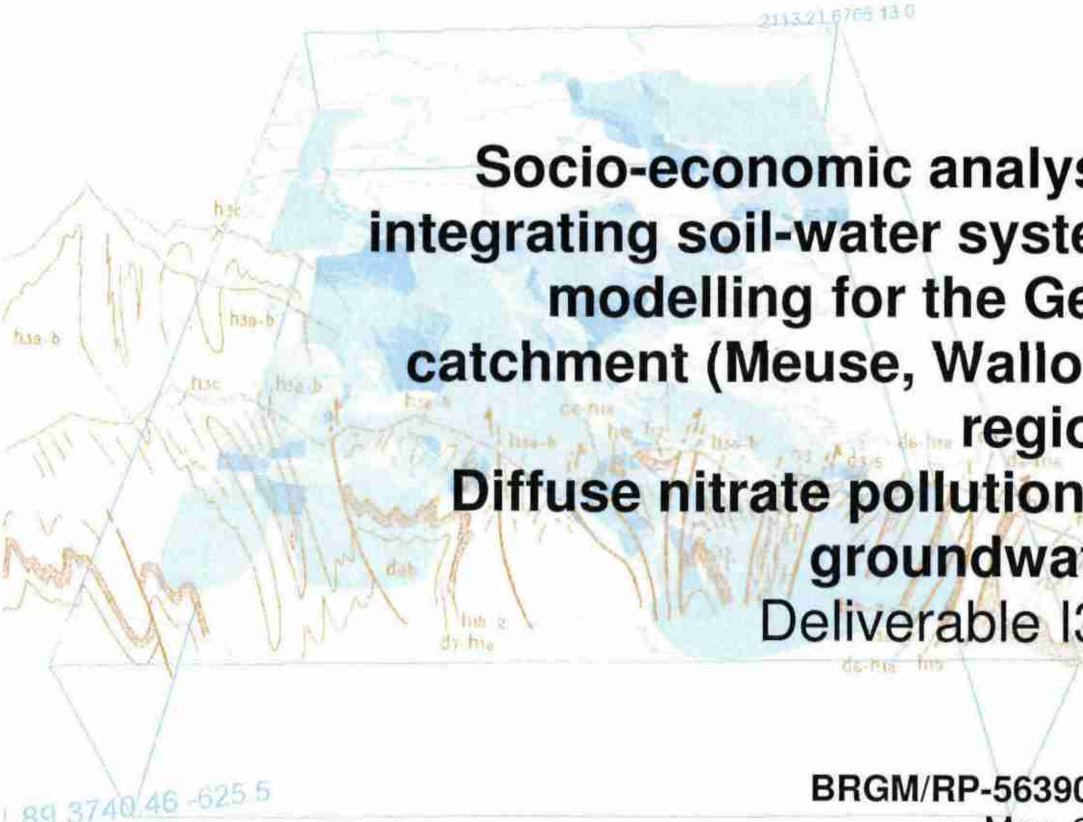

Socio-economic analysis integrating soil-water system modelling for the Geer catchment (Meuse, Walloon region) Diffuse nitrate pollution in groundwater

Deliverable I3.8

BRGM/RP-56390-FR

May, 2008

Geoscience for a sustainable Earth

brgm

BUREAU DE RECHERCHES GÉOLOGIQUES & MINIÈRES

Project no. 505428 (GOCE)

AquaTerra

Integrated Modelling of the river-sediment-soil-groundwater system; advanced tools for the management of catchment areas and river basins in the context of global change

Integrated Project

Thematic Priority: Sustainable development, global change and ecosystems

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Title: Socio-economic analysis integrating soil-water system modelling for the Geer catchment (Meuse, Walloon region) – diffuse nitrate pollution in groundwater

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PU	Public	
PP	*Restricted to other programme participants (including the Commission Services)*	
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SUMMARY

The Geer groundwater body (Belgium, Walloon Region) is at risk of not reaching good status by 2015 due to nitrate pollution. This report proposes combinations of measures aiming at improving groundwater quality selected through a cost-effectiveness analysis, following the requirements of the Water Framework Directive. Costs of such measures range from 4.6 to 15.6 million euros per year, depending on the objectives of decrease in nitrate pressures. As these costs may appear to be disproportionate and in order to select the combination that would ensure the highest net benefit to the society, a cost-benefit analysis on the different combinations of measures is undertaken. Major benefits are expected to occur for the drinking water sector and households. Benefits are assessed as avoided damage as a function of nitrate concentration evolution in each abstraction point obtained by the use of statistical and modeling tools developed on the Geer basin as part of Aquaterra project. Total expected discounted benefits of the proposed programmes of measures range from 188 to 207 million euros (€2008). A cost-benefit analysis leads to the selection of a programme of measures that would ensure positive net benefits at a 50 years time horizon for the Geer basin.

MILESTONES REACHED

This report contributes to the objective 1 of Integrator 3 i.e. 'Proposition of model on interaction between socio-economic activities and water-soil resources (physical modeling)'

It presents the conceptual framework established to analyze groundwater quality degradation in the Geer basin involving BASIN, TREND, HYDRO, COMPUTE and INTEGRATOR sub-projects. Quantified results presented in this report were obtained through a collaboration established between BASIN, TREND and INTEGRATOR sub-project.

Glossary

AT	Aquaterra
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CILE	Compagnie *Intercommunale Liégeoise des Eaux*
DGRNE	Direction Générale des Ressources Naturelles et de l'Environnement (Région Wallone)
DPSIR	Drivers – Pressures – State – Impacts - Responses
IMC	International Meuse Commission
HGULg	Hydrogeological group of the University of Liege
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij (Public Waste Agency of Flanders)
SP	Sub-project
SUFT3D model	Hydrogeological model developed by the University of Liege (see BASIN deliverable R3.16)
SWDE	Société Wallonne des Eaux
VMW	Vlaamse Maatschappij voor Water-voorziening
WFD	Water Framework Directive

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1. Introduction

CONTEXT AND OBJECTIVES

Integrator case studies

In 2007, three case studies were selected[1] by INTEGRATOR sub-project for a detailed and quantified economic analysis to illustrate interaction between socio-economic activities and water-soil physical modelling: two small case studies (i) the *Geer basin* (Meuse, Walloon region) – diffuse nitrate pollution in groundwater; (ii) the *Kempen area* (Meuse, Flanders and Netherlands) – soil contamination by heavy metals and one basin-scale case study: (iii) the *central Ebro* (Ebro, Spain) – water quality degradation due to high salinity. This report presents the results of the analysis carried out for the Geer case study.

The Geer basin

The Geer basin (480 km²) is located within the Meuse river basin, in the eastern part of Belgium, North-West of Liege. A very important groundwater resource located in this basin - the Hesbaye aquifer - is affected by diffuse agricultural pollution of groundwater resources. Presently, the mean nitrate concentration in groundwater is close to the drinking water limit of 50 mg/l set by Directive 98/83/EC. Future groundwater quality trend estimates show that the mean nitrate concentration of the water body will exceed the drinking water limit in the coming years: the Geer groundwater body was identified by Dgrne (2005) at risk of not reaching good water status by 2015. The main water user – the drinking water sector – is therefore very concerned with this contamination issue, especially since there is no sustainable alternative resource identified at the present time for the drinking water supply of Liege and its suburbs.

Figure 1. The Geer basin in the Meuse international river basin (Map provided by IMC, 2005)

[1] as agreed by the Steering Committee at the Frankfurt meeting of the 23rd of February 2007

The Hesbaye aquifer has been identified as the groundwater body the most affected by agricultural pressures in the Walloon Region (Dgrne, 2005): following the requirements of the Water Framework Directive (WFD) a programme of mitigation measures should be implemented to decrease these pressures and to reach the good chemical and ecological status of the groundwater body by 2015. Potential measures should be compared and selected according to their cost-effectiveness. If the costs required for the implementation of these measures appear to be disproportionate, a cost-benefit analysis may be necessary.

The main challenges of this case study are threefold:

- To design and assess the effects (in terms of effectiveness) of the implementation of preventative measures: *What should be done today in order to prevent groundwater quality degradation?*
- To assess the benefits of such measures for the society as avoided damage (impacts) that would occur due to nitrate pollution of groundwater in the coming decades if nothing was done (business as usual scenario): *How severe will be the phenomenon in the future in terms of environmental damage if nothing more is done?*
- To compare costs and benefits of selected programmes of measures: *if several programmes of measures are identified to reach good groundwater status, what it is worth spending to maximise society welfare?*

CONCEPTUAL MODEL AND LINKS BETWEEN SPS

Structuring framework

An integrated approach including socio-economic, decisional and biophysical processes has been developed since 2006, in close collaboration with AT researchers and local stakeholders. Figure 2 uses the DPSIR (Drivers, Pressures, State, Impacts, Responses) approach as a structuring framework of potential interactions between AT sub-projects and other sources of data.

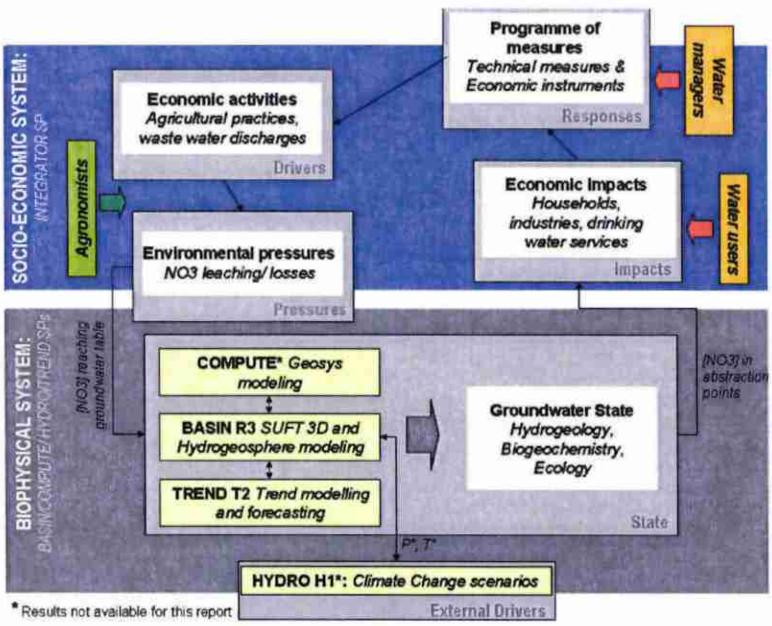

Figure 2. DPSIR scheme of relationships between Integrator, other AT-subprojects and stakeholders on the Geer case study.

Links between AT sub-projects

Several AT sub-projects investigating the area were identified by INTEGRATOR as potential contributors to the environmental and economic analysis: BASIN, TREND, COMPUTE and HYDRO in particular. Collaborations between these sub-projects have been set up during several meetings in the University of Liege (*23/01/06, 05/03/06, 29/06/06, 28/03/07, 17/03/08*) and at the Geer roundtable (*Menorca AT General Assembly, 24/04/07*). They are briefly described below:

- Socio-economic components are investigated by INTEGRATOR sub-project. It consists of (i) economic activities (*Drivers*) that exert pressures on groundwater (agriculture, waste water services), (ii) economic activities (*Impacts*) that are affected by groundwater degradation (households, agro-food industries and drinking water services) and (iii) measures that could be implemented to improve the situation (*Responses*).

- Biophysical components (*State*) are investigated by BASIN R3, COMPUTE, and TREND T2 sub-projects. Different tools have been identified and developed to evaluate the state of groundwater in the Geer basin. Within TREND T2, a general methodology has been developed by HGULg to infer, quantify and predict nitrate quality trends using pure statistical tools. Within BASIN R3 and TREND T2, a spatially distributed groundwater flow and solute model has been developed by HGULg using the *SUFT3D* code to model the temporal evolution of nitrate concentration in the chalky aquifer of the Geer basin. Within BASIN R3, HGULg is now developing a fully coupled surface water – groundwater model of the Geer basin with the *Hydrogeosphere* code (developed by the University of Laval, Prof R. Therrien, and Waterloo, Prof E. Sudicky) to assess the impact of climate changes on the groundwater resources. As COMPUTE (TUB, O. Kolditz, C. Bürger) sub-project also sub-project also is currently developing an integrated hydrosystem model (*Geosys*) on the Geer basin. As *Hydrogeosphere* and *Geosys* models are still under development, finalised results from these two models could not be made available for the economic analysis at this stage of the project. As a consequence, the framework of the economic analysis was based on results from the pure statistical approach and from the model developed with the *SUFT3D* code.

- Climate change as external driver was also proposed in 2007 to be taken into account in the economic analysis. Six different European models were used by the HYDRO H1 (UNEW, H.J. Fowler) sub project and downscaled to build climate change scenarios for the Geer basin (time series of temperature and rainfall). These scenarios were delivered to the University of Liege and are currently being integrated into *HydroGeoSphere* modelling activities. Climatic scenarios used in this study have been computed within HYDRO H1. After an important calibration step, first simulations were run on the flow model developed with *HydroGeoSphere*. As the transport model is still under development, results regarding the variation of nitrate contamination due to climate change were not available at this stage of the project and were not included in this analysis.

Other sources of data

As illustrated by Figure 2 complementary data were required for a better understanding of the different components of the socio-economic system of the Geer basin and to ensure that the case study would help local decision making. These data were mainly provided by stakeholders and non AT researchers and were related to three main components of the system:

- *Drivers and Pressures.* Agriculture was identified as the main driver of the diffuse pollution by nitrate in the Geer basin. Data about agricultural practices were gathered with the help of results of research activities of the University of Gembloux (Dautrebande and Sohier, 2004) and with the help of the Department of Science and Management of the Environment (B. Tychon) of the University of Liege. External references (AERM, 2006) were also used to assess the effects (in terms of decrease in pressures exerted on groundwater) of potential measures.

- *Impacts.* Potential impacted sectors include households, industrial companies (agro-food) and drinking water sector. Local stakeholders are particularly concerned with this environmental issue, especially the drinking water sector that aims to find solution to mitigate the impacts. Data concerning the impact for drinking water sector of potential groundwater contamination were gathered mainly with the help of the CILE (JM. Compère; CILE, 2007a and 2007b) and Aquawal references (Aquawal, 2005 and 2006).

