Assessing the cost of groundwater pollution: the case of diffuse agricultural pollution in the Upper Rhine valley aquifer

J.-D. Rinaudo, C. Arnal, R. Blanchin, P. Elsass, A. Meilhac and S. Loubier
BRGM (French Geological Survey), Water Department, 1039 rue de Pinville, 34000 Montpellier, France
(E-mail: jd.rinaudo@brgm.fr)

Abstract
This paper presents an assessment of the costs of diffuse groundwater pollution by nitrates and pesticides for the industrial and the drinking water sectors in the Upper Rhine valley, France. Pollution costs which occurred between 1988 and 2002 are described and assessed using the avoidance cost method. Geo-statistical methods (kriging) are then used to construct three scenarios of nitrate concentration evolution. The economic consequences of each scenario are then assessed. The estimates obtained are compared with the results of a contingent valuation study carried out in the same study area ten years earlier.

Keywords
Diffuse pollution; Europe; groundwater; nitrate; pesticides; pollution cost; scenario; Water Framework Directive

Introduction
During the late 1980s, the concerns expressed by the public in Europe about steadily increasing nitrate concentrations in drinking water resources triggered a policy debate on agricultural non-point source pollution. This led to the promulgation of the nitrate directive (91/676/EEC) in 1991, followed by a first wave of action by Member States in the farming sector. A recent communication of the European Commission (European Commission, 2002) which reviews the measures implemented between 1991 and 2000 shows that these measures have not been sufficient to reverse the trend and to achieve the targeted nitrate concentration of 50 mg/l in all declared vulnerable areas. This statement particularly applies to groundwater bodies, several number of which still show increasing nitrate concentration trends and are increasingly concerned by diffuse pesticide pollution.

The debate on diffuse agricultural pollution through nitrates and pesticides has been revived with the promulgation of the Water Framework Directive (WFD) (2000/60/EC) which imposes that Member States be able to maintain – or restore – “good chemical status” for all water bodies by 2015. This decision, which imposes that Member States reinforce pollution abatement measures, is provoking a new political and public debate in the national and regional political arenas. This debate increasingly focuses on the economic dimension of the problem, i.e. the assessment of the costs and the benefits of water protection. However, while farm organisations are often able to estimate the variation of income that would be induced by additional protection measures, very few estimates of the socio-economic costs that could be avoided by the implementation of protection measure are available. Because of this deficit of information on the costs of groundwater pollution, protection measures may be perceived as “disproportionately costly”. Stakeholders might therefore be tempted to ask for a derogation allowing them to achieve less stringent environmental objectives, as permitted by article 4 of the WFD. The fear that derogation be too widely used generates a new demand from public authorities for conducting economic assessment of the damages that can be avoided if the objectives set by the WFD can be achieved, i.e. of the benefits of protection.
The present paper addresses this issue through a case study conducted in the Upper Rhine valley aquifer. It begins with a description of the main physical and socio-economic characteristics of the study area. In the second section, we discuss the methodological framework to assess the economic costs of groundwater pollution. The third section then presents an assessment of the costs of diffuse pollution over the last 15 years. The fourth section presents an attempt to anticipate the possible evolution of diffuse pollution by 2015 and to assess the related socio-economic impact.

**Main characteristics of the study area**
The Upper Rhine valley aquifer extends over 4,200 square kilometres between Germany and France. With a reserve of approximately 45 billion cubic metres of water, it is one of the largest freshwater reserves in Europe. The water supply of three million inhabitants of the Alsace and Baden regions directly depends on this resource. Since the 1970s, it has increasingly been affected by diffuse nitrate and pesticide pollution, mainly due to agriculture intensification. Areas where groundwater shows high pesticide and nitrate concentration levels correspond to areas where maize or vine crops are cultivated.

