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Assessing the costs and benefits of groundwater quality improvement in the Upper Rhine valley quaternary aquifer (France)

Final report

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Contents

Abstract

This study, which was conducted as part of BRIDGE workpackage 5, presents the results of a case study where the costs and benefits of two **groundwater protection scenarios** (and corresponding environmental quality standards) are assessed. The case study focuses on groundwater pollution with chlorinated solvents, a group of substances widely used in industry and frequently detected in groundwater. It was conducted in the French part of the Upper Rhine valley, where a large alluvial aquifer (4000 km²) fulfilling respectively 50% and 80% of industrial and drinking water needs, is increasingly polluted with chlorinated solvents.

Two alternative programs of concrete remediation and prevention measures are designed. Whereas the technical measures implemented in the two scenarios are broadly the same, the two scenarios differ in terms of environmental objective and number of enterprises concerned by the measures. The first scenario aims at restoring **drinking water quality** in the entire aquifer. To reach this objective, remediation and preventive measures are applied to all enterprises and historical contaminated sites located in zones where concentration in solvents currently exceed drinking water threshold values (covering 12 municipalities). A total of 41 historical sites and 1562 enterprises are concerned. The total cost of the programme of measure is assessed at **22 millions €.** The second scenario aims at restoring **natural groundwater quality** through eliminating all traces of chlorinated solvents in the long term (50 years). The same technical measures are applied to 3033 enterprises and 114 historical contaminated sites, located in 128 municipalities. The total cost is estimated at **52 millions €.**

The second part of the study consisted in assessing the benefits associated to the two groundwater protection levels. The benefits were assessed through assessing population willingness to pay for the two levels of groundwater protection. A contingent valuation survey was carried out between March and July 2006 using a postal survey, after a first test of the questionnaire through 140 face to face interviews. A total of 668 usable questionnaires were returned out of the 5000 sent by mail. Sixty two percent of the respondents accept to contribute to the first scenario and their average Willingness to Pay amounts to 42€/household. Concerning the second scenario, 54% of the respondents are willing to contribute, the stated amount being on average 76€/household. These values can be compared with the 94€ found in a 1993 contingent valuation assessing WTP for groundwater protection in the same region (Stenger and Willinger, 1998). A major finding is the relatively high protest rate close to 53% for the first scenario (17% for the second). This attitude is mainly due to the fact that the scenario is perceived as inconsistent with the polluter pays principle. Based on these results, the total benefits associated with the two scenarios are estimated at 29 millions € for the scenario 1 (drinking quality level) and 46.5 millions € for scenario 2 (natural water quality level).

List of tables

List of figures

Acknowledgement

The method used to design the program of measures has been developed as part of a joint research program by Brgm and the Water Agency Rhin Meuse, run in parallel with BRIDGE. The authors would like to acknowledge the technical and financial support of **the Water Agency Rhin Meuse** for this methodological development. The Water Agency has also given free access to economic statistical data for this study. We particularly acknowledge the contributions of Sophie Nicolaï (economist at The Water Agency), Jean-Luc Salleron, Stéphane Petitgenet, Magali Marketto, Christian Szakowny, Philippe Ricourt, Bénédicte Hamon and Claire Riou.

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1. Introduction

Following the publication of the Water Framework Directive (2000/60/EC) in 2000, European Member States are currently initiating very ambitious water protection programmes aiming at restoring good ecological and chemical status for all water bodies before 2015. Whilst the directive defines environmental objectives for *surface* water bodies, it has not been considered appropriate to define new *groundwater* quality standards which would be applied uniformly to all groundwater bodies across Europe. Instead, the legislator has preferred to leave up to each Member State to determine concentration threshold values for all major polluting substances. According to the recent groundwater Daughter Directive, such thresholds values can be set at regional or local levels in order to reflect local natural or economic specific characteristics.

The Directive explicitly recognises that the costs of groundwater protection actions should remain proportionate with the environmental and economic benefits they generate. As a result, policy makers express a growing demand for economic assessment of costs and benefits associated to different levels of groundwater protection. However, existing studies generally focuses on a unique groundwater protection or restoration scenario and rarely assess the costs and benefits associated with different protection scenarios. This study presents an attempt to fill this gap through a case study where the costs and benefits of two groundwater protection scenarios (and corresponding environmental quality standards) are assessed.

The report first describes the case study area (chapter 2), located in the French part of the upper Rhine valley, where a large alluvial aquifer (4000 km²) fulfils respectively 50% and 80% of industrial and drinking water needs. This aquifer is increasingly affected by industrial pollution in particular with chlorinated solvents. The report then goes on with providing background information on chlorinated solvents (chapter 3), describing the major pollution sources, pathways and type of impacts, and providing an overview of existing legislation and regulation on chlorinated solvent use. Chapter 4 describes the methodology used to design and assess the cost of two alternative programmes of measures aiming at reducing groundwater pollution with chlorinated solvents. Chapter 5 presents the methodology and results of the contingent valuation survey which was carried out to assess the benefits associated to the two groundwater protection scenarios presented in chapter 4. A concluding chapter discusses the results of the cost benefit analysis and the implication for policy makers.

2. Case study description

2.1 Description of the case study area

The upper Rhine valley alluvial aquifer was selected to conduct a case study as part of the BRIDGE project. This cross-border alluvial aquifer, located between Germany and France, extends over 4200 square kilometres. With a reserve of approximately 45 billions cubic meters of water, that is approximately half of the volume of Lake Geneva, this aquifer is one of the largest fresh water reserves in Europe. Groundwater from the Rhine alluvial valley fulfils 75% of the drinking water needs and about half of the industrial water needs. More than three millions inhabitants of the Alsace Region (France) and the Land of Baden-Württemberg (Germany) directly depend on this resource for their water supply. Although usable for drinking purposes without prior treatment in most locations, groundwater has progressively been affected by diffuse and point source pollution since the 1970's.

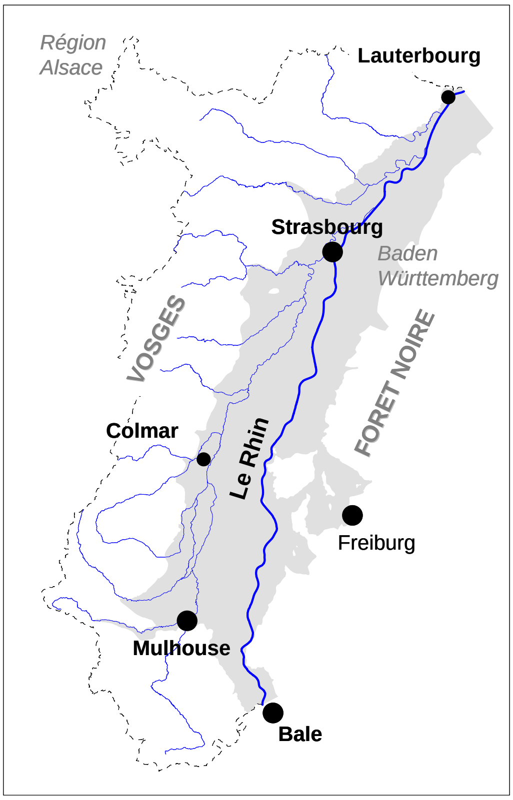

Figure 1: Location of the Upper Rhine Valley aquifer (shaded area)

The upper Rhine valley aquifer is severely affected by four major pollutions sources: nitrates, pesticides, chloride and Volatile Organic Compounds (VOC).

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 1100 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 is 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.

A large area is affected by chloride pollution, originating from the potash mining industry, on the French and German side of the aquifer. The latest maps produced in 2000 show that the plumes extend over approximately 40 kilometres. Chloride concentration exceeds 100 mg/l over approximately 187 square kilometres and 200 mg/l over more than 80 square kilometres. Because of the relatively higher density of saline water, deep layers are more affected than surface layers.

High concentrations in volatile organic chlorinated components (VOC) have been detected downstream of several industrial areas (Strasbourg, Freiburg, Obernai, Mulhouse, Molsheim, Chatenois, etc.). The most frequently observed molecules are trichloroethylene (TCE), tetrachloroethylene (PCE) and 111 trichloroethane (111 TRI). In a groundwater quality measurement campaign carried out in 1996-97, at least one of the three above VOC were found in 38% of the french 423 and german 533 groundwater samples. The measured concentrations were lower than 0.2 µg/l in 70% of the contaminated samples; values ranging between 0.2 and 10 µg/l are reported in 25% of the samples. Only 6% of the samples show concentrations higher than 10 µg/l, which is the maximum value for drinking water use according to the EU standard. The highest concentrations have been found in the region of Molsheim, France (1580 µg/l) and Lahr, Germany (204 µg/l) (Région Alsace, 2005, Région Alsace, 2000.Conseil Régional, 1998).

Other contaminants commonly have been reported, including heavy metals, polycyclic aromatic hydrocarbons (PAH) and oils. Contaminated areas are generally very local (industrial areas, military sites). Urban and industrial landfills are potential sources of contamination, but they are not sufficiently monitored – so their impact on groundwater is not well known.

2.2 Objectives and methodological steps of the case study

Looking at the overall objectives of the Bridge project, we propose to exclude the issue of nitrate and pesticides from the scope of the economic valuation study, given that the Groundwater Directive already establishes threshold values for these two groups of substances. Also, we propose to exclude the issue of chloride contamination, as this pollution originates from one large industrial site, which has to be considered as a "risk management area" (in other words, defining a threshold value for chloride at the aquifer level would not be a relevant option). We therefore propose that the case study concentrates on the issue of VOC contamination.

The overall objective of WP5 case studies is to carry out costs-benefits analysis (CBA) of different scenarios of groundwater quality improvements. From a theoretical point of view, the steps of the cost-benefit analysis to be carried out are the following:

1- The first step consists in designing several alternative programmes of operational measures aiming at, on the one hand, preventing any additional contamination with VOC and, on the other hand, remediation of existing contaminated sites.
2- The effect (or impact) of the measures on the status of the groundwater body is assessed using hydrodynamic models or expert judgement, depending on the complexity of the situation, the availability of data and financial resources. A criteria is defined to measure the status of the groundwater body (e.g. an average concentration value, a percentage of monitoring points where a threshold value is not exceeded, etc); the same criteria is used to assess the effectiveness of the different programmes of measures investigated. At the end of this step, it is possible to relate each specific set of measures with an indicator of the quality of groundwater.
3- The cost of various programmes of measures envisaged is assessed, taking into account investment and recurring (operation and maintenance) costs, direct and indirect costs and analysing the distribution of these costs among various categories of stakeholders.
4- The cost-effectiveness of the different programmes of measures is investigated in order to select a limited number of relevant options to be analysed in details in the next steps of the analysis. Other options are dropped out.
5- The benefits of the selected programmes of measures defined in 4 are assessed using contingent valuation method.

The method which was implemented in the French case study consists of 3 major steps:

1. General information on VOC was collected in order to better understand and describe (i) the list of substances to be considered in the analysis, (ii) migration paths in groundwater when a pollution occurs, (iii) existing legislations related to VOC emission control and (iv) technical measures which can be implemented to reduce emissions of remediate contaminated sites
2. Two alternative programs of measures for VOC groundwater pollution control were developed as follows. Activities for which a potential VOC pollution exists were first identified; specific measures were determined for each class of activity through a consultation of experts and professional and a literature review; the costs individual measures was estimated through real examples of pollution control; the total aggregate cost was then estimated for the whole Upper Rhine Aquifer using several databases.
3. The benefits of water quality improvement that can be achieved through the implementation of two programs of measures were then assessed through contingent valuation method.

3. Groundwater quality problems: the case of chlorinated solvents

3.1 Background information on chlorinated solvents

3.1.1 Chemical definition of the substances considered

- Chemical classification: Chlorinated solvents are Halogenated Volatile Organic Compounds. VOCs are a group of substances belonging to various chemical families having common properties (they are in particular volatile). The term VOC is used in regulatory contexts and their definition is a matter of law which means that it can differ from one country to another. VOC are defined in the European Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations. They are: "*any organic compound having at 293.15 K a vapor pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use. For the purpose of this Directive, the fraction of creosote which exceeds this value of vapor pressure at 293.15 K shall be considered as a VOC*". Generally, VOCs include aldehydes, kenones or hydrocarbons. HVOCs contain halogenated substitutes as bromine, chlorine, fluorine or iodine. As an example, chlorinated solvents that are found in the Alsace aquifer are: Chloromethane (Chloroform, Dichloromethane (CM), Carbon tetrachloride); Chloroethane (1,2 Dichloroethane, 1,1,1 Trichloroethane (TRI 111)); Chloroethene (1,2 Dichloroethylene, Trichloroethylene (TRI), Tetrachloroethylene (PER)).

- Health risks: VOC are a significant source of air, soil and water pollution. Being volatile, they are present in the atmosphere where they are ozone precursors. Their emission in air is regulated through several European Directives. VOC are also found in soils and groundwater where they can accumulate and constitute long lasting sources of pollution. Some of these VOC are toxic (Trichloroethylene, Carbon tetrachloride) or harmful for human health (Trichloroethane, Chloroform, Dichloromethane, 1,2 Dichloroethylene, 1,2 Dichloroethane): they can cause cancer, nerve, liver and kidney damages and impair heart function. For this reason, their presence in drinking water is strictly regulated[1].

- Properties of solvents: Volatile Organic Compounds or VOC are organic pollutants. VOC possess the following properties: they are volatile, non-inflammable, low sur-

[1] See appendix 1 for more details.

face tension, low water solubility, high mobility in soils, high octanol / water coefficient.

3.1.2 Economic uses of chlorinated solvents

Chlorinated solvents (CS) are used either as chemical intermediates or as solvents. In the later case, they are frequently used to dissolve oil, grease or for dry-cleaning. Other applications for solvents are adhesive coating, coating activities (vehicles, leather, textile, metallic, plastic and wooden surfaces), coil coating (steel, etc.), footwear manufacture, manufacturing of coating preparations, varnishes, inks and adhesives, manufacturing of pharmaceutical products, printing, rubber conversion, surface cleaning, vegetable oil and animal fat extraction and vegetable oil refining activities, vehicle refinishing, winding wire coating, wood impregnation, wood and plastic lamination (Annex I, Dir 1999/13/EC; (Thompson and Tidmarsh 2002)). CS are both used by industrial activities and domestic activities. These different sectors of CS uses involve different pollution schemes. As an example, industrial sites either abandoned or active can be considered as point source pollutions; commercial activities (dry-cleaning, paint-cleaning, etc.) or domestic activities (paints, cleaning products) involve more diffuse pollution as they are geographically spread and of little importance (in quantitative terms).

3.1.3 Possible pathways for chlorinated solvents pollutions

As their main characteristic is to be volatile, a major pollution is air contamination where CS are precursor to ozone. Part of CS can contaminate rainfall and become non-point source pollution (2 in Figure below). Although CS do not stay long in surface waters where they evaporate quickly, they are detected in significant concentrations in certain French rivers (Seine for instance). Surface waters are therefore contamination pathway. Soils contamination arises when solvents are discharged accidentally or through continuous storage or pipe leakages. In non-saturated soils, CS can take a vapor form and escape in the air. But due to their complex properties (density, etc.), they can also migrate through the soil and reach groundwater. In the saturated zone, they tend to migrate to the bottom. In industrial contaminated sites, they are point source pollution: as CS have a low solubility coefficient, they constitute permanent and long term pollution, creating a pollution plume from the source (3 in Figure below). In other pollution cases, like domestic and commercial contaminations, pollution intensity is lower and dispersed in many sites (urban treatment plans, small enterprises) in such a way that it is frequently considered as non-point source pollution (1 in Figure below).

During their migration from upper soil to groundwater, CS can take several forms: (i) vapor when they migrate in non-saturated zones of soils; (ii) solid when adsorbed by soils compounds; (iii) liquid when they are dissolved in groundwater. Chlorinated Solvents (CS hereafter) are easily absorbed by soils and stay there despite of high volatility (Figure 2). High density and low viscosity of CS stimulate their intrusion in soils until the aquifer. When they reach water, they tend to accumulate to the bottom of the aquifer and to slowly diffuse in groundwater (Figure 3).

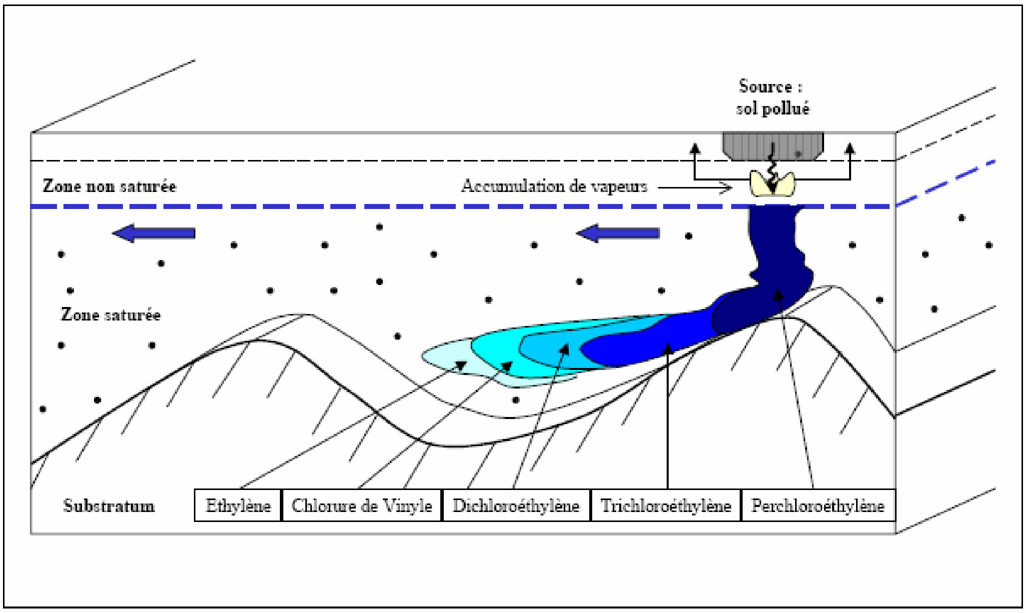

Figure 2: Example of PER evolution in groundwater. (Source: from Novak, 2002). ® Brgm.

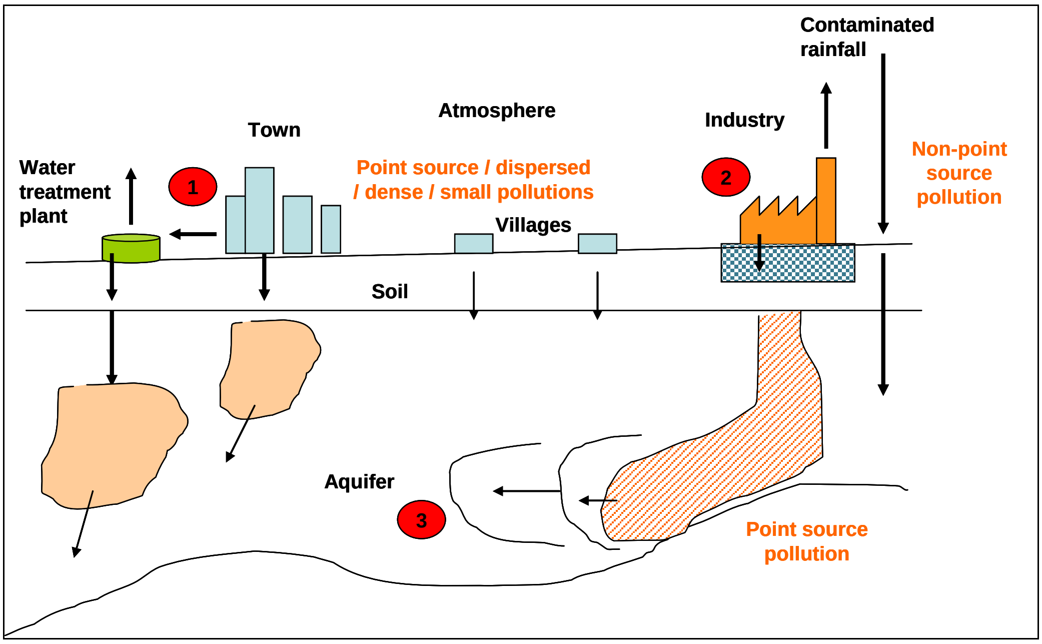

Figure 3 Pathways of chlorinated solvents contamination.