- *Responses.* The definition of the most appropriate and effective programme of measures to be implemented in the Geer basin to preserve the groundwater resource was done on the basis of the rural development plan of the Walloon Region (GW, 2007), with the help of French rural development plans (Draf-NPdC, 2001; MAAPAR, 2004) and the French methodology developed by Brgm with the Rhine-Meuse Water Agency (Hérivaux *et al.*, 2005; Hérivaux, 2008).

OVERVIEW OF THE METHODOLOGY

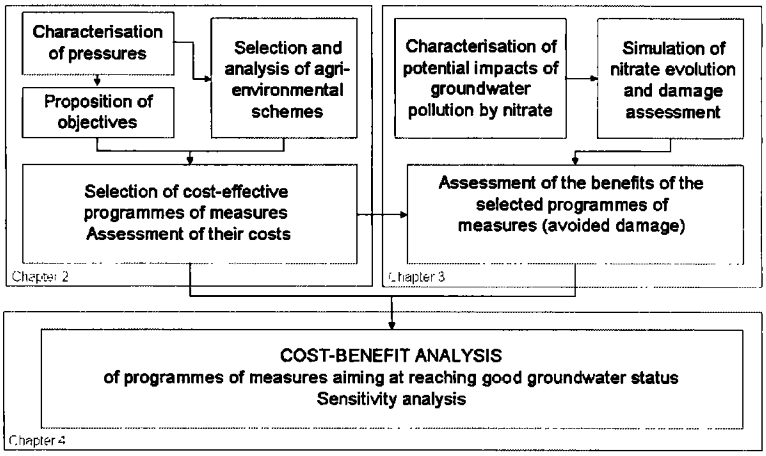

Figure 3. Overview of the methodological steps

This report presents the methodological steps developed for the Geer basin case study and the results of the economic analysis. It is structured into three main parts (Figure 3):

- Programmes of measures to improve groundwater quality and to reach good groundwater status in the future are designed: pressures exerted by nitrate are characterised, three levels of objectives to decrease the polluting pressures are proposed, agri-environmental schemes are selected and analysed, combinations of schemes are selected to reach the objectives according to their cost-effectiveness ratio, the cost of each programme of measure is assessed.

- Expected benefits provided by these programmes are assessed as the avoided damage in comparison with a "no action" scenario. The drinking water sector is considered as the main sector affected by groundwater nitrate pollution and is thus likely to be the highest source of benefits following the implementation of the programmes of measures.

- Costs and benefits of the programmes of measures are then compared through a cost-benefit analysis to select the programme maximising the society welfare. A sensitivity analysis is carried out.

2. Selection of cost-effective programmes of measures to improve groundwater quality

In response to the risk of groundwater pollution, and as required by the Water Framework Directive (WFD), programmes of measures should be designed to improve and protect groundwater quality in the Geer basin. These programmes should be selected according to a cost-effectiveness analysis (CEA) that is to say that they should be designed so as to reach a given objective at the lowest cost. The main objective is to maintain/ to decrease nitrate concentration in groundwater below the level of 50 mg/l[2]. In terms of 'operational objective' (i.e. to design the programme of measures) this means to decrease the nitrate concentration in leaching water at a level that would guarantee nitrate concentration in groundwater below 50 mg/l in the future. According to ULg hydrogeological experts, a decrease in the average nitrate concentration in leaching water below 50 mg/l is necessary (and sufficient) to reach good groundwater chemical status in the future (long term). A higher decrease in the nitrate concentration would also ensure to reach good chemical status but quicker. In the framework of this economic analysis, we will envisage three different objectives of decrease in nitrate concentration (A, B, C) and thus design cost-effective programmes of measures to reach these objectives.

The analysis is structured into 3 main parts (Figure 4): first we characterise the diffuse agricultural pressures exerted by nitrate in the Geer basin (§ 2.1), then we propose and analyse (§ 2.2) key agri-environmental schemes that could be implemented, third we design cost-effective combination of measures to reach the objectives (§2.3).

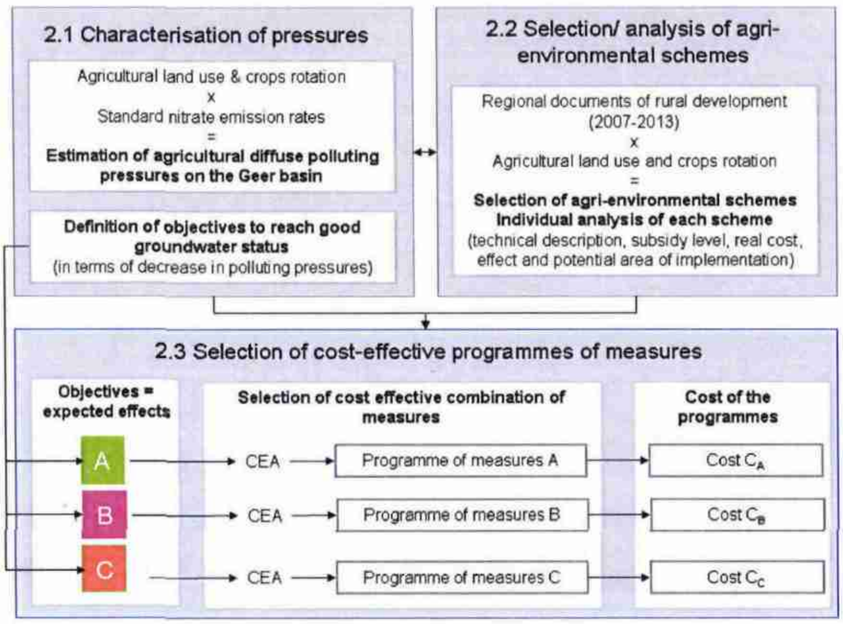

Figure 4. Overview of the methodology carried out to select programmes of measures

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[2] At least for 80% of the monitoring points as required by the WFD.

2.1. CHARACTERISATION OF NITRATE PRESSURES EXERTED ON GROUNDWATER

- **Main types of crops & rotations**

Due to its flat topography and to the loess deposits, the Geer basin is mainly covered by agricultural land that represents the main source of nitrate loads in groundwater[3]. Crops and pastures represent 83% of the basin; the remaining area is divided between housing (10%), forest (2.5%) and other uses (4%). Farms located in the Geer basin mainly specialise in field crops and cattle (dairying and fattening). In 2005 cereals and industrial crops (mainly sugar beets, flax and chicory) represent the main part of the agricultural land use (Figure 5). Pastures use about 14% of agricultural land. Dataset of the evolution of agricultural land use from 1997 to 2005 show a decrease in pasture area (-11%), cereals (-91%) and sugar beet (-16%), while other industrial and horticultural crops area increased (flax: +48%, chicory: +105%, horticulture: +96%) during the same period (dataset provided by B. Tychon, ULg-Arlon, 2006).

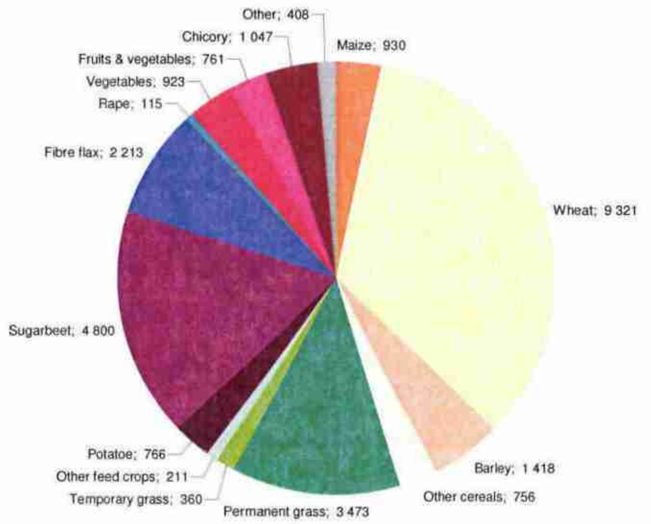


Figure 5. Agricultural land use (ha) in the Geer basin (Dataset provided by B.Tychon ULg-Arlon, 2006)

When considering a potential change in agricultural practices, it is important to take into account the whole crop rotation to assess the effect and the real cost of the measure. For instance, if we consider the measure "conversion of arable land into permanent grass", the conversion will impact the crop that would have been cultivated at time t, but also the crops that would have been cultivated at time t+k with k featuring the duration of implementation of the measure. Figure 6 describes the main types of crop rotation that may be found on the Geer basin, according to Dautrebande *et al.* (2004) and Draf NPdC (2001).

[3] It represents the main source of nitrate loads in groundwater, followed by the domestic effluents. According to Dautrebande *et al.* (2004), the respective contributions of diffuse agricultural and dispersed domestic sources in the Geer basin in relation to nitrogen losses by leaching near groundwater are 88% and 12% respectively. This chapter will only focus on the diffuse pressure exerted on groundwater by nitrate (NO_3) from agricultural activity.

Crops					Duration (years)
Sugar beet	→ Wheat	→ Barley	→ Chicory → Flax	→ Wheat	5
Sugar beet	→ Wheat	→ Maize → Potatoes → Rape	→ Wheat		4
Sugar beet	→ Flax	→ Wheat			3
Temporary grass	→ Temp. grass	→ Wheat			3
Sugar beet	→ Wheat	→ Wheat			3

Figure 6. Main types of crop rotation

- **Estimation of the polluting pressures exerted by nitrate**

Nitrate polluting pressures exerted on groundwater by agricultural crops have been estimated through the use of standard nitrate emission rate per type of crop (expressed as the mean nitrate concentration in leaching water). As specific data on the Geer basin were not yet available to be used in the framework of AT project, data from the Rhine-Meuse Water Agency (AERM, 2006) were gathered and adapted (see Annex). The mean nitrate concentration in leaching water under agricultural land I_{NO3} in the Geer basin can thus be expressed as follow, where S_i is the area covered by the crop i (expressed in ha) and β_i is the nitrate concentration in leaching water under crop i (expressed in mg/l). We estimate it at 67 mg/l for the Geer basin.

$$I_{NO3} = \sum_i \beta_i \cdot S_i \Big/ \sum_i S_i$$

- **Objectives to reach good groundwater status in the Geer basin**

According to ULg hydrogeological experts, a decrease in the nitrate concentration in leaching water below 50 mg/l is necessary (and sufficient) to reach good groundwater chemical status in the future (long term: several decades). No evidence of nitrate degradation has been highlighted in the Geer basin and nitrate acts thus as a conservative tracer. A higher decrease in the nitrate concentration would also ensure to reach good chemical status but quicker. In the framework of this economic analysis, we will envisage three different objectives of decrease in nitrate concentration: (i) objective A: 50 mg/l, (ii) objective B: 45 mg/l; (iii) objective C: 40 mg/l. All of them should enable to reach good chemical status in the future but with different laps of time. Cost-effective programmes of measures will be proposed for these three objectives in § 2.3. The current estimated mean nitrate leaching concentration in water in the Geer basin (67mg/L) exceeds the objectives A, B and C (50, 45 and 40mg/L).

2.2. SELECTION AND ANALYSIS OF AGRI-ENVIRONMENTAL SCHEMES

2.2.1. Description of the measures

- ***Policy context***

In the framework of the rural development policy, the European Community offers a menu of measures to promote the protection of the farmed environment and its biodiversity. There are, among others, possibilities of support for agri-environmental measures, which entail going beyond the usual Good Farming Practices. Agri-environment schemes were introduced into EU agricultural policy during the late 1980s as an instrument to support specific farming practices that help to protect the environment and maintain the countryside. With the Common Agriculture Policy (CAP) reform in 1992, the implementation of agri-environment programmes became compulsory for Member States in the framework of their rural development plans. Farmers who commit themselves, for a five-year minimum period, to adopt environmentally-friendly farming techniques that go beyond usual good farming practice, receive in return payments that compensate for additional costs and loss of income that arise as a result of altered farming practices (EC, 2008).

- ***Four agri-environmental schemes***

Four agri-environmental schemes have been selected as relevant measures to decrease diffuse agricultural pressures exerted by nitrate on groundwater in the Geer basin.

→ Conversion of arable land into grassland (M_1): This measure consists in replacing arable annual crops into permanent grass (at least during five years), thus decreasing the pressures exerted by nitrate through leaching water at the permanent grass level (25 mg/l). The proposed subsidy (MAAPAR, 2002) is 450 €/ha/year. This amount should theoretically cover the mean annual difference of gross margin between five years of grassland and the current pattern of crops rotation.

→ Conversion into organic agriculture (M_2): This measure consists in changing the current agriculture practices into organic farming practices for annual arable crops. The implementation of this measure should lead to a decrease in pressures exerted by nitrate (estimated at -30%) since mineral fertilisation is forbidden. The proposed subsidy (GW, 2006) is 460 €/ha/year. This should theoretically cover the difference of gross margin between a typical organic farming rotation[4].

→ Implementation of catch crops (M_3): This measure consists in inserting a catch crop in the gap between a winter crop and a spring crop (from before the 15th of September to the 1st of January at least). This measure enables to limit nitrate leaching during winter time. The proposed subsidy (GW, 2006) is 100 €/ha/year. This should theoretically cover (i) a 5% loss in spring crop yield, (ii) costs for seeds, soil preparation and sowing, (iii) benefits related to the decrease in nitrogen fertilisation for spring crops.

→ Decrease in nitrogen fertilisation (M_4): This measure consists in replacing winter cereals by malting barley or rye. These crops require less fertilisation and thus decrease nitrate concentration in leaching water. The proposed subsidy (GW, 2006) is 100 €/ha/year and should cover the difference of gross margin between the two types of crops.

Three of them are part of the Walloon rural development plan 2007-2013 (GW, 2007). One of them (conversion of arable land into grassland) belongs to the French rural development plan (MAAPAR, 2004) and was also studied in this report for its (generally accepted) effectiveness to improve groundwater quality.