The nitrate pollution problem is particularly acute on both sides of the Rhine. While the nitrate concentrations were lower than 50 mg/l in the entire aquifer in the early 1970s, 15% of the 1,100 monitored points showed in 1997 a nitrate concentration exceeding 50 mg/l and the European guide value of 25 mg/l was exceeded in 36% of the monitored points. Pollution by pesticides (in particular herbicides) is another very significant source of concern (Région Alsace, 2000). The presence of herbicides in groundwater is mainly due to agricultural practices (intensive use for maize and vine crops). On the French side of the aquifer, atrazine and its metabolite (desethyl-atrazine) are the most frequently encountered molecules: in 1997, the presence of these substances was detected in respectively 59% and 63% of monitored points. Concentrations exceed the drinking quality thresholds (0.1 µg/l) in 13% and 17% of the samples for respectively atrazine and desethyl-atrazine. The presence of simazine, desisopropyl-atrazine and diuron is also reported in respectively 21%, 13% and 6% of the samples (France and Germany), with concentrations exceeding the drinking water thresholds in respectively 2%, 3% and 2% of the samples.

The analysis of recent agricultural trends shows that the area under intensive crops rise whereas the area occupied by grassland steadily declines. The comparison of the two last agricultural census (1988 and 2000) shows that the area under vine has increased by 13%, the area under maize by 60% whereas area under wheat and grassland decreased by respectively 25% and 13%. This trend is not likely to be reversed since the French Government will not implement the reforms of the Common Agricultural Policy before 2013. Therefore, in spite of significant efforts made by professional farm organisations to promote more environmentally friendly practices, many experts expect that diffuse pollution is likely to continue increasing. The French local authorities are therefore increasingly concerned by the consequences on the local economy of further degradation of groundwater. They express a strong need for economic assessment of past damage costs of pollution and for a forecast of possible future damage costs that could be avoided. They expect that this information will increase public awareness and create a larger political support in favour of the implementation of more strict pollution control measures.

**Methodological framework**
Groundwater contamination generates different types of damage: (i) human health effects due to exposure to unsafe levels of substances in water; (ii) increased fear and anxiety within the community; (iii) avoidance costs for water users who have to undertake avert-
ing or corrective actions; (iv) ecological damage and loss of recreational value, when groundwater contamination has an impact on surface ecosystems (rivers, wetlands); and (v) loss of non-use value, such as option value and existence or bequest value. Different approaches and methodologies have been developed to assess these different costs.

- The cost of illness method aims at assessing costs generated by exposure to contaminants in drinking water, e.g. the cost of foregone wages for the victims of the contamination and the cost of treating the illness (see Harrington et al., 1989). This approach may be relevant in cases where health effects are the major component of the costs, as is the case with the arsenic or fluorine groundwater contamination in India and Bangladesh for instance. It does not seem relevant for the nitrate pollution problem in Europe where the concentrations found in drinking water never reach a very high level. The illness cost due to pesticide could be significant, but the lack of epidemiological studies do not allow any evaluation.

- The avoidance cost method (ACM) – or averting expenditure approach - consists in assessing the costs of actions undertaken to prevent or mitigate the adverse effects of contamination. Rooted in the household production function model, this approach assumes that consumption of goods or services can substitute for groundwater quality change. The implementation of this method offers a means to generate lower-bound estimates of an important component of the cost of groundwater pollution, namely the use of groundwater as a drinking water source. The averting behaviours reported include purchasing bottled water, monitoring of private borehole water quality and installation of filtering devices. Their estimated cost ranges between 125 and 330 US dollars per year and per household (for a review see Abdalla, 1994).

- The contingent valuation (CV) method aims at assessing the value that households assign to the preservation of the quality of groundwater. It consists of a household survey during which respondents have to state their willingness to pay (WTP) for hypothetical groundwater protection (or restoration) scenario. The stated WTP contains both use and non-use values, since households may want to preserve groundwater for their present or future consumption, for the consumption of future generations and/or for the resource as such. The estimated willingness to pay for groundwater protection can be considered as an estimate of the cost of groundwater degradation. CV is so far the most widely used method for assessing the benefits of groundwater protection (for a review see Stenger and Willinger, 1998; Görlach and Intervies, 2003).