3.2 Typology of contamination sources

Five main pollution sources can be distinguished: (i) historical contaminated sites; (ii) Industrial sites in activity; (iii) large scale accidental contamination (transportation, storage); (iv) dispersed point source pollution (economic activity); (v) diffuse pollution mainly due to atmospheric deposition. The table below indicates the types of environmental compartments (air, water, soils) which are mot likely impacted by these 5 pollution sources; it also indicates the database and other information sources which can be used to identify pollution sources.

	Point-source pollution			**Small intensity but numerous and dispersed point-source pollution**	***Diffuse pollution***
Origin	Historical contaminated sites	Industrial sites in activity	Accidents (transportation, storage)	Domestic and dispersed small industries pollution	*Atmospheric pollution*
Environmental compartments impacted	Soil, groundwater, surface water	Soil, groundwater, surface water, air	Soil, groundwater, surface water, air	Soil, groundwater, surface water, air	*Soil, groundwater, surface water*
Pollution vectors	Storage tanks & pipes leakages, waste dumps leachates	Seepages, air emissions, industrial wastewater discharges, storm water runoffs and leaching	Air emissions, wastes deposits, contamination of wastewater network	Transportation of VOC and delivery	*Contaminated rainfall*
Information sources and data bases	*BASIAS*	*BASOL, SIRENE*	*SIRENE*	*Local experts consultations, archives*	*BASOL, IREP register*

Table 1: Pollution origin, impact, pollution vectors and information sources available.

3.3 Existing legislation and regulation

Concerning VOC a number of EU and legislation pieces are already regulating the use and risk of environmental pollution (air, soils, water) with volatile organic compounds of which chlorinated solvents. The major pieces of regulation are listed bellow:

- Directive 1994/63/EC: This is a directive of the European Parliament and of the Council on the control of VOC emissions resulting from the storage of petrol and its distribution from terminals to service stations[2].

- Council Directive 1996/61/EC: This is a directive of 24 September 1996 concerning integrated pollution prevention and control (IPPC).

- Council Directive 1999/13/EC: This is a directive on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

- Council Directive 98/83/EC: This is a directive of 3 November 1998 on the quality of water intended for human consumption:1,2-dichloroethane 3,0 µg/l ; Tetrachloroethene and Trichloroethene 10 µg/l Sum of concentrations of specified parameters

- Decision No 2455/2001/EC: this is a directive of the Parliament and of the Council, of 20 November 2001, establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC. COV identified as priority substances: 1,2-Dichloroethane, Dichloromethane, Trichloromethane (Chloroform).

- Directive 2001/81/EC : This is a directive of the Parliament and of the Council, of 23 October 2001, on national emission ceilings for certain atmospheric pollutants. French emission ceilings for VOC to be attained by 2010: 1050 kilotonnes.

- Directive 2004/42/EC: This is a directive of the Parliament and of the Council, of 21 April 2004, on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC.

French regulation

- Arrêté of Mai, 2nd 2002 on general measures for the industrial installations under the IPPC[3] directive that must be declared under category n°2345 related to solvent use for dry cleaning and textile cleaning.

- Arrêté of 02/02/98 on water extraction and consumption and on every emissions of industrial installations under the IPPC directive that must be authorized.

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2 http://aida.ineris.fr/sommaires_textes/sommaire_thematique/index.htm

3 IPPC: Integrated Pollution Prevention and Control

- Arrêté of 08/12/95 on the minimisation of chlorinated solvents emissions from petrol storage and station distribution.

- Circulaire n° 95-80 of 03/07/95 on reduction of solvents atmospheric emissions during industrial car painting processes.

- Ministerial circulaire of 11/06/87 concerning reduction of solvents atmospheric emissions during industrial car painting processes.

In Europe, the strengthening of legislation resulted in a significant decrease of chlorinated solvents consumption. Since 1997, this consumption decreased of 4.6% per year on average. This reduction is partly explained by a shift from chlorinated solvents to other products and clean technologies; it is also explained by the development of on site solvent recycling techniques (http://www.belgochlor.be). In 2002 257000 tonnes of chlorinated solvents were used in Europe. In France 42000 tonnes were used in 2004 (Société Française de Chimie, (SFC: http://www.sfc.fr).

3.4 Contamination levels of the upper Rhine valley aquifer with chlorinated solvents

Chlorinated solvents concentrations are regularly monitored by different agencies, in particular the Rhine Meuse River Basin Agency operating a network of 41 points where samples are taken every 6 months; and the Région Alsace in charge of surveillance monitoring conducted every six years in over 700 points (Figure 4).

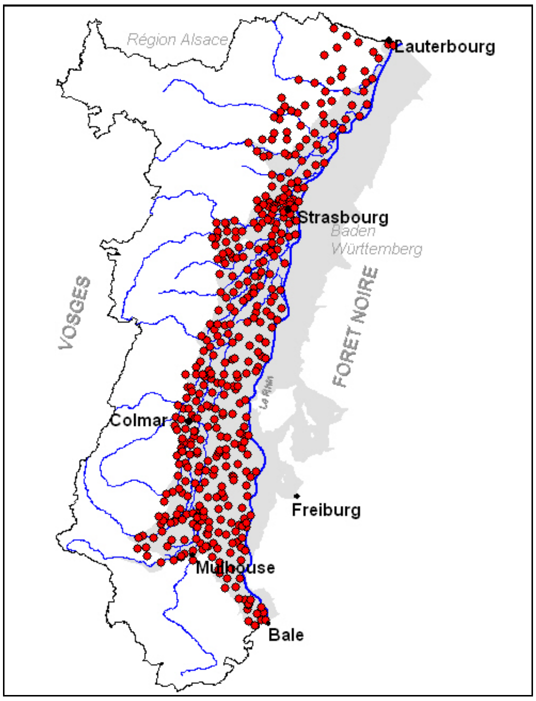

Figure 4: Groundwater quality monitoring network in the Upper Rhine valley aquifer.

In 1997, a number of major chlorinated solvents have been searched in 423 check points of the French part of the Upper Rhine aquifer (Agence de l'Eau Rhin-Meuse 2004): trichloroethylene (TRI), Tetrachloroethylene (PER), Trichloroethane (TRI 111), 1,2 Dichloroethylene and Carbon tetrachloride (Figure 5). TRI and PER were the most frequently detected chlorinated solvents. Of the whole set of points, 14 (3.3%) were up to the drinking water threshold of 10µg/l considering the sum of these two pollutants. When taking into account the whole CS tested, 5.7% of the point measurements were up to the threshold. Major contaminations occur in urban areas and around industrial sites. Some contamination observations remained unexplained in 1997.

In 2003, CS concentration measures have been realized in the 423 points (Région Alsace 2005). Results show that 3% of the set of points contains up to 10 µg/l for both TRI and PER. Anyway a diffuse and small pollution has been identified in 30% of the point measurements (Figure 6). These data are related to the whole aquifer (French and German part). In France, the areas of greatest contamination are either issued of punctual pollution from urban centers and industrial sites, or spread in diffuse pollutions, specially in North eastern of Mulhouse (Région Alsace 2005).

Then, no improvement in water quality seems to happen between the two inventories, whereas, as we will see later, many measures and controls have been implemented. Considering the behavior of CS in groundwater (cf. above paragraph), different conjectures could be exposed. The first one is the existence of remaining stocks of CS in the soils and the aquifer that continue to spread along pollution plumes. These stocks could be due to abandoned sites or pollution accidents. The second conjecture is the persistence of non-point source pollutions: rainfall or dispersed and small pollutions that are uneasy to manage.

As a result, the French and the German authorities in charge of implementing the Water Framework Directive have considered that the Upper Rhine aquifer was at risk of not achieving good chemical status by 2015, in particular due to pollution by chlorinated solvents (DIREN Alsace 2005).

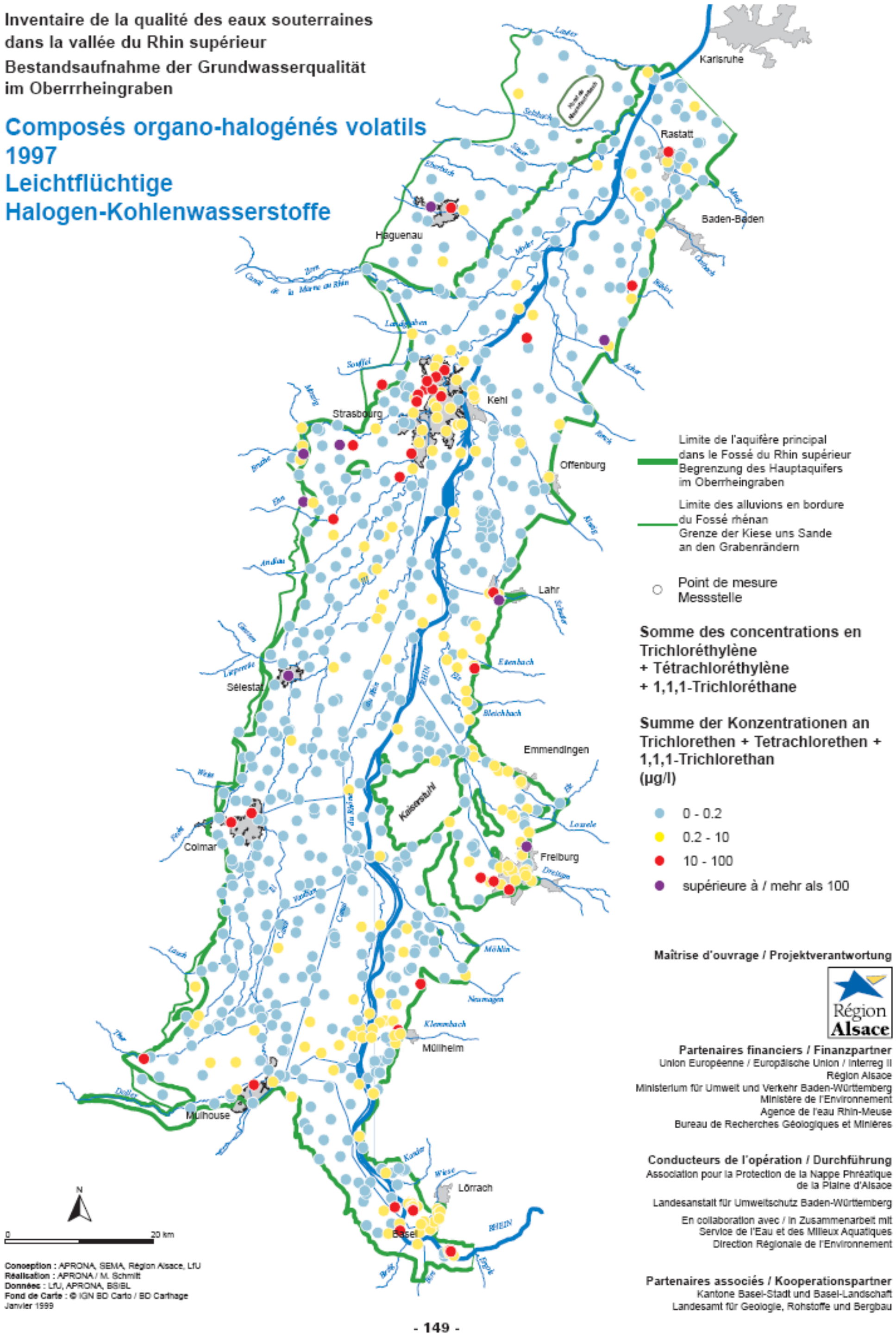

Figure 5: Chlorinated solvents concentrations in the Upper Rhine aquifer – 1997 water quality survey (France and German parts of the aquifer). Source: Région Alsace.

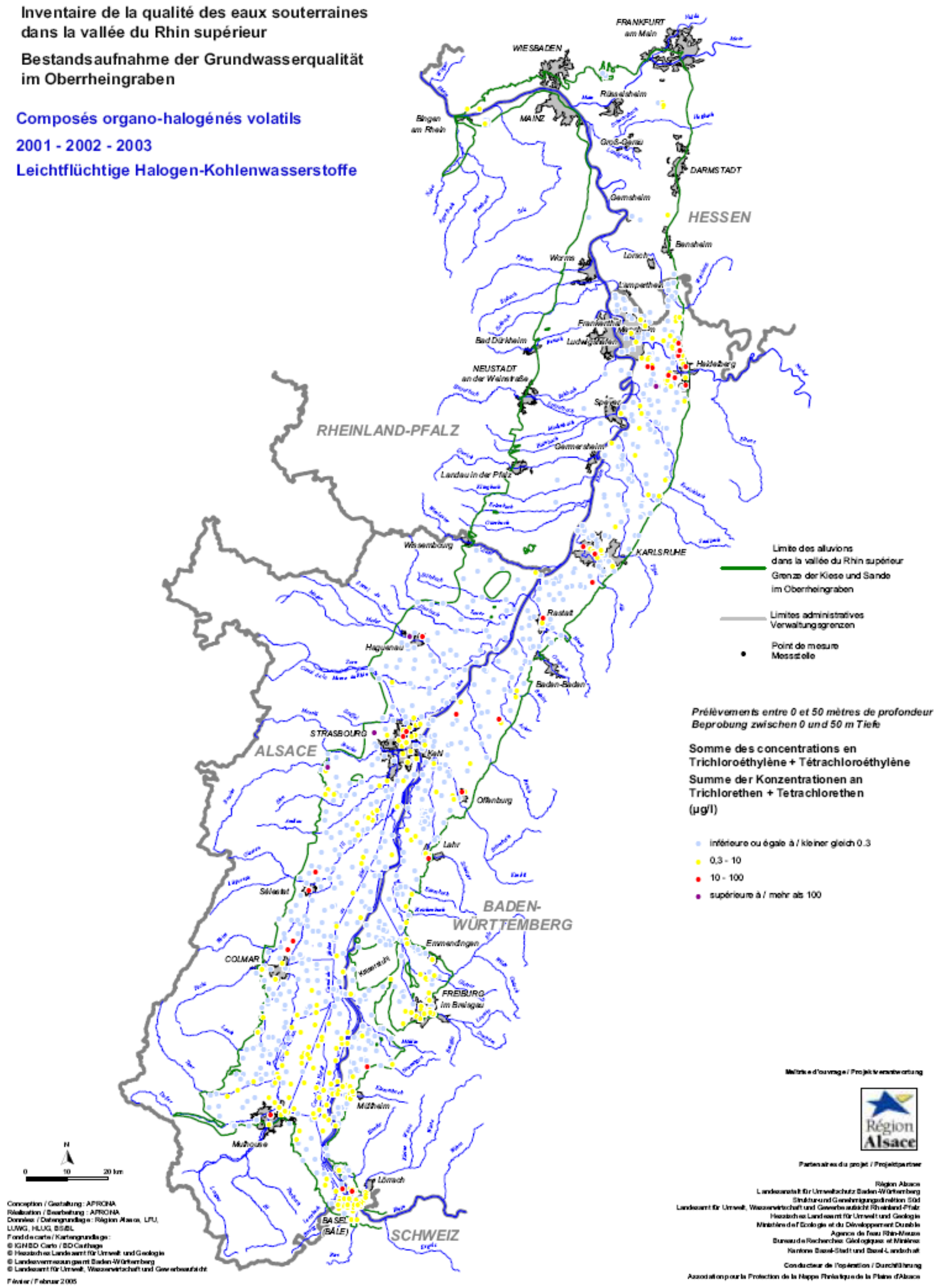

Figure 6: Chlorinated solvents concentrations in the Upper Rhine aquifer – 2003 water quality survey (France and German parts of the aquifer). Source: Région Alsace.

4. Designing a programme of measures for reducing pollution with chlorinated solvents in the upper Rhine valley aquifer

4.1 Overview of the methodology

The methodology developed consists in six major steps, as shown on Figure 7 below[4]:

1. Definition of the environmental objective to be achieved with the program of measures. Two distinct objectives were considered: the first objective consists in restoring drinking water quality, the second one consist in removing all traces of solvents (in the long term).

2. Identification of all groundwater monitoring points where chlorinated solvents are present in concentration exceeding the targeted threshold value. This step was carried out using the regional Groundwater quality database which comprises information for 423 monitoring points where most of the chlorinated solvents have been analysed (see previous section).

3. Identification of all activities generating a significant risk of pollution for the aquifer. This step was carried out based on an extensive literature review, internet search and a consultation of industrial experts. It resulted in a list of 111 economic activities identified as potential source of pollution.

4. Development of an integrated database compiling information related to groundwater quality and economic activity. The database was used to select all industries which activity belong to the list developed as part of task 2) and which are located in a municipality where groundwater is polluted.

5. Identification and description of the measures which can be implemented to reduce pollution for each of the 111 different activities. This task was also based on literature review and internet search as well as on expert consultation. For each measure, we assessed a unit cost (investment and O&M cost).

6. Definition of two alternative programmes of measures and assessment of their total cost, using the database developed in step 3 and the cost matrix developed in step 4.

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[4] This methodology was developed as part of a joint research programme by Brgm and the Water Agency Rhin Meuse, it has been applied to the Alsace case study aquifer as part of the BRIDGE project.

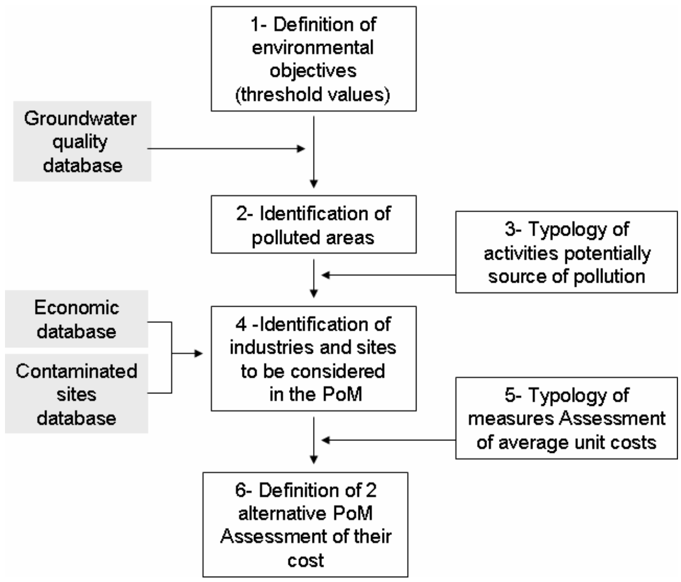

Figure 7: Overview of the methodology for designing the programme of measures.

4.2 Definition of environmental objective and identification of polluted areas

Two distinct objectives were considered: the first objective consists in restoring drinking water quality (scenario 1), the second one consists in removing all traces of solvents to restore natural groundwater quality in the long term (scenario 2).

