Collective action for water quality management in agriculture: The case of drinking water source protection in France

Laurence Amblard

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Laurence Amblard *

* Irstea, UMR Territoires

9 avenue Blaise Pascal, CS 20085
63178 Aubière, France
Tel: +33 4 73 44 06 31
E-Mail: laurence.amblard@irstea.fr

Abstract: Nonpoint source pollution from agriculture represents a major threat to the quality of water in the European Union (EU) context. As part of the implementation process of the EU Water Framework Directive in France, the cooperation between water suppliers and agricultural stakeholders has been recently promoted for limiting diffuse agricultural pollution at the water catchment level. Based on a conceptual framework combining transaction cost economics and the social-ecological system (SES) framework, this paper identifies the conditions under which such collective action is effective for the restoration/maintenance of water quality. The research relies on a cross-case comparison of cooperation in six drinking water catchments. A qualitative analysis of primary data collected at the national, water basin and local levels serves as a basis for the multi-case investigation. Variables related to the hydrogeological system, the stakeholders involved, the contracts governing cooperation and the economic and policy contexts are shown to interact in their influence on collective action. The results highlight the importance of the match between contract incentives and the characteristics of the local context and the potential complementarities between informational, regulatory and economic policy tools for enhancing the effectiveness of collective action for water pollution control.

Keywords: collective action; nonpoint source pollution; water drinking catchments; transaction costs; social-ecological system (SES) framework

Highlights:

- A cross-case comparative analysis of cooperation for water pollution control in France.
- A conceptual framework combining transaction cost theory and the SES framework.
- Features of the hydrogeological system, the involved actors and governance influence cooperation.
- Market and policy incentives play a major role in collective action.
- Identified variables interact in their influence on cooperation.

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1. Introduction

Despite an important reduction in the levels of nutrients in European freshwaters over the past two decades, nonpoint source pollution from agriculture still represents a major threat to the quality of surface and ground waters in Europe (EEA, 2015). In France, nitrate pollution, mostly from agriculture, remains high in surface waters. The contamination of ground waters by nitrates and pesticides has worsened in the past few years (CGDD, 2014).

While pollutants from point sources enter at discrete identifiable locations, pollutants from nonpoint sources follow indirect and diffuse pathways to the environment (Shortle and Horan, 2001). Diffuse pollution from agriculture has multiple environmental, social and economic impacts. High nitrogen and phosphorus levels in water lead to eutrophication, reducing biodiversity and affecting recreational and economic activities that depend on aquatic ecosystems (Shortle et al., 2001). Due to the human health risks posed by pollutants in drinking water, the European Union (EU) Drinking Water Directive established standards for nitrate and pesticide rates in water intended for human consumption (EU, 1998). In France, water utilities adopted costly curative (water treatments) or palliative strategies (resource blending or substitution) to comply with regulatory standards. In 2007, treatments were applied to 10% of the drinking water resources to reduce nitrate rates and to more than 20% of the drinking water resources to eliminate pesticide residues. Between 1998 and 2008, diffuse pollution was one of the main causes for catchment abandonment. In total, the extra costs incurred by water supply services to address nitrate and pesticide pollution were estimated to be between 580 and 1010 million euros (Bommelaer and Devaux, 2011).

Adopted in 2000, the EU Water Framework Directive established the objective of achieving a good water status for all water bodies. This directive more particularly encourages EU member states to ensure the protection of water bodies used for the production of drinking water "in order to reduce the level of purification treatment required" (EU, 2000).

As an alternative to curative/palliative approaches to drinking water quality management, decentralized cooperation between water suppliers and agricultural stakeholders for limiting nonpoint source pollution has recently been developing in the French and European contexts (Brouwer, 2003; De Groot and Hermans, 2009; Grolleau and McCann, 2012). Such cooperation involves water suppliers and agricultural stakeholders (farm organizations, farmers) who jointly define and implement action plans at the water catchment scale (Brouwer, 2003). The action plans include measures (e.g., reductions in nitrogen and pesticide use or the establishment of riparian buffers along watercourses) aimed at modifying agricultural practices known to influence the extent of contaminant leaching and runoff. The definition and implementation of action plans are based on self-organization among key actors: drinking water suppliers, farmers and other potential stakeholders (e.g., farm organizations and state agencies) (Brouwer, 2003).

In France, most cases of collective action for drinking water catchment protection have developed in the context of the "Grenelle" policy launched in 2009. More than 500 priority drinking water catchments were identified as being particularly threatened by nonpoint source pollution (Loi n° 2009-967, 2009). The policy prescribes the definition and implementation of action programs based on the cooperation between water suppliers and agricultural stakeholders. The implementation of actions targeting nonpoint source pollution at the water catchment level relies on the voluntary participation of farmers. The initial objective of the "Grenelle" policy was to protect all priority catchments by 2012; however, the action plans were effective in only 23% of the catchments at the end of 2014 (Ménard et al., 2014). In 2019, the share of catchments where an action program was implemented increased to 76% (MEDDE, 2019). While a few successful cases of drinking water catchment protection have been documented, to date, the "Grenelle" policy has not led to a significant improvement in water quality (Barataud et al., 2014a; Bénézit et al., 2014; AE Adour-Garonne, 2017).

The delayed implementation of the "Grenelle" policy as well as the diverse outcomes achieved by collective action initiatives in France highlight the need to better understand the conditions under which the cooperation between drinking water suppliers and agricultural stakeholders is effective for protecting the water resource from diffuse pollution. The objective of the paper is thus to identify the factors influencing the success or failure of collective action involving water suppliers and agricultural stakeholders for the definition and implementation of programs targeting diffuse pollution in France.

Similar to many environmental goods, water quality presents the characteristics of a public good (Baumol and Oates, 1988). Pure public goods are goods that are non-exclusive and non-subtractive (Ostrom, 2003). The restoration or maintenance of water quality constitutes a public good, as (i) everyone can benefit from the improvement in water quality without diminishing others' benefits (non-subtractability) and (ii) it is difficult (impossible) to prevent anyone from enjoying the benefits of water pollution reduction (non-excludability). The collective action dilemma at stake is thus similar to a public good provision problem (Esteban and Albiac, 2012; Villamayor-Tomas et al., 2014; Ban et al., 2015).

The analysis relies on a conceptual framework combining transaction cost economics and the social-ecological system (SES) framework. Within the framework of transaction cost economics, it is assumed that the development of cooperation depends on the benefits and costs, including transaction costs that accrue to the participating stakeholders. A growing body of research seeks to include transaction costs in the analysis of environmental policies and natural resource management (Birner and Wittmer, 2004; McCann et al., 2005; Coggan et al., 2010; Ménard, 2011; McCann, 2013; Thiel et al., 2012; 2016). Several studies have empirically measured the transaction costs linked to the implementation of environmental policies and showed their high significance (McCann and Easter, 1999; Falconer et al., 2001; Mettepenningen et al., 2009; McCann and Claassen, 2016). However, there is still a limited understanding of the factors influencing the type and the level of transaction costs associated with different modes of governance or environmental policy instruments (Coggan et al., 2010; Garrick et al., 2013). The SES framework was developed to analyze the patterns of interactions and outcomes in diverse social-ecological systems (Ostrom, 2009; McGinnis and Ostrom, 2014). This framework has been applied for descriptive, diagnostic, or, in association with various theories, explanatory purposes (Thiel et al., 2015; Partelow, 2018). We follow the third approach by using the SES framework to identify the factors affecting the benefits/costs and transaction costs of collective action for drinking water catchment protection. More particularly, the variables highlighted by Ostrom (2009) are used as initial assumptions regarding the factors that influence the cooperation between drinking water suppliers and agricultural stakeholders.

With the objective of identifying the factors that foster or constrain collective action, the adopted research strategy is an explanatory, multiple-case study design, structured by the conceptual framework combining transaction cost economics and the SES framework (Yin, 1994). Case study research is particularly helpful for disentangling complex causal processes involving interactions between multiple variables (Poteete et al., 2010). Based on a qualitative analysis of primary data collected at the national, water basin and local levels, six cases of successful and unsuccessful collective action for drinking water catchment protection in France were investigated.

This paper is organized as follows. Section 2 develops the conceptual framework used for the analysis. The methodology of the research is detailed in section 3, including background information on the six selected cases of cooperation. The factors identified as affecting the benefits and transaction costs of collective action are presented in section 4. The final section discusses the results and the insights they provide for understanding the cooperative processes involving water suppliers and agricultural stakeholders, their policy implications and future research areas.

2. Conceptual framework

Transaction cost economics are used as the theoretical framework for identifying the benefits and costs, including transaction costs, of cooperation for drinking water catchment protection (section 2.1.). The factors likely to affect the benefits and costs of collective action involving water suppliers and agricultural stakeholders are further identified on the basis of the SES framework (section 2.2.).

2.1. Transaction cost economics

Transaction cost theory relies on the assumption of bounded rationality proposed by Simon (1978). Due to uncertainty about the relevant elements that must be considered and cognitive limitations with regard to information processing, actors make decisions without considering all options and their consequences (Simon, 1979). Boundedly rational actors are unable to establish contracts forecasting all future contingencies. Such contract incompleteness allows for the participants' strategic behavior, which manifests as adverse selection, moral hazard or shirking (Williamson, 2000). Transaction costs are "the comparative costs of planning, adapting, and monitoring task completion under alternative governance structures" (Williamson, 1985). In the natural resource management and environmental policy field, *ex-ante* transaction costs are defined as information collection costs, decision-making costs and/or bargaining costs for reaching agreements, while *ex-post* transaction costs correspond to the monitoring and enforcement costs of agreements (Birner and Wittmer, 2004; McCann et al., 2005).

Participation in collective action for protecting water quality at the source involves potential benefits and costs as well as transaction costs.

The objective of water suppliers engaging in collective action for water catchment protection is to maintain or restore water quality to meet the regulatory standards for drinking water supplies (Brouwer, 2003; Lehmann et al., 2009). The water suppliers' incentives to cooperate depend on the opportunity costs of alternative options, such as purification treatments, to enhance drinking water quality (Abildtrup et al., 2012; Grolleau and McCann, 2012). The costs borne by water suppliers also encompass the economic resources devoted to water catchment protection, such as monetary payments delivered to farmers as compensation for changing their practices to improve water quality (De Groot and Herman, 2009). In turn, farmers participating in collective action incur costs for changing their practices (Lehmann et al., 2009; Abildtrup et al., 2012). These costs are opportunity costs, i.e., the loss of profit or revenue potentially induced by the adoption of measures that target nonpoint source pollution. They also include labor costs and investment costs; for example, changes in farming systems may require the acquisition of new equipment (De Groot and Hermans, 2009). Farmers may benefit from savings by changing their practices, for example, by reducing the expense of chemical inputs, without experiencing any decrease in yields (Buckley and Carney, 2013). Finally, economic incentives for farmers to participate in collective action also include potential benefits such as investment subsidies or monetary compensation (Lubell, 2004; Grolleau and McCann, 2012).

The transaction costs associated with collective action for drinking water protection correspond to the costs incurred for defining and implementing actions targeting nonpoint source pollution. The costs for defining the actions include the costs of collecting and processing information concerning the pollution sources, vulnerable areas and farming systems in the catchment and the consultation/negotiation costs of actions with farmers (Falconer et al., 2001; Mettepenningen et al., 2011). Farmers also bear decision-making costs regarding their participation in collective action, including the costs for accessing information on the measures to be implemented and their consequences for their farming system (Falconer, 2000; 2002; Lehmann et al., 2009; Mettepenningen et al., 2009). The implementation costs incurred by water suppliers are the control and enforcement costs of actions. These costs depend on the level of difficulty for observing changes in farming practices (Falconer, 2002). The ex-post transaction costs also include the time spent by farmers to fulfill the monitoring requirements and the costs related to sanctions in the case of noncompliance (Lehmann et al., 2009; McCann, 2009; Mettepenningen et al., 2009).

2.2. SES framework

The SES framework was developed for analyzing, from an institutional analysis perspective, the governance of common-pool resources (Ostrom, 2007a; 2009). This framework draws on the IAD (Institutional Analysis and Development) approach (Ostrom, 1998; Ostrom, 2011). It has been applied to diverse sectors, including the management of fisheries (e.g., Basurto et al., 2013; Ernst et al., 2013; Torres Guevara et al., 2016; Partelow et al., 2018a), irrigation systems (e.g., Meinzen-Dick, 2007; Ostrom and Cox, 2010), pond aquaculture systems (Partelow et al., 2018b) or grassland (e.g., Risvoll et al., 2014; Robinson et al., 2017). While the framework was originally designed for the study of common pool resource problems, recent developments have been aimed at broadening its scope of application. These developments include the analysis of the various public goods and services generated by SESs (McGinnis and Ostrom, 2014; Ban et al., 2015; Bennett and Gosnell, 2015) as well as investigations of sectors outside the natural resource management field (e.g., Blanco, 2011; Marshall, 2015). Several studies have used the IAD or SES framework for analyzing the emergence of partnerships for water quality management (Lubell et al., 2002; Sarker et al., 2008; Nagendra and Ostrom, 2014, Villamayor-Tomas et al., 2014) or for assessing the performance of community-based drinking water provision (Madrigal et al., 2011; Naiga et al., 2015). However, no study so far has applied the SES framework to the protection of drinking water catchments.

The SES framework gathers and structures the variables that have been found in previous research to influence the patterns of interactions and outcomes (focal action situations) in diverse SES (McGinnis and Ostrom, 2014). Four first-tier variables are considered as potentially important to analyze the outcomes achieved in a given SES: the characteristics of the natural resource considered (the resource system and the resource unit), the characteristics of the actors involved and the characteristics of the governance system. In addition, the broader social, economic and political contexts as well as the related ecosystems are included as first-tier variables interacting with the other variables (Figure 1).

