



**HAL**  
open science

## Defining Groundwater Remediation Objectives with Cost-benefit Analysis: Does It Work?

Jean-Daniel Rinaudo, Stéphanie Aulong

► **To cite this version:**

Jean-Daniel Rinaudo, Stéphanie Aulong. Defining Groundwater Remediation Objectives with Cost-benefit Analysis: Does It Work?. *Water Resources Management*, 2014, 28 (1), pp.261-278. 10.1007/s11269-013-0483-0 . hal-00934930

**HAL Id: hal-00934930**

**<https://hal.science/hal-00934930>**

Submitted on 22 Jan 2014

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# 1        **Defining groundwater remediation objectives with cost-** 2        **benefit analysis: does it work?**

3  
4        J-D. Rinaudo and S. Aulong

5  
6        BRGM (French Geological Survey) 1034 rue de Pinville, 34 000 Montpellier,  
7        France.

8        \*Corresponding author (E-mail: *jd.rinaudo@brgm.fr*)

## 9 10        **Abstract**

11        The use of cost-benefit analysis (CBA) is increasingly advocated as a tool for supporting  
12        water planning decisions, in particular at the local (site) level. This paper questions whether  
13        CBA is relevant for evaluating groundwater management options at the scale of large  
14        regional aquifers. It highlights the difficulties related to estimating the cost of groundwater  
15        protection and remediation measures at the regional (water body) level. It also identifies  
16        methodological challenges in estimating the economic value of the benefits of groundwater  
17        protection. The paper is based on an original case study carried out on the upper Rhine  
18        valley aquifer in eastern France. The methodology deployed combines engineering  
19        approaches to assess the cost of remediation and economic methods (contingent valuation)  
20        to estimate the benefits associated with groundwater improvement.

## 21 22        **Keywords**

23        Cost-benefit analysis; groundwater remediation; contingent valuation  
24        survey; volatile organic compounds (VOC); willingness to pay.

## 28 1. INTRODUCTION

29 Following the promulgation of the Water Framework Directive (2000/60/EC), the European  
30 Commission prepared and published a daughter directive (2006/118/EC) which focuses on  
31 groundwater-specific issues. One of the main purposes of this daughter directive was to  
32 establish a general framework and procedures for specifying the quality levels which should  
33 be achieved in various hydro-geological contexts (Quevauviler, 2008). The Directive  
34 recognises that groundwater quality objectives should be set considering the local geological  
35 context and natural background concentrations and that no uniform standards should apply  
36 uniformly across Europe.. The definition of groundwater quality objectives may also be based  
37 on an economic assessment of the costs and benefits of reaching different quality levels  
38 (Brouwer, 2008). This flexible policy approach leads to a new demand for methodologies and  
39 reference case studies which can be used to construct a practical Cost-Benefit Analysis (CBA)  
40 approach for application in groundwater protection programs. This paper employs a case  
41 study approach to discuss some of the key related methodological issues.

42 Implementing cost-benefit analyses of alternative groundwater protection or restoration  
43 scenarios is no trivial task. For historical reasons, CBA has been more widely used in the US  
44 than in European countries (Pearce, 1998) in particular for promoting efficient use of scarce  
45 financial resources allocated to soil and groundwater decontamination (Kiel & Zabel, 2001).  
46 Concerning industrial contamination, CBA has mostly been applied at the site (local) level  
47 (Hardisty & Özdemiroglu, 2005; Rinaudo & Loubier, 2005). CBA has also been used to  
48 assess agricultural pollution control programs, with one study considering a range of pollution  
49 levels (Yada & Wall, 1998). However, American studies have generally focused on situations  
50 where the benefits of groundwater protection and/or decontamination are related to direct  
51 groundwater use. Benefits are often considered as avoided costs – such costs consisting of  
52 health-damage costs (Sharefkin, Shechter & Kneese, 1984) or the cost of averting behaviours

53 (Abdalla, 1994, Yadav & Wall, 199). Even contingent valuation studies mainly consider use  
54 benefits (for a review see Hardisty & Özdemiroglu, 2005, Poe, Boyle & Bergstrom, 2001).  
55 This is a quite different situation from that of Europe, where the population is almost entirely  
56 supplied by public water systems. The only direct link that exists between groundwater  
57 quality and households' wellbeing is the price they pay for the drinking-water supply  
58 (increasing water treatment cost in case of pollution) and the possible impact of groundwater  
59 deterioration on groundwater-dependent ecosystems. Clearly, only a tiny minority of  
60 households depending on private wells would be directly concerned by health risks due to  
61 groundwater pollution or by the need to invest in private treatment. A consequence is that, in  
62 the European context, groundwater valuation studies should focus more on the ecological  
63 benefits generated by action programs, and less on direct use benefits alone. This is also  
64 required by the European Water Framework Directive.

65 The first methodological issue investigated in this paper is how to assess the economic value  
66 of ecological benefits associated with groundwater protection or remediation. The Contingent  
67 Valuation (CV) method can theoretically be used to assess such ecological benefits, if  
68 respondents are provided with precise information on the impact that the action scenario in  
69 question would have on a groundwater-dependent ecosystem (Carson et al, 2001; Brouwer,  
70 2008). However, a review of the literature shows that few studies have done this. Following  
71 the seminal study by Edwards (Edwards, 1988), a significant literature has addressed how to  
72 assess the economic value of groundwater protection benefits. In the USA, following the  
73 recommendation of the Water Resources Council, most of the studies have used the  
74 contingent valuation (CV) method. In their 2001 paper, Poe et al. identify 19 groundwater  
75 valuation studies using CV (Poe, Boyle & Bergstrom, 2001). However, Poe notes that many  
76 of these studies are valuing the improvement of groundwater quality when used by  
77 households for their own water supply. An extreme example is the study of Jordan &

78 Elnagheeb (1993) who assess the willingness of households to pay for treating groundwater  
79 before use. Fewer studies were designed to assess both use and non-use benefits, considering  
80 the impacts on groundwater-dependent ecosystems (Lazo, Schulze et al. 1992) and the  
81 interactions between groundwater and ecosystem-protection benefits (Randal, DeZoysa & Yu,  
82 2001). In Europe, published studies are still scarce and they do not really address the issue of  
83 the valuation of the ecological benefits of groundwater protection and remediation (Press &  
84 Söderqvist, 1998, Rozan, Stenger & Willinger, 1997, Stenger & Willinger, 1998, Tentes &  
85 Damigos, 2012).

86 The second methodological issue investigated in this paper relates to the evaluation of  
87 benefits associated with various groundwater-quality levels. Most of the studies found in the  
88 literature use the contingent valuation method to assess a population's willingness to pay  
89 (WTP) for achieving a specific predefined groundwater-quality target. This paper presents an  
90 attempt to fill this gap by means of a case study in which costs and benefits are estimated for  
91 several groundwater-quality levels. The originality of the approach lies in the combination of  
92 economic and engineering approaches: these are too often kept separate in the economic  
93 literature which focuses solely on benefits. The approach is implemented in a case study  
94 located in eastern France where the groundwater is polluted with Volatile Organic  
95 Compounds (VOC), a group of substances widely used (mainly as solvents) in industry and  
96 frequently detected in groundwater.

97 This paper is organised as follows. The next section describes the case study area and the  
98 methodology used to assess the cost of remediation and the benefits generated. Results are  
99 presented in the third section, and the paper concludes with a discussion of problems related  
100 to the use of contingent valuation in groundwater CBA.