A contingent valuation study, aiming at assessing households’ WTP to protect the aquifer, had been carried out a few years earlier in our study area (Stenger and Willinger, 1998). Discussions with local public decision makers highlighted that they considered WTP estimates as unreliable. Moreover, decision makers, experts and stakeholders have difficulties in deriving conclusions and policy recommendations from these estimates. Consequently, CV results have been of little use in the political debate accompanies the decision to reinforce groundwater protection measures. Decision makers are calling for cost estimates relying on behaviours that have actually been observed. They also expressed the need for an analysis of the distribution of the total cost between the different categories of users and interest groups – something that CV cannot achieve. For these different reasons, and because the avoidance cost method and related measurement procedure was thought to be more accessible to non-economists, the ACM was adopted to carry out the present study.

**The cost of past pollution**

The first step of this research consisted in assessing the damage cost of diffuse pollution for the main water uses. The objective was to demonstrate that groundwater protection
measures – if implemented earlier – could have avoided significant costs. Providing this information was considered as a prerequisite to further discussion of the economic implications of new groundwater restoration measures. The analysis below focuses on the past 15 years (1988–2002), as data could not be considered as fully reliable before 1988.

Damage cost of past pollution for the drinking water sector

The localities affected by diffuse pollution were identified from a review of past issues of a local newspaper; a consultation of the archives of the major public institutions financing the drinking water utilities (DWU) and 22 DWU interviews. The compilation of the different sources of information reveals that 28 drinking water utilities, supplying water to 432,000 inhabitants, are affected by nitrate and/or pesticide pollution. The concerned DWU have adopted very diverse strategies to respond to the pollution:

- **Desertion or reduced exploitation of the polluted water borehole without replacement** is a frequent temporary solution. It generates capital opportunity cost (“frozen” investments) and increases the vulnerability of a DWU to accidental pollution since the number of water sources used is reduced.

- **Replacement of polluted boreholes** with an alternative resource (a new borehole or a pipeline to import water from a neighbouring DWU). The construction of a new borehole is often seen as a long term solution whereas the construction of a pipeline is envisaged as a temporary solution waiting for the recovery of water quality.

- **The dilution of water extracted from the polluted water borehole** is the third strategy. It consists in continuing the use of the polluted borehole and mixing the water it produces with a better quality resource, so that the blend meets the drinking water standards. Dilution can be carried out within the DWU when it has access to different resources; this however requires that the distribution network be restructured so that water abstracted from the different sources can be mixed in a single tank before being distributed. Dilution can also be made with water imported from a neighbouring DWU, which induces significant investment costs (construction of a pipeline to connect the two DWUs) but also additional running costs (pumping costs to import water, cost of water purchase).

- **The construction of a treatment plant** to remove nitrates (ion exchange resin technology), pesticides (active coal filters) or both (reverse osmosis, combined systems) is a solution that can be adopted when nitrate and/or pesticide concentration regularly exceeds the drinking water thresholds and when no alternative resources can be substituted to the polluted borehole. Although this option is always considered in studies conducted by consultants, DWUs are reluctant to adopt it for three main reasons: first, the investment cannot be subsidised by financial institutions (whereas the construction of a new borehole or the connection with another DWU can be subsidised up to 80% of the total cost); second, the operation and maintenance costs are rather high (0.15 to 0.3 €/m³); third, the technology available is not adapted to small DWUs. In the Alsace region, one nitrate removal treatment unit and three activated carbon unit have been installed up to date.

- **Co-operative agreements** between DWU and farmers can also be established to reduce pollution and avoid heavy investment in water infrastructures. Farmers are compensated for the losses of income induced by the adoption of more environmentally friendly practices. For example, the compensation for turning arable land into permanent grassland ranges between 230 and 460€ per hectare and per year in the Alsace region. Seven of the eleven cases found in the Alsace region have not been implemented alone but combined with the construction of a new borehole or the connection to another network.
The purchase of the borehole catchment area is the last solution identified. Two DWU have chosen this option and turned the purchased area into permanent grassland or forest. This strategy, however, entails very high costs in a region where the price of agricultural land is very high; and it is not always effective as the pollution may come from areas located outside of the protected area.