2.2.2. Framework for the analysis of an agri-environmental scheme

The analysis of the potential implementation of an agri-environmental scheme is structured as follows: (i) first, the area where the measure can be implemented is assessed, (ii) the annual cost (standard or real) of the implementation of the measure is then assessed and (iii) the decrease in nitrate polluting pressures is assessed (effectiveness). The Figure 7 illustrates these 3 main steps that are described below:

→ Step 1: Assessment of the surface where the measure can be implemented

A major characteristic of the agri-environmental schemes is that their implementation is based on a voluntary participation of the farmer (in opposition to obligatory measures): the implementation of the measure will thus be strongly dependent on the subsidy (incentive) level, the information level,

[4] For instance, as promoted by GW (2006) : Temporary Grass → Temporary grass → Wheat → Barley → Sugarbeet → Pea → Cereals → Barley

environmental consciousness and potential aversion to changes of the farmer. The assessment of the surface S_x where a measure x can be implemented consists in crossing agricultural areas of the Geer basin, areas where the measure can technically be implemented S_{ix} (step 1a), areas where the subsidy level m_{ix} makes the measure economically attractive for farmers (step 1b) and the implementation rate θ_x (step 1c):

$$S_x = \sum_i \theta_x \psi_{ix} S_{ix}$$

Let us consider ψ_{ix} as an indicator of the attractive level of the measure x for the parcel i: $\psi_{ix}=1$ if the subsidy is sufficient to compensate the costs borne by the farmer due to the implementation of the measure x on the field i and $\psi_{ix}=0$ if the measure is not attractive. ψ_{ix} can be expressed as a function of the productivity p_{ix} of the parcel i and the subsidy level m_{ix} : $\psi_{ix}= f(m_{ix}, p_{ix})$.

θ_x represents the implementation rate (expressed in %) of the measure that takes into account potential lack of information or the fact that some farmers may be reluctant to implement the measure even if the incentive is sufficient and technically feasible.

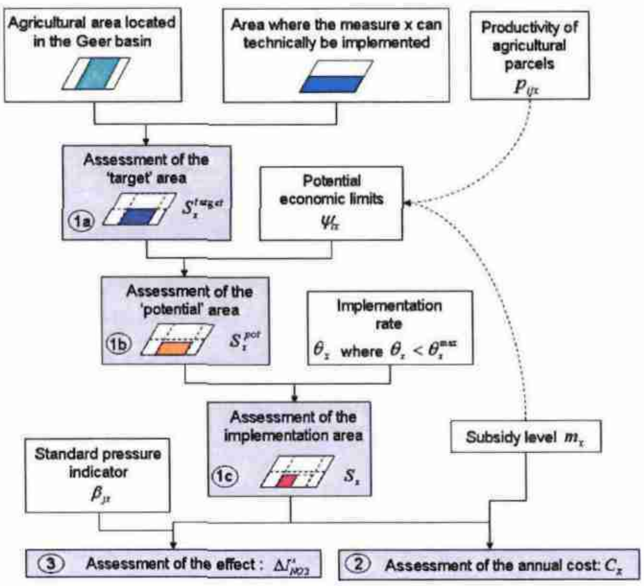


Figure 7. General framework to assess the potential implementation of a measure

→ *Step 2: Assessment of the cost induced by the implementation of the measure*

The annual cost C_x of the implementation of measure x can thus be expressed as follow:

$$C_x = \sum_i \theta_x \psi_{ix} S_{ix} m_{ix}$$

➔ Step 3: Assessment of the effectiveness of the measure

Let us consider ΔI^x_{NO3} the decrease in nitrate polluting pressures exerted on groundwater allowed by the implementation of the measure x (expressed in mg/l) and β_{ix} the indicator (expressed in mg/l) of nitrate polluting pressures exerted by the parcel i after the implementation of the measure x. ΔI^x_{NO3} can be considered as the effectiveness of the measure x and can be expressed as follow :

$$\Delta I^x_{NO3} = \sum_i \theta_x \psi_{ix} S_{ix} (\beta_{ix} - \beta_i) \Big/ \sum_i S_i$$

2.2.3. Cost-effectiveness analysis at the current subsidy level

The analysis of the potential implementation of each scheme with the actual subsidy level leads to the following results (Figure 8). The cost-effectiveness ratio r_x of each scheme x can be expressed as follow:

$$r_x = C_x / \Delta I^x_{NO3}.$$

It can be interpreted as the mean annual cost necessary to decrease the global nitrate pressures on groundwater in the Geer basin by 1 mg/l when implementing measure x. The table below compares the cost-effectiveness of the four agri-environmental schemes. Simulations show that at the current level of subsidy, M_4 is not attractive and thus would probably not be implemented in the Geer basin if the subsidy level is not increased. Moreover, the sum of individual effects of the measures shows that this would not be sufficient to reach the objectives set above (50 mg/l) as the decrease of nitrate leaching corresponding to the implementation of M_1, M_2 and M_3 (0.84 + 1.67 + 1.52 = 4.03 mg/l) is not sufficient to bring down the estimated nitrate leaching concentration (67 mg/l) to 50 mg/l. In the following paragraphs, we will test the effect of an increase in the subsidy level.

	Subsidy (€/ha/year)	Surface (ha)	Cost (k€/year)	Δ [NO3] (mg/l)	C/E ratio (k€/year/mg/l)
M_1	450	433	195	- 0.84	231
M_2	460	1,277	587	- 1.67	332
M_3	100	1,396	140	- 1.52	92
M_4	100	-	-	-	-

Figure 8. Potential surface, cost and effectiveness of the selected agri-environmental schemes

2.2.4. Cost-effectiveness analysis with an increase in the subsidy level

➔ Point 1: Potential surface and effects vary with the subsidy level

Figure 9 illustrates how the potential area and effect of a measure can vary with an increase in the subsidy level. For instance, at the current subsidy level ($m_1 = 450€/ha/year$: 0% increase) the measure M_1 may be implemented on $S_1 = 433ha$, decreasing the global nitrate pressures by $\Delta I^1_{NO3} = -0.84mg/l$ while with an additional subsidy of 160% the potential area of implementation would be $S_1 = 16{,}141ha$ with a decrease in nitrate pressures by $\Delta I^1_{NO3} = -26.7mg/l$.

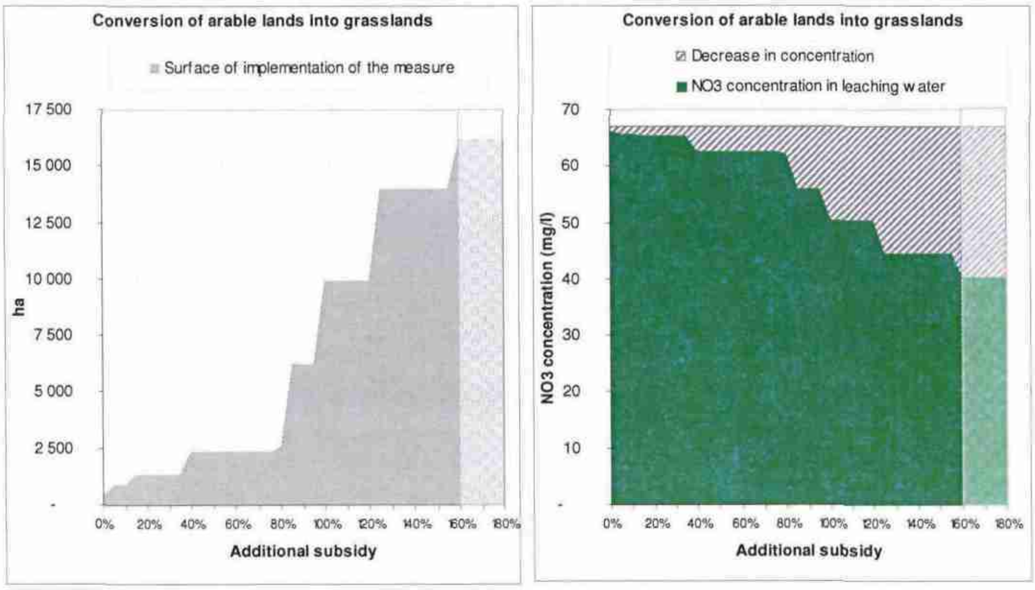


Figure 9. Surface and effectiveness of the implementation of M_1 as a function of the subsidy level

→ Point 2: Type of crops where the measure is undertaken vary with the subsidy level

Figure 10 illustrates how the types of crops where the measure M_1 is likely to be implemented vary with the subsidy level. While cereals and temporary grass are likely to be replaced by permanent grass at low level of increase in the subsidy level, industrial crops (e.g. fibre flax, sugar beet) require higher incentive levels. As the conversion into permanent grass will affect the whole crops rotation, several stages can be observed in Figure 10, corresponding to different rotation pattern (and related gross margin).

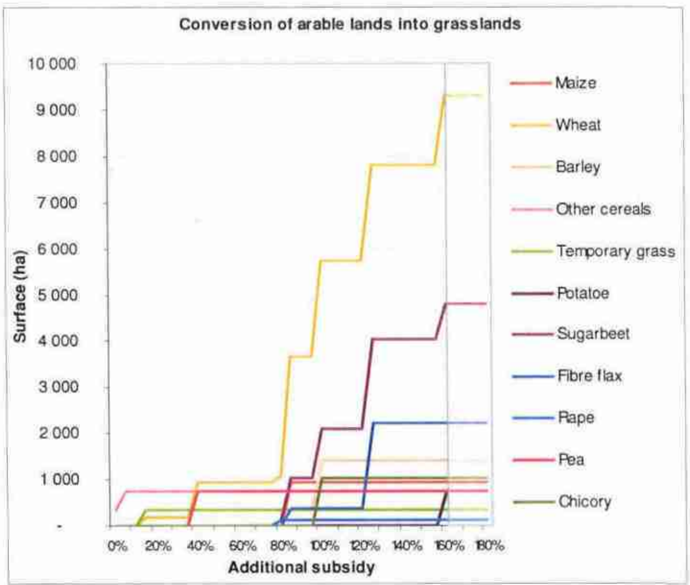


Figure 10. Surface where M_1 can be implemented as a function of the subsidy level

→ Point 3: Two hypothesis for an increase in the subsidy level

If an increase in the subsidy level of an agri-environmental measure is envisaged, we will assume here that it can take two different forms:

- H1: A 'uniform' subsidy level is proposed for each measure that is to say that the increase in the level of the subsidy will be the same for all crops in the Geer basin: this means that in some cases the subsidy level may exceed the real cost due to the implementation of the measure.
- H2: A 'differentiated' subsidy level is proposed according to the real cost borne by the farmers: an increase in the subsidy level results in several stages, all of them corresponding to the real cost borne by the farmer (i.e. the subsidy level is differentiated per type of crop or rotation).

Figure 11 illustrates for M_1 the principle of these two forms of increase in the subsidy level:

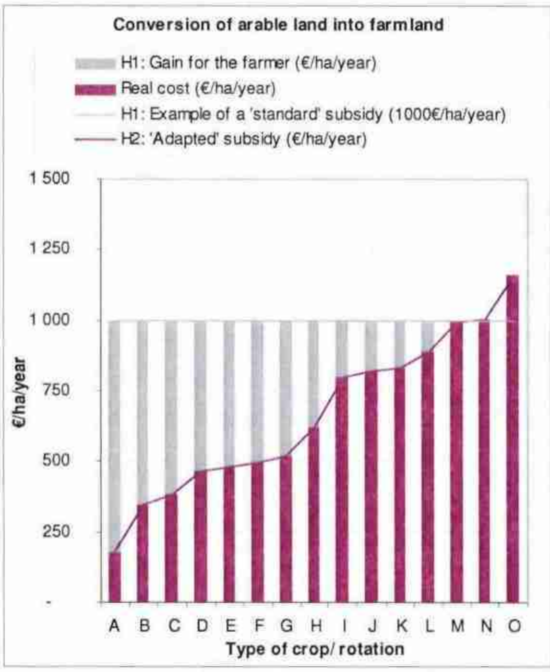


Figure 11. Comparison of a 'uniform' subsidy, a 'differentiated' subsidy and the real cost borne by the farmer when implementing M_1 according to the type of crop/rotation (H1 vs H2)

- H1: for instance, if $m_1 = 1{,}000€ / ha / year$, crops/ rotations from A to N are likely to implement the measure since the subsidy level is higher than the real cost borne by the farmer (red vertical lines). This 'uniform' subsidy level can thus result in gains for the farmer (grey vertical lines).
- H2: it consists in setting subsidies equal to the real cost borne by the farmer (from $m_1 = 180€ / ha / year$ to $m_1 = 1{,}170€ / ha / year$).

Figure 12, quite similar to Figure 9 illustrates the differences between these two different forms of increase in the subsidy level in terms of (i) the average subsidy level proposed in the Geer basin and (ii) the annual cost of the implementation of the measure M_1 on the Geer basin (from +18% to +36% between H2 and H1).

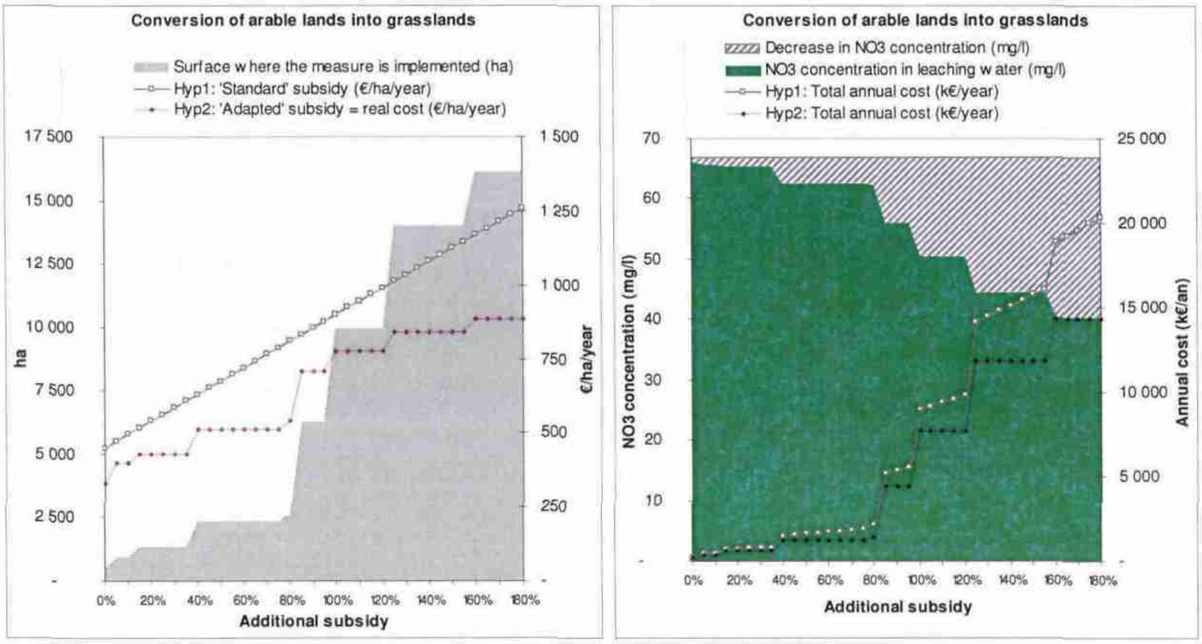


Figure 12. Surface, cost and effect of the implementation of M_1 as a function of the subsidy level (H1 vs H2)

<u>*Point 5: Cost-effectiveness ratios vary according to the subsidy level*</u>

Figure 13 and Figure 14 present the results of the analysis of each scheme: their maximal surface of implementation, their maximal effect, the average maximal level of subsidy on the Geer basin, the total annual cost and the cost-effectiveness rates (by testing a range of potential increase in the subsidy level). It clearly results from this analysis that M_3 and M_4 are the most cost-effective measures but they have limited potential effect at the Geer basin scale. M_1 and M_2 are less cost-effective but offer higher potential in terms of effectiveness.