## 101 2. CASE STUDY AND METHODOLOGY

### 102 2.1. Presentation of the case study

103 The upper Rhine valley alluvial aquifer is located between Germany and France, and covers  
104 4200 square kilometres. With a reserve of approximately 45 km<sup>3</sup> of water - approximately  
105 half of the volume of Lake Geneva - this aquifer is one of the largest fresh water reserves in  
106 Europe. Groundwater from the Rhine alluvial valley supplies 75% of the drinking water needs  
107 and about half of the industrial water needs of the region. More than three million inhabitants  
108 of Alsace (France) and Baden-Württemberg (Germany) directly depend on this resource for  
109 their water supply. Although usable for drinking purposes without prior treatment in most  
110 locations, groundwater has been progressively affected by both diffuse and point-source  
111 pollution since the 1970s. Four major pollutions sources threaten this aquifer: nitrates,  
112 pesticides, chlorides, and VOC. High VOC concentrations have been detected downstream of  
113 several industrial areas. The most frequently observed molecules are trichloroethylene (TCE),  
114 tetrachloroethylene (PCE) and 111 trichloroethane (111 TRI). In a groundwater-quality  
115 measurement campaign carried out in 1996-97, at least one of the three substances listed  
116 above was detected in 38% of the 423 French and 533 German groundwater samples. The  
117 measured concentrations were less than 0.2 µg/l in 70% of the contaminated samples. Values  
118 ranging between 0.2 and 10 µg/l are reported in 25% of the samples. Only 6% of the samples  
119 show concentrations higher than 10 µg/l, which is the maximum value for drinking water use  
120 according to the EU standard.

121

## 122 **2.2. Programme of groundwater-restoration measures: design and cost assessment**

123 The first part of the research consisted of developing a tool for designing and assessing the  
124 cost of the programme of measures required to achieve various groundwater-quality  
125 objectives. The major steps involved in the development of that tool are depicted in figure 1.  
126 The tool incorporates several databases and Visual Basic queries developed using Microsoft  
127 Access ®. Given a groundwater-quality objective (maximum concentration) specified by the

128 user, the tool successively performs the following steps:

129 (1) It first identifies all groundwater areas where the observed VOC concentration exceeds  
130 the targeted threshold value; this is done by using the regional groundwater-quality  
131 database, which comprises information for 423 monitoring points; this step defines the  
132 geographical scope of the programme of measures.

133 (2) The tool then identifies all sites and firms (industrial companies and other) located  
134 within the area selected in Step 1 which are likely to generate a significant risk of  
135 pollution. Companies are selected using a list of 110 potentially polluting activities  
136 which was established after an extensive literature review, internet searches, and  
137 advice from industrial experts. This step also uses statistical databases which provide  
138 detailed technical and economic information on all firms at the municipal level  
139 (SIREN database) and on historical contaminated sites (Basias and Basol databases).

140 (3) The third step consists of identifying the prevention and remediation measures that  
141 need to be implemented for all selected firms and historical contaminated sites. This is  
142 based on a matrix specifying a list of measures for each of the 110 economic activities  
143 considered (Table 1). This matrix was also established based on literature review,  
144 internet search, and expert advice.

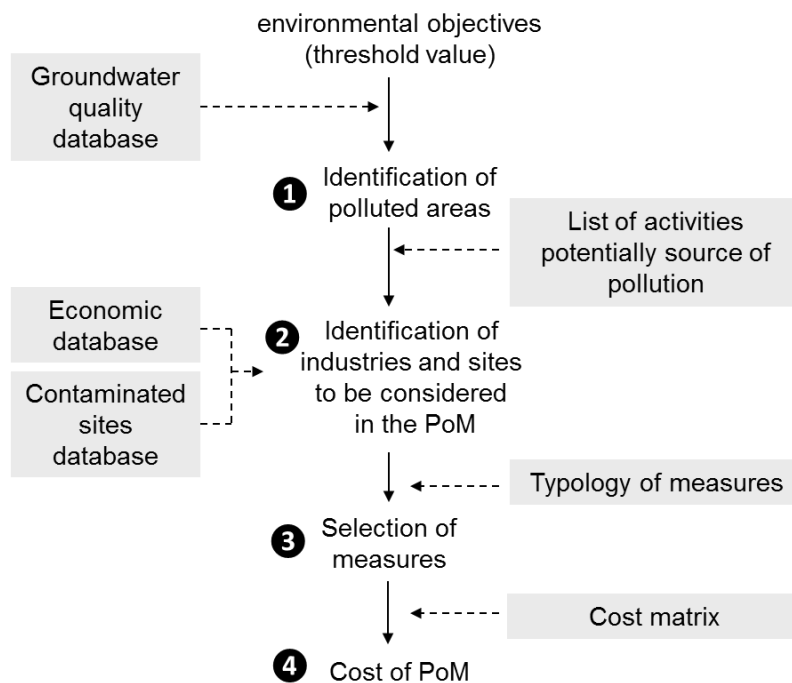
145 (4) Finally, the tool assesses the total cost of the programme of measures defined in Step  
146 3. This is based on a cost matrix which specifies the investment and recurring costs for  
147 all measures. An annual cost is estimated considering the technical lifespan of each  
148 measure, applying a 4% discount rate. More details on the types of measures and on  
149 cost estimation are provided in Appendix 1.

150 (5)

	Major point-source pollution			Dispersed point-source pollution	Diffuse pollution
<b>Origin</b>	Historical contaminated sites	Active industrial sites	Accidents (transportation, storage)	Households & small industries	Atmospheric contamination
<b>Type of measures</b>	Remediation measures: soil decontamination, pollution plume control (hydraulic barriers)	Remediation measures: soil treatment, plume control. Preventive measures: effluent treatment, monitored storage tanks, leach water collection, technological changes, recycling of solvents,	Remediation measures: pollution removal. Preventive measures: specific waste collection, ban on VOC in residential uses, additional treatment in sewage plants.	Remediation measures: soil treatment, plume control. Preventive measures: transport and delivery precautions, monitoring of roadside ditches and waters.	Preventive measures: limiting atmospheric VOC emissions (covered by existing regulations)

151 (6) Table 1: Overview of measures considered for remediation of VOC pollution.

152



153

154 **Figure 1: Main steps of the methodology used for designing the programme of measures.**

155

156

157



158 **2.3. Assessment of environmental benefits**

159 *2.3.1. Contingent valuation survey*

160 The second part of the research consisted of assessing the benefits associated with  
161 groundwater protection. The benefits were estimated by eliciting the population's willingness  
162 to pay (WTP) for the two levels of groundwater protection. A contingent valuation survey was  
163 carried out between March and July 2006 using a postal survey. The mail survey method was  
164 chosen to ensure that respondents would have sufficient time to get to know an unfamiliar  
165 subject, and think about preferences. Following a careful pre-test of the questionnaire in 140  
166 face-to-face interviews, the questionnaire was mailed out to 5,000 households selected in rural  
167 localities (2,000), urban areas (2,000) and in municipalities located outside the aquifer which  
168 used other water resources (1,000). The survey response rate was 13%, equally distributed  
169 between urban and rural municipalities (49 – 51%) and with respectively 79 and 21% of  
170 respondents located above and outside the aquifer.

