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Monitoring networks and modelling systems for assessing effectiveness of the EU Nitrates Directive Action Programmes: Approach by the Walloon Region (Belgium)

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1. Préambule

En juin 2003, une premier workshop « MonNO$_3$ »[1] a été organisé aux Pays Bas par le RIVM[2], le DMU[3] et le GEUS[4]. Ce workshop a rassemblé les expériences de 10 pays ou régions en matière de monitoring de l'efficacité des programmes d'actions mis en œuvre dans le cadre de la directive Nitrate (91/676).

GRENeRA avait participé à ce workshop ainsi qu'à la rédaction préalable d'un document de synthèse.

Le rapport de ce workshop est accessible à partir de l'URL suivant :
http://www.rivm.nl/bibliotheek/rapporten/500003007.html

En juin 2009, les mêmes institutions ont organisé un deuxième workshop « MonNO$_3$ » avec un accent plus particulier sur le monitoring en cas de dérogation au plafond de 170 kg Norg/ha.

GRENeRA a participé à ce workshop et a coordonné la rédaction préalable d'un document de synthèse repris dans les pages ci-après.

Treize pays/régions ont participé à ce workshop. Le rapport final n'est pas encore disponible.

[1] Monitoring NO$_3$

[2] Rijksinstituut voor Volksgezondheid en Milieu (Pays-Bas)

[3] National Environmental Research Institute (Danemark)

[4] Geological Survey for Denmark and Greenland (Danemark)

2. Abstract

Wallonia (Southern Region of Belgium) has implemented the Nitrates Directive by designating four vulnerable zones (now 42% of the territory) and introducing a first Action programme at the start of November 2002 and a second one in 2007.

The Action programmes entail various means of reducing the risks of the pollution of water by nitrate: (a) struggle against nitrate losses in fields using a range of good agricultural practices, including certain restrictions on the use of fertilisers (quantities, spreading periods, soil conditions, etc.), (b) keeping a balance on each farm between the organic nitrogen produced and spreading capacities on agricultural land, (c) adapting storehouses for livestock effluent to a capacity of 6 months and (d) promoting transfers of livestock effluent between farms in excess balance and farms which still have a way of using it on their land.

The paper presents the principle of “soil nitrate residue” measurements (APL in French) that permits a yearly monitoring of the farming practices and constitutes a self-evaluation tool for the farmers.

The paper also introduces the reference model EPICgrid dedicated to nitrogen transfer modelling in the context of the Walloon region. Following the first comparison exercise, these tools are consistent and complementary approaches to help farmers and authorities in nitrogen management.

In the context of the Walloon region, dealing with deep groundwater bodies, fast indicators of potentially leachable nitrogen and nutrient fate modelling are the most practical way of assessing effectiveness of the EU nitrate directive action programmes.

3. Introduction

3.1. General

The geology and land use of the Walloon territory (17.000 km²) are surprisingly varied for such a small area. All agriculture is intensive but significant differences exist between the regions and between farms within the same region.

Overall (955 control wells), the nitrate concentration in groundwater is far below 50 mg l^{-1}. In vulnerable aquifers, concentrations above 50 mg NO_3 l^{-1} appear in 19% of the monitored sites (Etat de l'Environnement wallon, 2007). Moreover, the trend is preoccupying. Surface water eutrophication is also present in vulnerable zones.

The programme to deal with nitrate of agricultural origin is therefore mainly focused on prevention, with a view to the sustainable management of nitrogen in agriculture. There are vulnerable zones (designated in 1994, 2002 and 2007), a code of good agricultural practices and one single action programme for these zones. The measures provided for in this programme are designed to meet the need to limit isolated and/or temporary cases of waste discharge, while limiting spreading to under 170 kg of organic nitrogen per ha on average on the territory as a whole.

Up to now, scientific studies have not proven that it was necessary to take account of the characteristics of each vulnerable zone in this first action programme. A pilot catchment and 33 reference farms spread over each zone are monitored in order to check the effects of the action programme and to adapt it to each zone if necessary. The action programme started off in November 2002 and was reviewed in 2007; it is developed on three complementary levels: the field, the farm and the Walloon Region.

In the field, the objectives are to limit nitrate leaching in winter and to prevent losses by leaking. The farmer must respect a number of good agricultural practices, particularly time periods for spreading manure and slurry, maximum doses of organic and mineral nitrogen per crop and per year, distances in relation to waterways, storage conditions for field manure, etc.

At farm level, the objective is to limit the pressure of organic nitrogen on agricultural land and to fight against point source pollution. The farmer must make sure to always take a soil-based approach, i.e. respect the balance between the organic nitrogen to be spread (coming from the herd or from the importation of matter) and the total spreading capacity on crops and pastures (calculated by multiplying the surface areas by maximum permissible levels according to the zones).

Finally, on the scale of Wallonia, the objective is to optimise the utilisation of organic fertilisers between farms. The action programme promotes transfers of livestock effluent between farms in surplus and those with low organic amounts. These transfers must be declared to the Administration to allow checks at farm level.

3.2. Description of natural factors influencing nitrate occurrence

The climate of the Walloon Region comes under the Atlantic temperate climate. Annual rainfall amounts to 1014 mm.year^{-1}, 119 mm.year^{-1} of which refill the subsoil water, 321 mm.year^{-1}) sustain the surface waters, and 582 mm.year^{-1} are reabsorbed into the atmosphere by evapotranspiration.

The geology and the soil types are rather varied: more than 60 associations of different soils are listed over the 17,000 km² of Wallonia, from deep sandy silt soils to very superficial clay-like, stony soils. When crossing the Region from the north to the south, one first sees wide agricultural plains with many crops and little grassland, followed by a landscape of small valleys in which crops, pastures and forests alternate, ending finally in the high Ardennes plateau that is mainly covered by forest and grassland, with deeper valleys.

The most used groundwater bodies are situated in the unconsolidated strata and the coherent rocks of the north and the centre of Wallonia. Overall, these reservoirs are situated deep in the ground and are covered by loams or sands. The nitrogen transfer times measured and modelled between the surface and the aquifer amount to 5 to 15 years according to the place.

In the more superficial aquifers, which are less used for drinking water production, the transfer times scarcely exceeds 3 years.

3.3. Description of human factors influencing nitrate occurrence

Global information on land use

The ten agricultural regions of Wallonia are characterised by pedological and climatic parameters (Fig. 1); two categories of regions can be distinguished:

- regions used for grassland and fodder crops: the Ardennes, Famenne, the grassland region of Liège, the Jurassic region, the Haute Ardenne and the grassland region of Fagnes (pastureland represents between 70% and 90% of the agricultural area);
- regions used for cereals and industrial crops (sugar beet and potatoes): the silt region, the Condroz and the sandy silt region.

In the regions used for grassland, forests take up an average of over 50% of the total area.

