Economic assessment of groundwater protection

Executive summary

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A project financed by the European Commission
ENV.A.1/2002/ 0019

May 2003
BRGM/RC-52323-FR

Outlines

1 Context and objective of the study

The Water Framework Directive (2000/60/EC) supplements existing legislation by expanding the scope of water protection to all waters, surface waters and groundwater. It requires that Member States enforce appropriate measures to achieve good ecological and chemical status of all water bodies by 2015 (with a possibility of justified derogation).

Concerning groundwater, the WFD does not define quality standards other than those already set by the existing legislation (nitrate, pesticide and biocide directives). However, article 17 stipulates that the Commission (or Member States if no agreement is reached at the community level) must adopt additional measures to prevent and control groundwater pollution in a groundwater daughter directive (GWD). The GWD must define criteria for assessing good groundwater chemical status. According to article 17[1], the selection of these criteria must be backed up by an economic analysis.

The objective of the present study is to conduct such an economic analysis, using results from existing studies described in the literature and primary data from three selected case studies. The Commission has agreed that it should focus mainly on economic issues raised by the choice of minimum quality standards. The analysis thus assesses the consequences that different definitions of "good chemical status" have on pollution abatement costs and on benefits accruing to groundwater users. Thereby the economic analysis provides some insights on the question whether the prospective benefits of certain protection levels justify the anticipated costs of meeting them?.

This document presents the key finding of the project titled "Economic Analysis of Groundwater Protection" which was conducted by the French Geological Survey BRGM and by Ecologic, the Institute for International and European Environmental Policy and executed from August 2002 to May 2003.

This reports comprises three main parts. The first one presents the key findings from the literature review. The second part presents the results of three case studies conducted using primary data. The case studies have been conducted in field sites (one trans-boundary located between France and Germany, one in France, one in Denmark) selected in consultation with the Commission. The third part relates the findings from the economic analysis with the issues raised by the formulation of the groundwater directive.

2 Summary of the Literature Review

The main objective of the literature review was to report results from case studies that have assessed the costs and the benefits of groundwater protection and remediation, either as a qualitative description or, where possible, in monetary terms. In assessing the costs and benefits of groundwater protection, this paper takes account of the focus of the Water Framework Directive, which is primarily concerned with the qualitative aspects of groundwater protection. Quantitative aspects have only been considered in so far as they have a connection to qualitative problems.

The report builds on evidence from scientific research papers, literature by international organisations, and publications by government agencies, consultants or other stakeholders. In order to identify potential unpublished reports, a "core contact group" of experts in the field of groundwater economics has been contacted with a specifically designed questionnaire. The summary first addresses the theoretical background and conceptual issues (2.1), then survey

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[1] Article 17 imposes that "in proposing measures the Commission shall have regard to the analysis carried out according to Article 5 and annex II" (i.e. "a review of the impact of human activity" and "an economic analysis of water use").

evidence on the cost (2.2) and benefits (2.3) of groundwater protection, and finally discusses ways of combining the evidence on costs and

2.1 Environmental Economics as a tool for political decision making

A central assumptions in standard economics is that, under normal conditions, the free play of market forces will achieve the socially optimal result: the 'invisible hand' of the market guarantees that while all agents only pursue their own interests, they achieve a result that is also optimal from the point of view of society as a whole. In some cases, however, the market fails to achieve the socially optimal outcome. A targeted government intervention can then increase social welfare. Two categories of such market failures are relevant in the case of groundwater: the case of externalities and the public good aspect of groundwater.

An example of a negative **externality** in the case of groundwater is nitrate pollution from a farm, which affects households and firms that draw their groundwater supply from the same aquifer. If nitrogen fertiliser applications are not regulated, the farmer will not consider nitrate pollution in deciding on the amount of fertiliser. The decision will then only be determined by 'internal' considerations such as available land, the cost of seeds, machinery, labour, and the price of fertiliser itself. However, the farmer does not take the *social* costs of his action into account: through nitrate leaching from fields, the farm imposes a cost on adjacent households and firms. Neighbours may suffer a financial loss due to the pollution - e.g. if they have to install devices to purify abstracted groundwater - or their quality of life may be impacted because of increased fear and anxiety. In any case, the neighbours of the farm would benefit if nitrate applications were reduced.

The second reason why unregulated markets fail to ensure groundwater protection is that groundwater has some characteristics of a **public good**. A pure public good is distinguished by two properties: there is no *rivalry* in consumption, i.e. if one person uses it, its value for someone else does not decline. And there is no *excludability* from consumption, meaning that it is not possible to restrict access by others. Pristine groundwater displays some characteristics of a public good. Since it is impossible to effectively prevent or monitor all pollution, there is at least partial non-excludability from consumption. At the same time, there is rivalry between different uses – if the groundwater body is used to absorb emissions, the water from it cannot be used as drinking water any longer; and if too much water is abstracted from an aquifer, the water table will fall. Therefore, groundwater is an impure public good or a *common pool resource*. The impossibility to exclude users means that the government must act as steward over the resource. Likewise, the partial absence of rivalry means that market prices for groundwater will be below the social optimum. Governments can therefore raise prices indirectly, by restricting access, or directly through taxation.

2.2 Peculiarities of Groundwater

In the case of groundwater, a number of factors complicate the application of economic instruments straight out of the textbook. The following problems need to be considered:

- Groundwater contamination is subject to considerable *time-lags*: contaminants may travel for decades before they reach the aquifer; this makes it particularly difficult to monitor the effectiveness of protection measures. In addition, these time lags are *variable*: they depend on a range of other factors, such as soil type, saturation, or precipitation. Once contaminants reach the groundwater body, they continue to spread, albeit at a slow pace.
- The impact that contaminant release has depends on the *hydrogeolocial conditions* of the site, such as the thickness and soil type of the topsoil layers; on the depth and volume of the aquifer; and on its connections to surface water bodies.
- The impact of groundwater contamination also depends on *groundwater uses*, such as the present and future groundwater abstractions for irrigation, drinking water or industrial uses, and on the vulnerability of groundwater-dependent ecosystems. However, many of

the linkages between groundwater, surface water and dependent ecosystems are poorly understood.

- Groundwater damage makes itself felt for a long period, but is difficult or impossible to correct: in many cases, pollution can at best be contained within a certain area, but a cleanup of polluted groundwater is usually not possible. The *irreversibility* of groundwater protection increases the cost of misjudgements when determining protection levels.
- Finally, concerning the benefits of groundwater protection, some groundwater functions have hardly been researched. This applies in particular to the non-use or preservation value of groundwater, and to groundwater-dependent ecosystems: very little is known about these effects of groundwater contamination and their economic costs.

These caveats and limitations imply that any assessment of groundwater pollution and protection is largely determined by local characteristics, and will have to be done in a site-specific way. In this context, the presented instruments from environmental economics can then be applied in a useful manner.

2.3 The Costs of Groundwater Protection and Remediation

2.3.1 Different cost categories of groundwater protection and remediation

Costs for groundwater protection arise for various actors: mainly agriculture, industry, transport, and private households.

For agriculture, costs arise from reduced *fertiliser and pesticide applications*. They comprise *diminished productivity* through less intensive farming practices; *information and learning cost* for better fertiliser or pesticide management; changing to *different crops*, or to different combinations or rotations of crops; employing alternative, more costly *weed eradication* methods; and switching to *alternative land uses*, i.e. from tillage to pasture or forestry. Other costs for agriculture emerge through better storage of pesticides, and storage and treatment of wastewater and manure from farms.

For industry, costs mainly emerge from protective measures that firms are obliged to install. These can be end-of-pipe measures to retain polluting substances, or more integrated measures, i.e. by changing production processes to reduce the use of certain substances. Opportunity costs arise if polluting activities have to be ceased altogether to comply with environmental rules. In addition, substantial clean-up costs arise after accidental spills of hazardous substances, or to make up for insufficient protection in the past. For historical contamination, these costs are frequently not borne by the polluters, but by local or regional authorities. The sectors that are most affected by this are chemical industries and mining.

In the transport sector, costs arise mainly from the installation of protective structures to prevent accidental spills of hazardous substances. Other cost factors are the substitution of methods used in the maintenance of roads and railways, such as road de-icing salts or pesticides used for weed eradication on railway tracks.

For the larger part, private households are indirectly affected by the costs of groundwater protection. Since households in most parts of Europe are connected to public sewerage systems, the cost for wastewater treatment is transmitted to them via water supply companies. Where there is no connection to the public wastewater system, cost arise for septic tanks etc. Apart from this, households are also affected by restrictions on pesticide use in private gardens, or by protection requirements for private underground storage tanks.

2.3.2 The cost-efficiency of different protection instruments

There are a number of instruments that can be used to influence the behaviour of consumers and producers towards less damaging practices, ranging from informational measures to direct regulations that ban certain behaviour. Economic instruments, which influence behaviour by changing the economic incentives that economic actors face, are gaining in relevance. However their applicability and efficiency is limited through gaps in the necessary knowledge. In addition, there are some cases where the reform of existing instruments will be helpful or necessary to improve groundwater protection.

However, in general it appears that it is not so much the type of instrument that determines the effectiveness and cost-efficiency, but rather its design. Well-designed standards that leave sufficient flexibility can be more effective than poorly designed taxes or cooperative agreements. A further general finding is that better groundwater protection is not necessarily connected to higher cost. There appears to be some potential for “no-regret solutions” whereby pressures on groundwater are reduced through better management of polluting activities. These potentials can be mobilised e.g. through information provision and cooperative agreements. The following pages give an overview of the different instruments.

TAXES AND SUBSIDIES

In the field of groundwater protection, environmental taxes are not used widely. In principle, a tax system based on emissions represents a highly efficient instrument for groundwater protection. However, due to the associated monitoring requirements, it is difficult to implement in practice. Instead, taxes on inputs for polluting processes (e.g. fertilisers) offer themselves as a second-best alternative.

Modell-based research finds that the cost of groundwater protection taxes for diffuse agricultural pollution are generally quite low at a maximum of 4% of farm profits, even if crop yield losses and the costs of labour-intensive substitutes for fertilisation and weed eradication are included. At the same time, depending on their specifications, taxes with a comparable effectiveness impose very different costs: for example, a taxation scheme based on actual exposure values imposes costs of less than 0,25% of farm profits.

Especially in the context of diffuse agricultural pollution, there is great potential also to change incentives through a subsidy reform rather than taxation. If polluting activities are subsidised, a reduction or redirection of subsidies would have the same effect on the incentive structure as a tax would, but at a lower administrational cost. In the ongoing discussions about the reform of the EU Common Agricultural Policy, these approaches are discussed under the heading of *cross-compliance*, whereby subsidies are partly conditional on compliance with good agricultural practice standards. This instrument so far was optional only and has not been applied widely.

COOPERATIVE AGREEMENTS

Cooperative Agreements are negotiated solutions where the polluter commits himself to reducing a polluting activity, and is compensated by the beneficiary of the pollution reduction. In the case of groundwater protection, cooperative agreements are typically concluded between water supply companies and agricultural polluters. Such agreements can be very efficient, since the cost of removing nitrates or pesticides from groundwater usually far exceeds the cost of reducing applications of these substances.