171 One of the main specific characteristics of the survey consisted of asking respondents to  
172 consider and value two scenarios (for a similar approach focusing on surface water, see  
173 Lienhoop & Messner, 2009). The first scenario, assumes that groundwater-remediation  
174 measures are implemented only in areas where pollutant concentrations exceed drinking-  
175 water standards. The main expected benefits consist of avoiding costly water treatment for  
176 present and future generations. Respondents are informed that traces of contamination remain  
177 in parts of the aquifer with possible impacts on groundwater-dependent aquatic ecosystems  
178 (wetlands, rivers). Drinking water supply may also contain traces of contaminants but at  
179 concentration levels below European standards (no health risk). This information is supported  
180 in the questionnaire by a groundwater-quality map. The second scenario assumes that  
181 groundwater-remediation measures are implemented in all areas where traces of VOC are  
182 detected. The benefits of this scenario derive from restoring pristine water quality. This also

183 means that tap water delivered to citizen is totally free of contaminants (not even traces); that  
 184 groundwater-dependent ecosystems are no longer threatened by residual groundwater  
 185 pollution; and that future generations inherit a much improved natural heritage. The main  
 186 features of the two scenarios which were presented to respondents are summarised in Table 2.  
 187

	Scenario 1	Scenario 2
Objective	Restoring groundwater potability	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	<ul style="list-style-type: none"> <li>- Remediation measures implemented in historical contaminated sites located in areas where CS exceeds drinking water threshold value</li> <li>- Preventive measures applied (through regulation) in all enterprises using chlorinated solvents and located in areas where concentrations in solvents exceed drinking water threshold.</li> </ul>	<ul style="list-style-type: none"> <li>- Remediation measures implemented in historical contaminated sites located in areas where traces of solvents are detected</li> <li>- Preventive measures applied (through regulation) in all enterprises using chlorinated solvents and located in areas where traces of solvents have been detected</li> </ul>
Expected benefits	<ul style="list-style-type: none"> <li>- Drinking water quality level restored within 10 years but traces of CS remain in the aquifer, with risk of impacts on ecosystems.</li> <li>- Reduction in future drinking-water treatment cost.</li> </ul>	<ul style="list-style-type: none"> <li>- Natural quality restored, traces of CS disappear within 50 years: natural attenuation contributes.</li> <li>- Environmental benefits for ecosystems and water-related species, absence of risk for humans using groundwater.</li> <li>- Heritage benefits (for future generations).</li> </ul>

188 *Table 2: Summary of groundwater scenario presented to respondents in the survey questionnaire.*

189 2.3.2. Contingent valuation questionnaire

190 The questionnaire is organised as follows. It starts with a brief description of the upper Rhine  
 191 valley aquifer, accompanied by a map intended to help respondents determine whether the  
 192 locality they live in is located above the aquifer or not. This is followed by a set of questions  
 193 related to the respondent's use of the aquifer (private well, drinks tap water or not, practice of  
 194 leisure activities related to water). It then focuses on respondent's perception and knowledge  
 195 of groundwater. Respondents are then informed about the groundwater contamination  
 196 problem and its expected future evolution. The four major pollution sources (nitrates,  
 197 pesticides, chlorides from the mining industry, and chlorinated solvents) are presented. We

198 explain that whereas the problems of nitrates, pesticides, and chloride should be solved by  
199 2015 by measures already implemented, pollution by chlorinated solvents will remain as an  
200 obstacle to good groundwater quality. The extent of today's pollution by chlorinated solvents  
201 is depicted on a map which shows in red the locations where solvents have been found in  
202 concentrations exceeding drinking-water thresholds, and in yellow where traces that do not  
203 exceed the drinking water threshold have been found. The text briefly identifies the origins of  
204 the contamination and outlines the future pollution trends if no remediation and preventive  
205 measures are undertaken to control the pollution. The description of the two action scenarios  
206 follows. Respondents are then asked how realistic the scenarios are and about their  
207 willingness to pay to obtain the related benefits. Follow-up questions are used to understand  
208 their motivations to pay (or to refuse payment). The questionnaire ends by collecting the  
209 respondent's socio-economic characteristics.

210 The two scenarios are presented successively to respondents<sup>1</sup>. Households are asked how  
211 much they would be willing to pay over ten years<sup>2</sup> on top of their water bill . A payment card  
212 is offered to the respondents to elicit their WTP. The card includes thirty five amounts, with a  
213 minimum of €2 (besides a zero bid which is also allowed) and a maximum of €500 (value  
214 chosen after the questionnaire was tested in face-to-face interviews, see below).<sup>3</sup>

215

216

---

<sup>1</sup> A careful pre-test of the questionnaire showed that the order in which the two scenarios were presented to respondents had no effect on stated WTP. In the postal survey, the two scenarios were presented in the same order in all questionnaires.

<sup>2</sup> Respondents are requested to state the amount they would be willing to pay over the ten years corresponding to the implementation of the program of measures. WTP is thus expressed in €/household/year over 10 years.

<sup>3</sup> For a discussion of the pro and cons of the payment card approach versus the dichotomous choice experiment approach, see Ryan et al, 2004.

217 3. **RESULTS**

218 **3.1. Cost of groundwater restoration**

219 In the first scenario, we assume that specific protection and remediation measures are applied  
220 to sites and firms located in areas where groundwater exhibits VOC concentrations exceeding  
221 the drinking-water quality threshold. No specific action is undertaken in other areas where the  
222 presence of VOC is detected but does not exceed the drinking-water threshold. The second  
223 scenario aims at suppressing all sources of VOC contamination. This scenario assumes that  
224 the same technical measures are applied to all sites and firms located in areas where traces of  
225 VOC have been detected, including locations where pollution does not exceed drinking-water  
226 standards. The programmes of measures corresponding to the two scenarios are assessed  
227 using the computer tool described in the previous section.

228 As shown in Table 3, the number of firms involved in the programme of actions is  
229 significantly larger for the second scenario than for the first one. The total cost, estimated at  
230 €52 million, is more than twice that of Scenario 1 (€22 million)<sup>4</sup>. One of the questions then  
231 raised by policy makers is whether the benefits generated by the overall higher water quality  
232 justify the additional cost of approximately €30 million.

233

	<b>S1</b>	<b>S2</b>
Number of enterprises	466	1 933
Number of employees	13 075	62 568
Turn over (million €)	3 081	17 504
Added value (million €)	734	3 793
Cost of action in millions €	22	52
(in % of added value)	(3%)	(1.4%)

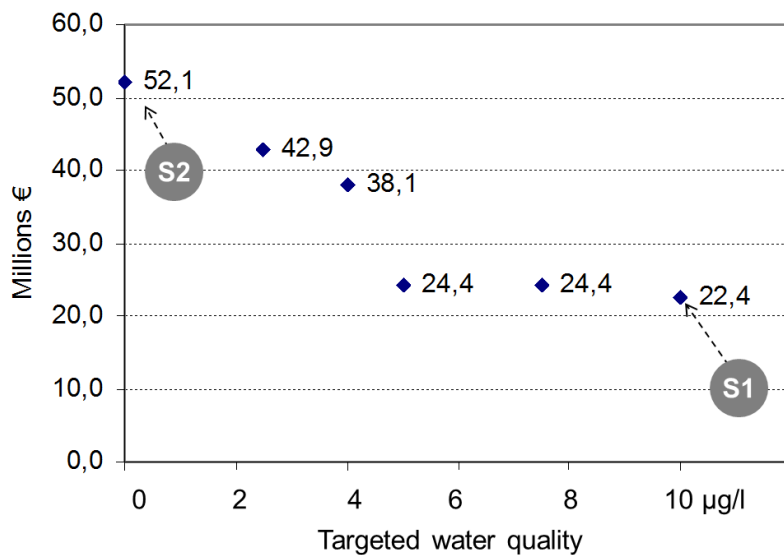
234 *Table 3: Enterprises located in areas where the presence of VOC is detected and for which preventive measures*  
235 *are implemented (Scenarios 1 and 2).*

236

---

<sup>4</sup> Investment costs that will be incurred at the beginning of the period represent respectively 82% and 86% for the two scenarios. Recurring operational and maintenance cost will spread over a ten-year periods. They are converted into net present value using a 4% discount rate.