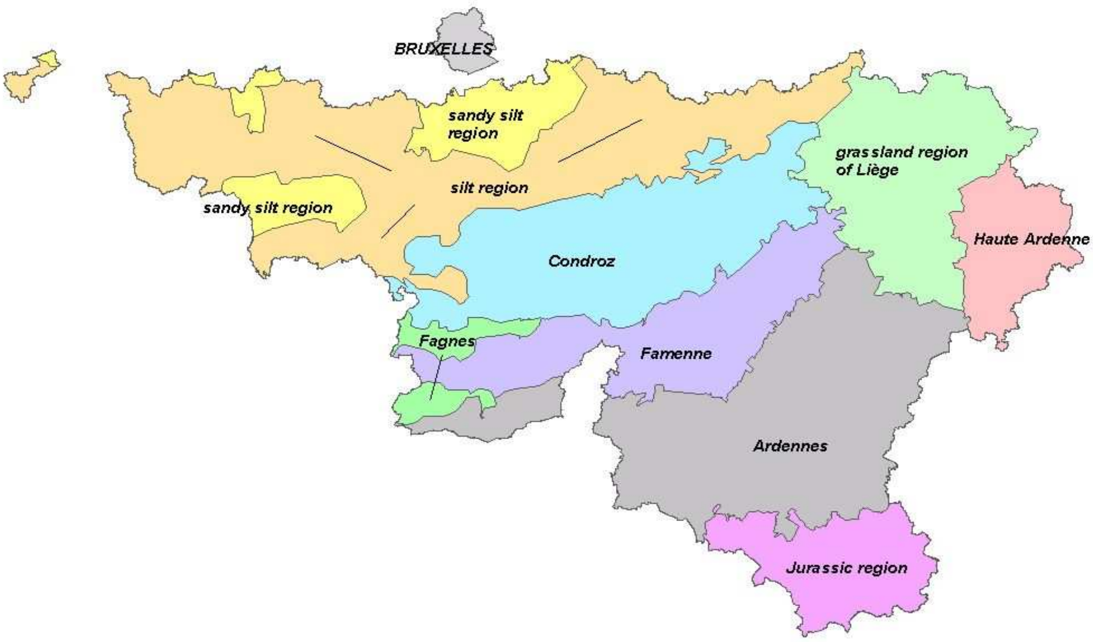


Fig. 1 **Map of the agricultural areas in the Walloon Region.**

Main crops

The utilised agricultural area (UAA) in the Walloon Region is 755,545 ha in 2005, that means 45% of the territory. Forests cover 32% of the territory. The rest is occupied by settlement areas, economic activity zones and road infrastructure. The UAA comprises 50% pastureland and 50% arable land, see Table 1 (Recensement agricole, 2005). Between 2000 and 2005, the UAA decreased by 0.2%.

Table 1 **Surface area (ha), percentage of utilised agricultural area and development of the area between 2000 and 2005 (%) for the main commodities in the Walloon Region.**

		Surface area (ha)	UAA (%)	Development 2000-2005 (%)
Grassland		374054	49.5	- 0.6
	Permanent grassland	345610	45.7	+ 2.6
	Temporary grassland	28444	3.8	- 3.2
Fodder crops				
	Silage maize	52817	7.0	+ 0.3
Main crops				
	Cereals	179163	23.7	- 0.8
	Sugar beet	52765	7.0	- 0.5
	Inulin chicory	12879	1.7	+ 0.2
	Textile flax	12553	1.7	+ 0.6
	Rapeseed	5495	0.7	+ 0.1
	Potatoes	24712	3.3	+ 0.5
Horticulture				
	Vegetable crops	12047	1.6	+ 0.3
	Fruit crops	1533	0.2	unchanged
Fallow		19817	2.6	+ 0.3

Maize cultivated for silage represents more than 90% of the area used for fodder crops other than grassland (52,000 ha). In the Walloon Region, irrigable land areas are very limited: 5513 ha in 1997, i.e. 0.7% of the UAA.

Characteristics of agriculture (agricultural practices)

In 2005, the Walloon Region had 17,000 farms. Between 2000 and 2005 the number of farms decreased by 4,000 farms. Consequently, between 2000 and 2005 the average farm size increased by 22%. In 2005, the average agricultural area of farms in the Walloon Region was 44 ha (Recensement agricole, 2005).

Arable crop farms are mainly situated in the silt and sandy silt regions and in the Condroz. Dairy specialisation predominates in the Haute Ardenne and the grassland region of Liège. The farming of livestock for meat is very common in the Ardennes, in the Jurassic region, Fagne and Famenne. Seventy-three percents of farms in the Walloon Region have cattle. The number of cattles continues to decrease since 1996 following the BSE crisis while the number of pigs and poultries increases (Table 2).

Table 2 **Livestock in the Walloon Region: animal numbers, production of nitrogen and development between 2000 and 2005.**

		Number of heads (x1000) and development (% between 2000 and 2005)		Number of heads ha^{-1}
		number	%	
Cattle		1348	- 8.9	1.78
	Dairy cows	230	- 15.7	
Pigs		366	+15.5	0.48
Poultry				
	Laying hens	1609	+ 79	2.12
	Broilers	3440	+ 14.7	4.55

Total organic nitrogen production on farms in the Walloon region totals 78.930 tonnes. The cattle stock produces 94% of this quantity of organic nitrogen, pigs 3% and poultry 2%. This annual production corresponds to 107 kg of organic nitrogen per ha of UAA. This average value disguises the disparities specific to agricultural regions dominated by certain commodities.

Production of effluent and use of fertilisers

In terms of volume and apart from direct pastureland recovery, two-third of organic fertilisation in Wallonia is in solid form (manure, compost) and one-third is in liquid form (liquid manure and slurry).

In 2005, the average annual mineral nitrogenous fertilisation is 109 kg $N.ha^{-}1$ for the main arable crops in different agricultural regions. This represents a decrease of about 10 kg N/ha in five year (Fig. 2).

In 2005, the uptake of phosphated mineral fertiliser was about 30 kg $P2O5.ha^{-1}$applied per hectare. There again, the downward trend in the consumption of phosphorated mineral fertilisers is clear to see.

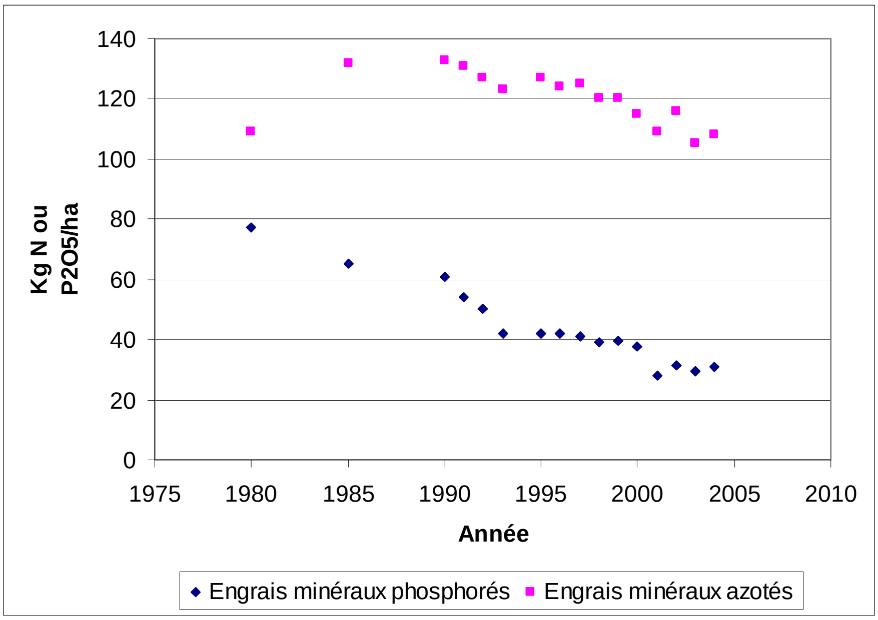


Fig. 2 **Changes in the consumption of mineral fertilisers in the Walloon Region**

4. Main points of the Action Programme

The Walloon Action Programme is a plan for the sustainable management of all forms of nitrogen in agriculture.

The Plan currently applies to entire extent of Wallonia with certain stricter conditions in vulnerable zones. This makes the Plan more demanding than the Nitrates Directive.

The Walloon Action Programme has a number of main lines: the storage and handling of manure from livestock rearing, the application of fertilisers (conditions and quantities) and the principle of the binding rate to the soil, the Nitrawal supervisory structure.

