Integrated Assessment of Economic Benefits of Groundwater Improvement with Contingent Valuation

21

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Abstract

This chapter investigates the potential and limits of the contingent valuation method for assessing the benefits of groundwater remediation or protection programs. The discussion is based on a review of the literature and on two original contingent valuation surveys conducted in France and in Belgium, in contexts where groundwater was expected to be particularly unfamiliar to respondents. Particular attention was paid to (i) people's perception and understanding of the resource under study, and (ii) type and quantity of information provided by the questionnaire. In both cases, we show that the population is concerned about groundwater remediation or protection, especially to guarantee the wellbeing of future generations. Overall, we highlight that assessing willingness to pay through contingent valuation surveys is helpful for conducting an integrated valuation of groundwater protection benefits. However, we also point out two main limits which might restrict the relevance of the results obtained: (1) the respondents' limited prior knowledge of groundwater and the risk that information provided by the questionnaire biases the elicitation process; and (2) two types of embedding effect, with the difficulty for respondents in considering the geographic extension of an aquifer and disentangling benefits derived from groundwater quality improvement from other environmental benefits.

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21.1 Introduction

Since the industrial revolution, the development of industrial and other economic activities has generated significant pressures on groundwater resources, in developed and in developing countries. Many aquifers were contaminated by point and non-point source pollution or were over-abstracted, sometimes leading to irreversible damages, such as sea water intrusion or land subsidence (see Chap. 2). Groundwater deterioration went relatively unnoticed for decades, due to the invisible nature of the resource, lack of knowledge, inexistent monitoring networks and insufficient institutional frameworks (Chap. 1). Yet, over time, a growing number of users were affected by this "silent" groundwater deterioration. The cost to society became tangible as municipalities, households, industries or farmers were forced to shut down contaminated wells. This progressively triggered response from public authorities including the elaboration of more comprehensive legal frameworks for groundwater protection (see Chaps. 6 and 22) and the implementation of groundwater protection and reclamation programs.

Due to difficulties in identifying the actors who caused groundwater deterioration (e.g. diffuse pollution), or because they no longer exist (e.g. abandoned industrial sites), costs of groundwater remediation projects often have to be borne by public agencies. Because of limited available financial resources, economic considerations have increasingly played a key role in setting priorities between competing groundwater protection programmes or remediation projects. Cost-benefit analysis (CBA) has been used to identify groundwater basins where groundwater decontamination or protection is likely to generate the highest return on investments for society. This rationale for instance underlies the Superfund programme in the USA (Kiel and Zabel 2001). Alternatively, CBA is also used to identify sites where no action should be undertaken because remediation costs are outweighed largely by the expected benefits. This approach is implemented in Europe where CBA can be used to waive the general requirement to restore good chemical and quantitative status imposed by the Water Framework Directive (Brouwer 2008; Quevauviller 2008; Rinaudo and Aulong 2014).

This paper focuses on two main "integration" challenges faced by economists trying to assess in monetary terms the benefits of groundwater remediation or protection. The first one lies in integrating in their analysis the full range of positive impacts of such programs. Restoring groundwater quality or quantity is likely to improve the economic situation of many economic actors who directly use groundwater, including drinking water utilities, households depending on private wells, farmers irrigating their crops, industries using groundwater in their process (*direct use values*). It will also generate indirect benefits, often related to recreational activities (e.g. swimming, angling, canoeing) for users of groundwater dependent ecosystems (e.g., rivers, wetlands, gravel pit lakes) where ecological status is improved together with groundwater (*indirect use values*). Last but not least, groundwater remediation may also generate benefits not related to a particular use of the resource: these benefits refer to *non-use values* such as those associated with the possibility for others to use a groundwater in good status (*altruistic value*), or to the protection of the groundwater resources for itself (*existence value*). Economic valuation aims at integrating all these positive impacts into one single monetary estimate.

The second challenge lies in integrating in monetary valuation *the long term dimension* of groundwater protection benefits and in particular the value of groundwater for future generations. Indeed, restoring groundwater quality not only provides a flow of benefits for present generations. It also represents an increase of natural capital which might become a source of wealth in the future. Economists usually distinguish the *option value* associated with potential future use for present generations from *bequest value* associated with the preservation of an environmental good (natural heritage) for future generations.

This paper investigates the potential and limits of a specific economic valuation methodology – the contingent valuation method – which has often been recommended for conducting an *integrated economic assessment* of groundwater restoration benefits. The main objectives of the chapter are: (1) to present to non-economists how the contingent valuation method can be used for conducting an integrated economic assessment of groundwater protection and restoration benefits; and (2) to discuss the advantages and caveats of this method. The discussion is based on a review of the literature and on two original case studies to feed the debate.

The chapter is organised as follows. In the next section, we describe the different methods that can be used to assess the economic benefits of groundwater protection and remediation, with a specific focus on the contingent valuation method which is increasingly used in environmental economics. The paper then presents two original groundwater valuation studies conducted in Belgium and France, based on the contingent valuation method and using a similar protocol. Materials and methods are presented in Sect. 21.3 and results obtained in Sect. 21.4. We then discuss in Sect. 21.5 the limitations of the method in the context of groundwater valuation studies before concluding the chapter.

21.2 Valuing the Benefits of Groundwater Protection with Contingent Valuation: A Review

21.2.1 Methodological Approaches for Valuing Groundwater Protection Benefits

A popular approach among practitioners to assess the benefits of groundwater protection is the *avoidance-cost method* (e.g., see Abdalla 1994; Rinaudo et al. 2005). It consists of assessing the cost of actions undertaken by economic agents to cope with groundwater degradation, and pollution in particular. Typical avoidance costs are those related to the closure and displacement of contaminated drinking water wells (public or private), the installation of sophisticated water treatment units (municipal or domestic) or the purchase of bottled water when groundwater can no longer be used as a safe source of drinking water. One of the main advantages of this method is that it measures tangible costs that correspond to real expenditures made by concerned economic agents (investment, operation and maintenance costs). Results obtained are thus easy to grasp by policy makers and stakeholders. Its main weakness is that it only focuses on *direct use benefits*. It does not consider less tangible benefits related to: the possible uses of groundwater in the future (*option value*); the positive impact on groundwater dependent ecosystems (*indirect use benefits*); the transmission of a well-protected natural heritage to future generations (*bequest value*); the opportunity for other individuals to use groundwater in good status (*altruistic value*); and the protection of the groundwater resource for its own integrity (*existence value*). Benefits assessed with avoidance cost methods are thus generally considered as lower bound estimates.

An alternative method, widely used for practical applications in the United States, is the *contingent valuation method (CVM)*. Unlike the avoidance-costs technique, this method is not based on the observation of actual behaviours of economic agents to cope with existing groundwater deterioration. Instead, it relies on the implementation of surveys to elicit people's willingness to pay (WTP) for hypothetical environmental improvement scenarios. The assumption is that individual-stated WTP reflects the intensity of the benefits each respondent derives from the scenario. After the survey is completed, stated WTP can be aggregated over the sample, and then extrapolated to the entire population concerned by the groundwater remediation scenario, in order to produce an estimate of the total economic benefits of the restoration scenario. The information provided to respondents should describe the full range of benefits they will derive from the groundwater protection/restoration scenario, including direct and indirect use, for present and future generations. In theory, the main advantage of this method is its ability to integrate all the benefits – direct and indirect, present and future – in a single monetary indicator. Let us now look at how the method has been used in practice.