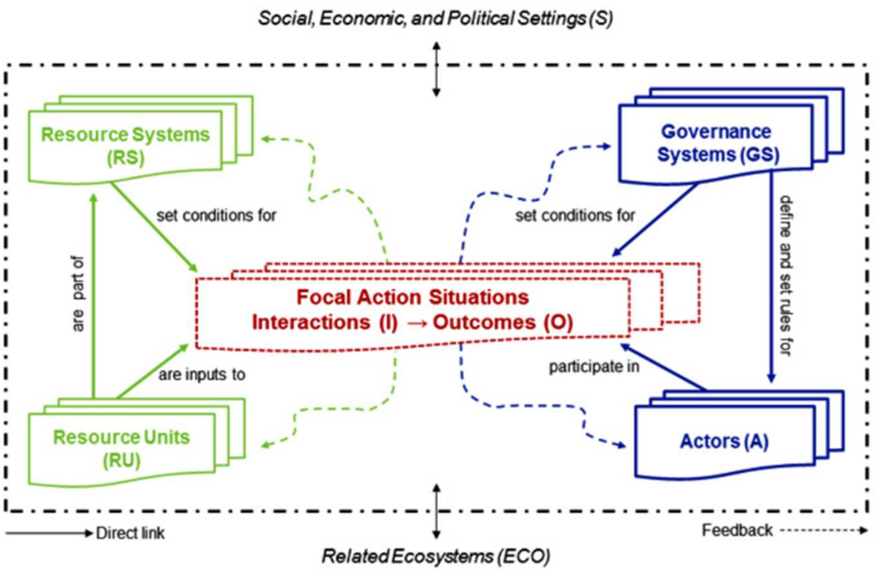


Figure 1: SES framework (Source: McGinnis and Ostrom, 2014)

Potential explanatory factors for the outcomes achieved are included in the SES framework as second-tier variables, which are defined as the characteristics of the first-tier variables (McGinnis and Ostrom, 2014). When applying the framework, the second-tier variables can be further characterized by third-tier variables and so on, if relevant for the analysis (Basurto et al., 2013; Partelow and Boda, 2015). Appendix A presents the list of second-tier variables that was updated by McGinnis and Ostrom (2014).

Among the second-tier variables identified as potentially relevant, a subset of ten factors likely to affect the benefits and costs of collective action has been found in previous research to be critical for users of a common-pool resource to successfully self-organize rules to manage the resource (Ostrom, 2009; Poteete et al., 2010).

While managing large resource systems involves higher transaction costs, a small size may imply a less valuable flow of products from the system. Thus, a moderate size of the resource system is seen as most conducive to self-organization (Chhatre and Agrawal, 2008; Ostrom, 2009). Unlike situations where the resource is either already exhausted or abundant, a moderate level of resource scarcity (productivity of the system) is also likely to induce collective action by users (Meinzen-Dick, 2007). A low predictability of the system dynamics will increase the management costs of the resource, thereby reducing the likelihood of self-organization (Ostrom, 1990; Agrawal, 2001). Management costs also depend on the resource unit mobility; stationary units (e.g., water in a lake) are less costly to manage than mobile units (e.g., water in a stream) (Schlager et al., 1994).

A larger number of users means higher transaction costs (Casari and Tagliapietra, 2018); however, a small group size may be a constraint on the pooling of resources needed to sustain collective action (Wade, 1987; Ostrom, 2010). The sharing of a common knowledge of the social-ecological system is seen as decreasing the perceived costs of organizing by users (Ostrom, 2009). The importance of the resource to users, in terms of economic or noneconomic value, will affect the expected balance of benefits and costs associated with collective action (Acheson, 2006). The presence of well-respected local leaders and the existence of norms of reciprocity and/or social capital within the group are actors' characteristics that are likely to decrease the transaction costs associated with collective action (Pretty and Ward, 2001; Meinzen-Dick, 2007). Leaders can reduce the costs of information diffusion and agreement formation (Villamayor-Tomas et al., 2014). Norms of cooperative behavior lower the negotiation and enforcement costs of agreements (North, 1990; Poteete et al., 2010).

Governance systems in the SES framework are conceptualized as being composed of multilevel sets of rules. Operational rules affect the decisions of actors with regard to the direct management of the resource. Collective-choice rules frame the collective-choice situations where operational rules are defined, and constitutional rules affect the constitutional situations where collective-choice rules are crafted (Ostrom, 2007b). A variable identified as crucial for the success of self-organization is the autonomy of users at the collective-choice level to define and enforce the operational rules governing resource management (Ostrom, 2009; Poteete et al., 2010).

The long-term sustainability of collective action will also depend on the match between operational rules and local conditions (the attributes of the resource and the characteristics of the actors). Furthermore, the effectiveness of governance systems also depends on the monitoring and enforcement of rules and on the interactions with the larger scale governance systems (Ostrom, 2009).

In this paper, we analyze collective action for the definition and implementation of programs targeting farming practices to control nonpoint source pollution at the water catchment level (I). The resource system (RS) considered is the hydrogeological system, from which water, as a resource unit (RU), is abstracted for drinking water production. Collective action involves two main sets of actors (A): drinking water suppliers and agricultural stakeholders (farm organizations and farmers). The contracts framing the implementation of actions are understood as operational rules defined by stakeholders at the collective-choice level (GS). The objective of the cooperation between water suppliers and agricultural stakeholders is to limit or reduce water pollution; thus, the outcome (O) of interest in the study is the restoration or maintenance of water quality.

The set of factors highlighted by Ostrom (2009) as affecting the costs and benefits of self-organization (Table 1) is used as initial assumptions for identifying factors affecting collective action in the case of drinking water catchment protection in France.

Table 1: Subset of factors identified as affecting the likelihood that common-pool resource users will engage in collective action to self-organize (adapted from Ostrom, 2009)

First-tier variable	Second-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action
Resource systems (RS)	RS3 – Size of resource system	A large resource system increases transaction costs	-
		A small resource system decreases benefits	-
		A moderate size of the resource system increases benefits and decreases transaction costs	+
	RS5 – Productivity of system	Resource exhaustion decreases benefits	-
		Resource abundance decreases benefits	-
		Moderate levels of resource scarcity increase benefits	+
	RS7 – Predictability of system dynamics	A high predictability of system dynamics decreases transaction costs	+
Governance systems (GS)	GS6 – Collective-choice rules	User autonomy at the collective-choice level decreases transaction costs	+
Resource units (RU)	RU1 – Resource unit mobility	Mobile resource units increase transaction costs	-
Actors (A)	A1 – Number of relevant actors	A large number of users increases available resources and transaction costs	-/+
	A5 – Leadership-entrepreneurship	The presence of entrepreneurs/local leaders decreases transaction costs	+
	A6 – Norms (trust-reciprocity)/social capital	Shared norms of reciprocity/trust between users decrease transaction costs	+
	A7 – Knowledge of SES	Shared knowledge of relevant SES attributes decreases transaction costs	+
	A8 – Importance of the resource	A more important resource to users increases benefits	+

3. Methodology

The identification of factors affecting collective action relies on the comparative analysis of six cases of cooperation. The multistep methodological approach followed in the research is presented in section 3.1. A short description of the six cases is provided in section 3.2.

3.1. Multistep methodological approach

The data collection and treatment followed a multistep approach summarized in Figure 2.

3.1.1. Identification of variables likely to affect collective action

In the **first step**, the initial set of assumptions drawn from the conceptual framework (Ostrom, 2009) was developed and adapted for (i) the specific case of cooperation between drinking water suppliers and agricultural stakeholders for nonpoint source pollution control and for (ii) the French context.

The revision of the assumptions regarding the variables likely to affect collective action was based on the following: (1) a review of the scientific literature focused on cooperative agreements for drinking water quality management in the French and European context; (2) a review of research and policy reports addressing collective action for drinking water catchment protection in France; and (3) 12 semi-structured interviews with water and agriculture policy stakeholders at the national and river basin levels (Table 2).

Table 2: Interviews conducted at the national and river-basin levels in 2013.

Organization	Number of interviews
Water Agencies	5
Ministries	2
Agricultural organizations	3
Private water operators	2

The selection of stakeholders to be interviewed was informed by a preliminary review of research and policy reports. The interviewees were chosen to include the main public and private stakeholders involved in the protection of drinking water catchments at the national and river-basin levels (Table 2). The semi-structured interviews were based on a common questionnaire to ensure a systematic collection of comparable data. The questionnaire was organized around two main sections. One section addressed the characteristics of cooperative agreements (stakeholders, types of contractual arrangements and their prevalence at the national or water basin level). Based on the initial set of assumptions, the second section was designed to assess the perception of the interviewees regarding each factor assumed to foster/constrain collective action for drinking water protection. In addition, interviewees were invited to indicate other variables that in their opinion have an impact on the cooperation between water suppliers and agricultural stakeholders.

The interviews were conducted either face-to-face (9) or by phone (3) between May and November 2013. The time spent for an interview ranged between one and three hours. Appendix B presents the interviews in greater detail. All interviews were recorded and transcribed by using the structure provided by the questionnaire. The transcripts were sent to the interviewees to verify the accuracy of the data collected and opinions expressed.

Through the triangulation of data sources (Yin, 1994), the evidence collected served as a basis for assessing the relevance of the initial set of SES second-tier variables and their hypothesized impact on collective action in the specific case of drinking water catchment protection in France. New third- and fourth-tier variables were also added, as they were found to be potentially relevant for explaining the outcomes of cooperation between drinking water suppliers and agricultural stakeholders. Those variables characterize either the initial second-tier variables or new second-tier variables identified in the list updated by McGinnis and Ostrom (2014) (Appendix A). The criterion used for adding a new variable was the identified impact of this variable on the benefits, costs or transaction costs of collective action. The inclusion of additional variables was thus theoretically motivated (Thiel et al., 2015; Cox et al., 2016) by using transaction cost economics. As suggested by Frey and Cox (2015) and Thiel et al. (2015), the development of the third-tier and the fourth-tier variables followed the logic underlying the SES framework as a multitier nested framework.

The first step led to a revised set of assumptions regarding the factors likely to affect the benefits, costs and transaction costs associated with collective action for drinking water catchment protection in France. Appendix C presents the revised set of assumptions.

	SES variables affecting the success/failure of self-organization by users of CPR (Ostrom, 2009)		**Methods**	**Data**
Step 1	↓	Revision of assumptions	Triangulation of data sources	- Scientific literature - Research and policy reports - Interviews (12)
	Assumptions regarding the SES variables affecting the success/failure of collective action for drinking water quality management in France			
Step 2	↓	In-depth case studies	Triangulation of data sources Process tracing	-Interviews (36) -Documents
	Factors affecting the success or failure of collective action in each case			
Step 3	↓	Cross-case comparative analysis	Pattern matching	- In-depth case studies
	Factors affecting the success or failure of collective action for drinking water quality management in France			

Figure 2: Multistep research design

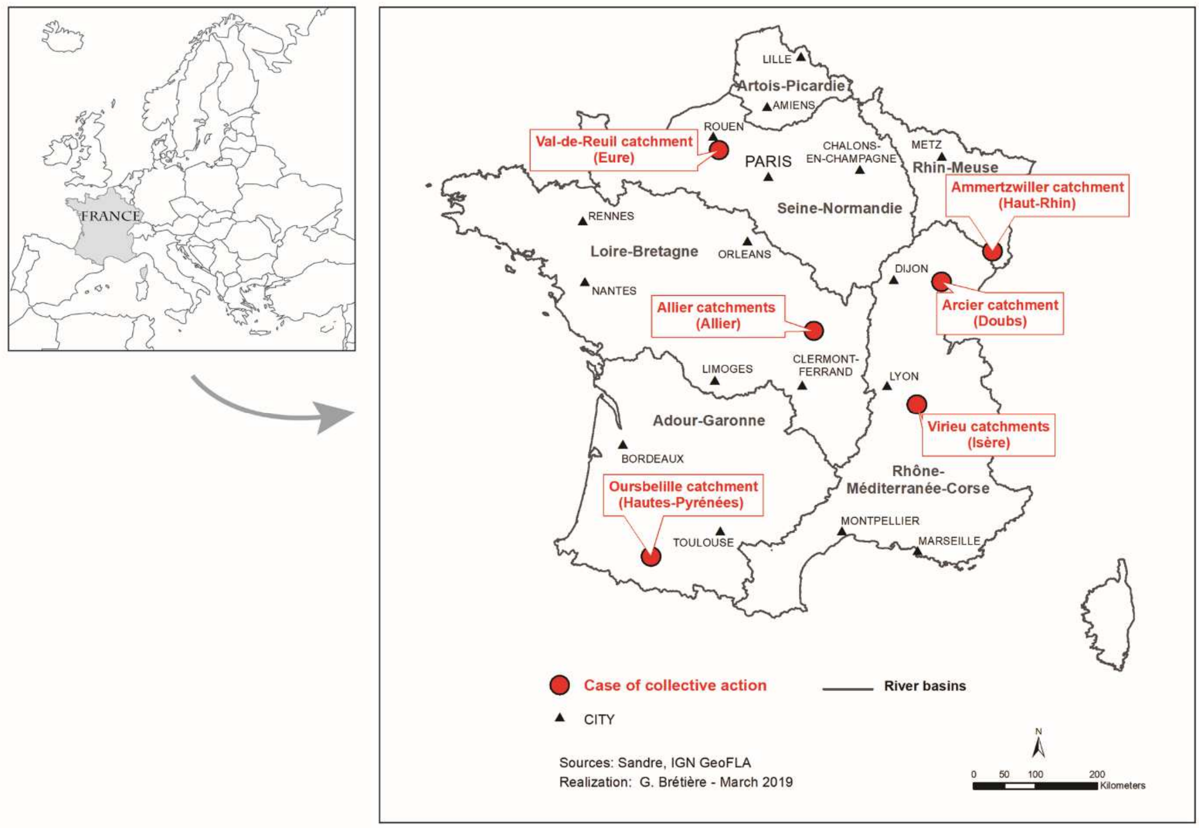
3.1.2. In-depth case studies

In a **second step**, in-depth case studies of collective action for the protection of six selected drinking water catchments were conducted.

Case study research is based on analytical rather than statistical generalization (Yin, 1994). Thus, the case selection followed a purposive sampling logic, which was framed by the conceptual framework of the analysis (Agrawal, 2003). The information collected in the first step was used for the selection of cooperation cases to be studied in depth (Map 1).

The cases were selected to represent the diversity of the types of contractual arrangements identified at the national and river-basin levels in order to gain insights into the specific influence of variations in the governance of collective action as a basis for policy recommendations. The review of the contractual arrangements realized in the first stage of the study shows that actions targeting water pollution control in the French context have been mostly implemented through Agri-Environmental Schemes (AES) co-funded by the EU as part of the rural development policy. Other, less prevalent, types of contracts have been established between water suppliers and farmers. These agreements include environmental land leases and purchase contracts for agricultural products (organic products used for collective public restaurants or low-input energy crops used for public district heating). In France, the choice of EU agri-environmental measures implemented locally is framed by a set of unitary commitments established at the national level by the Ministry of Agriculture. In contrast, local stakeholders have the autonomy to define the measures and compensation in environmental land leases and purchase contracts. Following Ostrom (2009), autonomy at the collective-choice level is assumed to be crucial for the success of collective action. Specific attention was also given to choosing both successful and unsuccessful cases of collective action with regard to the impact of cooperation on water quality. The indicators used to assess the success of collective action include the evolution of pollutant rates in water used for drinking water production. Due to the complexity and uncertainty surrounding the hydrogeological system dynamics, the observed short-term water quality trends may represent an imperfect measure of collective action success (Brouwer, 2003; Bennett and Gosnell, 2015). Thus, we also consider two intermediate collective action outcomes: (i) the farmers' participation in cooperation, which is defined as the adoption of measures included in the action plans, and (ii) the extent of the agricultural area covered by changes in farming practices in the drinking water catchment.