4.1. Maximum quantity of organic nitrogen

Legislation in Wallonia makes a distinction between arable land and grassland, which is less susceptible to the leaching of nitrate. It also makes an additional distinction between vulnerable zones and the rest of the Region.

For the whole of the Walloon Region, the maximum admissible dose of organic nitrogen – whether or not it originates from manure – is 115 kg/hectare on average per year on the arable land of a farm. For grassland, the maximum dose authorised is 230 kg/hectare on average per year on the grazing land of a farm.

In vulnerable zones, this restriction remains valid, but is strengthened by an additional condition: no farm may apply more than 170 kg of organic nitrogen per hectare over the whole of its utilised agricultural area.

These restrictions are significantly stricter than the Nitrates Directive, because in view of the proportion of arable land (73.6%) and grassland (24.4%) in the vulnerable zones, this is equivalent to an overall restriction on organic fertilisation to 145.3 kg of N on average per hectare.

4.2. Good farming practices

4.2.1. Application of fertilisers

For the whole of the Walloon Region, the application periods are regulated as shown below (Table 3) for the forthcoming action programme having started in 2007:

Table 3 **Periods of application of fertilisers in the Walloon Region**

		J	F	M	A	M	J	J	A	S	O	N	D
Grassland	Mineral N												
	Fast organic N												
	Slow organic N												
Crops	Mineral N												
	Fast organic N												
	Slow organic N												

Application not permitted

Soft manure not permitted

(hatched yellow)	Application not permitted except when followed by a nitrate catch crop or winter crop
(white)	Application permitted in compliance with maximum quantities

Organic fertilisers are subdivided into two, according to their speed of mineralisation:

- fast-acting fertilisers, of the slurry or liquid manure type, poultry manure, etc.
- slow-acting organic fertilisers, such as manure.

Soft manure behaves somewhere between slow-acting fertilisers and fast-acting fertilisers, and are assimilated with these with regard to application periods.

All forms of organic nitrogen are forbidden from 1st July, except when application is followed by a cover crop that can absorb the available nitrogen (winter crop or “nitrate catch” cover).

The application of all types of fertilisers is also forbidden less than 6 meters away from any surface water.

Other conditions are also restricting application on water saturated, snow covered, frozen or bare soils.

The total quantity (organic and mineral) of nitrogen applicable is also regulated, regardless of whether the area is vulnerable or not. The maximum annual dose is set at 250 kg of nitrogen on all arable land within the farm, and 350 kg for all grassland.

4.2.2. Coverage of soil

In vulnerable zones and for every farm, a proportion of 75% of the land intended for spring crops must be covered in the autumn (winter crops being covered by definition). In extreme pedological and/or climatic situations, this level may be adjusted by the relevant authorities.

Remaining areas may not be ploughed up in the autumn, because working the soil promotes the mineralisation of nitrogen.

4.2.3. Ploughing up grassland

Ploughing up permanent grassland causes the rapid and abundant mineralisation of the nitrogen stored. This is why special precautions are required in terms of nitrogen management. Ploughing grassland will only be authorised in vulnerable zones from 1st February to 31st May. It must then be followed for two years by one or two covers without leguminous crops.

The ploughed field may not be given any fertilisation during the first year after ploughing takes place, and no organic fertilisation for the 2 years following the ground being turned over.

4.2.4. Measurements of Soil Nitrate Residue (SNR)

See § 6.3.2.

4.3. Nitrawal supervisory structure

Nitrawal is a non-profit organisation that has been operating since 2001 to both assist and supervise farmers in managing their nitrogen levels on a day-to-day basis, as well as to assist the relevant authorities. The organisation is funded totally by the Region and is managed by representatives from the water producers, the farming unions and by the two regional universities that are active on this topic:

the Gembloux Agricultural University (Research group on the Environment and Nitrogen Resources (GRENeRA)), and the Catholic University of Louvain.

Nitrawal is a body oriented strictly towards providing advice and personalised supervision for farmers, mainly in the area of nitrogen fertilisation, ensuring storage infrastructures comply with standards and crop-growing practices. For this purpose, Nitrawal produces clearly explained documents designed for farmers, meetings, conferences or individual visits to farms.

The organisation is made up of some fifteen engineers and technicians who specialise in implementing the legislation in a practical and concrete manner in the field.

5. Trends in nutrient concentrations

5.1. Underground water

Since the first action programme came into effect in 2002, there has been a trend towards a stabilisation in changes to the level of pollution in layers of water by nitrate. In fact in some area, this level is even falling. The less deep layers have recorded the most favourable changes, because they have responded more quickly to the measures put into effect since 2002.

For each vulnerable zone or part-area displaying nitrate problems, an indicator is calculated on a selection of representative sites spread across the whole of the area in question (Fig. 3).

These indicators are put together here in an overall "vulnerable zone" indicator, the developments of which are shown below. It confirms what has been said above.

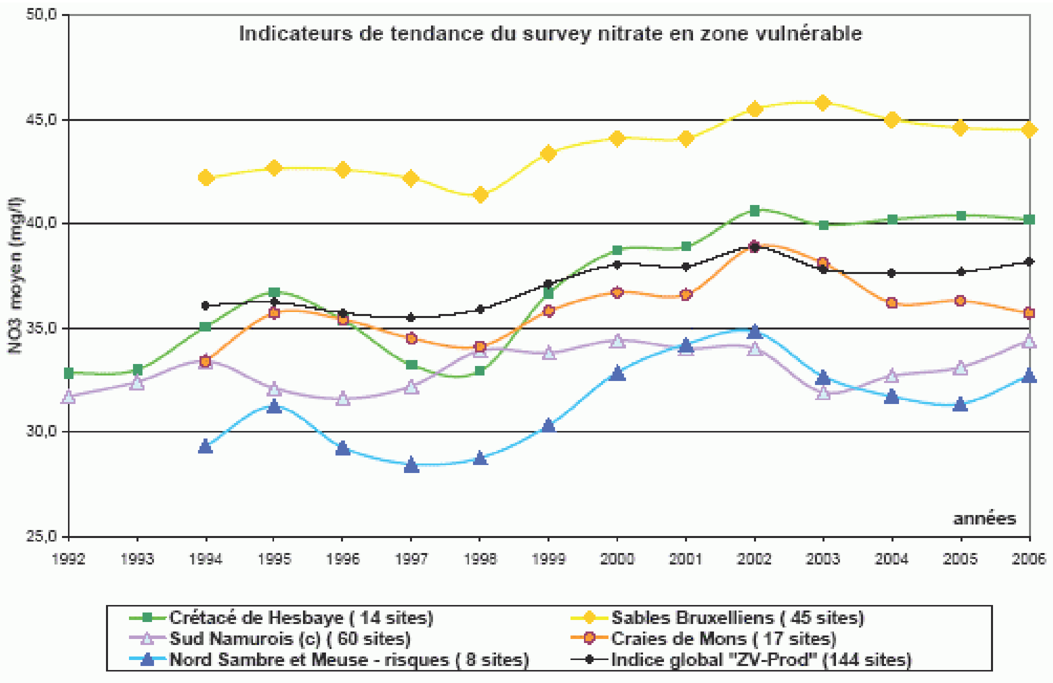


Fig. 3 **Aggregated results from the nitrate survey for the NVZ.**

5.2. Surface water

The map below (Fig. 4) show the trends between 2001 and 2005 for the stations that cover both years. So there is no symbol representing the trend for all stations. On the whole, there is almost no variation in either one direction or the other. The nitrate levels in watercourses have been relatively stable over the years. The biggest improvements (reductions in nitrate) are located to the north of the Sambre-Meuse furrow.