21.2.2 The Integrative Capacity of Contingent Valuation Method

The CVM was first, and predominantly, applied to assess groundwater restoration and protection benefits in the USA (see Table 21.1). The use of the method was recommended by the US Water Resources Council in 1983. Its use was fostered by the increasing number of groundwater contamination cases, affecting a very large number of households relying on private wells for drinking water supply. The first study was conducted by Edwards (1988) in a small Massachusetts community where water supply was fully dependent on groundwater. A survey was conducted to elicit the population's WTP for reducing the probability of water supply contamination. This seminal research was followed by a number of similar studies conducted in the 1990s. Overall, this first wave of groundwater contingent valuation studies primarily aimed at assessing people's WTP for an improvement in the quality of their domestic water supply (see for example Shultz and Lindsay 1990;

Table 21.1 CVM studies applied to groundwater valuation over the 1986–2013 period

Reference	Year[a]	Country	Location	Objective/issue	Average WTP (current currency value)[b]	Average WTP (PPP €2013)[c]
Edwards (1988)	1986	United States	Cape God, Community of Falmouth, Massachusetts	Benefits of reducing the probability of groundwater contamination	286–1130 $\$_{1986}$/hh/year	523–2065 €/hh/year
Wright (1988)	1987[a]	United States	Peninsula Township groundwater resources, Michigan	Benefits of protecting groundwater (nitrates)	296–696 $\$_{1987}$/hh/year	523–1230 €/hh/year
Shultz and Lindsay (1990)	1988	United States	Dover Community, New Hampshire	Benefits of reducing the probability of groundwater contamination, individual community	129 $\$_{1988}$/hh/year	220 €/hh/year
Sun et al. (1992)	1989	United States	Dougherty County, Georgia	Benefits to citizens of protecting groundwater supplies from agricultural chemical contamination	641 $\$_{1989}$/hh/year	1050 €/hh/year
Powell et al. (1994)	1989	United States	15 communities in Massachusetts, New York and Pennsylvania	Benefits of groundwater quality protection (agricultural chemicals, landfills, accidental spills and toxic chemicals)	62 $\$_{1989}$/hh/year	102 €/hh/year
Caudill (1992)	1990	United States	Michigan state	Benefits of protecting groundwater (nitrate and pesticides contamination)	34–69 $\$_{1990}$/hh/year	53–108 €/hh/year
Wattage (1993)	1991	United States	Bear Creek Watershed, Story and Hamilton counties, Iowa	Benefits of groundwater quality improvement (nitrates, pesticides)	90 $\$_{1991}$/hh/year	135 €/hh/year
Lazo et al. (1992)	1991[a]	United States	Denver, Colorado	Non-use benefits expected from groundwater quality improvement (domestic waste)	34–42 $\$_{1991}$/hh/year (2,81–3,54 $\$_{1991}$/household/month)	51–64 €/hh/year

(continued)

Table 21.1 (continued)

Reference	Year[a]	Country	Location	Objective/issue	Average WTP (current currency value)[b]	Average WTP (PPP €2013)[c]
McClelland et al. (1992)	1991	United States	National assessment	National benefits of cleaning groundwater contaminated by landfills, contaminates not specified	168 $\$_{1991}$/hh/year (14 $\$_{1991}$/household/month)	253 €/hh/year
Jordan and Elnagheeb (1993)	1991	United States	Entire state of Georgia, US	Benefits of improving drinking water quality	121–149 $\$_{1991}$/hh/year	182–224 €/hh/year
Poe and Bishop (1993)	1991–1992	United States	Portage County, Wisconsin	Benefits of protecting groundwater such that nitrate contamination levels would be below USEPA health advisory standards for the entire state of Georgia	225–685 $\$_{1991}$/hh/year	339–1031 €/hh/year
Stenger and Willinger (1998)	1993	France	10 communities located on the Alsatian aquifer	Benefits of preserving groundwater quality (various types of contaminants) – water users	617 FF_{1993}/hh/year	129 €/hh/year
Bergstrom and Dorfman (1994)	1993[a]	United States	Groundwater resource Dougherty County	Benefits of preserving groundwater quality (for domestic water supply)	320–2360 $\$_{1993}$/hh/year	455–3353 €/hh/year
de Zoysa (1995)	1994	United States	Maumee and Erie Lake Basin, Ohio	Benefits of groundwater quality improvement	53 $\$_{1994}$/hh/year	73 €/hh/year
Rozan et al. (1997)	1995	France	Two communities close to the Alsatian aquifer	Benefits of preserving groundwater quality (various types of contaminants) – non users	340 FF_{1995}/hh/year	69 €/hh/year
Lichtenberg and Zimmerman (1999)	1995	United States	Maryland, New York and Pennsylvania states, Mid-Atlantic region	Farmers' WTP for groundwater protection (pesticide leaching prevention)	1112–7078 $\$_{1995}$/farmer/year (17–35 $\$_{1995}$/acre/year)	1495–9517 €/agriculteur/an

Martin and Marceau (2001)	1997	Canada	Five districts North of Montréal	Benefits of groundwater status improvement (quality, quantity)	48 $\$CAN_{1997}$/hh/year	49 €/hh/year
Belloumi and Matoussi (2002)	1997	Tunisia	Oued Kheirate groundwater	Benefits of preserving groundwater quality (saline intrusion)	20 $dinars_{2002}$/hh/year	41 €/hh/year
Grappey (1999)	1997–1998	France	Bièvre-Liers plain aquifer, Isère	Benefits of preserving groundwater quality (nitrates)	251–402 FF_{1997}/hh/year	49–79 €/hh/year
White et al. (2001)	1999	New Zealand	Waimea plain (seven aquifers)	Benefits of improving the quantitative status of groundwater	183 $\$_{1999}$/hh/year	152 €/hh/year
Wei et al. (2007)	2004	China	Fengqiu County, Henan Province, North China Plain	Benefits of protection and restoration of groundwater (overexploitation)	1.26 $Yuan_{2004}$/hh/year	0.39 €/hh/year
Hasler et al. (2005)	2004	Denmark	National assessment	National benefits associated with increased protection of the groundwater resource (nitrates, pesticides)	711 DKK_{2004}/hh/year	87 €/hh/year
Rinaudo and Aulong (2014)	2006	France	Upper Rhine valley quaternary aquifer, France	Benefits of protecting and improving groundwater quality (chlorinated solvents)	42–76 $€_{2006}$/hh/year	47–85 €/hh/year
Brouwer et al. (2006)	2006	The Netherlands	Scheldt basin	Benefits of protecting and improving groundwater quality	31–72 $€_{2006}$/hh/year	36–84 €/hh/year
Miraldo Ordens et al. (2006)	2006	Portugal	Aveiro Quaternary aquifer	Benefits of protecting groundwater quality	38 $€_{2006}$/hh/year	54 €/hh/year
Pakalniete et al. (2006)	2006	Latvia	Shallow part of the groundwater body under Riga	Benefits of groundwater quality improvement	25 $€_{2006}$/hh/year	71 €/hh/year

(continued)

Table 21.1 (continued)