Map 1: Map of the selected cases of collective action for drinking water catchment protection



Data used for the in-depth case studies include data collected through 36 semi-structured interviews with local stakeholders involved in cooperation as well as data obtained from secondary sources.

The interviewees were chosen to include the main public and private stakeholders involved in the protection of drinking water catchments at the local level: water suppliers, farm organizations and local and regional state administrations. Participating and non-participating farmers were also interviewed in each case (Table 3). A preliminary review of the available documents and initial contacts with drinking water suppliers and/or farm organizations were used for the identification and selection of informants. While the information available at this stage of the study allowed for the adoption of a purposive selection strategy with regard to the choice of "institutional" stakeholders, the selection of interviewed farmers was more dependent on the guidance provided by the stakeholders. Nevertheless, the potential diversity in the farmers' perspectives could be assessed based on interviews with farm organizations, which fulfill a role of representing farmers in collective action processes.

Identical questionnaires were used for the interviews conducted across the six cases. The first section was dedicated to the collection of descriptive data concerning the water resource and drinking water catchment, the characteristics of the stakeholders involved, the governance and the broader policy context of cooperation. The questions in this first section were adapted to the specific area of expertise of the informants. The second section was based on the revised set of assumptions developed in the first step and was designed to collect in a systematic and comparable way the stakeholders' perceptions about the variables fostering or constraining collective action. The interviewees were asked whether each variable had an impact on collective action and whether the impact was positive or negative. They were also invited to elaborate on the reasoning behind their statement. The development of this section involved rephrasing the variables to clarify their content for the stakeholders having no scientific background (Delgado-Serrano and Ramos, 2015).

Table 3: Interviews conducted at the local level in 2014

	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Water suppliers						
Public water utilities	1	1	1	1	1	1
Private water operators			1			
Agricultural organizations						
Agricultural Chambers	1	1	1	1	1	
Regional organic farmers group						1
Organic supply chain association						1
Society for land and rural development		1				
Agricultural cooperative				1		
Farmers	1	2	2	2	2	2
Other stakeholders						
Watershed management boards		1		1		
Local/regional state administration	3					
Local offices of water agencies	1		1		1	1

The interviews were conducted during short-term stays at each case site between January and September 2014 (Appendix D). The time spent for an interview ranged between one and two hours. All interviews were recorded and transcribed by using the structure provided by the questionnaires. The transcripts were sent to interviewees to verify the accuracy of the collected data and opinions.

The information collected through face-to-face interviews was complemented with relevant documentation, such as environmental and agricultural diagnoses of water catchments, action plans, contracts, meetings minutes and evaluation reports. Documents were either accessed via the stakeholders' web sites or provided by the interviewees themselves.

The data were used to describe the collaborative processes and to identify the factors that favor or constrain collective action in each case. The descriptions of cooperation include the presentation of the water resource and agricultural land use context in the studied water catchments and the characterization of the cooperation process and its outcomes. The factors were assessed on the basis of indicators measured through a qualitative assessment of quantitative or qualitative data. Appendix E presents the indicators chosen, the type of data used and the criteria implemented for the assessment of variables. The characterization of the influence of factors on collective action was based on the triangulation of primary and secondary data sources (Yin, 1994). The perception of the interviewees regarding the impact of factors influencing collective action was critically assessed against the perception of other stakeholders as well as against the evidence from secondary sources. Process tracing was used as a complementary tool to characterize the causal relationships between the variables and the outcomes of collective action (Steinberg, 2007; Poteete et al., 2010). Appendix F presents a synthesis of the in-depth case studies, including the assessment of the factors and their impact on collective action in each case.

3.1.3. Cross-case comparative analysis

In a **third step**, the results of the individual case studies were compared in relation to the revised assumptions set in the first phase. Pattern matching (Yin, 1994) was used as a method for testing the revised assumptions against the case study evidence (Appendix G). The impact of each variable on collective action was compared across all cases to assess whether the pattern observed was similar to the corresponding revised assumption. Furthermore, systematic comparisons between cases presenting similarities on one or several variables were performed to consider the potential interactions between variables in their influence on collective action.

3.2. Background on the case studies

This section provides background information on the six selected cases of collective action. Table 4 displays the main characteristics of the water resource and the agricultural context in each case. The collective action processes and outcomes are presented in Table 5.

In the **Allier** case, ten drinking water catchments were classified as "Grenelle priority catchments" in 2009 because of increasing nitrate and pesticide rates. Approximately 120 mixed crop and livestock farms have all or part of their agricultural area in the large protection zone (8300 ha) (SMEA, 2013). Drinking water catchment protection relies on the cooperation between the Syndicat Mixte des Eaux de l'Allier (SMEA), representing the six intermunicipal water suppliers managing the catchments, and the departmental Agricultural Chamber. Collective action led to the establishment of an action plan in 2014. In addition to a free technical support program, EU Agri-Environmental Schemes (AES) were implemented. In 2015, a total of 71 farmers were involved in the support program, while only three farmers adopted agri-environmental measures, which covered 60 ha in the protection zone (SMEA, 2015). Water quality did not improve and deteriorated in some catchments.

The **Virieu** catchments are managed by the Syndicat Mixte d'Eau et d'Assainissement de la Haute-Bourbre (SMEAHB). They were identified as "priority" in the framework of the Grenelle policy in 2009 because of the noncompliance of the pesticide rates with the regulatory standard (AE Rhône Méditerranée Corse, 2013a). A Zone Soumise à Contrainte Environnementale (ZSCE) procedure, which gave the "département" state agency the option to prescribe regulatory measures if voluntary cooperation was not effective in restoring water quality after three years, was also adopted (Décret n°2007-882, 2007). Grassland represents two-thirds of the agricultural area in the catchments, where ten cattle breeding farms are located (Chambre d'Agriculture de l'Isère, 2012). In 2010, the water supplier became the owner of 17 ha of agricultural land within the catchments through land acquisition and exchange. The establishment of environmental land contracts (land leases and loan agreements) with five farmers led to the conversion of 27 ha of cropland into grassland, increasing the share of grassland from 60% to 87% of the agricultural area. The pesticide rates have shown a tendency to stabilize and decrease (AE Rhône Méditerranée Corse, 2013a).

The Syndicat Intercommunal d'Alimentation en Eau Potable (SIAEP) Tarbes-Nord relies on the **Oursbelille** catchment for its total drinking water production, for which supply is delegated to a private company. In 2009, the catchment was identified as a Grenelle "priority" catchment, as the nitrate rate regularly exceeded the regulatory standard between 2003 and 2008 (SIAEP Tarbes-Nord, 2013). Nineteen farmers own parcels in the catchment, with irrigated corn farming representing 88% of the agricultural area (Chambre d'agriculture Hautes-Pyrénées, 2012). The definition and implementation of actions are delegated to a consortium involving the water company, the Hautes-Pyrénées Agricultural Chamber and a regional development agency, the Semadour. The implementation of agricultural actions relies on AES co-funded by the EU and the Adour-Garonne Water Agency. In 2014, seven farmers had adopted agri-environmental measures, covering 73 ha in the catchment. The nitrate rates have decreased but are still close to the regulatory standard (SIAEP Tarbes-Nord, 2014).

Table 4: Main characteristics of the drinking water catchments in the six cases

	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Water resource						
Water management	Intermunicipal water utility (SMEA)*	Intermunicipal water utility (SMEAHB) *	Intermunicipal water utility (SIAEP Tarbes-Nord)*	City of Besançon*	Intermunicipal water utility (SIAEP Ammertzwiller-Balschwiller)*	Seine-Eure metropolitan area authority*
Hydrogeological system	Alluvial aquifers (Allier and Loire rivers)*	Perched aquifers**	Alluvial aquifer* (Adour river)	Karst aquifers**	Unconfined aquifer*	Karst aquifer**
Population supplied by the resource	39 900*	9 000 *	12 000*	50 000***	4 500**	40 000*
Share of total drinking water supply	51%*	20%*	100%**	45%***	30%**	67%*
Type of pollution	Nitrates/ Pesticides*	Pesticides***	Nitrates**	Pesticides*	Nitrate/ Pesticides*	-*
Level of contamination	Moderate*	High***	High**	Moderate*	High*	Low*
Agriculture						
Catchment area	8 300 ha*	115 ha***	396 ha*	10 200 ha*	363 ha**	127 ha***
Agricultural area	6 900 ha* (83%)	97 ha*** (84.3%)	325 ha** (82%)	4 146 ha* (41%)	234 ha* (64.5%)	110 ha*** (86.6%)
Number of farms	118*	10***	19**	72*	30*	7***
Type of farming systems	Mixed crop-livestock farming*	Livestock farming***	Arable crops**	Mixed crop-livestock farming*	Arable crops*	Arable crops***
Share of grassland (% of the agricultural area)	24%*	60%***	3%**	70%*	6%*	9%***
Share of arable crops (% of the agricultural area)	Cereals: 63%* Oleaginous: 9% Others: 4%	Corn: 14%*** Cereals: 13% Oleaginous: 13%	Corn: 88%** Cereals: 4% Others: 5%	Corn: 4%* Cereals: 21% Others: 5%	Corn: 59%* Cereals: 35%	Cereals: 91%***

Sources: Allier: *SMEA, 2013; Virieu: *AE Rhône Méditerranée Corse, 2013a, **DDAF Isère, 2009, ***Chambre d'agriculture de l'Isère, 2012; Oursbellile: *SIAEP Tarbes-Nord, 2013, ** Chambre d'agriculture des Hautes-Pyrénées, 2012; Arcier: *Ville de Besançon, 2013, **BRGM, 2005, ***AE Rhône Méditerranée Corse, 2013b; Ammertzwiller: *Chambre d'Agriculture du Haut-Rhin, 2008, **AE Rhin-Meuse, 2009; Val-de-Reuil: *CASE, 2014, **Levinson and Weiss, 2012, ***Safer Haute-Normandie, 2008.

The **Arcier** source is located 10 km from the city of Besançon. Between 1998 and 2003, the pesticide rates in the water displayed an upward trend. In 2004, the city decided to undertake the protection of the Arcier source catchment by collaborating with agricultural and non-agricultural stakeholders (Murgue and Afflard, 2013). Because of the importance of the population supplied, the catchment was later added to the list of the "Grenelle" catchments. Most of the 72 farms located in the Arcier catchment are dairy farms producing cheese under the Comté Protected Designation of Origin (PDO) label. Permanent and temporary grassland represents 70% of the agricultural area. The agricultural action program relies mainly on the implementation of AES co-funded by the EU and the Rhône Méditerranée Corse Water Agency. Between 2007 and 2013, approximately 20 farmers adopted agri-environmental measures that covered 808 ha in the catchment. A 27% decrease in pesticide use by participating farmers was observed between 2010 and 2012. Water quality improved between 2004 and 2013 (Ville de Besançon, 2013).

The **Ammertzwiller** well, managed by the SIAEP Ammertzwiller and Balschwiller, represents two-thirds of the water resources used for the drinking water supply (AE Rhin-Meuse, 2009). Because of the high nitrate and pesticide pollution levels, the Ammertzwiller catchment was classified in 2009 as "priority" in the Rhin-Meuse water basin management plan. Agriculture dominates land use in the catchment, where 30 farmers own land. While corn represents 59% of the agricultural area, grassland is only 6% (Chambre d'agriculture du Haut-Rhin, 2008). Agricultural actions include the implementation of AES, which are co-funded by the EU, the Rhin-Meuse Water Agency and the Haut-Rhin Departmental Council, and the development of a low-input energy crop (miscanthus). In 2011, the participation of farmers in AES covered 52 ha in the catchment (Ditner, 2014a). The introduction of miscanthus by farmers was supported by subsidies provided by the water supplier and the Rhin-Meuse Water Agency. Moreover, long-term contracts with guaranteed prices were offered to the farmers for supplying the municipal heating system. Sixteen farmers chose to grow miscanthus, the planting of which covered 27 ha in the catchment. Water quality improved significantly between 2009 and 2014, with a decrease in nitrate rates from 45 mg/l to 35 mg/l and a decrease in pesticide rates to levels below the regulatory standard (Ditner, 2014b).

The four wells located in the **Val-de-Reuil** catchment are used to supply two-thirds of the population of the metropolitan area Seine-Eure (40 000 inhabitants). The pollution rates of the water resource are well below the regulatory standards (CASE, 2014). However, the metropolitan authority responsible for drinking water production and supply initiated a collaborative process with agricultural stakeholders to limit the risk of diffuse pollution from agriculture in the catchment. In 2008, intensive cereal cropping was the main farming system in the area, with seven farmers renting land from a regional public land development agency (Safer Haute-Normandie, 2008). Between 2009 and 2011, the metropolitan authority became the owner of the rented land in the catchment (FNAB, 2014). Through partnerships with multiple local stakeholders involved in organic farming supply chains, including producers' groups and potential public and private consumers, environmental land leases were established with farmers. Based on the conversion of part of the cereal area and the development of organic produce production, collective action led to the effective development of organic farming in the Val-de-Reuil catchment.

Table 5: Collective action process and outcomes in the six cases

	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Regulatory framework	Grenelle	Grenelle ZSCE	Grenelle	Grenelle	Rhin-Meuse management plan	-
Start date	2009	2009	2009	2004	2008	2008
Main stakeholders involved at the collective-choice level	Water utility-Agricultural Chamber*	Water utility-Agricultural Chamber-Rural Land Agency-Farmers*	Private water supplier-Agricultural Chamber-Regional development agency*	City water service department - Agricultural Chamber-Regional plant protection agency*	Water utility-Agricultural Chamber-Farmers*	Metropolitan water service department-Organic farming/supply associations- Farmers*
Contracts (operational rules)	EU AES**	Environmental land leases**	EU AES**	EU AES**	EU AES** Supply contracts***	Environmental land leases**
Measures	Conversion to grassland**	Maintenance/ conversion to grassland**	Reduction in input use**	Conversion to grassland/ reduction in input use**	Reduction in input use** Miscanthus growing***	Organic farming**
Outcomes						
Farmer participation	3/118** (0.02%)	5/10** (50%)	7/19** (37%)	20/72** (28%)	16/30*** (53.3%)	4/7** (57.1%)
Agricultural area covered	60 ha**	27 ha**	78.5 ha**	808 ha**	79 ha***	110 ha**
Water quality trend	No improvement/ deterioration**	Improving trend**	No improvement**	Improving trend**	Improvement***	Maintenance of good quality**

Sources: Allier: *Interviews, **SMEA, 2015; Virieu: *Interviews, **AE Rhône Méditerranée Corse, 2013a; Oursbellile: *Interviews, **SIAEP Tarbes-Nord, 2014; Arcier: *Interviews, **Ville de Besançon, 2013; Ammertzwiller: *Interviews, **Ditner, 2014a, ***Ditner, 2014b; Val-de-Reuil: *Interviews, **FNAB, 2014.