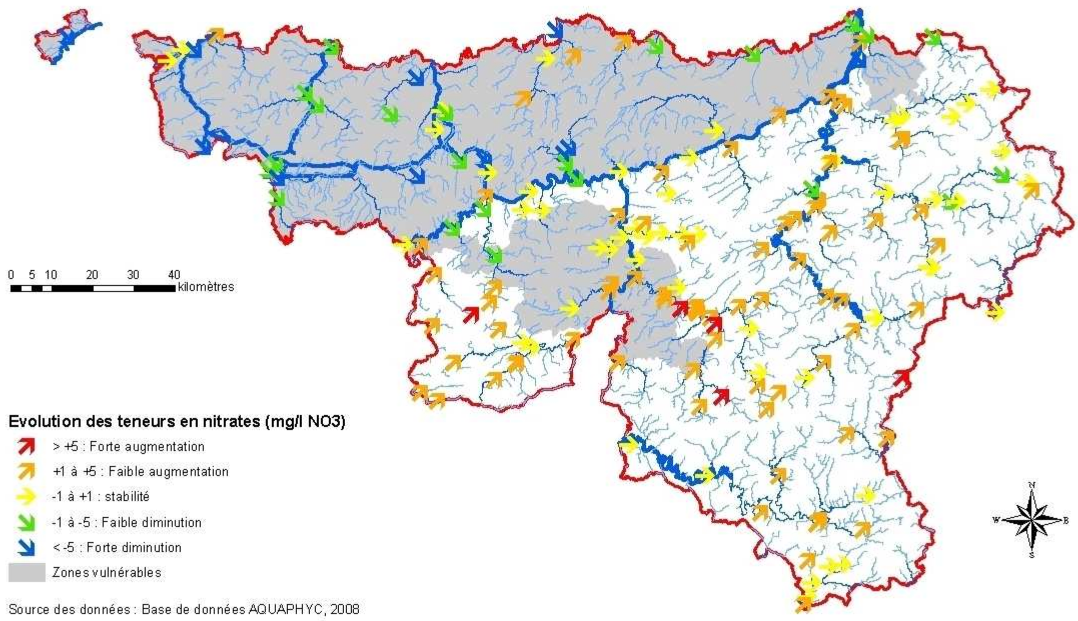
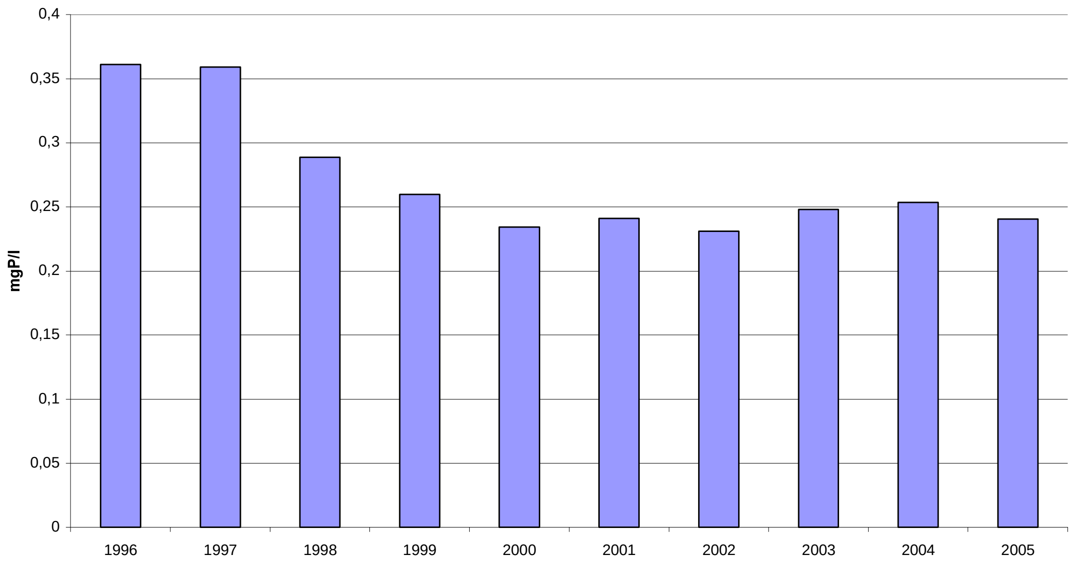


Fig. 4 **. Surface waters. Changes in nitrate levels between 2001 and 2005**

5.3. Phosphorus

Underground water in Wallonia does not contain phosphorus, with the exception of a particular thermal spring.

With regard to surface water, the following graph (Fig. 5) shows a steady decline in phosphorus in surface waters due partly to abandoning detergents containing phosphates in the 1980s and partly to the installation of stations equipped with denitrification and dephosphatation treatment processes.



Changes in total average phosphorus concentrations in Walloon watercourses over

the 146 monitoring sites for which the data covers the period 1996-2005.

Fig. 5 **Changes in phosphorus levels in surface water between 1996 and 2005 (146 sites)**

6. Overview of monitoring networks

6.1. Monitoring in groundwater

The network implemented by the Walloon Region for monitoring groundwater in order to meet the requirements of the Nitrates Directive and the Water Framework Directive is composed of some 950 measurement points spread across the whole of the region (Fig. 6). This represents one measurement point each 18 km2.

These monitoring points are of different types: first, 300 boreholes (abstraction wells and surveillance wells called piezometers), second, 650 superficial points (traditional wells and springs).

Piezometers are sampled at half depth (the pump is located in the middle of the filter screen, typically 3m under the water table). In traditional wells however, the small water column just allow to install the widely used submersible pumps.

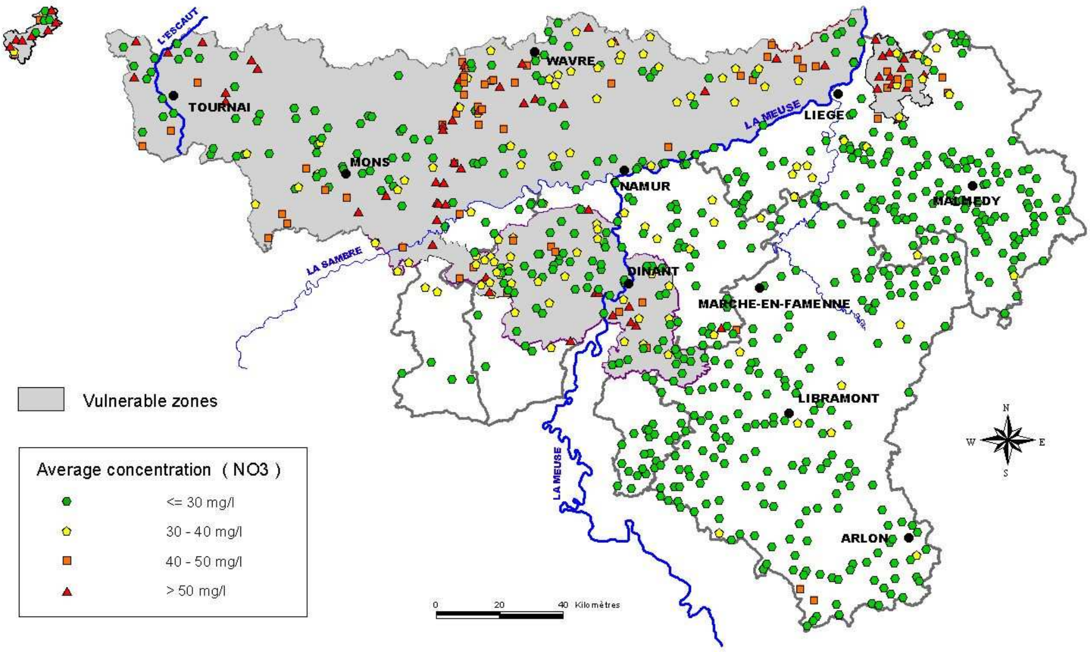


Fig. 6 **. Underground water quality monitoring network in the Walloon Region (2005)**

6.2. Monitoring in surface water

Since 2005, the network for measuring the quality of surface water has consisted of 357 stations at which nitrate is analysed (Fig. 7).