237 The calculations were then repeated for several water quality objectives. In each calculation,  
 238 the objective was defined by a target groundwater maximum VOC concentration which  
 239 ranges between 0 (removal of all traces of pollutant) and the drinking-water quality standards  
 240 (DWQS). The results, depicted in Figure 2 below, show that the cost of the programme  
 241 remains relatively stable for a targeted water quality of between 50% and 100% of the  
 242 DWQS. The cost of the PoM increases significantly when the quality objective goes below  
 243 40% of the DWQS. The increase which occurs around 40% is mainly due to an increase in the  
 244 number of historical contaminated sites involved in the programme of actions.



245  
 246 **Figure 2:** Evolution of the total cost as a function of the targeted quality threshold value  
 247 (expressed in percentage of drinking water standards for COV).

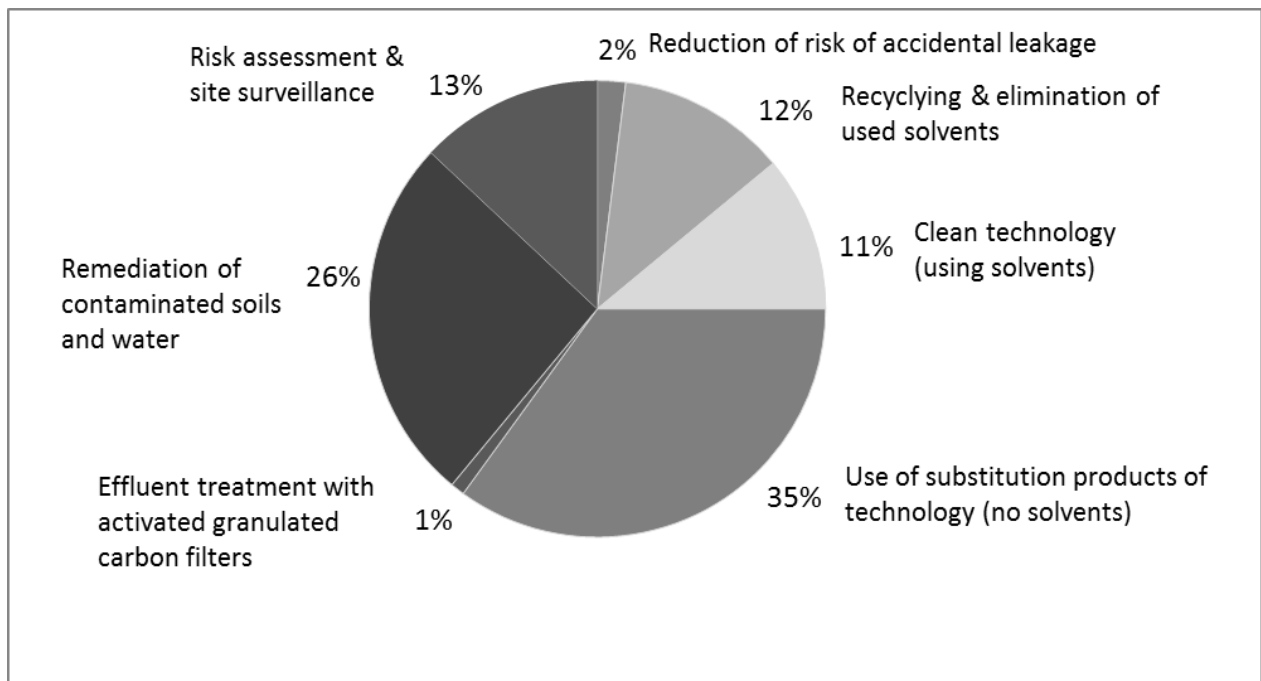
248  
 249  
 250 These results were presented to experts from the Rhine Meuse Water Agency. They  
 251 considered them to be a very useful input to their planning process. They emphasized the  
 252 difficulties they usually face when trying to assess the cost of groundwater remediation  
 253 programmes covering several hundreds or thousands of pollution sources. The systematic

254 approach implemented in this research provided useful elements for budget planning. They  
 255 were also very interested to learn that most of the cost was related to actions to be  
 256 implemented in three industrial sectors (see Table 4). Last but not least, the information  
 257 related to the distribution of cost per category of action (see Figure 3) was also considered to  
 258 be very useful when planning actions regarding the budget, and technical and human  
 259 resources.  
 260

Economic sector	Cost of PoM (€ 000)		% of total cost of PoM	
	S1	S2	S1	S2
Activities producing or using paint and varnishes	11,056	13,769	<b>49%</b>	<b>26%</b>
Mechanical industry	3,606	12,039	<b>16%</b>	<b>23%</b>
Contaminated sites	2,987	8,308	<b>13%</b>	<b>16%</b>
Metal-coating industry	1,891	5,566	8%	<b>11%</b>
Car and motorcycle repair workshops	1,097	4,408	5%	9%
Chemical industry	881	4,422	4%	9%
Printing	378	1,439	2%	3%
Textile industry	184	924	0.80%	2%
Manufacture of electrical /electronic products	166	471	0.70%	0.90%
Industrial-cleaning industry	60	396	0.30%	0.80%
Food and beverage industry	47	340	0.20%	0.70%
Metal-processing and cutting industry	46	60	0.20%	0.10%
<i>Total</i>	<i>22,405</i>	<i>52,147</i>	<i>100%</i>	<i>100%</i>

261 *Table 4: Enterprises located in areas where the presence of VOC is detected and for which preventive measures*  
 262 *are implemented (Scenarios 1 and 2).*

263



**Figure 3:** Distribution of the total cost per category of measures.

### 3.2. Willingness to pay for groundwater protection: survey results

The results of the survey highlight the fact that the population is concerned about groundwater protection. Groundwater pollution is identified as the second most important environmental problem after air pollution (45 and 48% respectively).

Sixty-two percent of respondents would agree to pay for remediating groundwater under Scenario 1, which consists of restoring drinking-water quality standards in the aquifer. The average stated WTP is €42/year/household (in 2006 €), which is in the lower range of values reported elsewhere in the world (see Bergstrom et al., 2001). It is also slightly lower (in constant euros) than the WTP values estimated by Stenger et al. (1998) in the same case study ten years earlier. Note that comparison of stated WTP in absolute value terms is a difficult exercise, since WTP values are highly dependent on the information provided to respondents (baseline scenario, information related to health impacts of pollution, etc.).