Reference	Year[a]	Country	Location	Objective/issue	Average WTP (current currency value)[b]	Average WTP (PPP €2013)[c]
Strosser and Bouscasse (2006)	2006	Slovenia	Krska kotlina aquifer	Benefits of protecting groundwater quality	1346–2493 SIT$_{2006}$/hh/year	120–222 €/hh/year
Chegrani (2009)	2006	France	Artois chalk and Lys valley aquifer	Benefits of improving groundwater quality (nitrates and pesticides)	24 €$_{2006}$/hh/year	27 €/hh/year
El Chami et al. (2008)	2007[d]	Lebanon	Byblos district	Benefits of the improvement of groundwater quality for irrigation (seawater intrusion)	102–167 \$$_{2007}$/irrigating farmer/year	104–170 €/hh/year
Rinaudo (2008)	2008	France	Lower Triassic Sandstone aquifer	Benefits of stopping the over exploitation of the aquifer	40€$_{2008}$/hh/year	43 €/hh/year
Tentes and Damigos (2012)	2009	Greece	Four towns located on the Asopos river basin aquifer	Industrial pollution, especially by Cr(VI) Benefits for restoring groundwater quality	180–239 €$_{2009}$/hh/year (15–20 €$_{2009}$/household/month)	227–301 €/hh/year
Hérivaux (2011)	2010	Belgium	Meuse alluvial aquifer near Liège	Benefits of restoring groundwater quality	40 €$_{2010}$/hh/year	42 €/hh/year
Martinez-Paz and Perni (2011)	2010	Spain	Gavilan aquifer, Segura basin	Benefits of improving water quality and quantity of the associated wetland	24 €$_{2010}$/hh/year	29 €/hh/year

[a] Year of the economic valuation

[b] hh: household

[c] Primary data are expressed in euro 2013, by using (i) the Purchasing Power Parity Index produced by the World Bank and OECD, et (ii) the Consumer Price Index produced by INSEE (French National Institute for Statistics and Economic Research)

[d] means that the year is not explicitly mentioned in the study

Sun et al. 1992; Powell et al. 1994; Caudill 1992; Jordan and Elnagheeb 1993; Poe and Bishop 1993; Lichtenberg and Zimmerman 1999). Estimated WTP were thus not reflecting the total value of groundwater improvement. Several studies have also shown that an important part of the elicited WTP may be related to the improvement of the groundwater resource itself or to the ecological services it provides through sustaining dependent ecosystems (see for example Lazo et al. 1992; McClelland et al. 1992).

In Europe, the use of the CVM to assess the economic value of groundwater protection has been more integrative. Studies were generally designed to capture a wider range of benefits and they were not solely focusing on the benefits associated with domestic water supply. In the first study, Stenger and Willinger (1998), followed by Rozan et al. (1997), designed a survey to assess the "patrimonial value" of the upper Rhine valley aquifer (Eastern France), explicitly considering the multi-generational dimension of groundwater. Their study was designed to elicit WTP of groundwater users and non-users. This integrative approach was further extended in the 2000s, following the publication of the Water Framework Directive, with a series of studies explicitly considering a wide range of potential benefits in Denmark (Hasler et al. 2005), France (Chegrani 2009; Rinaudo and Aulong 2014), the Netherlands (Brouwer et al. 2006), Portugal (Miraldo Ordens et al. 2006), Latvia (Pakalniete et al. 2006); Slovenia (Strosser and Bouscasse 2006), Greece (Tentes and Damigos 2012) and Spain (Martinez-Paz and Perni 2011). Similar studies have also been conducted in New Zealand (White et al. 2001), in China (Wei et al. 2007) and in Lebanon (El Chami et al. 2008).

One of the main findings of groundwater contingent valuation studies was to show that an important part of the elicited WTP may be associated with indirect use values or non-use values. In 1985, the USEPA reported that "*numerous cases have occurred where communities and public officials argue heatedly for complete clean-up of contaminated aquifers which are not even presently being taped*" Poe et al. (2000) shows in a meta-analysis that studies focusing only on use values had significantly lower WTP than studies that elicited total WTP for groundwater protection programs. Several studies have also shown that bequest values were quoted among the main reasons to contribute to a program of groundwater protection and may also statistically influence the willingness to contribute (e.g., Rinaudo and Aulong 2014).

21.2.3 The Limits of CV for Groundwater Economic Valuation

One of the main concerns with applying CVM to groundwater is that respondents may have a very limited knowledge of the environmental asset they are asked to value. In theory, CVM should only be used when respondents have what Lazo et al. (1992) call "perfect information," defined as: (i) a clear perception of the environmental asset they are asked to value; (ii) existing substitute commodities if any; and (iii) a good understanding of how changes in the level of provision of the commodity will affect them (e.g. the individual benefits of the scenario).

Evidence from various surveys shows that this is rarely the case. People generally have a very limited knowledge of groundwater resources and related management issues, even when they have a direct link to the resource through private wells. This is illustrated by the results of a survey conducted in 1995 in Massachusetts (Stevens et al. 1997) where 47 % of the respondents declared they knew little or nothing about groundwater, although half of the respondents had private wells and the second half was supplied by a municipal utility using groundwater. This knowledge problem is even worse in contexts where the population is supplied by public water networks and where "*the only link that exists between groundwater quality and households is the price they pay for the drinking water supply*" (Rinaudo and Aulong 2014). This is illustrated by the results of a series of European surveys: in the Netherlands, Brouwer et al. (2006) found that 40 % of the respondents were not familiar at all with groundwater; in Latvia, 46 % of the respondents connected to the domestic water supply network did not know the origin of their water and that 48 % of the respondents were not informed about the groundwater contamination problem (Pakalniete et al. 2006); in Eastern France, 82 % of respondents declared not being well-informed of groundwater management problems (Rinaudo and Aulong 2014).

In such situations, CVM specialists acknowledge that the method can still be used (Arrow et al. 1993). The burden of informing respondents about all the aspects of the environmental asset being evaluated then falls with the survey instrument. To avoid information bias, special attention should be paid to design the survey protocol and questionnaire, especially to select the nature, format and quantity of information provided to respondents. The researcher should ensure that this information is correctly understood by respondents by implementing a careful pretesting of the contingent valuation questionnaire. Complementary techniques can also be implemented. McClelland et al. (1992) for instance used a process of cognitive survey design, based on the pretesting of a 30–40 page perfect information questionnaire with randomly chosen people who were asked to speak continuously into a tape recorder as they completed the survey, in order to identify potential information problems. Mitchell and Carson (1989) conducted several focus groups to explore in-depth people's groundwater knowledge, concerns and preferences for groundwater protection. If sufficient information is provided "*in a way that is plausible, understandable and meaningful to respondents*" (Carson et al. 2001), some authors do not consider unfamiliarity as a problem for conducting a CV survey.

21.3 Empirical Case Studies: Objectives and Methodology

21.3.1 Context and Motivation for Conducting Two Additional Case Studies

The empirical research presented in this section was triggered by practical problems arising from the implementation of the European Water Framework Directive. In several European river basin districts, a number of groundwater bodies were so severely affected by human activities (overdraft or pollution) that stakeholders would not support the implementation of costly clean-up or replenishment programs. Clean-up or remediation costs were considered excessive as compared to financial capacities of actors and/or to the benefits that could be derived by potential groundwater improvement. However, justifying that benefits were much lower than remediation costs had to be supported by some evidence, which economists were asked to provide. The use of the contingent valuation method was advocated and several studies implemented in the framework of European and national research programs (see for example the Bridge-WFD program and the FRAC-WECO Belgian research project). The two case studies presented here were initiated in this context, with the intention of answering the following questions:

- Is contingent valuation an appropriate method for monetary valuation of benefits associated with groundwater protection and restoration, in locations where (1) people do not directly use groundwater through wells, and (2) where they have a very limited knowledge of groundwater resources?
- If appropriate, what type of information should be provided to respondents to make sure that they properly understand the multidimensional nature of the benefits associated with groundwater protection and restoration?
- Finally, what are people’s stated preferences for the different components of groundwater protection and restoration benefits? Do they integrate use and non-use benefits, short and long term benefits?