			H1 : 'Uniform sudsidy'			H2 : 'Differentiated subsidy'		
	Surface max (ha)	Δ[NO3] max (mg/l)	Average subsidy level (€/ha/year)	Cost (k€/year)	C/E ratio	Average subsidy level (€/ha/year)	Cost (k€/year)	C/E ratio
M_1	16,141	- 26.64	1,170	18,885	231 - 715	884	14,274	169 - 536
M_2	15,208	- 15.31	989	15,041	332 – 1,007	727	11,060	289 - 722
M_3	5,292	- 5.77	115	609	92 - 105	100	530	56 - 92
M_4	897	- 1.79	135	121	67	131	118	65

Figure 13. Comparison of the range cost-effectiveness ratios between measures (H1 vs H2)

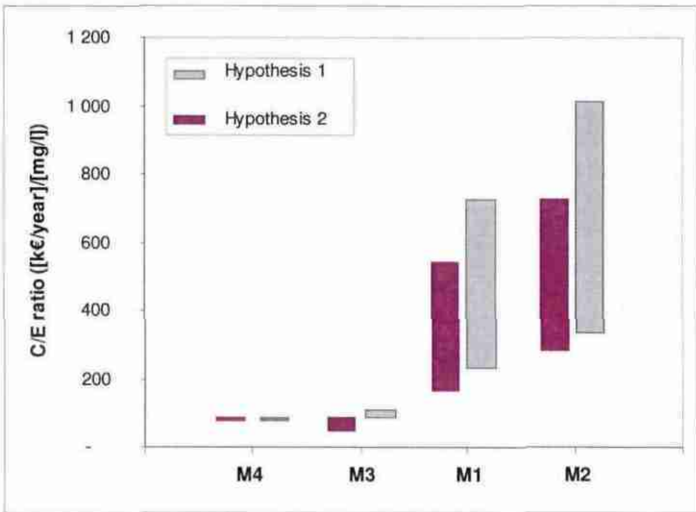


Figure 14. Illustration of the range of cost-effectiveness ratios of the selected schemes (H1 vs H2)

2.3. COST-EFFECTIVENESS ANALYSIS OF POTENTIAL COMBINATION OF MEASURES

2.3.1. General methodology

The programme of measures required by the Water Framework Directive should theoretically be composed of the most cost-effective combination of measures. The analysis of each agri-environmental scheme (§2.2) enabled to characterise cost-effectiveness rates and possible area of implementation on the Geer basin. The cost-effectiveness analysis approach consists in organising measures as a function of their capacity to improve groundwater water quality (i.e. to decrease exerted pressures on groundwater) at a given cost.

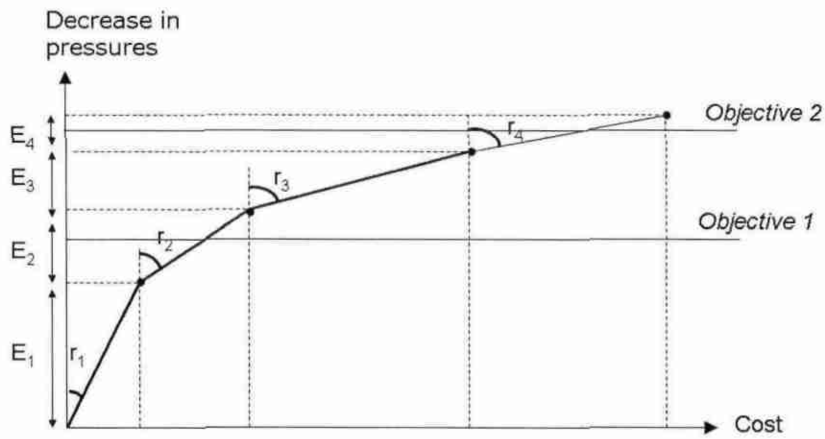


Figure 15. Cost-effective combination of measures to reach two levels of objectives

Let us suppose for instance four schemes A_1 to A_4 with rising cost-effectiveness rates from r_1 to r_4 and potential effects from E_1 to E_4. In order to reach objective 1, a CEA would recommend to implement A_1 and A_2 successively. Similarly a CEA would recommend to implement successively A_1, A_2, A_3 and A_4 to reach objective 2.

2.3.2. Combined effects of the measures should be taken into account to analyse a programme of measures

An important point is that combined effects of the measures should be assessed when undertaking a cost-effectiveness analysis of a combination of measures. For instance, Figure 16 illustrates how an increase in the subsidy level of M_2 can influence the land use pattern, making it necessary to analyse the costs and effects of combination of measures rather than analysing them individually. In this case, the implementation of measure M_2 will clearly influence for instance the potential surface available for the implementation of measure M_4.

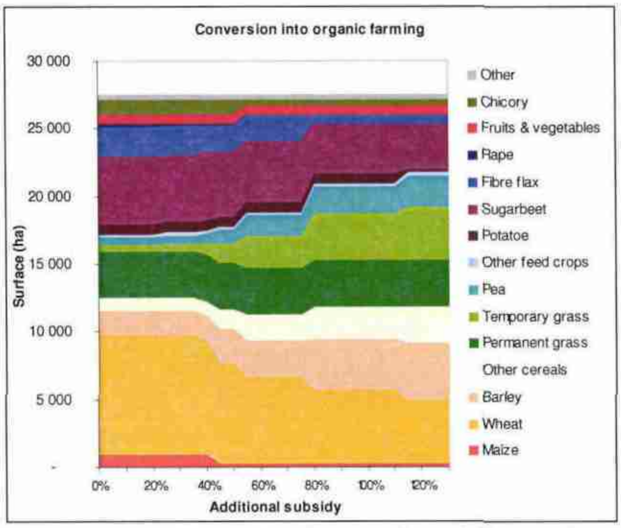
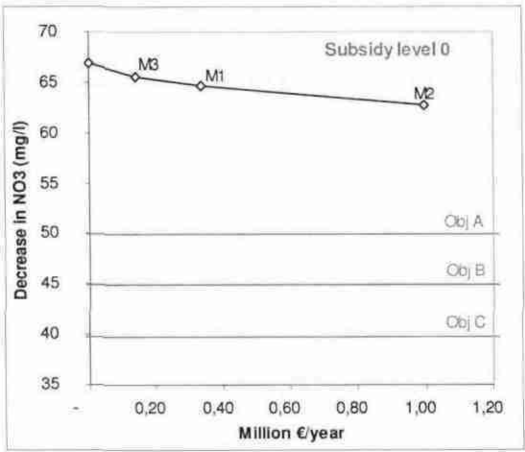


Figure 16. Change in land use related to the implementation of M_2 as a function of the subsidy level

2.3.3. Selection of cost-effective combinations of measures

- ***An increase in the level of subsidies is necessary to reach the objectives***

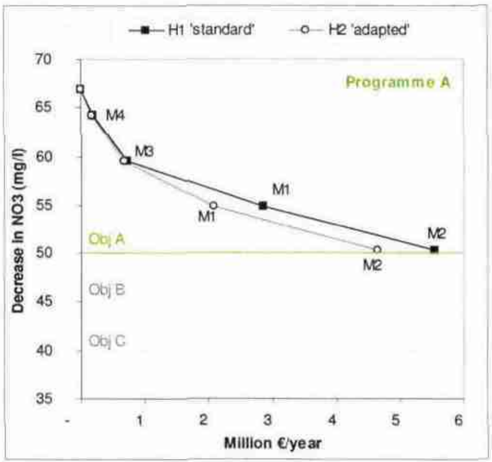


	Cost (k€/year)	C/E ratio	Δ[NO3] (mg/l)
M_3	140	103	- 1.4
M_1	195	231	- 0.8
M_2	661	332	- 2.0
P0	996	238	⇨ 63 mg/l

Figure 17. Cost and effectiveness of the combination of the measures at the current subsidy level

As it is mentioned in § 2.3.2 the current subsidy level may not be sufficient to reach the objectives set in this report (Figure 17). Consequently, increase in the subsidy level have been simulated (H1 and H2 forms) and integrated into a cost-effectiveness analysis. Six resulting programmes of measures composed of the most cost-effective combinations of measures have been selected to reach objective A (Figure 18), B (Figure 19) and C (Figure 20).

- ***Cost-effective programme of measures A to reach objective A***

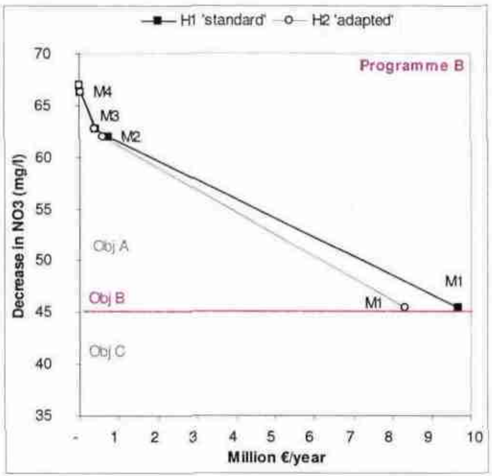


P_A = 1,389 ha x M_4 + 4,670 ha x M_3 + 2,612 ha x M_1 + 4,145 ha x M_2

	H1		H2		
	Cost (k€/year)	C/E ratio	Cost (k€/year)	C/E ratio	Δ[NO3] (mg/l)
M_4	187	67	182	65	- 2.8
M_3	537	116	491	106	- 4.6
M_1	2,139	451	1,411	297	- 4,7
M_2	2,688	592	2,554	562	- 4,5
PA	5,552	333	4,637	278	⇨ 50 mg/l

Figure 18. Cost and effectiveness of the programme of measures selected to reach objective A

- ***Cost-effective programme of measures B to reach objective B***

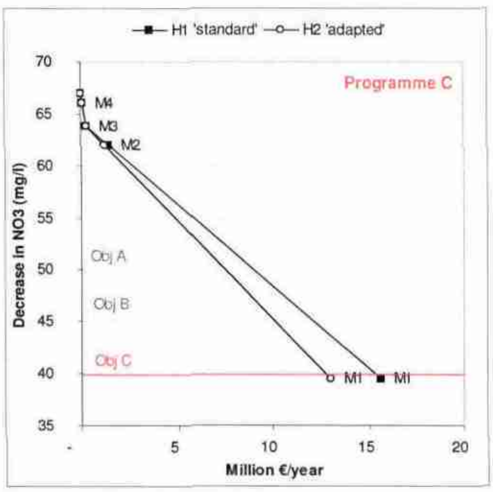


P_B = 349 ha x M_4 + 3,325 ha x M_3 + 504 ha x M_2 + 9,918 ha x M_1

	H1		H2		
	Cost (k€/year)	C/E ratio	Cost (k€/year)	C/E ratio	Δ[NO3] (mg/l)
M_4	47	68	46	66	- 0.7
M_3	382	107	356	100	- 3.6
M_2	313	462	214	316	- 0.7
M_1	8,927	540	7,696	466	- 16.5
PB	9,669	450	8,311	387	⇨ 45 mg/l

Figure 19. Cost and effectiveness of the programme of measures selected to reach objective B

- ***Cost-effective programme of measures C to reach objective C***



P_C = 472 ha x M_4 + 2,196 ha x M_3 + 1,596 ha x M_2 + 13,998 ha x M_1

	H1		H2		
	Cost (k€/year)	C/E ratio	Cost (k€/year)	C/E ratio	Δ[NO3] (mg/l)
M_4	64	68	62	66	- 0.9
M_3	253	114	236	107	- 2.2
M_2	1,101	600	916	499	- 1.8
M_1	14,173	631	11,791	525	- 22.5
PC	15,591	568	13,005	474	⇨ 40 mg/l

Figure 20. Cost and effectiveness of the programme of measures selected to reach objective C

2.3.4. Conclusion

Six different programmes of measures aiming at reaching good groundwater status in the future have been selected on the basis of a cost-effectiveness analysis. The implementation of such programmes would require annually from 4.6 to 5.6 million € for objective A, from 8.3 to 9.7 million € for objective B and from 13.0 to 15.6 million € for objective C (Figure 21 and Figure 22).

At the management plan time horizon (5 years), total costs of such programmes would range from 23 to 78 million €, depending on the objectives.