Concerning the restoration of drinking water quality (scenario 1), we considered all different chlorinated solvents present in the aquifer. For some substances which are not covered by the Drinking Water Directive, we used World Health Organisation standards or Environmental Quality Standards as a threshold value. The threshold values considered in this study are given in below:

Substance	Priority Substance	Dir. 86/280 QS surface water	Drinking Water Directive	French SEQ – groundwater	WHO	Threshold values considered in this study
1 2 Dichloroethane	Yes	10 µg/l	3 µg/l	3 µg/l		3 µg/l
Tetrachloroethylene + Trichloroethylene	No		10 µg/l	10 µg/l		10 µg/l
Tetrachloroethylene	No	10 µg/l		10 µg/l		10 µg/l
Trichloroethylene	No	10 µg/l		10 µg/l		10 µg/l
Vinyl chloride	No		0,5 µg/l			0,5 µg/l
Chloroform	Yes	12 µg/l		10 µg/l		12 µg/l
Dichloromethane	Yes				20 µg/l	Not considered
Carbon tetrachloride	No	12 µg/l		2 µg/l	4 µg/l	4 µg/l
12 Dichloroethylene	No				50 µg/l	50 µg/l
111 Trichloroethane	No			200 µg/l	2000 µg/l	2000 µg/l

Table 2: Summary of existing threshold values for chlorinated solvents.

Concerning the restoration of natural groundwater quality (scenario 2), we considered that the environmental objective was met in a specific point if none of the chlorinated solvent was quantified (threshold value = quantification limit).

The groundwater quality database of *Région Alsace* (2003 data) was the used to identify all monitoring points where threshold values listed above are exceeded. Yearly average concentrations were calculated for each substance and each monitoring point. We found that drinking water thresholds were exceeded in 12 monitoring points and that the presence of solvents was detected in 236 monitoring points, located in 128 different municipalities.

	Scenario 1	Scenario 2
Threshold value	Drinking water standards or similar values, see Table 2.	Analytical quantification limit
Number of monitoring points where threshold values are exceeded for at least one chlorinated solvent (out of which threshold value is exceeded for tri and tetra chloroethylene)	14 (12)	236 (193)
Number of municipalities where measures have to be implemented	12	128

Table 3: Number of monitoring points where threshold values are exceeded for the two scenarios considered.

4.3 Typology of economic activities and identification of industries and sites sources of pollution

4.3.1 Typology of industrial activities

A list of activities using chlorinated solvents and presenting significant pollution risk was elaborated based on extensive literature review and expert consultation[5]. The activities were then ranked in terms of level of pollution risk. A total of 126 activities presenting a significant risk of pollution were then selected (only 113 are present in polluted areas). Activities were selected using the official list of economic activities developed by the French Institute for Statistics and Economic Studies (INSEE). They were then grouped into 8 categories as follows:

- *Mechanical industries*: this group includes 45 different economic activities producing various mechanical equipments. The use of solvents is related to degreasing operations and cleaning before metal coating.

- *Car and motorcycle workshops* (2 activities) are also considered as potential sources of pollution; solvents are used to clean mechanical parts.

- *Activities producing or using paint*: this group includes 11 activities, out of which 3 industrial activities producing glue, varnishes and paint; 5 activities producing furniture (use of varnish and paint); a wood impregnation activity; 2 activities related to house painting and decorating;

- *Metal coating activities*: this group includes 18 activities where metal coating operations are very significant; solvents are used for cleaning metal pieces before applying paint or any other coating; cleaning is generally carried out using specific solvent based washing machine.

- *Metal processing*: this group includes 7 metal cutting activities; metal cutting activities are performed using a cutting fluid (oil) for preventing an excessive elevation of the temperature during the cutting operation; at the end of the process, metal pieces are cleaned suing solvents.

- *Textile activities*: 4 activities (dying, industrial laundry, fur and leather industry) use solvents and represent potential risks of pollution.

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[5] This part of the work was carried out as part of a project conducted by BRGM for the Water Agency Rhin Meuse.

- *Chemical industries*: this group includes 11 different activities producing perfumes, pharmaceutical products, agrochemical products, rubber and other plastic material, artificial fibers, chemical products for industrial use, etc. Solvents are used as raw material in the production process or as extracting agent for certain chemical reactions. The risk of pollution is mainly due to the storage and manipulation of solvents within the industrial compound.

- *Other activities*: this group includes 4 activities manufacturing electrical and electronics equipment, the production of essential oils and coffee (solvents are used as extracting agent), 3 printing activities, industrial cleaning activities,

For all these activities, pollution may be due to: (i) leakage of a storage tank; (ii) leakage of a pipe transporting the solvent inside the industrial site; (iii) to the storage of used solvents before they are recycled; (iv) leakage occurring during the industrial process itself. Past pollution may also have lead to the accumulation of solvents in the soil which are progressively released in the aquifer.

4.3.2 Identification of source of pollution

The use of the integrated database compiling information related to (i) groundwater quality (Inventaire 2003), (ii) contaminated sites (BASIAS database) and economic enterprises (SIRENE database) has led to the assessment of the number of pollution sources to be considered in the program of measures. The number of pollution sources differs for the two scenarios. Results of this assessment are given bellow:

For Scenario 1 which consists in restoring drinking water quality, measures are implemented in 12 municipalities where monitoring points exceed drinking quality standards.

- We identified 41 abandoned industrial sites of risk 1 where further studies have to be undertaken to assess the actual risk of chlorinated solvent CS contamination. All these sites are located in one of the four major cities of the region: Mulhouse, Sélestat and the surroundings of Strasbourg. We assume that a Simplified Risk Assessment study will be carried out in each of the 41 sites; that the impacts on groundwater will be monitored for 50% of the 41 sites; and that 20% of the sites will effectively need remediation measures.

- Preventive measures also have to be applied to a total of 466 enterprises of these 12 municipalities, employing over 13 000 persons and generating an annual turn over of 3 millions Euros (estimated value). In addition, preventive measures are applied to house painting and decorating enterprises (975 enterprises, 3900 employees) and industrial cleaning enterprises (121 enterprises, 13500 employees) at the regional level; since these enterprises are mobile and can generate pollution in different places, measures aiming at reducing their pollution must apply at the regional level.

Economic sector	Number of enterprises	Number of employees	Turn over (thous. €)	Added value (thous. €)
Chemichal	14	1224	592	104
Electrical and electronic equipements	18	672	161	44
Car and motorcycle repair workshops	140	727	121	26
Food and beverage industry	3	20	8	2
Printing industry	60	770	101	34
Mecanical industry	117	6897	1682	400
Industry producing or using paint	46	793	125	35
Textile industry	5	228	22	7
Metal coating activities	57	1669	260	78
Metal cutting and processing industry	6	75	11	3
Total	466	13075	3081	734

Table 4: Enterprises located in polluted areas for which preventive measures are implemented (scenario 1).

For Scenario 2 which consists in restoring natural water quality (removal of traces), measures are implemented in 128 municipalities where races of chlorinated solvents are detected.

- We identified 114 abandoned industrial contaminated sites of risk 1 located in these municipalities where further studies have to be undertaken to assess the actual risk of chlorinated solvent CS contamination. As for scenario 1, we assume that a Simplified Risk Assessment Study will be carried out for all the 114 sites; that additional monitoring will be implemented for 50% of the sites; and actual remediation action taken in 20% of the sites.

- Preventive measures are applied to all mobile enterprises as in the first scenario. They are also applied to all potential polluting industries located in the 128 municipalities (1937 enterprises, see table below for details) and to the 975 house painting and decorating enterprise as well as to the 121 industrial cleaning industries.

Economic sector	Number of enterprises	Number of employees	Turn over (thous. €)	Added value (thous. €)
Chemichal industry	71	7 459	3 145	684
Electrical and electronic equipements	46	1 142	244	69
Car and motorcycle repair workshops	574	2 698	439	98
Food and beverage industry	26	463	184	42
Printing industry	276	3 571	460	158
Mecanical industry	462	35 092	11 230	2 210
Industry producing or using paint	177	4 844	778	213
Textile industry	16	577	56	19
Metal coating activities	241	5 837	767	254
Metal cutting and processing industry	44	888	200	46
Total	1 933	62 568	17 504	3 793

Table 5: Enterprises located in areas where the presence of chlorinated solvents is detected and for which preventive measures are implemented (scenario 2).

4.4 Typology of measures and average unit cost

Two types of measures can be applied to the different pollution sources. Preventive measures aim at reducing new contamination of the aquifer whereas remediation measures aim at removing existing stocks of COV present in soils or groundwater.

	Large point-source pollution			**Small dispersed point-source pollution**	**Diffuse pollution**
Origin	Historical contaminated sites	Industrial sites in activity	Accidents (transportation, storage)	Domestic and dispersed small industries pollution	Atmospheric pollution
Type of measures	*Remediation measures*: soil decontamination, pollution plume control (hydraulic barriers)	*Remediation measures*: soils treatment, plume control. *Preventive measures*: effluent treatment, controlled storage tanks, leaching water collection, technological changes, solvents recycling, warning systems, recycling f used solvents.	*Remediation measures*: pollution removal. *Preventive measures*: specific waste collection, ban of VOC of domestic uses, additional treatment in sewage plants.	*Remediation measures*: soils treatment, plume control. *Preventive measures*: transport and delivery precautions, roadside ditches and water collection.	Preventive measures: limiting VOC air emissions Covered by existing regulations.

Table 6: Typology of measures available for remediation of chlorinated solvent pollution.

4.4.1 Remediation measures

Remediation measures can apply to large scale industrial sites (ancient sites or sites in activity) as well as to small sites (car repair workshops for instance). They consist either in decontaminating groundwater pollution plumes or contaminated soils located above the aquifer. Conventional groundwater remediation techniques used in France include air stripping; air sparging; biosparging; bioremediation; chemical oxydation / reduction; and natural attenuation[6]. Treatment costs differs from one technique to another according to physical, chemical and hydrogeological conditions; but finally, they are all around 20 to 100€/t of treatment water with an average around 25 to 50€/t for air stripping or air sparging methods. Some of the above techniques can be also used for soil treatment: bioremediation in situ, biosparging, air sparging or chemical oxidation / reduction. Costs are the same: around 20 to 100€/t of contaminated soil.

Concerning historical contaminated sites: for the purpose of the study, we have estimated average total costs of remediation per site, considering the nature of the contaminated sites registered in the BASIAS database. Estimated average costs (see Table 7) are based on a consultation of experts and on real cost data for a limited number of sites in Alsace. Figures provided by the Communauté Urbaine de Strasbourg, relative to remediation of a pollution generated by Steelcase company, have been used to assess the average cost of large contaminated sites (see box bellow).

Type of measure for contaminated sites registered in Basias database	**Percentage of sites concerned**	**Average cost per site**
Simplified Risk Assessment study (soil and water analysis using existing wells, field survey): cost 10 000 €	100 %	10 000 €
Soil and water surveillance monitoring: soil sampling at 3- 4 meters depth, drilling of piezometers : Investment = 10 000 € + yearly operational costs 5000 €	50 %	10000 € investment + 5 000€ operational cost (during years)
Design and implementation of remediation action plan: deep soil sampling (through drilling) 15 000 €, additional piezometers (10 000€), analysis (5000€), study and design (8000€), remediation (150 000€).	20 %	188 000 €

Table 7: Cost of remediation measures applied to contaminated sites registered in the Basias database.

[6] The most frequently used technique is air stripping, due to its lower cost and good decontamination yield. Nevertheless, a complementary treatment is needed to avoid CS vapour transfer into the atmosphere. CS can be adsorbed through Granular Activated Carbon (GAC), they can be burned or chemically destroyed.

Box 1: Cost of remediation of a contaminated site in Strasbourg.
Past activities of the company Steelcase (ex. Strafor) has generated a pollution plume with VOC which extends over 7 to 8 kilometres. Decontamination has been carried out by the company on site, soil and groundwater remediation outside the site has been undertaken by the Communauté Urbaine de Strasbourg, using public funds. Decontamination has led to the removal of 750 kg of tetrachloroethylene, recovered over two years. The total cost of decontamination has been assessed as follows:
Diagnosis phase: Pollution source identification: data analysis (4000 €), field survey (4000€), designing groundwater sampling campaign (550€), 20 soil sampling at 3 meters depth on a 10 ha area (5000€), 20 deep soil sampling (28 000 €), gaz sampling and analysis (7000€), drilling of piezometers (20 000€). Cost of water analysis (5000€).
Designing remediation actions: comparing possible remediation technologies (3200€), designing remediation strategy (5500 €).
Implementing remediation action: use of venting and sparging technology, with 13 injection wells and 10 extraction wells (13 to 15 meters depth). 150 000 €
Source: personal communication (Nov. 2006), Gilles Rink, Communauté Urbaine Strasbourg.

Concerning enterprises in activity, we also consider that small scale soil and water contamination occurs in enterprises in activity. Contamination is supposed to occur in a percentage of enterprises which varies depending on the economic activity. To assess the cost of the programme of measure, we assume: (i) a percentage of sites where remediation measures actually have to be implemented; (ii) a percentage of the enterprises where a risk assessment study has to be implemented and (iii) a percentage of sites where investigative and surveillance soil and water monitoring has to be implemented (see Table 8).

Type of measure for contaminated sites registered in Basias database	**Percentage of enterprises concerned**	**Average cost per site**
Simplified Risk Assessment study (soil and water analysis using existing wells, field survey)	20% to 40% depending on type of activity and average size of enterprises within he category	5 000 €
Simplified Risk Assessment Study and drilling of 1 water surveillance well (piezometer) and chemical analysis once a year		10 000€ investment + 750€ / year for chemical analysis
Simplified Risk Assessment Study and drilling of 2 water surveillance well (piezometer) and chemichal analysis once a year		15 000€ investment + 1500€ / year for chemical analysis
Remediation of contaminated site	5%, 10% or 20% depending on pollution risk for the activity	From 8000€ for very small enterprises to 500 000e to large size

Table 8: Cost of remediation measures applied to contaminated sites in activity (not registered in the Basias database).

4.4.2 Preventive measures to be implemented per branch of activity

Preventive measures which can be implemented to reduce recurring or accidental soil and groundwater contamination can be grouped into the five following categories

- Measures aiming at reducing accidental leakage by constructing watertight areas under storage tanks, removing all underground pipes and tanks, securing all areas where solvents are transported or manipulated, constructing pounds to recover solvents in case of accident, etc. The average estimated cost of this type of measures ranges between 1000€ for very small enterprises to 10.000€ for larger industrial sites.

- Measures aiming at collecting all used solvents and other wastes containing solvents; this implies constructing storage premises for used solvents (which are sometimes still discharged directly in sewage system or in the environment) and organising their collection by companies specialised in treatment and recycling of toxic wastes. The cost of this type of measures depends on the volume of solvents to be collected and treated (1€/liter of solvent). The volume is estimated for each branch based on expert judgement.

- Clean technologies reducing emission of VOC: this includes the use of technologies where VOC are recycled (printing industry, painting related activities, mechanical industries, etc. Cost of equipment (investment) varies significantly from one industry to another. Average values were estimated based on various examples found in the literature or identified by experts. Estimated investment costs range between 2000 and 200 000€. Operational and maintenance costs are assumed to be relatively unchanged (in many cases, they are even reduced by the technology change).

- Substitution of chlorinated solvents with other solvents and/or use of technologies which do not require CS. For instance, cleaning of equipments used for painting can be done with ultrasonic devices; metal cleaning before coating can be done using bacteriological processes instead of solvents; etc. Estimated investment cost range between 10000 and 200 000€ depending on the branch of activity and the size of the enterprise.

- Waste water treatment using activated coal filters of a stripping tower (where solvents evaporate) with an activated coal filter to remove solvents from the vapours. The costs considered are investment and operation costs. To assess operation costs, we assume a concentration in solvents and a total volume to be treated; we then calculate the quantity of activated granulated coal needed to treat waste water and the related cost. Waste water treatment is only considered for textile industry, coffee processing and essential oil extraction.

- Monitoring measures which consist in installing a piezometer downstream risk zones and conducting surveillance chemical analyses to detect any pollution trace before it can generate a plume in groundwater. Investment costs are assessed as follow. For large industrial sites, we assume that a Simplified Risk Assessment Study is carried out and two monitoring wells are drilled for a total cost of 25 000€. An additional 1500€ are counted in operational recurring costs. For medium size sites, one SRA study is carried out and one well drilled (15 000€) whereas small sites only have to conduct an SRA study (5000 €).

4.5 Total cost assessment

4.5.1 Methodology

The total cost of the programme of measures is then assessed using the integrated database. One-off investment and yearly operational costs are estimated separately for each type of measures separately.

Investment costs are assessed as follows:

$$C_m = \sum_i (\alpha^i_{t,m} - \alpha^i_{c,m}).N^i.c^i_m$$

where :

C_m is the total cost of the measure "m"
$\alpha^i_{t,m}$ is the targeted rate of adoption of measure "m" for industries of branch "i"
$\alpha^i_{c,m}$ is the current rate of adoption of measure "m" for industries of branch "i"
N^i is the number of industries of branch "i" which are concerned by measure "m"
c^i_m is the average unit cost of implementing measure "m" for one enterprise of branch "i"

In practice, each branch "i" is further split into several categories depending on the size (number of employees) and parameters such as unit costs c^i_m and percentage of adoption (current and targeted) are estimated for each size. The same type of calculation is carried out for recurring costs (operation and maintenance). The values for all parameters ($\alpha^i_{t,m}$, $\alpha^i_{c,m}$, N^i , c^i_m) were estimated based on a extensive expert consultation, which was conducted with significant support from the Water Agency Rhin Meuse.

Operational recurring costs are assessed similarly. Investment and operational costs are then aggregated assuming a 4% discount rate and **ten years duration** for the programme of measures (this assumption is also used when assessing the benefits in the CV survey).

4.5.2 Total estimated cost for the two scenarios

The total cost of scenario 1, which consists in restoring drinking water quality is estimated at **22.4 millions €.** Approximately 82% of this cost consist of investments (18 millions €). This corresponds to approximately **13 € per inhabitant** of the Alsace region (1.759 millions inhabitant). The cost of measures concerning one activity (activities producing or using paints) represents half of the total cost. Three activities together represent almost 80% of the total cost.

Economic sector	Cost of PoM (thous. €)	% of total cost of PoM
Activities producing or using paint and varnishes	11 056	49%
Mecanical industry	3 606	16%
Contaminated sites	2 987	13%
Metal coating industry	1 891	8%
Car and motorcycle repair workshops	1 097	5%
Chemichal industry	881	4%
Printing	378	2%
Textile industry	184	0,8%
Manufacture of electrical and electronical products	166	0,7%
Industrial cleaning industry	60	0,3%
Food and beverage industry	47	0,2%
Metal processing and cutting industry	46	0,2%
Total	***22 405***	***100%***

Table 9: Estimated cost of programme of measure for scenario 1 and distribution of the cost between sectors of activity.

The total cost of scenario 2, which consists in restoring natural water quality, is estimated at **52.1 millions €.** Approximately 86% of this cost consist of investments (45 millions €). This represents approximately **30€ per inhabitant** of the population of Région Alsace (1.759 millions inhabitants). Approximately 50% of the cost is related to 2 economic activities (mechanical industry and activities using or producing paint).

Economic sector	Cost of PoM (thous. €)	% of total cost of PoM
Mecanical industry	13 769	26%
Activities producing or using paint and varnishes	12 039	23%
Contaminated sites	8 308	16%
Metal coating industry	5 566	11%
Chemichal industry	4 408	9%
Car and motorcycle repair workshops	4 422	9%
Printing	1 439	3%
Textile industry	924	2%
Food and beverage industry	471	0,9%
Manufacture of electrical and electronical products	396	0,8%
Metal processing and cutting industry	340	0,7%
Industrial cleaning industry	60	0,1%
Total	***52 147***	***100%***

Table 10: Estimated cost of programme of measure for scenario 2 and distribution of the cost between sectors of activity.