The compilation of the different sources of information shows that, during the 1988–2002 period, nitrate and pesticide pollution has generated €26.4 million expenditures (constant 2001 €) for DWUs using the alluvial aquifer of the Alsace valley. 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. The construction of new water boreholes and the interconnection represents respectively 54% and 25% of this amount.

**Household avoidance costs**

In addition to the financial costs assessed above, the diffuse pollution of the aquifer generates significant fear and anxiety in the population, in particular because there is great uncertainty about exposure and its effects on health. This is illustrated by Stenger and Willinger (1998) who conducted a survey with 817 residential households of Alsace. They show that: 88.8% of the households are purchasing bottled water; 67% declare never to drink tap water; 42% can identify sources of pollution affecting groundwater quality; and approximately 78% perceive pollutants as a serious health risk. The national public opinion polls conducted by several independent institutes all corroborate these assumptions. According to a survey undertaken by CIEAU in 2000, only 12% of the households who declare using bottled water explain their choice by the fear of the presence of nitrates and/or pesticide in tap water. It can therefore be considered that groundwater pollution by nitrates and pesticides is responsible for part of the purchase of bottled water (avoidance cost).

To estimate this cost in the Alsace region, we assumed that: (i) 70% of the inhabitants receiving tap water pumped in the aquifer do consume bottled water (925,000 inhabitants); (ii) the fear of the presence of nitrates and pesticides in tap water only explains 12% of the consumption of bottled water; (iii) the “average” bottled water drinker purchases 1.5 litre per day at a cost of 0.5 €. Thus, the total annual expenditure for the 925,000 inhabitants involved is assessed at €20 millions (in 2002). Moreover, assuming that the consumption of bottled water has linearly increases from 10% in 1970 to 70% in 2002, the total annual cost over the last 15 years (a 15 year period is chosen to be consistent with the period over which the costs of pollution for the drinking water sector have been assessed) can be assessed at 247 M€ (in constant 2001 €). It is worth noting that this cost is nearly ten times higher than the financial costs for DWU assessed above.

**Cost of pollution for industry**

We then consulted a number of experts from the industrial sector to understand the consequences of diffuse pollution on the different branches of industry. The experts classified industries in three groups: (i) those not sensitive to nitrates and pesticides (paper mills, heavy industry, etc.) (ii) the very sensitive ones such as electronics, pharmacy or chemistry where the industrial process requires an extremely pure water that can only be obtained with reverse osmosis or distillation; and (iii) the food and beverage industry (F&B) where water is used as a basic ingredient and needs to comply with drinking water standards. Some experts were seriously concerned that a continuation of groundwater quality deterioration could lead to a generalisation of water treatment before use, increased production cost and/or changes in production processes. In the long term, this could result in a significant loss of competitiveness of this branch, possibly resulting in
relocation of some plants to other regions. Given the economic weight of the F&B industry in the regional economy (16,000 jobs, 570 enterprises plus a very large number of self-employed craftsmen), we undertook a survey of this branch. Thirty-two semi-structured interviews were carried out to: (i) describe water resources and uses; (ii) identify the water quality requirements and related constraints; (iii) describe the costs of past pollution; (iv) assess the perception of present water quality and (v) describe its possible evolution in the long term and its consequences on the company. The major findings are described below.

Some industries have had to stop using their boreholes contaminated by nitrates and/or pesticides. An in depth analysis of these cases however reveals that the decision to shut them down can be motivated by several other reasons, in particular the risk of accidental contamination by micro-pollutants (chlorinated solvents, bacteriological contamination). When this risk is too high, it becomes the major reason for shutting down the borehole but this is not always acknowledged by industrialists. Nitrate and diffuse pollution have also compelled some industries operating their own borehole to install treatment units. Although the cost of treatment is not negligible, it remains acceptable for all industries, the cost of water representing a small share of the total production costs (breweries included). For instance, one of the largest breweries, using 2.8 millions m$^3$ per year has invested over €10 millions since 1994 in nitrate removal technologies (investment and operation and maintenance cost). This amount could increase very soon since this company intends to drill new water boreholes in a different zone (€4.9 million).