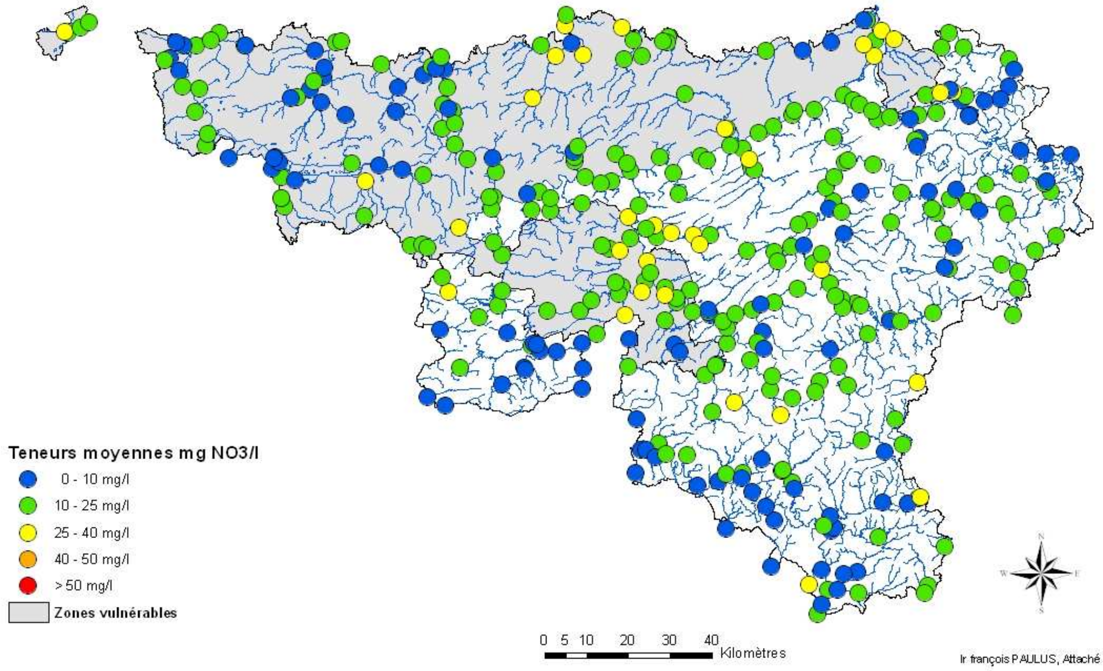


Fig. 7 **Surface water quality monitoring network in the Walloon Region (2005)**

6.3. Monitoring in agricultural practices

6.3.1. Binding to the soil

Each farm in Wallonia has to be bound to the soil, which means that the quantity of organic matter present in the farm over a one-year period must be lower than the maximum quantity that may be applied on the land of the farm. The result of the ratio between the quantity of organic nitrogen present and the land area of the farm is called the "level of binding to the soil". Depending on his own individual situation, the farmer has to maintain his level of binding to the soil below the unit, where necessary by entering into contracts with other farmers or by reducing his livestock. The Department has computerised data that each farmer sends in as part of the farm's CAP return, as well as the composition of his livestock. This data is used by a software program called "TALISOL", which makes it possible to calculate the situation for each farmer. As a result, each farm in the Walloon Region is systematically checked every year, with accuracy, with regard to its production and use of manure from livestock and other organic matter. If these levels should be breached, this check may lead to sanctions in relation to cross-compliance. This system represents a genuine tool for managing organic fertilisers application and is a major strong point in implementing the Region's Action Programme. It also takes account of forms of organic nitrogen other than manure from livestock.

6.3.2. Measurements of Soil Nitrate Residue (SNR)

In vulnerable zones, a special monitoring programme has been launched from 2007, so that the practices of farmers can be monitored and guided better, as well as the application of total maximum doses of nitrogen, and any farming practices that do not benefit water quality can be adjusted accordingly.

Consequently, each year, measurements of Soil Nitrate Residue will be carried out on arable land for a sample of 3% of farms in vulnerable zones, targeting in particular, delicate crops in regard to nitrogen management (maize, potatoes, etc.).

In parallel to this, these same dosages will be carried out each year in a network of some thirty reference farms where good farming practices are implemented (Vandenberghe et al, 2004). Those farms were selected on the basis, among other things, of pedological criteria, in order to be representative of the regions to which they belong. They constitute the referential for the "Agricultural Area Survey". Around 220 parcels of land were consequently chosen on these 33 farms.

These farms benefit from supervision consisting in suitable manuring advices, mineral nitrogen need advices; the aim of which is to minimise nitrogenous residue as much as possible at the beginning of the nitrate lixiviation period.

The nitrogenous residue reference values (Fig. 8) are established for eight categories of land use (sugar beet, maize, pasture, ...) on the basis of the measurements of Soil Nitrate Residue (SNR) developed two times each autumn (last week of October and first week of December) on the 220 parcels of land in the Agricultural Area Survey.

Studies were carried out to establish the soil sampling method as well in arable and grassland (Hennart et al, 2005).

More informations (in french) : www.grenera.be

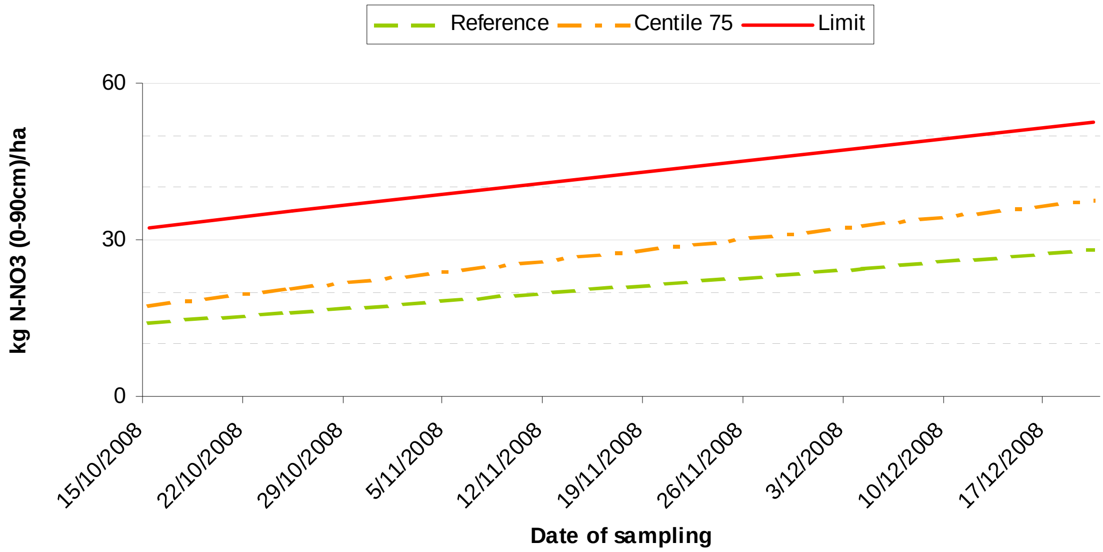


Fig. 8 **Soil Nitrate Residue (SNR) reference for sugarbeet (2008)**

This network, which is already in place since 2001, enables reference curves to be established each year for SNR for each category of crops, throughout the autumn.