The analysis of the distribution of the cost per type of measures (remediation of historical sites excluded) is depicted in Figure 8 and Figure 9. Figures show that, for scenarios 1 and 2, two types of measures represent more than 60% of the total cost (Use of substitution products or technologies and Remediation of contaminated soils and water).

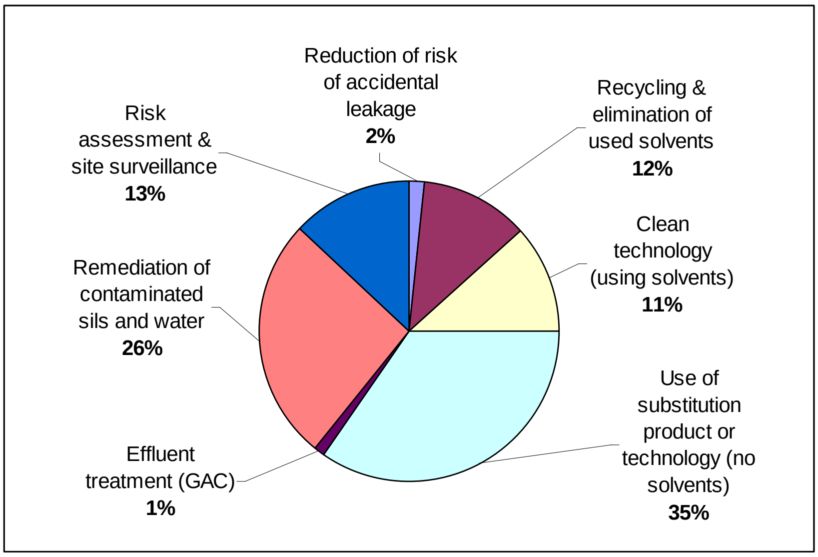

Figure 8: Distribution of the total cost per category of measures (scenario 1)

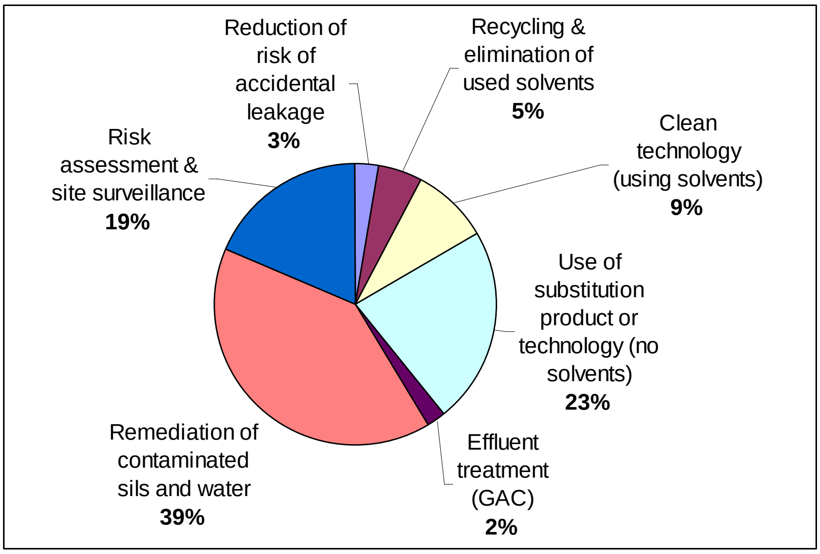

Figure 9: Distribution of the total cost per category of measures (scenario 2)

4.5.3 Financing the programme of measures

The total cost of the measures (remediation of historical sites excluded) has been compared to the total turn over and added value for each economic sector. The cost per employee has also been computed per economic sectors (see Table 11 and Table 12). The values estimated for these indicators show that the cost of the measures represents a significant share of the total turn over of concerned enterprises. The total cost even exceeds the total turn over for a number of economic sectors. This stresses that industries will not be able to finance the programme of measures and that financial transfers are necessary.

Economic sector	**Total cost (thous. €)**	**Cost / Turn over**	**Cost / added value**	**Cost/ employee**
Car and motorcycle repair workshops	*1 097*	*4,6*	*20,7*	*755*
Chemichal industry	*881*	*0,1*	*0,8*	*65*
Food and beverage industry	*47*	*6,2*	*25,7*	*2 364*
Food and beverage industry 'essential oils)	*0*			
Furniture industry	*297*	*0,5*	*1,7*	*75*
House painting and decoration	*10 685*	*42,9*	*150,5*	*6 737*
Industrial cleaning industry	*60*	*0,2*	*0,2*	*4*
Manufacture of electrical and electronical products	*166*	*0,2*	*0,6*	*41*
Mecanical industry	*3 606*	*0,0*	*0,2*	*12*
Metal coating industry	*1 891*	*0,4*	*1,4*	*63*
Metal processing and cutting industry	*45*	*0,6*	*2,2*	*87*
Printing	*378*	*1,3*	*3,7*	*164*
Production of paint and varnishes	*74*	*0,2*	*0,7*	*31*
textile industry	*184*	*2,1*	*6,2*	*203*
Wood impregnation	*0*			
Total entreprises	*19 417 347*	*0,2*	*0,9*	*50*

Table 11: Indicators to assess the significance of the cost per economic sector (Scenario 1). Remediation of historical contaminated sites excluded.

Activity	**Total cost** (thous. €)	**Cost / Turn over**	**Cost / added value**	**Cost/ employee**
Car and motorcycle repair workshops	4 422	18,3	83,5	820
Chemichal industry	4 408	0,7	3,8	54
Food and beverage industry	421	55,2	229,3	911
Food and beverage industry 'essential oils)	49	6,5	27,2	108
Furniture industry	1 154	1,9	6,5	48
House painting and decoration	10 685	42,9	150,5	1103
Industrial cleaning industry	60	0,2	0,2	4
Manufacture of electrical and electronical products	396	0,4	1,5	58
Mecanical industry	13 769	0,2	0,8	9
Metal coating industry	5 566	1,2	4,0	53
Metal processing and cutting industry	340	4,6	16,2	55
Printing	1 439	4,8	14,1	134
Production of paint and varnishes	170	0,5	1,6	12
textile industry	924	10,7	31,2	401
Wood impregnation	30	0,2	0,9	6
Total entreprises	43 838	0,5	2,0	24

Table 12: Indicators to assess the significance of the cost per economic sector (scenario 2). Remediation of historical contaminated sites excluded.

4.5.4 Sensitivity of the cost to targeted threshold value

The calculations presented above have been repeated for various threshold values corresponding to a percentage of the drinking water standards. The results depicted in the three figures below, show that the cost of the programme remains relatively stable for a targeted threshold value ranging between 50% and 100% of the drinking water threshold. The cost of the programme of measure then increases significantly (multiplied by 2) when the targeted threshold value goes lower than 40% of the drinking water standards. The increase which occurs around 40% is mainly due to an increase of historical contaminated sites when remediation is implemented (see Figure 11).

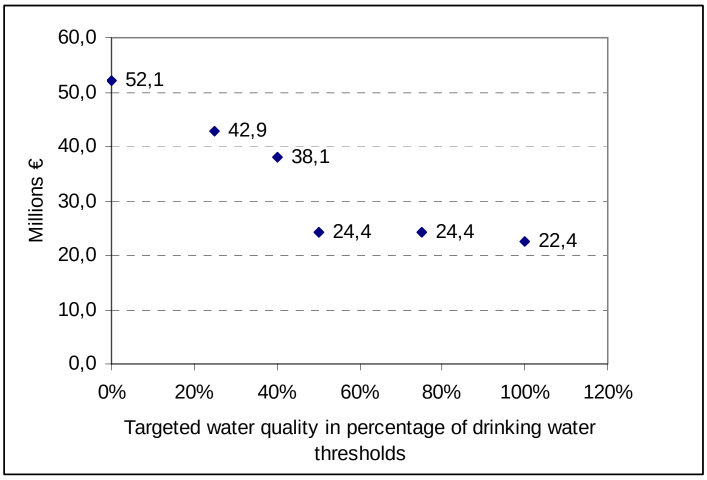

Figure 10 : Evolution of the total cost as a function of the targeted threshold value (expressed in percentage of drinking water standards)

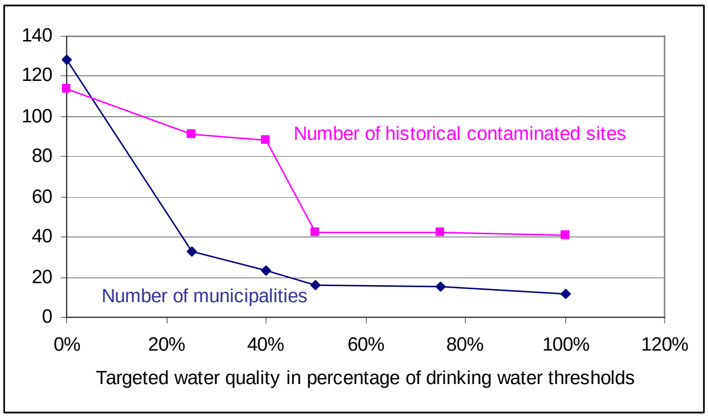

Figure 11 : Evolution of the total cost as a function of the targeted threshold value (expressed in percentage of drinking water standards)

5. Public perception of groundwater pollution: methodology and results of the survey

Assessing the benefits of groundwater remediation was the second key component of this case study which aims at conducting a cost-benefit assessment of alternative scenarios of groundwater protection and remediation. The benefits associated to the two scenarios described in the previous section were assessed using the contingent valuation method. This section describes the set up of the survey conducted in Alsace in spring 2006. It then describes public perception of groundwater pollution and of the two remediation scenarios, using descriptive statistics.

5.1 Survey set up

The implementation of a contingent valuation survey generally consists in 6 technical steps (Pearce, Ozdemiroglu et al. 2002): (i) the choice of survey method; (ii) the questionnaire design; (iii) the identification of targeted population and sample choice; (iv) the test of the questionnaire; (v) data collection and analysis; (vi) test of the validity and reliability of the results. The following paragraphs describe how these steps have been implemented in the present case study in the Upper Rhine valley.

5.2 Defining the good to be valued (scenarios)

The first step consisted in defining the environmental goods that respondents would have to value. The goods being distinct levels of "improvement of groundwater quality", their definition was based on three elements: (i) a description of the environmental improvement targeted by the scenario; (ii) a description of the impacts of that improvement on their utility and (iii) information on the technical measures which could be implemented to achieve the targeted environmental improvement. Concerning the description of the technical measures, it was rather difficult to find the appropriate level of details to be given to respondent: the test showed that insufficient technical information was weakening the credibility of the scenarios whereas an excess of information was resulting in respondents valuing the measures and not the environmental improvement.

The two scenarios differ in terms of intensity of the measures implemented, number of actors concerned by the measures and level of water quality achieved. The first scenario is such that allows a restoration of drinking water quality in the entire aquifer (defined as compliance with drinking water standards). The second scenario is based on more intensive measures allowing the restoration of groundwater natural quality, defined as a total suppression of all traces of chlorinated solvents in the long term (50 years). For both scenarios, it is assumed that action is taken by public authorities to solve the three other pollution problems, meaning that solving the chlorinated solvent problem is the only obstacle to achieving the drinking water quality (scenario 1) or natural water quality (scenario 2). The table below presents the main characteristics of the two scenarios.

	Scenario 1	**Scenario 2**
Objective	Restoring drinking groundwater quality	Restoring natural groundwater quality (no traces of solvents in the long term)
PoM timing	10 years	10 years
Actions implemented as part of the scenario	- Remediation measures implemented in historical contaminated sites located in areas where CS exceeds drinking water threshold value - Preventive measures applied (through regulation) in all enterprises using chlorinated solvents and located in areas **where concentrations in solvents exceed drinking water threshold**.	- Remediation measures implemented in historical contaminated sites located in areas where traces of solvents are detected - Preventive measures applied (through regulation) in all enterprises using chlorinated solvents and located in areas **where traces of solvents have been detected**
Expected benefits	- Drinking water quality level restored within **10 years** but traces of CS remain in the aquifer, with risk of impacts on ecosystems. - Reduction in drinking water treatment cost.	- Natural quality restored, traces of CS disappear within **50 years**: natural attenuation contribution. - Environmental benefits for ecosystems and water related species, absence of risk for humans using groundwater. - Heritage benefits (for future generations).

Table 13: Description of groundwater restoration scenarios.

The water bill is chosen as the payment vehicle for the survey. The WTP question is formulated as an open question. A payment card is offered to the respondents to elicit their WTP. The card includes thirty five amounts, with a minimum of 2€ (on top of the zero bid which is allowed) and a maximum of 500€ (value chosen after the questionnaire was tested through face to face interviews, see below).

5.2.1 Description of the questionnaire

The questionnaire is structured as follows. *An introduction letter* presents the objective of the survey and what the results will be used for. The letter is signed by the project coordinator at Brgm whose name and details are given so that respondents can ask for more information. Brgm internet address is also provided. We also ensure the respondents that their questionnaire will be kept anonymous, and thank them for cooperation.

The questionnaire starts with providing a *brief description of the upper Rhine valley aquifer* accompanied with a map showing the extension of this aquifer in the Upper Rhine valley.

The map intends to help respondents identify if the locality they live in is located above the aquifer or not.

The first set of questions is related to the *respondents' uses of the good*. These questions aim at identifying respondent uses of water (water related leisure activities such as fishing or canoeing, use of tap water as a drink or not, etc).. In particular one question aims at knowing if the respondent distinguishes between surface water and groundwater. Another question tries to quantify the part of the population that usually refuses to drink tap water and to identify the reasons. The last questions were about the respondent knowledge of its own water bill.

The questionnaire continues with a series of questions aiming at characterising *perception and attitudes towards the good*. The respondent is asked to rank (from the most to the less important to them) a series of general economic, social and environmental problems (including groundwater). Three additional questions aim at capturing the perception of good water status for the respondent and at characterizing its perception of present and past quality of ground and surface water. The other three last questions are related to pollution perception, in terms of contaminants and origins of pollution.

A short text accompanied with a map then presents the *current situation* (reference scenario). The text presents the four major pollution sources (nitrates, pesticides, chlorides from the mining industry and chlorinated solvents). It explains that, whereas the problems of nitrates, pesticides and chloride should be addressed by the authorities and solved by 2015, in response to European constraints, pollution with chlorinated solvents shall remain to a large extent unsolved. Pollution with chlorinated solvents is therefore presented as the only remaining obstacle to good groundwater quality. The extent of today's pollution with chlorinated solvents is depicted with a map which shows in red locations where solvents have been found in concentration exceeding drinking water thresholds and in yellow where traces not exceeding the drinking water threshold have been found. The text briefly identifies origins of the contamination and presents future pollution trends if no remediation and preventive measures are undertaken to limit the pollution. This part of the questionnaire ends with asking if the respondent was already informed of the current situation and if this description seems realistic to him.

The *two scenarios to be valued* are then presented. The description of the scenarios is followed by a series of questions aiming at assessing: the perception of the realism of the scenario; respondents' willingness to pay for the scenarios in principle; the amount he/she is willing to pay; the motivations for accepting (or refusing to pay). For scenario 2, we also ask how important it is for the respondent to restore natural quality.

The questionnaire ends with a series of questions related to the *socio-economic characteristics of the household* (age and sex of the respondents, composition of the household, education level, income, etc.).

5.2.2 Targeted population and sample

Questionnaires were sent by surface mail to 5000 households selected by a subcontractor, following Brgm's indications. We targeted three groups of the population: the first one consists of households living in localities located above the main aquifer in rural area (2000 questionnaires / 40%); the second consists of households living above the main aquifer but in urban areas[7] (2000 questionnaires / 40%); and a last group living in localities located outside the main aquifer (1000 / 20%). Then three lists of municipalities were prepared and households where selected randomly within each list. As shown in Table 14, the distribution of returned questionnaire within the three categories was corresponding to the intended distribution (38.5% rural aquifer, 40.5% urban aquifer, 21% outside aquifer).

The definition of these quotas was based on the expectation that WTP would differ significantly between these three samples. People living above the aquifer were expected to be more likely to contribute than others. Similarly, urban people were expected be more sensitive to the aquifer pollution that rural, given that they are more exposed to carious types of pollution sources.

	Above aquifer	Outside aquifer	Total
Rural municipalities	**236 (**48.56%*)	**104 (81.25%)**	**340 (55.37%)**
Urban municipalities	**250 (**51.44%)	**24 (18.75%)**	**274 (44.63%)**
Total	**486 (79.15%)**	**128 (**20.85%)	**614** (100%)**

* Bold numbers correspond to our 3 sub-samples. Rural and urban municipalities of the outside aquifer were recoded after the survey.
** We receive 668 useable questionnaires but not all the respondents give all the required information. That explains why the geographical distribution is made over 614 questionnaires.

Table 14: Distribution of returned questionnaire between rural and urban areas and between localities located above and outside the main aquifer area

The questionnaires were posted mid-April 2006 by the subcontractor. The deadline for returning of completed questionnaire was fixed to June 14th. To encourage households to return the completed questionnaire, the first hundred respondents were offered a book from a series called "Nature Wonders" edited by Brgm (dealing with issues such as water, fossil, volcanoes, etc.) of a value of 15€.

[7] Urban zones are defined according to INSEE classification of "urban area".

5.2.3 Pre-test results

The pre-test of the questionnaire was conducted in the streets of Strasbourg during three days between March 9th and 11th. The interviews were conducted by 9 interviewers (4 women, 5 men). Five of the interviewers were neither familiar with the methodology nor with groundwater management issues (students of IECS at Strasbourg). Overall, 140 interviews were conducted in three days.

The test helped at : (i) identifying difficulties encountered with some questions; (ii) testing whether to keep some questions open or closed; (iii) adjusting the quantity of information to be provided when presenting the scenarios; (iv) changing the elicitation method trying an open-ended method with an without payment card. The description of the scenario was clearly a critical issue, as it was found to influence the rate of protest answers, either because of insufficient information (respondents refusing to pay without understanding what would be done with their money) or because of an excess of information (respondents focussing on the description of measures and their cost instead of assessing the value of the benefits generated by the program).

5.2.4 Data analysis and reliability and validity of the results

Data entry has been managed by a subcontractor using an optical form reader. Open ended questions were entered manually by the authors after recoding. An extensive data cleaning procedure was then carried out through a series of test of consistencies of replies to interlinked questions. The data were then analysed using the statistical software STATA 9.0.

5.3 Sample characteristics and representativeness

With 668 complete and useable returned questionnaires, the response rate was 13.4%. This value corresponds to those found in other CVM studies. The fact that questionnaires were sent by post induces a bias questionnaires were returned by people more sensitive to environmental issues than the average inhabitant of Alsace. This sample represents less than 0.04% of the population of Alsace region[8].

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[8] According to INSEE (INSEE Alsace 2006), the total Alsatian population was composed of 1 759 000 habitants in 2004 which represent 735 000 households with an average of 2.4 persons per households. The Upper Rhine aquifer

Over the 668 respondents, 67% are women, whereas they represent 51.1% of the total population. Women are then over represented in our sample.