4. Results

The comparison of the results of the individual case studies (Appendix G) led to the identification of a set of factors favoring or constraining collective action for drinking water catchment protection in the French context. First, we present the variables influencing the benefits and costs that accrue to the stakeholders involved in collective action (section 4.1.). The second section describes the variables identified as affecting the transaction costs linked to cooperation (section 4.2). The identified second-, third- and fourth-tier variables and their influence on the benefits, costs and transaction costs of cooperation are presented in Table 6 and Table 7.

4.1. The factors affecting the benefits and costs of collective action

4.1.1. Water suppliers

The engagement of water suppliers in cooperation with agricultural stakeholders appears to be driven by the cost of using alternative approaches to enhance drinking water quality (A8.1.1). Water suppliers are more likely to engage in cooperation when the technical options for reducing the pollutant rates in drinking water, such as purification treatment or water blending/dilution, are nonexistent or very costly (Bosc and Doussan, 2009; Abildtrup et al., 2012; Grolleau and McCann, 2012). The SIAEP Tarbes-Nord depends on the Oursbellile catchment for drinking water production and has no other alternative for lowering nitrate rates than cooperating with farmers. In the Virieu, Arcier and Val-de-Reuil cases, the decision of drinking water suppliers to initiate cooperation with agricultural stakeholders for diffuse pollution control was also driven by the high costs of investing in and operating new water treatment units. In the Arcier case, the annual operating cost of a water treatment plant was estimated at 130 000 euros, whereas the annual cost of the preventive approach was 40 000 euros (Gouverne, 2013). In contrast, in the Allier case, the low-cost access to drinking water network interconnections for managing water quality reduced the water suppliers' interest in engaging in collective action.

Furthermore, the involvement of water suppliers depends significantly on the financial and human resources (A2.1), including technical skills, available to them. Smaller water suppliers may be especially constrained by available resources (Brouwer, 2003; Barraqué and Viavattene, 2009). In the Arcier and Val-de-Reuil cases, the financial resources available to the city of Besançon and the Seine-Eure metropolitan area authority fostered the development of cooperation with agricultural stakeholders. Since technical options such as water purification were favored until recently to limit the pollutant rates in drinking water in France (Becerra and Roussary, 2008), the water suppliers do not usually possess the necessary skills to implement preventive approaches involving agricultural stakeholders. In the Allier, Virieu and Oursbellile cases, the water suppliers' lack of knowledge of farming systems constituted a constraint to the development of cooperation. In Ammertzwiller, the establishment of contracts for the supply of miscanthus was hampered by the absence of legal expertise of the water supplier.

In a context where water suppliers may lack financial and human resources, the external support from public agencies (S4.1.1) enhances the suppliers' involvement in collective action (Lubell et al., 2002; OECD, 2013). In the Oursbellile case, the water supplier considered that there was a lack of technical support that could help them to face the complexity of cooperating with farmers to protect water at the source. Cooperation in the Allier, Virieu and Ammertzwiller cases benefited from public support programs. In Allier, the technical support provided by public agencies at the departmental, regional and water basin levels played a crucial role in the emergence of cooperation. In the Virieu case, a network coordinated by the "département" state agency allowed for information pooling and exchange between water suppliers at the Isère "département" level. Furthermore, five water suppliers, including the SMEAHB, pooled their resources and, with the financial support of the Rhône Méditerranée Corse water agency, hired a full-time facilitator.

The involvement of water suppliers in collective action also depends on their environmental preferences (A8.2.1), i.e., their preferences for the use of preventive approaches to solve diffuse pollution problems (Barraqué and Viavattene, 2009; Hellec et al., 2013). In Allier, the initial reluctance of water suppliers with regard to protecting source water hindered the emergence of cooperation in the context of the "Grenelle" policy. In the Virieu, Oursbellile and Arcier cases, the economic incentive to engage in cooperation with agricultural stakeholders was reinforced by the importance for the drinking water suppliers to protect water at the source. In the case of Ammertzwiller and Val-de-Reuil, the pro-environmental political stance of the elected representatives responsible for the water utilities was an important factor for the initiation of collective action.

4.1.2. Farmers

The type of farming systems (A2.2.1) was found to affect the costs associated with farmers' participation in collective action. Changes in intensive farming systems to protect water quality involve higher costs than those associated with changes in extensive farming systems (Brouwer, 2003; AE Rhône Méditerranée Corse, 2007). The importance of extensive cattle breeding farming systems in the Virieu and Arcier catchments had a positive effect on the involvement of farmers, while the dominance of intensive cereal crop farming in the Allier, Oursbellile and Ammertzwiller catchments was an obstacle to the implementation of actions targeting nonpoint source pollution.

Moreover, market conditions for agricultural products (S5.1) influence the economic benefits and costs associated with changes in farming practices and thus affect farmers' participation in collective action (Bosc and Doussan, 2009; Grolleau and McCann, 2012; OECD, 2013; Barataud et al., 2014a). The presence of economic operators offering outlets for low-input crops or organic products fosters the involvement of farmers in cooperation. In the Allier and Oursbellile contexts, most farmers have supply contracts with agro-industrial cooperatives that include specific requirements on product volumes and quality. The compliance of farmers with these requirements represents a constraint on the adoption of practices in favor of water quality. In contrast, the technical specifications of the Comté and Saint-Marcellin PDO labels limit the use of pesticides and require the use of grass rather than silage for animal fodder. These specifications favored the evolution of farming practices in the Arcier and Virieu catchments. In Val-de-Reuil, the presence of the largest French organic agricultural cooperative facilitated the conversion of cereal producers in the catchment.

Depending on the type of farming system and the market conditions for agricultural products, contract incentives (GS5.1) affect the farmers' adoption of measures targeting nonpoint source pollution (Brouwer, 2003; Lubell, 2004; Grolleau and McCann, 2012). In the Allier and Oursbellile catchments where highly profitable cereal farming is predominant, the financial compensation offered by the EU AES was considered insufficient to cover the costs of contracted measures. As a result, the participation of farmers in AES was low. In contrast, the AES implemented in Arcier to reduce the use of phytosanitary products were evaluated as attractive enough in the local farming context. In Virieu and Val-de-Reuil, the benefits linked to land exchanges and environmental land leases were considered by the farmers to be superior to the associated constraints. In the Ammertzviller case, the financial compensation and the guaranteed outlet offered by the water supplier for growing miscanthus covered the costs borne by farmers. Some of them considered that although net economic benefits could not be expected from their participation in the cooperative agreement, their willingness to contribute to water quality restoration reinforced the contract incentives.

Indeed, the participation of farmers appeared to also be driven by their attitudes towards environmental protection (environmental preferences) (A8.2.2), particularly towards water source protection (Lubell et al., 2002; Brouwer, 2003; Grolleau and Mc Cann, 2012). In the Allier and Oursbellile cases, the low concern of farmers for environmental protection limited their participation in collective action. In Virieu, Arcier and Ammertzwiller, the involvement of farmers was favored by their stronger sensitivity to protecting the water at the source. In Virieu and Ammertzviller, the agri-environmental programs that had been previously implemented in the catchments contributed to the development of attitudes in favor of environmental protection. In the Arcier catchment, the environmental awareness of Comté cheese producers has been increased by the technical specifications of the PDO label, which include limitations on pesticide use.

Table 6: Factors identified as fostering/constraining collective action

First-tier variable	Second-tier, third-tier and fourth-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems		
	S4.1 – Larger scale governance systems		
	S4.1.1 – External support from public agencies	External support from public agencies decreases costs	+
	S4.1.2 – Regulatory threat	A regulatory threat increases benefits The absence of a regulatory threat decreases transaction costs	Inconclusive
	S5 – Markets		
	S5.1 – Market conditions for agricultural products	Favorable market conditions for low-input/organic products increase benefits	+
Resource system (S)	RS3 – Size of resource system *		
	RS3.1 – Size of the water catchment	A large water catchment increases transaction costs	-
	RS5 – Productivity of system *		
	RS5.1 – Level of water contamination	High levels of water contamination increase benefits and transaction costs	-/+
	RS7 – Predictability of system dynamics *	A high predictability of system dynamics decreases transaction costs	+
Governance system (GS)	GS5 – Operational rules		
	GS5.1 – Contract incentives	An adequate financial compensation decreases costs	+
	GS6 – Collective-choice rules *		
	GS6.1 – Autonomy at the collective-choice level	The autonomy of local stakeholders increases benefits and transaction costs	-/+
	GS8 – Monitoring and sanctioning rules		
	GS8.1 – Contract enforcement	The implementation of a control system of farming practices decreases transaction costs	+

* Variables identified as crucial for self-organization by users of a common-pool resource (Ostrom, 2009)

Table 7: Factors identified as fostering/constraining collective action

First-tier variable	Second-tier, third-tier and fourth-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action
Actors (A)	A1 – Number of relevant actors *		
	A1.1 - Number of farmers	A large number of farmers increases transaction costs	-
	A2 – Socioeconomic attributes		
	A2.1 – Resources available to water suppliers	A high level of resources available to water suppliers decreases costs	+
	A2.2 – Farming systems		
	A2.2.1 – Type of farming systems	Intensive farming systems in the catchment increase costs	-
	A2.2.2 – Heterogeneity of farming systems	The heterogeneity of farming systems affects benefits and transaction costs, depending on the type of farming systems and the type of cooperation	-/+
	A5 – Leadership-entrepreneurship *		
	A5.1 - Leadership in the farming community	The involvement of local farm leaders decreases transaction costs	+
	A6 – Norms (trust-reciprocity)/social capital *	Shared norms of reciprocity/trust between water suppliers and agricultural stakeholders decrease transaction costs	+
	A7 – Knowledge of SES *	Shared knowledge of the hydrogeological system decreases transaction costs	+
	A8 – Importance of the resource *		
	A8.1 – Economic importance of the resource		
	A8.1.1 – Economic importance of the resource for water suppliers	High costs of using alternative approaches to enhance drinking water quality increase benefits	+
	A8.2 – Environmental preferences of stakeholders		
	A8.2.1 – Environmental preferences of water suppliers	A high level of preferences for the protection of water at the source increases benefits	+
	A8.2.2 – Environmental preferences of farmers	A high level of preferences for the protection of water at the source increases benefits	+

* Variables identified as crucial for self-organization by users of a common-pool resource (Ostrom, 2009)

The level of water contamination (RS5.1) by nitrates and/or pesticides also plays an important role in the stakeholders' incentives to cooperate in drinking water catchment protection (Lubell et al., 2002; Bosc and Doussan, 2009). In the case of the Oursbelille, Virieu and Ammertzwiller catchments, the regular peaks of pollutant rates above regulatory standards stimulated the involvement of both the water supplier and agricultural stakeholders in collective action because of the threat of application of regulatory measures. However, the moderate level of water pollution in the Allier and Arcier cases was identified as a positive factor that allowed cooperation to develop over a longer time frame. The case of the Val-de-Reuil catchment illustrates a situation where the absence of water pollution constitutes an impediment to the agricultural stakeholders' involvement (Garin and Barraqué, 2012). The good quality of the water resource appeared to be an obstacle to the participation of some farmers who questioned the legitimacy of undertaking costly changes in their farming practices in the absence of any observed pollution.

The presence of a regulatory threat (S4.1.2) was not found to have a clear-cut effect on farmers' participation in collective action, a finding that differs from previous studies (Abildtrup et al., 2012; Grolleau and McCann, 2012). In the Virieu catchment, the use of the ZSCE procedure as a complement to the "Grenelle" catchment protection enhanced the willingness of farmers to cooperate. In the Ammertzwiller and Oursbellile cases, the threat of activating the ZSCE tool if water quality further deteriorated beyond the regulatory standards was also effective in fostering the farmers' voluntary involvement. However, the choice of not resorting to the ZSCE regulatory threat in the Allier and Arcier cases was perceived as favorable to collective action, as it limited the costs of a potential confrontation with farmers.

4.2. The factors affecting the transaction costs of collective action

The hydrogeological systems differ in terms of the complexity of their dynamics and response time to measures targeting diffuse pollution. The predictability of resource system dynamics (RS7) affects the costs of defining actions and assessing their impact on water quality (Brouwer, 2003; AE Rhône Méditerranée Corse, 2007; Grolleau and McCann, 2012). In the Virieu, Arcier and Oursbellile cases, the complex dynamics and the low reactivity of the aquifers increased the level of uncertainty about the impact of the measures implemented to protect the catchment. Moreover, in Oursbellile, the absence of visible effects of actions on water quality reduced the farmers' motivation to participate, as noted in other studies (Grolleau and McCann, 2012). In contrast, the short response time of the aquifers in Allier and Val-de-Reuil reduced the costs of defining and assessing the impact of actions on water quality. In Ammertzwiller, the high level of predictability of the hydrogeological system dynamics enhanced the involvement of farmers in collective action.

The availability of scientific or expert knowledge (A7) regarding the hydrogeological system and the interactions between anthropogenic activities and water quality affects the capacity of stakeholders to identify pollution sources, the areas to target in the catchment and the relevant actions for limiting nonpoint source pollution (AE Rhône Méditerranée Corse, 2007). In the Oursbellile case, the lack of scientific knowledge regarding the alluvial aquifer increased the costs for defining the actions. Moreover, this lack of knowledge led to a controversy about the farming versus nonfarming source of water pollution, hindering the farmers' involvement in collective action. In contrast, the use of hydrogeological surveys and pollution source assessments in the Arcier, Ammertzwiller and Val-de-Reuil cases facilitated the identification of measures to be implemented. Moreover, sharing the results of these studies with farmers improved their own understanding of the impact of farming practices on water quality, thereby reducing the information collection and processing costs associated with their participation in collective action.

The size of the water catchment (RS3.1) was found to affect the development of collective action (Brouwer, 2003; Barraqué and Viavattene, 2009; Bosc and Doussan, 2009; Barataud et al., 2014b). In relation to the number of farms (A1.1), a larger catchment means higher transaction costs for defining and implementing action programs. The large catchment area in Allier and Arcier increased the information costs for defining the actions because of the large number of farms. In the case of Virieu, Oursbellile, Ammertzwiller and Val-de-Reuil, the small size of the catchments limited the negotiation and enforcement costs of agreements.