Calculations for the cost of reducing nitrate concentrations through cooperative agreements in the German Bundesland Hesse found an average cost of 0.29 € per m^3 of abstracted groundwater, based on the nitrate reductions in the soil of 20 to 60 kg N/ha that were achieved through the agreement. Groundwater protection by means of cooperative agreements is thereby a cost-efficient alternative to end-of-the-pipe treatment.

A central finding from the empirical literature is that the efficiency of cooperative agreements depends on their specific design: for example, the efficiency is enhanced if compensation payments are reduced over time, as farmers successively adopt less harmful cultivation methods. At the same time, agreements need not be based on compensation payments only. An alternative compensation is training for improved fertiliser management, which brings cost savings for water suppliers as well as higher crop yields from improved fertilisation.

STANDARDS AND REGULATIONS

In most EU countries, standards and regulations have long been the backbone of groundwater protection instruments. In the case of groundwater protection, they apply a.o. to the definition of *good practice* standards, the recommendation of *best available technologies*; the *production, use, storage, transport and disposal* of dangerous substances; *bans* on the use of certain substances, and regulations concerning land use in *protected areas*.

Generally, command-and-control measures have received little attention from economists: they are regarded as fairly inefficient economically, and therefore are usually considered as a benchmark only. This is the case because standards offer little or no incentives for behavioural changes once compliance with the standard has been achieved.

However, there are some cases where command-and-control measures are clearly preferable also from an economic point of view: this is the case where pollution would lead to very large or potentially irreversible damages, and where there is large uncertainty about the effectiveness of other instruments. Standards and regulations may also be preferable if the alternative instruments are associated with high monitoring and transaction costs.

INFORMATIONAL MEASURES

Informational measures are relatively inexpensive and uncontroversial, since they neither enforce specific behaviour, nor impose direct costs on the regulated parties. They are used most effectively in *win-win*-situations, where a change in behaviour is both economically beneficial and at the same time reduces environmental pressures. In the case of agriculture, possible win-win situations arise from improved irrigation management, which saves money for the farmer, and at the same time reduces leaching of pollutants. Other win-win situations stem from more targeted fertiliser and pesticide applications. Since the environmental effects of such applications depend on the timing of the applications and on local soil conditions, targeted application of fertilisers and pesticides offers itself as a cost-effective way of reducing groundwater pollution. Therefore, informational measures represent a cheap and uncontroversial way of enhancing awareness and knowledge of different technologies.

2.3.3 Costs of Remediation

Groundwater remediation relates to all instruments for dealing with groundwater contamination. It includes *restoration* measures that reduce or eliminate pollution, and *containment* measures that control pollution by limiting its spread within an aquifer. Groundwater remediation must be approached with a double caveat: first, in many cases it may not be possible to treat or to clean up contaminated groundwater. Secondly, even where it is possible, it is likely to be much more expensive than preventing pollution before it occurs. However, since the choice for a particular restoration or containment option depends on the kind of pollution and on local hydrogeological conditions, general conclusions are difficult.

RESTORATION

Restoration measures are intended to bring a groundwater body back to its unpolluted state. They are *source-oriented*, since they aim to remove the source of contamination from the polluted aquifer or soil. In general, two broad types of restoration technologies can be distinguished: *In situ measures* that treat the contamination within the aquifer. The actual technologies used can be both biological or physical/chemical. By contrast, *ex situ measures* are measures where groundwater is treated above the ground. The most common of these are *pump-and-treat* technologies, where groundwater is pumped to the surface, treated there with biological or physical/chemical technologies, and percolates back through the soil.

In both categories, a range of technologies are available. Whether it is at all possible to restore a contaminated groundwater body, and which kind of technology is appropriate, must be assessed site-specifically. US evidence reports costs for initial investment at an average of US$1.9 million per site, with average annual operating cost of $190,000. Unit costs per

1,000 litres of treated groundwater per year amounted to annual capital costs of US$ 25 per 1,000 litres, as well as US$ 4.75 of average annual operating cost per 1,000 litres.

CONTAINMENT

Containment comprises all measures used to prevent further spread of a contamination plume by isolating, limiting and controlling the source of contamination. Consequently, containment measures are only applicable in cases of point source pollution where the pollution is limited to a relatively small area, e.g. in the case of contaminated sites. The cost and feasibility of such measures depends largely on the hydrogeological situation and the size of the contamination plume.

It should be noted that containment only prevents further spread of contamination, but does not solve the problem at its source. Experiences with the treatment of contaminated sites in the US have shown that cleaning up a site by treating the contamination is usually more cost-effective than containment: although the costs of treatment are higher initially, it is often cheaper in the long run, since containment continues to impose high running costs.

The costs for both restoration and containment options are typically variable and can amount to very large sums. A Belgian report estimates the average cost of remedial activities at € 600,000 per site, whereby 60% of all projects cost less than € 100,000. This means that the average costs for the clean-up of contaminated sites are largely determined by the few most expensive projects: the bulk of the total costs is caused by the top 3,5% of all projects, with an average cost of more than € 12 million each.

2.4 The Benefits of Groundwater Protection

In order to evaluate the benefits of protecting groundwater, it is necessary to consider the economic value of the services it provides. Apart from providing drinking water, clean groundwater provides manifold other services. Only few of these are traded on the market, and consequently there is no market price for most of them. Yet in order to determine the social and economic benefits of groundwater protection, a monetary value is needed to assess the different services it provides, and how they are affected by pollution. This allows to judge whether the costs of groundwater protection are warranted by the benefits.

Because of the variety of services, there is also a variety of mechanisms to assess the value of groundwater. However, one thing is common to all of them: the benefits of groundwater protection can be seen as avoided damage costs. Rather than direct economic gain, the benefits take the form of fewer damages, less risks and anxiety, or less defensive expenditures for groundwater users. Therefore, assessments of the *damage* from *increased* groundwater pollution can be seen as assessments of the *benefits* from *reduced* pollution.

The economic value of a non-marketed environmental resource can be calculated as the sum of different components: an environmental resource has a *use value* and a *non-use value*, and potentially also brings *indirect benefits*. In the case of groundwater, the use value captures the benefits that can be derived if groundwater is put to a specific use, such as irrigation or drinking water provision. However, groundwater can also be valued by someone although there is no actual intention of using it; this part of its value is consequently referred to as non-use value. It includes the value that someone places on groundwater for use by future generations (patrimonial value), as well as the value of groundwater as a resource worthy of protection in its own right (existence value). In addition, it is also necessary to consider the indirect benefits of groundwater, also referred to as *ecosystem benefits*. An important service of groundwater is to sustain surface water flows and groundwater-dependent ecosystems. These surface water bodies and ecosystems themselves have an economic value – a part of which can be attributed to groundwater, since the value of the resources would diminish if groundwater discharges declined or if their quality deteriorated. These indirect effects are not usually included in the total economic value of groundwater, not least since the interaction between different aquatic ecosystems has become better understood in recent years only.

2.4.1 Benefits estimated as Avoided Damage

A direct approach of measuring the economic value of groundwater quality is to consider the costs that users have to bear if groundwater quality deteriorates. The underlying idea is that these cost would not have to be paid if groundwater quality could be restored: therefore, the benefits of groundwater protection take the form of *avoided damage costs*. The main strands of assessing these costs are the averting behaviour approach, which measures individual expenses to avoid polluted water, and the avoided treatment cost approach, which looks at the expenses for water purification by water suppliers. A third approach, which looks at the costs of illnesses from consuming polluted water, has rarely been investigated in practice since health risks from polluted groundwater used as drinking water are normally ruled out by the quality standards and monitoring systems for drinking water.

It should be noted that all three approaches are limited to assessing the value of groundwater used as drinking water. Moreover, the value of groundwater protection is estimated only on the basis of the groundwater that is actually abstracted, and possibly also the water that will be abstracted in the future. However, the fact that a pollution reduction would also benefit the larger part of groundwater which is not used, is not considered.

Different estimates have been produced on the cost of averting behaviour, primarily on the cost of using bottled water as a substitute of tap water. Various case studies from the US and Canada report expenses in the range of 100 to 250 € per household per year.

On the cost of treatment, calculations for the whole of Austria estimate the cost at 205 to 214 million on investments for drinking water treatment, and an additional € 21,6 to 39 million in annual running costs. Of this, by far the largest part was spent on the treatment of nitrate contamination. Similar calculations for France have estimated the investment cost of installations that reduce nitrate concentrations in drinking water at up to 870,000 € per plant. The total cost, combining investment, depreciation and running costs, ranges from € 0.24 to € 0.28 per m^3 for different treatment methods, which equals € 19.20 to € 22 per person per year.

2.4.2 Benefits estimated as Willingness to Pay

A different way of valuing unpolluted groundwater is to let individuals or households state their willingness to pay for a proposed measure that would improve groundwater quality. Such estimates are typically made through *contingent valuation* survey, whereby consumers in an area are asked to state their willingness to pay through mail survey or interviews. In order to receive more realistic answers, it is typically suggested that the interviewee would be obliged to pay the amount he or she offers to give.

A strength of this approach is that it directly addresses public concerns about groundwater pollution. These concerns need not be related to health risks only; depending on the formulation of the question and the proposed measure, it is also possible to estimate the non-use values that consumers place on clean groundwater.

A number of case studies on willingness to pay for groundwater protection have been conducted in the US. The results from the different case studies show a high variance, but usually arrive at significant results in the range between 72 and 1860 US$ per household and year, with about half of estimates ranging from 500 to 750 US$ per year. In the EU, there is much less empirical evidence on the willingness to pay for groundwater protection. The three studies we identified in this context arrived at a mean willingness to pay of 94 to 559 € per household and year. Note that, if these results are extrapolated to all affected households in the area, the potential for welfare increases from groundwater protection is substantial: one US case study argued that the implementation of a protection programme would deliver a social benefit of up to US$ 350 million.

The range of contingent valuation studies confirms that there is indeed a significant willingness to pay for improvements in groundwater quality. Hence, in the municipalities affected, stricter protection measures would enhance social welfare. Yet policy recommendations beyond the studied area are not easily derived from this: the willingness to pay has been calculated on the basis of regional surveys, taking into account highly localised demographic and geological parameters. The findings are therefore applicable only to the region where the survey was conducted - even more so if the region was chosen *because* it was affected by exposure to groundwater contamination above the national average. The transfer of results from previous case studies to other regions must be regarded with much caution. Next to methodological problems, the empirical base is considered as too small and therefore too unreliable to allow for such a benefit transfer.

Still, it can be concluded that willingness to pay is more than statistical “background noise”. There are solid relations for factors that influence willingness to pay, such as income, education, and environmental awareness. People do care about their groundwater, and are willing to pay for it. In particular, there is a substantial willingness to pay for non-use values as well: groundwater protection is a concern even if there is no intention to use it.