Industries using public water supply may also have to adapt their process when drinking water quality deteriorates from a very good status (e.g. nitrate concentration smaller than 25 mg/l) to a poor status (40 to 50 mg/l). Since water remains drinkable, nothing prevents the DWU to distribute it but the quality is not satisfying the industries which have more stringent quality standards. These standards can be due to a technical constraint (ex. of the brewery above) or to a commercial constraint: accessing the Japanese and the Canadian beverage market, for instance, requires that the final product contains less than 25 mg/l of nitrates. A second type of damage cost can occur due to occasional short term contamination of water with pesticides. In such cases, the public competent authority can authorise DWUs to supply water with pesticide concentration exceeding the European standards of 0.1 μg/l – as long as the concentration remains below the World Health Organization threshold value of 0.4 μg/l. Although water is considered as safe, non compliance with EU standards might have consequences on the F&B industry: first, traces of pesticides could be found in the final product; second, the distributors could refuse to include the products made using contaminated water in their list of references (situation already reported by one company); third, publicity on such cases could deteriorate the reputation of the Alsatian products.

**Anticipated future evolution**

Since the early 1970s, and because the deterioration of groundwater in the Upper Rhine aquifer was worsening, public actors involved in water management at the regional level have engaged significant resources in monitoring programmes: four general surveys of groundwater quality were undertaken in 1973, 1983, 1991 and 1997, each one providing information on a variety of pollutants for 300 to 700 monitoring points (depending on the date of the survey). The analysis of the three first surveys revealed a clear increasing trend in nitrate concentrations (Table 1) which was confirmed in 1997, thus reviving the debate in the regional political arena. This observation has motivated the decision of the
Regional Council to carry out an additional survey in 2003 and to undertake – in collaboration with the French Geological Survey (BRGM) – a study to anticipate the likely evolution of groundwater quality by 2015 and to assess the related socio-economic impact.

This analysis has been carried out with the existing data and the results of the 2003 survey. Owing to data availability constraints, it focuses on the nitrate problem. The 2003 survey indicates that the overall trend might have been reversed between 1997 and 2003, both in terms of average nitrate concentration and in terms of area where concentrations exceed 50 mg/l. The evolution is, however, very heterogeneous in space, the situation improving in some areas while worsening in others. This implies that, in spite of the overall improvement of the situation, additional damage costs are likely to occur in areas where the degradation continues to take place. Assessing these future damage costs (e.g. contamination of industrial or drinking water boreholes) can only be done on the basis of a spatial representation of the expected future nitrate concentration.

Such maps were constructed as part of this project, using the following methodology. First, the data of the regional surveys were used to produce a spatial representation of nitrate concentration for the five reference dates (1973, 1983, 1991, 1997 and 2003), using kriging estimation method and the GDM software developed by BRGM. The output of the kriging process consists in grid cell based maps of nitrate concentration (Figure 1), each one being accompanied by a map of the estimation of error (Figure 1). The concentration maps were then compared two by two in order to construct maps depicting the estimated nitrate concentration variation rate, on the same grid cell representation (Figure 2). Three different scenarios were constructed using these maps as a basis for extrapolation:

- The first scenario is constructed assuming that the average yearly concentration variation will remain equal to the value $\bar{e}$ observed between 1997 and 2003. The anticipated nitrate concentration in 2015 is thus estimated at: $C_{2015} = [C_{2003}] + 12 * [e]$

- The second scenario is constructed taking into account the error of the kriging estimation $\sigma_i$. It assumes that, for each grid cell, the actual concentration in 2003 is equal to the estimated values plus half of the estimated error; it further assumes that concentration will continue evolving at a rate equal to half of that observed between 1997 and 2003: $C_{2015} = [C_{2003} + \sigma_i/2] + 12 * [e/2]$

- The third scenario is similar to the second but it supposes that the concentration evolution rate is equal to $e_i$. Using the same notations: $C_{2015} = [C_{2003} + C_{2003} + \sigma_i/2] + 12 * [e_i]$

