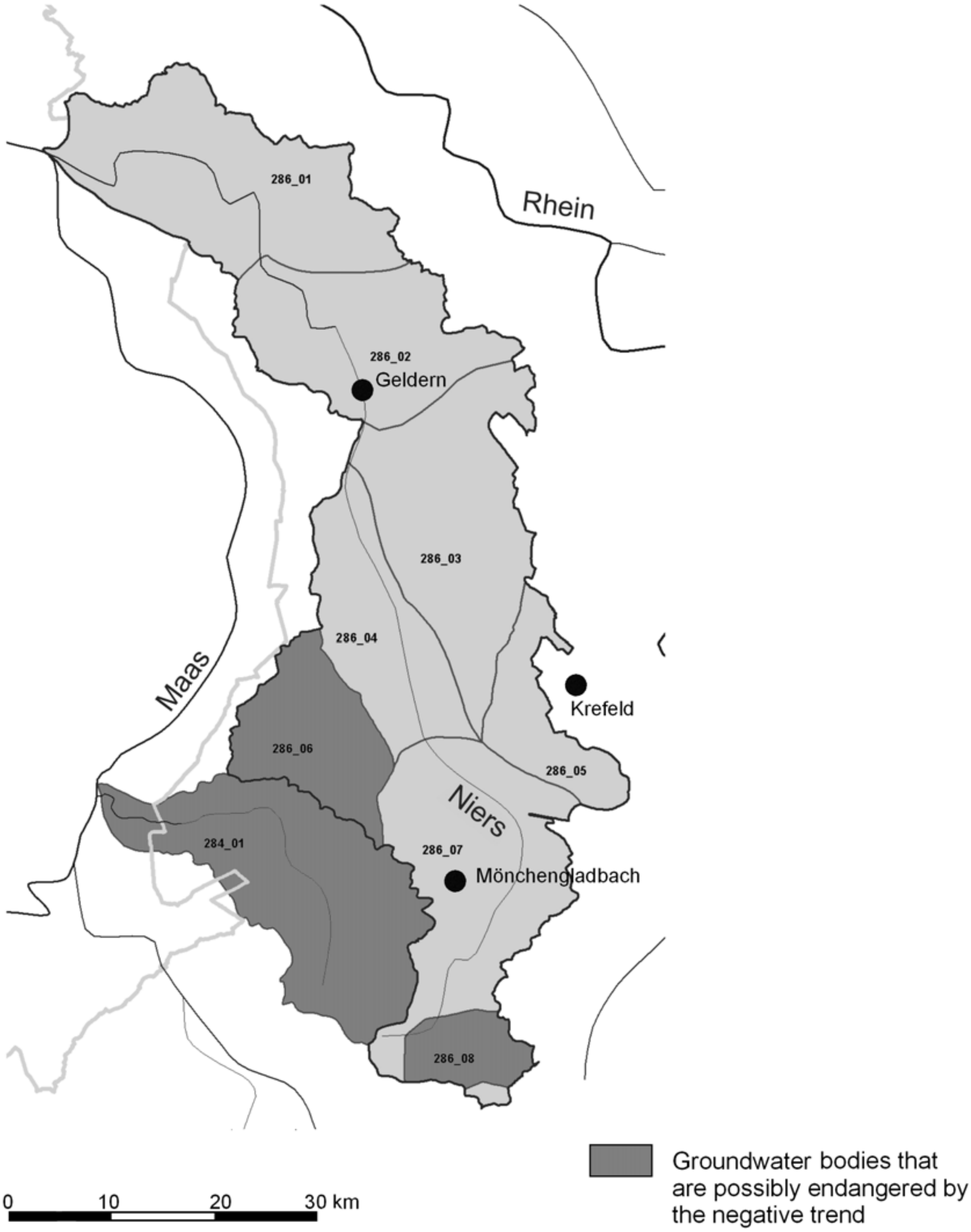


Fig. 2: Groundwater bodies for the Niers catchment area

Brown coal mining and the water frame directive

Brown coal mining is on the whole a massive interference in the natural balance of the ecosystem. Since the extraction of brown coal is carried out in dry mines extensive lowering of the groundwater and sumping measures are necessary. In Garzweiler II the groundwater has lowered more than 200 m; 80 - 150 million m³/a groundwater is extracted in a period of up to 40 years.

To compensate for the effects of the brown coal mining in Garzweiler II an extensive and ambitious catalogue of objectives has been drawn up (Brown Coal Plan). According to this, the groundwater in groundwater-dependent wetlands must, for instance, remain in the same state as before the impact of brown coal mining, and must be retained in their bio-diversity.

In order to meet these objectives, measures are being taken with a planning horizon of about 100 years. These include the infiltration of water into an aquifer, discharging water into the

surface water (approx. 40 - 89 million m³/a), water treatment and, from 2030, the transition of Rhine water to refill the remaining pit.
The effects of the groundwater lowering and the effectiveness of counter-measures have to be controlled by an overall monitoring system. The Monitoring Garzweiler II – an appropriately detailed system – is already in operation. It is an extensive, systematic program for spatial observation, controlling and assessment of all water management and ecologically relevant parameters (MUNLV 2000, 2001 u. 2002 and MEINERS & ODENKIRCHEN 2000 and 2001). Essential elements from “Monitoring Tailor Made“ (RIZA 1995, 1997, 2000) have been included in the planning of Monitoring Garzweiler II..
If one compares the WFD objectives for the quantitative condition with the status in the individual groundwater bodies in the catchment areas, Niers and Schwalm, it is clear that the good quantitative condition is jeopardised by the lowering of the groundwater. From a current point of view, the possibilities of dealing with this conflict of objectives in line with the WFD are as follows:

- Extension of time in accordance with Art 4 (4) WFD.
- Formulation of less strict ecological objectives in accordance with Art. 4 (5) WFD.
- Practicable provisions to minimise the negative effects in accordance with Art. 4 (7) WFD.

A decision on further proceedings has not yet been made. It is, however, certain that the extensive measures taken to date and in the future and the current Monitoring Garzweiler II can play an important role in the practicable provisions under the WFD (Art. 4 (7)).

Conclusion

Northrhine-Westfalia assessments following the WFD are being carried out for the groundwater in the German part of the Maas Basin. Due to the brown coal mining, a quantitatively good condition in some groundwater bodies can, in all likelihood, not be achieved. A decision has not yet been made as to how this will be dealt with in the future. Less strict environmental objectives can possibly be orientated towards the aims of the Brown Coal Plan, the observation of which is controlled by Monitoring Garzweiler II. Substantial material on this is already available.

Thanks to:
Mr. Odenkirchen (MUNLV), Mr. Ferdian (StUA Krefeld), Mr. F. Müller and Dr. Denneborg (ahu AG) and the "AG Grundwasser in Nordrein-Westfalen" who have done fundamental work on this and without which this paper would not have been possible.

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Karstic flows in the Meuse upper basin

Consequences for exchanges between hydrographical basins

S. JAILLET, P-J.FAUVEL, J. LE ROUX

Abstract: The Meuse and its tributaries get completely lost in low water levels in the Bajocian crossing of the upstream part of their basin, and flow in a karstic aquifer. The plotted courses (colours) introduced a century ago in this sector show the higher speed of this underground transit and the consequences of these flows for the exchanges between hydrographical basis. The case of the Meuse upstream of Neuchâteau and the Aroffe, one of its right bank tributaries, is discussed in particular.

Key words: Karst, karstic hydrogeology, exchanges between basins, Aroffe, Meuse.

Introduction

The upper basin of the Meuse is part of the sedimentary rings of the East of the Parisian Basin. Two major Jurassic carbonated formation are cut they by an incision of the Meuse hydrographical network: the Bajocian limestone and the Oxfordian limestone.
In cutting these limestone masses, the Meuse and its tributaries strip the soft formations, increase the hydraulic potential, and release the captive aquifers. This in turn karstifies the limestone, leading to raid underground flows and possible exchanges between the different hydrographical basins. The Meuse is here presented upstream from Neuchâteau and the Aroffe, one of its tributaries on the right bank (Fig. 1).

Karstic flows of the Upper Meuse

As soon as it penetrates the Bajocian limestone, the Meuse disappears. At low water, the entire river disappears in the karstic aquifer in the Bazoilles sector (photo. 1). Its main tributary, the Mouzon likewise disappears in the Rebeuville sector. Already in the 18th century, the Meuse suspected of underground flows that joined the springs in Neufchâteau (Dom Calmet, 1746 ; Durival, 1778, in Thomas, 1979). An initial plotting was undertaking using salt (NaCl) in the losses of the Meuse in 1864 by Lefebvre. A coloration of the Mouzon was carried out in the 1950s (Bodenreider and Lartillot, 1953 and 1954). Other plotting operations were undertaking in the 1970s (Thomas and Leroux, 1977 / 1980).
All these operations (added to the physical and chemical analysis of the karstic springs) have made it possible to propose a model of how the karstic aquifer flows from the Bajocian limestone (fig. 2). This model shows the role of the Bajocian / Bathonian contact in the division of the captive aquifer and the place of faults that compartmentalise the hydrogeological blocks and authorise the issue of the flows on various outlets.

The Aroffe: a tributary of the Meuse and the Moselle

Further downstream, the Meuse receives a tributary from the right bank: the Aroffe. The confluence of the Meuse and the Aroffe is effective only in a swelling period. At low water, the Aroffe disappears completely in the Bajocian limestone. This sector was studied in particular during the building of the A31 motorway (Thillay, 1979, Le Roux et Salado, 1980).
Karstic flows between the Aroffe and he Moselle Valley (Fig. 3) were suspected very early on. Durival, in 1778 mentioned the link between Aroffe / Moselle and Orly; in 1876, he showed the link between the Aroffe and Rochotte (a spring in the Moselle basin) from monitoring hydrological systems. In 1937, Obellianne carried out an initial coloration of the Aroffe. Since then, some thirty plotting efforts have been undertaken on this aquifer.

The many plotting operations have revealed with precision the flow rates of underground waters in the karst. If we compare these rates in accordance with the hydrological situations (Fig. 4), we note that the highest rates (between 300 and 600 m/h) are characteristic of high waters, while the lowest rates (between 50 and 200 m/h) are characteristic of low waters. This is a general case of flooded karstic flows, where the increase in flow rates leads to an increase in speeds. The plotting approach reveals in part these underground flows without having direct access to this karst. Speleological research studies have revealed a hydrological opening on a little more than one kilometre (i.e. less than 5% of the real course of the carstic flows).

Conclusion

These few examples illustrate the modalities of the carstic flows in the upper Meuse basin. Thus, the Aroffe, a tributary of the right bank of the Meuse, disappears upstream from its confluence and rejoins the Meuse basin via the aquifer of the Bajocian limestone. During the low water period, its bed is completely dry. Similarly, on the right bank of the Meuse, the Méholle and the Cousance receive the waters of the karstic losses of the Ornain and the Aire, to the detriment of the Seine basin. During the swelling period, however, all the karstic aquifers are saturated, and the surface flows take over.

These karstic flows are highlighted by crossing different methods: plotting, mapping hydrological outputs, morphostructural analyses, speleological reconnaissance expeditions. Their evaluation lends greater understanding to the layout of a hidden hydrographic network, a real prelude to the future reorganisation of the surface nature through captures.

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<u>List of figures</u>:

Figure 1: Location of the upper karst of the Meuse Basin in the crossing of the Dogger limestone ring.

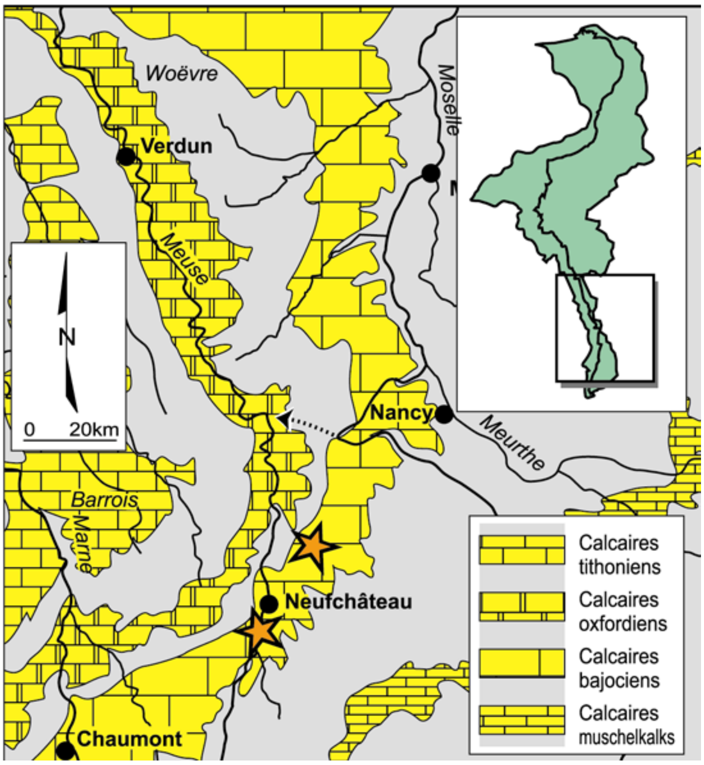


Figure 2: Block diagram of the underground flows of the Meuse and the Mouson upstream from Neufchâteau. Extract from Thomas 1979.

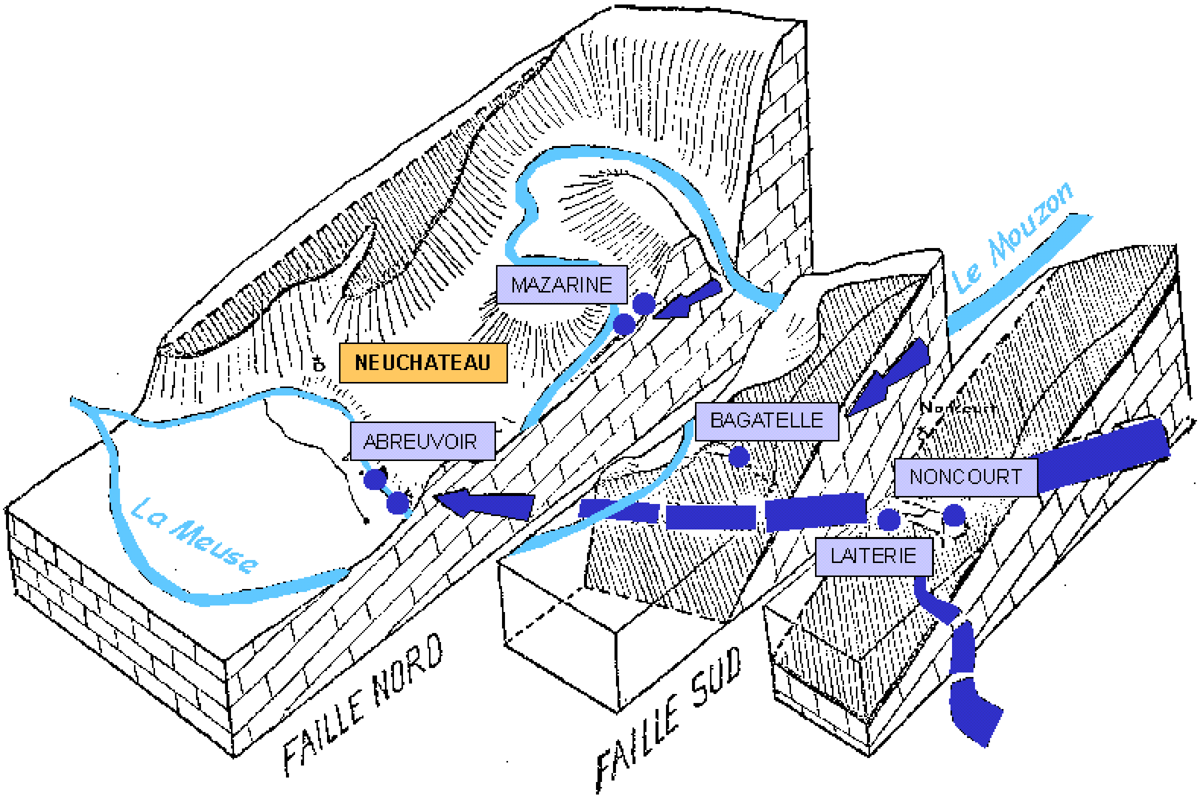


Figure 3: The Aroffe karst in its morphological context. The plotting operations in the sector have shown the diversion of the surface river flows to the benefit of the Moselle basin and to the detriment of the Meuse basin. Completed oro-hydrographic bottom.

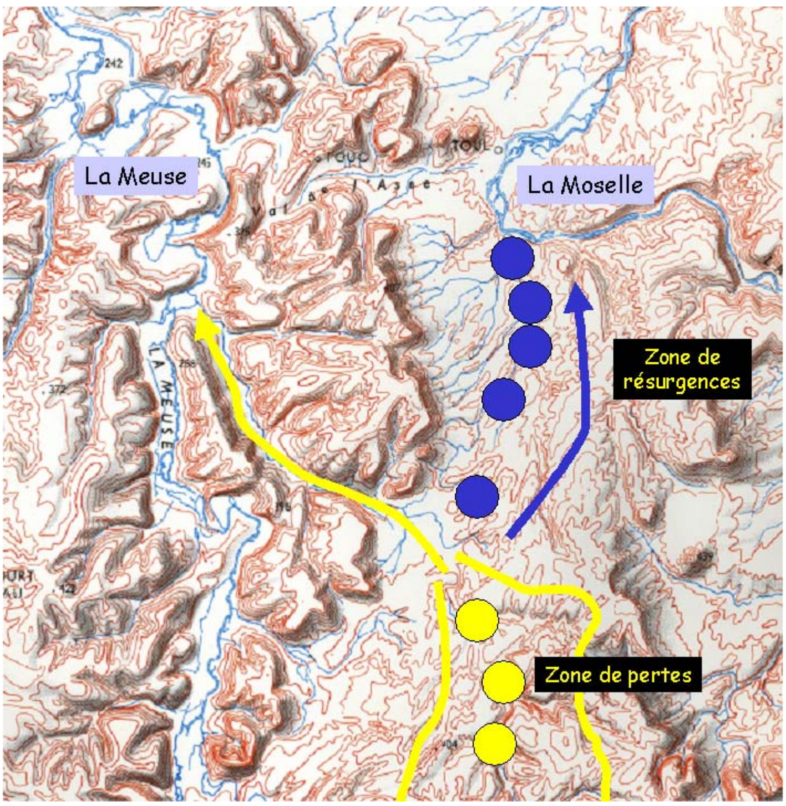
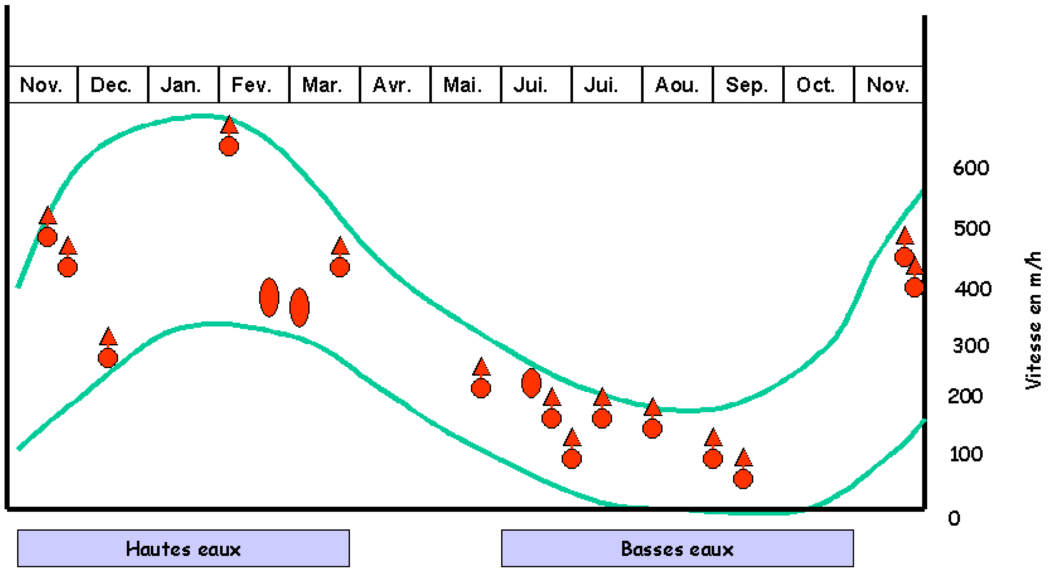


Figure 4: Distribution of water flow rates, obtained from plotting, according to the hydrological system. Note the high flow rates in winter (high waters) and the lower ones in summer (low waters). From Le Roux, Salado, 1980.



List of photos:

Photo 1: The karstic losses of the Meuse upstream from Bazoilles. Photo: Jean-Pierre DE-CLOUX

Photo 2: The Ochey pond is a temporary resurgence of the underground flows of the Aroffe, a tributary of the Meuse. Photo: Pierre-Jean FAUVEL

PROCEEDINGS

ORAL PRESENTATIONS

Topic 3:

Pressures and Effects

Do we know what we need to know about the quality water from the Meuse River?