2.4.3 Indirect and Ecosystem Values

The concept of ecosystem benefits captures the effects that groundwater has on groundwater-dependent ecosystems. From this perspective, the benefits of groundwater protection consist in the *avoided damage* that polluted groundwater would otherwise cause to groundwater-dependent ecosystems, such as wetlands, lakes and rivers. This means that, in order to assess the ecosystem benefits, a monetary estimate is required of how the economically relevant services of the ecosystem are affected if the quality of the discharged groundwater deteriorates. In other words, the calculation of the ecosystem benefits requires two pieces of information: the value of the ecosystem itself (i.e. the sum of all ecosystem services), and the impact of groundwater contamination on these ecosystem services.

Obviously, both questions are themselves difficult tasks. On the one hand, the valuation of a groundwater-dependent wetland could be done using the same procedures that were described above for the case of groundwater. The interaction between groundwater and surface ecosystems, on the other hand, has attracted the attention of environmental economists only in recent years. Consequently, very little theoretical work has been published on the ecosystem benefits of groundwater protection (see e.g. Abdalla 1994), and even less on empirical evidence.

In the past, much empirical research has been done on the valuation of ecosystems in general. In the context of groundwater, the research on wetlands would appear to be most relevant. Unfortunately, there appears to be no empirical study so far which examines the contribution from groundwater to the value of a wetland in monetary terms, and shows how this value is affected by groundwater contamination. Therefore it is not possible to offer economic estimates of the ecosystem benefits of groundwater protection.

Different empirical estimates have assessed the monetary value of wetlands. They typically consider wetland functions such as flood control, water supply, recreation and amenity, nutrient removal and retention of toxic substances, and maintenance of biodiversity and wildlife. The reported annual value differed strongly between different studies, depending on the methods used and on the ecosystem services included in the analysis. Overall, the estimates range from US$ 1.2 to 39,777 per hectare. The European studies contained in the sample arrived at somewhat lower values, ranging from US$ 34 to 1,300 per ha and year.

2.5 Combining Costs and Benefits

There are different procedures to assess the economic efficiency and the social desirability of different policy alternatives. From an economic perspective, the aim is to bring together the information on the costs and benefits of different measures in a structured way. Not all of the procedures can be used to derive optimal strategies, in some cases their aim is rather to make the available information comparable and present it in a structured way.

The most extensive method for evaluating different policy options is with a ***cost-benefit-analysis*** (CBA). It estimates both the total cost of carrying out a proposed policy and the benefits that the policy brings to different stakeholders in monetary terms. If this information exists for all possible alternatives, it allows choosing the option that maximises net social benefits, and defining the socially optimal level for environmental quality standards or taxes. Unfortunately, it is difficult to arrive at reliable estimates for the benefits of groundwater protection - in opposition to the costs, where there is usually sufficient evidence. Due to these extensive information requirements and the associated costs, a full CBA should only be considered if there is substantial doubt whether the costs of a measure are in line with the expected benefits. In the context of groundwater, it appears that a CBA is therefore unsuitable for assessing policy alternatives on a national scale, but that it should rather be used to assess whether a temporary derogation from a general protection target is justifiable.

The ***cost-effectiveness analysis*** (CEA) abandons the requirement of putting a monetary value on benefits. Instead, it compares the costs of different policy options that all lead to the same, predefined target. In contrast to the CBA, the target itself is thus not determined through the analysis but has to be set ‘exogenously‘, i.e. through a political decision. Hence, if there is consensus that the benefits of a proposed measure will outweigh the costs, or if there is the quality target itself is given beforehand, a cost-effectiveness-analysis will usually be sufficient.

A ***multi-criteria analysis*** (MCA) consists of two steps: in the first step, a range of objectives in different dimensions (environmental, economic and social) are identified, and the trade-offs between these objectives are specified for different policy alternatives. In a second step, the different options are compared by attaching weights to the different objectives. These weights can be purely monetary (in which case the analysis is similar to a CBA), but they can also be based on public participation. A key feature of multi-criteria analyses is therefore that they allow for different outcomes in terms of environmental effectiveness *and* costs.

An alternative mechanism to chose optimal protection levels and the optimal allocation of funds is through **risk-based management**. The underlying idea is that the resources for groundwater protection and remediation should be allocated in such a way that overall risks for human use are minimised, rather than eliminating all pollution everywhere. Essentially, risk depends on two factors: it increases with the *severity* of the impact and with the *probability* that the impact will occur. The severity of the impact, in turn, depends on the value of the affected groundwater resource, and its vulnerability to pollution. Risk-based management, in its broadest sense, relates to policy approaches that use risk minimisation as the main criterion for the decision on a particular policy option. Consequently, risk-based management focuses groundwater protection and remediation efforts primarily on those locations where pollution would have the most severe impact, and on those areas where it is most probable that contamination will occur.

2.5.1 The role of economics in setting target values and defining policies

In principle, a full cost-benefit analysis can guide the selection of the socially optimal policy solution, where the social benefits are maximised. In practice, such a full cost-benefit analysis of groundwater protection is limited by methodological problems as well as by the limited availability of economic data.

One of the main methodological problems is that estimates of the costs and benefits of groundwater protection are always *site-specific*, reflecting the local socio-economic, hydrogeological and biophysical conditions. This means that the comparability, transferability and completeness of findings is not guaranteed. In addition, the estimates of costs and benefits are most reliable for human uses of groundwater. By contrast, the valuation of non-human uses, i.e. ecosystem benefits, so far lacks a satisfying analytical framework.

Concerning data limitations, the available evidence on the costs and benefits of groundwater protection is patchy and not always consistent. Bearing in mind that benefit estimation procedures are necessarily site-specific, and given the limited European evidence particularly on the benefits of groundwater protection, it is difficult to draw quantifiable general conclusions.

Moreover, due to the inherent difficulties, there is a systematic danger that the benefits of groundwater protection are underestimated. An economic assessment of the benefits of groundwater protection is necessarily more complex than assessing its costs. Because of methodological difficulties (e.g. the focus on drinking water uses and the difficulties with assessing ecosystem benefits of groundwater protection), benefits are likely to be underestimated in relation to the costs. However, the fact that the benefits of groundwater protection are more difficult to quantify empirically does not mean that they are less tangible or less material than the costs; the problem is rather that they are harder to value economically.

Notwithstanding these limitations, some general findings can be derived from the various estimates of the value of groundwater. Groundwater protection is clearly perceived as an important issue; in many cases consumers have stated their demand for better protection as well as a significant willingness to pay for it. This clearly points to a demand for more effective protection measures in the studied regions. In particular, there is a widespread perception that groundwater resources should be preserved for future uses. This can be regarded as an indication of support for the principles of non-deterioration and trend reversal, as foreseen in the Water Framework Directive and embodied in the future Groundwater Directive.

Especially in cases of point-source pollution, many pollution problems arise from disposal practices that were considered as efficient and safe at the time, but which now have clearly emerged as insufficient, leading to high costs for the clean-up of contaminated soil and groundwater. In general, the contention is therefore that groundwater protection is almost always cheaper than to incur pollution first and clean up later.

Past episodes of pollution also provide evidence of the evolving knowledge of the mechanisms underlying groundwater contamination, and the growing concern with its protection. By now, many decisions taken in the past would appear to be irresponsible and short-sighted. Given the limited knowledge of the dynamics of groundwater flows and the behaviour of contaminants, and the limited understanding of the interconnections between surface- and groundwater bodies, it is equally possible that decisions taken today may appear uninformed if viewed 40 years from now. Therefore, taking into account the precautionary principle, it is economically appropriate to give preference to protective measures over remediation, and to include a safety margin in setting target values.

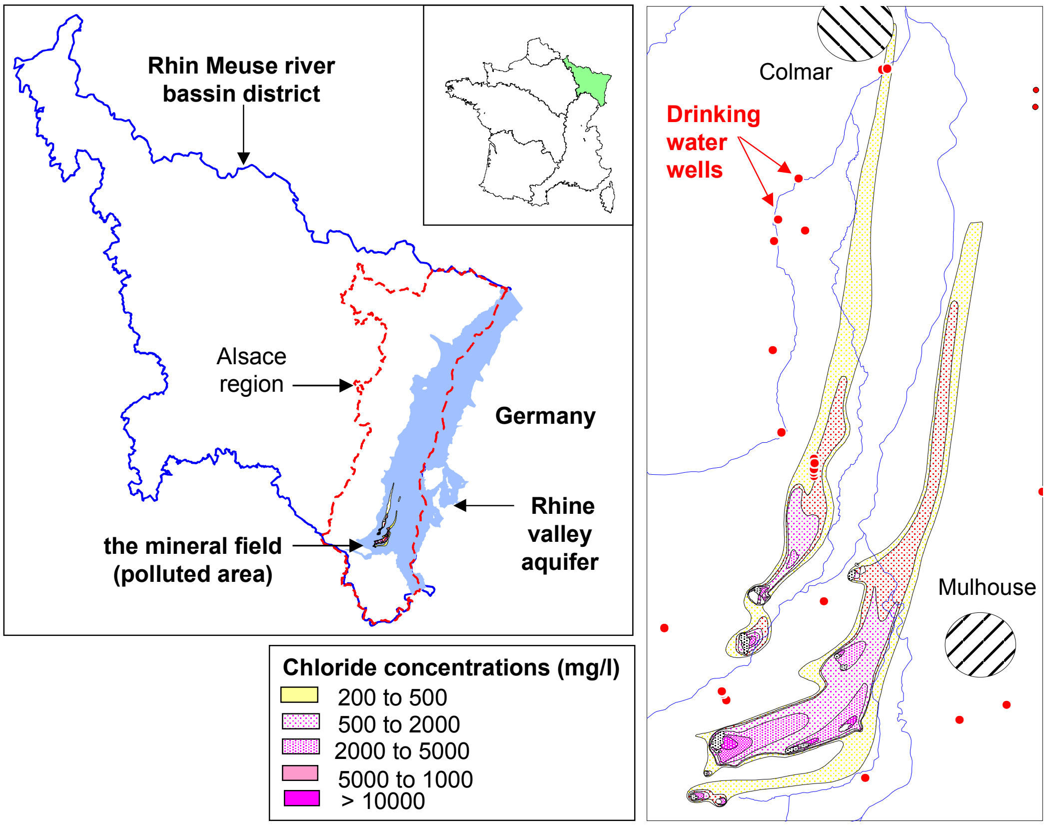
3 Case Studies

3.1 *Case Study on Potash Mining Fields, Alsace*

3.1.1 The field site

The case study presented in this section is located in a highly polluted area of the upper Rhine valley alluvial aquifer. This transboundary aquifer, which extends over 4,200 square kilometres in Germany and France (see map 1 below) has progressively been affected by diffuse and point source pollution. In particular, a large area is contaminated by chloride from the potash mining industry. This area is located in the south-eastern part of the Alsace region, near the industrial city of Mulhouse in France, and extends over approximately 180 square kilometres.

The pollution comes from tailings produced by the potash ore processing plants. These huge waste dumps (15) have been piling up since 1910. It is estimated that approximately 18.5 million tons of salt have been deposited in the waste dumps. For decades, the waste dumps have been leached by rainfall. Water percolates through the tailings and it almost reaches the saturation point, with salt concentrations frequently reaching 200 g/l of chlorides. It then infiltrates the aquifer, which has been progressively contaminated by this point source pollution. As a result, two huge pollution plumes covering an area of 80 square kilometres (with chloride concentrations higher than 200 mg/l) have spread over time following the flow lines in the aquifer (see map below). Today, the chloride concentration in groundwater can be very high, reaching 50 g/l in certain areas close to the waste dumps. It decreases as we move away from the source.