	[NO3] (mg/l)	Cost (M€/year)	Cost (€/ha/year)	Cost 2009-2014 (M€)
Programme A	50	4.6 - 5.6	169 - 202	23 - 28
Programme B	45	8.3 - 9.7	302 - 352	41.5 – 48.5
Programme C	40	13.0 - 15.6	473 - 567	65 - 78

Figure 21. Comparison of cost and effectiveness of programmes A, B and C (H1 vs H2)

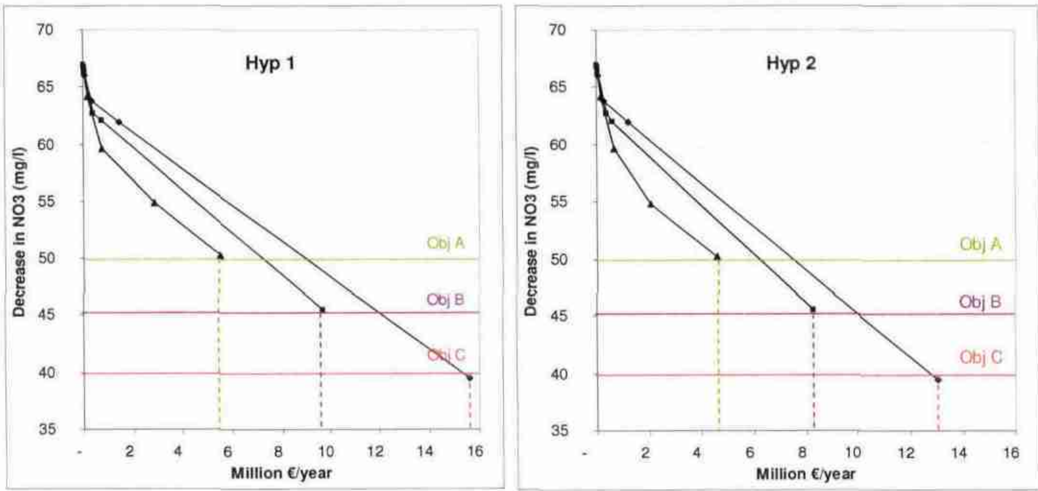


Figure 22. Cost-effectiveness curves of the programmes A, B and C (H1 vs H2)

However, as such programmes of measures would probably need to be implemented more than 5 years to guarantee a long term good status of the groundwater body we propose here to take a time horizon of 50 years for the assessment of the costs induced by the implementation of the programmes of measures. This results in a total cost C_X of programme of measures x expressed as follow:

$$C_X = \sum_{t=0}^{T} \frac{C_X(t)}{(1+a)^t}$$

a is the discount rate that we estimate here at 4% as recommended by the European Commission by public environmental investment (sensitivity of the economic results to the discount rate will be tested in Chapter 4).

$C_X(t)$ is the annual cost of the programme of measures x. We consider here that the annual cost of a programme of measures will evolve over time: farmers will certainly progressively adapt their agricultural system to the new agri-environmental schemes and the agricultural market system will probably evolve in favour of the farming systems the most respectful to the environment. To take into account this progressive adaptation we propose here to consider that the annual cost of the programmes of measures will decrease by r = 10% each 5 years. As a result, for instance, at T=50 years, we obtain $C(T) = C(t_0) \cdot (1+r)^{10} = 35\% \cdot C(t_0)$.

This leads to total discounted costs ranging from 79 to 94 million € to reach objective A, from 141 to 164 million € to reach objective B and from 221 to 265 million € to reach objective C (Figure 23).

	Total discounted costs (M€ 2008)
Programme A	79 - 94
Programme B	141 – 164
Programme C	221 - 265

Figure 23. Total discounted costs required for the implementation of the selected programmes of measures

3. Benefits related to the improvement of groundwater quality

Each programme of measures selected in chapter 2 should enable to reach good groundwater status in the future (at different time horizons[5]). The aim of this chapter is to assess (in monetary terms) and to compare the impacts of the implementation of these different programmes of measures.

This chapter is structured into three main parts (Figure 24): first, we characterise the main sectors likely to be affected by a change in groundwater quality and we propose a way to assess these impacts in monetary terms (§3.1); then the analysis of a scenario without programme of measures (scenario 0) is undertaken: nitrate evolution in groundwater abstraction points is simulated by the use of statistical and modelling tools and resulting economic damage are assessed (§3.2); the implementation of the different levels of programmes of measures is analysed: nitrate concentration in abstraction points is simulated by the use of modelling tools and benefits of the programmes are assessed as avoided damage (§3.3).

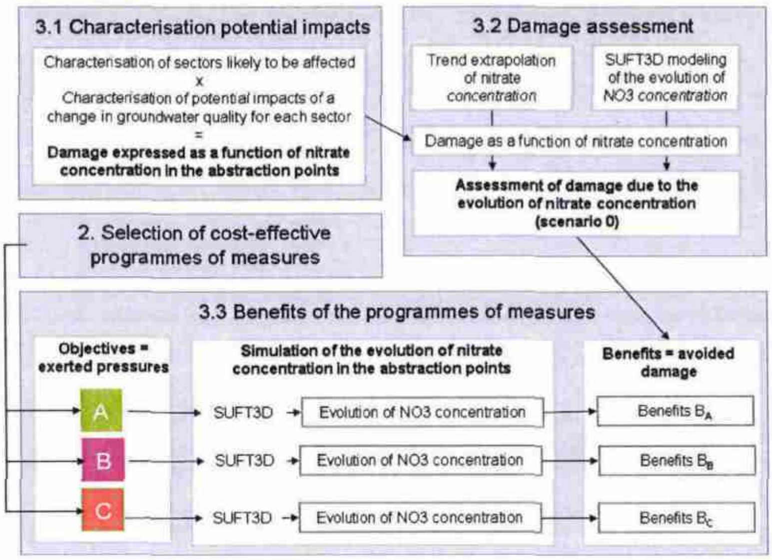


Figure 24. Overview of the methodology carried out for the assessment of benefits

3.1. CHARACTERISATION OF ECONOMIC IMPACTS RELATED TO A CHANGE IN GROUNDWATER QUALITY

The Hesbaye aquifer is one of the most exploited groundwater bodies in the Walloon Region, with about 24 million m^3 abstracted in 2003[6]. The main water user is the drinking water sector (85%), followed by the industrial sector (14%, mainly for cooling), then agriculture and services (1%). The increase in nitrate contamination can thus become a threat for these economic sectors in the coming decades. *Emphasize will be made in this report on the direct impact of groundwater quality change on* the drinking water sector and indirect impacts on the households.

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[5] The time horizon necessary to reach good groundwater status after the implementation of the programmes A, B and C has not been explicitly assessed in this analysis, even if it clearly appears that programme C would enable to reach quickly the good status than programme B that would also enable to reach the good groundwater status quicker than programme A. However this could be done by simulating the evolution of nitrate concentration for the points of the WFD monitoring network.

[6] Data on water abstraction were obtained for years 2002 and 2003 (source : Hydrogeology Unit – University of Liège).

3.1.1. Main sectors using groundwater as a resource on the Geer basin

- ***The drinking water sector***

Three companies exploit the Hesbaye aquifer for drinking water production: (i) the *Compagnie Intercommunale Liégeoise des Eaux* (CILE); (ii) the *Société Wallonne de distribution des Eaux* (SWDE); (iii) the *Vlaamse Maatschappij voor Water-voorziening* (VMW). The abstracted volumes are given in Figure 25. The locations of wells and galleries are shown in Figure 26.

Drinking water company	Abstracted volume in 2003 (million m3)
CILE	16.7 (81%)
SWDE	3.0 (15%)
VMW	1.0 (5%)
Total drinking water sector	20.7 (100%)

Figure 25. Abstration of groundwater for drinking water production (Data source : HGUlg)

The CILE

The production and distribution of drinking water in Liege have been the responsibility of the *CILE* since 1979. A total network of 48 km of galleries exploits the Hesbaye aquifer, allowing a production of approximately 17 million m^3/ year (45,000m^3/day on average). These galleries, dug in chalk between 30 and 60 meters of depth, are subdivided in two networks: the northern gallery and the southern gallery. The southern gallery uses a gravity feed system and a series of underground aqueducts to supply two reservoirs. The total volume abstracted in these reservoirs is about 16 million m^3/ year. Three wells pump water directly in the southern galleries in order to feed the villages of the Geer basin (approximately 1 million m^3/ year). The water collected in the northern galleries is raised by three pumping stations before being discharged via underground aqueducts into the southern gallery. Water from northern galleries is mainly used when the production of the southern galleries is insufficient or when the nitrate concentration is too high (dilution of water).

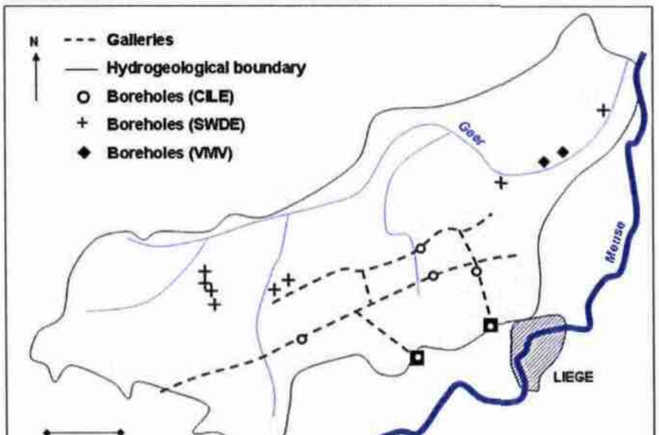

Figure 26. Wells and galleries in the Geer basin

The SWDE and VMW

The SWDE collects groundwater through eight wells located in the northern part of the Hesbaye aquifer. In 2003, the abstracted volume was about 3 million m^3. Five wells exploit the aquifer in the unconfined part of the aquifer (approximately 2.5 million m^3 in 2003). Along the Geer River, some wells belonging to *SWDE* and *VMW* exploit the semi-captive part of the aquifer (approximately 500,000 m^3 in 2003).

- ***The industrial sector***

The industrial sector may also be affected by deterioration in groundwater quality, depending on the nature of the activity. A first analysis of the abstracted water quantity gives the following results (Figure 27). The agro-food sector (0.9 million m^3 abstracted per year), where water is a basic ingredient and must correspond at least to drinking water requirements, is likely to be affected by groundwater pollution by nitrate. This impact will not be assessed in the framework of this report as we focus on the drinking water sector. Further investigations would be necessary to understand and assess the potential impact of groundwater degradation on the agro-food industries located in the Geer basin.

Branch of industry	Abstracted volume in 2003 (million m3)
Cooling	1.36 (53%)
Agro-food production	0.90 (35%)
Cleaning services	0.30 (11%)
Others	0.03 (<1%)
Total industrial sector	2.59 (100%)

Figure 27. Abstration of groundwater by types of industry (Data source : HGUlg)

- ***Households***

It is estimated that approximately 143,000 households are supplied with drinking water coming from the Hesbaye aquifer, representing a population of approximately 337,000 inhabitants (Figure 28). Degradation of groundwater quality may affect households through an increase in water prices. Households may also develop alternative options to improve the quality of their drinking water such as the purchase of individual purification systems or an increase of bottled water consumption, for example.

People connected to drinking water produced from the Hesbaye aquifer	337,000	estimation
Annual groundwater abstraction for drinking water production	20.7 million m^3	HGULg (2003)
Average network yield for the CILE company	83%	CILE (2007a)
Average network yield for the SWDE company	75%	SWDE (2007)
Annual total drinking water consumption	16.9 million m^3	Estimation
Annual domestic drinking water consumption	13.4 million m^3	Estimation
Mean domestic water consumption per inhabitant	109 l/inh./day	Aquawal (2006)

Figure 28. Estimated parameters for domestic water consumption

3.1.2. Assessment of the impacts related to a change in the Geer groundwater quality

We focus on impacts that may occur to the drinking water sector and (indirectly) to households. The Figure 29 illustrates how impacts occurring for the drinking water sector and households may be (schematically) linked to the evolution of nitrate concentration in wells and boreholes. We assume here that impacts may occur as soon as a 'threshold' nitrate concentration in the abstraction points is exceeded. We also consider that drinking water companies may undertake curative actions / households may change their behaviour before the drinking water limit: the threshold value is estimated at 48 mg/l (sensitivity of economic results to this threshold value will be tested in chapter 4). For each type of impact identified, damage D may be defined and assess as a function of the evolution of nitrate concentration.

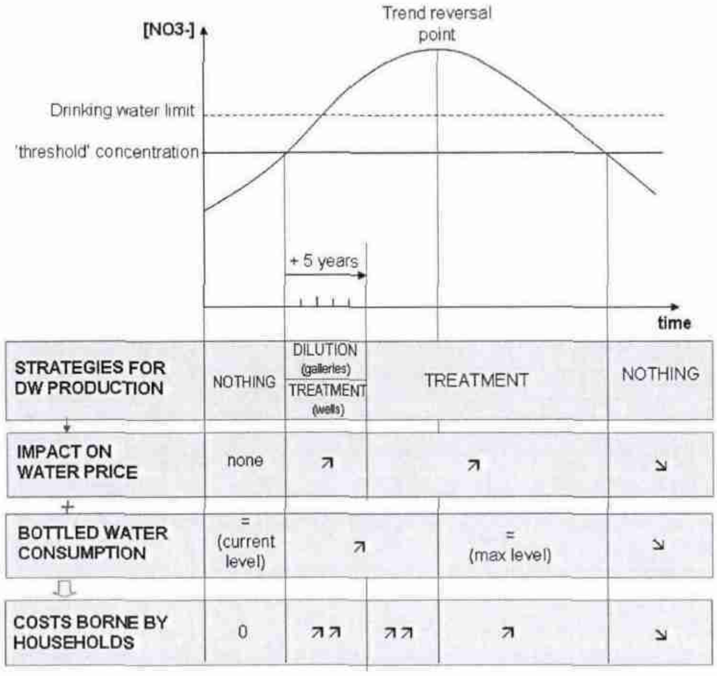

Figure 29. Potential impacts of groundwater quality variations on the drinking water sector

- ***Strategies for drinking water production in case of contamination***

In order to better understand which strategies are likely to be selected in the event of groundwater contamination, an expert of the *CILE* was consulted. The type of solutions to be considered is a question that was not resolved in the *CILE*, but the expert suggested three main types of strategies, depending on the duration of the contamination and the mode of production (galleries or wells): (i) the dilution of the contaminated water with surface waters of better quality; (ii) treatment by denitrification; (iii) treatment by reverse osmosis.

The first two options are recommended in the event of short-term contamination (less than 5 years). The dilution of groundwater implies the purchase of surface water of better quality to an other producer. Its production cost is higher than drinking water produced from groundwater (production itself, treatment and transport) with a transfer price established at 0.63 €/m^3. Depending of the level of dilution that is required, we estimated that the additional cost for drinking water production would range from 0.13 € to 0.28 € per m^3 produced. Treatment by denitrification could be used for the small intake points (approximately 5% of the production of the galleries). The cost of 0.28 €/m^3 generally found in the literature (Viavattene, 2006) will be used in this study.

The third option would be considered in the event of longer term pollution (> 5 years) and consists of carrying out a generalized water treatment, possibly coupled with a softening process (the hardness of Hesbaye water is approximately 42 French degrees). The operating cost of water treatment by reverse osmosis is currently under study in the Geer basin. As no estimation was available yet, we used the cost mentioned above for denitrification.