21.3.2 Case Studies

The two selected case studies are complementary in terms of type of territory, type of resource and use, and management problem (see Table 21.2). The Meuse alluvial aquifer (MAA) case study (under the city of Liège, Belgium, 360,000 inhabitants) focuses on a large urban section of an alluvial aquifer which is no longer used due to historical industrial pollution. If implemented, a clean-up program (decontamination of brownfields) would not only restore groundwater quality but also contribute to improving the ecological status of the Meuse River (indirect use benefit). It would also generate a moral satisfaction in transmitting to future generations a

Table 21.2 Main characteristics of the two aquifers selected as case studies

Characteristics	Meuse alluvial aquifer (MAA) Liège region, Belgium	Lower Triassic Sandstone (LTS) Lorraine region, France
Aquifer type and scale	Shallow alluvial aquifer (15 m depth) Local resource	Deep confined aquifer (0–800 m depth) Regional resource
Type of territory	Densely populated urban area	Rural area
Management problem	Industrial pollution (brownfield)	Overexploitation
Groundwater use	Industrial Drinking water wells abandoned due to pollution Very few private wells	Main resource for municipal supply, food and beverage industry, industrial water bottling and cattle farms
Expected benefits	Ecological improvement of dependent ecosystems (indirect benefit) Improvement of natural heritage (bequest value) and potential future use (option value)	Continued long term access to groundwater implying continuation of cheap municipal supply in the future; and reduced risk in case of drought or contamination of superficial water resources

better environment cleared from historical pollution, and potentially offering an alternative to currently used superficial water supplies.

The Lower Triassic Sandstone (LTS) case study (Lorraine region, in Eastern France) deals with a large confined aquifer that is increasingly depleted (−68 m between 1968 and 2000). This aquifer has a strategic role at the regional level, since over 100,000 inhabitants depend on it for their water supply. A programme of measures aiming at restoring a balance between recharge and abstraction is currently being considered. In the absence of remediation action, a number of wells will run dry in the medium term (15–50 years) and local communities will have to switch to surface water supply, entailing higher investment and operation cost and a greater exposure to drought and surface water contamination risk. Note that the restoration program would not have any indirect ecological impact since this confined aquifer does not interact with surface ecosystems.

21.3.3 Overview of the Common Methodology Deployed in the Case Studies

The methodology deployed in the two case studies comprises the four following steps (Hérivaux 2011; Rinaudo 2008): (1) preliminary social survey; (2) questionnaire design and test; (3) survey implementation; and (4) data analysis.

Step 1 consists of a series of qualitative interviews to analyse people's perception and understanding of the groundwater resource under study. In the LTS, a total of 72 semi-structured face-to-face interviews were conducted to capture the lay vision of the reservoir, its characteristics and geographic extension; and to assess the level of understanding of the water cycle underground, with specific attention being paid to the understanding of exchanges between ground and surface water. Respondents were also asked to identify the services provided by groundwater to society. In the MAA case study, the same issues were addressed through informal discussion during the pre-test of the questionnaire and several open-ended questions administered at the beginning of each interview.

The results of this first step were used to construct a structured questionnaire, which was then carefully tested with about 50 respondents in each case study (step 2). Although differing in their contents, to be adapted to each case study, the contingent valuation questionnaires were similarly structured into four main sections. Section 21.1 consists of the presentation of the aquifer under study and it is followed by a series of questions aiming at assessing respondent's prior knowledge of this resource. Section 21.2 summarizes the groundwater management problem today and in the future if no action is undertaken. Impacts of groundwater overexploitation/ pollution on the current uses of the resources are also presented. Respondents are asked about their prior knowledge of this situation. Section 21.3 presents the groundwater improvement scenario. Proposed measures and expected impacts on groundwater quality and groundwater uses are listed. Respondents are asked if they would be willing to contribute financially (each year for 10 years) for such a scenario using the water bill as a payment vehicle. Those who agree are asked to specify an amount in euros per year on a payment card (for the household). Respondents are then asked to explain their motivations for accepting or refusing to contribute. Section 21.4 deals with socio-economic characteristics of the respondents (gender, age, employment, education, size of the household, income, perception of environmental problems, etc.).

The quantitative survey was then completed, with respectively 530 and 650 respondents in the MAA and LTS case studies (step 3). Face-to-face interviews were used in the MAA case study and a mail survey in the French LTS case study. Both methods have their advantages and their limits. For the MAA case study, the in-person survey seemed to be the most appropriate to collect answers to open-ended questions on groundwater and to minimize the non-response rate which was expected to be particularly high in this "non-use context". The mail survey method was chosen for the LTS case study to ensure that respondents would have sufficient time to get to know an unfamiliar subject and think about their preferences. The return rate was about 11 %.

Data obtained were then statistically analysed to check the consistency of responses and to identify factors determining stated WTP for groundwater protection (step 4). Different econometric models were estimated. Further detail on this part of the work is provided in the Appendix.

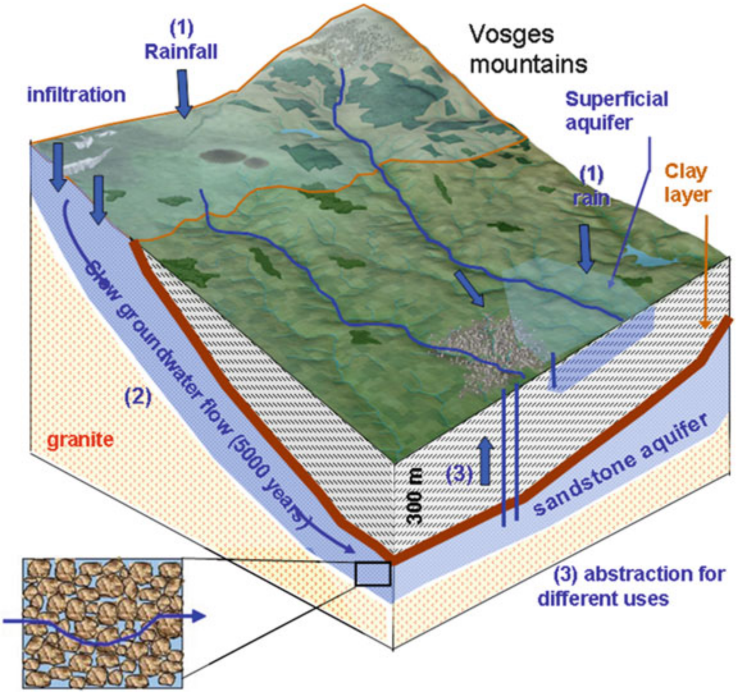


Fig. 21.1 Simplified representation of the Lower Triassic Sandstone aquifer (diagram used in the CV survey) (*Source*: Rinaudo 2008)

21.3.4 Sending Clear Messages About the Benefits of Groundwater Protection

When designing our CV survey, the main difficulty we had to address was to send clear messages about the benefits associated with the groundwater protection plan presented in the questionnaire. Given the complexity of the issue, we adopted a stepwise approach consisting of: progressive delivery of information on the groundwater resource itself and its current problems (Sect. 21.1); expected future evolution with a no-action scenario and possible consequences over time (Sect. 21.2); and a groundwater protection/restoration scenario, accompanied with a description of the potential benefits (Sect. 21.3).