The results of each set of samples taken in a monitored farm will be compared with these curves. In cases of the limit is exceeded in at least two of the three parcels of land monitored, the farmer will be required to adjust his practices (with help of the Nitrawal supervisory structure); other measurements will be carried out on his arable land, at his expense, in subsequent years. After three years of measurments, in case of unsatisfactory results, the farmer would have to pay a significant penalty.

This programme is aimed at making farmers aware of the danger of certain practices for ground water (such as applying excessive amounts of organic fertiliser on a crop) and conducting indirect checks on the overall level (organic and mineral) of fertilisation at these farms.

7. Effect monitoring of the Action PRogramme

7.1. Strategy for effect monitoring

The Walloon Region bases its effect monitoring strategy at three levels : the field scale, the catchment area scale and the regional scale.

Two indicators are used to monitore the agricultural practices and to assess the effectiveness of the Action Programme (Fig 9.) :

- the soil nitrate residue (SNR) measured at the beginning of the lixiviation period and
- the nitrate concentration in the water (NCW).

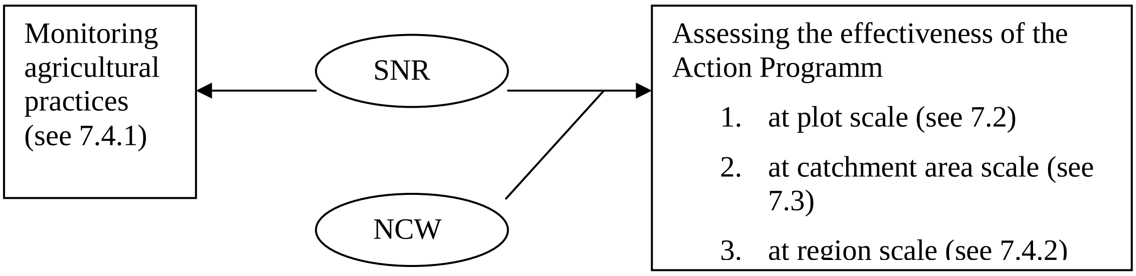


Fig. 9 **Effect monitoring of the Action Programme**

SNR : Soil Nitrate Residue

NCW : Nitrate Concentration in Water

7.2. Effect monitoring at the plot scale

In 2003, six lysimeters have been installed in two of the 33 reference farms. These lysimeters are 1.5 m. height, 1m² section and are placed 2 m. deep in the (loamy) soil so that agricultural practices (tillage, ...) are not prevented.

SNR and nitrate concentration in the water collected are regulary measured to evaluate the impact of agricultural practices (crop, manure use, fertilisation rate). The aim is also to show the link between SNR and nitrate concentration in the lixiviation water.

After five years of monitoring, it appears that :

- the level of SNR (kg N-NO3/ha) at the beginning of the leaching period is quite similar to NCW (mg NO3/l) collected in the lysimeter during the leaching period (Fig. 10);
- wheat followed by a catchcrop and sugarbeet are characterized by small SNR and NCW collected while potatoes and some vegetables (like leeks, spinach, ...) are characterized by high SNR and nitrate concentration in the water collected.

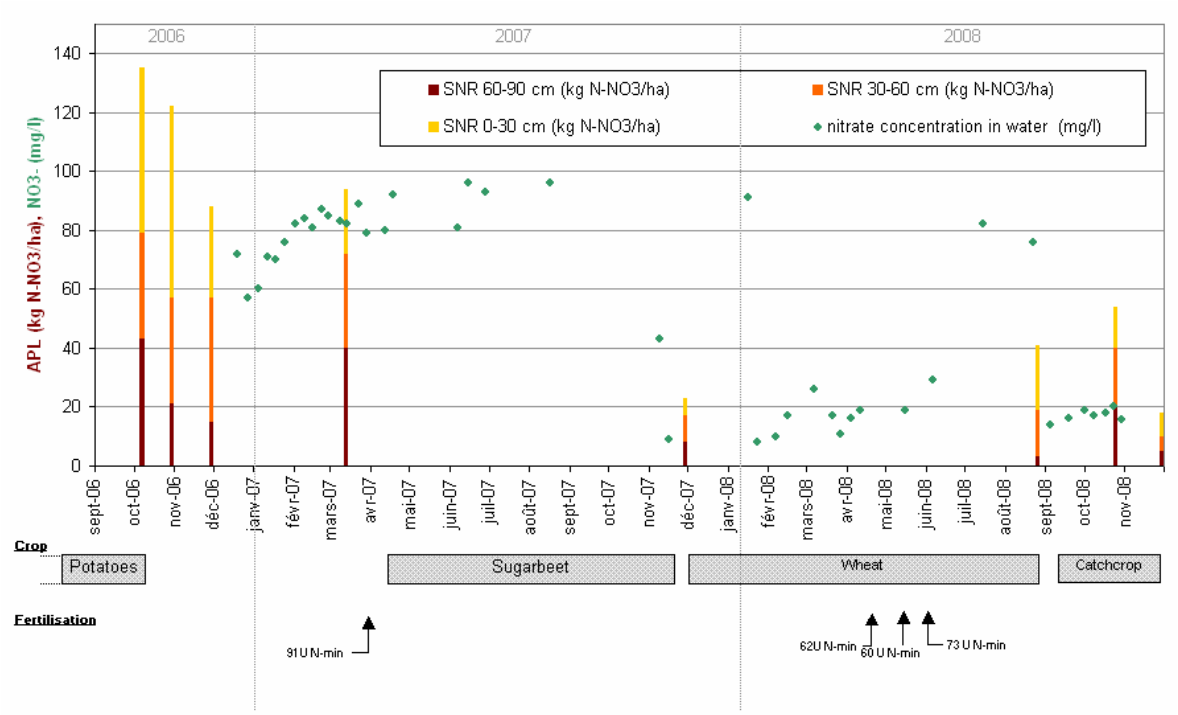


Fig. 10 . **Soil nitrate residue (SNR) and nitrate concentration in the wather (NCW) in the lysimeter of Bovenistier**

7.3. Effect monitoring at a catchment area scale

Since 2004, a small catchment area (100 ha) is monitored. In this area, land use is only crops (mainly wheat, sugarbeet, maize and potatoes) . The eight farmers concerned are educated by Nitrawal to apply good agricultural practices. The mean “level of binding to the soil” (see 6.3.1) of these farmers is around 0,65.

In each parcels, SNR is measured each spring to give mineral fertilisation advices and each automn to be compared to the references (see 6.3.2). In 2007, only 11% of the parcels showed unsatisfactory SNR.

Groundwater level is meanly ten meters deep and NCW (means of 11 measuring points sampled monthly by GRENeRA of the Gembloux Agricultural University) is around 60 mg/l.

Due to the relation between SNR and nitrate concentration in the lixiviation water (see § 7.2), a positive trend in nitrate concentration of the groundwater is expected within a few years.

Modelling with the software SWAT is used to predict the effect of possible modifications of the Action Programme for trend detection in nitrate concentration. The choice of the software SWAT was made following the evaluation of the most common similar models by Schoumans and Silgram (2003).

7.4. Effect monitoring at the region scale

7.4.1. Soil Nitrate Residue as a tool for monitoring agricultural practices

Since 2007, a few 800 different parcels are sampled in the vulnerable zone each year to evaluate the respect of a good nitrogen use. So, SNR is measured between the 15th october and the 10th december in those parcels. The results are compared to the reference (see 6.3.2) to allow their evaluation. In 2007, 30% of the sampled parcels show an unsatisfactory result.