Map 1: Location of the potash mining field of Alsace and extent of the chloride pollution in groundwater (source BRGM).

The two pollution plumes now affect various economic actors, most notably two Drinking Water Utilities (DWUs) whose water wells have been polluted, and approximately 50 farmers using groundwater for irrigation. The farmers suffer from increased corrosion of irrigation equipment (additional production costs) and decreased farm income as they have been forced to stop growing tobacco and shift to lower-value crops such as maize.

3.1.2 Objective and methodology

The objective of this case study was threefold and consisted in (i) describing and assessing the cost of the groundwater protection and restoration measures that have been implemented since the late 1970s in the potash mining field; (ii) investigating the technical efficiency of the measures implemented to date and identifying additional measures that should be implemented to reduce chloride concentrations to less than 250 mg/l by 2015; (iii) assessing the economic costs and benefits that would be generated by these additional measures.

The methodology adopted was the following. In a first step, existing official documents were reviewed to describe groundwater protection and restoration measures that have been implemented in the potash mining field. Interviews were then conducted with the staff of the mining company (MDPA) and officials from the Government agencies in charge of the monitoring of groundwater pollution and those in charge of industrial sites in order to quantify the cost of the measures implemented. The third step involved using a hydrodynamic model to simulate the impact of the current measures and define additional clean-up measures that would have to be taken to restore good chemical status (target concentration value of 250 mg/l of chloride in the entire risk management zone). The costs and benefits of clean-up measures were then assessed and compared.

3.1.3 Cost of groundwater protection and restoration measures

Since the mid-1970's, three types of measures have been implemented to prevent further degradation of the aquifer. Between 1976 and 1985, a number of water wells were drilled immediately downstream of the mining deposits in order to intercept the salt infiltrating the aquifer. The salt and water pumped by these wells was evacuated to the Rhine river though a pipeline. Since 1989, a number of waste dumps having a low salt content (less than 33 %) have been covered by geo-membranes and/or vegetation in order to make them watertight and reduce infiltration. Other waste dumps (containing more than 33 % salt) have been artificially dissolved by intensive leaching with high pressure water guns (accelerated dissolution). As a result, the pollution sources are decreasing and the inflow of salt into the aquifer has been reduced. Since this programme will not be completed before 2010, fresh salt continues to enter the aquifer.

The implementation of these measures have generated two types of costs: *investment costs* (construction of pumping wells, infrastructure to artificially dissolve waste dumps, watertight covering of waste dumps) and *operation and maintenance costs* (energy used by wells, maintenance of the pollution control infrastructure, financing of a team in charge of the pollution control programme). Overall, the total cost is estimated at over *€ 67 million* (2001 constant €) for the period 1976 to 2001, with over € 27 million in investment and close to € 40 million in operation and maintenance costs. Additional measures, which will be implemented between 2002 and 2010, should cost another *€ 44 million*, split into 30 million in investment and 14 million in operation and maintenance costs.

The analysis of the detailed expenditures of the MDPA environmental programme shows that the suppression of pollution sources (accelerated dissolution of waste dumps and waterproof covering) accounted for more than 70 % of the total cost during the 1987–2001 period. This percentage is likely to rise above 85 % in the coming decade.

3.1.4 Technical efficiency of groundwater restoration measures

The overall effectiveness of these measures was assessed using a hydrodynamic model simulating the evolution of the chloride concentration in the upper and lower layers of the aquifer. The simulation results (see maps below) show that if the measures already implemented are maintained ***until 2027***, the chloride concentration will drop below 250 mg/l in the entire polluted area and approximately 96 % of the salt in the aquifer in 2002 will be removed. In other words, the measures implemented are sufficient to restore the good status of water in the whole area, but after the deadline imposed by the WFD (2015).

Using the same hydrodynamic model, a more **intensive clean-up scenario** was defined. As shown on the map below, this scenario (which consist in installing additional wells to pump polluted water and prevent any further extension of the plumes) enables the restoration of chloride concentrations below 250 mg/l in the entire area by the year 2015. It is therefore beneficial for water users, who will have good quality water 12 years earlier than if only the current measures were implemented.

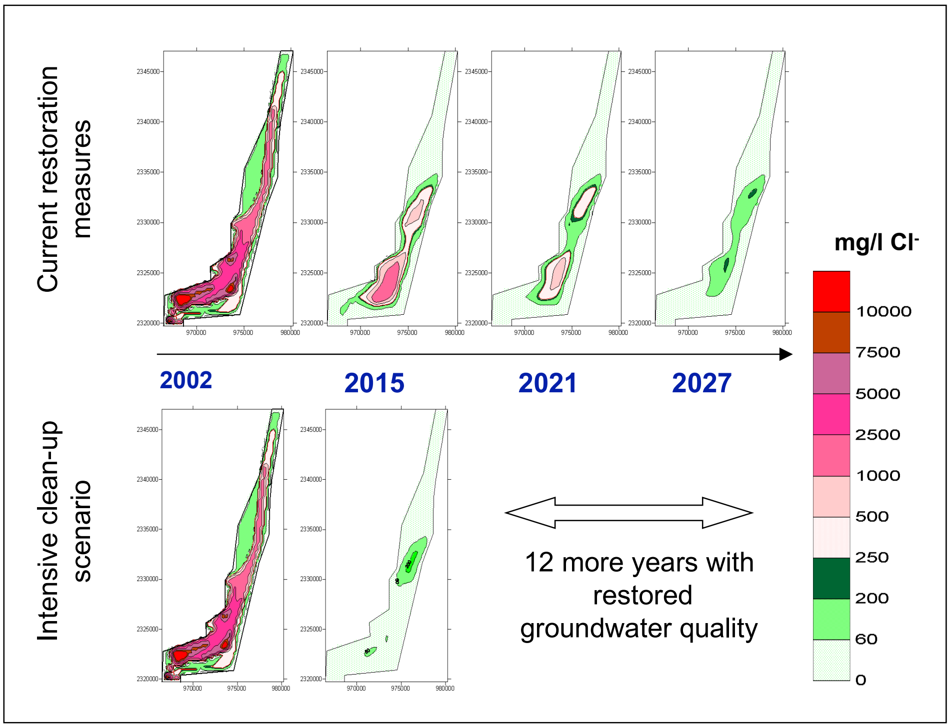


Figure 1: Maps showing the simulated evolution of groundwater chloride concentration with current restoration measures and with a more intensive cleaning-up scenario (case of the upper layer of the Eastern pollution plume).

3.1.5 Costs and benefits of accelerated clean-up

Additional costs

The additional cost of the intensive clean-up scenario has been estimated at over 23 million € for the Eastern plume, taking into account investment costs (construction of new pollution control wells), operation costs (energy, labour) and maintenance costs. The *additional* clean-up cost for the two plumes is roughly estimated at **50 million €**, taking into account that the Western plume contains more salt that the Eastern plume.

Definition of benefits

The benefits of the intensive clean-up scenario are the *additional* welfare accruing to water users as compared to the welfare they would derive from the current scenario. As shown on Figure 2, these advantages increase much more rapidly with the intensive scenario (green line) than with the current scenario (blue line). The additional benefits generated by the intensive restoration scenario are represented on the figure by the area of the triangle OAB.

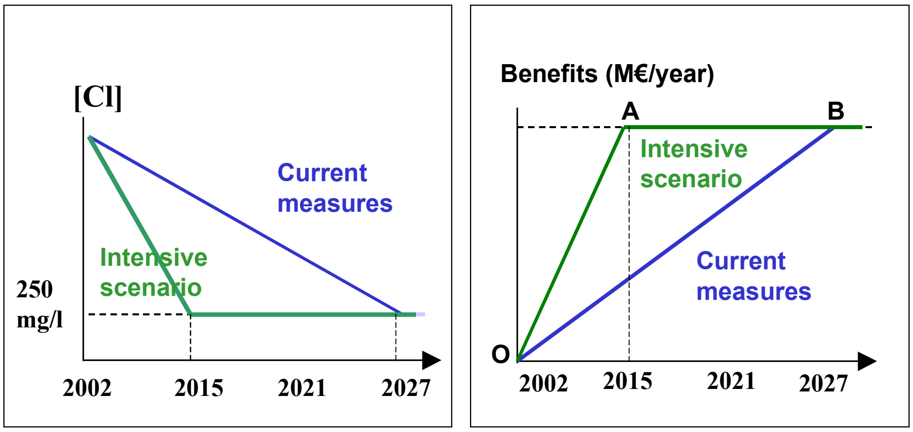


Figure 2 : Evolution over time of chloride concentration and related benefits.

Assessment of the benefits

The additional benefits generated by a rapid restoration of the aquifer have been identified through interviews and quantified in monetary terms (see main report for details on the methodology). The major additional benefits, estimated with a 3 % discount rate (D.R.), are the following:

- a reduction of drinking water production costs for the DWUs concerned over a 12-year period (10.7 million €) and a reduction of the amount of bottled water purchased by households whose trust in tap water is restored 12 years earlier than with the “current scenario“ (1.4 million €);
- a reduction of the cost of corrosion of irrigation equipment over a 12-year period (0.4 million €) and an increase in farm income due to the fact that tobacco can be grown during an additional 12-year period (1.4 million €);
- an increase in the welfare of citizens who derive satisfaction from the rapid restoration of the aquifer, which they perceive of as being part of their common heritage. This benefit is assessed in monetary terms using the results of a contingent valuation study of citizens' willingness to pay for groundwater protection in Alsace (3.8 million €).

Type of benefit	Estimate with D.R. 3 % (M€)	Estimate with D.R. 0 % (M€)
Drinking water sector		
Savings on production of drinking water	10.7	10.9
Reduced bottled water purchase by households	1.4	2.4
Farming sector		
Increased useful life of irrigation equipment	0.4	0.66
Increased income (tobacco)	1.4	2.44
Citizens (Protection of natural heritage: non use value)	3.8	6.6
Industrial sector (Avoided treatment costs)	not estimated	not estimated
Local territorial bodies	not estimated	not estimated
Increased development potential (& related fiscal income)		
Environmental benefits (rivers & wetlands, forests)	not estimated	not estimated
Total benefits	**> 16.5**	**> 21.1**

Table 1: Additional benefits generated by the intensive clean-up scenario.

Overall, the total monetary value of additional benefits ranges from 16 to 21 million € depending on the discount rate that is used. This estimate is, however, only partial as other benefits have not been assessed in monetary terms. In particular, the fact that groundwater quality is restored might reduce the production costs of some industries. It might also increase the attractiveness of the area and thereby accelerate its economic development. Consequently the estimate of 16 to 21 million € should be perceived and used as a *lower boundary value*.

Finally, these benefits can be compared to the estimated cost of the intensive clean-up scenario (50 million €). Knowing that the estimate of the benefit presented above is a lower boundary value, the decision whether the benefits of implementing this scenario justify the costs is not trivial. The decision remains a political act that must be informed and backed up not only by the economic analysis but also by technical, social and environmental information.