In Sect. 21.1, we developed several simplified schemes depicting the geometry of the aquifer and the circulation of water and/or pollution loads within the reservoir (Fig. 21.1). The understanding of these visual supports as well as of the vocabulary used was checked during the pre-test phase. Maps were also used to delineate the spatial extent of the management problem so that each respondent could see if they

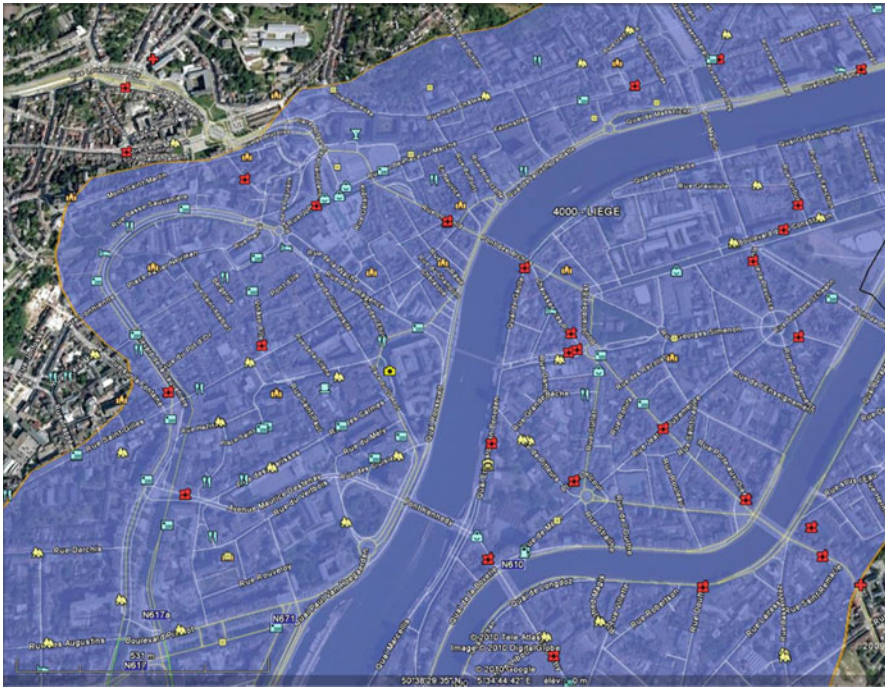
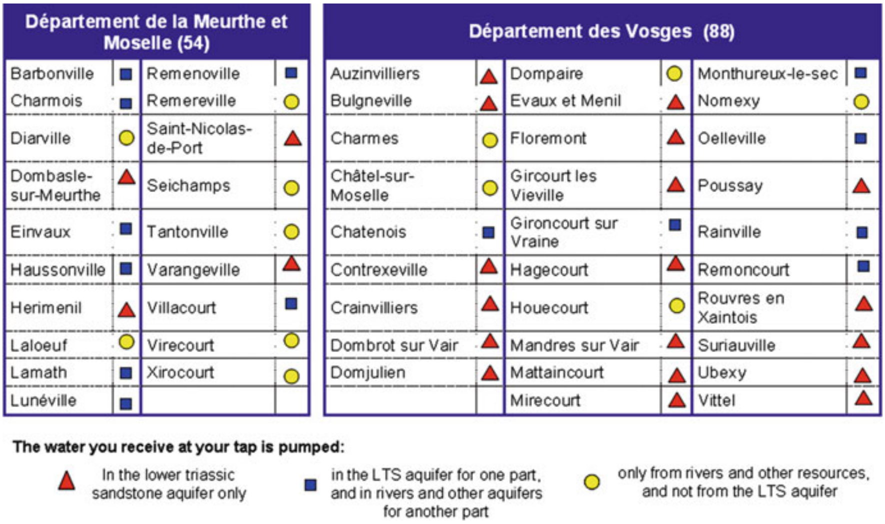


Fig. 21.2 Example of map combining aerial photographs and aquifer boundaries used during the survey (*Source*: Hérivaux 2011)

live above the aquifer or not, close or far from it. For the MAA case study, a series of maps combining Google Earth views and the aquifer boundaries were used during the survey to know if the respondent lives above the MAA (Fig. 21.2). Specific supports (maps or tables) were also used to show the origin of tap water for each municipality of the sample so that respondents could know if their water supply relies on the groundwater under study (Fig. 21.3).

When designing the questionnaire, specific efforts were made to describe the temporal dimension of groundwater deterioration (under the no-action scenario) or improvement (under the restoration scenario). In the LTS case study for instance, respondents were presented a map showing the date at which they would be impacted by groundwater depletion with the no action scenario (see Fig. 21.4). This map was elaborated based on the results of groundwater model simulations (Vaute et al. 2007). It was intended to help respondents in understanding if they would be personally concerned by groundwater protection benefits or if benefits would accrue to future generations.



Département de la Meurthe et Moselle (54)			
Barbonville	■	Remenoville	■
Charmois	■	Remereville	●
Diarville	●	Saint-Nicolas-de-Port	▲
Dombasle-sur-Meurthe	▲	Seichamps	●
Einvaux	■	Tantonville	●
Haussonville	■	Varangeville	▲
Herimenil	▲	Villacourt	■
Laloeuf	●	Virecourt	●
Lamath	■	Xirocourt	●
Lunéville	■		

Département des Vosges (88)					
Auzinvilliers	▲	Dompaire	●	Monthureux-le-sec	■
Bulgneville	▲	Evaux et Menil	▲	Nomexy	●
Charmes	●	Floremont	▲	Oelleville	■
Châtel-sur-Moselle	●	Gircourt les Vieville	▲	Poussay	▲
Chatenois	■	Gironcourt sur Vraine	■	Rainville	■
Contrexeville	▲	Hagecourt	▲	Remoncourt	■
Crainvilliers	▲	Houecourt	●	Rouvres en Xaintois	▲
Dombrot sur Vair	▲	Mandres sur Vair	▲	Suriauville	▲
Domjulien	▲	Mattaincourt	▲	Ubexy	▲
		Mirecourt	▲	Vittel	▲

The water you receive at your tap is pumped:

▲ In the lower triassic sandstone aquifer only

■ in the LTS aquifer for one part, and in rivers and other aquifers for another part

● only from rivers and other resources, and not from the LTS aquifer

Fig. 21.3 Table showing where tap water comes from in the municipalities selected for case study (used in the questionnaire) (*Source*: Rinaudo 2008)