When asked to justify why they contribute, most respondents explain they want to preserve an

280 option for potential future use of the aquifer for themselves (option value) or future  
281 generations (bequest value). Other reasons presented are the personal current direct use of the  
282 aquifer via the municipal water supply system (direct use value) and the satisfaction from  
283 preserving aquatic life in groundwater dependent ecosystems for present (indirect use value)  
284 and future generations (bequest value).

285 Another interesting result is that 54% of respondents in our survey are willing to pay more for  
286 improving groundwater quality beyond strict compliance with drinking-water quality  
287 standards (€76/year/household on average). Information collected by the authors when testing  
288 the questionnaire in face-to-face interviews helps understanding this result. Many respondents  
289 are concerned by the presence of dangerous substances in the water they drink, even if the  
290 authorities can guarantee that drinking-water standards are met. Most of these people are  
291 drinking bottled water because they do not place trust in tap water. They are therefore willing  
292 to pay to remove all traces of pollution so that they can again rely on tap water for daily use.  
293 Their WTP reflects an increased use value. Other respondents indicate their willingness to pay  
294 for removing environmental risks which are not related to health (potential impacts of VOC  
295 on fauna and flora). Their WTP indicate a non-use value. Overall, it was not possible from our  
296 survey to disentangle use and non-use values.

297 The study also reveals that the population is very sensitive to the implementation of the  
298 “polluter pays” principle. Many respondents, who refused to contribute to the scenarios for  
299 protest motives (see column “protest” in table 5), argued that polluters (industries) should pay,  
300 not citizens. Similar attitudes have been reported in other case studies where polluters are  
301 known and theoretically liable to pay for remediation costs (Tentes & Damigos, 2012).

302



Number of respondents	WTP > 0	WTP = 0	
		Protesters	True zero
Scenario 1	N = 381 (62%)	N = 170 (28%)	N = 63 (10%)
Scenario 2	N = 344 (56%)	N = 111 (18%)	N = 159 (26%)

303 *Table 5: Number of respondents accepting refusing to pay for the two scenarios.*

304

### 305 **3.3. WTP econometric analysis**

306 Econometric models were developed to investigate whether the expected relationships  
307 between WTP and independent variables hold. Separate models were tested and estimated to  
308 explain the stated WTP for Scenarios 1 and 2. We used both OLS regressions<sup>5</sup> (excluding  
309 zero values) and the Tobit model (for WTP ≥ 0 excluding protest bids). Both statistical models  
310 tend to underestimate WTP as compared to the observed (survey) values. However, we  
311 consider that the predictive capacity of the models is acceptable (Table 6)

312

Mean WTP	WTP > 0		WTP ≥ 0 without protest bids	
	OLS regression	<i>Observed</i>	Tobit model	<i>Observed</i>
Scenario 1	€29.2	€42	€20.4	€36.4
Scenario 2	€50.0	€76	€34.5	€52

313 *Table 6: Predicted WTP for Scenarios 1 and 2 with OLS and Tobit models.*

314 Overall, the econometric analysis confirms the validity of responses, since WTP correlates as  
315 expected with the main explanatory variables (see Table 7). WTP is positively correlated with  
316 income with an elasticity of 0.35 in Scenario 1 and 0.54 in Scenario 2 (significant at the 99%  
317 level). WTP is also negatively correlated with age (99% confidence level) and positively  
318 correlated with membership in a nature-protection association.

<sup>5</sup> The estimated model is a semi-log model:  $\text{Log}(\text{WTP}) = a_i \cdot X_i + b_i \log(Y_i) + C$  where  $Y_i$  are AGEZ, NUMBER OF CHILDREN and INCOME and  $X_i$  are all other dependent variables except income. All parameters  $b_i$  can directly be interpreted as elasticity.

319 WTP seems to be strongly determined by the motivations quoted by respondents when  
320 justifying their decisions to pay. Two binary variables were constructed to describe these  
321 motivations. The first one takes the value 1 if respondent has quoted some reasons which are  
322 related to use values (USE\_VALUE) and the second one if respondent has quoted reasons  
323 related to non-use values (NON\_USE\_VALUE). The estimated coefficients however show  
324 that the effect of the first variable is much greater than the second (approximately 4 times)  
325 and this holds for both scenarios. This means that individuals whose WTP is motivated by  
326 direct use benefits are likely to pay €17.3 more than others. By contrast, quoting a non-use  
327 benefit as WTP motivation only increases WTP by €1.3.

328 Another interesting result of the econometric analysis is that there is no statistical difference  
329 between the “willingness to pay” amounts declared by households living above the aquifer  
330 (and using it for their water supply) and others living outside the aquifer. The latter may not be  
331 aware of the boundaries of the aquifer, or wrongly believe their water supply currently  
332 depends from the aquifer. They may also consider that they will be able to use that resource in  
333 the new future if pipelines are constructed to import that water to where they live. This  
334 finding suggests that users and non-users are equally concerned by groundwater protection.

335

336

Variable	Description	Coeff.	T	Sig <sup>(*)</sup>
LEISURE_WATER	Indicator of the number & frequency of water-related leisure activities practiced	-0.015	-0.51	ns
WELL	Respondent has a private well	0.074	0.41	ns
NO_DRINK_TAP	Respondent never drinks tap water	0.260	1.09	ns
POLLUTION_EXP	Respondent had experience of tap water interruption due to a pollution problem	0.173	0.94	ns
KNOW_BILL	Respondent knows the amount of his water bill	-0.204	-1.45	ns
OTHER_ENV_PRO B	Sum of environmental problems that are definitely more important than groundwater pollution for the respondent	0.031	0.58	ns
INDUSTRY_POL	Respondent considers industries are major sources of pollution for Alsatian groundwater	-0.095	-0.73	ns
POL_SUBST	Number of groundwater contaminants quoted by the respondent (in a list)	0.107	2.35	**
CREDIBLE_REF	Respondent considers the description of the current situation quite or very realistic/credible	0.303	0.96	ns
CREDIBLE_SCENA RIO	Respondent believes it is possible to restore drinking water quality in the aquifer (Scenario 1)	0.067	0.38	ns
USE_VALUE	Respondent is willing to pay for reasons revealing a use value	2.850	14.16	***
NON_USE_VALUE	Respondent is willing to pay, for reasons revealing non-use value	0.322	2.18	**
LOG_AGE	Logarithm of age	-0.071	-0.33	ns
LOG_CHILDREN	Logarithm of number of children in the household	0.069	0.40	ns
LOG_INCOME	Logarithm of income	0.345	3.67	***
WTP_DIFFICULT	Respondent found it difficult to answer the WTP question	-0.171	-1.15	ns
INFO_INSUF	The information provided was not considered sufficient to answer the WTP questions	-0.135	-0.90	ns
ENV_NGO	Respondent is a member of an environmental association	0.582	3.09	***
INTERCEPT		-2.69	-2.45	ns
337	N= 342	LR chi2(19) = 393	Prob > chi2 = 0.0000	Pseudo R2 = 0.23

338 (\*): Sig stands for statistical significance. "ns" indicate that the variable is not significant; \*\* and \*\*\* indicate  
339 the variable is significant at the 95% and 99% level. All variables included in the model improve the overall fit.  
340 Others have been removed.

