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Defining groundwater remediation objectives with cost-benefit analysis: does it work?

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Abstract

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

Keywords

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

1. INTRODUCTION

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

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

(Abdalla, 1994, Yadav & Wall, 199). Even contingent valuation studies mainly consider use benefits (for a review see Hardisty & Özdemiroglu, 2005, Poe, Boyle & Bergstrom, 2001).

This is a quite different situation from that of Europe, where the population is almost entirely supplied by public water systems. The only direct link that exists between groundwater quality and households' wellbeing is the price they pay for the drinking-water supply (increasing water treatment cost in case of pollution) and the possible impact of groundwater deterioration on groundwater-dependent ecosystems. Clearly, only a tiny minority of households depending on private wells would be directly concerned by health risks due to groundwater pollution or by the need to invest in private treatment. A consequence is that, in the European context, groundwater valuation studies should focus more on the ecological benefits generated by action programs, and less on direct use benefits alone. This is also required by the European Water Framework Directive.

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

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

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

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

2. CASE STUDY AND METHODOLOGY

2.1. Presentation of the case study

The upper Rhine valley alluvial aquifer is located between Germany and France, and covers 4200 square kilometres. With a reserve of approximately 45 km^3 of water - 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 supplies 75% of the drinking water needs and about half of the industrial water needs of the region. More than three million inhabitants of Alsace (France) and 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 been progressively affected by both diffuse and point-source pollution since the 1970s. Four major pollutions sources threaten this aquifer: nitrates, pesticides, chlorides, and VOC. High VOC concentrations have been detected downstream of several industrial areas. 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 substances listed above was detected in 38% of the 423 French and 533 German groundwater samples. The measured concentrations were less 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.

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

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

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

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

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

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

(5)

	Major point-source pollution			**Dispersed point-source pollution**	***Diffuse pollution***
Origin	Historical contaminated sites	Active industrial sites	Accidents (transportation, storage)	Households & small industries	*Atmospheric contamination*
Type of measures	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)

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

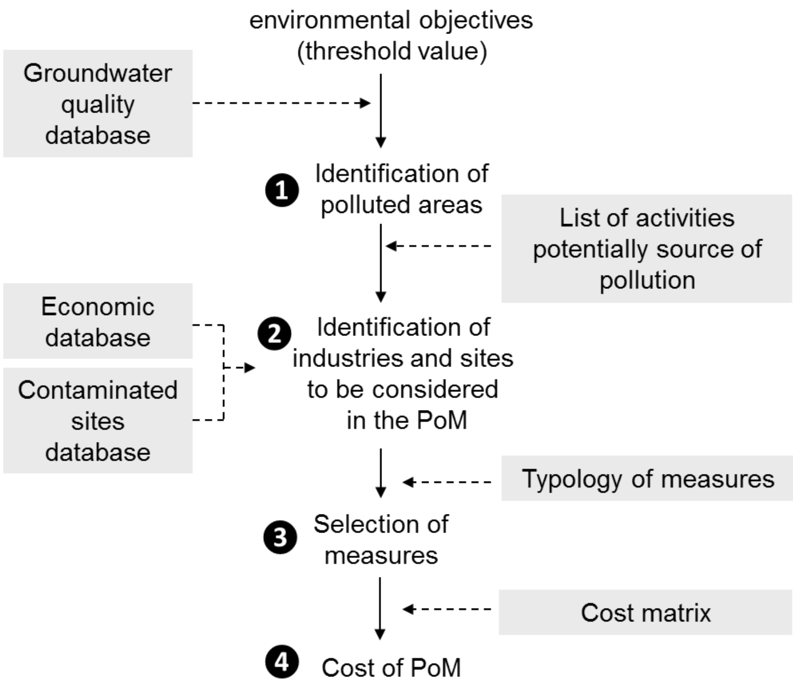

Figure 1: Main steps of the methodology used for designing the programme of measures.