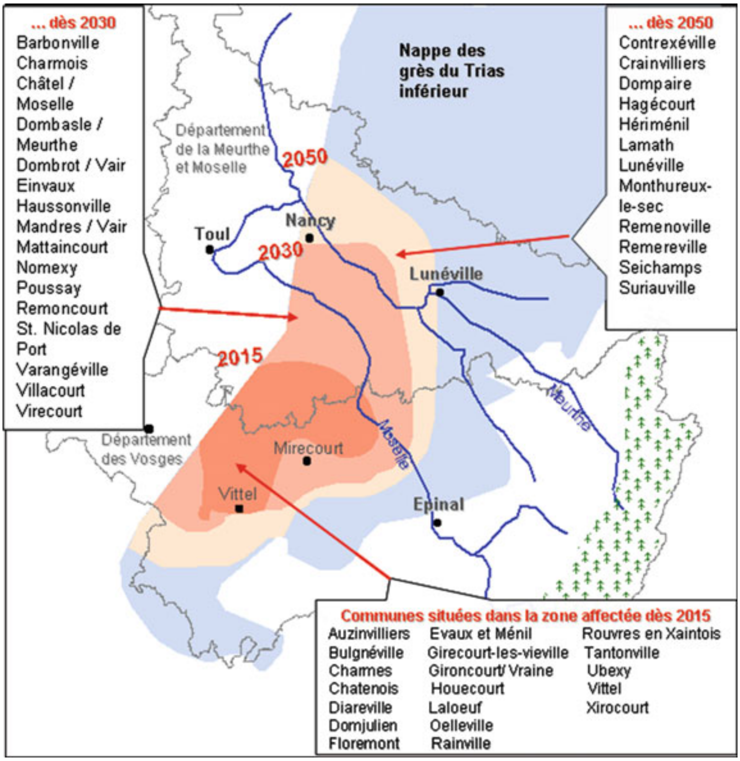


Fig. 21.4 Map depicting the area likely to be affected by the decline of water tables at three different dates. A list of municipalities included in each coloured pocket is provided so that respondents can locate themselves on the map (*Source*: Rinaudo 2008)

21.4 Empirical Results

21.4.1 The Impact of Prior Knowledge and Information Supply on WTP

In line with past research conducted in similar European contexts, these two case studies confirm that respondents are quite unfamiliar with groundwater. Many of them discovered the existence of the resource and its management problems as they completed the questionnaire (LTS) or answered the interviewer (MAA). In both case studies, there is a large percentage of the population that does not even know of the existence of the groundwater body presented in the survey - 80 % in the MAA case study and 46 % in the LTS. Few respondents were also aware of the pollution or overexploitation problems threatening local groundwater (76 % and 54 % of the respondents for the MAA and LTS case studies). And less than half of them knew if their water supply was dependent or not on groundwater (see Fig. 21.5).

One of the reasons for this limited knowledge is obviously that most respondents have no direct use of groundwater. Their lack of interest for groundwater is further accentuated by the limited coverage of this issue by the media and local political

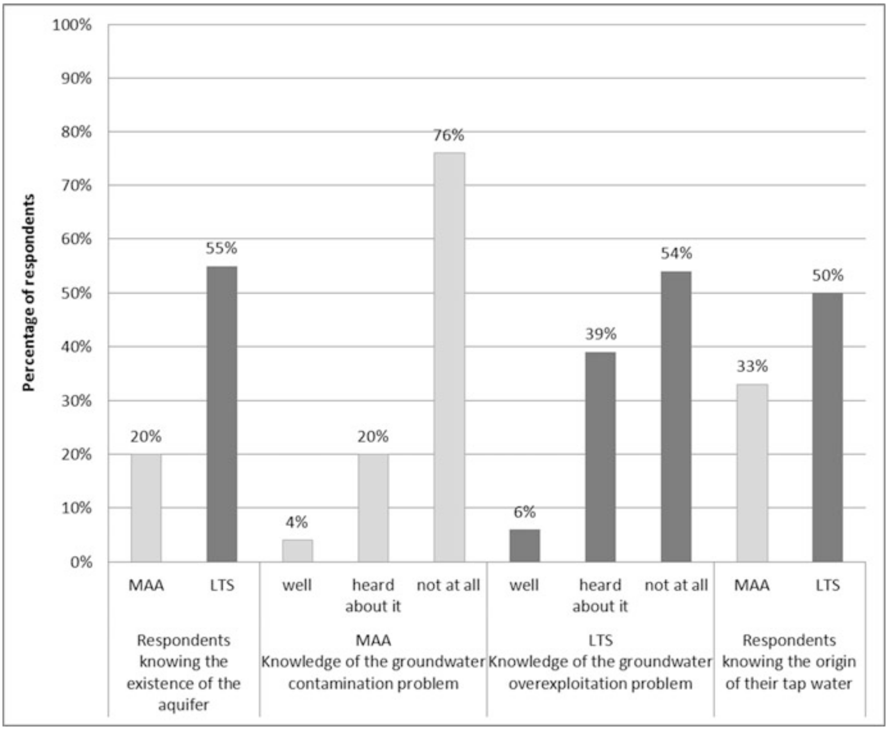


Fig. 21.5 Respondents' prior knowledge level (*MAA* Meuse alluvial aquifer, *LTS* Lower Triassic Sandstone aquifer)

debate. The second reason, identified through semi-structured interviews conducted in the LTS case study relates to the public's mental representation of groundwater. Although lay people have a general understanding of what groundwater is, they do not spontaneously grasp the concept of an aquifer, defined as a three-dimensional geological reservoir and the water it contains. Laymen can hardly locate water resources on a map and find it very difficult to explain how and why water moves underground, eventually reaching the surface through springs or river banks. Groundwater is generally perceived as a ubiquitous resource, not as a well spatially-defined object.

Despite limited prior knowledge, the two case studies show that it is possible to supply adequate information during a survey, either through face-to-face interviews (MAA case study) or postal surveys (LTS). Maps and diagrams presented to respondents present no major understanding challenges because "*they echo what they learnt on the water cycle at secondary school*" (quote from several respondents). The information provided was considered by respondents as sufficient to inform their decision to contribute financially to groundwater restoration (e.g., 84 % in the MAA).

However, one can wonder how the information supplied influences stated WTP. While the questionnaires provide the same information to the respondents through a detailed description of the aquifer, its uses, its management problem and the benefits expected from a good status, the appropriation of this complex information can be different between those who discovered the aquifer under study during the survey (situation of preferences construction) and those who had a prior knowledge of the aquifer and its management problem (situation of established preferences). This was actually tested in the two case studies by comparing the average WTP of respondents with and without prior knowledge of the problem. No statistically significant impact was found in the MAA. By contrast, respondents' prior level of information had a significant negative impact on WTP in the LTS case study (see the statistical results in the Appendix). Variable "info" in the OLS model has a negative sign. It is significant at the 5 % level. This suggests that the information provided in the questionnaire may have a WTP enhancing effect. Similar findings were reported by Venkatachalam (2004) who found that additional information, provided about drinking water quality to respondents who possessed different levels of information about the water quality, can significantly influence the WTP values.

21.4.2 Motivations Underlying WTP

In the two case studies, about two third of the respondents accepted paying, revealing a real concern for groundwater protection. The average stated WTP was approximately 40 €/ household/year over 10 years in each of the two case studies. This value lies at the lower bound of the range of WTP reported in the literature. Multivariate regression analyses were performed using several econometric models

Table 21.3 Willingness to pay and underlying motivations in the two case studies (motivation statements were listed in the questionnaire and selected by respondents)

	Meuse Alluvial Aquifer		Lower Triassic Sandstone aquifer	
	Willingness to pay % accepting to pay Average WTP/year/household	66 % 40 €	**Willingness to pay** % accepting to pay Average WTP/year/household	67 % 39 €
	Main motivation for paying		**Main motivation for paying**	
Bequest value	To pass on to future generation groundwater of better quality	49 %	Groundwater is what my grandchildren will drink in 40 years	52 %
Indirect use value	To improve the quality of dependent ecosystems (fauna, flora) in the Meuse valley	22 %		
Option value	To make possible future use of the aquifer for the city of Liège if needed	22 %	I prefer to pay now for groundwater protection than later to bring water from far away	19 %
Direct use value	To keep the possibility of using groundwater through a private well	3 %	I accept to pay because I use this aquifer/my drinking water supply depends on it Depleting this aquifer would represent a handicap for the local economy	20 % 9 %

to check the consistency of answers. Some three models were estimated: a logistic regression model to explain the yes/no response to the WTP question; an ordinary least square regression model to explain the positive WTP amounts; and a Tobit regression model to explain positive or true zeros WTP amounts. Results of various multivariate regression models are presented in the Appendix. The analysis was useful in understanding how various motivations for paying influence the stated amount.