341 *Table 7: Estimated Tobit model for log(WTP) in Scenario 1.*

342

### 343 3.4. WTP aggregation and cost benefit analysis

344 The main objective of the contingent valuation survey was to assess the benefits of two  
345 scenarios for groundwater pollution remediation. The total benefits of each scenario can be  
346 roughly estimated by extrapolating the average stated WTP to the entire population affected  
347 by groundwater quality. The extrapolation can be done by simply multiplying the average  
348 WTP by the number of households in the region and by ten years (period during which

349 respondents have agreed to pay). The aggregation procedure is more complex if the survey  
350 sample is not representative of the regional population. As this was the case in the present  
351 survey, the bias was corrected before extrapolating the results<sup>6</sup>. The aggregate willingness to  
352 pay for the entire region (considered as a proxy for groundwater protection benefits) was  
353 subsequently estimated at €236 million over a ten-year period for Scenario 1 (drinking-water  
354 quality level) and €377 million for Scenario 2 (natural-groundwater quality level). Table 4  
355 shows that the net present value for the two groundwater restoration scenarios is largely  
356 positive (resp. € 224 and 340 million). From a pure welfare economics perspective, the results  
357 suggest that the second scenario should be preferred. This conclusion should however be  
358 considered with caution, considering uncertainties related to the population concerned (benefit  
359 extrapolation) and the cost estimation (assumptions related to measure adoption rates, see  
360 appendix).

361

## 362 4. DISCUSSION

363 The main objective of the case study presented in this paper was to investigate the relevance  
364 of cost benefit analysis for assessing groundwater remediation, considering two scenarios  
365 targeting different water quality objectives. It highlights a number of methodological  
366 difficulties related to costs and to benefit-estimation procedures which are discussed in this  
367 section.

368

### 369 4.1. Cost estimate uncertainty

370 Concerning costs, one of the main challenges lies in the scale at which WFD remediation

---

<sup>6</sup> The sample bias was corrected as follows. We calculated an average WTP per professional category in our sample, using the national occupational classification system. The adjusted values were then used to extrapolate results of the survey to the entire regional population.

371 programmes have to be defined. While engineers are used to designing decontamination  
372 programmes at scales ranging from a few hectares to few square kilometres, it is much more  
373 difficult to assess the level of effort – both in technical and financial terms – required to  
374 improve the quality of an aquifer extending over several thousand square kilometres,  
375 particularly in the case of non-agricultural pollution. The case study presented in this paper  
376 illustrates the complexity associated with the identification of multiple potential pollution  
377 sources and the definition of technical measures that should be implemented to prevent any  
378 further emission, or to contain and/or decontaminate existing pockets of contaminated  
379 groundwater. The approach proposed in this paper, which consists of combining various  
380 sources of statistical data with expert advice, allows a gross estimate of the total cost to be  
381 produced. However, a high uncertainty is attached to the results obtained. This uncertainty  
382 could probably not be reduced without engaging over costly surveys and studies to  
383 characterise the actual pollution level in thousands of potentially contaminated or  
384 contaminating sites and firms. If we accept that the uncertainty of the cost estimate is  
385 irreducible, then the value to decision makers of the numerical results of CBA remains  
386 limited, whatever efforts are made to assess the benefits. We contend however that the  
387 economic approach provides a useful analytical framework for putting together pieces of  
388 knowledge which are scattered among a large number of experts and stakeholders. In that  
389 sense, the main outcome of an economic evaluation of costs and benefits is not the precise  
390 figures that are produced, but the fact that it helped to construct a shared knowledge base on  
391 which decision makers may rely when making and justifying their decisions.

392

#### 393 **4.2. The limits of CVM for assessing the benefits of groundwater protection**

394 The paper also addresses several questions related to the use of contingent valuation for  
395 assessing the benefits of groundwater protection in the European context. One of the main

396 challenges is related to the nature of the benefits to be estimated. While most previous CV  
397 studies focussed on areas where groundwater was intensively used, the WFD requires  
398 Member States to assess the benefits of groundwater protection for all types of aquifers,  
399 including those which are not exploited. Economists are therefore asked to assess non-use  
400 benefits, including the indirect benefits of groundwater remediation for dependent ecosystems  
401 such as rivers and wetlands, and option and bequest values. One of the main problems is then  
402 to accurately describe this indirect effect in CV surveys. This is all the more difficult that  
403 water scientists themselves are not able to model the complex relationships that determine  
404 pollution transfer from aquifers to rivers and wetlands, and the subsequent impacts on flora  
405 and fauna. If the information presented in the questionnaire is too vague, what does WTP  
406 actually measure? In the present case, the difference between stated WTP for Scenarios 1 and  
407 2 actually measure relatively “fuzzy” benefits (Lienhoop et Messner, 2009) and there are few  
408 options for reducing this fuzziness.

409 Another key difficulty related to the use of CV for evaluating groundwater protection benefits  
410 is that respondents generally know very little about groundwater, how the resource works, the  
411 threats that endanger it, and the benefits associated with its protection or remediation. This is  
412 again more pronounced in the EU situation where only a few households rely solely on  
413 private wells for their drinking-water supply. Let us recall that, in our case study, 82% of the  
414 respondents considered that they were not well informed about the groundwater problem  
415 described in the questionnaire, although more than half had already heard about groundwater  
416 pollution, with 20% being able to quote a precise example. To make sure that all respondents  
417 value the same good, questionnaires should therefore be designed to convey adequate  
418 information on groundwater, its problems, and the benefits associated with its protection. As  
419 already mentioned in the literature, this may have a WTP-enhancing effect. Another concern

420 is that households may be in a situation of preference construction<sup>7</sup> when stating their WTP,  
421 which cast doubts on the validity of the values elicited (Slovic, 1995).  
422 We also found, during the pre-test of the questionnaire, several people refusing to pay  
423 (protesters) because they did not believe it would be technically feasible to restore  
424 groundwater quality when pollution sources were so many and spread over so large an area.  
425 To strengthen the credibility of our scenario, and to reduce the rate of protest bids, we had to  
426 provide some technical description of the actions that would actually be undertaken to reach  
427 the environmental objectives. Although we tried to minimise this information and to  
428 emphasise the benefits that would be derived from the scenario, there is a risk that some of the  
429 respondents may have evaluated their WTP with reference to what they thought the cost  
430 would be, instead of truly evaluating scenarios in terms of increased utility. We believe this  
431 risk is inherent to groundwater valuation: since respondents are not aware of how an aquifer  
432 functions, they need to receive information not only on the resource and the services it  
433 provides, but also on the technical actions that will be implemented to improve its quality.

434

### 435 **4.3. From WTP to aggregated benefits**

436 Once WTP has been estimated, another challenge of CBA lies in aggregating WTP at the  
437 regional level. This involves identifying the population affected by the protection of the  
438 specific aquifer under study. One approach suggested by Bateman consists of using distance  
439 decay functions, which are estimated econometrically by adding distance as one explanatory  
440 variable in the econometric model (Bateman, Day, Georgiou & Lake, 2006). While this  
441 approach is appealing for surface waters, which are often used for recreational purposes, it is  
442 not clear whether it applies to groundwater or not. In the case study presented in this paper,

---

<sup>7</sup> Economists generally assume that CV survey respondents have pre-existing preferences for the environmental good under study, based on the level of satisfaction or utility it provides. Some authors however argue that people's preferences are sometimes constructed in the process of elicitation. This might be the case when respondents are not familiar with the good they are requested to value, groundwater in particular.