Implications for the GWD

This case study illustrates that benefits generated by intensive groundwater quality restoration in zones affected by point source pollution may be significant, although they depend on the type and economic significance of water uses in the polluted area. This suggests that an economic analysis of groundwater clean-up scenarios should systematically be done before deciding whether or not it is socially desirable to restore groundwater quality in such areas. In other words, derogation should not be systematically allowed but justified on a case to case basis.

3.1.6 The benefits of early action

The case study also clearly shows that belated action to protect and restore the aquifer generated significant costs that could have been avoided with early action to prevent the extension of the pollution plumes. These additional costs include clean-up costs and economic damages for water users.

<u>Clean-up costs</u>: As shown in section 3.1.3 above, more than 70 % of the cost of the measures implemented since the 1970s are related to the elimination of pollution sources (waste dumps) and the containment of the pollution around the sources. Early implementation of these measures would not have changed that cost but would have saved between 5 and 15 million € in pumping costs.

<u>Avoided damages</u>: A preventive approach could have avoided the losses incurred by the DWUs (increased costs for producing drinking water), households (bottled water purchase) and the farming sector (corrosion of irrigation equipment, loss of income). Using the same data and assumptions as in the previous section (see main report), the total damages that could have been avoided are estimated at 30 million €.

Economic sector affected	Description of impact of pollution	Past cost in M€ (until 2002)
Drinking water supply	Investment (new well, connection of DWUs) Increased water production cost Household expenditures on bottled water	**11.93** **3.185** **2.6**
Agriculture/irrigation	Corrosion of irrigation equipment. Loss of income (and employment)	**1.7** **3.8**
Industrial sector	Polluted wells abandoned Construction of treatment plants	Not assessed
All citizens	Cumulative loss of non-use value due to groundwater pollution in the potash mining field.	**6.6**
Total cost		**~ 30**

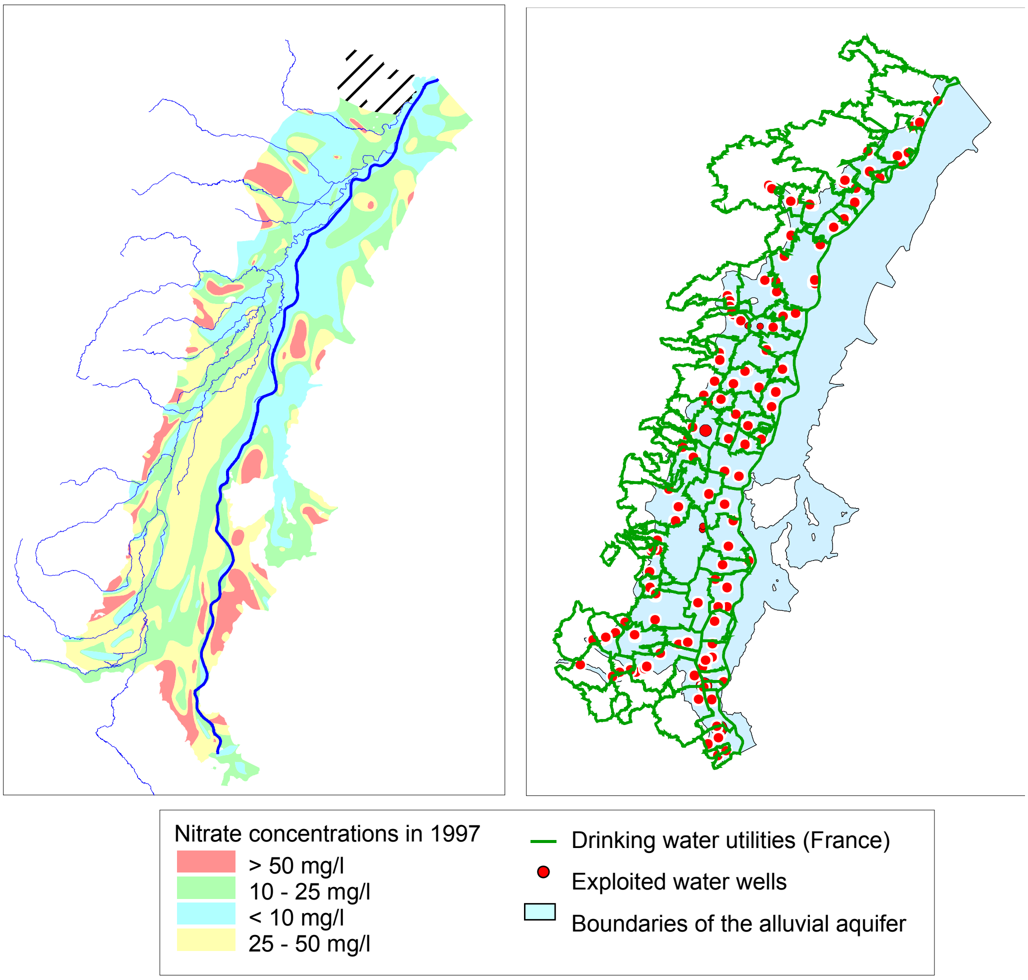
Table 2 : Economic damages generated by chloride pollution until 2002

This example shows that monitoring should be reinforced in zones affected by point-source pollution to reduce the risk of undetected pollution leakage. The additional cost would be counter-balanced by benefits, especially if drinking water users are located downstream from the pollution sources.

3.2 Case Study on Nitrate and Pesticide Pollution, Alsace

3.2.1 The field site and objective of the case study

The development of intensive agriculture in the alluvial plain of the Alsace region, France, has resulted in increasing nitrate concentrations in the upper Rhine valley alluvial aquifer (see previous section). While the nitrate concentrations were lower than 44 mg/l in the entire aquifer in the early 1970s[2], values now exceed 50 mg/l in many areas, as shown on the map below. This quality problem has generated significant costs for economic sectors using groundwater. The objective of this case study was to estimate these costs, focussing on the pollution by nitrates and pesticides.



Map 2 : Nitrate concentrations in the upper Rhine valley alluvial aquifer in 1997 (source: Région Alsace, France) and location of DWUs and drinking water wells.

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[2] The maximum acceptable value for drinking water in the 1970s in France was 44 m/l, according to the French Drinking Water Standard..

3.2.2 Methodology

The following methodology, consisting of four major steps, was developed and implemented.

- Firstly, we consulted the archives of three major public institutions that partly finance the development of the drinking water sector. This work, conducted with the financial support of **Région Alsace**, enabled us to identify a number of public water utilities that have been affected by non-point source pollution by nitrate and pesticide in the recent past (last 15 years). The result of this census was then cross-checked with a review of the press coverage by the major local newspaper.
- Secondly, we conducted a series of interviews with staff from 22 public water utilities affected by nitrate and/or pesticide pollution. The interviews addressed the customers' sensitivity to nitrate and pesticide pollution, the pollution problems faced in the past and the solutions adopted, the avoidance strategies adopted by water users as a reaction to nitrate and pesticide pollution, and their "vision" of future groundwater quality.
- The third step consisted in assessing costs other than those born by public water utilities. Several food and beverage industries were interviewed and one was chosen for an in-depth case study to assess the cost generated by nitrate pollution for that specific industry. The costs born by households who increasingly purchase bottled water (or install filtering devices) were also assessed and compared to those born by the public water utilities.
- The fourth and last step consisted in developing a scenario. Assuming that the nitrate and pesticides concentration in groundwater would continue to rise (due to the inertia of groundwater systems), we estimated the possible future cost of pollution for the drinking water sector.

3.2.3 The cost of groundwater pollution during the last 15 years

Extent of the problem for drinking water utilities

The interviews conducted as part of this case study identified 28 drinking water utilities severely affected by nitrate and pesticide pollution during the last 15 years. By DWU severely affected by pollution, we mean those who have been compelled to undertake investments to cope with rising nitrate and/or pesticide concentrations. Only 89 DWU exploit the alluvial aquifer of Alsace, which means that more than 30 % of the DWU are concerned. As shown in the following table, these 28 DWU supply water to 177 municipalities representing a total population of 432,000 inhabitants. Nitrates are the major cause of economic costs for DWUs, with 16 DWUs severely affected (over the 15 years period) whereas only 7 have been concerned by pesticide pollution, and 5 by both nitrates and pesticides.

		Nitrates	Pesticides	Nitrates + pesticides	Total
Alsace	DWUs	16	7	5	28
	Municipalities	75	80	22	177
	Inhabitants	141,00	82,300	208,700	432,000

Table 3: Number of DWUs severely affected by nitrate and/or pesticide pollution over the last 15 years and population concerned.

Solutions adopted by the DWUs

The following table summarises the solutions that have been adopted by the DWUs in response to nitrate and pesticide pollution. Among the strategies observed, drilling a new well to replace a polluted one is the most frequently adopted solution (11 cases). Measures to change farming practices in the well catchment area have also been widely adopted, although not all led to positive results. 7 others DWUs have chosen to import water from neighbouring DWUs, which has imposed to construct a physical connection between the two distribution networks. Only one DWU has installed a nitrate removal treatment unit in response to the pollution. The interviews also revealed that several DWUs affected by pesticide pollution were planning to invest in filtering devises (active coal filters), which are less expensive and easier to operate and maintain.

Solutions adopted	Total
New water wells	11
Changes of farming practices	11
Interconnection to another DWU	7
Renovating springs	2
Treatment	1

Table 4: Solutions adopted by DWUs in response to the pollution by nitrates and/or pesticides.

Investments made in the water sector to cope with nitrate and pesticide pollution

Nitrate and pesticide pollution has generated expenditures of € **26.4 million** (constant 2001 Euros) for DWUs using the alluvial aquifer of the upper Rhine valley in France. More than three quarters (77%) of these expenditures are due to nitrates, 16% are linked to the presence of both nitrate and pesticides whereas 7% are due to pesticide only.

	Nitrates	Pesticides	Nitrates & pesticides	Total
Total cost in constant € (millions)	20.2	1.9	4.34	26.4
% of total	77%	7%	16%	100 %

Table 5: Total investment generated by non-point source pollution per type of pollution (period 1988-2002). Source: Région Alsace

The drilling of new water wells and the interconnection of network represents, respectively, 54 % and 25 % of this amount. The cost of other measures represents only 16 % of the total cost, and studies 5 % [3].

Cost for the industry

Estimating the cost of pollution for the industrial sector is very difficult because it requires access to private accounting data. This case study is, therefore, only an illustration of the type of costs born by the industry.

The case study focuses on a very large brewery, established in the region more than a century ago, that produces approximately 40 % of the volume traded on the French market. The brewery uses 3.5 million m^3 of groundwater a year. Since the end of the 1980's, the nitrate content of the water exceeds 35 mg/l, which is the maximum concentration acceptable for the production of beer. The brewery had to install a first nitrate removal plant in 1991 (ion exchange resin system) and a second one in 2002 (reverse osmosis). Since the well water is still complying with the drinking water standards (less that 50 mg/l of nitrate) it continues to be used for washing, cooling and other uses. Only 1.5 million cubic meters are treated every year. The construction of these 2 treatment unit required an investment of € 7.19 million (constant 2001 €). The operation and maintenance of these units since 1991 has generated an additional cost estimated at € 2.3 million €. Another € 0.5 million has been spent on searching for alternative groundwater resources. Nitrate pollution, therefore, has already cost this firm alone more than € 10 million in monetary damages. This could increase very soon

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[3] We here consider all the studies conducted by consultants for DWUs to identify the origin of nitrates affecting water wells, etc.

since it is expected that a new water well will be drilled in the coming years at a cost of several million €.