The main motivations underlying the decision to pay are given in Table 21.3. These motivations are helpful in identifying to which component of the total economic value different individuals are sensitive. Looking at the main motivation quoted, we can distinguish four groups of respondents:

- In the first group, the concern for future generations is the main motivation for paying (respectively 49 % and 52 % of the MAA and LTS samples). Groundwater is clearly perceived as a natural heritage which should be preserved to guarantee future generations wellbeing, either as a clean, cheap and protected drinking water source or as a support of the local economy. For these respondents, higher WTP may reflect a feeling of moral responsibility for contributing to the protection of groundwater for future generations. WTP reflects altruism more than economic self-interest. In the LTS, the econometric analysis shows that respondents ranking by future generation as a first motivation have an 11 % higher WTP (variable "futgen" significant at the 1 % level, see Appendix).

- The second group comprises respondents whose main motivation is protecting (LTS) or restoring (MAA) the groundwater resource which they could personally be using in the future. WTP stated by these respondents thus reflects the *option value* of groundwater, defined as the benefits that could be derived from potential future use. Their WTP is not statistically different from the average.
- The third group is mainly motivated by the protection of a resource which they already use, either directly through a private well, or indirectly when their municipal water supply depends on groundwater. They represent approximately 20 % of respondents in the LTS, but only 3 % in the MAA where the aquifer is not usable in its current status. In LTS, these respondents have a statistically lower WTP than the sample average.
- The fourth groups say their main motivation is to contribute to the environmental improvement of dependent ecosystems. They represent 22 % of the MAA sample. This motivation is not expressed in the LTS due to the confined nature of the aquifer, and the absence of an impact on surface dependent ecosystems.

Overall, these results highlight that stated WTP is an indicator that actually captures the different dimensions of groundwater protection benefits: direct use benefits; indirect use benefits (dependent ecosystems); option value (opportunity to use in the future); and bequest value (value for future generations).

21.4.3 Mental Models and Embedding Effects

An abundant literature describes the potential bias associated with the use of contingent valuation for valuing environmental goods (Venkatachalam 2004). Our case studies suggest that there are additional problems related to the specific characteristics of groundwater and to what environmental economists call an *embedding effect* or a *part-whole effect*. This embedding effect seems to be closely related to the "mental model" of joint products highlighted by Schulze et al. (1998): respondents may have different mental models, often strongly held, which will replace whatever mental model the researcher intended to impose on the respondent. Some respondents will accept the implicit mental model used by the researcher in designing the survey while others will not. Increased information does not address the possibility that individuals may have different mental models. Our results highlight two kinds of potential embedding effects:

- Due to insufficient knowledge, some respondents perceive groundwater as a ubiquitous and uniformly distributed resource, rather than a collection of well-defined and spatially delineated reservoirs. These respondents are thus not able to make a clear distinction between protecting groundwater in a broad sense on the one hand, and protecting a specific aquifer on the other hand. This remains true even if maps and schemes are provided in the survey. The existence of such an embedding effect is supported by much evidence in our two case studies: in the MAA, we asked respondents who accepted to contribute if they would be willing to contribute for any other groundwater body. The answer was positive for 71 %, with 41 % declaring the same WTP. In the LTS, 44 % of the respondents declared they would consent to pay a similar amount for the protection of any other aquifer in France. Such results cast doubts on the meaning of elicited WTP values, which could be considered as the WTP to protect groundwater resources in general (and not specifically the groundwater body under study).

- The second embedding effect is more specifically linked to situations where groundwater protection or restoration programs generate a wide range of environmental benefits. This effect is observed mainly in the MAA case study where some respondents faced difficulties in clearly disentangling those benefits derived from groundwater quality improvement from those of other environmental benefits. Especially in the context of orphan brownfields management, it is clear that actions aiming at improving groundwater quality will also bring other types of benefits to the population (positive landscape amenities, improvement of soil quality, etc.). Even if a survey clearly focuses on groundwater resources we cannot be sure that all respondents accept the implicit mental model used by the researcher in designing the survey. Results provide evidence of this risk: respondents who declare being concerned by a high number of environmental problems have a higher probability of accepting to pay, and a greater WTP. This reflects a difficulty for respondents to disconnect groundwater resources from other environmental compartments (air, soil, surface water, etc.). The survey may have influenced them in that direction by explaining the link between contaminated soil and groundwater quality on the one hand, and groundwater quality and surface ecosystems on the other hand. Such a result raises doubts as to the meaning of the WTP value, which could be considered as their WTP to improve the environment quality in general in their community (and not specifically the groundwater resource).

21.5 Discussion, Conclusions and Recommendations

In a context of mounting financial constraints, policy makers and the managers of river basins increasingly tend to use economic appraisal techniques to screen and compare competing groundwater protection and remediation projects. This generally involves assessing and comparing the costs and benefits associated with such projects. One of the main difficulties reported by economists is conducting an integrated assessment of the wide range of benefits generated by groundwater protection. Indeed groundwater protection or remediation not only improves the welfare of economic agents exploiting this resource (households, municipalities, industries, farmers), it also contributes to improving ecological services produced by groundwater dependent ecosystems (e.g. rivers and wetlands). Moreover, there are clear long term benefits associated with the protection of groundwater resources for future generations, considering their buffering role in situations of drought or extreme pollution events for instance.

One of the methods recommended and widely used to assess all these benefits is contingent valuation. The method comprises eliciting people's WTP for improving groundwater and the associated benefits. One of the strengths of this method is providing a single monetary estimate that theoretically includes direct and indirect use values as well as option and bequest values. A number of applicative studies, reviewed in this chapter, illustrate the integrative potential of the method. They also highlight some of its limitations and caveats. In particular, doubts exist about the validity of the method when applied to situations where respondents have a very limited knowledge of groundwater; and where direct uses being limited, most of the benefits are linked to indirect impacts on dependent ecosystems.

Two original case studies representative of this situation are presented in the chapter. They show how the method can be used in contexts where respondents are not familiar with groundwater. Overall, selected results highlight that WTP is an indicator that captures the whole range of groundwater protection benefits. Assessing WTP through contingent valuation surveys therefore is helpful for conducting an integrated valuation of groundwater protection benefits. Based on the results from the surveys, the message to water planners and policy makers is that people do care for groundwater protection and remediation, especially to guarantee the wellbeing of future generations.

However, the studies also point out some limits that might restrict the relevance of the results obtained. The first limit is related to the respondents' limited prior knowledge of groundwater. Our case studies suggest that it is possible to convey sufficient information to support respondents' contribution decision. However, there is a clear risk that this information biases the elicitation process, either enhancing or reducing WTP. This statement also raises doubts as to the representativeness of the sample of CVM respondents, as the survey sample on average is more informed about groundwater than the public in general. The second limit is related to two types of the so-called embedding effect: (1) because lay people often perceived groundwater as a uniformly distributed resource, some of them may be unable to assess the benefits associated with the protection of a distinct aquifer, considering its geographic location and extension and its specific hydrogeological properties; and (2) in situations where the groundwater management actions are expected to bring a wide range of environmental benefits (e.g. on water quality but also on landscape amenities and soil quality), respondents may face difficulties to clearly disentangle benefits derived from groundwater quality improvement from other environmental benefits.