443 for instance, we did not find any significant difference in WTP between respondents located  
444 above the aquifer and others. This result is consistent with the observation that most  
445 respondents justify their WTP decision by a concern for future generations. The question then  
446 becomes how to identify the population that may be affected by the protection of the aquifer?  
447 The problem was easily solved in our case study owing to the very specific geographical  
448 configuration in which the aquifer occupies more than half of the region's area and is  
449 surrounded by mountains that also delineate the region's boundaries<sup>8</sup>. Assuming that the  
450 entire regional population is concerned was a reasonable assumption. But what should be  
451 done in other contexts where the boundaries of the aquifer do not correspond to any relevant  
452 territory from a political, cultural or economic perspective? Again, improving the accuracy of  
453 WTP estimates is of limited use if their aggregation remains highly uncertain.

454 Another caveat of cost-benefit analysis that should be acknowledged is that, when dealing  
455 with groundwater-management issues, we generally do not properly consider time effects.  
456 Even where hydrodynamic groundwater models are available, there is often great uncertainty  
457 concerning the time-lag between the moment when remediation measures are implemented  
458 (and costs paid) and the date at which benefits will fully appear. Even with a low discount rate  
459 (typically 2 to 4% for groundwater, depending on the country), an error of 5 to 10 years can  
460 totally change the results of the analysis.

#### 461 **4.4. Conclusion**

462 A major innovation of the European Water Framework Directive (2000/60/EC) (WFD) is to  
463 explicitly recognise that economics should play a key role in the development of river basin  
464 management plan. Although Cost Benefit Analysis is not mentioned in the Directive, some

---

<sup>8</sup> We assume that the German population living on the other side of the Rhine (state of Baden Württemberg) does not feel concerned by groundwater protection on the French part of the alluvial valley. Indeed, hydrogeologists tell us that pollution occurring in one country will generally not impact the other one, the Rhine river acting as a hydraulic barrier (a few exceptions reporter though). Whether German citizen perceive things like this should however be checked though a specific survey.



465 experts are suggesting using it to support the definition of water quality objectives (Brouwer,  
466 2008). They suggest that CBA could be used to justify derogation under article 4 if it can be  
467 proven that the costs of implementing the WFD outweigh the benefits of reaching good  
468 ecological status. By extension, the same argue that CBA could be used to set groundwater  
469 quality objectives, under the general rules set by the Groundwater Directive (2006/118/EC).

470 For all the reasons advocated in the discussion above, and based on the case study presented  
471 in this paper, we argue here that the use of CBA is inappropriate to justify derogations as part  
472 of the Water Framework Directive under present conditions. Additional research needs to be  
473 conducted to ensure that non-use benefits can actually be captured by stated preference  
474 methodologies when considering large-scale aquifers in the European context. Also, given  
475 that primary studies are not feasible in each specific case study, significant efforts must be  
476 devoted to the production of a set of CV studies representative of European groundwater  
477 situations. These studies should be produced with a uniform methodology, in order to  
478 facilitate benefit transfers in the longer term. Additional research is also needed on the  
479 engineering side of the analysis.

480 CBA nonetheless provides a very relevant framework for incorporating in a single coherent  
481 picture complex environmental, engineering and economic information related to  
482 groundwater contamination, pollution sources, measures that need to be implemented and  
483 economic consequences. Many CBA analysts agree that, while this evaluation technique helps  
484 organizing and structuring the arguments that support social decision making processes, it  
485 does not replace them (see case studies reported in Brouwer & Pearce, 2005). It also helps  
486 confronting and integrating the visions of the different parties concerned. And it can be used  
487 as a tool for communicating the rationale behind decisions to various stakeholders. Provided  
488 that values used are scientifically sound.

489

490 **Acknowledgements:** The research presented in this paper was part of the EU funded project  
491 Background cRiteria for the IDentification of Groundwater thresholds (BRIDGE), Contract n°  
492 SSPI-2004-006538. We would like to thank Alain Saada (Brgm) for identifying and  
493 characterising groundwater remediation measures. Roy Brouwer and Sebastiaan Hess (IVM,  
494 Free University of Amsterdam) for the support they provided in drafting and testing the  
495 contingent valuation questionnaire. We also acknowledge the contribution from Hélène  
496 Bouscasse and Mathieu Rouzère (students) and the technical support provided by Agence de  
497 l'Eau Rhin Meuse (Sophie Nicolaï and Jean-Luc Salleron).

## REFERENCES

- 498 Abdalla, C. W., 1994 - Groundwater values from avoidance cost studies : implication for  
499 policy and future research, *American Journal of Agricultural Economics*, 76, pp.
- 500 Bateman, I. J., Day, B. H., Georgiou, S. and Lake, I., 2006 - The aggregation of  
501 environmental benefit values: Welfare measures, distance decay and total WTP, *Ecological*  
502 *Economics*, 60, pp. 450-460  
503 Bergstrom, J.C., Boyle, K.J., Job, C.A., Jo Kealy, M., 1996.  
504 Assessing the economic benefits of ground water for environmental policy decisions. *Journal*  
*of the American Water Resources Association* 32, 279-291.
- 505 Brouwer, R (2008) The potential role of stated preference methods in the Water Framework  
506 Directive to assess disproportionate costs. *Journal of Environmental Planning and*  
507 *Management*, 51(5): 597-614
- 508 Brouwer, R. and Pearce, D. (2005). *Cost benefit analysis and water resources management.*  
509 Cheltenham / Northampton, Edward Elgar Publishing.
- 510 Carson, R.T., Flores, N.E., Meade, N.F., 2001. Contingent Valuation: Controversies and  
511 Evidence, *Environmental and Resource Economics* 19, 173-210.
- 512 Edwards, S. F., 1988 - Option prices for groundwater protection, *Journal of Environmental*  
513 *Economics and Management*, 15, pp. 475-487
- 514 Hardisty, P. E. and Özdemiroglu, E., 2005 - *The economics of groundwater remediation and*  
515 *protection*, CRC Press, p.
- 516 Jordan, J. L. and Elnagheeb, A. H., 1993 - Willingness to pay for improvements in drinking  
517 water quality, *Water Resour. Res.*, 29, pp. 237-245
- 518 Kiel, K. and Zabel, J., 2001 - Estimating the Economic Benefits of Cleaning up Superfund  
519 Sites : the case of Woburn, Massachusetts, *Journal of Real Estate Finance and Economics* 22,  
520 pp. 163 à 184
- 521 Lazo, J. K., Schulze, W. D., McClelland, G. H. and Doyle, J. K., 1992 - Can Contingent