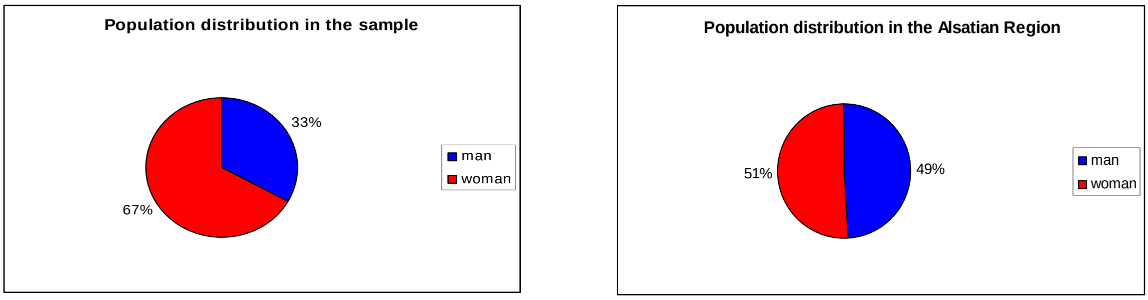


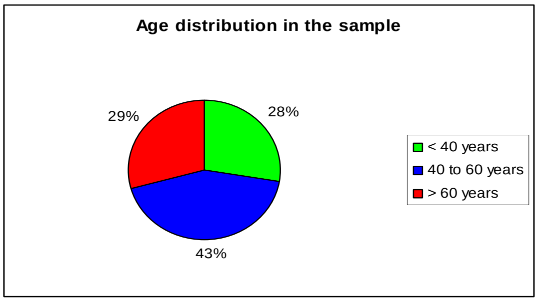
Figure 12: Male and female distribution in the sample (left) and in Alsace (right).

The individual age variable can give an idea of mean age of the household. In our sample, the population is spread as shown in Table 15, compared to the Alsatian data. The respondents sample is over representing the categories above 40 years old.

Age categories	% in our sample	% in Alsace
<40 years	**27.8%**	**53.8%**
40 to 60 years	**42.9%**	**27.8%**
> 60 years	**29.3%**	**18.5%**

Table 15: Distribution per age of the sample population and of the population of Alsace. Source: (INSEE Alsace 2006).

covers around half of the Alsatian region, being the most populated part of it since the biggest urban centres are located there. Roughly 1 million people live above the aquifer (estimated using INSEE 1999 figures).


Age distribution in the sample
29%
28%
43%
< 40 years
40 to 60 years
> 60 years

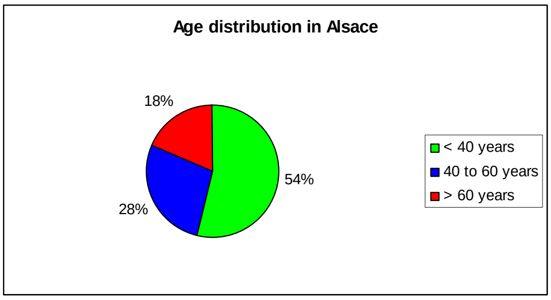

Age distribution in Alsace
18%
54%
28%
< 40 years
40 to 60 years
> 60 years

Figure 13: Population age distribution in the sample (left) and in Alsace region (right).

In our sample, 31.4% of the respondents are born in the Alsatian Region and 81.2% have been living in the Region for more than 20 years. According to INSEE data (INSEE Alsace 2006), 72.3% of the Alsatian population was born in Alsace.

Almost half of the sample has obtained a high educational degree against 19.7% having at least a first university degree at the regional level (INSEE Alsace 2006).

Sample households are composed of 2.7 persons (from one to nine) with an average of 0.84 children per household (from 0 to 5), which is quite consistent with the 2.4 person per household calculated at the regional level (INSEE Alsace 2006).

Around 19% of the respondents are working in the industrial sector, which seams to over represent this professional category (Figure 14). With more than 28% of the respondents, retired workers are also over-represented, an observation which confirms the age bias. Some economic sectors such as tourism, recreation, restoration and agriculture sectors are under-represented in the sample. The same statement applies for unemployed persons.

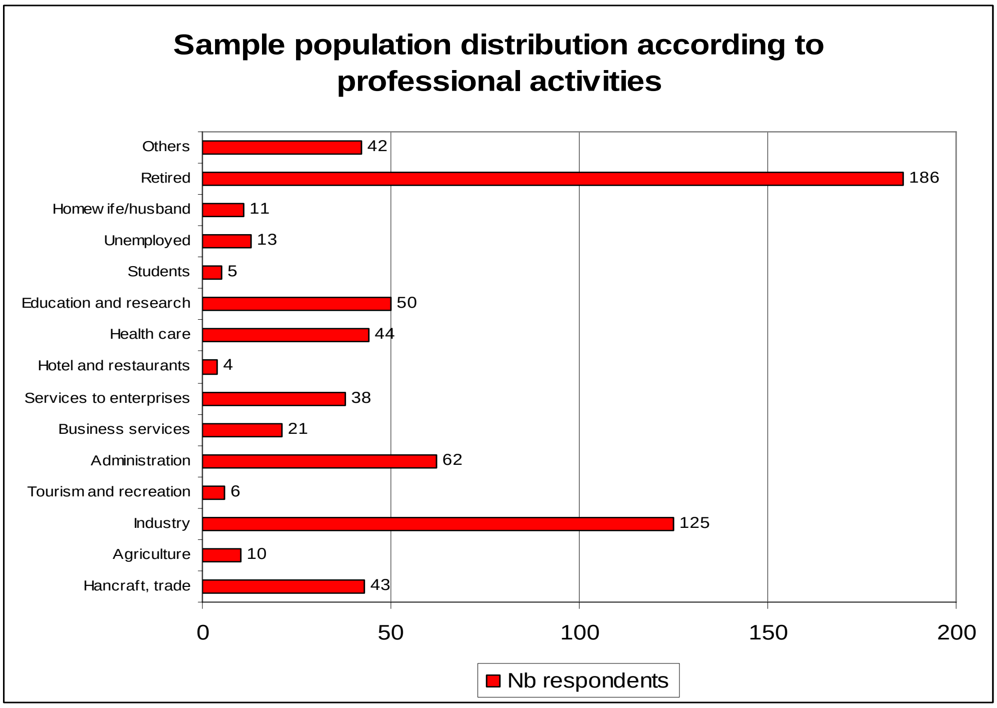


Figure 14: Distribution of the sample according to sector of professional activity (total number of respondents 668).

Concerning households' income, about 20% of the sample households earns less than 1500€/year, 45.5% earns between 1500 and 3000€ and 35% earns more than 3000€. High incomes are obviously over-represented in our sample, possibly reflecting a correlation between environmental sensitivity and income level.

A total of 14.5% of the sample persons are members of an environmental association. This is another bias induced by the sampling method.

As a conclusion, we can say that sample bias will be a major problem in order to extrapolate households' willingness to pay to the whole Alsatian Region population.

5.4 Public water uses and perception of groundwater quality

5.4.1 Description of water uses

Water related activities of the respondents are the following. Almost all respondents (97%) declare *walking along rivers and lakes*. Around 76% of them are often or very often walking near water. As a contrary, *fishing* in gravel pits (groundwater) is only practiced by 9.7% of the respondents, fishing in the rivers and lakes by 17.5%. Forty three percents of respondents are occasionally *swimming* in gravel pits, but not very frequently. Some 22% of the respondents are practicing *other water related activities*.

Only 15% of the respondents <u>*own a well or a spring*</u> of which 12.4% are located above the aquifer and 2.6% outside (they use local small aquifers or mountain springs). Most of them use water for outside purposes (car washing, gardening). When the water is used inside the house, it is for toilets (9% of respondents). Only 6% of them (half) use it for showering, cooking or drinking.

40.6% of the respondents are <u>*drinking tap water*</u> everyday whereas 9% never drink it and 31% rarely do. The main reasons why people never or rarely drink tap water are the following: 57.7% prefer mineral water or other kind of drinks; 44% do not trust tap water quality; 53.2% find tap water has a bad taste due to the presence of chlorine or because it is too hard; 50.6% say they got used to drink bottled water.

More than 14% of the respondents declare having already experienced a <u>*tap water pollution*</u> problem, which is a significant part of the sample. Concerning the <u>*water bill*</u>, 61.9% of the respondents know the amount they pay for water each year. Though, only 53.5% of the respondents are able to quote precisely the amount of their bill. The stated amount is of 316€ on average per household, that is around 117€/person/year.

5.4.2 Perception of water quality

We propose to the respondents to consider *how important some problems were to them in Alsace*. Some of the problems are considered as very important: air pollution (for 47.6% of the respondents), groundwater pollution (44.6%) and health problems (42.6%). All other problems and quoted as important enough by the respondents: noise (with some trends towards not important at all), employment, surface water pollution, security problems, ground pollution and biodiversity erosion.

Respondents chose different *definition of what a good quality water is* (multiple answers allowed). The following assertions are accepted as shown in Table 16 below:

For you, a water of good quality is …	Yes
…which can be drunk without any prior treatment	82%
… such that it provides optimal living conditions for fauna and flora	70%
…in its natural state, it has not been affected by human activity	67%
… such that one can swim and fish in it, use it for watering gardens	44%
… which can be used by industry without significant treatment	25%

Table 16: Perception of various definitions of water quality

The quality of water in the environment is perceived as follows. Close to 48% of the respondents think that rivers and lakes are of medium quality whereas only 22.6% think it is good or very good. Gravel pit lakes. The quality of water in gravelpit lakes and groundwater is perceived similarly, with 37% of the respondents find that gravel pits lakes are of medium quality (36% for groundwater) and 23% thinking that they are of good to very good quality (32% for groundwater). Note that the percentage of respondents who have no idea of gravel pits lakes and groundwater quality is quite high (respectively 27.1% and 18.1%).

The same remark can be done concerning the perceived evolution of groundwater quality evolution: over 20% of the respondents have no idea about quality trends, 45% perceive degradation whereas 27% do not perceive any significant change.

Concerning the *perception of groundwater pollution*, 22% of the respondents never heard about Upper Rhine pollution aquifer cases whereas 54% do. Only 21% can give concrete examples of Upper Rhine aquifer pollution cases and 2.6% have been personally exposed to this kind of pollution.

According to the respondents, *the main causes of groundwater pollution* are agriculture and industry. Respectively 88% and 86% of respondents consider that agriculture and industry are “very” or “quite polluting” activities. Other activities are les quoted and only considered as very or quite polluting by 55% for mining activities, 50% for domestic activities, 44% for transport, 35% for small enterprises and 16% for craftsmen.

When asked to identify within a *list the polluting substances* which are present in the aquifer, respondents mainly quote nitrates (86%) and pesticides and herbicides (84%). They are fewer to quote heavy metals (44%), chlorides (45%) and hydrocarbons (33%). Chlorinated solvents are quoted by 53%, putting them in third position after nitrates and pesticides.

5.5 Public willingness to pay for groundwater quality improvement

5.5.1 Perception of the description of the reference situation and policy scenarios

After having read the description of the current situation in terms of water quality in Alsace, 82% declare that they were not well (or not at all) informed about it before reading the text. While most of the respondents consider the description of the reference situation as realistic and credible (48%) or very realistic and credible (48%), only 3% of declare that the information provided to them is not credible (0.8% not at all credible). The analysis of manuscript observations reveals that the concerned respondents reject the assumption that the nitrate and pesticide pollution problem will be solved within ten years.

Most respondents consider the two proposed hypothetical scenarios as credible (79% for the first one and 80% for the second). Respectively 1.7% and 1% consider the first and the second scenario as *not at all* credible. More than 27% of respondents who consider the first scenario (restoration of drinking water quality) as not credible still accept to pay for it.

Overall, while the willingness to pay related questions are perceived as very difficult to answer by 5% of the respondents and quite difficult to answer by another 23%, 72% did not feel any difficulty to estimate their willingness to pay.

5.5.2 Willingness to pay for restoring drinking water quality (scenario 1)

Only 62% of the respondents accept that their water bill be increased to cover the cost of the measures required to improve water quality up to the drinking water standards. The average amount declared by respondents willing to pay is 42€ per household (corresponding to 13% of the average water bill for a household of 4 persons in Alsace), with a minimum of 2, a maximum of 500€ and a median of 30€. Only 6.4% of respondents willing to pay in principle were not able to specify the amount of their bid. The distribution of WTP is presented in Figure 15 below. The WTP logarithm seams to be quite adapted to approximate the distribution (Figure 16).

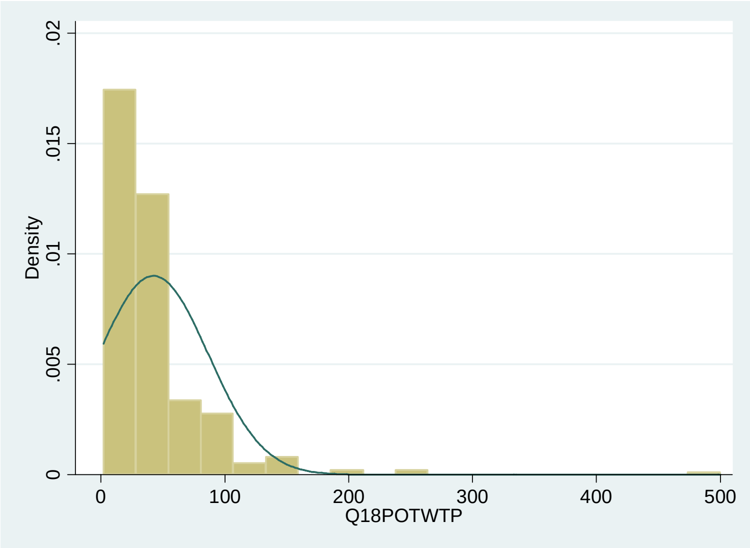


Figure 15: Distribution of willingness to pay amounts for the first scenario.

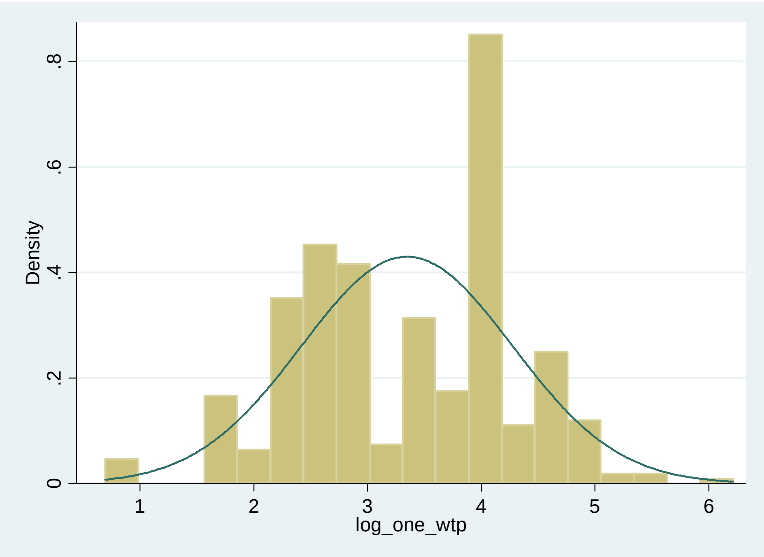


Figure 16: distribution of the log(WTP) for the first scenario.

Unexpectedly, the average willingness to pay of respondents living above with aquifer is not higher than WTP declares by respondents living outside the aquifer – which was one of the assumptions to be tested. We did expect that people living above the aquifer and thus connected to groundwater especially through public water services would be more likely to contribute. Secondly, respondents coming from urban localities above aquifer contribute more than rural respondents confirming our expectations.

	Above aquifer	Outside aquifer	Total
Rural municipalities	**38.17€**	47.62€	**40.98€**
Urban municipalities	46.35€	**39.64€**	45.74€
Total	**42.31€**	46.06€	**42.39€**

Figure 17: Average WTP in localities located above and outside the aquifer.

When asked to describe their motivations to pay, most of the respondents justify their contribution by the fact that the Alsatian population will need an aquifer of drinking water quality in the future (for 67% of the persons who accept to pay), which corresponds to an altruist use value (or an option value). Other reasons advocated are the personal direct use of the aquifer by 64.4% (direct use value), preference to pay now for protecting the resource as compared to pay later for treating drinking water (option value) quoted by 62% and the protection of aquatic life by 58.5% (non use value). More than 47% of the respondents also asset that they pay for the protection of this aquifer as they would pay for any other (pointing at a possible risk of warm glow effect), but given that this answer was suggested, we do not eliminate respondents who have quoted this reason.

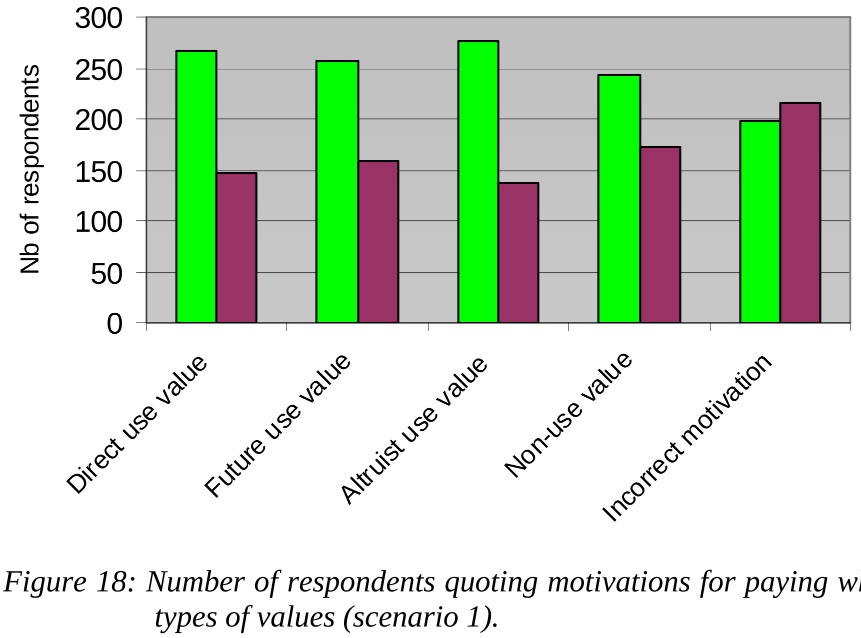


Figure 18: Number of respondents quoting motivations for paying which relate to different types of values (scenario 1).

Respondents refusing to pay have frequently used text to explain their position (56% of respondents refusing to pay). A detailed analysis of the reasons advocated show that most of the hand written explanations correspond to protest positions (96% of them), mainly due to the fact that the scenario is inconsistent with the polluter pays principle. Another 17% reject the scenario due to the proposed payment vehicle and assert that they would be willing to pay but not through an increase of their water bill[9]. Overall, approximately 73% of respondents refusing to pay are protesting. There are much fewer to advocate income constraints (31%). A bit less than 12% do not feel concerned by the pollution of the aquifer and only 2.4% consider this is not an issue of priority for them. Given that multiple answers were given for this question (although the instruction specified this was not allowed…), we consider that all respondents who have given at least one answer corresponding to a protest are protesting.

5.5.3 Willingness to pay for restoring natural water quality (scenario 2)

Although 98% of the respondents consider quite (30%) or very (68%) important to restore natural water quality in the entire aquifer, only 80% believe this is a realistic (or quite realistic) objective, while 20% consider it unrealistic.

The percentage of respondents refusing to pay for this scenario (43%) is slightly higher than for the first scenario (38%). Overall, more than 54% of the respondents accept to pay for the first and the second scenario, and 2% accept to pay for the second scenario whereas the rejected the first one. A total of 8% of the respondents accept to pay in principle but they are not able to give a specific amount. The average stated WTP is 34€ per household and per year, this amount being a *contribution offered in addition to the first one*. The minimum is 1€ and the maximum 500€. After adding the two stated WTP, the average total WTP for the second scenario is 76€ per household and per year and the median is 50€.

Similarly to what we found for the first scenario, the difference of WTP stated by population located above and outside the aquifer area is not significant. The difference is also not significant between rural and urban populations (see table below).

	Above aquifer	Outside aquifer	Total
Rural municipalities	**68.73€**	85.80€	**74.01€**
Urban municipalities	82.96€	**62.00€**	80.71€
Total	**75.90€**	80.70€	**76.06€**

Table 17: Average WTP stated in urban and rural municipalities and in municipalities located above and outside the aquifer.

[9] This attitude is not really surprising given the intensity of the debate on the price of water which took place a few months before the survey and which has been widely covered by the press.