Sensitivity thresholds

Another important finding that emerged from the interviews was the identification of *sensitivity thresholds*, defined as *pollutant concentration values above which water users are forced to implement a strategy to mitigate the effect of the pollution*.

In the drinking water sector, two thresholds values were identified (through the 22 interviews): 25 and 40 mg/l. When the first threshold (25 m/l) is exceeded, DWUs start to pay attention to and carefully monitor the evolution of nitrates in the groundwater they pump. The second value represents a threshold beyond which the decision is generally taken to drill a new water well or hook up to a neighbouring DWU. From an economic point of view, this means that **the damage occurs before 50 mg/l are reached**. The attitude towards pesticides is slightly different because the government agency that monitors drinking water quality allows DWUs to distribute water even if its concentration in pesticides exceeds 0.1 µg/l (water is considered as safe up to 0.4 µg/l).

In the industrial sector, these threshold values vary significantly from one activity to another. For example, breweries need water containing less that 20 to 25 mg/l of nitrate to produce beer under optimal conditions because the other ingredients used to produce beer (namely malt and hops) are also a source of nitrate. Beer made with water containing 20 mg/l of nitrate will, therefore, contain around 30 mg/l of nitrate at the end of the process. Also, the biological activity of brewers‘ yeast is optimal for nitrate concentrations ranging between 10 and 25 mg/l. Above this threshold, brewers need to treat water. The sensitivity of the food and beverage industry to the presence of pesticides is even greater. Indeed, most companies have to prove to their customers (supermarkets and other integrated distribution companies) that there is **no trace** of pesticides in the final product and sometimes even in the water used as an ingredient.

3.2.4 Looking towards the future

The results presented above show that the current strategy adopted by DWUs to deal with nitrate and pesticide pollution consist in finding alternative groundwater resources when the water wells they exploit are contaminated. Water wells are abandoned and others drilled elsewhere in the same aquifer.

However, clear signs show that this strategy is not sustainable. Firstly, some DWUs have already encountered severe difficulties in finding alternative water resources and have been forced to buy water from another DWUs. Secondly, interviews of DWU employees and key policy makers and planners have shown that the siting of new wells is increasingly difficult because of:

(i) the extent of areas affected by nonpoint source pollution (nitrate, pesticides) and point source pollution (solvents, hydrocarbons, chloride from the potash mining field)

(ii) the extension of built-up areas, which are source of potential accidental pollution (roads, industrial areas, etc);

(iii) the presence of numerous domestic landfill sites, downstream of which wells cannot be sited.

In the future (2020), assuming that the economic development of the region (and the consequent increasing use of space) will continue at the same rate, it will soon be impossible to find suitable sites for new water wells. Consequently, if areas polluted by nitrate and pesticides continue to expand, the only option left to DWUs affected by nonpoint source pollution will be to treat groundwater in order to remove nitrate and/or pesticides.

To estimate the cost of this scenario, we made the following assumptions:

(i) In 2020, nitrate concentration will exceed 50 mg/l in all areas where the concentration of this pollutant currently exceeds 25 m/l. This assumption is justified by the fact that there is a long time lag between the emission of the pollutant and the effective contamination of groundwater (i.e., the pollution level of the aquifer in 2020 will reflect today's farming practices). We also assume that pesticides will be found in most places.

(iv) Technological innovation in the field of water treatment and the adoption of these technologies by a large number of DWUs will lead to a reduction of the treatment cost to 0.15 €/m^3 of distributed water (capital, operating and maintenance costs).

We identified 37 DWUs that will potentially be affected by nitrate and pesticide pollution in 2020. Assuming that the total volume pumped by these DWUs remains constant over time, we estimate that the total volume that might have to be treated in 2020 is **39 million m^3** per year, generating an additional cost of **€ 5.9 million per year**

3.3 Case Study on Diffuse Agricultural Pollution, Drastrup (Denmark)

The field site under study consisted of a small sandy aquifer in the North Jutland Region of Denmark (Map 3). This aquifer is affected by diffuse pollution from agricultural: pesticides and nitrate. Its recharge area is approximately 1000 ha and the annual potential withdrawal is 2.8 million m^3. Only 2.2 million m^3 are currently withdrawn and contribute one third of Aalborg's drinking water needs.

To reverse the pollution trend, a project named Drastrup, initiated by the local Government and supported by the LIFE European Commission programme began in 1997. The initial land use in the recharge area was 900 ha of conventional agriculture and 100 ha of residential occupation near the village of Frejlev. The aim of the project was to shift from agricultural land use to other land uses that would preserve groundwater quality. This was achieved through the afforestation of 500 ha and permanent grazing on the remaining 400 ha.

The main objectives of the project were to ensure that groundwater quality would comply with European drinking water standards and avoid the need to implement the costly treatment measures that would have been necessary if the groundwater protection measures had not been taken. A cost benefit analysis of groundwater protection measures was undertaken as part of this project. Most of the data used in the report come from that study.

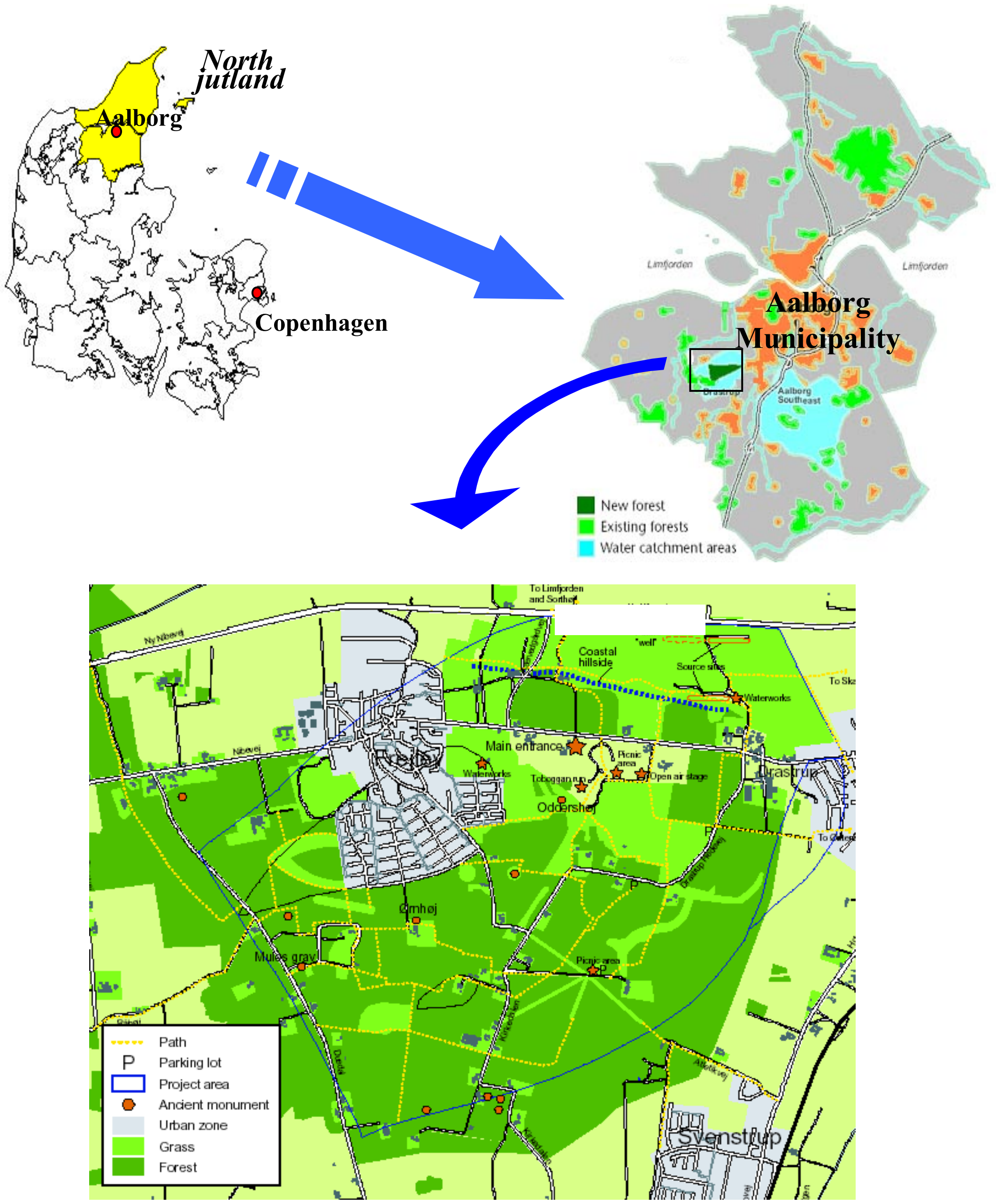
3.3.1 Methodological Objectives

The objective of this case study is not to refine the existing cost-benefit analysis but to show to what extent the results of the cost-benefit analysis are determined by the hydrogeological characteristics of the aquifer and by the economic characteristics of the region that surrounds it. We also show that the results depend to a great extent on the value chosen for the discount rate.

The methodology implemented is the following:

- Firstly, we developed a simple integrated model of the aquifer that simulates the evolution of nitrate concentration in the aquifer (over a 50-year period), for various land use scenarios. The model also estimates costs and benefits for each given nitrate concentration evolution (using the findings of the economic assessment conducted as part of the LIFE project mentioned above). To estimate costs and benefits, 1997 was used as the reference year and all costs and benefits are expressed in € from the year 2000.
- The model was then used to study the consequences on social welfare of delaying the implementation of restoration measures. We tried to answer the following question: Do the prospective benefits of achieving good groundwater status in 2015 justify the anticipated cost of the restoration programme?

- Thirdly, the model was used to simulate the sensitivity of the costs and benefits to changes in (i) the hydrogeological characteristics of the aquifer such as the pollutant travel time ; (ii) the economic characteristics of the surrounding region ; (iii) the discount rate value chosen to assess future costs (in current monetary units) and benefits, and (iv) a combination of all of these elements.



Map 3: Drastrup area location

3.3.2 The Drastrup project cost-benefit analysis

A cost-benefit analysis consists in comparing the forecasted costs and benefits of a groundwater remediation scenario with the anticipated costs and benefits of a business-as-usual scenario. In the present case, the business-as-usual scenario represents the continuation of the intensive agriculture that prevailed before 1997, whereas the remediation scenario is the afforestation programme.

Nature of costs and benefits

The first step of the cost-benefit analysis consists in identifying the types of costs and benefits accruing to various agents and economic sectors for the two scenarios. The four main sectors affected by the Drastrup project are: (i) agriculture, (ii) water supply, (iii) the environment and (iv) households benefiting from the amenities and recreation possibilities offered by the new forest.