This leads us to formulate two main recommendations. The first one is that a 30-min or so face-to-face interview or an eight-page questionnaire, say, may not be sufficient for people to correctly understand the characteristics of the aquifer under study and the benefits ensuing from its protection. More time should be dedicated to this preliminary step to ensure that respondents adopt the “mental model” used by the survey designers. Techniques such as focus groups could be used to achieve this objective. The second recommendation is to favor assessing the benefits of groundwater protection programs for the full range of expected environmental improvements at the local scale (rather than only for the groundwater quality improvement), either by the use of the CVM or by the use of other types of revealed preferences methods such as choice experiments which could be more appropriate.

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Appendix

Detailed Description of Survey Results

Tables 21.4 and 21.5 provide the results of the estimated econometric models. The logistic model aims at identifying variables determining the probability that a given respondent accepts contribution. The dependent variable is 1 if the respondent is willing to pay, 0 otherwise.

The Ordinary Least Square (OLS) regression model aims to identify the variables that determine the amount respondents are willing to pay. The OLS model only uses strictly positive WTP, zeros being excluded. The Tobit model is a variant of this model, which accounts for zeros.

Table 21.4 Results of the econometric models (Meuse alluvial aquifer case study)

			Logistic regression		OLS regression		Tobit regression	
Type	Variables	Description	Coef.	z	Coef.	t	Coef.	t
	Intercept		−4.308***	−5.67	2.418***	8.17	−1.382**	−2.06
Geographic location	hnappe	The respondent lives above the RWM073 groundwater body (0/1)	0.655***	2.88				
	distance	Distance from the centroid of the commune to the Meuse (km)			−0.106**	−2.26	−0.129*	−1.74
Groundwater use	aepnappe	The respondent is supplied at least partly from the Meuse alluvial aquifer (0/1)	0.829**	2.45				
	eaupuits	The respondent uses water abstracted from a well (0/1)	−0.966*	−1.72			−1.334***	−3.14
Perception	nbrisque5	The groundwater quality constitutes a risk for five types of uses (0/1)	2.010**	2.02				
	rpot	The groundwater quality may constitute a risk if the water is used for gardening (0/1)			0.227*	1.90		
Likelihood/ realism	realiste	Level of realism attached to the improvement scenario (from 0: not realistic at all to 3: quite realistic)	0.414***	3.59				
	realiste1	The respondent finds the improvement scenario rather realistic (0/1)					−0.298*	−1.72
Importance	import	Level of importance attached to the improvement of the groundwater quality (from 0: not important at all to 3: quite important)	1.158***	4.74			1.007***	4.72
Benefits	nbbenef5	Five motivations for contributing are quoted (0/1)			0.763**	2.04		
	bpusage	The main motivation for contributing is related to the direct use of the aquifer today or in the future (0/1). Other possible			−0.304***	−2.63		

		motivations are: the possibility to transmit a groundwater body of better quality to the future generations and improvement of the quality of water feeding the Meuse, improvement of flora and fauna living conditions						
	bnappebis	The respondent would also contribute for another aquifer, with a lower WTP (0/1)			0.388***	3.54		
Environmental problems	nbprobleme	Number of environmental problems encountered by the respondent (from 0 to 6), among noise, water, atmospheric, soil pollution, loss of biodiversity, waste problems, other environmental problems	0.132**	2.30				
	nbproblemebis	The respondent is affected by at least five environmental problems (0/1)			0.334***	2.61		
	epolsol	The respondent is affected by soil pollution (0/1)					0.458**	2.43
Socio-economic characteristics	sexe	Gender (0 for man/1 for woman)	−0.481**	−2.23	−0.237**	−2.32	−0.457***	−2.85
	enfant1	1 child < 18 years lives in the household (0/1)	−0.611**	−2.16	0.290*	1.95		
	educ	Level of education (from 1 to 6)			0.099**	2.24	0.285***	4.26
	etud	The respondent is a student (0/1)	1.745***	4.24				
	rev	Average monthly household income (k€)	0.351***	3.50			0.290***	4.54
	sqrt_rev	Square of average monthly household income			0.008**	2.20		
Questionnaire	qdiff3	The respondent estimates the WTP question as very difficult			−0.360*	−1.74		

(continued)

Table 21.4 (continued)

			Logistic regression		OLS regression		Tobit regression	
Type	Variables	Description	Coef.	z	Coef.	t	Coef.	t
			N = 520 LR chi2(11) = 101 Prob > chi2 = 0.0000 Pseudo R2 = 0.1537		N = 319 F(12,306) = 6.21 Prob > F = 0.0000 R2 = 0.1958 Pseudo R2 = 0.1643		N = 397 LR chi2(8) = 92 Prob > chi2 = 0.0000 Pseudo R2 = 0.0619	

Note: *Coef.*: coefficient
*10 % significance level, **5 % significance level and ***1 % significance level

Table 21.5 Results of the econometric models (Lower Triassic Sandstone confined aquifer case study)

			OLS regression		Tobit regression	
Type	Variables	Description	Coef.	t	Coef.	t
	Intercept		2.556***	13.88	0.986***	5.06
Information/ knowledge	info	The respondent considers himself as well informed about the groundwater overexploitation problem and the origin of his tap water (0/1)	−0.238**	−2.00		
Likelihood/realism	cred_ref	The respondent finds the reference scenario not credible (0/1)	−0.832**	−2.56	−0.974**	−2.46
Benefits	before2015	The respondent lives in a municipality where the benefits will take place in the very short term (before 2015) (0/1)	0.248**	2.14		
	benef_15Y	The respondent can expect to benefit from groundwater improvement for more than 15 years in the locality where he/she lives			0.227*	1.74
	futgen	The following sentence is quoted as a motivation for paying : “This groundwater is what my children and grandchildren will drink in 40 years’ time” (0/1)	0.584***	4.70	1.440***	10.56
	warm_glow	The respondent agrees with the following statement: “I am willing to pay for this aquifer as I would be willing to pay for any other aquifer in France” (0/1)	0.759***	3.43	1.485***	5.66
Water bill and savings	wat_price	The respondent perceives water as expensive (0/1)	−0.446***	−3.95	−0.66***	−5.18
	wat_sav_fin	The respondent makes significant efforts to reduce his water consumption and declares doing so for financial reasons (0/1)	−0.290**	−2.40		
	wat_sav_env	The respondent make significant efforts to reduce his water consumption and declares doing so for environmental concerns.			0.385**	2.24

(continued)

Table 21.5 (continued)

			OLS regression		Tobit regression	
Type	Variables	Description	Coef.	t	Coef.	t
Other	Leisure	The respondent practices often or very often at least one activity related to water, including fishing, canoeing, swimming or walking among rivers and lakes (0/1)	−0.261**	−2.26		
Socio-economic characteristics	Income	Yearly net income of the household	0.000***	6.97	0.000***	4.80
	Education	Education level			0.153***	3.35
			N = 354 R2 = 0.2976 Pseudo R2 = 0.2792		N = 347 LR chi2(9) = 215 Prob > chi2 = 0.0000 Pseudo R2 = 0.1490	

Note: *Coef*. coefficient
*10 % significance level, **5 % significance level and ***1 % significance level

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