2.3. Assessment of environmental benefits

2.3.1. Contingent valuation survey

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

One of the main specific characteristics of the survey consisted of asking respondents to consider and value two scenarios (for a similar approach focusing on surface water, see Lienhoop & Messner, 2009). The first scenario, assumes that groundwater-remediation measures are implemented only in areas where pollutant concentrations exceed drinking-water standards. The main expected benefits consist of avoiding costly water treatment for present and future generations. Respondents are informed that traces of contamination remain in parts of the aquifer with possible impacts on groundwater-dependent aquatic ecosystems (wetlands, rivers). Drinking water supply may also contain traces of contaminants but at concentration levels below European standards (no health risk). This information is supported in the questionnaire by a groundwater-quality map. The second scenario assumes that groundwater-remediation measures are implemented in all areas where traces of VOC are detected. The benefits of this scenario derive from restoring pristine water quality. This also means that tap water delivered to citizen is totally free of contaminants (not even traces); that groundwater-dependent ecosystems are no longer threatened by residual groundwater pollution; and that future generations inherit a much improved natural heritage. The main features of the two scenarios which were presented to respondents are summarised in Table 2.

	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	- 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 future drinking-water treatment cost.	- Natural quality restored, traces of CS disappear within 50 years: natural attenuation contributes. - Environmental benefits for ecosystems and water-related species, absence of risk for humans using groundwater. - Heritage benefits (for future generations).

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

2.3.2. Contingent valuation questionnaire

The questionnaire is organised as follows. It starts with a brief description of the upper Rhine valley aquifer, accompanied by a map intended to help respondents determine whether the locality they live in is located above the aquifer or not. This is followed by a set of questions related to the respondent's use of the aquifer (private well, drinks tap water or not, practice of leisure activities related to water). It then focuses on respondent's perception and knowledge of groundwater. Respondents are then informed about the groundwater contamination problem and its expected future evolution. The four major pollution sources (nitrates, pesticides, chlorides from the mining industry, and chlorinated solvents) are presented. We explain that whereas the problems of nitrates, pesticides, and chloride should be solved by 2015 by measures already implemented, pollution by chlorinated solvents will remain as an obstacle to good groundwater quality. The extent of today's pollution by chlorinated solvents is depicted on a map which shows in red the locations where solvents have been found in concentrations exceeding drinking-water thresholds, and in yellow where traces that do not exceed the drinking water threshold have been found. The text briefly identifies the origins of the contamination and outlines the future pollution trends if no remediation and preventive measures are undertaken to control the pollution. The description of the two action scenarios follows. Respondents are then asked how realistic the scenarios are and about their willingness to pay to obtain the related benefits. Follow-up questions are used to understand their motivations to pay (or to refuse payment). The questionnaire ends by collecting the respondent's socio-economic characteristics.

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

[1] 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.

[2] 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.

[3] For a discussion of the pro and cons of the payment card approach versus the dichotomous choice experiment approach, see Ryan et al, 2004.

3. RESULTS

3.1. Cost of groundwater restoration

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

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

	S1	**S2**
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 € (in % of added value)	22 (3%)	52 (1.4%)

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

[4] 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.