The main cost of the groundwater remediation programme is the loss of income for the agricultural sector, the land being shifted from intensive production to permanent grazing. The loss is estimated at 290 € per hectare.

The benefits of the programme are the following:

- Reduction of treatment costs for the drinking water sector: Depending on the evolution of the nitrate concentration in the aquifer, the drinking water suppliers will have to invest in water treatment as soon as the nitrate content exceeds 50 mg/l. In that case, the treatment cost per cubic meter is estimated at 0.2 €, or a total annual cost of 440,000 €.
- Reduction of CO_2 emissions due to the development of the forest: The value of the related environmental benefits is assessed using the value of the Danish CO_2 tax per ton of CO_2 multiplied by the total quantity of CO_2 absorbed by the new forest. Assuming an absorption capacity of 8 tons per year and per hectare and a price of 13.5 €/ton CO_2, it leads to an environmental benefit of 54,000 €/year for the Drastrup Project.
- Creation of amenities: Another indirect benefit of the project is that the forest would create new recreation opportunities for the inhabitants of a densely populated and urbanised area. Since the new forest is located near a residential area, the economic value of the amenities created by the project has increased property values. This increase was used to estimate the economic value of the amenity (hedonic price method), which is estimated at 375,000 € per year.

Valuation of the costs and benefits of the Drastrup project

The model was first used to simulate the impact of the Drastrup project on nitrate concentration in the aquifer. The results show that, due to the length of time it takes for water to percolate through the unsaturated zone, the nitrate concentration might increase for 20 years and exceed 50 mg/l before starting to decrease. During the first 20 years, the nitrate concentration will continue to rise even if the surface nitrogen leaching is totally eliminated. Investment in a treatment plant would still be necessary some 17 years after the implementation of the remedial measures (figure 3).

The integrated model also shows that the Drastrup project creates a positive net social benefit as soon as it is implemented. Afforestation is preferable to conventional agriculture from a social point of view because of the high amenity benefits it produces. Therefore, the afforestation of the Drastrup catchment area to restore groundwater quality is a programme that does not need any incentives or statutory constraints to be adopted. The net benefit enables the local government to compensate different interest groups without imposing a financial loss on any of them.

3.3.3 Impact of delayed implementation on costs and benefits

We then simulated the impact of a delayed implementation of the remedial measures. The results show that such a delay would require maintaining drinking water treatment over a longer period and would also delay the date at which drinking water standard are met (figure 3). As a result, any delay would reduce net social benefits. Figure 4 illustrates this relationship–a 5-year delay would reduce the benefits by 27 % and a 10-year delay would cut them in half.

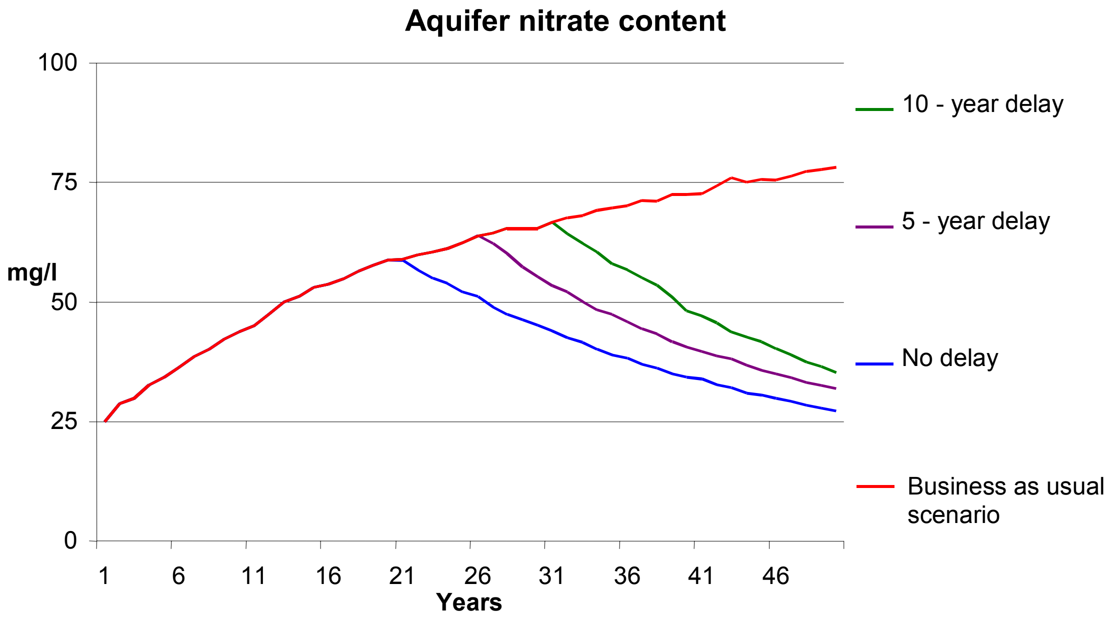


Figure 3: Simulation of the evolution of the nitrate concentration in abstracted groundwater.

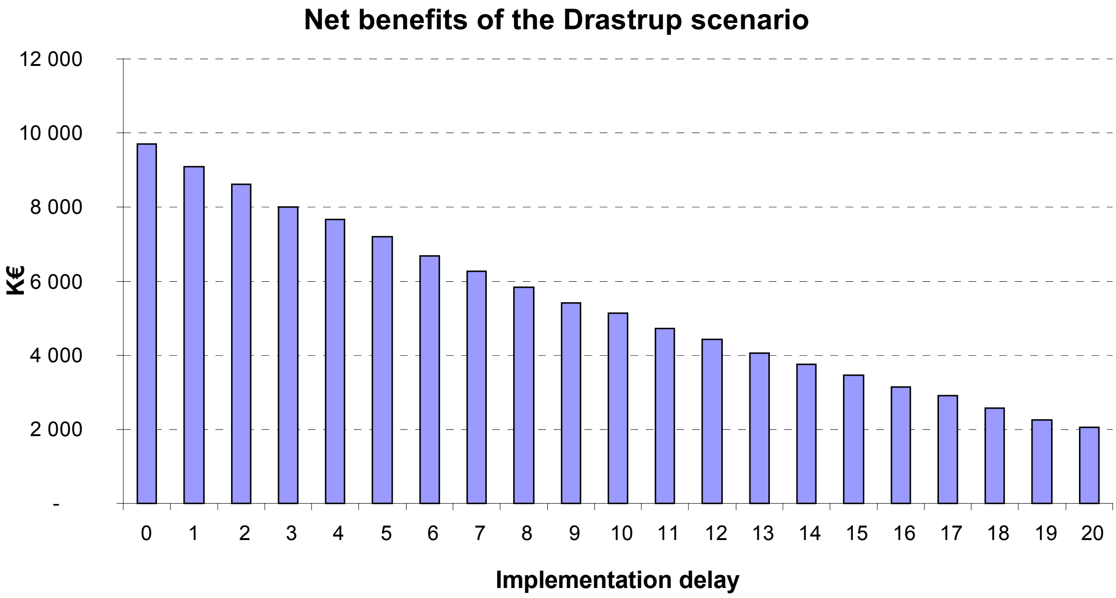


Figure 4 : Evolution of the net social benefit of the afforestation programme as a function of the implementation delay.

3.3.4 Sensitivity to economic parameters

The results of the cost-benefit analysis is highly dependent on two economic parameters: the discount rate and the significance of recreational benefits created by the forest.

Sensitivity analysis of the discount rate

The results of the cost-benefit analysis depend partly on the discount rate used (a high discount rate reduces the current value of future costs and benefits). The analysis of a given case study can therefore produce different results depending on the discount rate recommended by the national authorities. In Denmark, the United States and Norway, the recommended discount rates vary from 2 or 3 % to 7 or 8 %. In Great Britain, a unique 6 % rate is recommended.

To illustrate this, we repeated the cost-benefit analysis done above (with a rate of 3 %) with a 6 % discount rate. Assuming all other factors remain unchanged (i.e., no implementation delay), changing the discount rate from 3 to 6% results in a 65 % reduction of the net social benefit.

Sensitivity to the recreational benefits

The high recreational benefits of the Drastrup afforestation programme are largely due to the presence of a residential area near the new forest. As shown by a Danish study, the recreational value of the forest would be significantly lower if the residential area were not so nearby.[4] If the surroundings of the aquifer catchment area were sparsely populated, the project would become socially costly. Moreover, if we consider there are no recreational benefits at all, the net social benefit would become negative (estimated at -2.8 million € for an immediate implementation).

3.3.5 Sensitivity to the pollutant travel time between the surface and the aquifer

Results are also very dependent on the travel time of pollutants between the surface and the aquifer. In the Drastrup area, this duration was estimated to be 20 years[5]. If the travel time is divided by two (10 years), the net social benefit of the project would increase by 44 %. This is due mainly to the fact that the period during which drinking water has to be treated would be shortened.

3.3.6 Sensitivity to combined variation

The model was also used to study the *combined effect* of changes of all of the above parameters: (i) delay in implementation of the programme (from 0 to 20 years); (ii) presence of recreational benefits (with or without) and (iii) pollutant travel time (10 or 20 years).

A first simulation was done to assess the combined impact of changes in pollutant travel times and delayed implementation. Table 6 shows that the shorter the pollutant travel time, the less subject the net benefits of the afforestation programme are to a delayed implementation. In such a case, where the net benefits variation is small, decision-makers might wish to delay the implementation of an afforestation programme if they anticipate a possible increase in agricultural revenues or when suppliers anticipate a reduction of treatment costs through technological progress.

Pollutant travelling time	Implementation delay	
	5 years	10 years
10 years	- 5 %	- 16 %
20 years	- 27 %	- 48 %

Table 6 : Net benefit variation of the remedial programme induced by a 5- and 10-year delay and for two pollutant travel time.

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[4] This study, using the hedonic price method (HPM), showed that the value of the recreational benefit generated by the forest would decrease by 5 to 10 % for each extra kilometre between the houses and the forest.

[5] This assumption does not take into consideration the fact that nitrate transfer in the unsaturated zone is a very complex phenomenon. At a given place, nitrates might migrate at various speeds (existence of preferential migration paths). Therefore, this assumption (as well as the results of the simulations) should be seen simply as a necessary step in the economic analysis and not as a deterministic representation of the natural processes.

A second simulation was done to assess the impact of changes of three parameters. Figure 5 below illustrates the evolution of the net social benefit of the Drastrup project for a pollutant travel time of 10 years, with and without recreational benefits. The absence of recreational benefits divides the potential net social benefit by 10. In the absence of recreational benefits, therefore, it is socially desirable to delay the implementation of the remedial programme because the net social benefit increases with time, with an optimum date after 8 years. In this case, the economic rationality would suggest that the implementation of the programme be delayed.