For each abstraction point i, the annual damage $D_i(t)$ due to groundwater quality degradation (expressed in €/year) may thus vary with time t (expressed in years) and can be expressed as follow:

$$D_i(t) = V_i^0 \cdot (1+\alpha)^t \cdot \psi_i(t) \cdot c(\phi_i(t))$$

V_i^0 is the volume of groundwater abstracted at year 0 (expressed in m^3/year)

α is the water demand annual growth rate in % (estimated by the expected population annual growth rate in the Province of Liege[7])

$\psi_i(t)$ is the indicator of groundwater quality with $\psi_i(t)=1$ if the concentration exceed the threshold value at which curative actions are undertaken and $\psi_i(t)=0$ if not

$c(\phi_i(t))$ is the annual cost of the selected curative strategy ϕ_i (dilution, denitrification or reverse osmosis) expressed in €/m^3 abstracted

At the Geer basin scale, the total annual damage for the drinking water sector $D_{DW}(t)$ resulting from groundwater quality degradation may thus be expressed as follow:

$$D_{DW}(t)=\sum_i V_i^0\cdot(1+\alpha)^t\cdot\psi_i(t)\cdot c(\phi_i(t))$$

- ***Resulting impact on water bill borne by households***

An increase in drinking water production cost because of groundwater quality degradation will in turn be passed on to the drinking water consumers through the water bill.

The structure of water prices in the Walloon Region was established by a decree in 2004[8]. The water bill is composed of (i) a fixed part (tax that is associated to each water meter) and (ii) a variable part depending on the volume of water consumption. Both are established on the basis of three parameters: the distribution truth cost (*'Coût Vérité Distribution'*: CVD), the sanitation truth cost (*'Coût Vérité Assainissement'*: CVA) and the tax for the water social fund (*'Fonds Social'*: FS). The value added tax (VAT) applies to both parts of the water bill. The CVD should contain the real costs required to produce and distribute potable water, that is to say that an increase in the production cost due to dilution or treatment will be passed on to the consumers through increasing the CVD. The table below gives the general water tariffs structure in the Walloon Region.

Fixed part (tax)	(20 CVD + 30 CVA) x (1+ VAT)
Variable part: (from 0 to 30 m3)	(½ CVD + FS) x (1+ VAT)
Variable part: (from 30 to 5,000 m3)	(CVD + CVA + FS) x (1+ VAT)
Variable part: (more than 5,000 m3)	(0.9 CVD + CVA + FS) x (1+ VAT)
Variable part: (more than 25,000 m3)	(aCVD + CVA + FS) x (1+ VAT) with 0.5 ≤ a ≤ 0.9

Figure 30. Water tariffs structure in the Walloon Region (from Aquawal, 2006)

The annual average impact on water bill for a household at year t can thus be expressed as follow (combination of the two first levels of water tariffs):

$$\Delta bill_{DW}(t)=(\gamma+5)\cdot\Delta c(t)\cdot(1+VAT)$$

[7] http://www.statbel.fgov.be/figures/t26/PopProv_fr.xls

[8] Décret du Conseil Régional Wallon du 27 mai 2004 relatif au livre II du code de l'environnement.

γ is the average water consumption of a household in the Walloon Region (expressed in m^3/year/household).

$\Delta c(t)$ is the additional cost of water production at year t due to groundwater contamination (expressed in €/ m^3 consumed).

$$\Delta c(t) = D_{DW}(t)/V_C(t) \quad \text{with} \quad V_C(t) = \sum_i \tau_i \cdot V_i^0 \cdot (1+\alpha)^t$$

$D_{DW}(t)$ is the damage to the drinking water sector due to groundwater quality degradation at year t (expressed in €/year)

$V_C(t)$ is the volume of water consumed at year t (expressed in m3/year)

τ_i is the network yield of the abstraction point I (expressed in %)

- ***Potential change in bottled water consumption***

Households may also be affected by the progressive degradation of the resource by increasing the quantity of bottled water in their daily water consumption: loss of confidence in tap water quality may lead them to increase their bottled water consumption (Rinaudo, 2005). Although the nitrate concentration of distributed water can not exceed the limit of 50 mg/l (according to the requirements of the Drinking Water Directive), the quality degradation may encourage households to consume bottled water, which results in additional costs. This may partly be explained by the fact that consumers generally prefer clean groundwater to water that has been polluted and treated to clean (Hasler *et al.*, 2005).

In the Walloon Region, it is estimated that ω_{BW}^0 = 20.4% of the population do not trust the quality of distributed tap water and that 60% drink bottled water rather than tap water (Aquawal, 2005). The average bottled water consumption in 2001 is estimated at 127.1 l/inh/year in Belgium (Aquawal, 2006) whereas it was 95.4 l/inh/year in 1990 (i.e. a $\alpha_{BW} = 2.6\%$ annual increase). The cost due to household bottled water consumption by the households at year t instead of tap water because of nitrate pollution will be assessed as follow:

$$D_{BW_i}(t) = pop_i^0 \cdot (1+\alpha)^t \cdot \omega_{BW}(t) \cdot v_{BW} \cdot (p_{BW} - p_{DW})$$

pop_i^0 is the population supplied with the water produced from the abstraction point i

$\omega_{BW}(t)$ is the percentage of people that do not trust tap water quality and thus only drink bottled water. We consider that (i) $\omega_{BW}(t)$ increases at the annual rate $\alpha_{BW} = 2.6\%$ when the nitrate concentration in the abstraction point increases and is above the threshold level (when dilution or treatment is required) ; (ii) $\omega_{BW}(t)$ stays at the same level when the nitrate concentration in the abstraction point starts to decrease and (iii) $\omega_{BW}(t)$ decreases at the annual rate $\alpha_{BW} = 2.6\%$ when the nitrate concentration decreases below the threshold value (dilution or treatment are not required anymore). We also consider that $\omega_{BW}(t)$ can not exceed 40% (percentage of people that currently drink tap water rather than bottled water).

v_{BW} is the volume of bottled water consumed each year by 'non confident' people (l/year)

p_{BW} is the average price of bottled water (€/l)

p_{DW} is the average price of tap water (for an annual consumption of γ) expressed in €/l.

The results obtained with these 'rules' should be treated with caution since they are based on a significant number of assumptions. In order to improve and provide quality control for this analysis a survey could be conducted with the local population concerning their change in behaviour in case of groundwater contamination by nitrate.

Note that the increased bottled water consumption generates an environmental cost which is not negligible. The production and transport of bottles requires much more energy than tap water production. Plastic bottles may also be a source of pollution for environment. This environmental cost has not been assessed in this report.

- ***Total damage***

Damage due to the evolution of nitrate concentration in groundwater can be expressed in different ways, for instance:

(1) as a sum of the discounted costs that could occur to the drinking water companies and to the households through an increase in bottled water consumption:

$$D = D_{DW} + D_{BW} = \sum^{T} \frac{D_{DW}(t)}{(1+a)^t} + \sum^{T} \frac{D_{BW}(t)}{(1+a)^t}$$

(2) as a sum of the additional average annual costs that would have to be borne by a household (related to an increase in water tariffs and an increase in bottled consumption), with N_{HH} being the number of households supplied by tap water abstracted from the Geer aquifer:

$$\Delta bill_{HH} = \Delta bill_{DW} + \Delta bill_{DW} = \sum_{t=0}^{T} \frac{\Delta bill_{DW}(t)}{(1+a)^t} + \sum_{t=0}^{T} \frac{D_{BW}(t)}{N_{HH}(1+a)^t}$$

In the next paragraph, these damage functions will be coupled with the predictions of evolution of nitrate concentration obtained by the use of statistical and modelling tools.

Cost of surface water purchase for dilution	0.6332 €/m3	CILE (2007b)
Average nitrate concentration in (treated) surface water	2.8 mg/l	SWDE website
Cost of treatment	0.28 €/m3	Viavattene (2006)
Non confidence in tap water quality in the Walloon Region (% of population)	20.4%	Aquawal (2005)
Average annual increase in bottled water consumption on the period 1990-2001	2.6%/year	Aquawal website
Average bottled water consumption per 'non confident' inhabitant	1.5 l/inh./year	estimation
Average cost of bottled water	0.42 €/l	Aquawal website
Coût Vérité Distribution (CVD)	1.8622 €	CILE & SWDE (2007)
Coût Vérité Assainissement (CVA)	0.795 €	CILE (2007)
Fonds Social (FS)	0.1487 €	Aquawal (2006)
Value added tax (VAT)	6%	Aquawal (2006)

Figure 31. Socio-economic data for damage assessment

3.2. DAMAGE ASSESSMENT IN A SCENARIO WHERE NO ACTION IS TAKEN

3.2.1. Simulation of the evolution of nitrate in groundwater

- ***Trend extrapolation results***

A statistical approach was proposed and applied by TREND sub-project for trend detection and quantification in groundwater quality (nitrate) datasets in the Geer basin, based on a three-step statistical analysis methodology as detailed in Deliverable T2.4 (Broers *et al.*, 2005a) and by Batlle Aguilar *et al.* (2007).

The statistical analysis provided point-by-point estimates of nitrate trends, in the form of slopes expressed by an increase or a decrease in nitrate concentration per year. In the Geer basin, a general upward trend is observed in the entire basin. Two zones can be distinguished in the basin: the southern part corresponding to the unconfined part of the chalk aquifer where high nitrate concentrations are observed, and the northern part corresponding to the confined part of the aquifer, where nitrate has not been detected (or at very low concentrations only).

A rough estimation of the time remaining before the threshold concentration of 50 mg/l would be exceeded, was calculated based on a point-by-point extrapolation of current nitrate contamination levels using nitrate trend estimates. To do so, the present contamination level was estimated at the different groundwater abstraction points used for drinking water production (Figure 26). This estimation was based on a point-by-point calculation of mean nitrate concentration over the period 1999-2003, a period for which the nitrate dataset is well furnished. Then, using the calculated slope value at the nearest available point, an estimation of the year at which the drinking limit will be reached was performed (Figure 32).

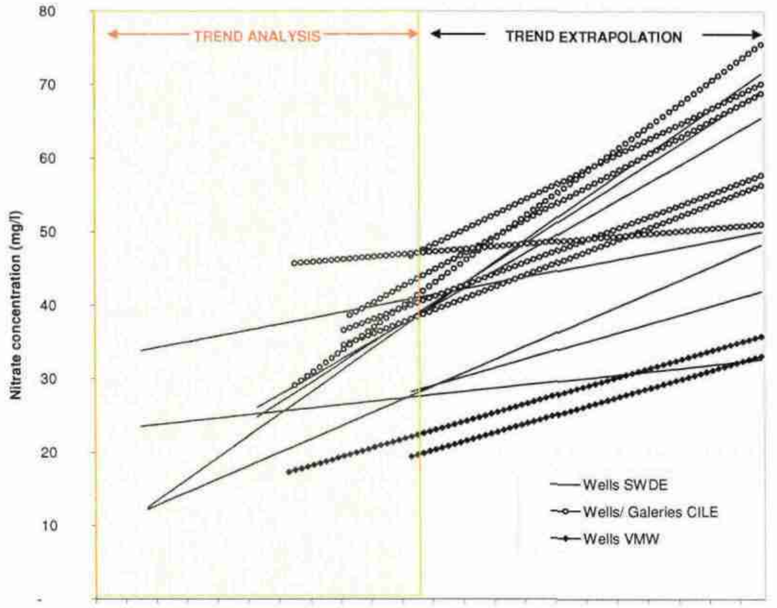

Figure 32. Dataset provided by Orban, ULg-HG (2006)

This statistical approach has two types of limitations:

- First, statistical techniques do no allow identification of trend reversal and are not usually used as prediction tools because they do not consider possible changes in the inputs: they can not be used to compare the effects of programmes of measures for instance. However, in a context such as in the Geer basin, i.e., where a thick unsaturated zone overlies the aquifer, there is a strong delay between changes at the land surface (i.e. manure reduction) and the observed impacts in the aquifer (i.e. trend reversal). Because changes in agricultural practices have started recently, one can anticipate that the trends observed presently are not likely to reverse until years into the future. Based on this assumption, a "simple" trend extrapolation is relevant in order to estimate the time remaining before groundwater is unusable for public water supply.

- Secondly, results obtained for trend extrapolation of nitrate concentration in the drinking water reservoirs are difficult to interpret since these two points are not abstraction points but correspond to water reservoirs. They are fed with groundwater abstracted in two galleries in function of the water demand and nitrate concentration level. Due to the different location and depth of these two galleries, nitrate concentrations are not the same: nitrate concentration is lower in the northern gallery than in the southern one. Water quality in the reservoirs is thus strongly dependent on the mix rate between various portions of the galleries that may change from one year to another. Trend extrapolation is certainly not the best way to predict nitrate concentration evolution in these reservoirs.

- ***SUFT3D modelling results***

HGULg has developed in collaboration with BASIN sub-project a spatially distributed physically-based deterministic groundwater flow and solute transport model for the Geer basin. A new concept for large-scale solute transport modelling, the *Hybrid Finite Element Mixing Cell technique* (*HFEMC*) developed by HGULg and implemented in the 3D simulator *SUFT3D* has been used to develop this model. Available data and conceptual choices made to develop the model were presented in the deliverables R3.16 (Orban *et al.*, 2006), R3.18 (Orban and Brouyère, 2006) and T2.8 (Broers *et al.*, 2007) and T2.10 (Broers *et al.*, 2008).

Two datasets were used for the calibration of the transport model, one corresponding to tritium data acquired during winter 2004-2005 (deliverable T2.8), the second to nitrate datasets and trends in nitrate groundwater quality (Deliverable T2.4). The advantage of tritium is that the concentration in the infiltration can be easily estimated because it is essentially a function of latitude. Nitrate concentrations in the infiltration are more difficult to determine as they are function of land use and their time evolutions (Deliverable T2.2). As spatially distributed estimation of nitrate fluxes as computed with the EPIC-Grid model were not available a simplified uniform scenario of input was defined. Based on information found in literature, the nitrate concentration in the leaching water is assumed to be equal to 15 mg/l at the beginning of the fifties, increase between 1950 and the mid of the eighties to reach a plateau with a concentration equal to 70 mg/l (Figure 33).