Several studies suggest that the heterogeneity of farming systems (A2.2.2) increases the costs of defining and negotiating the measures for controlling diffuse pollution (Grolleau and McCann, 2012; OECD, 2013). Indeed, the homogeneity of the farming systems in Allier and Oursbellile was identified as limiting the costs associated with the definition of actions. However, in the Oursbellile case, the similar orientation of production systems towards intensive corn farming was also perceived as a constraint on the evolution of farm practices due to the higher costs of developing alternative farming techniques and systems within the catchment. Furthermore, the heterogeneity of cattle breeding systems in Virieu appeared to be a factor that enhanced the collaborative land exchange process. The complementarities between the preferences of dairy and meat farms for arable parcels and grassland allowed for the transfer of grassland within the boundaries of the catchment.

The analysis highlights the role of trust and social capital (A6) in lowering the costs of reaching agreements and the costs of monitoring and enforcing these agreements (Lubell et al., 2002; Brouwer, 2003; Lubell, 2004; Lehmann et al., 2009). Pre-existing links between water suppliers and agricultural stakeholders were found to enhance cooperation. These links may have developed through local social interactions (Barraqué and Viavattene, 2009). In Virieu and Ammertzwiller, the involvement of some farmers in the municipal council was the basis for the development of trust and norms of reciprocity between the farming community and the public water supplier. In contrast, in the Arcier case, the distance between the city of Besançon and the protected watershed initially acted as an obstacle to cooperation. The previous implementation of water quality programs involving farmers and water suppliers also fosters cooperation (Barataud et al., 2014b). In the Ammertzwiller case, the voluntary Agri-Mieux operations implemented in the region since 1997 led to the development of links between the water supplier and agricultural stakeholders. In Allier and Val-de-Reuil, the absence of previous interactions between water suppliers and farmers was identified as a constraint for the development of collective action.

The involvement of farming community leaders in collective action (A5.1) was also found to foster farmer participation (Barraqué and Viavattene, 2009). In the Virieu, Oursbellile and Val-de-Reuil catchments, well-respected producers acted as intermediaries between the institutional stakeholders and farmers, thereby limiting the information collection costs for both parties. Similarly, the participation of agricultural representatives in drinking water catchment protection positively impacted cooperation in the Arcier case. In particular, the participation of a farmer, who was also an elected representative on the Agricultural Chamber board and a vice-president of the main agricultural cooperative in the area, had a positive effect on farmers' participation in collective action.

The greater autonomy in contract design (GS6.1) associated with contracts established between water suppliers and farmers (environmental land leases and purchase contracts) appeared to have a positive effect on cooperation by allowing for a better adaptation of incentives to the local farming and environmental context (Lehmann et al., 2009; AE Adour-Garonne, 2012). In the Allier and Oursbellile cases, the lower autonomy of the local stakeholders in designing EU AES contracts was a constraint on the match between the measures and compensation and the characteristics of the local context. In contrast, the negotiation of contract terms with farmers in Virieu, Ammertzwiller and Val-de-Reuil was identified as crucial for considering the specificities of local farming systems. However, greater autonomy in contract design comes with higher transaction costs (Abildtrup et al., 2012). In the corresponding cases, the small number of farmers and/or the pre-existing trust between the water suppliers and agricultural stakeholders limited the costs for defining and negotiating contract terms.

The implementation of a control system of farming practices (GS8.1) limits the risk of opportunistic behavior of farmers (AE Rhône Méditerranée Corse, 2007; Abildtrup et al., 2012; Grolleau and McCann, 2012). Such a monitoring system was in place and identified as effective in reducing the enforcement costs in Virieu, Oursbellile, Arcier and Ammertzwiller. For the EU AES implemented in the Oursbellile and Arcier cases, the control costs are borne by the national public agency in charge of monitoring the implementation of EU Common Agricultural Policy in France. For contracts established between water suppliers and farmers (environmental land leases, purchase contracts), the water suppliers are responsible for monitoring the farmers' practices. In Virieu, the choice of contracting for the conversion of farmland into grassland reduced the control costs compared to the choice of other measures, such as, for example, a reduction in input use. Similarly, in the Ammertzwiller case, the planting and maintenance of miscanthus only required low-cost visual control by the water supplier. Thus, also noted by Abildtrup et al. (2012) and Grolleau and McCann (2012), the type of measure chosen influences the control and enforcement costs incurred by water suppliers.

5. Discussion and conclusions

The cross-case comparative analysis shows that the effectiveness of collective action involving water suppliers and agricultural stakeholders (farm organizations and farmers) aimed to protect drinking water resources depends on a number of interacting conditions related to (i) the characteristics of the hydrogeological system, (ii) the characteristics of the actors involved, (iii) the governance of cooperation and (iv) the economic and policy context of collective action.

All the factors considered to be crucial for the self-organization of users of a common-pool resource (Ostrom, 2009) (Table 1) were also identified as playing a role in collective action for water quality management in France, with the exception of the resource unit mobility (Table 6-7). The difference between the benefits and costs of water management in the respective cases of surface streams and groundwater has been analyzed in previous research (Schlager et al., 1994), including studies focusing on cooperative agreements for drinking water protection (Brouwer, 2003). The specific impact of the resource unit mobility could not be captured in this research, as the empirical cases selected do not vary along this dimension: all the cooperation processes involve groundwater bodies.

Furthermore, the results highlight the role of other variables in the SES framework as important conditions for successful cooperation to protect drinking water resources. First, the socioeconomic attributes of both drinking water suppliers and farmers were shown to strongly affect the benefits and costs associated with their involvement in collective action. Additionally, market and policy incentives were found to be important in explaining the outcomes of cooperation for the control of diffuse pollution at the catchment level. While the early common-pool resource scholarship has been criticized for overlooking the influence of the policy and market environment on resource management (Agrawal, 2001), several studies have since highlighted the role of market incentives (Delgado-Serrano and Ramos, 2015; Torres-Guevara et al., 2016) and state policies (Mansbridge, 2014) in local collective action for natural resource governance.

In a context where the level of financial and human resources available to drinking water suppliers is limited, their involvement in collective action is dependent on external support from public agencies at higher scales, in the form of funding or technical support. This result is in line with findings from SES studies dealing with community-based drinking water provision (Madrigal et al., 2011; Naiga et al., 2015).

For farmers, the benefits and costs associated with collective action depend on the interactions among the type of farming system, the market conditions for agricultural products and the economic incentives provided by contracts. In particular, the match between the incentives provided by contracts and the characteristics of local farming and agro-food systems proves to be crucial for encouraging farmers' participation. Autonomy in contract design enhances the ability to adapt measures to the local agro-food context. While the EU AES have evolved towards greater decentralization and the involvement of local stakeholders, their implementation in the French context is still considered to be constrained by a lack of flexibility in contract design, leading to reduced environmental impacts (ECA, 2011; Kufhuss et al., 2012). Enhancing the local stakeholders' autonomy to adapt the measures and compensation to the local context could improve the effectiveness of cooperation to the extent that higher transaction costs, which may be prohibitive in large water catchments and/or in situations where water suppliers lack the necessary resources, are addressed through adequate public support.

In addition to economic costs and benefits, the participation of water suppliers and farmers in collective action appears to be driven by their environmental preferences and more particularly their concern for the preservation of the water resource. Recent SES studies have emphasized the need for taking into account noneconomic values in the analysis of decision-making processes for resource management (Basurto et al., 2013; Villamayor-Tomas et al., 2014; Delgado-Serrano and Ramos, 2015; Partelow and Winkler, 2016). In the agri-environmental field, many studies have shown that farmers' attitudes towards environmental protection affect their participation in conservation programs (Giovanopoulou et al., 2011; Lastra-Bravo et al., 2015). Our results highlight the importance of strengthening information and advisory policies to modify the stakeholders' attitudes towards environmental protection, as a complementary tool to regulatory and economic incentives (Blackstock et al., 2010; Mills et al., 2018).

The results corroborate the insights provided by the literature on cooperative agreements for drinking water management (Lehmann et al., 2009; Abildtrup et al., 2012; Grolleau and McCann, 2012). However, two variables deserving additional investigation are highlighted by the analysis.

First, the analysis qualifies the findings of previous studies in which the heterogeneity of farming systems was shown to increase the transaction costs of drinking water catchment protection (Grolleau and McCann, 2012; OECD, 2013). In line with the broader common-pool resource literature (Agrawal and Gibson, 1999; Poteete and Ostrom, 2004), the results suggest that heterogeneity in farming systems may also play a positive role in collective action. While the homogeneity of farm types reduces the costs of defining actions, it increases costs related to the diffusion of alternative farming techniques/systems in settings where intensive farming systems dominate. Furthermore, some forms of cooperation may benefit from complementarities between heterogeneous farming systems, as illustrated by the collaborative land exchange process in the Virieu case. Thus, the impact of the diversity of farming systems on collective action involves trade-offs between benefits and transaction costs, which are contingent upon the type of farming systems and cooperation. These trade-offs would need to be disentangled in future research.

Second, the results suggest that the impact of a regulatory threat on voluntary cooperation is not straightforward. Resorting to the ZSCE tool or the threat of activating this procedure induced farmers' cooperation in situations where the level of water contamination was critical in terms of regulatory standards (Virieu, Ammertzwiller, Oursbellile). In contrast, the absence of a regulatory threat positively affected farmers' participation in collective action in settings where water contamination was considered to be moderate (Allier, Arcier). The positive effect of a regulatory threat, stressed in previous studies on drinking water management (Abildtrup et al., 2012; Grolleau and McCann, 2012) as well as in the broader literature about common-pool resource management (e.g., Mansbridge, 2014), may depend on its legitimacy, from the agricultural stakeholders' perspective, in relation to the level of water degradation. This hypothesis calls for future research. Understanding the conditions under which regulatory tools provide (dis)incentives for voluntary collective action would contribute to the design of efficient combinations of policy options.

Combining transaction cost economics and the SES framework proved to be useful for explaining the outcomes of collective action for drinking water catchment protection in France. While transaction cost theory was instrumental in the characterization of causal links between SES variables and collective action, the SES framework provided a structure for collecting and analyzing data across the cases (Partelow, 2018).

The case study approach adopted in this research allowed for the identification of factors impacting benefits and costs, including transaction costs, which accrue to stakeholders at different stages of the cooperation process. Furthermore, the in-depth qualitative approach used in this study highlighted the interdependencies among the variables affecting collective action (Poteete et al., 2010). However, the results, which were obtained on the basis of a small purposive sample of cases of cooperation, cannot be considered as representative, in a statistical sense, of drinking water catchment protection processes in the French context. In future research, the identified factors could serve as theoretically and empirically informed assumptions to be tested on a larger sample of cases. Furthermore, analyzing cases of collective action in other countries, both inside and outside the EU, would provide insights into the role of factors related to the EU and national institutional contexts.

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Appendix A: Second-tier variables of a social-ecological system (McGinnis and Ostrom, 2014)

First-tier variable	Second-tier variables
Social, economic and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (S)	RS1 – Sector (e.g., water, forests, pasture, fish)
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	GS1 – Government organizations
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules
Resource units (RU)	RU1 – Resource unit mobility
	RU2 – Growth or replacement rate
	RU3 – Interaction among resource units
	RU4 – Economic value
	RU5 – Number of units
	RU6 – Distinctive characteristics
	RU7 – Spatial and temporal distribution
Actors (A)	A1 – Number of relevant actors
	A2 – Socioeconomic attributes
	A3 – History or past experiences
	A4 – Location
	A5 – Leadership-entrepreneurship
	A6 – Norms (trust-reciprocity)/social capital
	A7 – Knowledge of SES
	A8 – Importance of the resource (dependence)
	A9 – Technologies available
Action situation: Interactions (I) - Outcomes (O)	I1 – Harvesting
	I2 – Information sharing
	I3 – Deliberation processes
	I4 – Conflicts
	I5 – Investment activities
	I6 – Lobbying activities
	I7 – Self-organizing activities
	I8 – Networking activities
	I9 – Monitoring activities
	I10 – Evaluative activities
	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)
	O3 – Externalities to other SESs
Related ecosystems (ECO)	ECO1 – Climate patterns
	ECO2 – Pollution patterns
	ECO3 – Flows into and out of focal SES

Appendix B: Interviews conducted at the national and river-basin levels in 2013

At the river-basin level, the representatives from five water agencies were interviewed (representing five river basins on the six covering the French metropolitan territory). Water agencies are in charge of the implementation of watershed management plans for reaching the objectives set by the EU Water Framework Directive. Under the framework of multiyear intervention programs, they levy fees on water uses and provide financial incentives to public and private stakeholders for sustainable water management. More particularly, water agencies provide financial and technical support to local stakeholders engaging in cooperation for protecting drinking water catchments from nonpoint source pollution.

At the national level, the interviews conducted with representatives of the Ministries of the Environment and Agriculture allowed for a better understanding of the regulatory and policy context framing collective action at the drinking water catchment level.

The perspective of agricultural stakeholders was comprehended through interviews held with representatives of the national network of Agricultural Chambers, the national federation of organic farmers' groups and the think tank "Saf agr'iDées". The Agricultural Chambers (regional and departmental public organizations led by representatives of agricultural and other rural stakeholders) and the organic farmers' groups (regional and departmental associations supporting the development of organic farming) are the main agricultural organizations involved locally in collective action for drinking water quality management. The think tank "Saf agr'iDées" is devoted to the study and debate of evolutions in the agricultural and agro-industrial sectors.

Finally, interviews were conducted with the two main French private water operators in order to characterize their involvement in local collective action.