Cooperation - the key to a clean Meuse

L. VAN BREEMEN

The Meuse River (known as “de Maas” in the Netherlands and “La Meuse” in France and Wallon-Belgium) is used for a broad range of activities. In addition to functions such as the discharge of water, navigation, recreation, agriculture and cooling water, the Meuse (with an approximate volume of 450 million m^3 of water per year) is an important source of raw material for the production of drinking and industrial water.
The diversity of the functions for which the Meuse is used determines the necessity of a joint target, as laid down in the Meuse Action Programme of the International Commission for the Protection of the Meuse (known by its acronym ICBM and CIPM):
“The maintenance and improvement of the quality of the Meuse, with particular attention to physicochemical quality, ecological quality, drinking water supplies and other water uses”

This means a “clean and healthy Meuse”. The question is: how clean? It is important that the users who are related to the various functions should quantify the parameters the Meuse must meet and then inform the water management boards accordingly.

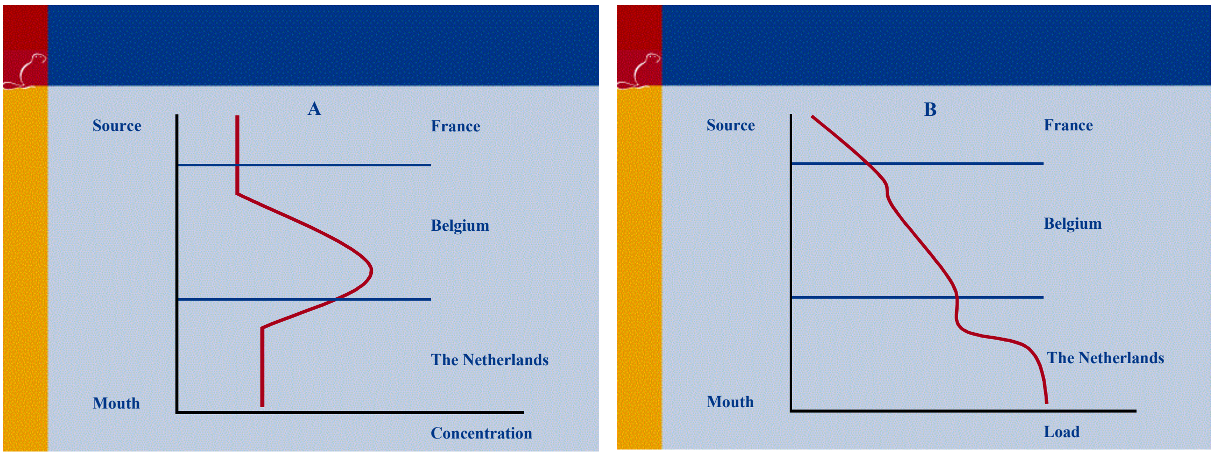


Figure 1: Water quality indicated by point contamination and diffuse contamination in the Meuse catchment area

The quantification of the parameters that the water quality must meet is often a subjective process. The type of pollution (Figure 1) can greatly influence the conclusion as to whether the water quality at a particular point in the Meuse catchment area does, or does not, meet the requirements for a specific function. However, it is indeed these conclusions that enable the water management boards to qualify and quantify the more general quality targets.
The water of the Meuse is continually exposed to threats from direct and diffuse emissions of organic micropollutants. This necessitates having a good overview of the (groups of) organic compounds that occur in the Meuse catchment area, as well as those that can in any way end up in Meuse water via emission. Health and hygiene aspects (and whether or not organic micropollutants can be removed from drinking water in the existing aggregate of treatment systems) determine the priority given to the prevention of Meuse water contamination.

Approximately 25 % of the organic micropollutants cannot be isolated (Figure 2). Of the estimated 10,000 (some still unidentified) substances in the Meuse, a couple of hundred are possibly relevant from a toxicological point of view while 100 may be specifically relevant with regard to drinking water.

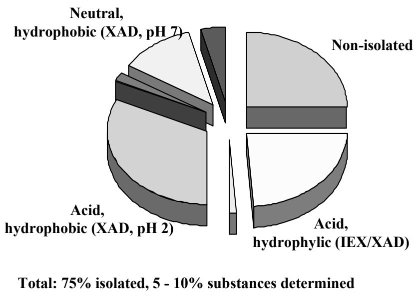


Figure 2: Diagram of the amount of isolated and non-isolated organic micropollutants in river water (Source Kiwa)

For the *unknown substances,* it is important to monitor the more polar organic substances that are consequently more genotoxicologically relevant.
The sources of emissions are of primary importance in determining which substances fall into this category. Specific studies can be carried out on the basis of an inventory of all such sources throughout the whole of the Meuse catchment area.
We have now arrived at a point at which the “tangible” (known) water quality problems are under control. However, the “intangible” (partially unknown) problems are not under control and the utilization of “broad spectrum” monitoring is very important here.
On-line biomonitoring, in which the system automatically registers the activity of organisms, has been utilized since the 1980’s as an “Early Warning” system.

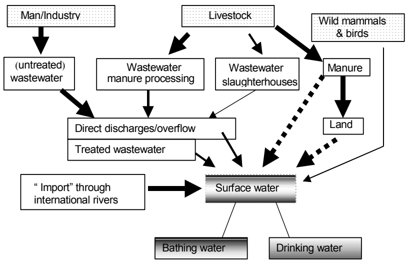
The application of bioassays, in particular, often involves extensive specialist work and can therefore not be easily realized for water quality monitoring. A great deal will have to be done if operational applications are to be achieved.
It will be necessary in the future to cooperate more and more.

In some parts of its catchment area, the Meuse is heavily contaminated with faeces. As a result, pathogenic microorganisms can be shown to be present in Meuse water. In concrete terms, this means that if Meuse water is to be used as raw material for drinking water, there is then an obligation to measure the protozoa *Cryptosporidium, Giardia,* and enteroviruses. The presence of pathogenic microorganisms is also an indication that other relevant pathogens must be measured. There are more than 100 pathogenic microorganisms that are transmissible via water. With our current knowledge, it is possible to select the most critical pathogens for the treatment of surface water.
Due to the development of molecular typing methods, it is now possible to classify the protozoan cysts (and oocysts) in the water as pathogenic or non-pathogenic.

Quantitative information is needed regarding the occurrence of the most critical of the living and infectious pathogens in Meuse water. The related decontamination policy requires international coordination. The new policy and regulations regarding the safety of drinking water necessitate bringing this topic up for international discussion.

“...on the look out for relevant new substances, both known and unknown...”

Two aspects can be distinguished in the monitoring and evaluation of the quality of Meuse water:
- Ascertaining known contaminants (“anticipatory monitoring”)
- Identifying and researching unknown contaminants (“safeguarding water quality from unknown substances”)
It is primarily the complexity of the interactions between the various activities in the Meuse catchment area (Figure 3) that will determine the approach to identifying the bottlenecks in, and threats to the quality of, Meuse water.
Foreknowledge of the various activities and potential emission sources in the Meuse catchment area is necessary for a thorough, comprehensive study into the stressors and their effects on the Meuse water quality. Specific insight can thus be obtained for realizing the different functions of the Meuse and ascertaining what (new) threats are present so that we can



continue to guarantee the various uses of the Meuse.

Figure 3: Overview of activities in the Meuse catchment area (Source RIWA)

Modelling of the knowledge already acquired increases the certainty of predictions regarding which pollution had to be prevented and what the required effects must be. It also results in the optimization and underpinning of an international warning system in the Meuse catchment area for timely safeguarding the downstream functions of Meuse water in the event of any catastrophes.

Conclusions:
- Know your catchment area
- Cooperation and actively contributing to the study of the various “users” increases the chances of timely identification of the bottlenecks and (new) threats in Meuse water quality.
- The trigger for research is the coordination and (fore)knowledge of the activities in the Meuse’s catchment area.
- Collective interest groups must actively participate in (inter)national Meuse organizations.
- Successfully integrated water management can be realized by being aware of all the Meuse water’s functions.
- Cooperation reinforces the support for, and power of, ICBM/CIPM and the water management boards.

Identification of Diffuse Sources in NRW

HERIBERT NACKEN, SABINE BARTUSSECK, CARLOS RUBÍN, PAUL WERMTER, FRANK MÜLLER

According to the status review required by the EC Water Framework Directive, a specialized information-system is being developed based on the available data and information. The main objective of this project is to carry out a reliable investigation and quantification of the following aspects: risk potential of soil erosion, risk potential of leaching, discharge quantification of harmful substances, definition of the boundaries and relevant fields concerning the interaction between surface- and ground-water.
GIS-based approaches for each task have been developed for estimating the risk potential. The information-system covers the 13 sub-schemes in North Rhine-Westphalia (NRW). This project is carried out by an interdisciplinary group of various planning companies under the leadership of the section of engineering hydrology, Aachen University of Technology (RWTH-Aachen / Germany). This article describes the various implemented approaches and the reached results.

Description of the problem and the objective

A specialized information-system Diffuse Sources (FIS DQ) is being developed at the moment for the 13 sub-schemes in NRW to be used as a basis for the status review required by the EC Water Framework Directive. The first part of the project FIS DQ provides investigations throughout NRW about significant anthropogenic impacts caused by diffuse sources referring to surface waters. The objective of this project is to carry out a reliable investigation and evaluation of the risk potential of soil erosion and of leaching as well as of the risk potential of diffuse substances due to landuse concerning the surface waters. The investigations are based on the available data and information in NRW. Since a diffuse pollution of surface waters via the path of ground-water is possible, also the area with a significant ground-water inflow in general is identified. Quantifications of the specific nutrient flows are not yet carried out. The analyses of the first part are intentionally designed to be open for any kind of model in order to be integrated later into existing balancing models.

Proceeding

With regard to the pressure potentials the first part of the FIS DQ project is structured following a classical risk analysis. Areas with a risk potential result from the intersection of site specific data of sensitivity (risk of soil erosion, risk of leaching) and data of risk potentials due to landuse. In the resulting areas the effects of the pressures have to be evaluated.
With regard to the interaction between the surface water bodies and the groundwater a method is developed based on the available data in NRW to identify those areas, which have a ground-water inflow to the surface water.

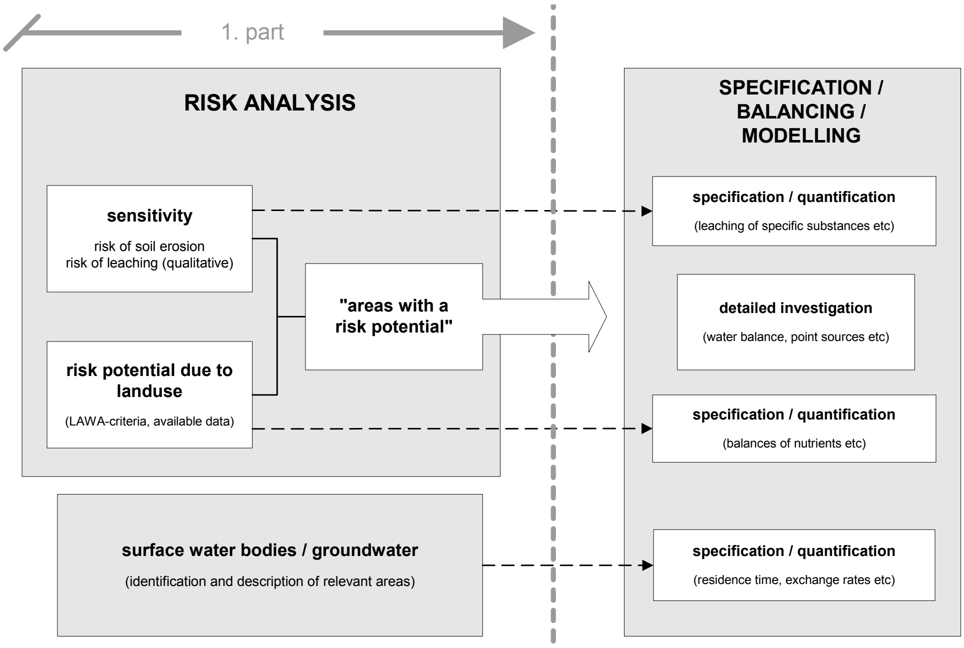


Fig. 1: General conception of the project

In the following the various implemented approaches are being presented.

Risk Potential caused by Soil Erosion

Soil erosion caused by water is a primary factor for the diffuse input of substances into the water bodies. The slope of the area and the precipitation together with the soil properties influence the natural erosion risk of a site. The consideration of the landuse facilitates qualitative statements about the actual erosion risk of the sites.

In the first part of the FIS DQ project the average annual soil loss A is being calculated with the "Allgemeinen Bodenabtragsgleichung" (ABAG)

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad [t/(ha \cdot a)]$$

to get a qualitative estimation of partial areas with a risk of erosion throughout NRW.

Tab. 1: Factors of the ABAG

Factor	Subject	Base of data
rainfall-runoff erosivity factor **R**:	erosivity of precipitation	isoerodent contours NRW
soil erodibility factor **K**:	susceptibility of soil to erosion and rate of runoff	digital soil map NRW 1:50.000 (BK50)
slope length factor **L**:	effect of slope length	constant value (L = 2)
slope steepness factor **S**:	effect of slope steepness	digital terrain model DGM5
cover-management factor **C**:	effects of cropping and management practices	Amtlich Topografisch-Kartografisches Informationssystem ATKIS
support practice factor **P**:	effect of erosion support practices	-

These factors can be derived from the available data in NRW except for the slope length factor L. At the moment it is not possible to evaluate the L factor for the entire North Rhine-Westphalia. Therefore it is fixed as a constant value (L = 2). Support practices are not taken into account for the qualitative description of the risk potential.

The data of the landuse is taken from the „Amtlich Topografisch-Kartografischen Informationssystem ATKIS“. The different types of the ATKIS data are combined to classes of equal risk of erosion giving them a value for the factor C . The derivation and presentation of the factors and the risk potential of soil erosion are based on grids. They are performed with a Geographical Information System (GIS). The results of the risk potential of erosion are given in classes of potentially annual soil loss in t/(ha·a). The resulting map of risk potential delivers data about the contribution of diffuse input for each partial area regarding the current distribution of landuse. Additionally the results serve as input data for more detailed investigations by transport models. Moreover they are used as a basis for analyses referring to measures (slope dependant identification of banks strips) during the next working phases of the EC Water Framework Directive.

Risk Potential of Leaching

Besides the input caused by erosion the leaching of harmful substances represents a considerable input path for the diffuse pollution of surface waters. In the first part of this project a qualitative estimation of the risk potential of leaching is designed. Later on more detailed quantitative analyses are planned.
Analyses of specific substances are not yet carried out but an overview with the leading parameter nitrate.

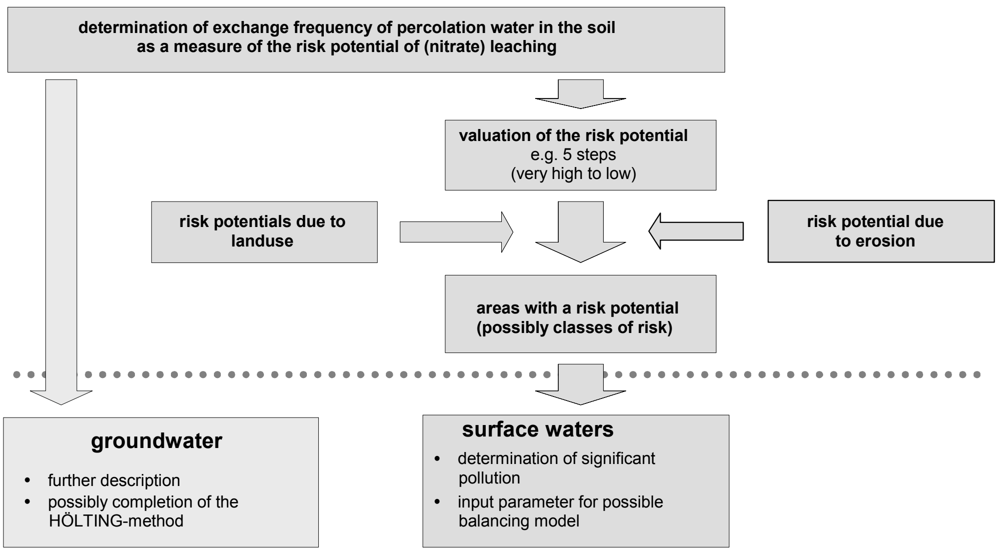


Fig. 2: Risk potential of leaching

The decisive factors for the risk potential of leaching are the soil defining parameters as well as climatic parameters. In this project the following analyses are provided following the commonly used methods to determine the risk potential of leaching:

- exchange frequency as quotient of the percolation rate for the available field capacity and the field capacity in the effective root zone
- displacement velocity as quotient of percolation rate and field capacity

The percolation rate is a parameter that depends on the landuse. To illustrate the risk potential of leaching the data of the percolation water has to be assigned in a first step to the following types of landuse: field, grassland and wood. For this step aggregated data of ATKIS is utilized.

Risk Potentials of Diffuse Inputs of Substances due to Landuse

The identification of areas with a risk potential of diffuse inputs of substances due to the landuse is done in a first step referring to a paper of LAWA („Kriterien zur Erhebung von anthropogenen Belastungen und Beurteilung ihrer Auswirkungen zur termingerechten und aussagekräftigen Berichterstattung an die EU-Kommission“ (02.09.2002)). In this paper the criteria about the investigation of anthropogenic pressures and its effects for the reporting to the

European Commission are named. The information used comes from the ATKIS landuse data as well as from the agricultural data on community level of the State Office for Statistics NRW. Apart from this data of the first description of the groundwater and further data of actual or potentially impacts, which is available for throughout NRW, is used in the analyses.
The data is edited digitally so that areas can be identified with a high or very high risk potential due to landuse concerning the diffuse sources of harmful substances.

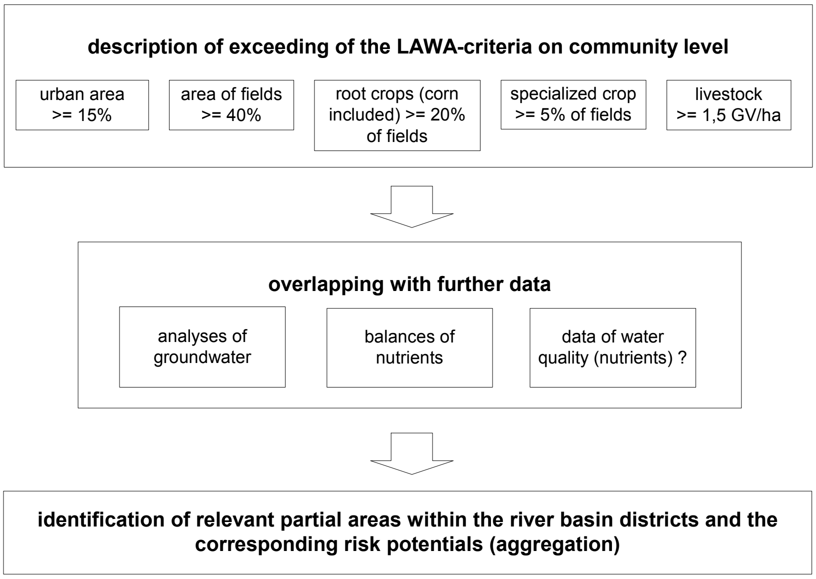


Fig. 3: Risk potentials due to landuse

Delimitation and Valuation of relevant areas concerning the Interaction between Surface Water Bodies and Groundwater

Concerning the input of harmful substances via diffuse sources surface waters and groundwater cannot be seen separately. In some areas the input of substances via the path of groundwater can be seen as a decisive factor for the quality of the surface water body. This has a special significance, because in accordance with the EC Water Framework Directive groundwater only has a good (quantitative/qualitative) status, if the environmental aims in the affiliated surface water are not at risk due to groundwater induced factors. The objective of this part of the project is to identify those areas where the ground-water inflow to the surface water and therefore its quality is decisive. The performed analyses are a first step to the comprehensive contemplation of the correlation between surface waters and groundwater concerning the status review required by the EC Water Framework Directive.
In some local areas differentiated analyses to the affiliation of the groundwater to the surface water bodies are available. But since these analyses are not available for all of NRW a methodology is worked out for the used scale at issue (1:50.000), which can only give an overview analysis for the whole area. For this analysis hydrological data of the running waters´ condition and data of the isobaths of the ground-water table, derived from the soil map, are being applied. The resulting knowledge can be used for further examinations especially to name potential paths of input.
In some parts the decomposition of the nitrate in the soil passage can lead to the fact, that in spite of high risk potentials due to the site and landuse there is not a decisive input of substances to the surface water via the ground-water inflow. Therefore general information on the nitrate reduction capacity of the soil is provided in addition to the above given details. The nitrate reduction capacity is derived from the type of soil in accordance to the digital soil map 1:50.000.