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

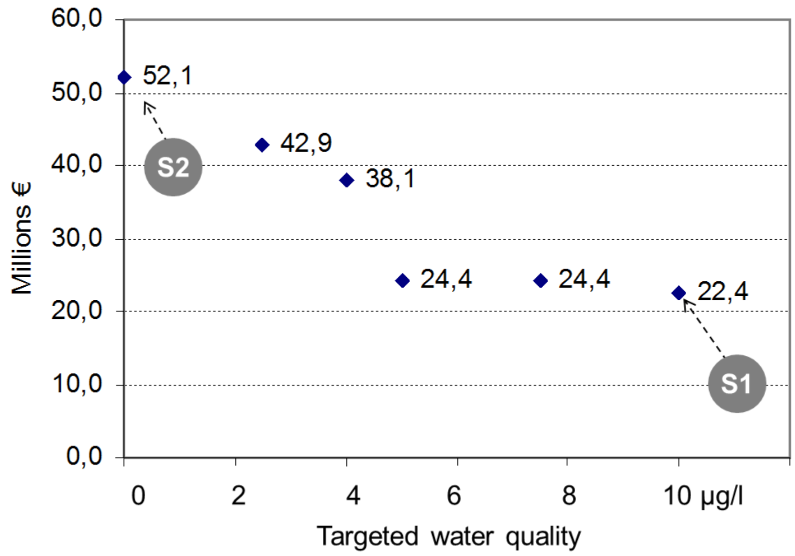

Figure 2: Evolution of the total cost as a function of the targeted quality threshold value (expressed in percentage of drinking water standards for COV).

These results were presented to experts from the Rhine Meuse Water Agency. They considered them to be a very useful input to their planning process. They emphasized the difficulties they usually face when trying to assess the cost of groundwater remediation programmes covering several hundreds or thousands of pollution sources. The systematic approach implemented in this research provided useful elements for budget planning. They were also very interested to learn that most of the cost was related to actions to be implemented in three industrial sectors (see Table 4). Last but not least, the information related to the distribution of cost per category of action (see Figure 3) was also considered to be very useful when planning actions regarding the budget, and technical and human resources.

	Cost of PoM (€ 000)		% of total cost of PoM	
Economic sector	S1	S2	S1	S2
Activities producing or using paint and varnishes	11,056	13,769	**49%**	**26%**
Mechanical industry	3,606	12,039	**16%**	**23%**
Contaminated sites	2,987	8,308	**13%**	**16%**
Metal-coating industry	1,891	5,566	8%	**11%**
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%
Total	*22,405*	*52,147*	*100%*	*100%*