Table B.1: List of interviews conducted in 2013 at the national and river-basin levels

Organization	Interviewee	Field of expertise	Type of interview	Date/Location	Duration
Water agencies					
Seine-Normandie	Project coordinator	Agriculture-related water issues	Face-to face	5/17/2013 Nanterre	2:21
Adour-Garonne	Project coordinator	Agriculture-related water issues	Phone	7/16/2013	1:15
Rhône Méditerranée Corse	Project coordinator	Pesticide management	Face-to-face	7/15/2013 Lyon	1:43
	Project coordinator	Drinking water management			
Rhin-Meuse	Head of department	Natural and rural areas	Phone	7/18/2013	2:00
Loire-Bretagne	Head of department	Agriculture and territorial water governance	Face-to-face	10/15/2013 Orléans	2:20
Ministries					
Ministry responsible for the environment	Policy officer	Agriculture and the Water Framework Directive	Face-to-face	6/7/2013 Paris	1:15
Ministry responsible for agriculture	Policy officer	Agri-environmental management	Face-to-face	11/8/2013 Paris	1:07
Agricultural organizations					
National network of Agricultural Chambers (APCA)	Project coordinator	Water management	Face-to-face	5/27/2013 Paris	1:47
National federation of organic agriculture (FNAB)	Project coordinator	Water management	Face-to-face	10/14/2013 Paris	2:56
Think tank Saf agr'iDées	Project coordinator	Environment	Phone	10/21/2013	1:43
Private water operators					
Suez Environnement	Project coordinator	Environmental engineering	Face-to-face	11/8/2013 Paris	1:00
Veolia Eau	Project coordinator	Sustainable development partnerships	Face-to-face	11/12/2013 Paris	1:05

Appendix C: List of variables identified as likely to affect collective action for drinking water catchment protection in France (Step 1)

Table C.1: The characteristics of the resource

First-tier variable	Second-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action	References
Resource system (RS)	RS3 – Size of resource system			
	RS3.1 – Size of the water catchment	A large water catchment increases transaction costs	-	Brouwer, 2003 Barraqué and Viavattene, 2009 Bosc and Doussan, 2009 Barataud et al., 2014b
	RS5 – Productivity of system			
	RS5.1 – Level of water contamination	High levels of water contamination increase benefits	+	Lubell et al., 2002 Bosc and Doussan, 2009 Garin and Barraqué, 2012
	RS7 – Predictability of system dynamics	A high predictability of system dynamics decreases transaction costs	+	Brouwer, 2003 AE Rhône Méditerranée Corse, 2007 Grolleau and McCann, 2012
Resource units (RU)	RU1 – Resource unit mobility	Mobile units increase transaction costs	-	Brouwer, 2003

Table C.2: The characteristics of the actors

First-tier variable	Second-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action	References
Actors (A)	A1 – Number of relevant actors			
	A1.1 - Number of farmers	A large number of farmers increases transaction costs	-	Brouwer, 2003 Bosc and Doussan, 2009
	A2 – Socioeconomic attributes			
	A2.1 – Resources available to water suppliers	A high level of resources available to water suppliers decreases costs	+	Brouwer, 2003 Becerra and Roussary, 2008 Barraqué and Viavattene, 2009
	A2.2 – Farming systems			
	A2.2.1 – Type of farming systems	Intensive farming systems in the catchment increase costs	-	Brouwer, 2003 AE Rhône Méditerranée Corse, 2007
	A2.2.2 – Heterogeneity of farming systems	The heterogeneity of farming systems increases transaction costs	-	Grolleau and McCann, 2012 OECD, 2013
	A5 – Leadership-entrepreneurship			
	A5.1 - Leadership in the farming community	The involvement of local farm leaders decreases transaction costs	+	Barraqué and Viavattene, 2009
	A6 – Norms (trust-reciprocity)/social capital	Shared norms of reciprocity/trust between water suppliers and agricultural stakeholders decrease transaction costs	+	Lubell et al., 2002; Brouwer, 2003 Lubell, 2004; Lehmann et al., 2009 Barraqué and Viavattene, 2009; Barataud et al., 2014b
	A7 – Knowledge of SES	Shared knowledge of the hydrogeological system decreases transaction costs	+	AE Rhône Méditerranée Corse, 2007
	A8 – Importance of the resource			
	A8.1 – Economic importance of the resource			
	A8.1.1 – Economic importance of the resource for water suppliers	High costs of using alternative approaches to enhance drinking water quality increase benefits	+	Bosc and Doussan, 2009 Abildtrup et al., 2012 Grolleau and McCann, 2012
	A8.2 – Environmental preferences of stakeholders			
	A8.2.1 – Environmental preferences of water suppliers	A high level of preferences for the protection of water at source increases benefits	+	Barraqué and Viavattene, 2009 Hellec et al., 2013
	A8.2.2 – Environmental preferences of farmers	A high level of preferences for the protection of water at source increases benefits	+	Lubell et al., 2002 Brouwer, 2003 Grolleau and McCann, 2012

Table C.3: The characteristics of the governance system

First-tier variable	Second-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action	References
Governance system (GS)	GS5 – Operational rules			
	GS5.1 – Contract incentives	An adequate financial compensation decreases costs	+	Brouwer, 2003 Lubell, 2004 AE Adour-Garonne, 2012 Grolleau and McCann, 2012
	GS6 – Collective-choice rules			
	GS6.1 – Autonomy at the collective-choice level	The autonomy of local stakeholders increases benefits and transaction costs	-/+	Lehmann et al., 2009 Abildtrup et al., 2012 AE Adour-Garonne, 2012
	GS8 – Monitoring and sanctioning rules			
	GS8.1 – Contract enforcement	The implementation of a control system of farming practices decreases transaction costs	+	AE Rhône Méditerranée Corse, 2007 Abildtrup et al., 2012 Grolleau and McCann, 2012

Table C.4: The characteristics of the social, economic and political settings

First-tier variable	Second-tier variables	Impact on the benefits/costs and transaction costs of collective action	Impact on collective action	References
Social, economic and political settings (S)	S4 – Other governance systems *S4.1 – Larger scale governance systems*			
	S4.1.1 – External support from public agencies	External support from public agencies decreases costs	+	Lubell et al., 2002 AE Rhône Méditerranée Corse, 2007 OECD, 2013
	S4.1.2 – Regulatory threat	A regulatory threat increases benefits	+	Albidtrup et al., 2012 Grolleau and McCann, 2012
	S5 – Markets			
	S5.1 – Market conditions for agricultural products	Favorable market conditions for low-input/organic products increase benefits	+	Bosc and Doussan, 2009 Grolleau and McCann, 2012 OECD, 2013 Barataud et al., 2014a

Appendix D: List of interviews conducted at the local level in 2014

Table D.1: Interviews conducted – Allier and Virieu cases

Type of organization	Organization	Interviewee	Date/location	Duration
Allier				
Water supplier	Syndicat Mixte des Eaux de l'Allier (SMEA)	Facilitator for the non-agricultural action plan	1/30/2014 Yzeure	01:30
Agricultural Chamber	Chambre d'agriculture de l'Allier	Facilitator for the agricultural action plan	1/13/2014 Saint Pourçain sur Sioule	01:17
Territorial state administration	Direction Départementale des Territoires de l'Allier (DDT Allier)	Head of the Environment Department	1/14/2014 Yzeure	01:12
Regional environmental state administration	Direction Régionale de l'Environnement, de l'Aménagement et du Logement - Auvergne (DREAL Auvergne)	Head of the Water and Biodiversity Department	1/23/2014 Clermont-Ferrand	02:08
Regional agricultural state administration	Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt – Auvergne (DRAAF Auvergne)	Head of the Agriculture and Environment Department	1/23/2014 Lempdes	01:10
Local office of the Loire-Bretagne water agency	Délégation Allier-Loire amont de l'Agence de l'eau Loire-Bretagne	Project coordinator - Agriculture	1/30/2014 Lempdes	02:15
Farmer			1/30/2014 Marcenat	0:55
Virieu				
Water supplier	Syndicat Mixte d'Eau et d'Assainissement de la Haute-Bourbre (SMEAHB)	Director of the water utility	3/24/2014 Le Passage	02:12
Watershed management board	Syndicat Mixte d'Aménagement du Bassin de la Bourbre (SMABB)	Project coordinator – Agriculture and water	3/27/2014 La Tour du Pin	02:09
Agricultural Chamber	Chambre d'agriculture de l'Isère	Head of the Agro-environment Department	3/24/2014 Grenoble	02:00
Rural land Agency Rhône-Alpes	Société d'aménagement foncier et d'établissement rural Rhône-Alpes (Safer Rhône-Alpes)	Director of the agency	3/25/2014 Grenoble	01:17
Farmer			3/26/2014 Virieu-sur-Bourbre	01:05
Farmer			3/26/2014 Blandin	01:30

Table D.2: Interviews conducted – Oursbellile and Arcier cases

Type of organization	Organization	Interviewee	Date/location	Duration
Oursbellile				
Water supplier	Syndicat Intercommunal d'Alimentation en Eau Potable Tarbes-Nord (SIAEP Tarbes-Nord)	President of the water utility board	7/2/2014 Andrest	1:46
Private water operator	Veolia Eau	Coordinator of drinking water protection	7/4/2014 Laloubere	1:10
Agricultural Chamber	Chambre d'agriculture des Hautes-Pyrénées	Facilitator for agricultural action plan	7/1/2014 Vic En Bigorre	1:43
Local office of the Adour-Garonne water agency	Délégation de Pau de l'Agence de l'eau Adour-Garonne	Project coordinator	7/3/2014 Pau	2:00
Farmer			7/2/2014 Oursbelille	1:29
Farmer			7/3/2014 Oursbelille	1:27
Arcier				
Water supplier	Ville de Besançon	Head of the water services department	9/3/2014 Besançon	1:39
Natural area management board	Syndicat Mixte du Marais de Saône (SMMS)	Project coordinator	9/2/2014 La Veze	1:29
Agricultural Chamber	Chambre d'agriculture du Doubs	Extension agent	9/4/2014 Besançon	1:13
Agricultural cooperative	Coopérative Terre-Comtoise	Technical adviser	9/4/2014 Saône	1:05
Farmer			9/2/2014 Saône	0:54
Farmer			9/3/2014 Le Grasterris	1:24

Table D.3: Interviews conducted – Ammertzwiller and Val-de-Reuil cases

Type of organization	Organization	Interviewee	Date/location	Duration
Ammertzwiller				
Water supplier	Syndicat Intercommunal d'Alimentation en Eau Potable d'Ammertzwiller et environs (SIAEP)	President of the water utility board (also a farmer and mayor of Ammertzwiller)	4/14/2014 Ammertzwiller	02:10
Agricultural Chamber	Chambre d'agriculture du Haut-Rhin	Project coordinator – Environment and innovation	4/15/2014 Sainte-Croix-en-Plaine	01:52
Local office of the Rhin-Meuse Water Agency	Service territorial « Rhin supérieur et Ill » de l'Agence de l'eau Loire-Bretagne	Project coordinator – Water and agriculture	4/17/2014 Rozérieulles	01:35
Farmer			4/16/2014 Ballschwiller	00:59
Farmer			4/16/2014 Ballschwiller	00:58
Val-de-Reuil				
Water supplier	Communauté d'Agglomération Seine et Eure (CASE)	Head of the water services department	5/23/2014 Louviers	01:30
Regional group of organic farmers	Groupement Régional d'Agriculteurs Biologiques de Basse-Normandie	Project coordinator – Water and territory	5/22/2014 Bois Guillaume	01:36
Organic supply chain association	Interbio Normandie	Project coordinator – Organic food systems	5/21/2014 Bois Guillaume	01:32
Local office of the Seine-Normandie water agency	Direction territoriale "Seine-Aval" de l'Agence de l'eau Loire-Bretagne	Project coordinator – Agriculture and aquatic environment	5/22/2014 Louviers	01:23
Farmer			5/21/2014 Val-de-Reuil	01:19
Farmer			5/22/2014 Val-de-Reuil	01:03

Appendix E: Indicators, data and criteria for the assessment of the variables in case studies

Table E.1: The characteristics of the resource system

Variable	Definition	Indicator	Data type	Criteria for variable assessment	
Size of the water catchment (RS3.1)	Size of the water catchment	Drinking water catchment area (ha)	Quantitative	Area <1300 ha*	Small
				Area > 1300 ha * Median size of priority drinking water catchments in France (Barataud et al., 2014b)	Large
Level of water contamination (RS5.1)	Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Quantitative	Pollutant rates below regulatory standards (Nitrates: 50 mg/l; Pesticides: 0,1 µg/l)	Low
				Pollutant rates below regulatory standards with an increasing trend	Moderate
				Pollutant rates beyond regulatory standards	High
Predictability of system dynamics (RS7)	Degree to which stakeholders are able to assess the impact of farming practices on water quality	Hydrogeological system's response time to measures targeting diffuse pollution	Qualitative	Short	High
				Long	Low

Table E.2a: The characteristics of the actors

Variable	Definition	Indicator	Data type	Criteria for variable assessment	
Number of farmers (A1.1)	Number of farmers with land in the drinking water catchment	Number of farmers with land in the drinking water catchment	Quantitative	Number <45 *	Small
				Number >45 *Median number of farmers in priority drinking water catchments in France (Barataud et al., 2014b)	Large
Resources available to water suppliers (A2.1)	Financial and human resources available to water suppliers	Budget devoted to catchment protection (€)	Quantitative	Small/moderate/large	
		Skills-preventive approaches to water pollution control	Qualitative		
Type of farming systems (A2.2.1)	Dominance of intensive/extensive farming systems	Share of grassland in agricultural area in the catchment	Quantitative	Share of grassland <50%	Intensive
				Share of grassland >50%	Extensive
Heterogeneity of farming systems (A2.2.2)	Diversity of types of farming systems in the catchment area	Number of different types of farming systems	Quantitative	1	Low
				2	Moderate
				> 2	High
Leadership in the farming community (A5.1)	Involvement of "farm leaders" in collective action	Involvement of "farm leaders" in collective action	Qualitative	No/Yes	

Table E.2b: The characteristics of the actors

Variable	Definition	Indicator	Data type	Criteria for variable assessment	
Norms (trust-reciprocity)/social capital (A6)	Existence of trust/norms of reciprocity between drinking water suppliers and farmers	Pre-existing links between water suppliers and farmers	Qualitative	No	Absent
				Yes	Present
Knowledge of SES (A7)	Shared knowledge of hydrological system dynamics	Existence of hydrogeological studies/pollution source assessments	Qualitative	No	Lacking
				Yes	Available
Economic importance of the resource for water suppliers (A8.1)	Cost of alternative approaches to water catchment protection	Access to palliative/curative options	Qualitative	Yes	Low
				No	High
Environmental preferences of water suppliers (A8.2.1)	Level of concern for the protection of water at source	Level of concern for the protection of water at source	Qualitative	Low/high	
Environmental preferences of farmers (A8.2.2)	Level of concern for the protection of water at source	Previous implementation of agri-environmental programs	Qualitative	No/yes	No/no: low No/yes: high Yes/no: high Yes/yes: high
		Previous involvement in eco-friendly supply chains	Qualitative	No/yes	

Table E.3: The characteristics of the governance system

Variable	Definition	Indicator	Data type	Criteria for variable assessment	
Contract incentives (GS5.1)	Match between compensation and costs of changing farming practices	Perception of a match between compensation and costs of changing farming practices	Qualitative	No match	No
				Partial match	Partly
				Match	Yes
Autonomy at the collective-choice level (GS6.1)	Autonomy in contract design	Type of contract	Qualitative	EU Agri-Environmental Schemes (AES)	Low
				Environmental land leases/supply contracts	High
Contract enforcement (GS8.1)	Procedures for limiting the risk of opportunistic behavior by farmers	Implementation of a system for monitoring farming practices	Qualitative	Absence/presence	

Table E.4: The characteristics of the social, economic and political settings

Variable	Definition	Indicator	Data type	Criteria for variable assessment
External support from public agencies (S4.1.1)	Existence of financial/technical support from public agencies at a higher level	Share of total cost funded by public agencies	Quantitative	No financial support and no technical support: Absent Financial or technical support: Present
		Existence of a technical support program at higher levels	Qualitative	
Regulatory threat (S4.1.2)	Perspective of application of regulatory measures in case of collective action failure	Use of the ZSCE procedure or threat of activating it	Qualitative	No/Yes
Market conditions for agricultural products (S5.1)	Presence of eco-friendly agro-food supply chains	Presence of agro-food operators offering outlets for low-input/organic products	Qualitative	Absence/Presence

Appendix F: Individual case studies

1. The case of Allier

1.1. Description

In the **Allier** case, ten drinking water catchments were classified as "Grenelle priority catchments" in 2009 because of increasing nitrate and pesticide rates. Approximately 120 mixed crop and livestock farms have all or part of their agricultural area in the large protection zone (8300 ha) (SMEA, 2013). Drinking water catchment protection relies on the cooperation between the Syndicat Mixte des Eaux de l'Allier (SMEA), representing the six intermunicipal water suppliers managing the catchments, and the departmental Agricultural Chamber. Collective action led to the establishment of an action plan in 2014. In addition to a free technical support program, EU Agri-Environmental Schemes (AES) were implemented. In 2015, a total of 71 farmers were involved in the support program, while only three farmers adopted agri-environmental measures, which covered 60 ha in the protection zone (SMEA, 2015). Water quality did not improve and deteriorated in some catchments.