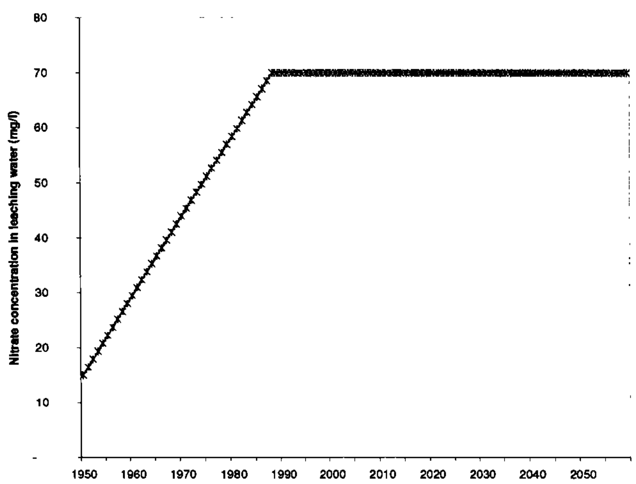

Figure 33. Evolution of nitrate concentration in leaching water for scenario 0

Evolution of nitrate concentration in groundwater has been computed for the main groundwater abstraction points for drinking water production (Figure 34). Evolution of nitrate concentration in the two reservoirs was assessed by dividing the galleries into five sections (three for the northern gallery, two for the southern gallery) as a function of their geometry and the destination of the abstracted groundwater.

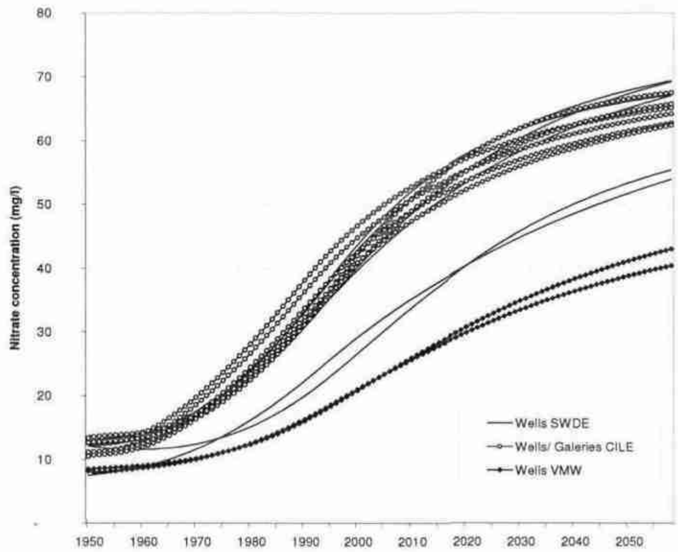

Figure 34. Evolution of nitrate concentration in the abstraction points used for drinking water production (scenario 0): dataset provided by Orban (2008)

The computed nitrate concentrations are of the same order of magnitude as the observed one (Figure 35). The general increasing trend is reproduced by the model. A more detailed comparison between the modelling results and the statistical trend analysis results is not so relevant since the nitrate input applied to the model remains relatively arbitrary, at least affected by a large uncertainty. Nevertheless, results presented here prove however the capability of the model to reproduce nitrate concentrations and their time evolutions.

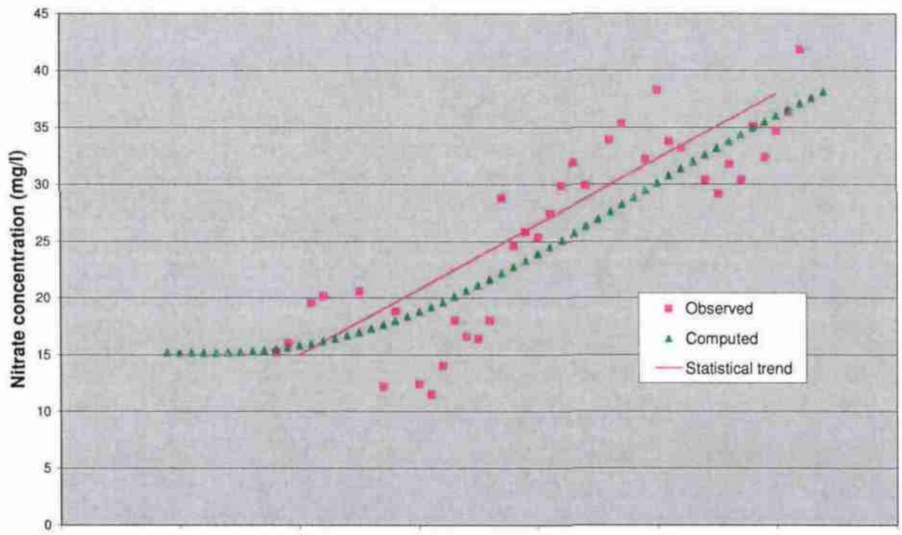

Figure 35. Comparison between the computed and observed time evolution of nitrate concentration in the well H7

3.2.2. Assessment of damage due to groundwater quality deterioration

The integration of these nitrate concentration evolutions into the damage functions presented in §3.1 leads to the following results (Figure 36): at a 50 years horizon, total discounted expected damage due to nitrate pollution are estimated at 159 million $€_{2008}$ or 1,855 $€_{2008}$ per household with the statistical approach; at 254 million $€_{2008}$ or 2,829 $€_{2008}$ per household with the modelling tools. This gap is mainly due to difference in the prediction of nitrate concentration evolution in the reservoirs between the statistical and the modelling approaches. In the next paragraph, as statistical techniques do no allow identification of trend reversal (§ 3.2.1) benefits of the selected programmes of measures will be assessed as avoided damage by using the modelling approach.

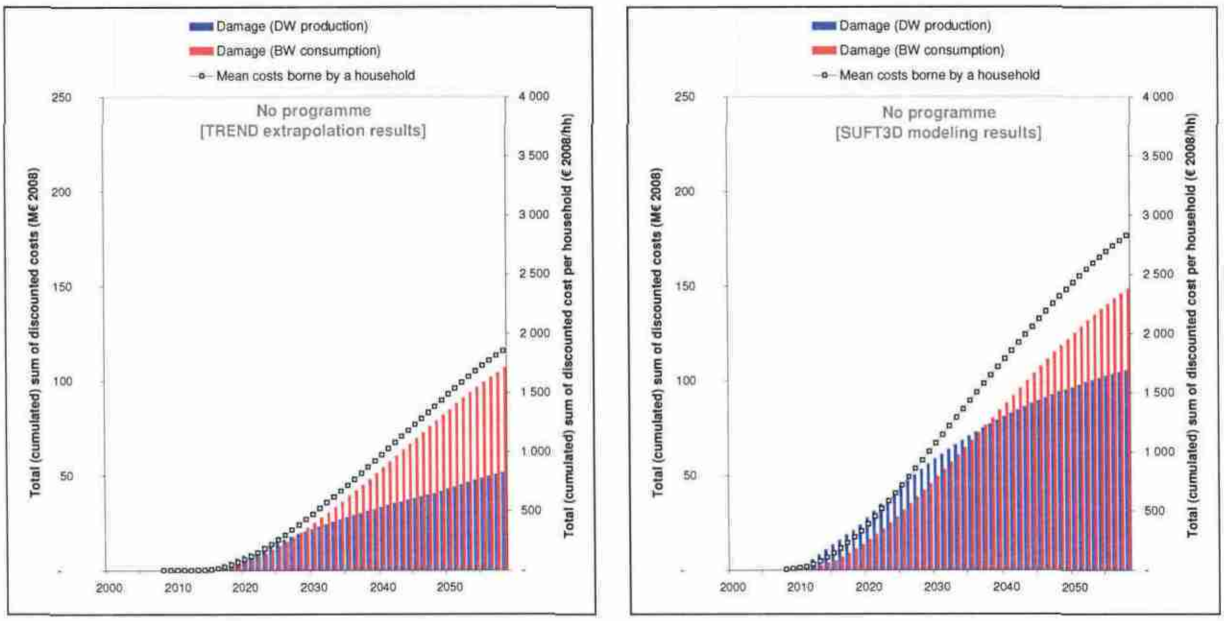

Figure 36. Annual cost of groundwater quality degradation in a scenario without programme. Comparison of results obtained with TREND extrapolation and SUFT3D modelling

3.3. POTENTIAL BENEFITS PROVIDED BY THE IMPLEMENTATION OF SELECTED PROGRAMMES OF MEASURES

3.3.1. Evolution of nitrate concentration

In the framework of the cost-benefit analysis carried out in this report, the three levels of objectives (A, B, C) for the programme of measures were computed (as uniform nitrate concentration in the leaching water) with the model developed within BASIN and TREND sub-projects. These three scenarios are similar for the period 1950-2008 and are different for the period 2009-2058 (Figure 37). Based on information found in literature, the nitrate concentration in the leaching water is assumed to be equal to 15 mg/l at the beginning of the fifties, increase between 1950 and the mid of the eighties to reach a plateau with a concentration equal to 70 mg/l. After 2008, three different evolutions of nitrate concentrations in the leaching water are computed: 50 mg/l (scenario A), 45 mg/l (scenario B), 40 mg/l (scenario C).

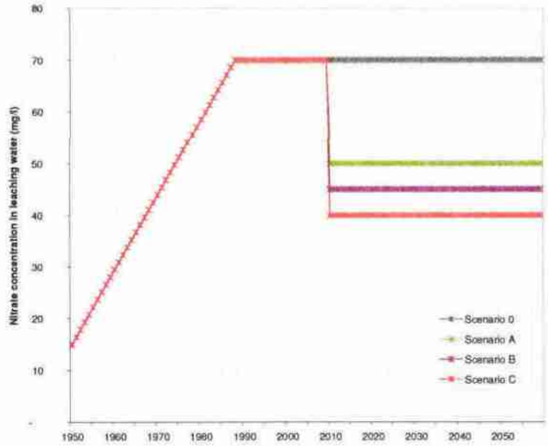

Figure 37. Evolution of nitrate concentration in leaching water for scenarii 0, A, B and C

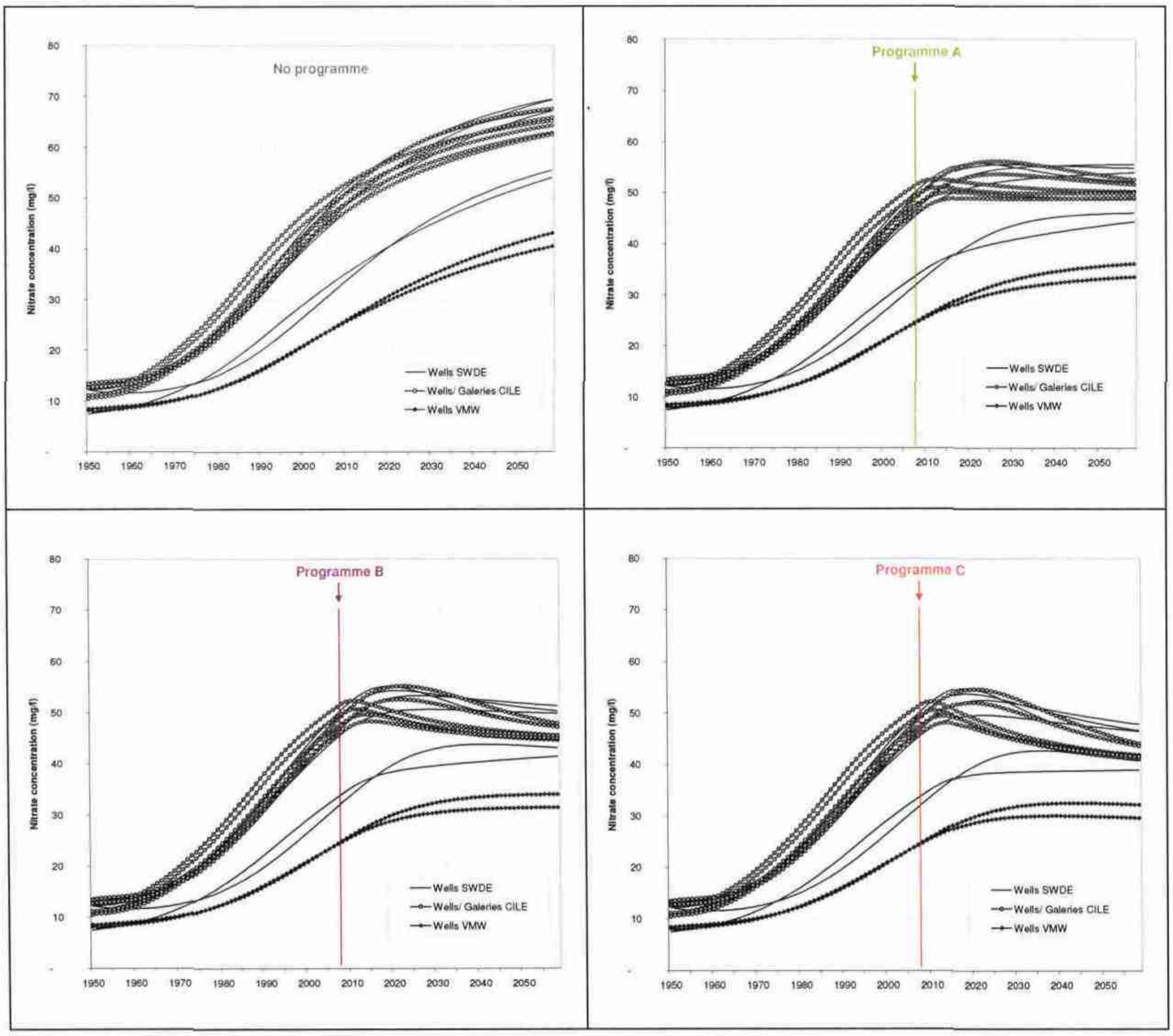

Figure 38. Evolution of nitrate concentration in the abstraction points used for drinking water production (scenarii 0, A, B and C): dataset provided by Orban (2008)

Figure 38 presents the results of nitrate evolution in groundwater abstraction points for the scenario A, B and C and compares them to the analysis carried out for scenario 0. These results show that even if the implementation of 'Programme A' may allow to reach good chemical status in the long term, good status may not be reached at the time horizon considered in this study (50 years). In the following, programme A will thus be eliminated and the analysis of costs and benefits will focus on programmes B and C.