- 522 Valuation Measure Nonuse Values?, *American Journal of Agricultural Economics*, 74,  
523 December 1, 1992, pp. 1126-1132
- 524 Lienhoop, N. and Messner, F., 2009 - The Economic Value of Allocating Water to Post-  
525 Mining Lakes in East Germany, *Water Resources Management*, 23, 2009/03/01, pp. 965-980
- 526 Pearce, D., 1998 - Environmental Appraisal and Environmental Policy in the European  
527 Union, *Environmental and Resource Economics*, 11, 1998/04//, pp. 489-501
- 528 Poe, G. L., Boyle, K. J. and Bergstrom, J. C. (2001). A preliminary analysis of contingent  
529 values for ground water quality revisited. *The Economic Value of Water Quality*. J. C.  
530 Bergstrom, K. J. Boyle and G. L. Poe. Cheltenham, U.K., Edward Elgar: 137-162.
- 531 Press and Söderqvist, T. (1998). On estimating the benefits of groundwater protection : a  
532 contingent valuation study in Milan. *Regulating chemical accumulation in the environment:  
533 the integration of toxicology and economics in environmental policy making*. T. Swanson and  
534 M. Vighi. Cambridge, Cambridge University Press: 278.
- 535 Quevauviler, P., 2008 - From the 1996 groundwater action programme to the 2006  
536 groundwater directive - what have we done, what have we learnt, what is the way ahead ?,  
537 *Journal of Environmental Monitoring*, 10, pp. 408-421
- 538 Randal, A., Dezoysa, D. and Yu, S. (2001). Groundwater, surface water and wetland  
539 valuation in Ohio. *The economic value of water quality*. J. C. Bergstrom, K. J. Boyle and P.  
540 G. L. Cheltenham UK, Edward Elgar: 83-99.
- 541 Rinaudo, J.-D. and Loubier, S. (2005). Cost-benefit analysis of large scale groundwater  
542 remediation in France. *Cost Benefit Analysis and Water Resources Management*. R.  
543 Brouwer and D. Pearce. Cheltenham /Northampton, Edward Elgar Publisher: 290-314
- 544 Ryan, M., Scott, D.A., Donaldson, C., 2004. Valuing health care using willingness to pay: a  
545 comparison of the payment card and dichotomous choice methods. *Journal of Health  
546 Economics* 23, 237-258.
- 547 Rozan, A., Stengter, A. and Willinger, M., 1997 - Valeur de préservation de la qualité de l'eau  
548 souterraine : une comparaison entre usagers et non-usagers, *Cahiers d'Economie et Sociologie  
549 Rurales*, 45, pp. 62-92
- 550 SharefkinN, M., Shechter, M. and Kneese, A., 1984 - Impacts, costs, and techniques for  
551 mitigation of contaminated groundwater: A review, *Water Resour. Res.*, 20, pp. 1771-1783
- 552 Slovic, P., 1995 - The construction of preference *American Psychologist*, 50, pp. 364-371.
- 553 Stenger, A. and Willinger, M., 1998 - Preservation value for groundwater quality in a large  
554 aquifer: a contingent valuation study of the Asatian aquifer, *Journal of Environmental  
555 Management*, 53, pp. 177 - 193
- 556 Tentes, G. and Damigos, D., 2012 - The Lost Value of Groundwater: The Case of Asopos  
557 River Basin in Central Greece, *Water Resources Management*, 26, pp. 147-164
- 558 Yadav, S. N. and Wall, D. B., 1998 - Benefit-cost analysis of best management practices  
559 implemented to control nitrate contamination of groundwater, *Water Resour. Res.*, 34, pp.  
560 497-504  
561

## APPENDIX

### Selection of measures and estimation of cost of programme of measures

#### A.1. DEFINITION OF MEASURE AND UNIT COST ESTIMATE

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.

##### A.1.1. Remediation measures

Remediation measures can apply to large scale industrial sites (abandoned sites or sites in activity) as well as to small sites (car repair workshops for instance). Concerning historical abandoned sites, they consist in (i) conducting risk assessment studies in 100% of the sites, (ii) implementing soil and water sampling, analysis and surveillance (installation of monitoring wells in 50% of the sites) and decontaminating groundwater pollution plumes or contaminated soils located above the aquifer (approximately 20% of the sites are concerned). The type of measure to be implemented in each site was selected considering the extent of soil and water contamination (described in the BASIAS database). The cost was estimated for each site through an extrapolation of real cost data obtained from a limited number of sites in the case study area.

We also consider that small scale soil and water contamination occurs in firms in activity but no detailed database allows locating where exactly this happens. The probability of soil and water contamination varies depending on the economic activity. To assess the cost of the programme of measure, we assume, for each branch of activity, the percentage of firms where: (i) a risk assessment study has to be implemented (cost of about €5000), (ii) investigative and surveillance soil and water monitoring has to be implemented (cost ranging

587 from € 10 000 to 16 000) or (iii) remediation measures actually have to be implemented (cost  
588 from € 8000 for small firms to € 500 000 for large ones).

### 589 **A.1.2. Preventive measures**

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

592 - Measures aimed at reducing accidental leakage by constructing watertight areas under  
593 storage tanks, removing all underground pipes and tanks, securing all areas where  
594 solvents are transported or manipulated, constructing retentions to recover solvents in  
595 case of accident, etc. The average estimated cost of this type of measure ranges from  
596 €1,000 for very small firms to €10,000 for larger industrial sites.

597 - Measures aimed at collecting all used solvents and other wastes containing solvents:  
598 this implies constructing storage premises for used solvents (which are sometimes still  
599 discharged directly into sewage systems or into the environment) and organising their  
600 collection by firms specialised in the treatment and recycling of toxic wastes. The cost  
601 of this type of measure depends on the volume of solvents to be collected and treated  
602 (€1/litre of solvent). The volume is estimated for each industrial branch, based on  
603 expert judgement.

604 - Clean technologies for reducing emissions of VOC: these include the use of  
605 technologies where VOC are recycled (printing industry, painting-related activities,  
606 mechanical industries, etc.) Cost of equipment (investment) varies significantly from  
607 one industry to another. Average values were estimated based on various examples  
608 found in the literature or identified by experts. Estimated investment costs range  
609 between €2,000 and €200,000. Operational and maintenance costs are assumed to be

610 relatively unchanged (in many cases, they may even be reduced by the change in  
611 technology).

612 - Substitution of chlorinated solvents by other solvents and/or use of technologies which  
613 do not require CS. For instance, cleaning of equipment used for painting can be done  
614 with ultrasonic devices; metal cleaning before coating can be done using  
615 bacteriological processes instead of solvents; and so on. Estimated investment costs  
616 range from €10,000 to €200,000 depending on the branch of activity and the size of  
617 the company.

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

625 - Monitoring measures, which consist of installing a piezometer downstream from risk  
626 zones and conducting surveillance chemical analyses to detect any traces of pollution  
627 before it can generate a plume in groundwater. Investment costs are assessed as  
628 follows. For large industrial sites, we assume that a Simplified Risk Assessment Study  
629 is carried out and two monitoring wells are drilled for a total cost of €25,000. An  
630 additional €1,500 are estimated for recurring operational costs. For medium-size sites,  
631 one SRA study is carried out and one well drilled (€15,000) whereas small sites have  
632 to conduct an SRA study only (€5,000).

633

634 **A.2. COST ESTIMATION**

635 One-off investment and yearly operational costs are estimated separately for each type of  
636 measure separately.

637 Investment costs are assessed as follows:

638 
$$C_m = \sum_i (\alpha_{t,m}^i - \alpha_{c,m}^i) \cdot N^i \cdot c_m^i$$

639 Where:

640  $C_m$  is the total cost of the measure “m”,

641  $\alpha_{t,m}^i$  is the targeted rate of adoption of measure “m” for industries of branch “i”,

642  $\alpha_{c,m}^i$  is the current rate of adoption of measure “m” for industries of branch “i”,

643  $N^i$  is the number of industries of branch “i” which are involved in measure “m”,

644  $c_m^i$  is the average unit cost of implementing measure “m” for one company of branch  
645 “i”.

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

652 Recurring operational costs are assessed in the same way. Investment and operational costs  
653 are then aggregated assuming a 4% discount rate and ten years duration for the programme of  
654 measures (this assumption is also used when assessing the benefits in the CV survey).

655 The tool can be used to assess the cost of achieving various groundwater quality objectives.