1.2. The factors identified as fostering/constraining collective action

1.2.1. The characteristics of the resource system

The large size of the protection zone (RS3.1) increased the definition and implementation costs of the action plan, as there were a large number of farms located in the area (A1.1). The short response time of the alluvial aquifers (RS7) limited the costs of assessing the impact of changes in farming practices and the costs of adapting actions. The moderate level of water contamination (RS5.1) was found to facilitate collective action, as the stakeholders had more time to define actions.

1.2.2. The characteristics of the actors

1.2.2.1. Water suppliers

The low-cost access to resource blending through network interconnections (A8.1) increased the opportunity costs for water suppliers to engage in cooperation with agricultural stakeholders for limiting nonpoint source pollution. As drinking water quality was managed until then based on this palliative strategy, the involvement of the drinking water suppliers in collective action was further limited by their low concern for the protection of water at the source (A8.2.1) and their lack of skills regarding preventive approaches to water pollution control (A2.1).

1.2.2.2. Agricultural stakeholders

Despite the large number of farmers, the homogeneity of the farming systems in the Allier catchment (A2.2.2) limited the costs of defining actions. However, the dominance of intensive farming in the catchment (A2.2.1) acted as a constraint on the participation of farmers in collective action because of the high costs associated with changes in such farming systems. Furthermore, the low concern of farmers for environmental protection (A8.2.2) limited their involvement.

1.2.2.3. Norms (trust-reciprocity)/social capital

In the absence of pre-existing interactions between drinking water suppliers and agricultural stakeholders, the lack of trust and norms of reciprocity among stakeholders (A6) acted as a barrier to collective action.

1.2.3. The characteristics of the governance system

The measures implemented through the EU Agri-Environmental Schemes (AES) were considered insufficiently adapted to the characteristics of the farming systems in the area. The financial compensation involved was more particularly evaluated as not covering the costs associated with changes in farming practices (GS5.1). As a result, farmers' participation in AES was limited. The low level of autonomy of the local stakeholders in designing contracts in the framework of the EU AES (GS6.1) was identified as a constraint to adapting the measures and compensation to the characteristics of the local agricultural context.

1.2.4. The characteristics of the social, economic and political settings

In a context where the drinking water suppliers did not hold any skills or previous experience regarding water catchment protection, the technical support provided by public agencies at the departmental, regional and water basin levels (S4.1.1) played a crucial role in the emergence of cooperation. Furthermore, the public financial aids granted (59% of the total cost of the program between 2014 and 2018) (SMEA, 2013) allowed, among other actions, the hiring of an agricultural technical advisor to facilitate interactions with the farmers. The choice of not resorting to the ZSCE procedure in the Allier department was seen by local stakeholders as likely to favor farmers' participation in collective action. Opting for a voluntary approach without a regulatory threat (S4.1.2) was considered as lowering the risk of conflict with farmers. Most farmers in the water catchment are under contract with large agro-industrial cooperatives for the production of seed corn and/or high quality wheat. The restrictions on fertilization associated with the participation in drinking water protection would affect the capacity of farmers to fulfil the conditions of the contracts in terms of product volume and quality. Thus, market conditions for agricultural products (S5.1) did not favor farmers' participation in collective action for diffuse pollution control.

Sources

Préfet de l'Allier, 2012, Arrêté n°3060/12. Délimitation des aires d'alimentation et des zones d'action prioritaires des 10 captages prioritaires du département de l'Allier pour la mise en œuvre du programme d'actions. https://www.smea.fr/wp-content/uploads/2018/06/Arr%C3%AAt%C3%A9_pr%C3%A9fectoral.pdf (accessed 27.02.19).

Syndicat Mixte des Eaux de l'Allier (SMEA), 2015. Contrat territorial de l'Allier (2014-2018), Bilan annuel 2015.

Syndicat Mixte des Eaux de l'Allier (SMEA), 2013, Contrat territorial des captages prioritaires du département de l'Allier (2014-2018).

Table F1a: The factors identified as fostering/constraining collective action in Allier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	59% (SMEA, 2013)	Present	+
		Existence of a technical support program at higher levels	Yes (Interviews)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	No (Préfet de l'Allier, 2012)	No	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	No (Interviews)	Absent	-
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	8300 ha (SMEA, 2013)	Large	-
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Nitrate and pesticide rates below regulatory standards with an increasing trend (2008-2012) (SMEA, 2013)	Moderate	+
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Short (Interviews)	High	+

Table F1b: The factors identified as fostering/constraining collective action in Allier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	No match (Interviews)	No	-
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	EU AES (SMEA, 2015)	Low	-
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Control and sanction system associated with EU AES (SMEA, 2015)	Present	°

Table F1c: The factors identified as fostering/constraining collective action in Allier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	118 (SMEA, 2013)	Large	-
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	187 890 € (2014-2018) (SMEA, 2013)	Moderate	-
		Skills-preventive approaches to water pollution control	No (Interviews)		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	24% (SMEA, 2013)	Intensive	-
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	1 Mixed crop-livestock farming (SMEA, 2013)	Low	+
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of “farm leaders” in collective action	No (Interviews)	No	°
	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	No (Interviews)	Absent	-
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	Yes (Interviews)	Available	°
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	Yes (Interviews)	Low	-
	A8.2 – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at the source	Low (Interviews)	Low	-
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	No (Interviews)	Low	-
		Previous involvement in eco-friendly supply chains	No (Interviews)		

2. The case of Virieu

2.1. Description

The **Virieu** catchments are managed by the Syndicat Mixte d'Eau et d'Assainissement de la Haute-Bourbre (SMEAHB). They were identified as "priority" in the framework of the Grenelle policy in 2009 because of the noncompliance of the pesticide rates with the regulatory standard (AE Rhône Méditerranée Corse, 2013a). A ZSCE procedure was also adopted, giving the option to the "département" state agency to prescribe regulatory measures if voluntary cooperation was not effective in restoring water quality after three years (SMEAHB, 2014). Grassland represents two-thirds of the agricultural area in the catchments, where ten cattle breeding farms are located (Chambre d'Agriculture de l'Isère, 2012). In 2010, the water supplier became the owner of 17 ha of agricultural land within the catchment through land acquisition and exchange. The establishment of environmental land contracts (land leases and loan agreements) with five farmers led to the conversion of 27 ha of cropland into grassland, increasing the share of grassland from 60% to 87% of the agricultural area. The pesticide rates have shown a tendency to stabilize and decrease (AE Rhône Méditerranée Corse, 2013a).

2.2. The factors identified as fostering/constraining collective action

2.2.1. The characteristics of the resource system

The small size of the drinking water catchment (RS3.1) reduced the costs associated with the definition and implementation of actions, as there were a small number of farms located in the area (A1.1). The high level of water contamination (RS5.1) was an important driver of the drinking water supplier's involvement in collective action. The long response time of the hydrogeological system (RS7) increased the uncertainty regarding the impact of actions on water quality.

2.2.2. The characteristics of the actors

2.2.2.1. Water suppliers

The high costs of investing in and operating a new water treatment unit (respectively one million euros and 100 000 euros/year) (AE Rhône Méditerranée Corse, 2013a) as an alternative to participation in catchment protection (A8.1) favored the involvement of the drinking water supplier in collective action. The pro-environmental attitude of the elected representatives at the board of the intermunicipal water utility (A8.2.1) reinforced the commitment to the preventive approach of water pollution control. However, the small financial and human resources available (A2.1) constituted a constraint on the water supplier's participation in collective action. Especially, the initial lack of skills regarding collaborative catchment protection induced delays in the cooperation process.

2.2.2.2. Agricultural stakeholders

The dominance of extensive cattle breeding farms (A2.2.1) reduced the costs associated with changes in the farming systems, thereby favoring the participation of farmers in collective action. The diversity of the cattle breeding systems (A2.2.2) enhanced the collaborative land exchange process. The complementarities between the preferences of dairy and meat farms for arable parcels and grassland allowed for the transfer of grassland within the boundaries of the catchment. Furthermore, several agri-environmental programs previously implemented in the area increased the concern of farmers for protecting the water at the source (A8.2.2). The involvement of farmers was also facilitated by the intermediary role played by a well-respected retired farmer (A5.1).

2.2.2.3. Norms (trust-reciprocity)/social capital (A6)

The elected position previously held by some farmers at the municipal or intermunicipal levels led to the development of trust between the drinking water supplier and the farmers. This trust (A6) limited the negotiation and enforcement costs of environmental land contracts.

2.2.3. The characteristics of the governance system

The benefits linked to land exchanges and environmental land leases (access to grassland in the catchment, access to arable land outside the protected zone and/or the regrouping of farm parcels) were considered by the farmers as superior to the costs induced by the conversion from arable into grassland in the catchment (GS5.1). The negotiation of contract terms between the water supplier and farmers (GS6.1) allowed for the consideration of the individual farm specificities. The negotiation costs were limited by the small number of farmers in the catchment and the pre-existing trust between farmers and the water supplier. The water supplier is responsible for controlling the environmental requirements included in the environmental land lease contracts (GS8.1). However, the control costs are reduced by the choice of contracting the easily observable conversion of cropland into grassland.

2.2.4. The characteristics of the social, economic and political settings

Collective action in the Virieu case benefited from public support programs (S4.1.1). Supported by the Rhône Méditerranée Corse water agency, five water suppliers, including the SMEAHB, pooled their resources to hire a full-time facilitator. Furthermore, a network coordinated by the "département" state agency allowed for information pooling and exchange between water suppliers at the Isère "département" level. The use of the ZSCE procedure as a complement to the "Grenelle" catchment protection (S4.1.2) favored the participation of farmers in collective action. The conversion of cropland into grassland is compatible with the evolution of the Saint-Marcellin PDO label technical specifications, which involve raising the share of grass for animal fodder. Thus, the involvement of farmers was favored by the local market conditions (S5.1).

Sources

Agence de l'Eau Rhône Méditerranée Corse (AE RMC), 2013a, Protection des captages de Virieu-sur-Bourbre via des acquisitions foncières, Document de travail, 13 pages.

Chambre d'Agriculture (CA) de l'Isère, 2012, Compte-rendu du diagnostic des risques de pollutions sur les captages de Layat, Frêne, Barril et Vittoz, commune de Virieu-sur-Bourbre, 25 pages + appendix.

Direction Départementale de l'Agriculture et de la Forêt (DDAF) de l'Isère, 2009. Captages Frene, Barril, Vittoz et Layat. Délimitation de l'aire d'alimentation du captage.

Gouverne, L., 2013a, La Haute-Bourbre, Des captages foncièrement protégés, in : Ces hommes qui font vivre les rivières, Agence de l'Eau Rhône Méditerranée Corse, 31-41.

Syndicat Mixte d'Eau et d'Assainissement de la Haute-Boubre (SMEAHB), 2014, Convention pour la mise en œuvre du programme d'actions de reconquête de la qualité des eaux des captages Frêne, Vittoz, Barril, Layat (commune de Virieu-sur-Boubre), 8 pages + appendix.

Syndicat Mixte d'Eau et d'Assainissement de la Haute-Boubre (SMEAHB), 2013, Environmental land lease contract – standard form, 6 pages.

Table F2a: The factors identified as fostering/constraining collective action in Virieu

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	80% (AE RMC, 2013a)	Present	+
		Existence of a technical support program at higher levels	Information exchange network (Interviews)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	ZSCE (SMEAHB, 2014)	Yes	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	Saint-Marcellin cheese PDO supply chain (Interviews)	Present	+
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	115 ha (CA Isère, 2012)	Small	+
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Pesticide rates beyond regulatory standards (2005-2011) (CA Isère, 2012)	High	+
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Long (Gouverne, 2013a)	Low	-

Table F2b: The factors identified as fostering/constraining collective action in Virieu

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	Match (Interviews)	Yes	+
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	Environmental land leases (AE RMC, 2013a)	High	+
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Regular monitoring by the water supplier (SMEAHB, 2013)	Present	+

Table F2c: The factors identified as fostering/constraining collective action in Virieu

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	10 (CA Isère, 2012)	Small	+
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	32 385 € (2010-2013) (AE RMC, 2013a)	Small	-
		Skills-preventive approaches to water pollution control	No (Interviews)		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	60% (CA Isère, 2012)	Extensive	+
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	2 Beef and dairy cattle breeding farms (CA Isère, 2012)	Moderate	+
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of “farm leaders” in collective action	Yes (Interviews)	Yes	+

Table F2d: The factors identified as fostering/constraining collective action in Virieu

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	Yes (Interviews)	Present	+
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	Yes (DDAF Isère, 2009)	Available	°
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	No (AE RMC, 2013a)	High	+
	A8.2. – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at the source	High (Interviews)	High	+
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	Yes (Interviews)	High	+
		Previous involvement in eco-friendly supply chains	Yes (Interviews)		

3. The case of Oursbellile

3.1. Description

The Syndicat Intercommunal d'Alimentation en Eau Potable (SIAEP) Tarbes-Nord relies on the **Oursbelille** catchment for its total drinking water production, for which the supply is delegated to a private company. In 2009, the catchment was identified as a Grenelle "priority" catchment, as the nitrate rate regularly exceeded the regulatory standard between 2003 and 2008 (SIAEP Tarbes-Nord, 2013). Nineteen farmers own parcels in the catchment, with irrigated corn farming representing 88% of the agricultural area (CA Hautes-Pyrénées, 2012). The definition and implementation of actions are delegated to a consortium involving the water company, the Hautes-Pyrénées Agricultural Chamber and a regional development agency, the Semadour. The implementation of agricultural actions relies on AES co-funded by the EU and the Adour-Garonne Water Agency. In 2014, seven farmers, representing 73 ha in the catchment, adopted agri-environmental measures. The nitrate rates have decreased but are still close to the regulatory standard (SIAEP Tarbes-Nord, 2014).