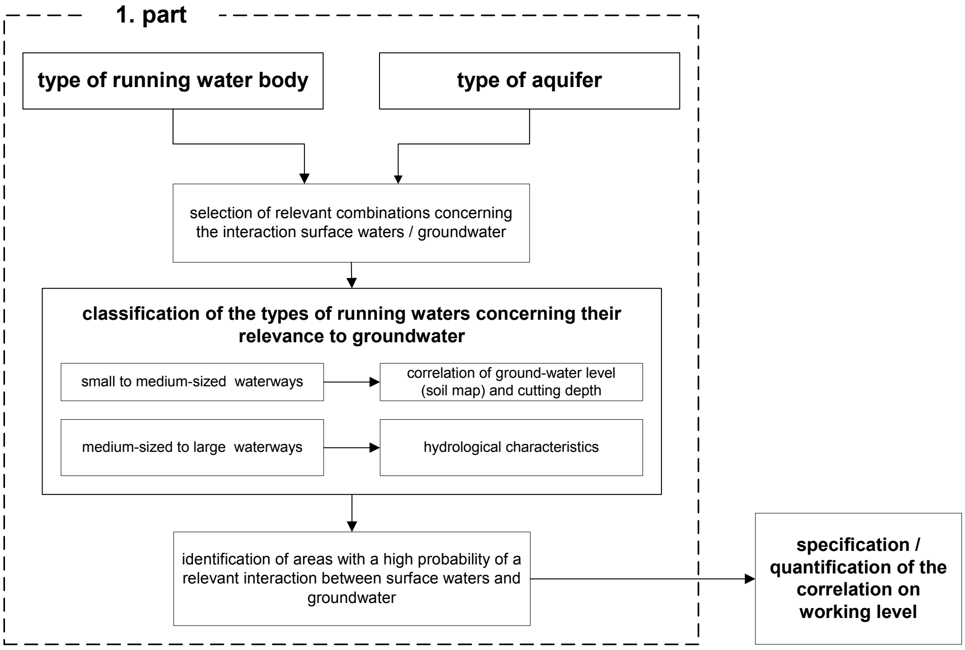


Fig. 4: Interaction surface water bodies / groundwater

Generation of GIS-maps

All information is edited suitable for GIS and afterwards modelled by clipping and GIS-based operations. It has been paid attention to the fact, that each operation is comprehensible at any time, interim results are documented and they can be used independently of the scale where possible. Apart from the comprehension this is in particular necessary for possible further working on a different scale. The implementation is mostly based on data processing and GIS. Concerning a possible integration later on into the national data processing systems the data management of the interim and final results is based on databases. A direct access to the initial data in different formats and databases will be realized in the following. The results will be put at the river basin district based offices disposal in an ArcGIS based information system throughout NRW.

Presentation of the water quality evaluation systems developed in France by the Ministry of the Environment and the Water Boards

LAPUYADE - BRESSON

The enactment of the French Water Act of 3 January 1992, and in particular the Planning and Management Master Plans, have lead the Water Boards and the Ministry of the Environment to:

- reconsider the quality grids used in these last thirty years. It seems essential, in fact, to take into account the diversity of the types of pollution (micropollutants in particular); and to
- construct a system for evaluating the quality of underground waters.

Since 1971, the quality of the waters of streams in France was evaluated using a grid that, for a series of physical, chemical and hydrobiological parameters, associated threshold values to 5 class qualities represented by colours. This grid led to a summary and global evaluation of the aptitude and main uses and functions.
Its multi-use character has given rise to varied applications which have made it difficult to share and compare data. The quality objectives of surface waters were fixed on this grid.

For underground waters, although certain grids had been established by organisations for their own use, no grid to date was intended for a wide adherence by potential users.

The Water Boards and the Ministry of the Environment wanted to upgrade the evaluation system for the quality of streams and, on the basis of the same principle, introduce an underground water quality evaluation system that could indicate the specific nature of underground waters, while remaining consistent with the system developed for surface waters.

Three needs emerged, namely to:

HARMONISE practices
MODERNISE methods
SHARE results

To meet these needs, the Ministry of the Environment undertook works to develop quality evaluation instruments for:

STREAMS and UNDERGROUND WATERS;
And also,
STRETCHES OF WATER, COASTAL WATERS, and LITTORAL WATERS.

The system intended for the streams will be composed of three instruments for evaluation the: WATER, HYDROMOROPHOLOGY and BIOLOGY

This presentation will detail the common principles of the:
- River Water Evaluation System, and the
- Underground Water Evaluation system

Work on two instruments commenced in 1990 for river waters and in 1995 for underground waters.

They are the most advanced and offer, already, a validated operational version at national level. The first computerised version of the river water evaluation instrument is posted on the

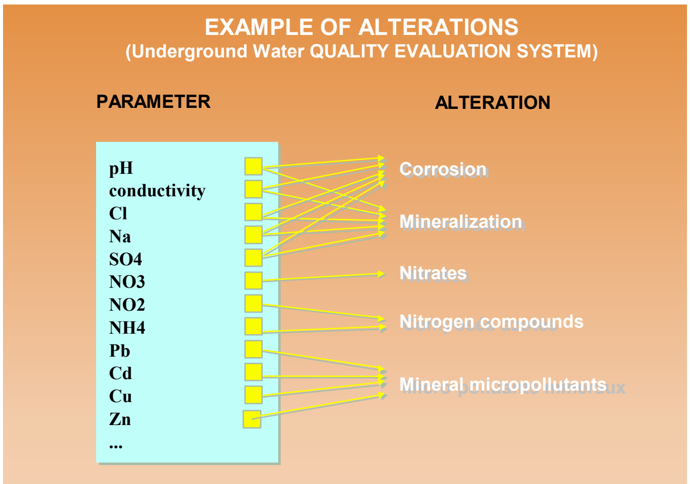
Internet. A new, more elaborate version will be offered in 2003, as well as an initial version of a tool for underground waters.

One of the main problems is the quantity of parameters to take into account. These parameters are not easy to understand for non-specialists.
For a simple and pertinent approach, the parameters have been regrouped:

- By nature or effect
- Depending on the strategies for action; and
- To facilitate the communication of the diagnoses

One of the main notions illustrated by these new systems is the evaluation of the different quality components. These components are called "alterations." The parameters of common nature or effects are grouped in the same alteration.

The illustration below shows some alterations of the Underground Water Quality Evaluation System.



The systems provide evaluations of the physical and chemical quality of the waters for each of the defined alterations. The same parameter can be interpreted in several alterations. Specific evaluation grids are used to evaluate the parameter in line with one or another alteration it concerns.

At the present time, the evaluation systems use the results of physical, chemical and bacteriological analyses. In the long run, other types of data could be processed, i.e. ecotoxicological data or radio elements, for instance.

Another difficulty in water quality evaluation is the fact that this notion s relative and depends on the use for which the water is intended.

There is no intrinsic quality of a water a prior, but water qualities that can satisfy this or that use.

The other main notion illustrated by the new systems is the evaluation of effects of quality on ecological functions and on human use. This evaluation of the impact on the ecological function and on the aptitude level of streams for potential human use is consistent, without however being directly identified, with the regulations that apply to the actual use.

Five types of use have been defined in the current versions.
Three of these types are common to both systems: production of drinking water, watering and irrigation.
Four other uses are specific:

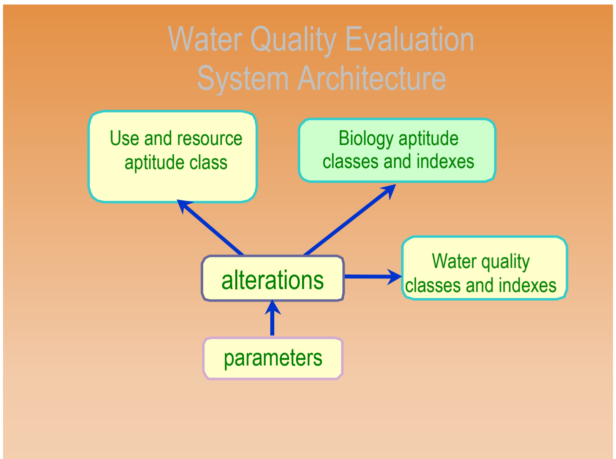
- Industry and energy, for underground waters.
- Spare time activities and aquacultures for river waters.

For underground waters, the Resource Evaluation was defined to gauge the degree of degradation of water from pressure exerted by social and economic activities on the phreatic tables.

In addition to the type of use, the biological function of the water is evaluated. This is the biology aptitude concept. It translates the potential of the water to host a more or less complex biological edifice.
The aptitudes of the water for the types of use and the biological function are evaluated for each of the alterations that have an impact on the use or the aptitude considered.

<u>Architecture of the systems:</u>

- The parameters are grouped in water quality alterations.
- The alterations are evaluated for different types of defined water use.
- A biology aptitude class is proposed (in this connection an index is calculated in the second version of the river water quality evaluation system).
- A quality index and class are used to communicate a global diagnosis per alteration.



The use aptitude is defined by 5 classes at most. These classes range from a very good aptitude (blue) to total inaptitude (red).

One to three intermediate classes are defined, depending on the pertinence of these classes. There are, for instance, only 3 aptitude classes for “Water sports and free time activities.” These classes are based on the notions of guide level and imperative level.

The definitions and classes are specific to each use. They take account of the regulations, recommendations and opinions of experts.

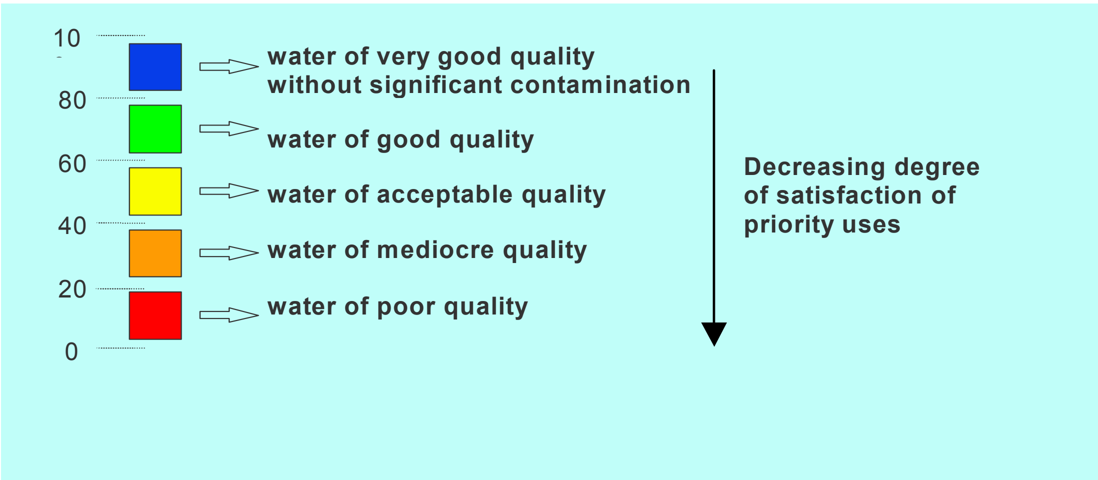
The resulting diagnoses are used to facilitate communication with decision makers and the general public.

A quality index is defined for each alteration. It integrates the biological function and the main uses.
For each measure of a parameter, and for each alteration in which it appears, alteration curves are used to go to one quality index per parameter. The term "quality index per alteration" refers to the lowest value of actually measured constituent parameters of the alteration. The index ranges from 0 (poor quality) to 100 (very good quality). This index is used to evaluate trends with precision.

To simplify communication, this index may be converted into a quality class. Each quality class covers a range of 20 index points.

From 0 to 20: water of poor quality; from 20 to 40: water of mediocre quality, and so on.

These classes provide an easy overall picture of the notion of quality for an alteration (see illustration).



Thirteen alterations have been defined to this day in the underground water evaluation instrument (for instance, the alteration "Organic and oxidisable matter," the alteration "Nitrates," the alteration "pesticides."

Only uses influenced by alterations are given.

It is possible to determine the overall water quality as well as the overall aptitude for uses by applying the limiting factor principle.

For the evaluation of surface waters, five alterations were defined in the initial version of the instrument. A sixteenth appears in the second version.

Physical and chemical states corresponding to the generalisation of the notion of biology aptitude are calculated.

They define the biological potentiality level of the water with respect to:

- general parameters called macropollutants. These include parameters describing organic matter, nutrients, etc.;
- non-synthetic micropollutants, essentially metals; and
- synthetic micropollutants (pesticides, chlorinated solvents, aromatic hydrocarbons, etc.).

The structure of the water evaluation quality systems is that of a box tools for water environments.

These systems will be upgradeable by improving the tools or creating new ones as the need arises.

- Additional parameters could be added in the alterations.
- New alterations could be created.
- New types of use or other natural functions could be defined.

In conclusion, the Quality Evaluation Systems have been constructed in a modular manner, making them adaptable to regulatory, scientific and technical developments.

- These tools are common all French Water partners
- They are consistent with the European Framework Directive
- They can be used to assess the environment and resource stakes
- They provide links between technicians, decision makers and users (of the water).

They are instruments for decision making, monitoring and planning of policies for the restoration and protection of aquatic environments.

In France, in anticipation of a European definition of "GOOD CONDITION," the Quality Evaluation Systems (QESs) will be used totally or partially to help assess the current state of water masses and the risk of not attaining the good condition level in 2015. the notion of good quality of the QESs is not easily assimilated to the good ecological quality of the European Framework Directive, which can be defined differently.

The Flemish eel monitoring network: PCB-concentrations in eel from the Meuse catchment area.

GEERT GOEMANS, CLAUDE BELPAIRE (INSTITUTE FOR FORESTRY AND GAME MANAGEMENT)

Introduction

The Institute for Forestry and Game Management (IBW) has build out a monitoring network for public water bodies in Flanders (Belgium) using eel (*Anguilla anguilla*) as a biomonitor.
The sampling started in 1994, by 1999 +/- 80 localities were sampled. Since 2000 there has been a systematic standardised sampling of eel ranging from 30-50 cm. At present, the monitoring network represents +/- 300 localities in Flanders, 45 of these are situated in the catchment area from the river Meuse. The analyses done on the tissue of these eels included PCB's, organochlorinepesticides and heavy metals. The analyses were complemented with a.o. genetic research, the presence and tracing of pseudo-oestrogen disrupting substances, the measuring of dioxins (CALUX-method) and the analyses of Brominated Flame Retardants. These analyses were respectively done by the KUL (Catholic University Louvain), the UG (University Ghent), RIKILT (State Institute for Quality Control of Agricultural Products, NL) and RIVO (Netherlands Institute for Fisheries Research).
Eel was used for sampling because it is a very fatty fish (strong lipophylic character of a.o. pesticides and PCB's), benthic, 'sedentary' (during the yellow eel phase) and occurs as well in non-polluted as in polluted waters. Two other big advantages of eel are the absence of a seasonal effect through reproduction and it's place on the trophic ladder.
Part of the river Meuse is one of the 5 most polluted Flemish waters concerning PCB's. In the Meuse catchment area almost 90 % of all investigated sites exceeded the new Belgian PCB-standard (75 ng/g body weight).
As a comparison we will compare the PCB results for the Meuse catchment area with the other catchment areas in Flanders and compare the Flemish data with contamination data from eel caught in the Dutch part of the river Meuse.

Sampling strategy, methodology and chemical analyses

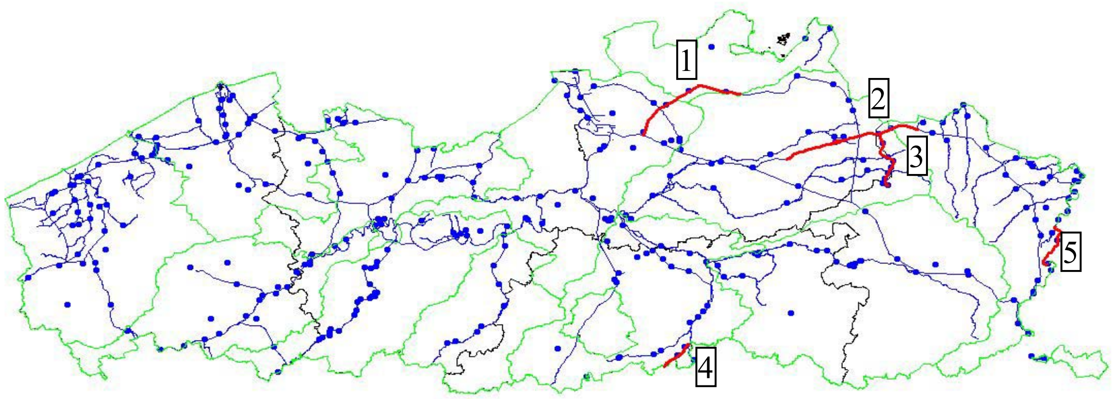
The eel sampling sites were spread over all types of surface water bodies i.e. rivers, canals, polder waters and closed water bodies. An important choice for the exact location was the aim to link as much localities as possible with the sediment-monitoring network of the Flemish Environmental Agency (VMM). Specific fishing-conditions sometimes obliged us to deviate from these VMM-localities. To get a representative idea about the pollution on these watersystems we chose a sampling site on the canals and bigger rivers every 20 kilometres. The sampling was done by electrofishing (wading or by boat) and/or fyke-nets (2 different types). Our aim was to collect 10 yellow (sedentary) eels with a length between 35-45 cm, catching restrictions obliged us to broaden this range to 30-50 cm. At present the eel monitoring network represents more than 300 localities. 1850 eels from these localities were processed, 1400 being in the range of 30-50 cm.
45 sampling localities are situated in the Meuse catchment area, representing 260 processed eels, 200 being in the range of 30-50 cm.
The chemical analyses on PCB's and organochlorine pesticides are done by the SFD (Sea Fisheries Department, Centre for Agricultural Research) in Ostend. Fat extraction is done using Bligh and Dyer (1959) and the analyses are done by GCMS.

Catch and release obligation in Flanders

After the new Belgian PCB-standard for the sum of the 7 indicator PCB's (75ng/g body weight) took effect (Belgisch Staatsblad, 2002a), a ministerial decree was published on May 25, 2002 which stated a 'catch and release obligation' for **eel** on all public surface waters (Belgisch Staatsblad, 2002b).

On the 5 most polluted waters in Flanders (fig 1) there is a ‘catch and release obligation’ for **all fish**. This decree was based on the results of the Flemish eel monitoring network. In 80% of the localities from this network mean PCB-concentrations exceeded the Belgian standard. The 5 ‘most polluted’ waters in Flanders were chosen because the average PCB-concentration in eel from these waters was above 2000 ng/g body weight or because of severe heavy metal load.
This ministerial decree will be valid until 2005. By that time all 300 sampling localities in Flanders should be resampled and the results should be evaluated again.
The Flemish minister for the environment and agriculture has put it as a priority to do a close following-up of the five most polluted waters. The intention is to sample these ‘black points’ yearly by the Institute for Forestry and Game Management (IBW) for analyses on eel and other fish-tissue and simultaneously by the Flemish Environmental Agency (VMM) for analyses on the abiotic compartments.

Fig. 1: Most polluted sites in Flanders where a **‘catch and release obligation’** for all fish is in force until 2005



1: Canal from Dessel to Schoten
2: Canal from Bocholt to Herentals
3: Beverlo Canal
4: River Laan
5: River Meuse

Catch and release obligation
Catchment areas
Sampling localities
Waterways
Provinces

PCB-contamination in the Meuse catchment area

If we consider the most contaminated localities in Flanders concerning indicator PCB’s we see that 60 % of these localities are situated in the Meuse catchment area, irrespective of the fact if we look at concentrations in body weight or fat weight (see figs. 2 & 3). This very high proportion of Meuse catchment localities is even more alarming because the localities in the Meuse catchment area only count for 15 % of all localities sampled in Flanders.

If we take in account the situation in the Netherlands we can see the same alarming results for the Meuse catchment area compared to the other catchment areas (van Leeuwen *et al*., 2002).