The distribution of the stated WTP is given in the two figures below.

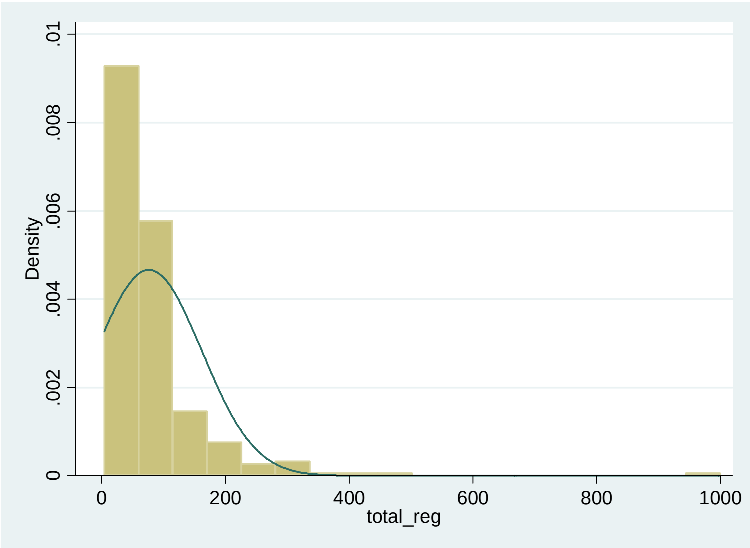


Figure 19: Distribution of WTP for the second scenario.

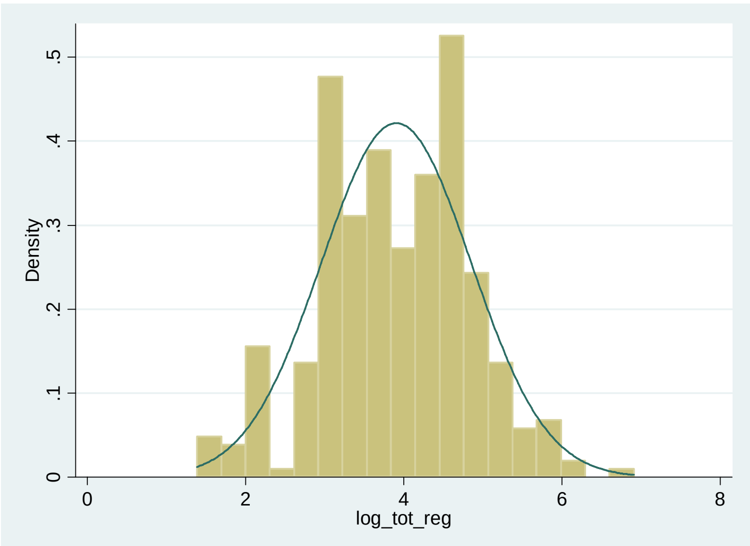
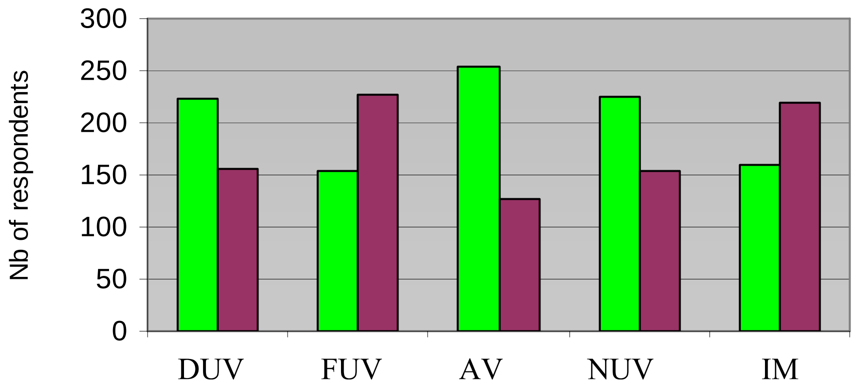


Figure 20: Distribution of the log(WTP) for the second scenario.

Concerning the stated motivations for paying, the most frequently quoted responses correspond to option use value, direct use value and non use value. The motivations have been quoted as follows:

- "the Alsatian population will need natural groundwater in the future: 66.7% of the responses (option value or altruist value);
- "to protect the aquatic life": 59.4% (non use value)
- "because I use the groundwater": 59.10% (direct use value);
- "I will be able to drink tap water again if all contaminants disappear": 40.4% (direct use value). This suggests that 40% respondents would not drink tap water as long as there are still traces of toxic substances in it, even if it complies with drinking water standards.
- "I contribute as I would for any aquifer": 41.9% (risk of warm glow effect as already identified above)



DUV : Direct Use value. FUV : Future Use Value. AV: altruist value
NUV: Non Use Value. IM: Incorrect Motivation for Paying
Green bars = Quoted. Purple bars = Not quoted

Figure 21: Number of respondents quoting motivations for paying which relate to different types of value (scenario 2).

Concerning refusal to pay, 41% of respondents refusing to pay are protesting, 37% advocate a budget constraint and 15% are already satisfied with their contribution to the first scenario. An additional 12% say they do not feel concerned by the pollution problem and 2% do not consider the restoration of natural quality as a priority.

5.5.4 Consistency of attitudes and responses for the two scenarios

Each respondent may have a different attitude towards the willingness to pay question of the first or the second scenario. While 54.6% of the respondents accept to pay for the two scenarios successively, 7.5% accept to pay for the first one but refuse to increase their payment for the second scenario. More surprisingly, almost 2% refuse to pay for the first scenario but accept the second one (restoration of natural quality). The two scenarios are refused by 35.7% of the respondents.

6. Factors explaining stated willingness to pay

A multivariate analysis is then conducted to identify the factors determining willingness to pay for the two scenarios of groundwater quality improvement. The statistical analysis is conducted in two steps. We first model the decision to participate financially to the scenario (binary variable taking the value 1 if the respondent accepts to pay in principle, 0 otherwise). We then conduct a multivariate analysis to identify the factors explaining the amount offered by respondents willing to pay. The conceptual frameworks and the results of this econometric analysis are presented in the following sections.

6.1 Explaining contribution acceptability (Logit model)

6.1.1 Conceptual framework

The relationship between possible explanatory variables and the decision to contribute to the scenario was studied with multivariate analysis. The decision to contribute in principle is measured as a dichotomous dependent variable that takes the value 1 if the respondent accepts to pay (otherwise 0). We consider that this binary response variable is the result of an underlying (unobservable or latent) variable, the *net expected benefit of contributing*, noted b and defined as follows:

$$b_i = U_i^s\left(y_i - WTP_i^s, x_s\right) - U_0\left(y_i, x_0\right)$$

where: y_i is the (fixed) income of individual i.

$WTP^i s$ is the maximum amount individual i is willing to pay for benefiting from the groundwater restoration scenario S; here, S=1 when the scenario consist in restoring drinking water quality, 2 if the scenario consists in restoring natural water quality.

x_s is the quality of groundwater if scenario S is implemented, x_0 is groundwater quality in the reference situation ($x_s > x_0$)

$U^i{}_s$ is the utility derived by individual i if the scenario is implemented, $U^i{}_0$ is the individual's utility in the reference situation;

Respondents only accept to contribute to the scenario if b is positive. As the distribution of the net benefit cannot be observed, we assume that it its distribution follows a logistic function (Logit model). The model to be estimated can be formulated as follows:

$$b_i = x_i .\alpha + \mu_i$$

where: b_i is the (not observable) net expected benefit for accepting to pay of indi vidual *i* (latent variable);

$y_i = 1$ if $y_i^* > 0$ (observed variable);

x_i is the vector of regressor values for individual *i*;

α is the vector of estimated coefficients;

μ_i (residual) follows a logistic distribution;

The coefficients of this model are estimated with the maximum likelihood method and using the software STATA 9.0.

6.1.2 Choice of explanatory variables

The choice of explanatory variables was carried out in three steps:

- The first step consisted in *identifying factors theoretically explaining the latent variable b* and identifying the variables which could be used to reflect these factors. The following groups of explanatory variables were introduced in the model: (i) household socio-economic characteristics such as income (log), age (log), sex, economic sector of activity, membership of an environment protection NGO; (ii) variable describing the use of water by the respondent (drink tap water or not, owns a private well or not, practice leisure activities related to water or not, etc.); (iii) variable describing the perception of environmental and water related problems.

- The second step consisted *defining the variables and the coding system*. Several variables can systematically be created using the answers to the same question, depending on coding choices made. For instance, for a question where 4 levels of answers are possible (very satisfied, quite satisfied, quite unsatisfied, very unsatisfied), we can create (at least) 3 variables (1 if very satisfied, 0 otherwise; 1 if very or quite satisfied, 0 otherwise; 1 if very unsatisfied, 0 otherwise). All questions related to water uses, water and pollution perceptions, scenarios valuation, and socioeconomic characteristics could therefore be coded differently and be used to generate different variables. For each regression model, we did try the best fitted variable that improves the model. All the variables and their description are presented in Appendix 1.

- The third step consisted in *assessing possible correlations* between explanatory variables. We then systematically avoided using correlated variables in the regression models. For example, the variable “info-situation” is strongly linked to the variables on leisure (*q1loisir*, *peche*, *marche*, etc.); the variables on pollution problem perception (*pb_env*, *pb_nappe*, *pb_nappe2*) are correlated to several socioeconomic variables as *log_age*, *sexe*, *sans_travail*; at last, the variable *log_income* is correlated to other socioeconomic variables like *etudes_superieures*, *sans_travail* or *sec_ind*. According to the variables choices, several scenarios are feasible, which have been tested. We will discuss hereafter the best scenario we found in the case of the Logit regression.

6.1.3 Results for the first scenario (restoring drinking water quality)

The best reduced model estimated for the first scenario is presented in table below. The calculated R-square is of 8.63%[10]. Estimated coefficients generally have the expected sign (see Appendix 1 for a description of expected sign). However, a number of estimated are counter-intuitive:

- The variable “frequency of leisure activities related to water” (*q1loisir)* has a negative sign, meaning that the more frequent are these activities, the less ready to participate the respondent is. However, the coefficient of the variable becomes positive with the second scenario (see below). One interpretation is that respondents who are often practicing water related leisure activities prefer supporting the second scenario rather than the first one, considering that restoring drinking water quality is not sufficiently ambitious. This coefficient is however not significant.
- The “perception of groundwater problem” (which is coded 0 if the problem is considered as the most important among a list of environmental problem, positive otherwise) variable also has a positive sign, meaning that the more the groundwater is considered as an important problem, the less respondent accepts to pay in principle. This coefficient is also not significant.
- The age (*log_age)* also have a negative (unexpected) sign, suggesting that the older respondents are, the less willing to participate they are (whereas we expected that elder would be more willing to pay for transmitting a natural heritage in good conditions to future generations).
- The household (*log_q27prfenf*) is also counter-intuitive, suggesting that the larger the household is, the less it is likely to be willing to pay. This may reflect a budget constraint (income per capita is smaller for large size households).
- The knowledge of the water bill (*q6facteau)* is found to be negative. This means that a respondent who knows his water bill is less likely to accept paying than a respondent who does not know his water bill.

[10] Stenger and Willinger (Stenger and Willinger 1998) obtained similar results in similar economic valuation of the Alsatian aquifer in 1998.

Logistic regression — Scenario 1

Number of obs = 488
LR chi2(14) = 42.75
Prob > chi2 = 0.0001
Pseudo R2 = 0.0680
Log likelihood = -292.80856

q17potac	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
q1loisir	-.0388534	.0450092	-0.86	0.388	-.1270699	.049363
q2puit	.3665211	.2813201	1.30	0.193	-.1848561	.9178983
freq_tap_w~r	**.4000523**	**.2056253**	**1.95**	**0.052**	**-.0029659**	**.8030706**
q5distrpol	.005608	.2790467	0.02	0.984	-.5413135	.5525295
q6facteau	-.2318023	.2209524	-1.05	0.294	-.664861	.2012564
pb_nappe	.0156403	.0843727	0.19	0.853	-.1497272	.1810077
poll_indus~s	-.2693017	.2062646	-1.31	0.192	-.673573	.1349696
subst_poll	.061832	.0717338	0.86	0.389	-.0787637	.2024276
situation_~e	**.8607737**	**.431483**	**1.99**	**0.046**	**.0150825**	**1.706465**
one_progra~c	**.5469368**	**.2489254**	**2.20**	**0.028**	**.059052**	**1.034822**
log_age	**-1.26276**	**.3552239**	**-3.55**	**0.000**	**-1.958986**	**-.5665339**
log_q27prf~f	**-.5798394**	**.2620281**	**-2.21**	**0.027**	**-1.093405**	**-.0662738**
log_income	**.325762**	**.1343498**	**2.42**	**0.015**	**.0624413**	**.5890828**
q30asso	**.6268109**	**.3187228**	**1.97**	**0.049**	**.0021258**	**1.251496**
_cons	1.729821	1.738225	1.00	0.320	-1.677038	5.136679

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 18: Results of the logistic regression for scenario 1.

The coefficients of seven variables are statistically significant:

- The age of the respondent (*log_age*) has a very significant influence (p<0.01) on the decision to participate to the scenario. Older respondents have a greater propensity to refuse to participate to the scenario. They feel less concerned by pollution than the younger generations, and apparently, they do not feel like they having a duty towards future generations neither.
- Five variables are significant at the 95% level: the realism and credibility of the described situation concerning the Alsatian aquifer pollution state (*situation_realiste)*, the realism of the scenario proposed to increase groundwater quality until the drinkable level *(one_programme_realistic)*, the number of children in each household, (*log_q27prfenf),* the membership in environmental association (*q30asso)* and the income (*log_income*). Except for the third one, the variables show the expected sign.
- One variable is significant at the 10% level: the frequency of tap water consumption (*freq_tap_water*).

Among the remaining variables, two are surprisingly not significant: the experience of a tap water interruption due to pollution (*q5distrpol*) and the sum of environmental problems that are considered as more important than groundwater one (*pb_nappe*). Whether the respondent has already experienced tap water pollution or not has no effect on the decision to participate. In the same way, whether the number of environmental problems that are considered as more important that the groundwater one is great or not, it has no impact on decision. It is all the more surprising for the second variable, that the sign is not the expected one.

6.1.4 Results for the second scenario (restoring natural groundwater quality)

The best reduced logit model is presented below. With a calculated R-square of 12.47%, this model is slightly better than the previous one. Variables found to be significant are also different from the previous model.

Some variables still do not have the expected sign:

- Frequency of tap water consumption *(freq_tap_water)* has a negative sign, indicating that if a respondent consumes tap water every day, he is less likely to accept paying for restoring natural level restoration;
- Having experienced tap water pollution in the past *(q5distrpol)* also has a negative sign, meaning that respondents who have already suffered from a pollution of their tap water are less likely to contribute than others.
- Respondents who identify households as important pollution sources *(poll_menages)* also have a smaller propensity to accept paying for the second scenario (which includes measures aiming at reducing household pollution);
- The number of children in household *(log_q27prfenf)* has a negative sign, as in the first scenario. Similarly, the number of years spent in the region *(duree)* has a negative impact (the longer respondent has lived in the area, the less he is willing to contribute[11]). Unemployment (*sans_travail)* also has a positive sign (unemployed people are more willing to contribute than others). And the localization of the household above the aquifer (*nappe)* has a negative impact on willingness to pay. *Sex* has a negative coefficient: women seem to be more sensitive to restore groundwater natural quality than men.

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[11] This observation confirms partially the conclusions of Stenger and Willinger. The authors remark that natives seem to refuse to contribute to groundwater improvement.

```
Logistic regression                               Number of obs   =        513
Scenario 2                                        LR chi2(17)     =      72.11
                                                  Prob > chi2     =     0.0000
Log likelihood = -310.68087                       Pseudo R2       =     0.1040

------------------------------------------------------------------------------
    q23natac |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    q1loisir |   .0333486   .0456727     0.73   0.465    -.0561683    .1228654
      q2puit |   .5208721   .2837307     1.84   0.066    -.0352298    1.076974
freq_tap_w~r |   -.018596   .2023557    -0.09   0.927    -.4152059    .3780139
  q5distrpol |  -.1314781    .278212    -0.47   0.637    -.6767635    .4138074
   q6facteau |  -.2066828   .2097572    -0.99   0.324    -.6177993    .2044338
      pb_env |   -.402797   .1977438    -2.04   0.042    -.7903677   -.0152264
 poll_menages |  -.1925328   .5362893    -0.36   0.720     -1.24364    .8585748
situation_~e |   .7052593   .4411472     1.60   0.110    -.1593734    1.569892
q21naturel~p |   1.279202    .704164     1.82   0.069    -.1009345    2.659338
two_progra~c |   .9254696   .2560194     3.61   0.000     .4236808    1.427258
        sexe |  -.4147685    .220355    -1.88   0.060    -.8466563    .0171193
log_q27prf~f |  -.4267504   .2529312    -1.69   0.092    -.9224864    .0689856
       duree |  -.4946927   .2457321    -2.01   0.044    -.9763187   -.0130667
     sec_ind |   .0809067   .2736577     0.30   0.767    -.4554525     .617266
sans_travail |   .8842334   .2321958     3.81   0.000      .429138    1.339329
     q30asso |   .6682801   .2968442     2.25   0.024     .0864763    1.250084
       nappe |  -.3992631   .2498045    -1.60   0.110     -.888871    .0903448
       _cons |  -1.554818   1.007611    -1.54   0.123      -3.5297    .4200636
------------------------------------------------------------------------------
```

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 19: Results of the logistic regression for the second scenario.

In this second model, nine variables are significant. Realism of the second scenario (*two_programme_realistic*) and unemployment (*sans_travail*) are significant at 99% level. Three variables are significant at the 95% level: the concern about environmental problems (*pb_env*), time spent in Alsace (*duree*), environmental association membership ("*q30asso*"). The significance of the variable time spent in Alsace is all the more crucial than the sign is not intuitive. At least, four variables are significant at the 90% level: well ownership *(q2puit)*, importance to restore groundwater natural quality *(q21naturelle_imp*), sex (*sexe)* and the number of children in the household (*log_q27prfenf*). The significance of the variable well ownership is quite intuitive in the case of the second scenario since it means that water uses could be extent to domestic ones without any fears. Compared to the first scenario, it is interesting to see here that sex have a great impact on decision to contribute to the second scenario. *Income* has been removed from the model because it is strongly correlated to education, unemployment and industrial worker (*sec_ind*). The other variables have no impact on the decision to participate to the second scenario.

6.2 Explaining the willingness to pay amount (linear regression model)

The second step of the statistical work consisted in a multivariate analysis of factors explaining the amounts stated by respondents willing to pay for groundwater quality restoration. The analysis was conducted for the two scenarios separately as was the case with the Logit model.

6.2.1 Choice of a statistical model

Several models were tested in order to explain the WTP amounts. The first model is a linear regression on positive amounts using ordinary least square (OLS), the zero bids being excluded from this model. The second model is a Tobit model including zero bids and using maximum likelihood technique.

The Tobit model allowed first coding the refusal as zero bids, and second to make the comparison between a set of data with or without protest zero bids. As it has been already noted in descriptive statistics section, protests are the respondents who refuse to participate to the scenarios by principle. We have also observed that protests are a main part of refusal reasons. In case of protests, the scenarios would probably increase the respondent's utility but he considers he doesn't have to pay to solve a problem he has not generated.

We use the logarithm of WTP as a dependant variable, as it increases the explanatory power of the models. We recode as zero the logarithm for the zero bids in the tobit model.

6.2.2 OLS linear regression results

- ***Scenario 1: Improving groundwater quality up to the drinkable quality level***

The best reduced model has a R-square of 13.48% which is very acceptable in the case of contingent valuation.