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

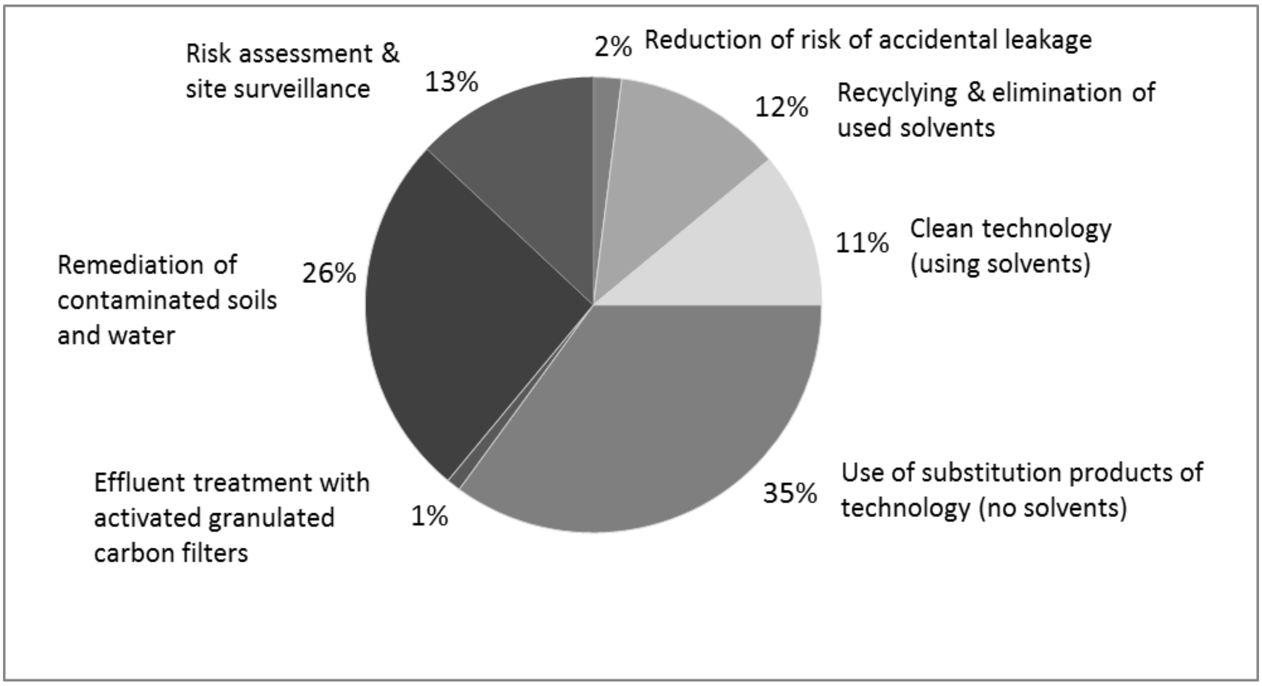

Figure 3: Distribution of the total cost per category of measures.

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

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

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

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%)*

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

3.3. WTP econometric analysis

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

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

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

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

[5] The estimated model is a semi-log model: $\text{Log(WTP)}= a_i.X_i + b_i \log(Y_i) + C$ 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.

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

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

Variable	Description	Coeff.	T	Sig (*)
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_PROB	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_SCENARIO	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
N= 342	LR chi2(19) = 393	Prob > chi2 = 0.0000	Pseudo R2 = 0.23	

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

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

3.4. WTP aggregation and cost benefit analysis

The main objective of the contingent valuation survey was to assess the benefits of two scenarios for groundwater pollution remediation. The total benefits of each scenario can be roughly estimated by extrapolating the average stated WTP to the entire population affected by groundwater quality. The extrapolation can be done by simply multiplying the average WTP by the number of households in the region and by ten years (period during which respondents have agreed to pay). The aggregation procedure is more complex if the survey sample is not representative of the regional population. As this was the case in the present survey, the bias was corrected before extrapolating the results[6]. The aggregate willingness to pay for the entire region (considered as a proxy for groundwater protection benefits) was subsequently estimated at €236 million over a ten-year period for Scenario 1 (drinking-water quality level) and €377 million for Scenario 2 (natural-groundwater quality level). Table 4 shows that the net present value for the two groundwater restoration scenarios is largely positive (resp. € 224 and 340 million). From a pure welfare economics perspective, the results suggest that the second scenario should be preferred. This conclusion should however be considered with caution, considering uncertainties related to the population concerned (benefit extrapolation) and the cost estimation (assumptions related to measure adoption rates, see appendix).

4. DISCUSSION

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

4.1. Cost estimate uncertainty

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

[6] 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.

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

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

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

Another key difficulty related to the use of CV for evaluating groundwater protection benefits is that respondents generally know very little about groundwater, how the resource works, the threats that endanger it, and the benefits associated with its protection or remediation. This is again more pronounced in the EU situation where only a few households rely solely on private wells for their drinking-water supply. Let us recall that, in our case study, 82% of the respondents considered that they were not well informed about the groundwater problem described in the questionnaire, although more than half had already heard about groundwater pollution, with 20% being able to quote a precise example. To make sure that all respondents value the same good, questionnaires should therefore be designed to convey adequate information on groundwater, its problems, and the benefits associated with its protection. As already mentioned in the literature, this may have a WTP-enhancing effect. Another concern is that households may be in a situation of preference construction[7] when stating their WTP, which cast doubts on the validity of the values elicited (Slovic, 1995).

We also found, during the pre-test of the questionnaire, several poeple refusing to pay (protesters) because they did not believe it would be technically feasible to restore groundwater quality when pollution sources were so many and spread over so large an area. To strengthen the credibility of our scenario, and to reduce the rate of protest bids, we had to provide some technical description of the actions that would actually be undertaken to reach the environmental objectives. Although we tried to minimise this information and to emphasise the benefits that would be derived from the scenario, there is a risk that some of the respondents may have evaluated their WTP with reference to what they thought the cost would be, instead of truly evaluating scenarios in terms of increased utility. We believe this risk is inherent to groundwater valuation: since respondents are not aware of how an aquifer functions, they need to receive information not only on the resource and the services it provides, but also on the technical actions that will be implemented to improve its quality.