Fig. 2: Mean concentration for the sum of the 7 indicator PCB's in Flanders (ng/g body weight)
localities in the Meuse catchment area are marked in red

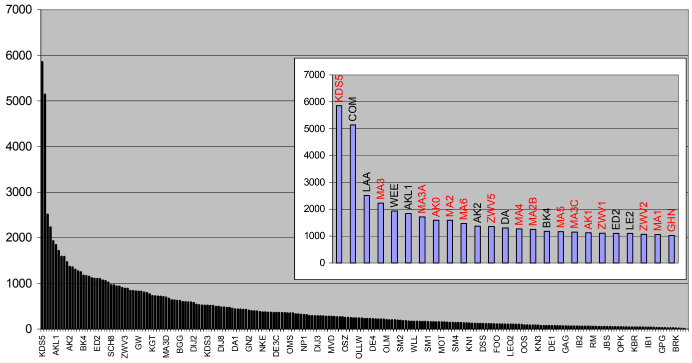
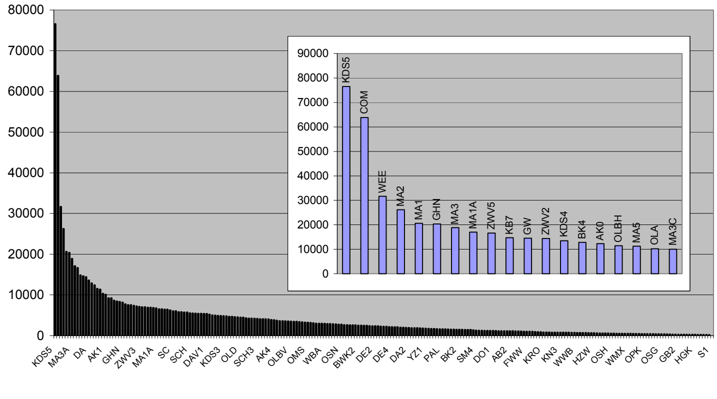


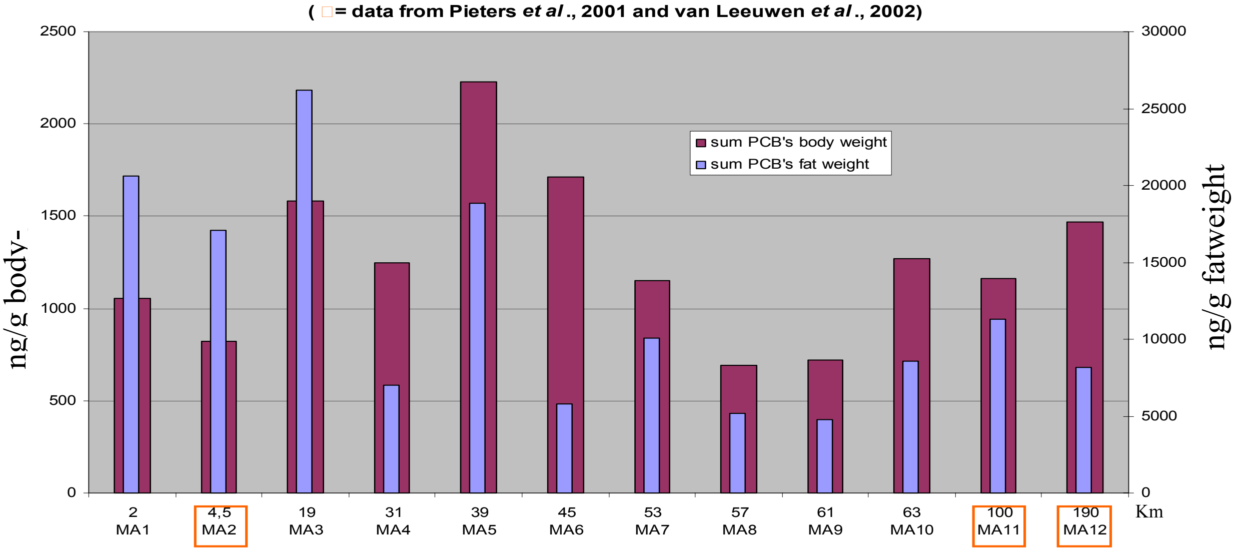
Fig. 3: Mean concentration for the sum of the 7 indicator PCB's in Flanders (ng/g fat weight)
localities in the Meuse catchment area are marked in red



PCB-contamination on the 'Bordermeuse'

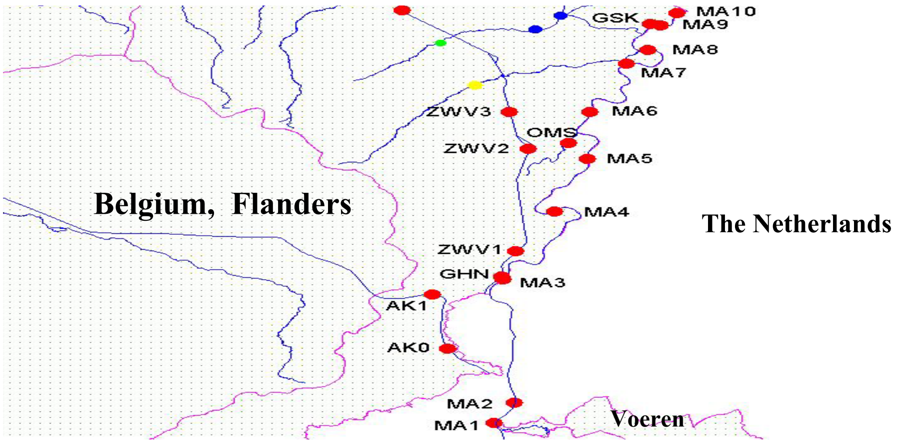
If we focus on the PCB-concentration in eel originating from different localities from the river Meuse (fig. 4 and 5) on a **body** weight basis we notice an increase in concentration going up to a peak value around MA5 which is situated at km 39, with an intermittent peak concentration around MA3 (km 19). Downstream MA5 we notice a clear decrease until MA8 (km 57) at what point it stays constant until just before the point where the 'Bordermeuse' flows over into the river Meuse again. These peak concentrations suggest potential PCB-contamination sources somewhere before or around km 19 and km 39.

Fig. 4: Course of the sum of the 7 indicator PCB's in eel originating from 9 localities on the 'Bordermeuse' between Flanders and Holland, supplemented with 3 localities in Holland.
(= data from Pieters *et al*., 2001 and van Leeuwen *et al*., 2002)

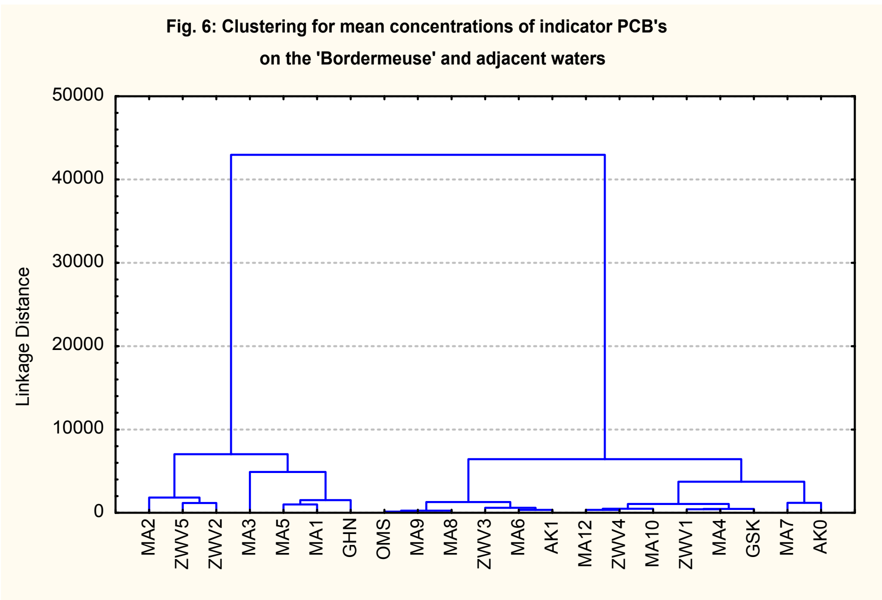


When we look at the course of the PCB-concentration in eel originating from different localities from the river Meuse (fig. 4 and 5) on a **fat** weight basis we can see that the main peak is at MA3, falls down to 1/4 at MA4 and peaks again at MA5 and falls down again to around 5000 ng/g fat weight. From this point more or less the same course is followed as on a body weight basis. The same conclusions could be drawn as above that these peaks could mean there is a PCB-contamination somewhere before or around MA3 and MA5.
For these concentration-courses we should take in account that the distances in between the consecutive localities is not at all constant, especially in the case of the last two localities situated in The Netherlands.

Fig. 5:Overview of the sampling sites on the river Meuse and sites in the near prox-



Is (standardised) eel a good bioindicator for the contamination-load of a specific site?
The similarity in mean PCB-concentration between MA1 and MA2 (fig. 4), which are only 2.5 km apart, suggest so. What makes it even more convincing is the fact that MA1 are our data and the data for MA2 come out of two RIVO-reports (Pieters *et* al., 2001 and van Leeuwen *et al*., 2002).
Another strong suggestion is the clustering in fig. 6 of the 'upstream' sites of the Bordermeuse (MA1 - MA5) with the gravelpool 'Hochterbampt' in Neerharen (GHN). This gravelpool is in the very close proximity of MA3.
In fig. 6 we can see that the gravelpool in Kessenich (GSK) clusters in the same subgroup as MA10, nevertheless it is geographically closer to MA9. Probable reason: hydrographically MA10 is just downstream the debouching of GSK into the 'Bordermeuse'.



Suggestions for further research

Internationally data should be collected on concentrations of PCB's and other contaminants in biota from all over the Meuse catchment area. In this way we could get a better view on sources, intensity and spreading of these contaminants.

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PROCEEDINGS

ORAL PRESENTATIONS

Topic 4:

Ecology

Flora and avifauna of the French upper Meuse floodplain: effect of management, indicators for policy.

BRANCIFORTI J., GREVILLIOT F., VECRIN M.P & MULLER S.

Introduction

The Meuse floodplain in northern France harbours rich communities with rare and protected plant species (Gratiola officinalis, Inula britannica, Teucrium scordium, Mentha pulegium, Triglochin palustre and Ranunculus lingua) and threatened bird species (Crex crex, Numenius arquata, Saxicola rubetra…) which have seriously declined in Western Europe in recent times (Grévilliot, 1996; Broyer, 1994, Rocamora & Yeatman-Berthelot, 1999). The meadows cover 75% of floodplain in a 2500 ha study area in the French upper Meuse valley. Meadows can be flooded for long periods and are traditionally managed with two cuts (or one cut followed by aftermath grazing) without fertiliser inputs. They have recently been subjected to more intensive farming practices (Duvigneaud, 1958; Grévilliot, 1996) in terms of (a) increased use of fertilisers, (b) earlier and more frequent cutting, (c) development of silage, (d) cropping of dry areas, and (e) spread of intensive pasturing. Thus 15 % of the floodplain is now cultivated and 25% of the meadows are pastured. Many studies realised on vegetation (Grévilliot, 1996; Grévilliot & Muller, 2002; Vécrin et al., 2002) have shown the great interest of this floodplain and its sensitivity to agricultural practice modifications. The decline of some bird species has stressed the lack of knowledge on ecology of most threatened species. In order to identify bird requirements in terms of habitat and agricultural practices breeding avifauna of the upper Meuse is studied since 1999. Results were expected to respond to managers wondering: What causes drastic decline of grassland birds during previous decades: habitat losses, degradation of breeding conditions ? Which concrete ways should be used to limit/stop this decline ?

Floristic interest and sensibility

Influence of hydric level on plant communities

Plant communities are either influenced by abiotic (rain fall, soil characteristics, water table fluctuations, flood frequencies and duration…) or agricultural (cutting or fertilisation pressures, grazing intensity, cultivation) factors.

The floodplain holds semi-natural mown meadows representing three main grassland communities (Grévilliot & Muller 1995; Grévilliot & Muller 2002). The meadow communities are structured along the topographic gradient reflecting different flood frequencies/duration and water table deepness with:

(a) The Colchicum autumnale and Festuca pratensis meadows (mesophilic) only flooded for short periods in the higher areas of the valley include mesophilic species like Sanguisorba minor, Bromus erectus, Salvia pratensis, Briza media, Colchicum autumnale, Primula veris, Ranunculus bulbosus.

(b) The Senecio aquaticus and Oenanthe silaifolia meadows (meso-hygrophilic) which are more frequently flooded, and for longer periods, than the previous ones. The water table is closer to the ground soil surface. They cover large areas at an intermediate topographical level (Grévilliot & Muller, 1997). It is a meadow community dominated by grasses, but it is the mesohygrophilic and mesophilic species (Centaurea jacea,, Holcus lanatus, Anthoxanthum odoratum, Senecio aquaticus, Galium verum, Rumex crispus) which particularly characterise this intermediate grassland type.

(c) The Gratiola officinalis and Oenanthe fistulosa meadow (hygrophilic) in the lower areas are very frequently flooded and influenced by the water table. They are characterised by more hygrophilic and helophytic species i.e. Agrostis stolonifera, Oenanthe fistulosa, Caltha palustris, Equisetum limosum, Eleocharis palustris, Carex acuta and Glyceria maxima.

Influence of agricultural practices on the floristic cortège: implications for biodiversity conservation

The mown meadows are usually cut twice a year, sometimes grazed afterwards and can be fertilised (mean value of 45 kg Nitrogen/ha/yr). When they are fertilised a significant decrease (proportional to the fertilisation level) of species has been shown (Grévilliot et al., 1998). Affected species were numerous: Galium palustre, Myosotis scorpioides., Achillea ptarmica, Galium verum, Lychnis flos-cuculi. Filipendula ulmaria, Lotus corniculatus, Trifolium pratense.. The frequency and/or the cover of two eutrophic grasses Lolium perenne and Alopecurus pratensis increase. The cessation of fertiliser applications could be followed by the re-establishment of some of the lost species if they are represented in the soil seed bank or in adjacent patches (Muller et al., 2000). In all cases, this phenomenon is slow and the restoration of a high richness is not ensured.
When the meadows are grazed the floristic cortège is heavily changing. Many mown meadow species are decreasing or disappearing like Achillea ptarmica, Galium palustre, Lotus corniculatus, Festuca rubra, Crepis biennis, Mentha aquatica. Eutrophic or refused species are increasing like Lolium perenne, Hordeum secalinum, Cirsium arvense, Urtica dioica and species which are adapted to compacted or bare soils appear e.g. Plantago major, Poa annua, Capsella bursa pastoris (Grévilliot & Muller, 2002). The mean number of species per relevé is decreasing from to 34 to 20 (mean for all the meadow types).
The cessation or heavy decrease of the human regulating activity (less than one cut every two years) lead to a quick modification of the meadows into fallows dominated by Arrhenatherum elatius, Filipendula ulmaria or Carex spp depending from the water level (from dryer communities to wettest ones, Grévilliot & Muller, 2002). The floristic richness is fallen from 34 to a mean of 21. The restoration of cutting activity could restore very quickly the composition of a semi-natural mown meadow if the delay between the two management activities is not too long (less than 5 years).
When they are cultivated in crop, the floristic cortège is lost and the reversion in diverse meadows after cessation of culture is very hard, slow and hazardous depending on the history and the duration of the cultivation stage and the presence of a viable seed source (Vécrin et al., 2002). Usually many meadow species especially oligotrophic ones are lost (Briza media, Oenanthe fistulosa, Anthoxanthum odoratum, Myosotis scorpioides) or present at a very low density.
It finally appears that the floristic composition of flood meadows is in equilibrium with environmental factors. The modification, even slight, of one parameter conducts to the modification of the floristic cortège of meadows. Human activities in floodplain should be respectful from this sensitivity having always in mind that when the biodiversity is lost it is never sure to find it again after restoration of traditional farming or water management.

Avifaunistic value and sensitivity

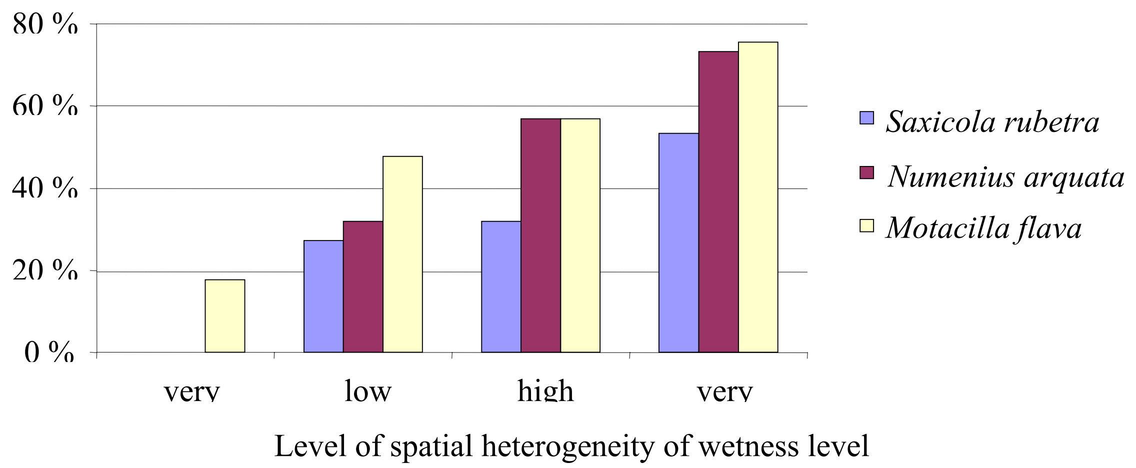
Floodplains of the French Upper Meuse present greatest interest for the ecological value of their avifauna. Avifaunistic biodiversity reaches here high levels: as an example, more than 150 bird species were recorded in four years, on the 2500 ha-study area. This value is very important for this type of homogeneous open area (Grévilliot et al., 2000).
The presence of many of these species depends on the expression of large flooded areas. During interbreeding seasons, some species gathered in large flocks (up to several dozens of thousands of Vanellus vanellus, Grus grus, Larus ridibundus, Pluvialis apricaria,…). In breeding season, avifauna is dominated by typical species of wet, open and/or grassy areas (e.g. Crex crex, Porzana porzana, Numenius arquata, Anas querquedula, Saxicola rubetra, Acrocephalus palustris, Acrocephalus schoenobaenus, Emberiza schoeniclus,...). Some of them are endangered species, at national and European levels (e.g. Saxicola rubetra, Numenius

arquata,...), or even at world level (Crex crex) (Tucker & Heath, 1994; Rocamora & Yeatman-Berthelot, 1999). Wet grassland threatened species actually contribute in a large part in bird value of Meuse floodplain. Moreover wet grassland habitats (hay-meadows and pastures) are listed at the 3rd rank of habitat types where higher number of nationally endangered birds species live (Rocamora & Yeatman-Berthelot, op. cit.).

Influence of water level and of its spatial layout on grasslands birds

Schematically, birds require three resource types for nesting: food, space and time (Lavelle, 1985). It is also obvious they have some peculiar needs in term of vegetation cover, which directly influences nesting conditions and amount of invertebrate preys.
Among studied species in the Upper Meuse valley, some show specific distribution patterns in relation with water level: some species select only the wettest areas, whereas others have more mesophilic affinities.
If the relation between birds and soil moisture is not directly observed most species seem to respond to the spatial organisation of wet and dry plant communities. For example, three grassland species were absent when spatial heterogeneity of water gradient is low, whereas they have a higher probability to be present when a mosaic of plant community is higher (Fig.1).

Figure 1: Influence of the spatial heterogeneity of water gradient on bird occurrence probability. Spatial heterogeneity is here measured by the length of the ecotons between plant communities per area unit. The 4 classes were defined by quartiles.



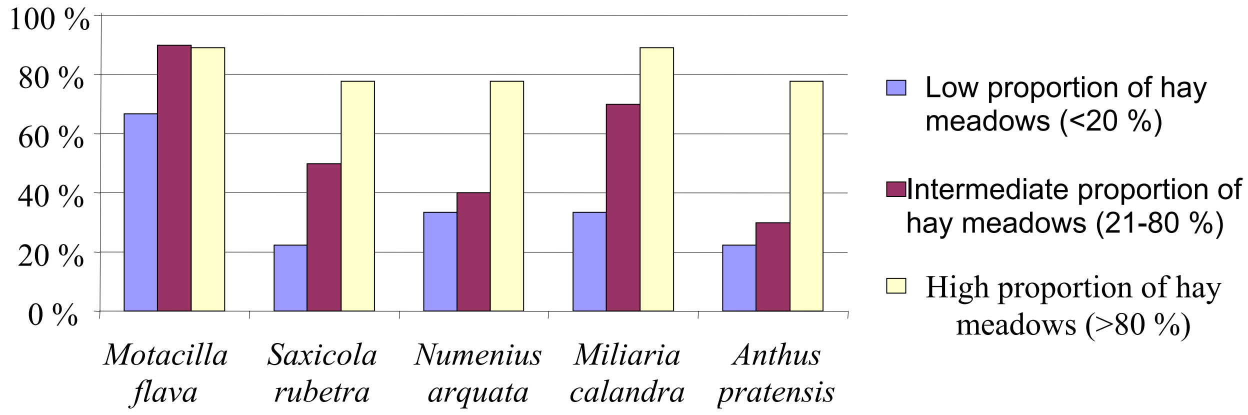
Influence of agricultural practices on birds communities

Because agricultural practices are partially determined by water gradient, it is obvious that agricultural use of floodplain should have an influence on bird populations. Agricultural practices actually influenced both breeding habitat (as an breeding habitat resource for birds) and a time window for achieving nesting cycle (as a time resource). Moreover, some studies have shown that modalities of agricultural use have strong effects on invertebrate populations, which are used as a food resource for most grassland birds (Aebisher & Ward, 1997; Brickle & Harper, 1999, Ewald et al., 2002).