The results below show that unexpected signs are again observed: the variables on leisure practice (*q1loisir2*), the frequency of tap water consumption (*freq_tap_water*), the experience of tap water pollution (*q5distrpo*), the use value of groundwater put forward as a motivation to contribute (*q19potvalusage*) have a negative sign, and the variable on concern about groundwater problem (*pb_nappe*) has a positive sign. The sign of use value motivation is quite surprising in the first scenario case. It means that use value of groundwater has a negative effect on WTP amount. Perhaps the respondent accepts to pay but only a small amount, relying on others to share the burden.

Linear regression — Scenario 1

Number of obs	= 314
F(18, 295)	= 2.31
Prob > F	= 0.0021
R-squared	= 0.1348
Root MSE	= .87177

log_one_wtp	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
q1loisir2	-.1338252	.0614521	-2.18	0.030	-.2547653	-.012885
q2puit	.0606671	.1248786	0.49	0.627	-.1850987	.306433
freq_tap_w~r	-.0692308	.1031826	-0.67	0.503	-.272298	.1338364
q5distrpol	-.0481493	.1362729	-0.35	0.724	-.3163396	.220041
q6facteau	-.2511293	.1104671	-2.27	0.024	-.4685327	-.0337259
pb_nappe	.0762135	.0409211	1.86	0.064	-.0043208	.1567478
poll_indus~s	-.0910288	.1053235	-0.86	0.388	-.2983094	.1162519
subst_poll	.0581349	.036764	1.58	0.115	-.014218	.1304879
situation_~e	.0864804	.3720691	0.23	0.816	-.6457658	.8187267
one_progra~c	.2807262	.1488416	1.89	0.060	-.0121998	.5736522
q19potvalu~e	-.0470717	.2212831	-0.21	0.832	-.4825652	.3884218
q19potvaln~e	.1980412	.1050523	1.89	0.060	-.0087056	.4047881
log_age	.1065005	.1765107	0.60	0.547	-.2408793	.4538804
log_q27prf~f	-.1718076	.1409732	-1.22	0.224	-.4492483	.1056331
log_income	.2641097	.1595885	1.65	0.099	-.0499664	.5781859
diffwtp	-.1371221	.1230652	-1.11	0.266	-.379319	.1050749
suff_info	-.0127608	.1238657	-0.10	0.918	-.2565333	.2310117
q30asso	.3745541	.1415722	2.65	0.009	.0959346	.6531736
_cons	.8128516	1.572673	0.52	0.606	-2.282229	3.907933

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 20: Regression of WTP amounts using OLS (scenario 1)

There are seven significant variables. One is significant at the 99% level that is the environmental association membership (*q30asso*). Water leisure (*q1loisir2*) and knowledge of water bill (*q6facteau*) are significant at the 95% level, having an important but negative impact on the WTP amount declared. Four other variables are significant at the 90% level of which the non-use value of groundwater (*q19potvalnonusage*). This means that perceived non-use value of groundwater has an important and positive impact on WTP amount. This also means that drinkable quality level seems not to be a good proxy to clearly delimitate use and non-use values, as it is often done.

Comparing Logit and OLS regression, we can distinguish between variables that have a greater effect on decision and variables that have greater impact on WTP amount. Indeed, the frequency of tap water consumption, the realism of initial described situation, the age and the number of children in household have greater impact on the decision to pay or not, whereas the leisure, the knowledge of water bill, the concern about groundwater pollution influence mostly the WTP amount.

- ***Scenario 2: Improving groundwater quality in order to restore an almost natural quality level***

The best reduced model has a R-Square of 0,158, which is better than in the first scenario.

Concerning the sign of variable coefficients and compared with the first scenario, one variable has an unexpected sign. The importance to restore groundwater natural quality (*q21naturelle_imp*) decreases the WTP amount whereas it encourages contributing. This can express a suspicion concerning scenario efficiency: the respondent try to limit his contribution in case the scenario can't reach the objectives. In this second scenario, the use value of groundwater has the expected positive sign.

Five variables are significant in the models of which three causing a decrease of the WTP amount. The income is no more significant in the model.

Linear regression
Scenario 2

Number of obs =	284
F(19, 264) =	2.74
Prob > F =	0.0002
R-squared =	0.1584
Root MSE =	.86878

log_tot_reg	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
q1loisir2	**-.1540173**	**.0698701**	**-2.20**	**0.028**	**-.2915909**	**-.0164437**
q2puit	.1069688	.1299674	0.82	0.411	-.1489358	.3628735
freq_tap_w~r	-.1070642	.1060549	-1.01	0.314	-.3158853	.1017569
q5distrpol	-.0093988	.1463656	-0.06	0.949	-.2975912	.2787936
q6facteau	**-.252722**	**.1158362**	**-2.18**	**0.030**	**-.4808024**	**-.0246416**
pb_nappe	**.0863358**	**.0455433**	**1.90**	**0.059**	**-.0033386**	**.1760102**
poll_indus~s	-.0181284	.1068515	-0.17	0.865	-.228518	.1922612
subst_poll	.0319438	.0392759	0.81	0.417	-.0453901	.1092777
situation_~e	.1561757	.406855	0.38	0.701	-.644918	.9572694
q21naturel~p	**-.9550887**	**.5102668**	**-1.87**	**0.062**	**-1.959799**	**.0496217**
two_progra~c	.2634047	.1645315	1.60	0.111	-.0605561	.5873656
q25natvalu~e	.1388614	.1673375	0.83	0.407	-.1906245	.4683473
q25natvaln~e	.1590197	.1143822	1.39	0.166	-.0661978	.3842371
log_age	.2432438	.1871698	1.30	0.195	-.1252918	.6117794
log_q27prf~f	-.2186178	.1583585	-1.38	0.169	-.5304243	.0931887
log_income	.1965147	.134555	1.46	0.145	-.0684228	.4614522
diffwtp	-.133453	.130267	-1.02	0.307	-.3899475	.1230414
suff_info	-.0614415	.1328555	-0.46	0.644	-.3230326	.2001497
q30asso	**.408734**	**.1436584**	**2.85**	**0.005**	**.1258721**	**.691596**
_cons	2.240611	1.40545	1.59	0.112	-.5267078	5.007929

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 21: Regression of WTP amount using OLS (scenario 2)

6.2.3 Tobit regression results

- ***Scenario 1: Improving groundwater quality up to the drinkable quality level***

Results with protest zero bids

- The Tobit model including protest zero bids shows a R-square of 0.7327, which means an explanatory power of the model of 73.27%. This is a quite good result in the case of contingent valuation. The inclusion of zero bids increases significantly the explanatory power of the predicted WTP amounts.

- Three variables have an unexpected sign: frequency of water leisure (*q1loisir*), frequency of tap water consumption (*freq_tap_water2*) and concern about groundwater pollution problem (*pb_nappe*). We can observe here, that after three kinds of regression models, three variables seem to have systematically the unexpected sign: the frequency of water activities, the knowledge of water bill (the sign wasn't clearly intuitive though), and the concern about groundwater pollution problem.

- Three variables plus the constant term are significant at the 99% level: the use value of groundwater (*q19potvalusage*), the income (*log_income*) and the environmental association membership (*q30asso*). It is to be noted, that the variable use value of groundwater has got the highest coefficient: the use value increases the WTP amount of 4€. The tobit model increases the comparative effect of this variable on the other ones. Three other variables are significant (95% level): the knowledge of the water bill (*q6facteau*), the number of contaminants found in groundwater (*subst_poll*) and the non-use value of the groundwater (*q19potvalnonusage*).

- After adding zero bids, main changes are (i) the loss of the significant variables on leisure and concern about groundwater pollution; and (ii) the gain of on a significant variable on the number of contaminants found in the aquifer.

Tobit regression — Scenario 1 with protest

		Number of obs	=	459
		LR chi2(18)	=	620.17
		Prob > chi2	=	0.0000
Log likelihood = -542.73553		Pseudo R2	=	0.3636

log_one_to~t	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
q1loisir	-.0093297	.0315147	-0.30	0.767	-.0712673	.052608
q2puit	.1283065	.186475	0.69	0.492	-.2381836	.4947965
freq_tap_w~2	.3364394	.2493308	1.35	0.178	-.1535848	.8264636
q5distrpol	.1182658	.1864596	0.63	0.526	-.248194	.4847256
q6facteau	**-.309203**	**.1450122**	**-2.13**	**0.034**	**-.5942039**	**-.0242022**
pb_nappe	.0449841	.0565335	0.80	0.427	-.0661244	.1560926
poll_indus~s	-.1239892	.1360729	-0.91	0.363	-.3914211	.1434427
subst_poll	**.1010737**	**.0477302**	**2.12**	**0.035**	**.0072667**	**.1948807**
situation_~e	.2692327	.3223925	0.84	0.404	-.364384	.9028494
one_progra~c	.1949324	.1801357	1.08	0.280	-.1590987	.5489636
q19potvalu~e	**4.095792**	**.2007165**	**20.41**	**0.000**	**3.701312**	**4.490271**
q19potvaln~e	**.3650788**	**.1616893**	**2.26**	**0.024**	**.0473015**	**.6828562**
log_age	-.0649593	.2318095	-0.28	0.779	-.520548	.3906293
log_q27prf~f	.0454244	.1786914	0.25	0.799	-.3057682	.396617
log_income	**.253406**	**.0981527**	**2.58**	**0.010**	**.0605008**	**.4463112**
diffwtp	-.024318	.1565344	-0.16	0.877	-.3319641	.2833281
suff_info	-.1787616	.1562089	-1.14	0.253	-.485768	.1282448
q30asso	**.58016**	**.1924627**	**3.01**	**0.003**	**.2019018**	**.9584182**
_cons	**-3.298469**	**1.173441**	**-2.81**	**0.005**	**-5.604701**	**-.992237**
/sigma	1.258541	.055021			1.150405	1.366677

Obs. summary: 168 left-censored observations at log_one_tobit<=0
291 uncensored observations
0 right-censored observations

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 22: Result of the Tobit model including protest zero bids (scenario 1)

Results without protest bids

- Removing the protest zero bids does not change the results of the Tobit model. The explanatory power is equal ($R^2 = 0.7223$).
- The knowledge of the water bill is no more significant. This confirms a past observation that information on water bill is a main origin of protest behaviours.

Tobit regression — Scenario 1 without protest

Number of obs = 342
LR chi2(18) = 293.46
Prob > chi2 = 0.0000
Pseudo R2 = 0.2308

Log likelihood = -488.99859

log_one_to~t	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
q1loisir	-.0153164	.0300859	-0.51	0.611	-.0745048	.0438721
q2puit	.0739899	.1804732	0.41	0.682	-.2810573	.4290371
freq_tap_w~2	.2603686	.2398656	1.09	0.279	-.2115221	.7322592
q5distrpol	.1730499	.1835775	0.94	0.347	-.1881045	.5342043
q6facteau	-.2036369	.140477	-1.45	0.148	-.4799992	.0727253
pb_nappe	.0317246	.0546917	0.58	0.562	-.075871	.1393202
poll_indus~s	-.0954704	.1307719	-0.73	0.466	-.3527397	.1617988
subst_poll	.1073365	.0456801	2.35	0.019	.0174696	.1972035
situation_~e	.3033712	.317127	0.96	0.339	-.3205168	.9272592
one_progra~c	.0674073	.1786695	0.38	0.706	-.2840916	.4189062
q19potvalu~e	2.850543	.2013121	14.16	0.000	2.454499	3.246586
q19potvaln~e	.3223079	.1479884	2.18	0.030	.0311684	.6134473
log_age	-.0715848	.2166131	-0.33	0.741	-.4977306	.354561
log_q27prf~f	.0694918	.1745229	0.40	0.691	-.2738494	.412833
log_income	.3457726	.0942794	3.67	0.000	.1602954	.5312497
diffwtp	-.1710978	.1483896	-1.15	0.250	-.4630265	.1208309
suff_info	-.1349635	.1505872	-0.90	0.371	-.4312157	.1612887
q30asso	.5816127	.1881762	3.09	0.002	.2114113	.9518142
_cons	-2.688914	1.095778	-2.45	0.015	-4.844653	-.5331758
/sigma	1.145032	.0491535			1.048332	1.241733

Obs. summary: 52 left-censored observations at log_one_tobit<=0
290 uncensored observations
0 right-censored observations

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 23: Results of the Tobit model excluding protest zero bids (scenario 1)

- ***Scenario 2: Improving groundwater quality in order to restore an almost natural quality level***

Results with protest bids

- The explanatory power of the second scenario regression is higher: 72.37%. A great number of variables don't have the expected sign. They are: the frequency of water leisure, the well ownership, the frequency of tap water consumption, the concern about groundwater pollution, the age, the number of children in the household, the insufficiency of given information (respectively *peche2*, *q2puit*, *freq_tap_water3*, *pb_nappe*, *log_age*, *log_q27prfenf*, *suff_info*). Compared to the Logit and OLS models, the unexpected sign variables are quite the same.

Tobit regression — Scenario 2 with protest

Number of obs	=	497	
LR chi2(19)	=	592.32	
Prob > chi2	=	0.0000	
Log likelihood = -631.74481	Pseudo R2	=	0.3192

log_tot_tob	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
peche2	**-.368962**	**.2020237**	**-1.83**	**0.068**	**-.7659263**	**.0280023**
q2puit	-.0460732	.2349479	-0.20	0.845	-.5077316	.4155852
freq_tap_w~3	-.2755211	.176778	-1.56	0.120	-.6228791	.0718369
q5distrpol	.3572842	.2313957	1.54	0.123	-.0973942	.8119627
q6facteau	**-.4779898**	**.1841994**	**-2.59**	**0.010**	**-.8399303**	**-.1160492**
pb_nappe	.0277785	.0713606	0.39	0.697	-.1124407	.1679976
poll_indus~s	-.2387741	.1705248	-1.40	0.162	-.5738449	.0962968
subst_poll	**.0982603**	**.0594838**	**1.65**	**0.099**	**-.0186217**	**.2151424**
situation_~e	.3903437	.4070005	0.96	0.338	-.4093876	1.190075
q21naturel~p	.0539664	.6159398	0.09	0.930	-1.156318	1.264251
two_progra~c	**.501463**	**.2358936**	**2.13**	**0.034**	**.0379464**	**.9649797**
q25natvalu~e	**4.219529**	**.2302818**	**18.32**	**0.000**	**3.767039**	**4.672019**
q25natvaln~e	**.871107**	**.2061218**	**4.23**	**0.000**	**.4660902**	**1.276124**
log_age	**-.8008763**	**.2991974**	**-2.68**	**0.008**	**-1.388781**	**-.2129716**
log_q27prf~f	-.3356667	.232119	-1.45	0.149	-.7917665	.1204331
log_income	**.4087845**	**.1223363**	**3.34**	**0.001**	**.1684011**	**.6491679**
diffwtp	-.1001026	.2007202	-0.50	0.618	-.4945056	.2943004
suff_info	.0350448	.1966886	0.18	0.859	-.3514364	.4215261
q30asso	.36583	.2386514	1.53	0.126	-.1031054	.8347654
_cons	-1.390599	1.587384	-0.88	0.381	-4.509712	1.728514
/sigma	1.624618	.0737036			1.479795	1.769441

Obs. summary: 213 left-censored observations at log_tot_tob<=0
284 uncensored observations
0 right-censored observations

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 24: Result of the Tobit model including protest zero bids (scenario 2)

- Eight variables are significant of which five at the 99% level: the knowledge of the water bill, both variables on groundwater value plus the age of respondents and the income (*q6facteau*, *q25natvalusage*, *q25natvalnonusage*, *log_age*, *log_income*). Again, the groundwater use value coefficient is higher than for other variables: the perception of use values for groundwater increased WTP amount of 4.2€. One variable is significant at the 95% level: the realism of the second described scenario. At last, two other variables are significant at the 90% level. They concern water uses and groundwater pollution perception which is quite logical speaking of the second scenario. Indeed, one would expect that water uses would have a greater influence on contribution when the aim is to restore the natural quality of groundwater. These variables are: the frequency of water leisure and the quantity of contaminants that are expected to be found in the aquifer.

Results without protest bids

- Without the protest zero bids, the explanatory power of the model is of 70.10%.
- There are no major changes concerning both unexpected sign variables, unless the well ownership that is positive.

```
Tobit regression                                  Number of obs   =        379
Scenario 2 without protest                        LR chi2(19)     =     387.99
                                                  Prob > chi2     =     0.0000
Log likelihood = -568.10896                       Pseudo R2       =     0.2546

------------------------------------------------------------------------------
 log_tot_tob |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      peche2 |  -.2854638   .1905848    -1.50   0.135    -.6602632    .0893357
      q2puit |    .132654   .2248403     0.59   0.556    -.3095113    .5748194
freq_tap_w~3 |  -.2171553   .1662845    -1.31   0.192    -.5441664    .1098558
  q5distrpol |   .4017265   .2202798     1.82   0.069    -.0314704    .8349235
    q6facteau |  -.2476991   .1718729    -1.44   0.150    -.5857002     .090302
    pb_nappe |   .0646902   .0666705     0.97   0.333    -.0664225    .1958028
poll_indus~s |  -.1979733   .1594799    -1.24   0.215    -.5116025    .1156559
  subst_poll |   .1460818   .0550794     2.65   0.008     .0377639    .2543996
situation_~e |   .4338849   .3735062     1.16   0.246    -.3006433    1.168413
q21naturel~p |   .6456891   .5333935     1.21   0.227    -.4032694    1.694648
two_progra~c |   .3538232   .2285415     1.55   0.122    -.0956208    .8032672
q25natvalu~e |    3.03367   .2140632    14.17   0.000     2.612698    3.454642
q25natvaln~e |   .6669264   .1828298     3.65   0.000     .3073777    1.026475
     log_age |  -.8026687   .2739451    -2.93   0.004    -1.341402    -.263935
log_q27prf~f |  -.3559352    .215117    -1.65   0.099     -.778979    .0671086
  log_income |   .5386145   .1131059     4.76   0.000     .3161833    .7610457
     diffwtp |  -.3266698   .1884713    -1.73   0.084    -.6973128    .0439731
   suff_info |   .1322657    .187311     0.71   0.481    -.2360956    .5006269
     q30asso |   .3605046   .2222234     1.62   0.106    -.0765145    .7975237
       _cons |  -2.035466   1.472323    -1.38   0.168    -4.930901    .8599696
-------------+----------------------------------------------------------------
      /sigma |   1.435979   .0636744                      1.310758    1.561199
------------------------------------------------------------------------------
  Obs. summary:         95  left-censored observations at log_tot_tob<=0
                       284     uncensored observations
                         0 right-censored observations
```

Rows in red show variables significant with a 1% confidence; in green at 5%; in blue at 10%.

Table 25: Results of the Tobit model excluding protest zero bids (scenario 2)

- There are eight significant variables. The ones concerning leisure and knowledge of water bill disappear when the protest bids are removed. But pollution perception gets more significant.

6.3 Synthesis of the results of regression models

The best reduced models for each regression have just been presented. We also try to choose one combination of variables and to keep it to test each kind of regressions. This allowed us to precise some results, whether in terms of coefficient signs or of variables significance.

6.3.1 Comparative results about variable signs

- Two variables have an **unexpected sign** whatever the regression or the scenario: the frequency of water leisure and the concern about groundwater pollution problem.

Variables	Expected sign (whether decision or WTP amount)		Why	Sign of estimated coefficient	
	Decision	WTP		Decision	WTP
q1loisir, q1loisir2, peche, marche, marche2	+	+	Important water uses = higher utility	-	-
pb_nappe	-	-	Higher probability of refusal because respondents are more concerned by other environmental problems	+	+

Table 26: Variables for which the sign of the estimated coefficient is unexpected.