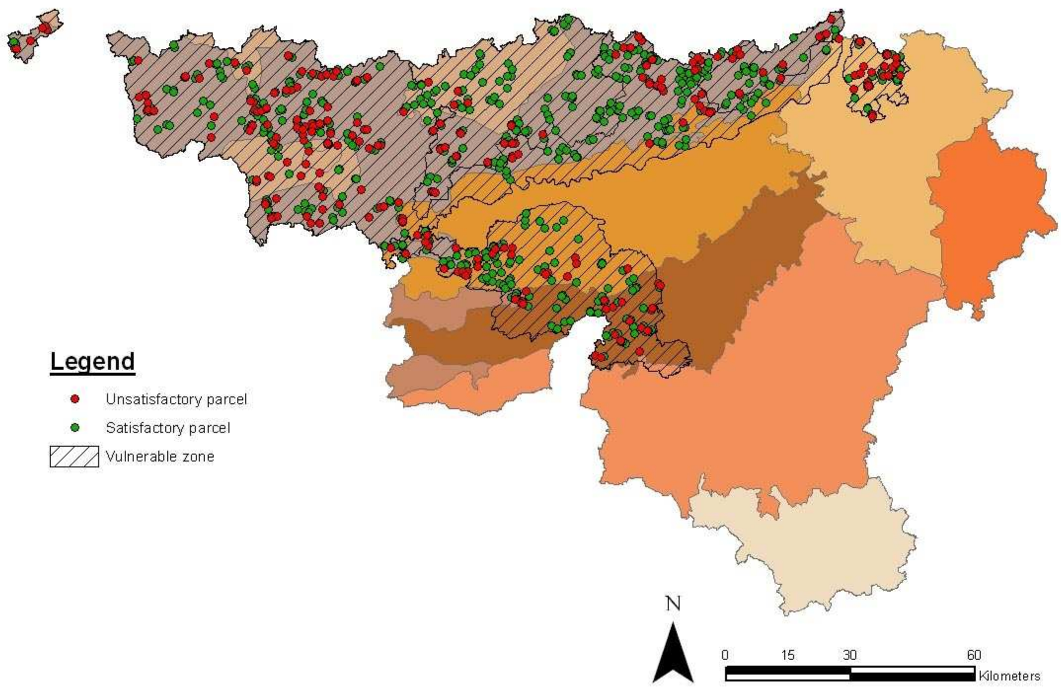


Fig. 11 **. Monitoring of the soil nitrogen residue in the vulnerable zones**

Within a few years, due to the penalties included in the Action Programme, it is expected that this percentage will diminish, showing therefore a increasing taking into account of the code of good practices by the farmers.

7.4.2. Modelling

Mathematical models simulating the complex processes in a watershed are useful tools to understand the problems and to find solutions through land-use changes and best management practices (Borah and Bera, 2003). In their review of 62 nitrogen dynamic models, Cannavo et al. (2008) pointed EPIC (Williams, 1995) as one of the few mechanistic models that represent all the N processes (mineralization, leaching, volatilization, nitrification, denitrification, uptake, and N_2 fixation). They also noted that EPIC supports a large number of crop species and uses parameters that do not require heavy laboratory measurements.

In Walloon Region, the EPIC code has been modified (Sohier et al, 2009). The local pedology description was introduced using the Belgian soil map (Tavernier et Marechal, 1972). The reservoirs depths between the top soil layer and the 1.5 m depth layer (root zone) were adapted to fit the pedological horizons. We also introduced the pedotransfer function proposed by Rawls and Brakensiek (1989), as it was shown by Masereel and Dautrebande (1995) to be the most practical choice in the Walloon Region.

Under the root zone, we introduced new reservoirs, taking into account the geological description down to the groundwater table. Original equations from the EPIC model (Sharpley and William, 1990) that are also included in the SWAT model (Gassman et al., 2007) were adapted to these new reservoirs for water flows and nitrogen transfer. EPIC (and SWAT) model incorporate a mobile and an immobile fraction of nitrate in each soil layer (Neitsch et al., 2002). The mobile nitrate can leave the topsoil layer because of surface runoff, percolation, and lateral flow. The mobile nitrate in the underlying soil layers can move by lateral flow and percolation only. The algorithms for calculating organic nitrogen losses from the topsoil due to surface runoff were given by Neitsch et al. (2002).

The crop growth module of the EPIC model includes main Belgian crop productions. Nevertheless some light modifications were included into the code concerning wheat, potato and sugar beet (Masereel and Dautrebande, 1995; Cocu et al., 1999). Observed data relative to some fields were used to perform the calibration of the model (Cocu et al., 1999).

Then, the extended EPIC model was linked with a GIS (geographical information system) and the Belgian territorial databases.

A regular squared grid composed of 1 km²-cells each was used to represent the region (16 902 km²). Inside each 1 km²-cell we identified the main hydrological response units (HRU) considering four inputs: soil description, slope, land use (including crop and technical operations), and meteorological data (Sohier et al, 2009).

Model results are water and nutrient flows in an ASCII matrix. It is very flexible so that different indicators can be built for different time periods with a GIS.

To carry out the simulations since 1961, we have reconstituted the crop rotation history, the animal husbandry, the mineral fertilisation at the scale of the agricultural sub-regions (10 sub-regions in the Walloon region of Belgium) using a five-year time step until 2000 and exploiting data from the Belgian institute of statistics. We referred to Borgers et al. (2007) for the current situation. The simulations were carried on a daily time step until 12-31-2005. Only the results from 01-01-1971 to 12-31-2005 are taken into account.

Some validations, concerning water balances at watershed scale and deep nitrate transfer are presented in Sohier et al, 2009. This new model is called EPIC-Grid (Hydrology and Hydraulic Eng., Gembloux Agricultural University).

5.4.3. Comparison of soil nitrate residue measurement and modelling results

Following the systematic campaign of measurements put into practice in the Walloon Region, Sohier et al. (2008a) modelled water and nitrogen flows for the main three-year crop rotations identified by Borgers et al. (2007) in the different agro-hydrological sub-regions. They modelled the soil nitrate nitrogen content in the same soil layer. Figure 12 shows a comparison between modelling results and measurements of nitrate residue after wheat crop harvest (Sohier et al., 2008b).

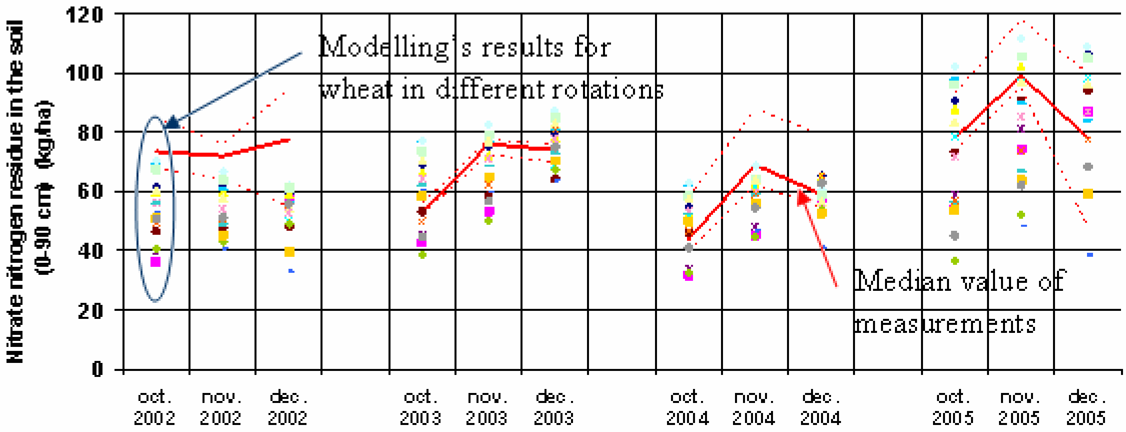


Fig. 12 . Potentially leachable nitrate nitrogen after wheat crop harvest: comparison of measured and simulated values with modified EPICgrid model (RMSE = 12.8 kg) mean standard deviation of measured values : 22.8 KgN, mean standard deviation of modelled values : 11.2 Kg N.