Influence of agricultural land use on bird distribution

By comparing bird response to different agricultural management types (i.e. crops, pasture, hay-cutting), it clearly appeared that distribution of most bird species was under influence of agricultural practices. As an example, Fig. 2 shows that grassland species are positively influenced by the superficies covered by hay-meadows in flood area (some species respond in a lesser extent to this parameter than others, e.g. Motacilla flava compared to Anthus pratensis).

Figure 2: Influence of superficies of hay meadows on bird occurrence probability (in %). Proportions of hay meadows are measured per 4 ha unit.



Influence of the intensification level on population dynamic

Bird populations directly depend on available time window for achieving their nesting cycle. As all grassland species nest on the ground in vegetation canopy, they are particularly aware of agricultural activities: nests or nestlings can be destroyed by cattle (pastures), harvesting (crops) or hay-cutting (hay meadows). In the study area, mowing dates have a strong influence on nesting success of grassland birds: according to Tab. 1, in a parcel cut at late May, breeding pairs have no chance to produce fledglings (100 % of nests/nestlings destroyed by agricultural activity) whereas in a more extensive parcel, negative impact of hay-cutting is really lower. That is why hay cutting should not occur before late June if purpose of management would be to maintain breeding avifauna (late July in the case of Crex crex).

Table 1: Influence of mowing date on nesting success of three endangered species (Mouzay, years 1999 to 2001)

Mowing date	Agricultural destruction rate of nests/nestlings		
	Saxicola rubetra	*Numenius arquata*	*Crex crex*
30th May	100 %	100 %	100 %
15th June	53 – 85 %	50 – 68 %	100 %
30th June	0 – 18 %	9 – 56 %	100 %
15th July	0 %	0 – 26 %	75 – 100 %
31st July	0 %	0 %	0 – 7 %

Inferring policy

Investigating factors influencing distribution and population health of grassland avifauna provides to managers some useful guidelines. Stakeholders can use it in order to integrate avifauna conservation requirements among others aspects (including economical and social considerations) when making decisions related to regional planing and agriculture.

Conclusion

The French upper Meuse still harbours rich and preserved ecosystems whose life is pulsed by water fluctuations (water table and flood). Modification of the water level will conduct to the alteration of the plant communities and to changing in the agricultural practices (e.g. intensification of farming in case of drying of the floodplain). That is why we have to take care not to modify the natural water functioning of the French Meuse valley. Moreover, agricultural requirements are stronger and the floodplain grasslands are heavily and quickly intensified and disappearing. Flora and avifauna are both influenced by agricultural management. The more the farmer management is closer to traditional farming, the more chance we have to preserve the meadow plant and bird diversities.

Results of ecological studies have also been used in a number of programs aimed to conservation of local patrimonial species (flora, avifauna) and habitats. The French Meuse floodplain is now partly under the application of agri-environmental schemes aimed reducing fertiliser inputs and postponing cutting dates (Muller et al., 2000): regulation EEC 2078/92 since 1992 and Natura 2000 issues (also by applying agri-environmental schemes) since 2002.

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Ground beetles as indicators for the Meuse riverbank habitat integrity.

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Carabid beetle assemblages were described along the river's longitudinal gradient, in order to determine biogeographical, river dynamic and bank structure related explanatory variables for the composition of the riverbank communities. For the assessment of 'river health' and riverbank habitat integrity, the habitat templet approach is useful for comparison and evaluation over and between river sections (Townsend e.a. 1997, Fairweather 1999, Karr 1999). The integration of species and habitat data in this approach is a crucial step in the integrity assessment. Predictor variables for the habitat integrity in the river system were investigated within the framework of an international research program on flood protection measures for the Rhine and the Meuse, the IRMA-SPONGE Intermeuse project (Geilen e.a. 2001). The selection and inter-correlation of the predictive variables with their critical ranges, results in an evaluation method for flood protection strategies. For the scale-sensitive character of the analysis, predictors at basin and pilot stretch level were identified.

The use of templets has benefits in defining responses and indicators in river systems with immediate relations to the physical conditions (Stork 1990, Bornette e.a. 1994, Townsend & Hildrew 1994, Townsend e.a. 1997, Norris & Thoms 1999, Palmer e.a. 2000). It starts from a classification identifying clear hydrological and morphological zones, unifying the whole river Meuse. Responses to specific river conditions for these templets, detected by correspondence analysis and logistic regression, are useful in the evaluation of river management and flood protection measures in particular. A hierarchical set of filters is used to identify the species and habitats most at risk, based on a screening of basin wide management related variables (Hansen e.a. 1999).

The main research focus was on flow regime related variables that have impact on the biotic communities and habitat integrity. The following hydrological variables, used in flow regulation assessment, were defined (Growns & Growns 2001):

1. baseflow index (BFI) = (lowest daily discharge/mean daily discharge) x 100.
2. coefficient of variation (CV) = (standard deviation of monthly discharge/mean monthly discharge) x 100.
3. peak frequency (PF) = number of discrete flood events during the summer period (may to october, the active period for the carabid fauna), selected from long year flow data.
4. peak velocity (PV) = the peak flux over hourly or daily discharges, as the slope of the hydrograph
5. rising speed (RS) = the velocity of the waterlevel rise, as a measure for the hydrodynamics on the riverbank habitat.

Some further variables, relevant in riverbank habitat description, were included: river kilometre, summer peak amplitude, winter peak frequency, width/depth-ratio, density of bars and islands, texture of substrate and vegetation cover.

Predictor variables in the Meuse basin

The river Meuse has been strongly regulated over the last 150 years, heavily inflicting the flow regime, bed form and riverbank habitat conditions (Micha & Borlée 1989).
For the different gauging stations (Stenay, Lorraine Meuse (France)/ Borgharen-Smeermaas, Common Meuse (Belgium)/ Venlo, Sand Meuse (Netherlands) the CV-values over the last 10-100 years were analysed (Jochems & Van Looy 2001c). CV-value ranges over 10 year summer periods for the historical (1911-1920) and present-day (1989-1998) data were calculated. The resulting values with their standard deviation are presented for Borgharen and Stenay in figure 1.

The 1911-1919 CV-values, representing Meuse discharges before large-scale flow regulation took place, are close to the Stenay-values. The present day Borgharen CV-values show a significant alteration of the flow regime. This is shown by the comparison of 1911 and 1998 CV values at Borgharen (figure 2). Summer discharge fluctuations have increased significantly by weir management for water distraction to the canals and by the hydro-electric power plant of Lixhe. This comparison shows for the Common Meuse stretch the impact of regulation activities (weirs and hydraulic power installations) and alteration of water runoff at catchment's level. At low discharge levels (during summer), the discharge variability is threefold bigger than in natural circumstances. This imposes high stresses on the riparian communities.

Data gathering

In a field survey, data were collected on riverbank carabid fauna and vegetation during 3 consecutive years along the river Meuse. For additional information on ground beetle communities and species distribution in the Meuse basin, data of several carabid fauna surveys of riverbank communities along the Meuse and its main tributaries were consulted (Baufays 1994, Desender e.a. 1995, Richir 2000, Turin 2000).

A standardised pitfall trapping method was used to sample riverbanks along 600km of the river Meuse in 2000. 14 stations were sampled in 3 Meuse stretches, the Lorraine Meuse, the Common Meuse and the Sand Meuse. Each station consisted of two plots; one higher on the riverbank and one along the waterline. Each plot consisted of three replicas in the form of pitfalls. The sampling for the year 2000 from may-september, with 14-day interval periods, yielded 4.881 ground beetles extracted from the pitfalls and 77 species were determined.

In the research on the Common Meuse, in 1998 and 1999 over 16.000 carabid beetles were sampled and determined over a 34 plots pitfall network on the riverbanks of a 40 km river stretch. In june-september 1999, a fine-filtering pitfall network was installed on 2 gravel bar banks, with 30 sample plots on each bank. This survey envisaged the fine-tuning of the larger network sampling results and the underpinning of population and species traits. This intensive survey was done in three weeks of daily sampling.

Method

The habitat templets are derived from an ordination of species groups/communities from the sampling set. The defined templets will be related to biotic and abiotic characteristics, in order to build a response model for the evaluation method. The habitat templet approach follows the steps in figure 3.

Results

With a k-means clustering, habitat templets for the riverbanks of the Meuse were determined.
Flooding regime, soil texture and vegetation are the main discriminating parameters in the grouping. The distribution and restriction of species to specific zones in the river margin is well pronounced for the indicator species groups of the habitat templets (figure 4). The different groups all have specific river species with high indicator values (INDVAL, specificity and fidelity indicator value, Dufrêne & Legendre 1997). The large number of river specific species within each habitat templet is an indication of the specificity of the species assemblages at riparian habitats.

Species traits in habitat templets

The habitat specificity of the species is due to preference to substrate and vegetation cover, in relation to foraging strategies. The selection of habitat can be illustrated for vegetation cover by indicator species of the different habitat templets (figure 5).
The habitat preference is linked to foraging strategies. Feeding strategies were recorded as guiding principle in characterisation of habitat requirements and indicator assessment (Hering

& Plachter 1997, Hering 1998). In the detailed survey, species of the pioneer gravel bars were detected as foraging on collemboles and stranded organisms on the waterfront, with immediate and frequent reaction to waterlevel fluctuations.

The detrended correspondance analysis (DCA) showed a strong influence of the river dynamic characteristics, with a gradient of pioneer bars to flood channel plots in the winterbed. The other axis was related to the naturalness/modification of the riverbank, where the plots with high diversity and habitat specific species groups are situated opposite to the plots with more ubiquitous species with dominating influence and inflow of species from adjacent cultural lands. In the clustering and correspondence analysis, the stream order and geographical location do not prevail the divisions and explanatory value. With no longitudinal transition in community composition, the biological integrity of the different Meuse stretches can be highlighted unbiased, in contrast with the macroinvertebrate community interpretation (Usseglio-polatera & Beisel 2002). The species and habitat diversity over the pitfall sampling stations along the Meuse (figure 6 and 7), show the lower integrity in the Ardennes Meuse and Sand Meuse stations. The heavily regulated Belgian and Dutch Meuse stretches show a drastic decline of stream integrity, with a strong recovery in the un-navigable Common Meuse stretch. Stream canalisation efforts for navigation in the Ardennes and Sand Meuse, with embankments and groins, reduced the available riparian habitats for terrestrial as well as aquatic macroinvertebrate communities dramatically.

In the Multivariate and Covariance analysis indicator species for biotic integrity and specific river management variables were derived. With multiple logistic regression response and optimum ranges for the river management variables width/depth ratio, peak velocity, rising speed and habitat diversity were detected.

Discussion and evaluation method

Carabid beetles are commonly referred to as a good indicator group, in their habitat selection, dispersal capacity and colonising strategy, knowledge and number of taxonomic groups and easy sampling. The combination of these abilities allows the distinction of indicator groups for environmental characteristics, habitat configuration and integrity in river systems, and even for larger rivers in a global context (Gerken et al. 1991, Sustek 1994, Greenwood et al. 1995, Boscaini et al. 1998, Maiolini et al. 1998, Plachter & Reich 1998, Armitage et al. 2001, Eyre et al. 2001, Bonn et al. 2002). The multivariate analysis results show the main explanatory variables for the ground beetle community repartitions. These results show that river management practices can be successfully evaluated based on the responses of the ground beetle communities to river parameters. The main explanatory variables width-depth ratio and habitat diversity indicate the responses to local management practices of riverbed widening and bank lowering in a positive sense, and encroachment and embankments in the negative way. Nevertheless the hydraulic management on the river basin level is a trigger factor for peak frequency, peak velocity and rising speed, equally explanatory variables for the ground beetle assemblages. Therefore, regulation activities, weir management, retention strategies and increasing the upstream sponge function, are important measures for the biological integrity throughout the whole river basin (Van Looy & Jochems 2001a & b).

The responses to water management were analysed and quantified for the habitat integrity assessment in the three Intermeuse scenarios. (Van Looy & Jochems 2001c). The SPONGE-scenario has its strongest influence on the lowering of peak velocity, the RETENTION-scenario reduces peak frequency and in the WIDENING-scenario the width-depth ratios are at play. Responses to these variables were identified for the indicator species of the habitat templets at risk. The resulting impact on habitat integrity can be assessed with the multiple logistic regression results (fig 8).

Positive effects were highlighted for the SPONGE and WIDENING scenario's, in the responses to reducing peak velocities and rising width-depth ratio's. The retention scenario might have negative impact on peak frequency, since natural fluctuation of discharges and the associated hydro-morphological activity is of importance for the riverbank communities (Plachter & Reich 1998). From the presented analysis, qualitative and quantitative evaluation and guidelines for flood protection measures and integrated river management strategies can be proposed.

Analysis of the low flow fluctuations in the Common Meuse

The possibilities for the quantitative application of the presented habitat templet approach and evaluation method, can be illustrated for the hydropeaking problems in the Common Meuse stretch. Unnatural high fluctuations in the summer low flow regime, have been registered (see above). To determine ecologically acceptable discharge fluctuations, the most relevant hydrological parameters have been included in the analysis (Salverda e.a. 1998, Saltveit e.a. 2001). Redundancy analysis for the environmental variables and the carabid beetle community at risk, the pioneer gravel bar habitat templet, showed the Peak Velocity to be the hydrological variable with the highest score. This factor is strongly related to the weir management on this river stretch. The unnatural fluctuations, caused by the hydro-turbines management, are gradually damped over the stretch. Due to the hydro-electric power station at Lixhe, the Peak Velocity, as the increase in the discharge in an hour, expressed as a percentage of the discharge at that moment, is very high close to the power station (41 at Smeermaas), and damped gradually over the 50 km stretch to a value of 16 at Maaseik (the most downstream sampling station along the Common Meuse).

A significant covariance was found between the species diversity in the pioneer gravel bar habitat templet (14 species) and the Peak Velocity over the Common Meuse sampling plots (ANOVA F:315,12, $p < 0.0000$) and with a multiple regression, a significant regression function was found for the species diversity (beta=-0.56, F:29.9, p: 0.000001).

The linear regression for the species diversity shows the optimum condition for the carabid communities in PV< 30 where the man-induced discharge fluctuations are damped. This was illustrated by the average plot species richness in figure 9. The indicator species for the peak velocity, Harpalus affinis, and Bembidion decorum, showed significant correlations (chi^2= 25.9, $p<0.0000004$ and chi^2= 22.1, $p<0.0000026$), confirming the optimising value of PV 30. At the weir of Borgharen, measures were taken to damp the strong fluctuations caused by the turbines of Lixhe. Following these results for the situation in 2000, fluctuations should be further damped for ¼.

Conclusion

Research and evaluation tools in flood protection and river restoration projects focus mainly on hydraulic relationships, only recently the geomorphic aspect has gained attention. The presented habitat templet approach envisages the geomorphology and river dynamics of the studied object, the riverbank, by detecting ecological groups in species communities, based on species and habitat traits. The need for quantification of physical variables (impact of scenario's on flow regime parameters) remains a main issue for the evaluation of flood protection measures. Apart from water level effect prediction, a set of parameters describing peak characteristics and morphodynamics should at least be estimated in evaluation methods.

A very important element in larger gravel rivers of the temperate regions are the low and middle ranges of flows. Most hydraulic models and assessments focus mainly on higher peak discharges and the resulting water levels. Morphological processes and low flow characteristics still remain unexplored. For ecological predictions there is mostly an important lack of knowledge on these aspects of low flows and the dynamics of the flow regime, which are crucial in the impact assessment.

The Carabid beetles proved successful in providing indicators for biological and ecological integrity of the riverbanks. The responses of indicator species for specific river variables, are useful in the elaboration of evaluation methods for river management strategies and practices.

The presented physical habitat evaluation tool works both at the global as the local level.

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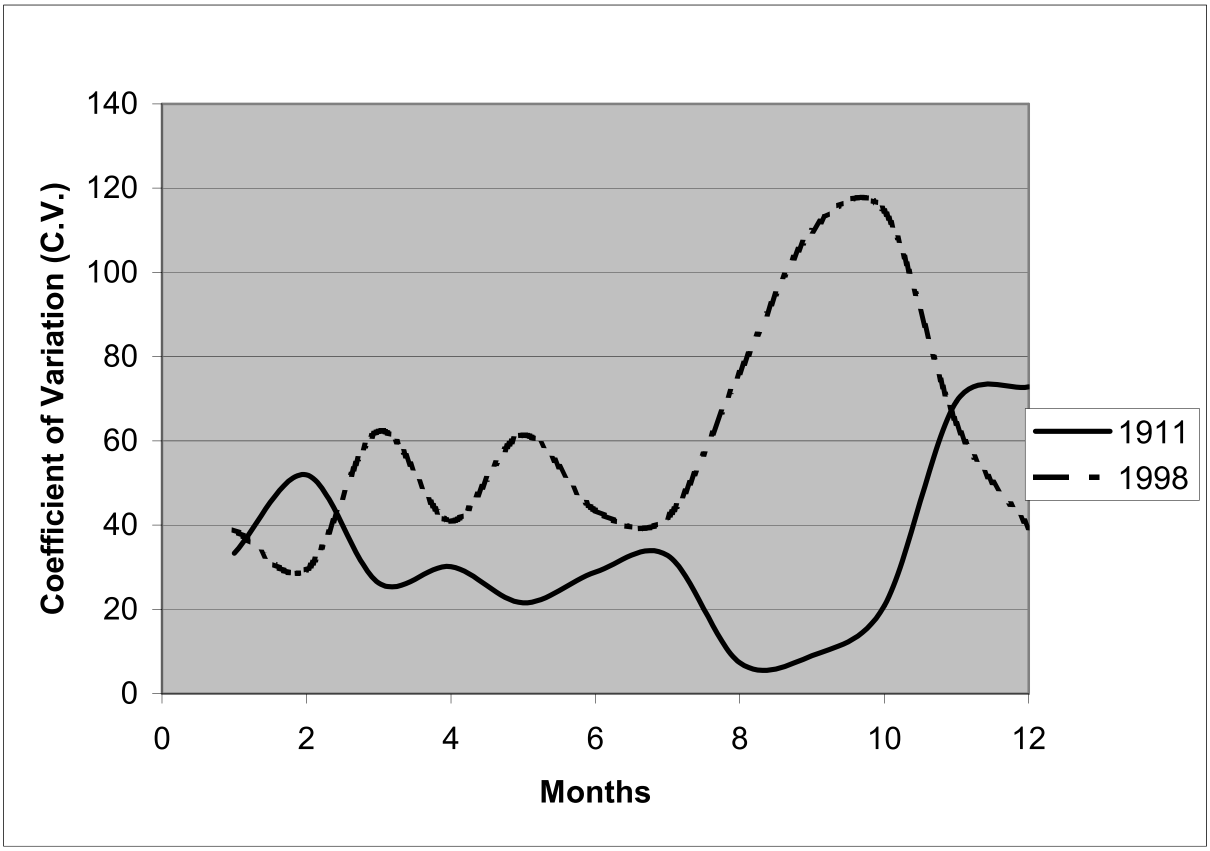


Figure 1. Comparison between historical and present-day Coefficient of Variation (CV) at the Common Meuse stretch (Borgharen).

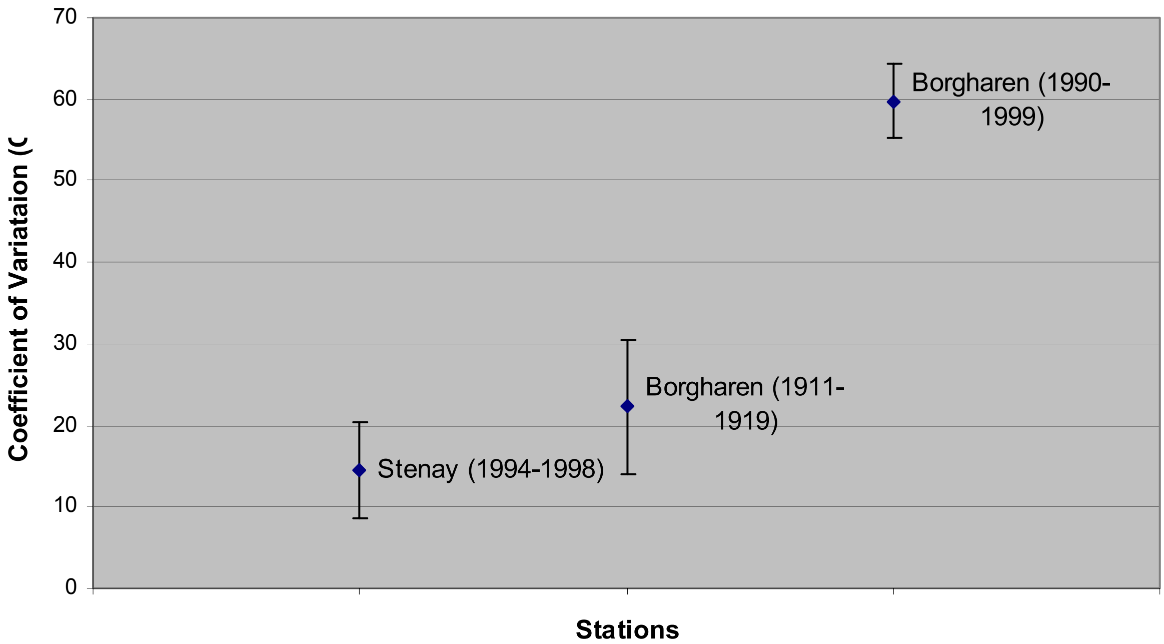


Figure 2. Comparison between summer mean Coefficient of Variation (CV) values (with SD) for Stenay, Borgharen (present) and Borgharen (historic).