- Signs were **uncertain** for several variables (see Appendix 1). We learn through the regressions that the knowledge of water bill (*q6facteau*) has a systematic negative sign. Anyway, the amount of the household water bill (*lbill_amount*) has a positive sign in the OLS regression and tobit models and a negative one in logit models. It generally better explains the WTP amount (better R^2) but decreases the sample size. This results show that better public information has a double effect: first it has a negative impact on decision to contribute, but once the respondent is really willing to pay, information has a positive effect on the amount he gives. We were unsure of the variable “number of contaminants that you think are found in groundwater” (*subst_poll*). It has finally a positive sign, meaning that the more substances, the more the respondents will participate and contribute. The variable *sexe* is generally negative: women are more likely to accept and contribute to groundwater quality improvement. The age (*log_age*) is also generally negative, but tends to be positive when speaking of effect on the WTP amount. Older respondents are likely to refuse to participate to the financing of measures; but when they do, they contribute more. The number of children in the household (*log_q27prfenf*) is almost always a negative variable: perhaps the risk of water pollution is too crucial when speaking of children, and respondents prefer to buy bottled water than pay a tax to fight against groundwater pollution and get standard tap water.

Variables	Expected sign (whether decision or WTP amount)		Why	Real sign	
	Decision	WTP		Decision	WTP
q6facteau	?	?		-	-
lbill_amount	?	?		-	+
subst_poll	+	+/-	Accept to pay because consciousness of the complexity of pollution problem. But, may be negative impact on WTP amount through will to share the burden	+	+
sexe	?	?		-	-
log_age	+	+/-	More experience, better awareness of complexity and importance of the problem	-	+
log_q27prfenf	+	+/-	Should tend to accept to pay to "protect" children, but may be the contribution won't increase because of sanitary risk for children	-	-

Table 27: Analysis of the sign of estimated coefficient for doubtful variables.

- The experience of tap water interruption due to a pollution (*q5ditrpol*) seams to have a negative effect especially on WTP amount, whereas it helps to the decision to contribute. The effect can be explained through the respondent will to share the cost of water protection among the different stakeholders.

6.3.2 Comparative results about variables significance

- Looking at the whole significant variables in the six models, it appears that some influence more the decision to participate or the WTP amount. The table below tries to sum up the main conclusions. Amazingly, the variables that best influence the WTP amount, knowledge of water bill, concern about groundwater pollution and water activities have also an unexpected sign that tends to decrease the WTP amount. In addition, the use and non-use values of groundwater have a big and positive impact on WTP amount.

Significant variables	Influence scale of variables on	
	Decision to participate	WTP amount
freq_tap_water	++	
situation_realiste	++	
one/two_programme_realistic	++++	
log_age	+++	+
log_q27prfenf	++++	
pb_nappe		++++
q6facteau		++++
q1loisir2, marche2		+++
q19pot/25natvalusage	+	++++
q19pot/q25natvalnonusage	+	++
q30asso	+++	+++
log_income	+++	++
subst_poll	**+++**	**++**

Table 28: Statistical significance of explanatory variables in different models.

6.3.3 Comparative predicted WTP

The table below shows that Tobit regressions tend to underestimate the WTP amount, which is consistent with the model since it includes zero bids.

Estimated mean WTP	OLS regression	Tobit with protests	Tobit without protest
Scenario 1	29.238€	19.357€	20.361€
Scenario 2	50.028€	35.198€	34.529€

Table 29: Average WTP estimated with OLS regression, Tobit excluding (or including) protest zero bids.

6.4 Benefit analysis: the WTP aggregation problem

The main objective of the contingent valuation survey was to assess the benefits of two scenarios of groundwater pollution remediation. The total benefits of each scenario can be roughly estimated by extrapolated average stated WTP to the entire population concerned by groundwater quality. The extrapolation can simply be done by multiplying the average WTP by the number of households in the region, if and only if the sample is representative of the regional population. Since this was not the case in this survey – the bias being mainly due to the choice of a postal survey – adjustments had to be made.

6.4.1 Sample bias problem

The sampling bias can easily be corrected using variables weighting methods (Amigues, Boulatoff, Broadhead et al. 2002; Cho, Newman et al. 2005; Soto Montes de Oca and Bateman 2006). For doing so, we would then need to compare the characteristics of the households of our sample with those of the regional population of households. This comparison could be done using criteria such as: population age, professional categories or household income, criteria which are usually taken for aggregation. This would however suppose that (i) the variables used for aggregation be significant in the models and (ii) that regional statistics exist to characterise households' characteristics (and not individuals) for the selected variables.

A key problem encountered is that, whereas WTP is assessed for the complete household, the socio-economic characteristics collected through the questionnaire relate to the individual who answered the questionnaire.

Several assumptions were made to conduct the aggregation. It was first decided to aggregate WTP per professional categories. Second, we have INSEE data that describe population distribution, in terms of individuals, through five socio-professional classes (workers, unemployed, retired, students, other non-workers). Available data from our sample are the number of persons by household, the number of children by household, the WTP by household, whether directly from the sample or predicted by the OLS regressions, and the respondent profession. Then, we keep the number of adults by household and calculate the WTP/adult. The method is detailed in next section.

6.4.2 Aggregation results

- ***Method***

The figure below shows how we create a new sample of the population from our original one. Data are taken from scenario 1 example. Over the 668 households who replied, we distinguished contributors, whether positive ones or those who don't know how much they should give and non contributors, whether true zero bids or protest bids.

Then, we keep the values of the sample every time it is possible, that is, when there are no missing data and we isolate the protest zero bids. Indeed, for this specific population, the zero responses do not correspond to a loss of utility or no utility at all produced by the proposed scenario. They are protesting "by principle". The corresponding WTP of these protests are then evaluated through the predictions of the OLS model of each scenario 1. Then, we get a sample of 581 household WTP.

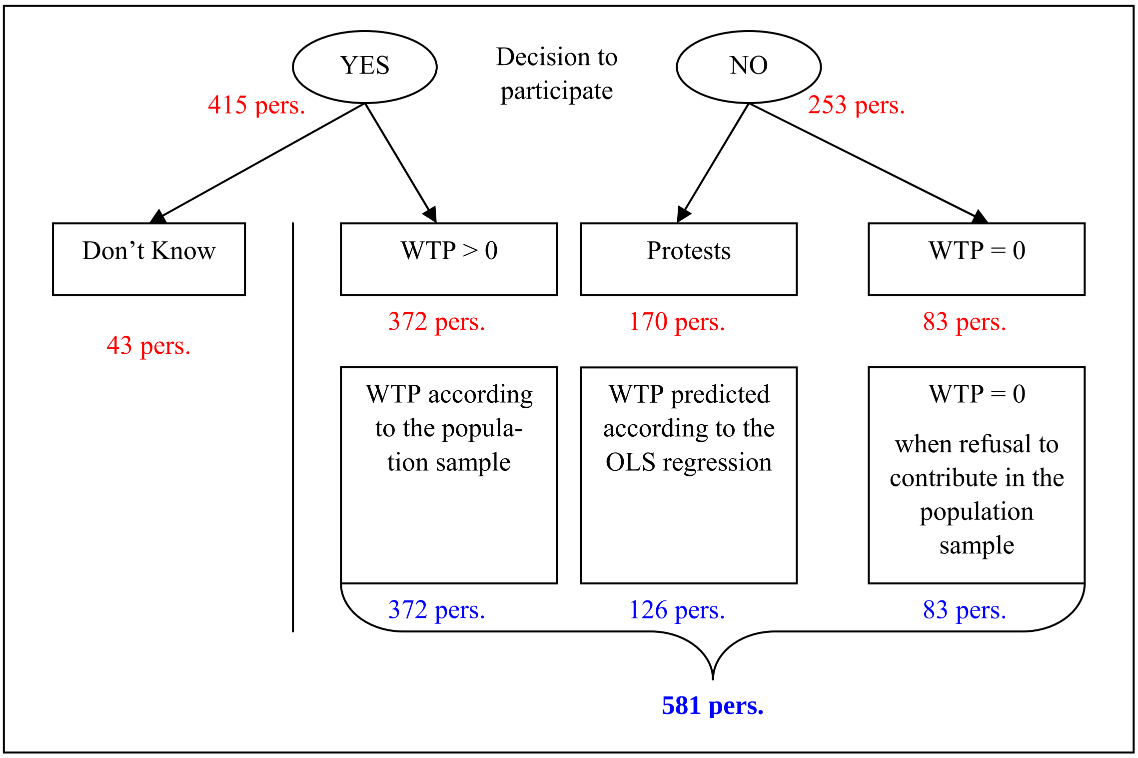

Figure 22: Distribution of respondents according to answers to WTP questions.

In a second step, we calculate the mean WTP per adult in each household. Thus, we get a new sample of 566 individual WTP that we have to share among socio-professional activities. Taking into account missing data, we get a total of 562 individual WTP.

Next step of the method consists in a benefit analysis of each scenario. Average WTP/adult are calculated per professional activities according to INSEE classes. Aggregate WTP by classes are summed to find the average amount the Alsatian population is willing to pay for each scenario during 10 years long. We exclude of the addition the student category which contains whether young children who are not able to contribute or older students. Then, an additional 7.8% of the Alsatian population won't contribute to the scenarios. The total discounted value of the Alsatian aquifer is calculated using a discount rate of 4%.

- ***Results***

Scenario 1: Improving groundwater quality up to the drinkable quality level

	Nb of sample adults	% of the sample	Mean WTP	% in Alsace (INSEE 2006)	Aggregate WTP (€/year)
Working population	**365**	**64,9%**	**20,527**	**50,0%**	**18 053 497**
real workers	355	63,2%	20,977	44,8%	**16 530 547**
unemployed	10	1,8%	4,552	5,2%	**416 362**
Non working population	**160**	**28,5%**	**14,550**	**50,0%**	**12 796 725**
retired	147	26,2%	14,464	17,6%	**4 477 823**
students	5	0,9%	24,666	7,8%	-
other non workers	45	8,0%	17,901	24,6%	**7 746 013**
Total	**562**	**100%**		**1 759 000**	**29 170 746**

Table 30: Estimated aggregate willingness to pay for groundwater protection in Alsace for the first scenario.

The annual mean WTP of the Alsatian population to improve the groundwater quality up to a drinkable quality is of 29.17 millions Euros. The resulting undiscounted benefit over 10 years is 291.7 millions Euros. With a 4% discount rate, the present value of benefits is estimated to 236.6 millions Euros.

Scenario 2: Improving groundwater quality in order to restore an almost natural quality level

	Nb of sample adults	% of the sample	Mean WTP	% in Alsace (INSEE 2006)	Aggregate WTP (thous €/year)
Working population	**361**	**65,3%**	**32,115**	**50,0%**	**28 245**
real workers	350	**63,3%**	32,964	44,8%	**25 976**
unemployed	11	**2,0%**	5,089	5,2%	**465**
Non working population	**156**	**28,2%**	**23,131**	**50,0%**	**20 343**
retired	144	**26,0%**	22,953	17,6%	**7 105**
students	5	**0,9%**	37,666	7,8%	-
other non workers	43	**7,8%**	30,063	24,6%	**13 008**
Total	**553**	**100%**		**1 759 000**	**46 556**

Table 31: Estimated aggregate willingness to pay for groundwater protection in Alsace for the second scenario.

In the case of the second scenario, the annual mean WTP of the Alsatian population is higher: 46.55 millions Euros. The discounted present value of benefits is estimated to 377.6 millions Euros that is a gain of around 60% of the total value of the aquifer when it reaches a drinkable quality level.

7. Conclusions

7.1 General implications for setting groundwater quality thresholds

The results of the survey highlight that the population is concerned by groundwater protection. The average stated willingness to pay amounts was estimated at 42€ per households and per year for restoring drinking water quality and 76€ for restoring natural. These estimates are comparable with the results of a previous survey where the WTP was estimated at 94€ (1994 €).

There is no statistical difference between willingness to pay amounts declared by households living above the aquifer (and using it for water supply) and others living outside the aquifer. This suggests that groundwater **option value** and **non-use value** are significant. The methodology implemented however did not allow assessing separately direct use value, option value and non use values.

The study also reveals that the population is very sensitive to the implementation of the **polluter pays principle**. Many respondents have refused to contribute to the scenarios, arguing that polluters (industries) should pay. Similar attitudes would probably be encountered for all pollution issues where pollution damage cost can be attributed to legal entities - theoretically liable to pay for remediation costs.

7.2 Implications of cost benefit analysis

The main conclusion of the study is that the estimated benefits associated to groundwater protection and remediation exceeds the cost of measures required. The net benefit associated with the restoration of drinking water quality is estimated at 7 millions €. The net benefit of restoring natural groundwater quality is estimated at -6 millions (see Table 32). From pure welfare economy perspective, these results suggest that the first programmes of actions should be implemented and that restoring natural groundwater quality is not economically relevant.

The analysis of the distribution of the costs and their comparison with financial capacities of industrial actors however show that financial transfers will be necessary. Industrial actors do not have the financial capacities to cover the cost of measures. The programme will have to be financed either through public subsidies or through collection of a tax imposed over all the enterprises using solvents for instance

A simple calculation shows that if this programme of measure was to be financed by tax payers, the total cost would be equal to respectively 13€ and 30€ per inhabitants for the first and second scenario. Knowing that a household comprises 2.3 persons on average in Alsace, this cost is equal to 30€ per households for the first scenario and 70€ for the second scenario. Given that this total cost could be spread over several years (5 for instance), there would be no acceptability problem to finance this programme through taxes.

	Scenario 1	Scenario 2
DESCRIPTION OF SCENARIO		
Objectives	Restoring drinking groundwater quality	Restoring natural groundwater quality
Times needed to achieve objective	10 years	50 years
Programme of measures timing	10 years	10 years
COSTS		
Total number of enterprises concerned by the programme of measures (total number of employees)	466 (13 000 employees turn over: 3 M€)	1933 (62 500 employees, turn over: 17,5 M€))
Total number of historical (abandoned) contaminated sites to remediate	41	114
Total number of mobile enterprises concerned by the scenario	1066 (17 459 employees turn over: 0,74 M€)	1066 (17 459 employees turn over: 0,74 M€)
Total cost of the program of measures (millions € per year)	22,4 millions € Equivalent to: 13 € / inhabitant 727 % yearly turn over of the concerned enterprises	52,1 millions € Equivalent to: 30 € / inhabitant 298 % yearly turn over of the concerned enterprises
BENEFITS		
Average Willingness To Pay (stated amount)	42 €/ household/ year during ten years	76€/ household/ year during ten years
Estimated groundwater protection benefit	29 millions €	46,5 millions €

Table 32: Summary of the cost-benefit analysis of the two scenarios.

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Appendix 1:

List of explanatory variables

Variable name in Stata©	Description	Coding	Expected sign on acceptation	Expected sign on WTP
q1loisir	Sum of scores (ranging from 0 to 3) obtained for 5 kinds of leisure activities linked to water	quantitative	+	+
q1loisir2	Maximum score among the 5 leisure activities	quantitative	+	+
peche	Sum of scores for fishing in rivers or lakes and in gravel pits ≥ 4	1 if yes, 0 if no	+	+
peche2	Never fish at all	1 if yes, 0 if no	-	-
marche	Respondent use to very frequently walk near water	1 if yes, 0 if no	+	+
marche2	Respondent use to frequently or very frequently walk near water	1 if yes, 0 if no	+	+
q2puit	Have a private well	1 if yes, 0 if no	+	+
q2usagdobo	Water well is used for showers and drinking	1 if yes, 0 if no	+	+
q2usagint	Water well is used for toilets, showers and drinking	1 if yes, 0 if no	+	+
Freq_tap_water	Drink tap water several times a week or every day	1 if yes, 0 if no	+	+
Freq_tap_water2	Never drink tap water	1 if yes, 0 if no	-	-
Freq_tap_water3	Drink tap water every day	1 if yes, 0 if no	+	+
q5distrpol	Experience tap water interruption due to a pollution problem	1 if yes, 0 if no	+	+
q6facteau	Respondent know his water bill	1 if yes, 0 if no	unknown	unknown
lbill_amount	Logarithm of the water bill amount	quantitative	unknown	unknown
pb_env	Over proposed problems, respondent is more concerned by social than environment problems	1 if yes, 0 if no	-	-
pb_nappe	Sum of environmental problems that are strictly more important than groundwater	quantitative	-	-

	pollution			
pb_nappe2	There are no environmental problems more important than groundwater	1 if yes, 0 if no	+	+
pb_nappe3	Groundwater pollution is not an important problem or don't know	1 if yes, 0 if no	-	-
q11polnap	Never heard of Alsatian aquifer pollution cases	1 if yes, 0 if no	-	-
poll_industries	Industries are very polluting sources for the Alsatian groundwater	1 if yes, 0 if no	-	
poll_menages	Households are very or quite polluting sources for the Alsatian groundwater	1 if yes, 0 if no	+	+
q13subsc	Chlorinated solvents are pollutants found in the Alsatian aquifer	1 if yes, 0 if no	+	+
subst_poll	Sum of contaminants found in the Alsatian aquifer	quantitative	+	-/+
info_situation	Well informed of the current situation related to Alsatian groundwater quality	1 if yes, 0 if no	+	+
situation_realiste	The description of the current situation is quite or very realistic/ believable	1 if yes, 0 if no	+	+
one_programme_realistic	It is quite or very possible to reach the drinkable quality level through scenario 1	1 if yes, 0 if no	+	+
q19potvalusage	Respondent contribute because groundwater has a use value	1 if yes, 0 if no		+
q19potvalnonusage	Respondent contribute because groundwater has a non-use value	1 if yes, 0 if no		+
q20protest	Respondent refuse to contribute by pure protest (for example because of polluter payer principle)	1 if yes, 0 if no		-
q21naturelle_imp	It is quite to very important to restore groundwater natural quality	1 if yes, 0 if no	+	+
two_programme_realistic	It is quite or very possible to reach the natural quality level through scenario 2	1 if yes, 0 if no	+	+
q25potvalusage	Respondent contribute because groundwater has a use value	1 if yes, 0 if no		+
q25potvalnonusage	Respondent contribute because groundwater has a non-use value	1 if yes, 0 if no		+
q26protest	Respondent refuse to contribute by pure protest (for example because of polluter payer principle)	1 if yes, 0 if no		-

sexe	Respondent is a man	1 if yes, 0 if no	Unknown	Unknown
log_age	Ln(age)	quantitative	+	+/-
enfant	Respondent has got at least one child	1 if yes, 0 if no	+	+/-
log_q27prfenf	Ln(nb of children in the household)	quantitative	+	+/-
duree	Respondent live in Alsace since more than 20 years	1 if yes, 0 if no	+	+
q27prfprs	Number of persons in the household	quantitative	+	+/-
etudes_superieures	Respondent is high graduated	1 if yes, 0 if no	+	+/-
sec_ind	Respondent is working in industrial sector	1 if yes, 0 if no	+	-
sans_travail	Respondent is not working (unemployed, retired or else)	1 if yes, 0 if no	-	-
log_income	Ln(income)	quantitative	+	+
q30asso	Respondent is a member of an environmental association	1 if yes, 0 if no	+	+
diffwtp	It is quite to very difficult to give a WTP	1 if yes, 0 if no		-
suff_info	Given information is not or not at all sufficient to answer the questions	1 if yes, 0 if no		-
nappe	Live above the aquifer and de facto receiving tap water from the aquifer	1 if yes, 0 if no	+	+
nappe_rurale	Live above the aquifer, in rural area	1 if yes, 0 if no	-	-
rural	Live in rural area either above or not the aquifer	1 if yes, 0 if no	-	-