3.3.2. Benefits/ avoided damage

Figure 39 presents the benefits and residual damage resulting from the evolution of nitrate in abstraction points simulated above. For a programme of measures X, the expected benefits are assessed as the avoided damage: $B_X = D_0 - D_X$.

- Benefits provided by the implementation of programme B are expected to reach 188 million $€_{2008}$ (254-66). Total average costs borne by one household are estimated at 670 $€_{2008}$ /household (instead of 2,829 $€_{2008}$ without programme).
- Benefits provided by the implementation of programme C are expected to reach 207 million $€_{2008}$ (254-47). Total average costs borne by one household are estimated at 464 $€_{2008}$ /household (instead of 2,829 $€_{2008}$ without programme).

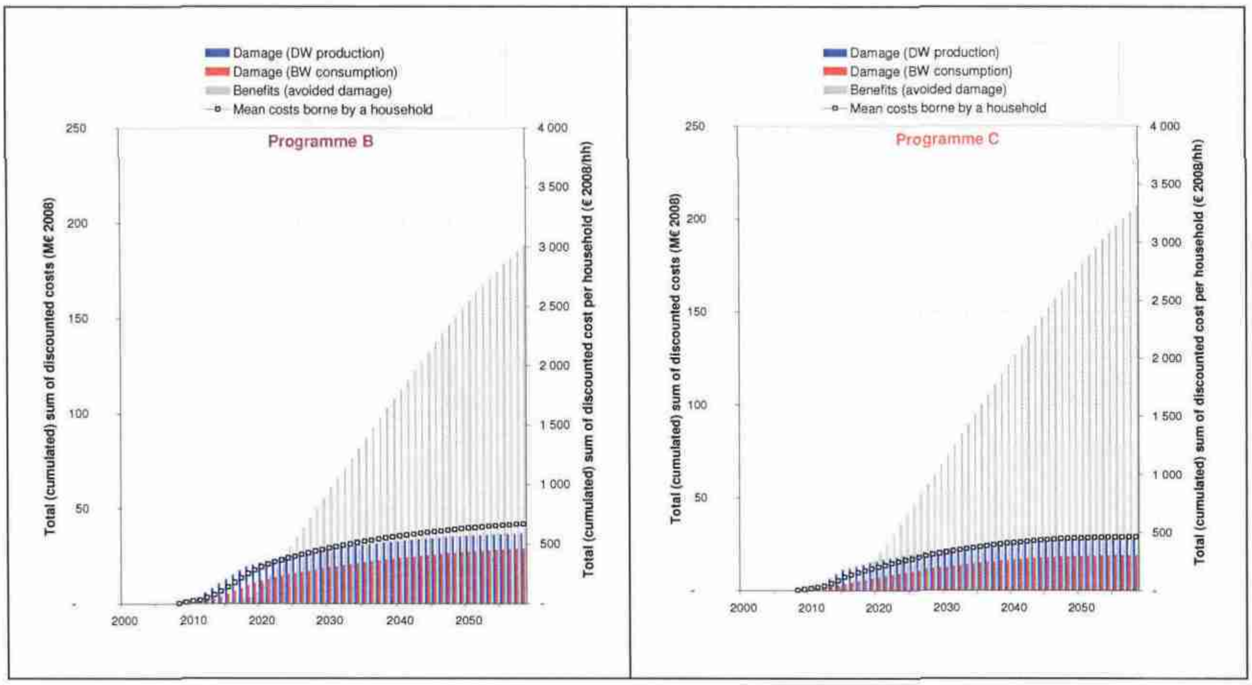

Figure 39. Annual benefits and residual damage of the programmes of measures

4. Cost-benefit analysis of the selected programmes of measures

4.1. GENERAL APPROACH

A cost benefit analysis consists in comparing costs and benefits resulting from the implementation of management measures, for a given time period. In the framework of this analysis we consider a $T = 50$ years period so as to take into account in the analysis benefits that may occur several years after the beginning of programme of measures (given to the hydrogeological conditions with long transfer time).

The comparison between costs and benefits occurring at different periods of time can be done by using discounted sums. We consider in this analysis a discount rate $a = 4\%$ as recommended by the European Commission for public environmental investment.

By comparing discounted sums of the annual costs $C_X(t)$ and benefits $B_X(t)$ over time of a programme of measures X we obtain its net present value NPV_X:

$$NPV_X = \sum_{t_0}^{T} B_X(t)/(1+a)^t - \sum_{t_0}^{T} C_X(t)/(1+a)^t$$

4.2. COST BENEFIT ANALYSIS

Comparison between costs and benefits related to the implementation of programme B and C indicate that the implementation of programme B would provide the highest net benefits on the Geer basin (Figure 40). We considered here the costs of the programme of measures with H1 assumption (uniform subsidy, programme with the highest costs) as it may be the most likely form of programme to be implemented (according to the current administrative framework).

The net present value of programme B is estimated at 24 million $€_{2008}$, with benefits representing 115% of the costs required for the implementation of the programme.

	No programme	Programme B	Programme C
Residual damage (M€ 2008)	254	66	47
Damage no programme (M€ 2008)	-	254	254
Benefits (M€ 2008)	- 254	188	207
Costs of the programme (M€ 2008)	-	- 164	- 265
Net Present Value (M€ 2008)	**- 254**	**24**	**- 57**

Figure 40. Costs and benefits related to the implementation of the programmes of measures

The Figure 41 illustrates how annual costs and benefits (not discounted) related to the implementation of programme B are distributed as a function of time. Whereas the costs required for the implementation of the programme start in 2008, benefits are expected to appear several years after the beginning of the programme.

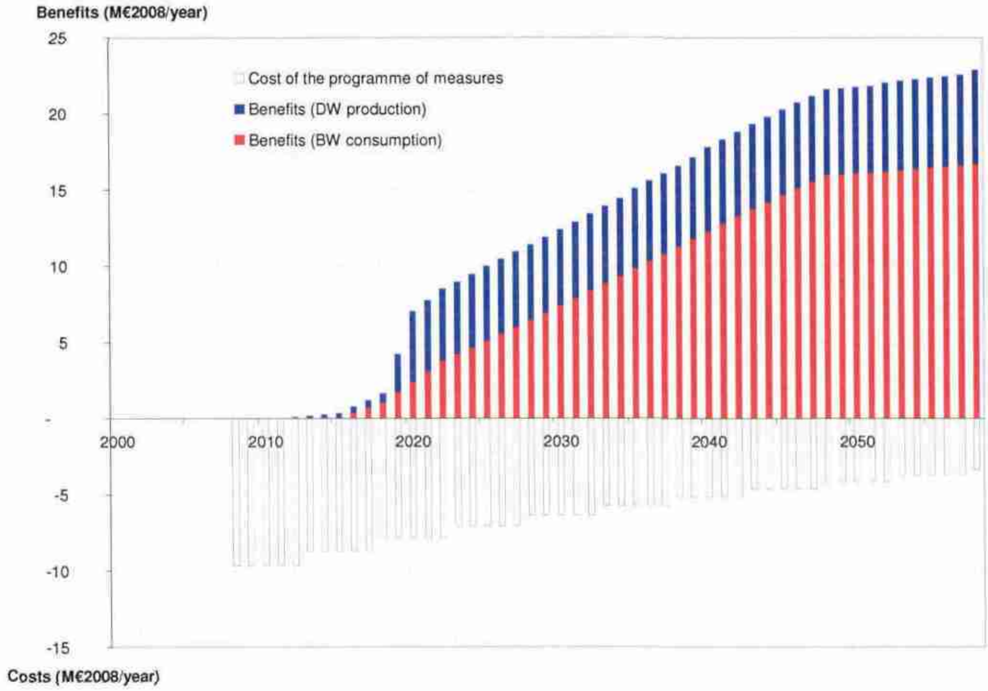

Figure 41. Annual costs and benefits related to the implementation of programme B

4.3. SENSITIVITY ANALYSIS

We should keep in mind that the analysis is based on several assumptions. Sensitivity of the net present value has been tested for four selected parameters. Results are presented in Figure 42.

- ***Sensitivity to the discount rate.*** The result of the cost benefit analysis is highly dependent on the discount rate, especially due to the hydrogeological conditions of the Geer basin (benefits can be expected only several years after the implementation of programmes of measures): a high discount rate reduces the current value of future benefits. Assuming all other parameters remain unchanged, changing the discount rate from 4% to 5% results in a NPV close to zero while changing the discount rate from 4% to 3% results to a 158% increase in the NPV.

- ***Sensitivity to the threshold value at which curative actions start to be undertaken.*** As explained in chapter 3 we considered in this study that curative actions of the drinking water sector and averting behaviours of households are undertaken before the drinking water limit is exceeded. This threshold value was estimated at 48 mg/l. Sensitivity analysis shows that if changes in behaviours and curative actions start to be undertaken earlier (for instance as soon as the nitrate concentration of 46 mg/l is exceeded) the NPV would decrease (close to zero for a threshold value at 46 mg/l) while for a threshold value at 50 mg/l, the NPV would remain unchanged. A complementary survey with the drinking water companies and the households would be necessary to reduce the uncertainties concerting the threshold value.

- ***Sensitivity to the annual increase in bottled water consumption in case of contamination.*** As explained in chapter 3 we considered in the analysis that an increase of nitrate concentration above the threshold value will lead to an increase in bottled water consumption. This annual growth rate was estimated as the average annual increase of bottled water consumption in the Walloon Region for the 1990-2001 period. Results of the sensitivity analysis show that the NPV is highly dependent on this rate: the NPV becomes negative for an annual rate lower than 2% and would increase by 119% for a change from 2.6% to 3.9% of annual rate. A complementary survey with the drinking water companies and the households would be necessary to elicit this type of uncertainty.

- ***Sensitivity to the rate of decrease in the annual costs of the programme of measures through farmers' adaptation.*** The sensitivity analysis shows that the NPV would become negative for a 5-years rate of decrease in the costs of the programme lower than 5% but would increase for higher adaptation rate (e.g. +79% in the NPV for a change in the rate from 10% to 15%). Eliciting this uncertainty would require an accurate understanding of farming systems and practices on the Geer basin (use of linear modelling for instance).

	Tested parameter		Net Present Value	
	Value	*% variation*	Value (M€)	*% variation*
Discount rate (%)	3%	*-25%*	63	*158%*
	4%	*0%*	24	*0%*
	5%	*25%*	- 2	*-107%*
Threshold value (mg/l)	46	*-4%*	- 1	*-103%*
	48	*0%*	24	*0%*
	50	*4%*	25	*1%*
Treatment costs (€/m3)	0,25	*-10%*	18	*-27%*
	0,28	*0%*	24	*0%*
	0,31	*10%*	31	*27%*
Annual increase in bottled water consumption (%)	1,3%	*-50%*	- 33	*-235%*
	2,6%	*0%*	24	*0%*
	3,9%	*50%*	53	*119%*
5-years decrease in costs of the programme due to farmers' adaptation (%)	5%	*-50%*	1	*-98%*
	10%	*0%*	24	*0%*
	15%	*50%*	44	*79%*

Figure 42. Sensitivity analysis of the net present value of programme B to selected parameters

5. Conclusion and implementation of the results

5.1. CONCLUSION

Three levels of objectives have been proposed to improve the Geer groundwater quality concerning diffuse agricultural pollution by nitrate. Programmes of agri-environmental measures have been designed according to a cost-effectiveness analysis. Costs of such programmes would range from 4.6 to 15.6 million euros per year, depending on the level of objective.

Integration of these scenarios into the statistical and modelling tools developed on the Geer basin enabled to assess the benefits that may be provided by the implementation of these programmes: Total expected discounted benefits for households and the drinking water sector of the proposed programmes of measures range from 188 to 207 million euros (€2008).

Cost-benefit analysis leads to the selection of the programme of measures B that may bring the highest net benefits to the society estimated at 24 million euros (€2008). As benefits were estimated only for the potable water sector, values assessed in this report should be seen as lower bound estimates of the total benefits that may result from the implementation of this programme of measures: benefits that may arise for the industrial sector (particularly for the agro-food industry) or those related to the non use values of the aquifer have not been assessed.

Sensitivity analysis of the CBA results shows that complementary research work would have to be undertaken to reduce the uncertainties:

→ Concerning the characterisation of nitrate pressures exerted by agriculture, an integrated approach involving the EPIC-Grid model (Dautrebande and Sohier, 2004) would enable (i) to spatialize the pressures exerted by nitrate; (ii) to improve the accuracy of the assessment of the effects of programmes of measures (thus improving the results of the cost-effectiveness analysis); (iii) to improve the results of the SUFT3D model by improving the assumptions concerning the nitrate concentration in leaching water.

→ Micro-economic modelling of farming systems on the Geer basin would also help to improve the accuracy of results by a better assessment (i) of the attractiveness of the agri-environmental subsidy level and (ii) of the evolution of the costs of such measures taking into account farmers' adaptation.

→ A complementary survey with households would be helpful to improve the understanding of their potential change in behaviour (in terms of bottled water consumption) in case of groundwater contamination.

→ Further results from simulations on the integrated surface – subsurface model developed by HGULg with HydroGeoSphere will bring more detailed information about quantitative impacts of climate change on groundwater reserves. More particularly, the study will examine the possible desaturation of some important water abstraction infrastructures in the Geer basin, what would make this infrastructure unusable and induce important water supply problems for the city of Liège (Belgium). Additionally, further work on the transport model will be used to assess what could be the possible impacts of climate change on the evolution of the nitrate contamination.

5.2. IMPLEMENTATION OF THE RESULTS

This study demonstrates successfully the integration between biophysical scientific results produced in AquaTerra and socio-economic science. It is the results of strong involvement from socio-economist and biophysical scientists and of interaction between AT partners and local actors and stakeholders. The combination of biophysical and socio-economic sciences helps to improve the understanding of the system as a whole and to anticipate the impact of a programme of measures with respect the environmental benefits and the economic costs. This multidisciplinary understanding of the system is a powerful tool to assist decision making. The results will be sent to the Dgrne (Direction générale des ressources naturelles et de l'environnement) for information and may be further used in a context of decision making after further steps of validation.

The same conceptual framework may be used to integrate future data from the *Hydrogeosphere* and the *Geosys* models (outside the scope of AquaTerra, due to time limitations). The approach developed in this innovative socio-economic study may also be used to assess other programme of measures needed in other context and to solve other type of key issue associated with river basin management.

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