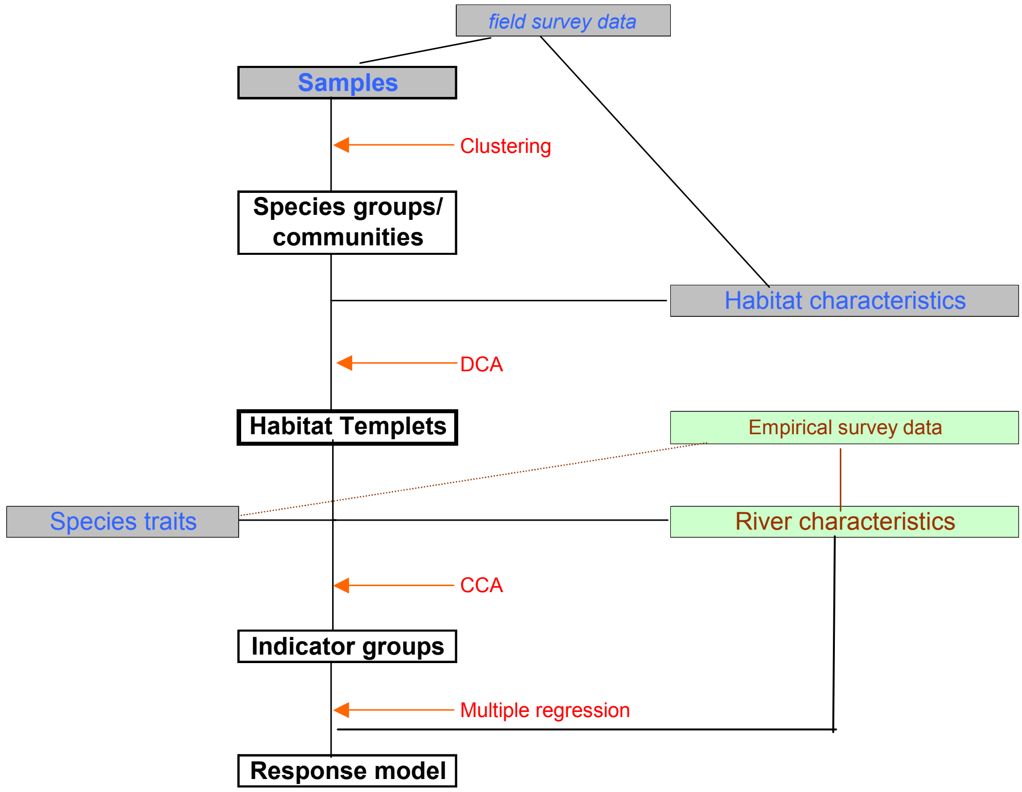


Figure 3 Flow shart of habitat templet approach.

Figure 4. The habitat templets and indicator species groups for the Meuse riverbanks.

gravel bar	higher bar	wooded bar	steep bank - cut-off bank	higher banks	silty bank - flood channel	sand bar
Bembidion decorum	Bembidion femoratum	Blaphrus aureus	Bembidion tetracolum	Pterostichus cupreus	Bembidion dentellum	Lionychus quadrillum
Bembidion punctulatum	Loricera pilicornis	Agonum micans	Agonum moestum	Pterostichus melanarius	Bembidion articulatum	Tachys micros
Bembidion atrocoeruleum	Dyschirius thoracicus	Stenolophus mixtus	Amara similata	Patrobus atrorufus	Bembidion varium	Tachys parvulus
Perileptus areaolatus	Agonum albipes	Stenolophus teutonus	Bembidion semipunctatum	Clivina fossor	Bembidion gilvipes	Amara bifrons
Thalassophilus longicornis	Agonum marginatum	Agonum assimile	Harpalus affinis	Clivina collaris	Chlaenius nigricornis	Dyschirius angustatus
Trechus quadristriatus	Chlaenius vestitus	Pterostichus vernalis	Harpalus rufipes		Pterostichus diligens	Amara fulva
		Pterostichus anthracinus	Dyschirius aeneus			

Figure 5. Frequency of Bembidion punctulatum (n= 203), Agonum muelleri (n=706), Bembidion tetracolum (n=1577) and Agonum micans (n=50), indicator species habitat templets with increasing vegetation cover, from open gravel bar to wooded bar.

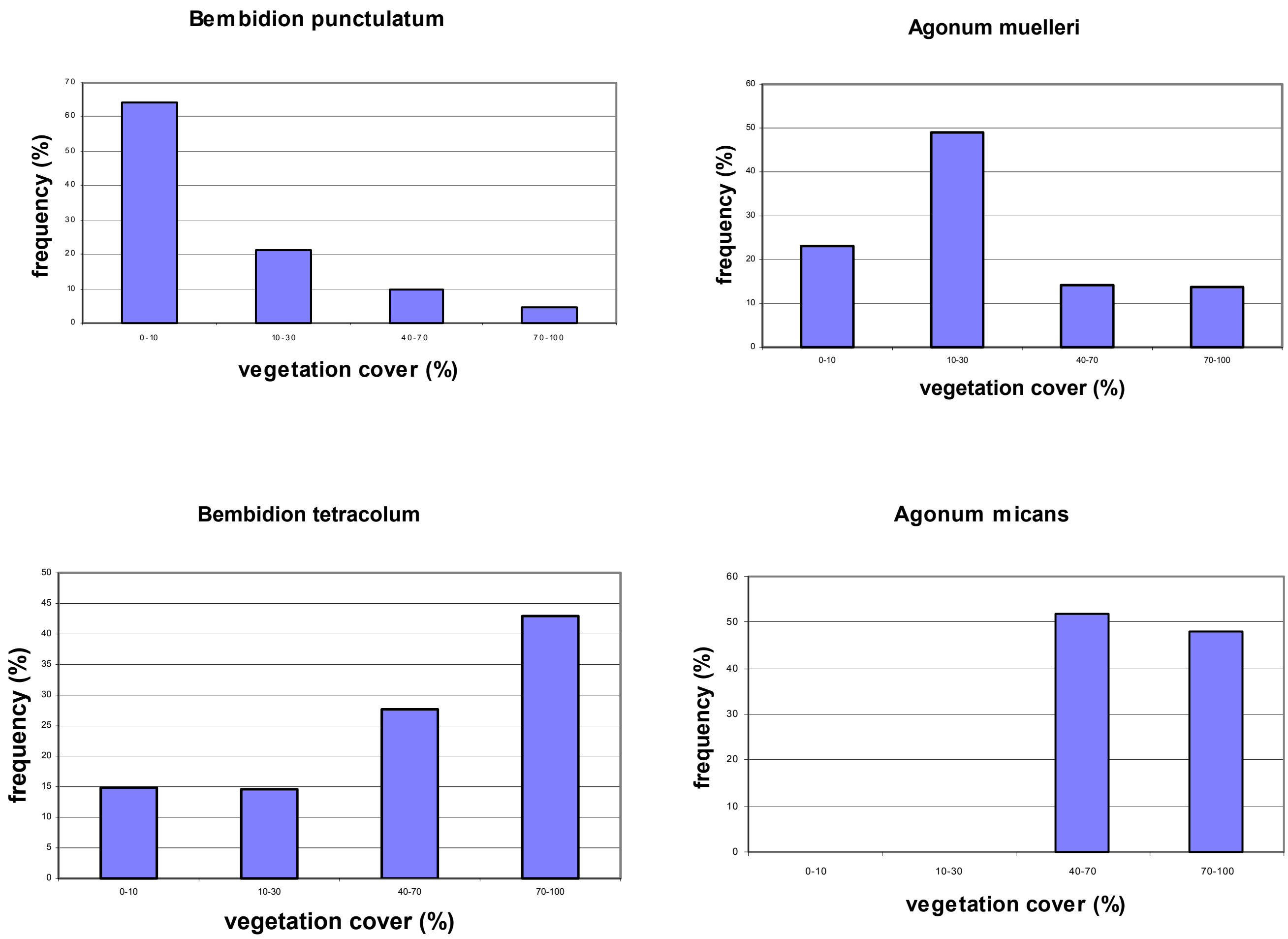


Figure 6 Carabid sampling stations along the Meuse. The colour of the symbols represents the quality of the present habitat templets, detected by the indicator species.

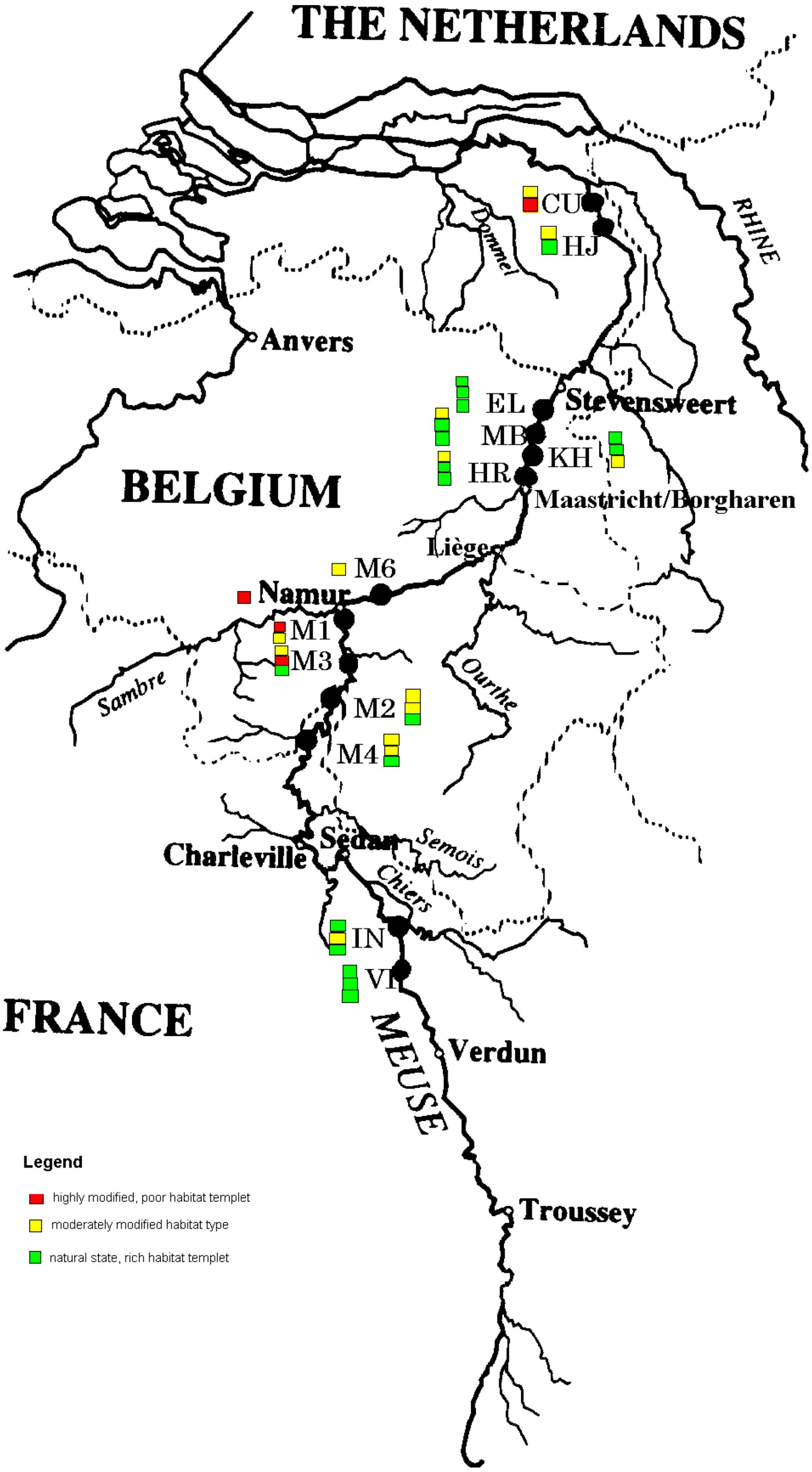
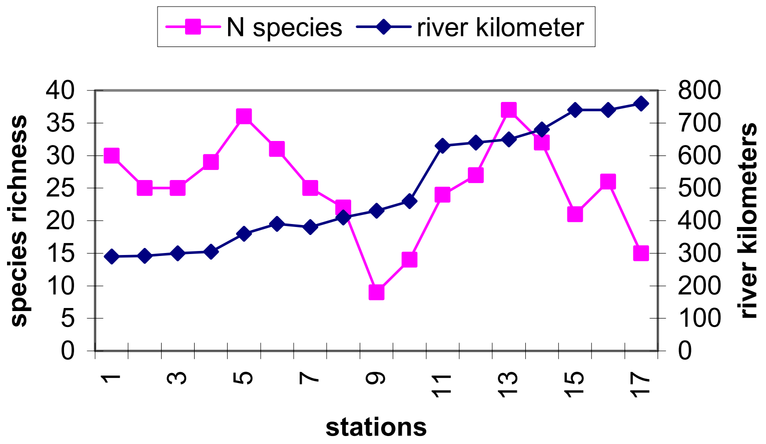
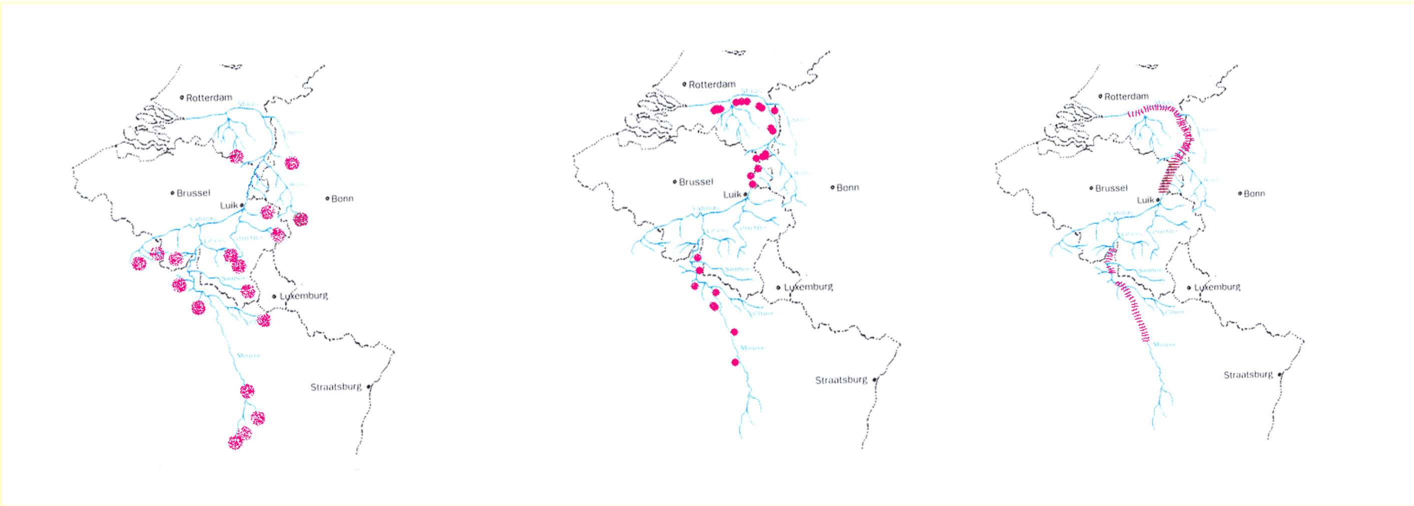


Figure 7. Species richness over the sampling locations of the Meuse.





sponge

Indicator Bembidion decorum
for peak velocity < 30

retention

Indicator Amara similata
for peak frequency > 9

widening

Indicator Bembidion punctulatum
for width/depth >25

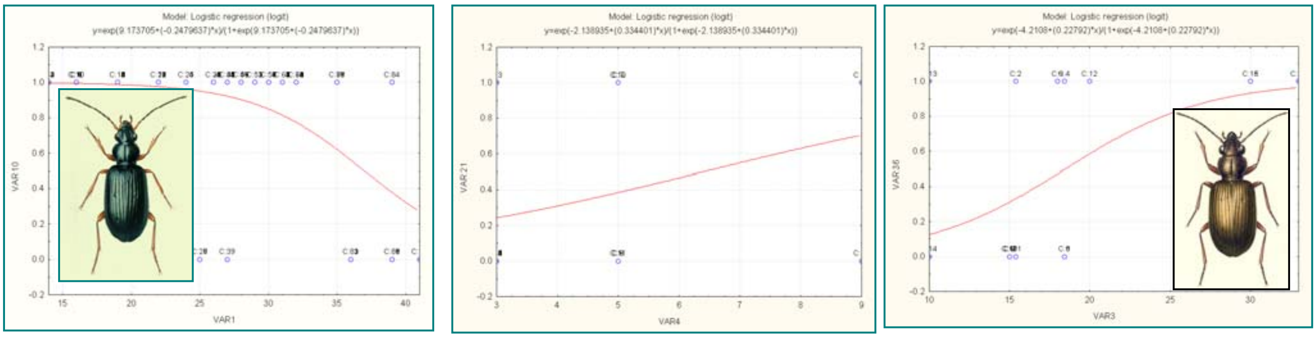


Figure 8. Intermeuse flood protection strategies for the Meuse and corresponding indicator response functions.

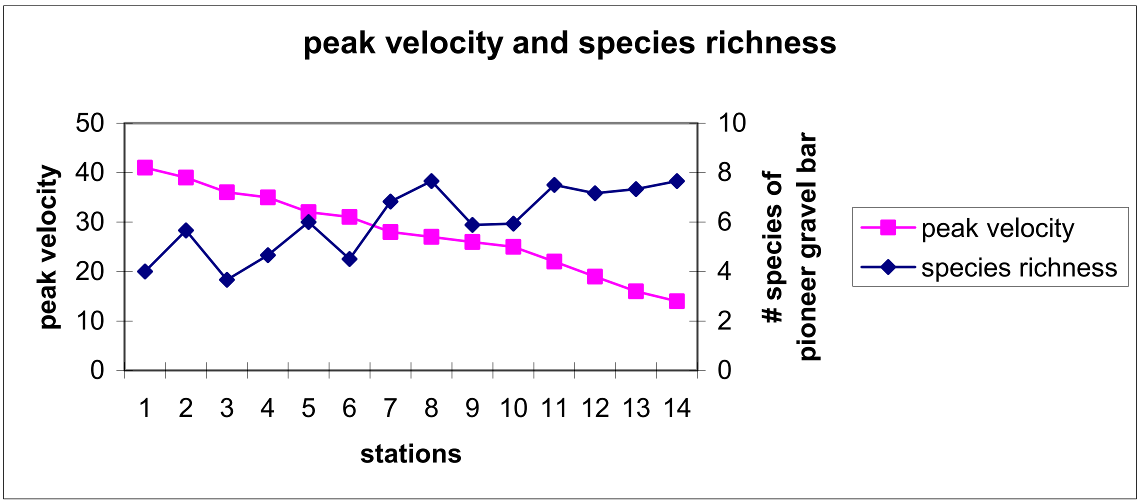


Figure 9. Average species richness in the plots along the Common Meuse, with the dampening peak velocity values.

Fishes of the River Meuse: biodiversity, habitat influences and ecological indicators

P. KESTEMONT, D. GOFFAUX, J. BREINE, C. BELPAIRE, A. DE VOCHT, J.C. PHILIPPART, E. BARAS, N. ROSET, J. DE LEEUW & P. GÉRARD

Introduction

The integrity of the River Meuse basin has been impacted since several centuries by human activities, modifying both the quality of its water and the diversity of its habitats. All these human impacts have modified the original structure and composition of fish assemblages and communities. This paper describes some main features of the Meuse ichthyofauna, with a special emphasis on the biodiversity (species richness and composition), the influence of habitat on fish composition, both in abundance and type of species as well as in fish size distribution, and the ecological quality of the river as evaluated by the application of a newly developed fish-based index.