The RMSE is equal to 12.8 kg during the 2002-2005 period and reaches 8.4 kg considering the 2003-2005 period. It can be noted that, except in 2002, the model is quite representative of the amount of nitrate residue after harvest and its evolution during autumn.

5.4.4. Modelling results

The model has enabled us to produce different maps about the distribution in depth and fate of nitrate in soil water. These maps present

- the spatial distribution of nitrate concentration in the water leaving the root zone (figure 13),
- the spatial distribution of nitrate concentration in recharge water just above the groundwater body (figure 14),
- the time for the nitrate transfer in unsaturated zone from 1.5 m depth to the upper groundwater table (depth between 1.5 m and a maximum of 104 m)(figure 15).

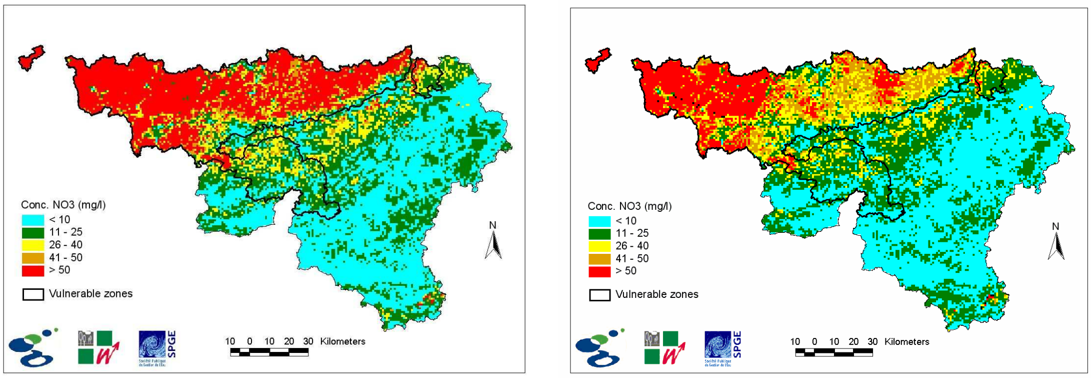


Fig 13 : Spatial distribution of nitrate concentration in the water leaving the root zone (left : mean value for 1994 - 1999 period, right : mean value for 2000-2005 period).

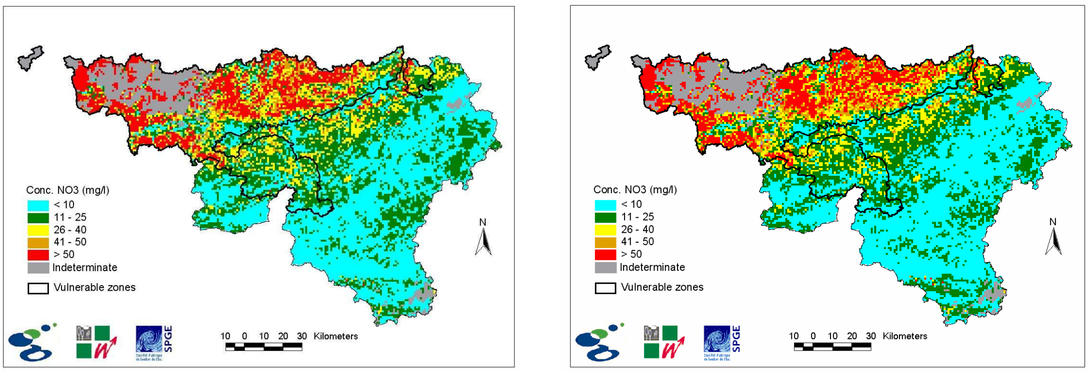


Fig 14 : Spatial distribution of nitrate concentration in recharge water just above the groundwaterbody (left : mean value for 1994 - 1999 period, right : mean value for 2000-2005 period).

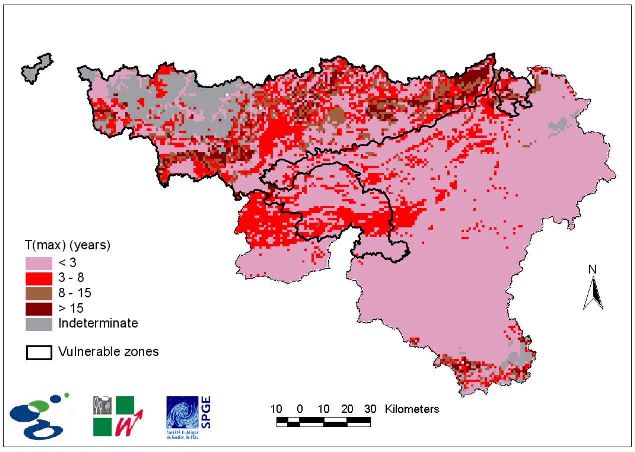


Fig 8 : time for nitrate transfer in unsaturated zone from 1.5 m depth to the upper groundwater table (depth between 1.5 and a maximum or 104 m).

On the one hand nitrate concentration under the root zone (figure 13) is a fast indicator of the effect of cropping and grazing systems on nitrate concentration. On the other hand the nitrate concentration in recharge water (figure 14) shows the direct pressure on the groundwater body, as a consequence of the cropping history and the characteristics of the upper vadose zone.

Figure 15 illustrates the mean transfer delay from the root zone to the groundwater table in the Walloon Region. One can see that in a few zones, the delay exceeds 15 years. This means that 15 years are needed for a new cropping practice to influence the groundwater recharge quality.

8. Discussion and conclusion

8.1. Soil nitrate residue

The Walloon Region launched recently a vast monitoring and control programme based upon the measurement of Soil Nitrates Residues (SNR) at the beginning of the leaching period.

Comparison studies involving lysimeters showed a good correlation between SNR and nitrate concentration just under the root zone.

The current monitoring of a small river catchment area should also confirm soon a good correlation between SNR and nitrate concentration measures in the water table.

Besides this, the control programme will enable:

- an individual monitoring of the agricultural practices of each ‘non satisfactory’ farm up to when satisfactory results are obtained;
- an evaluation – at the vulnerable zone level – of the improvement of the agricultural practices, by a yearly comparison between farms controlled for the first time.

8.2. Modelling

As the nitrate directive was implemented in 2002 (Vandenberghe and Marcoen, 2004), modelling shows that some areas will not be impacted by the expected effects of new practices before a decade. It highlights the importance of fast indicators of cropping practice performances to help policy-making and the importance of transfer modelling through the vadose zone to take into account the cropping history of the field. The fast indicators can be field measurements of potentially leachable nitrogen (Vandenberghe and Marcoen, 2004) but also modelling results of nitrate concentration in soil water under the root zone (figure 6). The first results from the field monitoring of “potentially leachable nitrate” after wheat harvest confirm the accuracy of the model even if more samples are needed to validate the calculation for the main crops. See Sohier et al. (2008b) for more details. The monitoring of the upper groundwater quality also shows a good relevance of the modelling results (Sohier et al., 2009). Therefore the main maps produced by EPIC Grid model constitutes major tools for nitrogen management at a regional level

8.3. Conclusion

The networks implemented to monitor water quality and agricultural practices and the modelling systems developed, enable the Walloon Region to evaluate with a good accuracy the efficiency of its Action Programme. These tools contribute also to improving it.

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