4.3. From WTP to aggregated benefits

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

[7] 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.

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

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

4.4. Conclusion

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

[8] 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.

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

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

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

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REFERENCES

Abdalla, C. W., 1994 - Groundwater values from avoidance cost studies : implication for policy and future research, American Journal of Agricultural Economics, 76, pp.

Bateman, I. J., Day, B. H., Georgiou, S. and Lake, I., 2006 - The aggregation of environmental benefit values: Welfare measures, distance decay and total WTP, Ecological Economics, 60, pp. 450-460Bergstrom, J.C., Boyle, K.J., Job, C.A., Jo Kealy, M., 1996. Assessing the economic benefits of ground water for environmental policy decisions. Journal of the American Water Resources Association 32, 279-291.

Brouwer, R (2008) The potential role of stated preference methods in the Water Framework Directive to assess disproportionate costs. Journal of Environmental Planning and Management, 51(5): 597-614

Brouwer, R. and Pearce, D. (2005). Cost benefit analysis and water resources management. Cheltenham / Northampton, Edward Elgar Publishing.

Carson, R.T., Flores, N.E., Meade, N.F., 2001. Contingent Valuation: Controversies and Evidence, Environmental and Resource Economics 19, 173-210.

Edwards, S. F., 1988 - Option prices for groundwater protection, Journal of Environmental Economics and Management, 15, pp. 475-487

Hardisty, P. E. and Özdemiroglu, E., 2005 - The economics of groundwater remediation and protection, CRC Press, p.

Jordan, J. L. and Elnagheeb, A. H., 1993 - Willingness to pay for improvements in drinking water quality, Water Resour. Res., 29, pp. 237-245

Kiel, K. and Zabel, J., 2001 - Estimating the Economic Benefits of Cleaning up Superfund Sites : the case of Woburn, Massachussetts, Journal of Real Estate Finance and Economics 22, pp. 163 à 184

Lazo, J. K., Schulze, W. D., McClelland, G. H. and Doyle, J. K., 1992 - Can Contingent

Valuation Measure Nonuse Values?, American Journal of Agricultural Economics, 74, December 1, 1992, pp. 1126-1132

Lienhoop, N. and Messner, F., 2009 - The Economic Value of Allocating Water to Post-Mining Lakes in East Germany, Water Resources Management, 23, 2009/03/01, pp. 965-980

Pearce, D., 1998 - Environmental Appraisal and Environmental Policy in the European Union, Environmental and Resource Economics, 11, 1998/04//, pp. 489-501

Poe, G. L., Boyle, K. J. and Bergstrom, J. C. (2001). A preliminary analysis of contingent values for ground water quality revisited. The Economic Value of Water Quality. J. C. Bergstrom, K. J. Boyle and G. L. Poe. Cheltenham, U.K., Edward Elgar: 137-162.

Press and Söderqvist, T. (1998). On estimating the benefits of groundwater protection : a contingent valuation study in Milan. Regulating chemical accumulation in the environment: the integration of toxicology and economics in environmental policy making. T. Swanson and M. Vighi. Cambridge, Cambridge University Press: 278.

Quevauviler, P., 2008 - From the 1996 groundwater action programme to the 2006 groundwater directive - what have we done, what have we learnt, what is the way ahead ?, Journal of Environmental Monitoring, 10, pp. 408-421

Randal, A., Dezoysa, D. and Yu, S. (2001). Groundwater, surface water and wetland vakuation in Ohio. The economic value of water quality. J. C. Bergstrom, K. J. Boyle and P. G. L. Cheltenham UK, Edward Elgar: 83-99.