Fish diversity

Ichthyofauna of the River Meuse basin has been investigated and described by several authors during the last decades, but papers usually refer to geographically limited parts of the whole watershed (Philippart et al., 1988, Breine et al., 1999, Middelkoop & van Haselen, 1999, Philippart, 2000, Liefveld et al., 2001, Van Thuyne & Breine, 2002). The diversity of fishes in the Meuse basin differs according to the definition of this concept. The total number of fish species is presently estimated at 51 species, while the number of native species is 34, and the number of exotic species reaches up to 17 species, from which 13 species are considered as naturalised (i.e. are able to reproduce successfully in the Meuse basin). Eight species are extinct: Atlantic salmon *Salmo salar*, Allis shad *Alosa alosa*, Twaite shad *Alosa fallax*, European sturgeon *Acipenser sturio*, houting *Coregonus oxyrhynchus*, sea lamprey *Petromyzon marinus*, river lamprey *Lampetra fluviatilis*, flounder *Platichthys flesus*. The former species is now under rehabilitation (Meuse Saumon 2000) and adults are now regularly captured in the Dutch and, very recently, in the Belgian parts of River Meuse, while the two latter ones, as well as the burbot *Lota lota* and the spiny loach *Cobitis taenia* are virtually extinct in most parts of the Meuse basin since they were not (or exceptionally) captured during this last decade. Some of these species are, however, present (but very rare) in the Dutch part of the Meuse. Causes of extinction or rarefaction are multiple, but the building of weirs for navigation (reducing or suppressing the migration of fish species), the industrial and, to a lesser extent, the domestic pollution, the commercial over fishing of some endangered species, and the destruction of spawning and nursery habitats are cited as the most important factors. Introduction or invasion of exotic species are due to voluntary or accidental restocking and the natural migration of species, facilitated by the construction of artificial canals allowing the linking with other European river basins such as Rhine and Danube.

Compared to other European river basins, the fish diversity of the River Meuse can be considered as medium, higher than the diversity of some large river basins as, for example, the Douro in Portugal or the Thames in UK, but surprisingly lower than the one of the Schelde (Belgium) which contains up to 64 species (including 36 marine or estuarine species) (Table 1). As shown by Oberdorff et al. (1995), the number of species is highly correlated with the size of the river system as indicated by main channel length or basin area. Based on the relationship provided by these authors, and assuming a total watershed area of about 36,011 km^2, the fish diversity of the River Meuse can be considered as medium (all species included) to relatively poor (only native species) (Figure 1).

Several methods can be used to sample fish from the River Meuse: electrofishing, gillnetting, control of fish passes installed at the dams, fish harvesting during drainage of backwaters, etc. The relative abundance of fish species is largely influenced by the method used to monitor fish communities. In the River Meuse the main species is the roach Rutilus rutilus, regardless of fishing gear or monitoring method. Other abundant species are the bleak Alburnus alburnus, the gudgeon Gobio gobio, the chub Leuciscus cephalus, the nase Chondrostoma nasus and the bream Abramis brama. But the proportions vary with the method of captures (Table 2). Eel Anguilla anguilla is still abundant, but the populations are declining.

Influence of habitat on fish composition

Many aspects of habitat may affect the structure and function of fish communities. The influence of habitat can be related to the changes of river climate (water flow, temperature), river geomorphology (width, depth and slope, type of river banks, nature and structure of bottom substrate, as well as to the existence of floodplains and backwaters, and associated submerged vegetation. In large rivers, the type of banks has been stressed as one of the predominant factors affecting the composition of fish species and the structure of fish populations. In this regard, the banks of the River Meuse have been modified, particularly in the Belgian section, with the presence of vertical concrete banks, artificial stone pitching and boulders. As reported by a study conducted in 2000 by The University of Namur (Dos Santos et al., 2000), the populations of roach Rutilus rutilus and chub Leuciscus cephalus, two abundant species of the River Meuse, are largely affected by the type of banks (natural or artificial, with steep slope or shallow profile) (Figure 2). Chub significantly prefer the natural banks with steep slope, during both day and night, while artificial and natural shallow banks are rejected during the daylight and night-time periods, respectively. The preference for a given habitat type may also vary with the fish size, since small chub (individuals smaller than 100 mm) were captured evenly on all habitat types during the night, while medium and large chub clearly prefer natural banks. Preferences of roach are relatively similar to those of chub, with a more systematic rejection of artificial stone pitching, during both day and night. More recently, the University Centrum of Limburg, in collaboration with the University of Liège, has investigated, in the Border Meuse, the influence of habitats on juvenile populations of various cyprinid species (De Vocht et al., 2002). Juveniles from up to 18 species were caught by electrofishing from July to October. As shown in figure 2, abundance of barbel Barbus barbus juveniles was strongly influenced by the habitat type, with a clear preference for islands and shallow riffles, and secondarily for gravel banks, while chub juveniles occupied all bank types. This study also suggested an ontogenetic shift in the habitat use by barbel, from the edges of gravel bars to riffles as fish increase in size.

Fish as indicators of ecological river quality

Relationships between fish communities and water and/or habitat characteristics of rivers have been suggested since many decades (Huet, 1949, Verneaux, 1976). More recently, a multiparametric fish-based index was developed, initially in the mid-West of the United States by Karr and his co-workers (Karr, 1981, Karr et al., 1986). This index, named Index of Biotic Integrity - IBI, is based on some ecological features of fish assemblages, using metrics classified into 3 broad categories: species richness and composition, trophic composition, and abundance and condition of fish. Pristine, or least impacted sites, are selected as reference sites and, for each metric, deviations between reference sites and altered sites are calculated. From 1993 to 1997, a research project conducted by the University of Namur, in collaboration with the Ministry of Walloon Region, adapted the IBI concept to the Walloon part of the Meuse basin. Based on standard samplings by electrofishing in 106 stations, 6 main metrics were selected to evaluate the ecological quality of the Meuse basin (number of native species, number of benthic species, % of intolerant individuals, bullhead/loach ratio, % of individuals as specialised spawners and presence of fry, juveniles and adults) (Kestemont et al., 2000). Similar studies were performed for barbel zone waters in Flanders, including some rivers from the Meuse basin (Belpaire et al, 2000).

A second step in the assessment of the Meuse basin ecological quality was initiated in 1998, with the Life-IBIP project, regrouping 4 partners from 3 countries (Conseil Supérieur de la Pêche, France, University of Namur, Instituut voor Bosbouw en Wildbeheer and Ministry of

Walloon Region, Belgium, Rijksinstituut voor Visserij Onderzoek, The Netherlands). Based on a database including 698 sampling stations distributed from France to The Netherlands, the IBI concept was adapted to the whole River Meuse basin, using two distinct approaches: the trisection method index and the multivariate method index. Both methods provided similar results, selecting 11 metrics to assess the ecological quality of the River Meuse basin (Table 3). The application of this new index on the main channel indicates that the Meuse can be regarded as a river having fair (moderate) ecological quality (Goffaux et al., 2001).

Conclusions

The River Meuse has a moderate to relatively poor fish species diversity: 8 species are extinct or virtually extinct, several species are considered as endangered, and it contains 17 exotic species. Fish captures are largely affected by sampling gears, both in number and type of species, as well as in fish sizes. Habitats largely influence the abundance and size distribution of fish species ; shallow riffles and islands are important for the presence of rheophilic species in the Border Meuse. Despite some highly disturbed spots, the application of a newly developed fish-based index indicates that the River Meuse can be regarded as a fair ecological quality.

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Table 1. Number of fish species present in some European river basins.

River basin	Number of taxa
Parseta (Poland)	22
Douro (Portugal)	24
IJzer (Belgium)	28
Drawa (Poland)	30
Severn (United Kingdom)	34
Yorkshire (United Kingdom)	35
Thames (United Kingdom)	35
Trent (United Kingdom)	40
Göta Alv (Sweden)	42
Seine (France)	49
Meuse (France, Belgium, The Netherlands)	***51***
Nemunas (Lithuania)	52
Loire (France)	61
Garonne (France)	61
Schelde (Belgium, The Netherlands)	64
Rhône (France)	65
Rhine (France, Germany, The Netherlands)	65
Danube (Austria, Slovakia, Hungary, Yugo-slavia, Romania)	> 100

Table 2. Relative abundance (% of total) for the 10 main species caught by different sampling gears or monitoring methods.

Species	*Electro-fishing*[1]	*Gillnet*[1]	*Control of fish pass (Lixhe dam)*[2]	*Drainage of backwater*[3]
Roach Rutilus rutilus	*31.2*	*33.3*	*60.5*	*69*[4]
Gudgeon Gobio gobio	*20.4*	*4.51*	*<1*	*<1*
Chub Leuciscus cephalus	*17.1*	*2.06*	*<1*	*<1*
Bleak Alburnus alburnus	*16.2*	*15.1*	*28.0*	*6*
Nase Chondrostoma nasus	*3.93*	*2.71*	*1.5*	*<1*
Perch Perca fluviatilis	*3.31*	*3.85*	*<1*	*3*
Barbel Barbus barbus	*1.06*	*1.71*	*<1*	*<1*
Bream Abramis brama	*0.87*	*13.0*	*2.7*	*13*
Ruffe Acerina cernua	*0.42*	*4.49*	*<1*	*4*
Silver bream Blicca bjoerkna	*0.37*	*16.0*	*<1*	*<1*

1. Data from Goffaux et al., 2001. 2. Philippart et al., 2001 (data on eel not included). 3. Gérard, 2000.
4. Data of rudd included

Table 3. List of biological metrics selected during the Life-IBIP Project in order to assess the ecological quality of the whole River Meuse basin by fish communities (Goffaux et al., 2001).

Metrics
Species richness
Total number of fish caught per unit of effort (100 m^2)
Total biomass of fish caught per unit of effort (100 m^2)
Percentage of lithophilous species minus exotic and tolerant
Percentage of rheophilous species
Percentage of intolerant species
Percentage of tolerant species
Percentage of intolerant individuals
Percentage of tolerant individuals
Percentage of invertivorous individuals
Percentage of omnivorous individuals

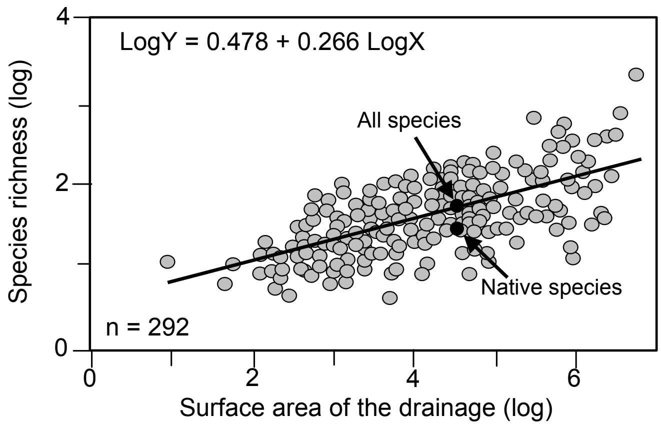

Figure 1. Species richness of freshwater fish for 292 rivers from different continents as a function of total surface area of the drainage basin (modified from Oberdorff et al., 1995). Black spots indicate the species richness of the Meuse basin, based on total or native species.

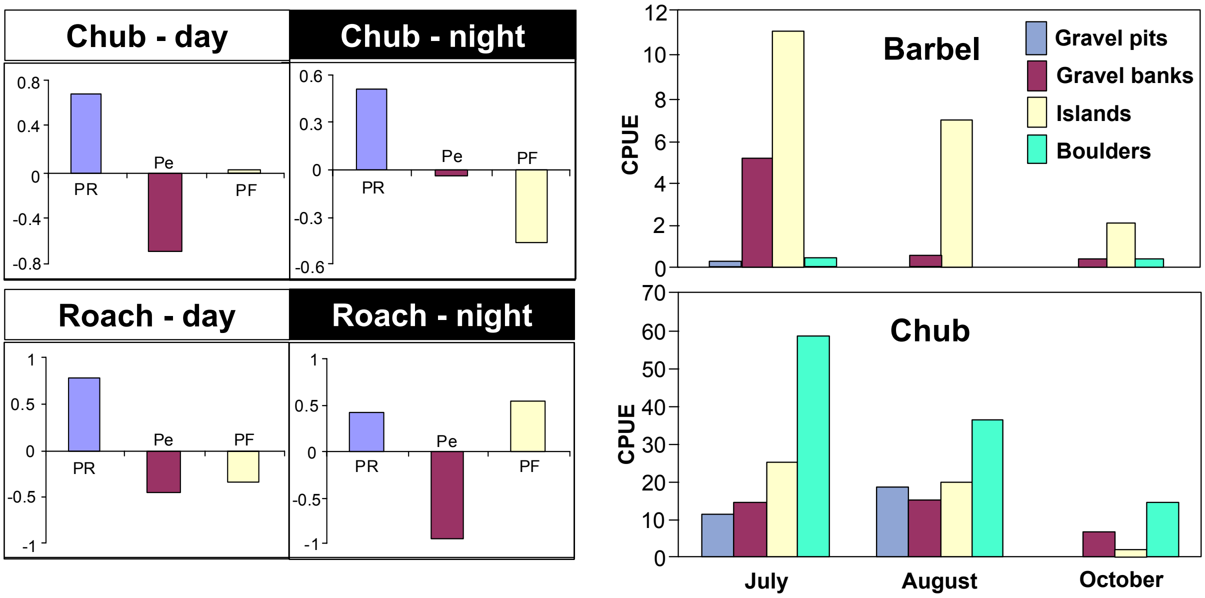

Figure 2. Left: Diel use of banks by populations of chub and roach in the River Meuse. PR = natural bank with steep slope, PE = artificial stone pitching with steep slope, PF = natural shallow bank. Data are expressed as Z-score. Values higher than 0 indicate preferences for a given type of bank while negative values indicate a rejection (from Dos Santos et al., 1999). Right: Abundance (capture per unit of effort – CPUE) of barbel and chub juveniles in different habitat types of the Border Meuse, as estimated by electrofishing (point abundance sampling method) (from De Vocht et al., 2002).

Comparative microhabitat use of 0+-juvenile fish in the Border Meuse.

DE VOCHT A, F. VAN BELLEGHEM, E. BARAS EN J.C. PHILIPPART

Habitat use of 0^+-juvenile fish in the Border Meuse was investigated by point abundance sampling in July, August and October 2001. Both natural and semi-natural river banks were sampled in three locations; Herbricht, Maasmechelen and Maaseik. Habitat variables such as water velocity, depth, oxygen content, substratum or gravel size, presence of plants or perilithon were recorded. 0^+-juvenile of 19 fish species were encountered. Transverse transects showed highest abundance of juvenile fish 2 to 4 meters out of shore. The highest number of juvenile barbel was present near the islands at Maasmechelen (0.46 barbel/U.E. to 0.02 and 0.08 barbel/U.E. in August). Barbel was only present on gravel banks and in riffles, while chub occupies all bank types and is found in highest number in the boulder assemblages. For investigation of the habitat preference, abundant fish species were divided into length classes for correspondence analysis. In early summer (July) discrimination between taxa and size classes, was explained essentially by water velocity near the substratum and upstream-downstream distance. The organisation of chub and roach at least partly along this axis, suggest that they drift in numbers. Barbel shows an ontogenetic shift in habitat use, from the edges of gravel bars to riffles as fish increase in size.
The distribution of barbel is extremely clumped. In the three sampling periods, the largest numbers of fish were captured in the same station, which corresponds to the place where adults were tagged and remained during spring and summer. The largest barbel are found in the same place, which presented the highest diversity of microhabitats. The very low density in August may be related to a lack of suitable riffle habitats under low floods. The growth of barbel is much faster than in the Ourthe, and this probably due to the warmer thermal regime of the Meuse.

Migrations, home range and seasonal habitat use of adult Barbel in the Border Meuse

DE VOCHT A, F. VAN BELLEGHEM, E. BARAS EN J.C. PHILIPPART

Fourteen adult (F.L 47,5 – 57 cm) barbel (*Barbus barbus*) were radio tagged (40 MHz) in the Border Meuse (Borgharen – Maaseik): 5 in May 2001, 3 in October 2001 and 6 in April 2002. From May 2001 till September 2002 fishes were localised weekly throughout the year and daily in April and May in order to localise spawning grounds and investigate seasonal migrations and habitat use.
In winter with flows ranging from 250 to 2.500 m^2/s four barbel present at the time were found in the main river bed at all times. Large structures such as boulders and trees were used as shelter. No migrations to different parts of the river occurred. In spring five out of seven fishes near Maasmechelen migrated to a spawning ground near one of the islands. Both upstream (0,2 km) and downstream migrations (up to 2,6 km) were observed. The spawning ground was characterised by the presence of fine gravel. Three barbel present in the Geul, a tributary of the Meuse, showed distinctive different migrations towards potential spawning places. Migrations in summer and autumn are directed by changes in flow and habitat suitability. The home ranges of the barbel, ranging from 0.5 tot 27.3 km, differ significantly in size between different parts of the river. Microhabitat suitability is determined by water depth, water current, flow and bottom structure. In spring daily migrations of up to 1.1 km are observed. In summer and winter daily migrations are usually limited.
Reproduction of barbel in this part of the river Meuse is hypothecated by the availability of fine gravel, high water velocities and hydro peaking in spring. Home ranges of fishes occupying highly structured parts in the river, with continuous availability of suitable habitat for spawning as wells as resting and foraging in both summer and winter, are significantly smaller.

Eutrophication in the River Meuse

J.-P. DESCY

Abstract

Eutrophication is a profound disturbance of the aquatic ecosystem, caused by an excess of nutrient inputs into water bodies. Nutrient enrichment, especially in phosphorus, leads to excess development of plant and/or algae, which affect water quality and ecosystem integrity. In this contribution, eutrophication in rivers is briefly treated, with special reference to the River Meuse. The present situation is analysed on the basis of data from the ICM monitoring network: it appears that, as far as phytoplankton development is concerned, most of the algal growth takes place in the French stretch of the R. Meuse, leading to maximal biomass (chlorophyll a) being recorded in the Walloon stretch. Downstream of Namur, algal biomass decreases regularly, with some occasional peaks remaining at lower levels than in Wallonia. Algal biomass is not correlated to total phosphorus. Strategies for the control of eutrophication are outlined. In particular, it is suggested that a strong reduction of all P inputs should be achieved, especially in the French part of the river, to obtain significant results in reduction of phytoplankton development in the whole river. Finally, the efforts for eutrophication reduction should also target nitrogen, which maybe responsible for harmful algal blooms in the coastal zones.

Introduction

Eutrophication may be defined as a disturbance of the aquatic ecosystem caused by excess nutrients inputs, the consequences being excess growth of the primary producers, when all conditions for their proliferation are met. The impact on ecosystem integrity and water quality appears at different levels: in the short-term, plant metabolism may result in diel variations of pH and oxygen, with a variable amplitude depending on biomass present, light an temperature. In the mid to long term, the organic matter produced by algae and plant growth will be broken down by heterotrophic bacteria, with possible oxygen deficits and possible production of toxic by-products.

In continental waters, phosphorus (P) is the main nutrient stimulating algae and plant growth: this has been well established for lakes decades ago, notably by whole-lake experiments (Schindler, 1974). Since then, considerable work has been done, which has confirmed the overwhelming importance of phosphorus in eutrophication of continental water bodies (Wetzel, 1983; Reynolds, 1992). At the scale of watersheds, P inputs are mostly attributable to industrial and domestic sewage discharges, although inputs from fertilisation may be locally significant.

Eutrophication in rivers is widespread: many rivers of developed countries support an excess of dissolved phosphorus readily available to algae and plants. However, the consequences of the high P loading in rivers have not been studied as well as in lakes. The effects on excess nutrients inputs on the river ecosystem vary depending on the type of river. In shallow, clear rivers (like the upper part of the R. Meuse): development of aquatic plants and filamentous algae is the visible result of eutrophication. The effects on water quality are easily detected by physical and chemical monitoring: on a diel basis, rise of pH and O_2 during the day, decrease at night; on a seasonal basis, large O_2 deficits may occur when plants and algae die (mainly in the end of summer). However, these effects are attenuated in fast-flowing, well-aerated streams. A constant feature of eutrophicated rivers with benthic plant and algae growth is the change of bottom structure and flow velocity: regularly the bottom substrates get clogged by vegetation, which is often a nuisance to bottom fauna. The consequences are often not visible in the short term, but may result in the long term in loss of invertebrate biomass and diversity, and may also affect fish through diminished resources and reproduction.

Deep, turbid rivers are, among other features, characterised by the development of phytoplankton (suspended microscopic algae), which may grow up to a biomass as high as in eutrophic lakes in favourable conditions. Again, excess phytoplankton development may have several adverse effects on water quality and ecosystem integrity:

- diel variations of pH and oxygen;
- oxygen deficits when algae die: in rivers like the R. Meuse, the organic matter in the algal biomass may be several times higher than organic matter from sewage;
- reduction of transparency, leading to decrease of aquatic plants on the river bed;
- deposition of organic suspended matter on the river bottom by sedimentation at low discharge, with adverse effects on aquatic plants and invertebrates.