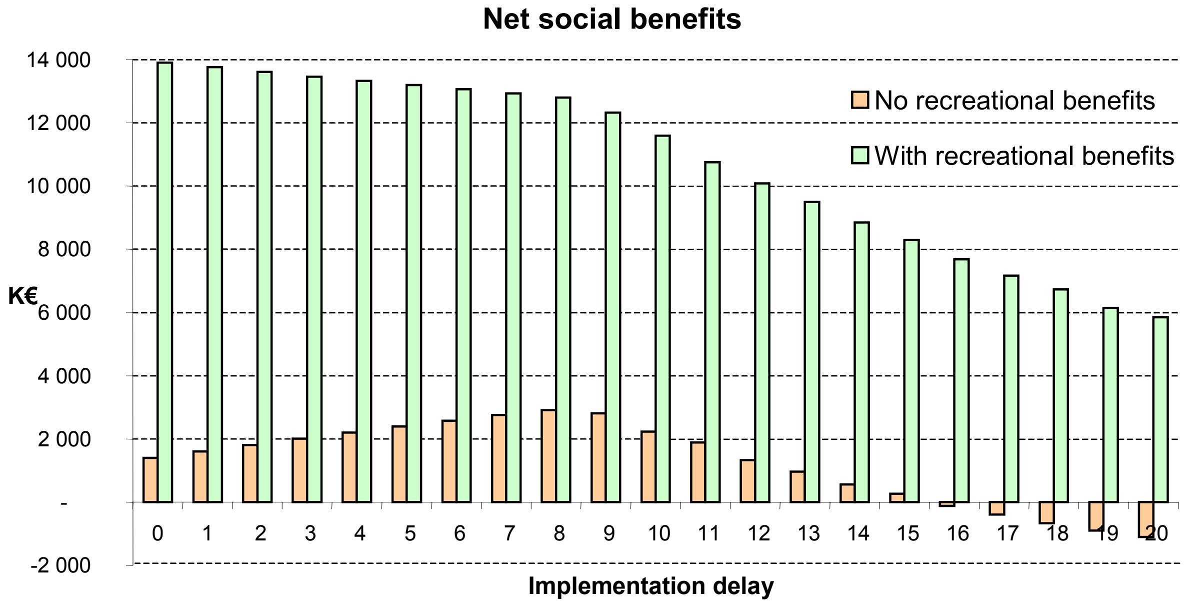

Figure 5: Impact of implementation delay on the net social benefit of the forestation programme for 2 recreational benefit scenarios (with recreational benefits and without) and assuming a 10-year pollutant travel time.

3.3.7 Conclusions and implications

The Drastrup afforestation programme case study shows that, in some aquifers, nitrate concentration can continue to increase in spite of intensive measures taken to reduce or even eliminate pollution sources. Therefore, due to natural constraints, the trend reversal clause of the Groundwater Directive might be difficult to apply.

Secondly, the case study shows that costs and benefits of groundwater protection measures are highly dependent on local economic and physical conditions. Therefore, it seems very difficult to draw general conclusions on the net economic benefits that can be generated by different levels of groundwater protection.

Thirdly, it proves that the use of a different discount rate can lead to completely different results. If economic valuation is to be used by Member States as a decision support tool, a common discount rate must be used so that economic analyses can be compared.

4 Lessons learned and implications for the Groundwater Directive

4.1 A limited number of existing studies

The analysis of exiting studies revealed that, in Europe, there is little experience with the application of economic approaches and tools to support policy making in the field of water protection. Even in pioneering countries such as the UK, where economic assessment of costs and benefits is mandatory for all environmental policy proposals, the experience with respect to groundwater protection is still limited. Most of the studies that have been identified were conducted by academic research teams, which tend to focus on methodological aspects only, and in particular on the development of methods to assess non-marketable environmental goods (contingent valuation, hedonic price methods, etc.).

As a result, the results from existing studies are too limited to provide the main basis for supporting the choice of criteria (and related threshold values) to be used to assess the status of groundwater bodies:

- Empirical data concerning the costs and benefits of groundwater protection is still fragmentary and incomplete. Most studies focus either on the assessment of the costs or on the benefits of groundwater protection, and very few have developed a comprehensive framework to compare costs with benefits for different water protection scenarios. Therefore, a thorough Europe-wide assessment of the costs and benefits of groundwater protection remains a remote target.
- Research tends to remain very compartmentalised in terms of disciplines. Economic studies may present very sophisticated economic approaches (and models), but they rely on very simple representations of aquifers, and frequently ignore important processes. There is a definite need for *integrated research* on the economics of groundwater protection –empirical and theoretical work has focused mainly on particular aspects or instruments of groundwater protection. Concerning cost estimates, more research is needed on the efficiency of different sets of remedial measures and their integration with local hydrogeological conditions. To assess benefits, better integration with ecosystem approaches would be desirable.
- The availability of data on the benefits of groundwater protection is more unsatisfactory than concerning the costs. Benefit assessments have focussed primarily on the valuation of groundwater as a source of drinking water. More indirect benefit estimates, such as the effects of groundwater pollution on dependent ecosystems and surface water bodies, are still scarce.

4.2 Limitations of economics as a decision support tool

While economics can, admittedly, provide relevant insights in the question of groundwater protection, the results of this study reveal several limitations of economics as a decision support tool:

- The results of both the literature review and the three case studies clearly show that economic study results are site specific. Little research has been carried out to determine under what conditions the results from site specific studies can be transferred to other contexts (meta-analyses) and most scientists are reluctant to extrapolate results. Indeed, the costs and benefits of groundwater protection are very dependent on the socio-economic and hydrogeological characteristics of the study area, and by the current and future uses of an aquifer. Therefore, specific statements on the economically efficient level of groundwater protection should be assessed primarily on a site-by-site basis.
- As demonstrated by the third case study, the results of a cost-benefit analysis are very sensitive to the discount rate used. Two economic valuation studies assessing costs and

benefits of the same set of protection measures, applied to the same aquifer but using different discount rates could, therefore, lead to different recommendations to policy makers. This weakness of economics as a decision support tool is all the greater because each Member State recommends different guideline values for the discount rate (in Denmark, the United State and Norway, the recommended discount rate varies from 2 or 3 % to 7 or 8 % according to Ministries or departments, while in Great Britain, a unique 6 % rate is recommended). The problems associated with the choice of a discount rate are increased by the fact that some of the benefits and/or costs are spread over a long period of time. In many remedial cases, for instance, the fact that costs for aquifer protection and clean-up accrue immediately (investment) whereas benefits accrue in the future biases the results of the analysis against restoration.

- Cost-benefit analysis often leads to an under-estimation of the benefits, in particular because of how difficult it is to estimate (in monetary terms) non-use values of groundwater. As shown by the literature review, this is especially the case for the ecological benefits of groundwater protection (e.g., for groundwater-dependent wetlands), which can be significant where groundwater bodies have extensive interconnections to dependent ecosystems. However, estimates of the contribution of groundwater to these ecosystems are rare.
- The results of the three case studies show that the outcome of economic valuations are highly dependent on the assessment of non-use benefits, which represent a significant percentage of the total benefits. Given the uncertainty attached to non-marketable environmental benefits and the controversies on the methods used (in particular, contingent valuation), a precautionary approach should be adopted and the uncertainties associated with economic assessments of groundwater protection studies must be thoroughly understood when economic valuations are used for decision making.
- Last but not least, the study showed that costs and benefits are very dependent on groundwater dynamics , on the fate, spread and travel time of pollutants, and on the interaction between ground- and surface water bodies. Here, the reliability of economic analysis is weakened by the uncertainty associated with our knowledge of physical and chemical processes that determine pollutant migration in the unsaturated zone

These limitations imply that a precautionary approach be adopted when using the results of existing economic evaluations of groundwater protection. More specifically:

- Whereas cost-benefit analysis seems to be a useful tool to inform decisions made at the water body level (when designing River Basin Management Plans, for example), it can provide only rough insights to define “groundwater quality standards” at the European scale in the absence of background information on specific groundwater bodies. Site-specific use of economic assessments should therefore be considered as a useful tool to support the selection of cost-effective sets of remedial measures (including the identification of pollutants and thresholds representative of groundwater bodies at risk) according to the Water Framework Directive. They could also be used to establish the relevant economic basis for derogation according to Article 4 of the WFD. This applies particularly to assessing the justification of time and quality derogations.
- Economics provides just one of several perspectives that can be used to assess the social desirability of various policy options. It can contribute important insights to the formulation of cost-effective groundwater protection policies. However, it should not be seen as the sole instrument for the determination of groundwater protection levels. The final decision remains a political act that has to be informed by an assessment of the impact of alternative scenarios using different and non comparable insights such as economics, ecology, human health, etc.

4.3 Implications for the formulation of the Groundwater Directive

1- The results of the literature review show evidence of concern about groundwater and **dissatisfaction with current protection levels**. A number of studies have found that households in many regions of Europe (as well as in the US) are willing to give up some income in exchange for improved groundwater protection. This finding provides strong evidence that the current situation in both regions is perceived as unsatisfactory. Unfortunately, the small number of available European case studies does not enable us to make any further generalisations.

2- Examples found in the literature review as well as results from the three case studies show that groundwater pollution has already caused **significant direct costs** for water users. They also suggest that these costs are likely to continue increasing in the coming years because of the high inertia of groundwater systems. Therefore, a more intensive groundwater protection policy is likely to yield significant economic benefits. However, the fact that some of the benefits will be spread over a long period of time whereas costs will be immediate may reduce the political support base for the adoption of such a policy.

3- **Protection measures are always cheaper than clean-up**. As illustrated by the first case study, they also avoid significant damages for current water users. From an economic point of view, this implies that a precautionary approach should be adopted in all areas characterised by a significant risk of point-source pollution. In particular, a more intensive monitoring strategy could be imposed by the GWD in zones affected by point-source pollution. The additional monitoring costs would be counter-balanced by the damages avoided (positive net anticipated benefit).

4- More generally, the study confirms that **areas affected by severe and historical point-source pollution should be considered separately from the water body they belong to**. As stressed above, monitoring requirements could be reinforced in such zones. The restoration targets (water quality threshold values and deadline to achieve the objective) could also be defined separately. However, the definition of less stringent objectives in these polluted areas must be justified by an economic analysis that proves that protection and restoration costs for achieving good status would be disproportionately high.

5- Concerning non-point source pollution (in particular by nitrate and pesticides), the definition of “groundwater quality standards” should take into account the fact that **economic damages can occur before drinking water quality thresholds are reached**. For example, the second case study showed that Drinking Water Utilities start investing in new infrastructures (new wells, treatment plants) before nitrate concentrations reach 50 mg/l. Similarly, the food and beverage industry suffers damages as soon as traces of pesticides are found in the water they use. “Groundwater quality standards” must, therefore, be lower than the current drinking water standard for this substance

6- Concerning **trend reversal**, the literature review as well as the third case study show that, in certain aquifers, reversing trends may not be possible before the deadline (2015), due to very long pollutant transfer times. This suggests that derogations to the trend reversal obligation might be justified on the basis of a scientific analysis of hydrogeological conditions.

5 References

More details can be found in the following reports produced for the Commission as part of this project :

Görlach, B. and Interwies, E. (2003). Economic Assessment of Groundwater Protection: a survey of the literature. Berlin: Ecologic. (83 p.)

Rinaudo J-D. (2003) Economic Assessment of Groundwater Protection: Groundwater restoration in the potash mining fields of Alsace. Case study report N°. 1. Orléans: BRGM.

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Full texts of the studies available from www.agire.brgm.fr/ or www.ecologic-events.de/ecodown/