Rinaudo, J.-D. and Loubier, S. (2005). Cost-benefit analysis of large scale groundwater remediation in France. Cost Benefit Analaysis and Water Resources Management. R. Brouwer and D. Pearce. Cheltenham /Northampton, Edward Elgar Publisher: 290-314

Ryan, M., Scott, D.A., Donaldson, C., 2004. Valuing health care using willingness to pay: a comparison of the payment card and dichotomous choice methods. Journal of Health Economics 23, 237-258.

Rozan, A., Stengter, A. and Willinger, M., 1997 - Valeur de préservation de la qualité de l'eau souterraine : une comparaison entre usagers et non-usagers, Cahiers d'Economie et Sociologie Rurales, 45, pp. 62-92

SharefkinN, M., Shechter, M. and Kneese, A., 1984 - Impacts, costs, and techniques for mitigation of contaminated groundwater: A review, Water Resour. Res., 20, pp. 1771-1783

Slovic, P., 1995 - The construction of preference American Psychologist, 50, pp. 364-371.

Stenger, A. and Willinger, M., 1998 - Preservation value for groundwater quality in a large aquifer: a contingent valuation study of the Asatian aquifer, Journal of Environmental Management, 53, pp. 177 - 193

Tentes, G. and Damigos, D., 2012 - The Lost Value of Groundwater: The Case of Asopos River Basin in Central Greece, Water Resources Management, 26, pp. 147-164

Yadav, S. N. and Wall, D. B., 1998 - Benefit-cost analysis of best management practices implemented to control nitrate contamination of groundwater, Water Resour. Res., 34, pp. 497-504

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

A.1.2. Preventive measures

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

- Measures aimed 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 retentions to recover solvents in case of accident, etc. The average estimated cost of this type of measure ranges from €1,000 for very small firms to €10,000 for larger industrial sites.
- Measures aimed at collecting all used solvents and other wastes containing solvents: this implies constructing storage premises for used solvents (which are sometimes still discharged directly into sewage systems or into the environment) and organising their collection by firms specialised in the treatment and recycling of toxic wastes. The cost of this type of measure depends on the volume of solvents to be collected and treated (€1/litre of solvent). The volume is estimated for each industrial branch, based on expert judgement.
- Clean technologies for reducing emissions of VOC: these include 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 €2,000 and €200,000. Operational and maintenance costs are assumed to be

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

- Substitution of chlorinated solvents by other solvents and/or use of technologies which do not require CS. For instance, cleaning of equipment used for painting can be done with ultrasonic devices; metal cleaning before coating can be done using bacteriological processes instead of solvents; and so on. Estimated investment costs range from €10,000 to €200,000 depending on the branch of activity and the size of the company.
- Wastewater treatment using activated coal filters in a stripping tower (where solvents evaporate) with an activated coal filter to remove solvents from the vapours. The costs considered are investment and operational costs. To assess operational costs, we assume a concentration of solvents and a total volume to be treated; we then calculate the quantity of activated granulated coal needed to treat the wastewater and the related cost. Wastewater treatment is considered only for the textile industry, coffee processing, and essential oil extraction.
- Monitoring measures, which consist of installing a piezometer downstream from risk zones and conducting surveillance chemical analyses to detect any traces of pollution before it can generate a plume in groundwater. Investment costs are assessed as follows. 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 €1,500 are estimated for recurring operational costs. For medium-size sites, one SRA study is carried out and one well drilled (€15,000) whereas small sites have to conduct an SRA study only (€5,000).

A.2. COST ESTIMATION

One-off investment and yearly operational costs are estimated separately for each type of measure 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 <u>targeted</u> rate of adoption of measure “m” for industries of branch “i”,

$\alpha^i_{c,m}$ is the <u>current</u> rate of adoption of measure “m” for industries of branch “i”,

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

c^i_m is the average unit cost of implementing measure “m” for one company 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 (operational and maintenance). The values for all parameters ($\alpha^i_{t,m}$, $\alpha^i_{c,m}$, N^i, c^i_m) were estimated based on extensive expert consultation, which was conducted with significant support from the Rhin Meuse Water Agency.

Recurring operational costs are assessed in the same way. 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).

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