Therefore, besides generating water quality problems, eutrophication in lowland rivers has also short- and long-term effects on biocenoses. Regarding the use of water by man, planktonic eutrophication in lowland rivers may reduce, and increase the cost of production of drinking water in water treatment plants. Although the risk of proliferation of nuisance algae is relatively reduced in most rivers, reservoirs storing water abstracted from nutrient-rich rivers may present harmful algal blooms.

Finally, the effects on coastal zones should not be ignored: inputs of organic matter and nutrients (N, P) and changes in nutrient proportion may cause adverse effects in estuaries and marine coastal areas, like nuisance algae proliferations (e.g. *Phaeocystis* blooms in the North Sea).

Therefore, there are good reasons to address the eutrophication problem when dealing with management and improvement of the water quality and of the ecosystem of lowland rivers. Hereafter, we give a short assessment of the present situation in the R. Meuse and we outline the possible strategies for eutrophication management.

The situation in the R. Meuse

Available data on the nutrient concentrations, phytoplankton composition and biomass in the R. Meuse are numerous, from water quality monitoring and from scientific studies. For instance, AWW (Antwerpse WaterWerken) data go back to the 1970s, and some scientific studies were done as early as in the 1950s and the 1960s (e.g. Symoens, 1957). Although there are hints of a increase of phytoplankton development in the river since the 1980s (Léglize & Salleron, 1988; Descy, 1992), there is evidence that the Meuse has been eutrophic for a long time, at least for several decades. However, the main concern of the ICM is to assess the present situation and to promote restoration measure. Therefore, we use only data from the monitoring network of the CIM, extracted from the last report of the working group "water quality".

Chlorophyll a concentration, which is a standard measure of phytoplankton biomass, is shown in fig. 1 for the year 2000. All profiles (average, maxima and P90) show clearly an increase along the river course in the first 500 km of the river, i.e. the French stretch; top values are found in the Walloon stretch, but there is a clear trend to a progressive decrease from km 500 to km 800.

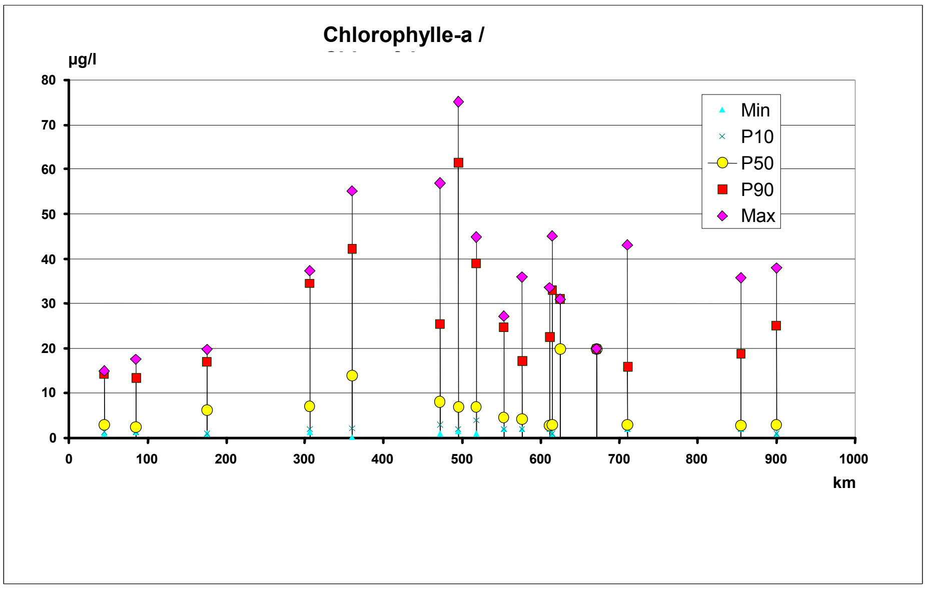

Fig. 1. Chlorophyll a concentration in the R. Meuse, year 2000. Data from the monitoring network of the CIM. Statistics are based on monthly sampling (n = 12 or 13).

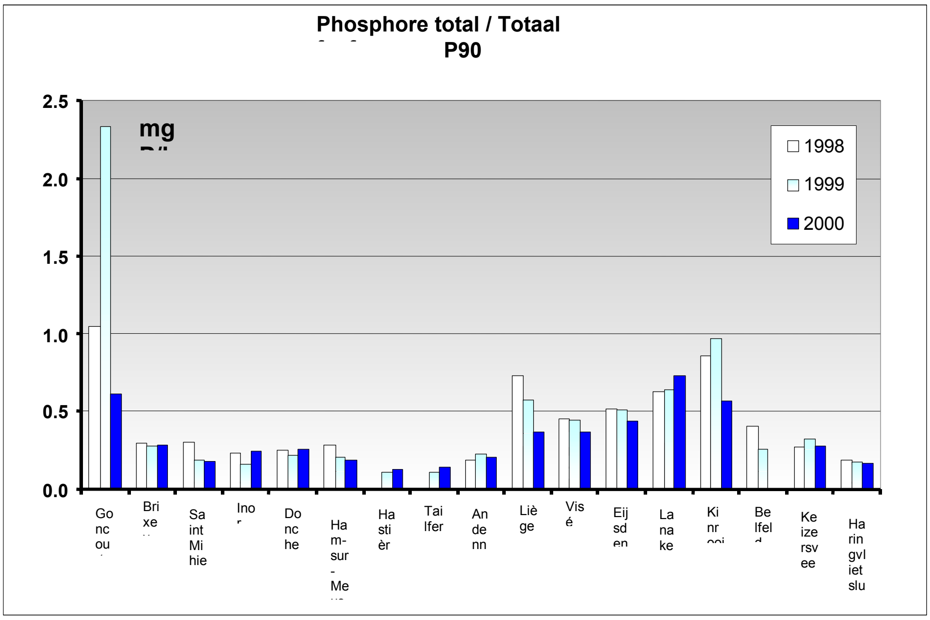

Fig. 2. Total phosphorus concentration (P90) in the R. Meuse, years 1998-2000. Data from the monitoring network of the CIM. Statistics are based on monthly sampling (n = 12 or 13).

Total phosphorus (TP) concentration (Fig. 2) is very high at all sites (minimum P90 around 0.2 mg l-1), and maxima appear upstream of the French sector. There is also a steady increase of TP from Liège to Kinrooi, followed by a decrease in the Dutch part of the Meuse. With regard to the P loading (not shown), it is low in the upper part of the river and increases, logically, with increasing discharge. There are however important rises at two sites of the Walloon stretch, that may be related to wastewater inputs: at Andenne (downstream of Namur and of the R. Sambre) and in Liège. The maximum loading of 1500 tonnes TP par year is reached downstream of the Liège city, where TP concentrations range between 0.5 et 1 mg l-1, mainly as dissolved P. The data for 2001, based on more frequent sampling and measurements for chlorophyll a and nutrients, show similar trends.

Discussion and conclusion

It can certainly be stated that high nutrient concentrations favour phytoplankton growth in the R. Meuse, as in any surface water body. However, observations on phytoplankton biomass shows that, in most conditions prevailing during the growing season (mostly March to October), phytoplankton development occurs essentially in the French part of the river. The biomass maxima recorded in the Belgian Meuse is actually made of algae transported from upstream, which hardly able to grow further. It can be demonstrated that nutrient levels are high enough to “saturate” algal growth, i.e. that nutrients are in a range where further increase in their concentration does not increase significantly the growth rate of algae (Fig. 3). In such conditions, phytoplankton growth depends only on temperature and available light in the water, which in turn depends on incident light, water transparency and depth. Such adequate light conditions are met in the French stretch of the R. Meuse. Other factors controlling algal development are flow rate and dilution by tributaries (Descy et al., 1987; Wehr & Descy, 2000). A clear evidence of lack of control by nutrients can be seen in the data presented above (Figs. 1 & 2): there is no correlation between chlorophyll a and TP. Fig. 3 shows why P does not influence algal growth rate above a certain concentration level.

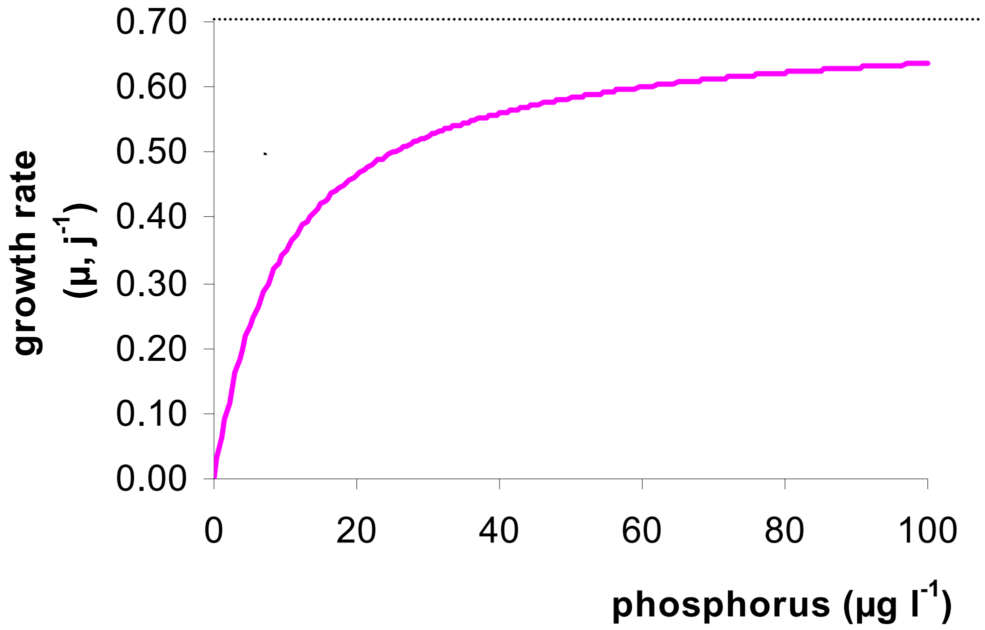

Fig. 3 Typical relationship between growth rate and dissolved phosphorus, for species of algae abundant in the R. Meuse.

Still, the only feasible and practical strategy for reducing phytoplankton biomass in the river is to achieve sufficient P reduction in wastewater discharges, through appropriate treatment in sewage plants. Indeed, one can hardly act on the other factors involved. Furthermore, the strategy for nutrient reduction in a river system is complicated by the downstream transport of algal cells, which have the opportunity to take up nutrients from multiple sources, and to store those nutrients, thereby avoiding limitation in low-input river stretches.
Therefore, an efficient restoration strategy should involve strong reduction of P at all sources, especially in the upstream course of the river, where conditions for plants and algae growth are well met. Clearly, the complexity of the problem would be adequately addressed by using simulation models for testing P reduction scenarios. For instance, will compliance to the EC urban wastewater directive be sufficient for achieving eutrophication control in the Meuse?
One can also think of additional measures: for instance, actions that favour return of the macrophytes on the river bed and banks are certainly welcome; hopefully plants will be able to compete for nutrients with phytoplankton. Such restoration measures have been applied successfully in shallow lakes, along with other measures (Moss, 1998). Finally, If P control may be one of the key action for improvement of the river ecosystem and water quality, it should be kept in mind that reduction of nitrogen inputs is also needed to achieve better protection of the costal zones: for this, better control of fertilisation and agricultural practices will likely be necessary.

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Assessment of river restoration works on the French part of the Meuse

P. GOËTGHEBEUR

Introductory

The River Meuse has these last years been subjected to very many actions on French territory. Its different constituent sections from its source have, for the most part maintained their ever so interesting biological functioning and potential, close to the natural state in certain cases, in spite of what are at times disturbing regional planning works.
We can distinguish, from upstream to downstream:
- The upstream part from the source to the outlet in the "Department" of the Vosges, which has been marked by hydraulic operations (cleaning, rectification, clearing of trees), but retains a notable functioning potential.
- The middle part, corresponding to the "Department" of the Meuse, which has remained very natural, even if the downstream part has been in part disturbed by works connected to the canal. This sector has preserved a remarkable dynamic functioning and biodiversity of European interest both for the minor bed and the wet meadows.
- The downstream part, that crosses the "Department" of the Ardennes, which is fully navigable and has been widely deprived of its originality.

At present, most of the operations have been carried out on the upstream and middle sectors, in particular under the Meuse River Contract.
This river contract pertained to the entire Meuse line of the river on areas that still have rather undisturbed hydraulic and biological functions.
For example, during low waters, the major bed, still used mostly as meadows, is widely flooded and crossed by low water channels, some of which are very active.

***Left**: The Meuse, during low water at Neufchâteau (Vosges): natural functioning of the hydraulic annexes (photo AERM).*
***Right**: The Meuse on its middle course (Department of the Meuse): major bed liable to flooding, with preserved functionalities. (photo AERM)*

This functioning, still dynamic, induces the presence of many hydraulic annexes, exceptionally wet areas and (still) natural banks.
In light of the foregoing, the main types of works have been:

*Soft management of the vegetation,
*Replanting actions,
*Reconnecting dead arms,
*Management of banks in plant technique.

Restoration of vegetation
The restoration of vegetation is aimed at managing the alluvial woods by preserving as much as possible the diversity of ages and species of trees and bushes; more specifically, to manage any hydraulic problems (ice jams that cause erosion, additional flooding), while preserving, as much as possible the functions of this river forest (protection of the banks, foliage, biodiversity, and above all the capacity to filter pollutants that pass through to the minor bed infiltrating the phreatic table and running waters of the catchment basin – nitrates and pesticides).

There are two possibilities on the Meuse
On the upstream part, the rather narrow stream has often been lined, after major devegetations, by a rather banal bushing edge, often monospecific and quite dense.
This "livid" vegetation was dragged in the stream clogging it and creating complete obstacles to flow.
The proposed treatment has consisted of selective pruning to correct these bushy ports into more tree-like ports. This operation was necessarily completed by replanting actions to reconstitute a diversified river forest.

The Meuse on its upstream course (Haute-Marne): river forest and minor bed. (photo AERM)

On the middle part, the vegetation consists essentially of old trees (essentially willows, most of which are conformed in pollard) accompanied by a very limited, and not very diversified edge.
This situation is the result of cuts that have been repeated for dozens of years and have left increasingly larger sections denuded or at least highly devegetised.
The presence of livestock in large numbers on the edge of the Meuse makes it difficult to reconstitute the river forest naturally.
On these sectors, the main aim of management has been maintaining a maximum of the subjects in place. Only hydraulic emergencies (ice jams, protruding trees, etc.) by pruning and reconforming the old subjects to extend their life and therefore their presence on the bank to the maximum. The rest of the vegetation has been kept and replanting actions are making it possible to diversify this river forest have been carried out in places.

The Meuse on its middle course (Department of the Meuse): aging and discontinued vegetation of the banks, diversity of the minor bed preserved. (Photos: AERM)

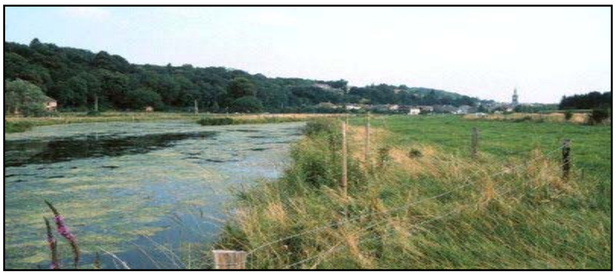
The Meuse in the Department of the Meuse: diversified but discontinued sectors of shoals (helophytes, trees, and bushes). (Photo: AERM)

Replanting operations

The replanting operations are carried out according to a list of autochthonous species adopted to each station; they are aimed at reconstituting a balanced river forest that can, in particular, play a filtering and shading role in what are currently denuded and calm areas, and therefore to limit the effects of eutrophisation. As of now, several tens of thousands of trees have been planned or already planted on the Meuse.

These works are aimed at planting sets of trees and bushes per sector (some twenty species characteristics of the edges on the Meuse have been defined). These planting operations are to be protected from livestock by means of various techniques, and constitute colonisation points for the plants in question. More specifically, the objective is to have the systems evolve naturally and thus allow the river to adapt its course.

The various sections of plants and colonisations (by seeds or cuttings) will lead to a diversified river forest.



Planting on the edge of the Meuse in the Vosges: diversified autochthonous species (trees and bushes), protected against livestock by fences. (Photos AERM)

Planting on the Meuse in Haute-Marne (opposite),
To reconstitute a diversified river forest, often deprived of its originality by excessive cutting. (Photos AERM).

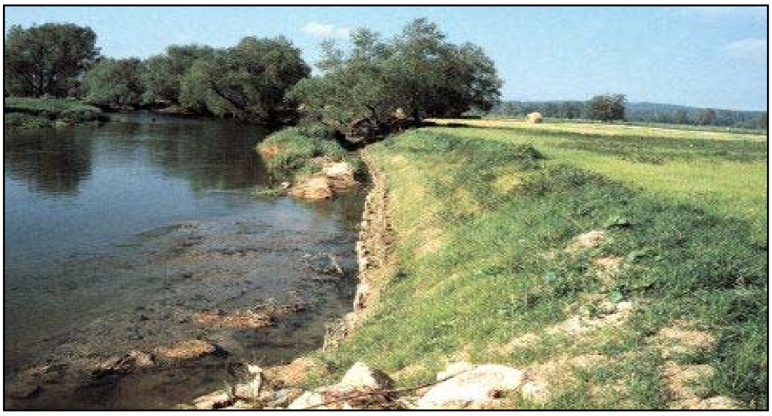
These works are currently given priority and constitute a preventive intervention method. More specifically, given the state of devegetation of the banks, many sectors of the Meuse are currently suffering from extensive erosion. The management of these problems is particularly complex and costly. It is therefore imperative to reconstitute a protective covering with plants on what are now stable banks.
Furthermore, as the value of river forest functions no longer needs proof, the management of sectors with only a deteriorated river forest (sparse and monospecific) cannot be limited to the simple management of plants that already exist, and must therefore include a replanting phase.

Protection of the banks

A major change of approach on the protection of the banks has been under way for some ten years in France. The important role of these phenomenon on restoring the hydraulic balance of the river is put strongly to the fore. Before any intervention, an analysis of the causes of the phenomenon, the stakes and compared costs (protection works and threatened property) has been carried out.
Numerous eroded areas of the river are therefore considered as fundamental elements of the dynamic of the river and, except in isolated cases, are not protected in rural areas.

As a general rule, only the hard points or areas of general interest (communication lines, built areas, etc.) are protected. This approach entails a management of position hard points near streams, and in particular in mobility areas. At present, mobility areas have been defined over the entire part of the Meuse in the Department of the same name, with extensive constraints of occupation of these spaces.

When the priority to protect an area is accepted by all the partners, banks are, as a matter of priority, protected by using plants.



Protection of the banks of the Meuse in the Vosges using plant techniques: by fascines, bio-degradable geotextiles, grass seeding, willow cuttings (Photos: AERM).

Reconnecting secondary arms

The Meuse has several dozen arms from old natural as well as artificial cuts, the latter as part of hydraulic operations (upstream) or from old arms from mills.
At present, the natural cuts of entire meanders are nearly non-existent.
Now, existing arms play a major role in the hydraulic and biological equilibrium of the river, by adding a great deal to the diversity of the banks, the bottom, and the major bed. Nevertheless, their natural evolution gradually fills their links with the Meuse and leads to a general alluvial deposit of the sites.

Reconnecting them therefore constitutes a choice to and to preserve these sites so as to restore a general diversity of the aquatic environment, for the flows and for biology, in particular fish farming.
From 1994 to 2001, nearly thirty arms were managed and some other ten are planned in the short term.
The works consist of very soft management of vegetation and a reconstitution of the hydraulic links through light cleaning of the links with the Meuse and the excessively silted parts of the arms.
These cleaning operations entail a reasoned management and the reconstitution of cross sections, lengthwise, and the most diversified banks possible.

Reconnection of an arm cut in the 1970s during a hydraulic operation on the upstream part. (Photos: AERM).

Reconnection of a "natural" dead arm being filled on the middle part. (Photos AERM)

Complete re-creation of a dead arm on the downstream part. (Photo AERM)

Prospects

The management of thresholds and dams: the Meuse is dammed by many sills and works that have in the past been used, in the upstream and middle part, to organise water intakes for mills, and on the downstream part to manage navigation, water intakes for canals, and various mills.
The dilapidated state of these works, some of which are virtual ruins (upstream), is to be managed globally, both under the River Meuse Contract, and the Public Authority for the Regional Planning of the Meuse and its Tributaries (known by the French acronym EPAMA).
Compromises have now been found in the Department of the Vosges to lower the crests of the works and to equip them for fish passages (see photo below).

PHOTO: AERM

In a general manner, the equipment of the fish passage devices is a priority and will be considered for all operations to come.

General management of rises in water level – creation of a public management authority for the Meuse

After the rises of the river in the 1990s, a public management authority for the Meuse was created, bringing together all the partners, and in particular the public authorities concerned.
For several years now, a general modelling study of the river's rises has been in under way, and is intended to improve their forecasting, while defining a programme of action to limit their effects in the French part downstream.