The results of the extrapolation show that the situation will continue deteriorating in certain areas. The area with concentrations ranging between 40 and 50 mg/l will continue increasing (+1.4% to +4.4%), compelling the local Drinking Water Utilities to secure alternative water supplies. The area with nitrate concentration exceeding the EU

### Table 1 Evolution of nitrate concentration and area polluted in regional surveys

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average concentration (mg/l)</td>
<td>12</td>
<td>24</td>
<td>27.5</td>
<td>28.6</td>
<td>27</td>
</tr>
<tr>
<td>Area with $[NO_3] &gt; 50$ mg/l</td>
<td>1%</td>
<td>3.7%</td>
<td>7%</td>
<td>8.2%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Source: Région Alsace

J.-D. Rinaudo et al.
drinking water standard will also increase (+3.6% to +5.6%), with the same consequences (Table 2).

**Anticipated socio-economic impact**

The last step of the study (ongoing work) consists in assessing the future socio-economic impact of the forecasted evolution of water quality (by 2015). A geo-referenced data base, compiling information from different sources on drinking water utilities and population characteristics has been developed. The GIS functionality of the data base is used to select all the economic entities located in the area where nitrate concentration is expected to exceed 40 mg/l in 2015. Assuming the degradation described in scenario 3 takes place, we identify 37 drinking water utilities likely to be affected by nitrate and/or pesticide diffuse pollution. Considering that these utilities would have to purify water (nitrate and pesticide removal), the additional cost for drinking water utilities is assessed at 5.9 million € per year.

**Table 2** Anticipated concentrations and affected areas with three scenarios

<table>
<thead>
<tr>
<th>Average concentration (mg/l) and area concerned (%)</th>
<th>Entire aquifer</th>
<th>Area with 40 &lt; ( \text{NO}_3 ) &lt; 50</th>
<th>Area with ( \text{NO}_3 ) &gt; 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>27</td>
<td>44.1 mg/l (6.60%)</td>
<td>66.1 mg/l (5.40%)</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>28.5</td>
<td>44.5 mg/l (8%)</td>
<td>74.7 mg/l (9%)</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>28.7</td>
<td>44.1 mg/l (10%)</td>
<td>76.3 mg/l (11%)</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>28.9</td>
<td>44.2 mg/l (11%)</td>
<td>70.7 mg/l (9%)</td>
</tr>
</tbody>
</table>

**Figure 1** (Left) Estimated nitrate concentration value in 2003. (Right) Error (in mg/l) of the estimation of nitrate concentration in 2003
Conclusion

Using the avoidance cost approach, we have calculated a lower-bound estimate of the costs incurred through diffuse groundwater pollution during the 1988–2002 period. The cost borne by drinking water utilities, and passed on to the customers through price increase, is assessed at €1.8 million per year. Households’ averting behaviour costs (mainly bottled purchase) are more than ten times higher (€20 million per year). A detailed case study also suggests that a significant cost has also been borne by industries. These rough estimates give an order of magnitude of the economic transfer that occurs between water users and polluters. They, however, have to be considered as a lower-bound estimate as they do not take into account the loss of non-use value (option or bequest value). The significance of this component of the cost is highlighted by several studies showing that individuals are willing to pay substantial amounts to protect groundwater for future generation use (Edwards, 1988). In spite of this caveat, the estimates calculated are consistent with the results of the contingent study carried out in the same study area by Stenger and Willinger in 1993 who estimated the total benefit of preventing groundwater pollution at €61 million per year, split into €24.5 million of use benefit and €36.5 million of non-use benefits.

From a methodological standpoint, we have developed an innovative approach for constructing a baseline scenario, as required by the water framework directive.
This approach combines the use of geo-statistical methods to construct a spatial representation of water quality in 2015 with the use of the avoidance cost method, in order to assess the economic implications of the anticipated water quality maps. Given the uncertainties attached to the estimation of future water quality maps, the approach does not pretend to forecast a realistic 2015 scenario. It only aims at producing contrasting pictures of different plausible futures, intended to fuel the debate between stakeholders and not to be used as a decision support tool.

References