3.2. The factors identified as fostering/constraining collective action

3.2.1. The characteristics of the resource system

The small size of the drinking water catchment (RS3.1) had a positive effect on collective action, as there were a small number of farms located in the catchment (A1.1). The costs of diagnosing farming practices at the individual farm level and monitoring their evolution were kept limited. However, the complex dynamics and the low reactivity of the alluvial aquifer increased the level of uncertainty about the impact of the measures implemented to protect the catchment (RS.7). The high level of water contamination (RS5.1), with regular peaks of pollutant rates above regulatory standards, stimulated the involvement of both the water supplier and the agricultural stakeholders in collective action because of the threat of activating a ZSCE procedure.

3.2.2. The characteristics of the actors

3.2.2.1. Water suppliers

The involvement of the SIAEP Tarbes-Nord in collective action was favored by the absence of access to curative or palliative options to lower the nitrate rates (A8.1). The high level of concern of the president of the board of the intermunicipal water utility for the protection of water at the source (A8.2.1) strengthened this involvement. However, the limited financial resources available and the initial lack of expertise with regard to agriculture and farming systems (A2.1) constituted a constraint to the initiation of cooperation with the farmers.

3.2.2.2. Agricultural stakeholders

The high costs associated with changes in intensive corn single-crop farming systems (A2.2.1) were an obstacle to the implementation of actions targeting nonpoint source pollution. Moreover, the level of concern of farmers for protecting the water at the source was low (A8.2.2), which further prevented their participation in collective action. The involvement of local agricultural "leaders" (A5.1) in collective action had a positive impact on collective action. The homogeneity of the farming systems (A2.2.2) limited the costs associated with the definition of actions. However, by increasing the costs of developing alternative farming techniques and systems within the catchment, the similar orientation of production systems towards intensive corn farming was also perceived as a constraint on the evolution of farm practices.

3.2.2.3. Norms (trust-reciprocity)/social capital (A6)

According to the interviewed stakeholders, the absence of previous interactions partially explains the absence of trust between the water supplier and farmers. This lack of trust (A6) did not favor collective action.

3.2.2.4. Knowledge of the resource system (A7)

The lack of scientific knowledge about the alluvial aquifer (A7) increased the costs for defining the actions. Moreover, this lack of knowledge led to a controversy regarding the farming versus nonfarming source of water pollution, limiting the farmers' involvement in collective action.

3.2.3. The characteristics of the governance system

In a context where the dominant farming system is highly profitable corn farming, the financial compensation offered by EU AES (GS5.1) was considered insufficient for covering the costs of the contracted measures. As a result, the participation of farmers in AES was low. The low level of autonomy of the local stakeholders in designing the AES contracts (GS6.1) was identified as a constraint to adapting the measures and compensation to the characteristics of the local agricultural context. The control system implemented in the framework of the EU AES (GS8.1) limited the risk of opportunistic behavior by the participating farmers.

3.2.4. The characteristics of the social, economic and political settings

The development of cooperation for the protection of the Oursbelille catchment benefited from financial support by the Adour-Garonne water agency (S4.1.1). However, the water supplier found that there was a lack of technical and legal support to help them face the complexity of cooperating with farmers. The threat of activating the ZSCE tool if water quality further deteriorated beyond the regulatory standards (S4.1.2) was found to be effective in fostering the farmers' voluntary involvement. Nevertheless, the integration of corn farming into high economic-value agro-food supply chains (S5.1) acted as a constraint on farmers' participation in collective action.

Sources

Chambre d'Agriculture (CA) des Hautes-Pyrénées, 2012. Diagnostic territorial multi-pression de l'AAC d'Oursbelille, comprenant le Diagnostic Territorial des Pressions Agricoles (DTPA).

Préfet des Hautes-Pyrénées, 2013, Arrêté n°2013361-001 autorisant le SIAEP Tarbes Nord à distribuer à titre dérogatoire aux abonnés une eau destinée à la consommation humaine présentant un taux de nitrates supérieur à 50 mg/l sans excéder 70 mg/l.

Syndicat Intercommunal d'Alimentation en Eau Potable (SIAEP) Tarbes-Nord, 2014. Plan d'Action Territorial sur l'Aire d'Alimentation du Captage d'Oursbelille. Présentation au comité technique du 10/09/14, http://www.pat-oursbelille.fr/images/pdf/CT_N9_100914.pdf (accessed 04.07.19).

Syndicat Intercommunal d'Alimentation en Eau Potable (SIAEP) Tarbes-Nord, 2013. Projet de Plan d'Action Territorial de lutte contre les pollutions diffuses sur l'AAC d'Oursbelille, comprenant le Plan d'action agricole sur la zone de protection.

Table F3a: The factors identified as fostering/constraining collective action in Oursbellile

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	50% (SIAEP, 2013)	Present	-/+
		Existence of a technical support program at higher levels	No (Interviews)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	Threat of activating ZSCE (Préfet des Hautes-Pyrénées, 2013)	Yes	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	No (Interviews)	Absent	-
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	396 ha (SIAEP, 2013)	Small	+
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Nitrate rates beyond regulatory standards (2003-2008; 2013) (CA Hautes-Pyrénées, 2012)	High	+
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Long (Interviews)	Low	-

Table F3b: The factors identified as fostering/constraining collective action in Oursbellile

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	No match (Interviews)	No	-
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	EU AES (SIAEP, 2013)	Low	-
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Control and sanction system associated with EU AES (SIAEP, 2013)	Present	+

Table F3c: The factors identified as fostering/constraining collective action in Oursbellile

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	19 (CA Hautes-Pyrénées, 2012)	Small	+
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	83 750 € (2012-2016) (SIAEP, 2013)	Small	-
		Skills-preventive approaches to water pollution control	No		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	3% (CA Hautes-Pyrénées, 2012)	Intensive	-
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	1 Corn single-crop farming (CA Hautes-Pyrénées, 2012)	Low	-
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of “farm leaders” in collective action	Yes (Interviews)	Yes	+

Table F3d: The factors identified as fostering/constraining collective action in Oursbellile

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	No (Interviews)	Absent	-
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	No (Interviews)	Lacking	-
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	No (CA Hautes-Pyrénées, 2012)	High	+
	A8.2 – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at the source	High (Interviews)	High	+
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	No (Interviews)	Low	-
		Previous involvement in eco-friendly supply chains	No (Interviews)		

4. The case of Arcier

4.1. Description

The **Arcier** source is located 10 km from the city of Besançon. Between 1998 and 2003, the pesticide rates in the water displayed an upward trend (Ville de Besançon, 2013). In 2004, the city decided to undertake the protection of the Arcier source catchment by collaborating with agricultural and non-agricultural stakeholders (Murgue and Afflard, 2013). Because of the importance of the population supplied, the catchment was later added to the list of the "Grenelle" catchments. Most of the 72 farms located in the Arcier catchment are dairy farms producing cheese under the Comté Protected Designation of Origin (PDO) label. Permanent and temporary grassland represents 70% of the agricultural area. The agricultural action program relies mainly on the implementation of AES co-funded by the EU and the Rhône Méditerranée Corse Water Agency. Between 2007 and 2013, approximately 20 farmers adopted agri-environmental measures, covering 808 ha in the catchment. A 27% decrease in pesticide use by participating farmers has been observed between 2010 and 2012. Water quality improved between 2004 and 2013 (Ville de Besançon, 2013).

4.2. The factors identified as fostering/constraining collective action

4.2.1. The characteristics of the resource system

The large size of the Arcier drinking water catchment (RS3.1) increased the definition and implementation costs of actions targeting nonpoint source pollution because of the large number of farmers (A1.1) and other stakeholders in the catchment. Moreover, the complexity of the karstic hydrogeological system (RS7) increased the costs of defining actions and assessing their impact on water quality. The level of water contamination by pesticides was moderate (RS5.1), with no peaks beyond the regulatory standard; providing time for the cooperation process to unfold, this factor favored collective action.

4.2.2. The characteristics of the actors

4.2.2.1. Water supplier

The willingness of the drinking water supplier to avoid the high costs of investing in and operating a water treatment unit (A8.1) was a strong driver of the initiation of the cooperation with agricultural stakeholders. Indeed, the annual operating cost of a water treatment plant was estimated at 130 000 euros, whereas the annual cost of the preventive approach was 40 000 euros (Gouverne, 2013b). The involvement of the water supplier in collective action was also sustained by the pro-environmental attitude of the members of the Besançon city council (A8.2.1). The large resources available to the city (A2.1) were sufficient to cover the costs associated with the collaborative water catchment protection. More particularly, a facilitator holding agricultural technical skills was hired by the water supplier to support the cooperation process.

4.2.2.2. Agricultural stakeholders

The dominance of extensive mixed crop-livestock farming (A2.2.1) favored the participation of farmers in collective action, as changes in farming practices induced limited costs. The involvement of farmers was also driven by their high level of concern regarding environmental protection (A8.2.2). The environmental awareness of farmers producing Comté cheese has been increased by the PDO label's technical specifications, which include limitations on pesticide use, and by the previous agri-environmental programs implemented in the area. The participation of agricultural representatives in drinking water catchment protection positively impacted cooperation. In particular, the participation of a farmer, who was also an elected representative on the Agricultural Chamber board and a vice-president of the main agricultural cooperative in the area (A5.1), had a positive effect on farmers' participation in collective action.

4.2.2.3. Norms (trust-reciprocity)/social capital (A6)

The Arcier catchment is located 10 km away from the city of Besançon. Moreover, farmers in the area are not themselves consumers of the drinking water produced from the Arcier source. The absence of previous interactions between the water supplier and farmers initially acted as an obstacle to cooperation.

4.2.2.4. Knowledge of the resource system (A7)

The completion of a hydrogeological study (A7) contributed to reducing the high level of uncertainty regarding the potential impact of actions aiming at improving water quality. Additionally, the sharing of the results with all stakeholders, including farmers, increased the stakeholders' level of concern regarding the protection of water at the source.

4.2.3. The characteristics of the governance system

The implementation of the EU AES leaves little room for local stakeholders to choose the measures targeting diffuse pollution and the corresponding financial compensation for farmers (GS6.1). However, given the local agricultural context characterized by the dominance of extensive dairy farming, the financial compensation provided by the AES contracts was considered sufficient to cover the costs associated with the required changes in farming practices (GS5.1). The incentives provided by AES contracts favored the adoption of measures by farmers. The control system implemented in the framework of the EU AES (GS8.1) reduced the risk of opportunistic behavior of contracting farmers.

4.2.4. The characteristics of the social, economic and political settings

Collective action benefited from the financial support provided by the Rhône-Méditerranée Corse water agency (S4.1.1). The absence of a regulatory threat (S4.1.2) was identified as favoring the voluntary commitment of farmers to cooperation. By limiting the use of phytosanitary products and requiring the use of grass rather than silage for animal fodder, the technical specifications of the Comté cheese PDO label (S5.1) favored the evolution of farming practices in the Arcier catchment.

Sources

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Table F4a: The factors identified as fostering/constraining collective action in Arcier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	50% (AE RMC, 2013b)	Present	+
		Existence of a technical support program at higher levels	No (Interviews)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	No (Préfet du Doubs, 2012)	No	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	Comté PDO cheese supply chain (Ville de Besançon, 2013)	Present	+
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	10 200 ha (Ville de Besançon, 2013)	Large	-
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Pesticide rates below regulatory standard with an increasing trend (1998-2003) (Ville de Besançon, 2013)	Moderate	+
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Long (BRGM, 2005)	Low	-

Table F4b: The factors identified as fostering/constraining collective action in Arcier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	Match (Interviews)	Yes	+
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	EU AES (Ville de Besançon, 2013)	Low	°
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Control and sanction system associated with EU AES (Ville de Besançon, 2013)	Present	+

Table F4c: The factors identified as fostering/constraining collective action in Arcier

First-tier variable	**Second-tier, third-tier and fourth-tier variables**	**Indicators**	**Indicator values (Sources)**	**Variable assessment**	**Impact on collective action**
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	72 (Ville de Besançon, 2013)	Large	-
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	230 350 € (2004-2013) (AE RMC, 2013b)	Large	+
		Skills-preventive approaches to water pollution control	Yes (Interviews)		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	70% (Ville de Besançon, 2013)	Extensive	+
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	1 Mixed crop-livestock farming (Ville de Besançon, 2013)	Low	°
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of “farm leaders” in collective action	Yes (Interviews)	Yes	+

Table F4d: The factors identified as fostering/constraining collective action in Arcier

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	No (Interviews)	Absent	-
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	Yes (BRGM, 2005)	Available	+
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	No (Gouverne, 2013b)	High	+
	A8.2 – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at the source	High (Interviews)	High	+
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	Yes (Ville de Besançon, 2013)	High	+
		Previous involvement in eco-friendly supply chains	Yes (Ville de Besançon, 2013)		

5. The case of Ammertzwiller

5.1. Description

Managed by the SIAEP Ammertzwiller and Balschwiller, the **Ammertzwiller** well represents two-thirds of the water resources used for drinking water (AE Rhin-Meuse, 2009). Because of the high nitrate and pesticide pollution levels, the Ammertzwiller catchment was classified in 2009 as "priority" in the Rhin-Meuse water basin management plan. Land use is dominated by agriculture in the catchment, where 30 farmers own land. While corn represents 59% of the agricultural area, grassland only counts for 6% (Chambre d'agriculture du Haut-Rhin, 2008). Agricultural actions include the implementation of AES, co-funded by the EU, the Rhin-Meuse Water Agency and the Departmental Council, and the development of a low-input energy crop (miscanthus). In 2011, the participation of farmers in AES covered 52 ha in the catchment (Ditner, 2014a). The introduction of miscanthus by farmers was supported by subsidies provided by the water supplier and the Rhin-Meuse Water Agency. Additionally, long-term contracts with guaranteed prices were offered to the farmers for supplying the municipal heating system. Sixteen farmers, representing 27 ha, chose to grow miscanthus in the catchment. Water quality improved significantly between 2009 and 2014, with a decrease in nitrate rates from 45 mg/l to 35 mg/l and a decrease in pesticide rates to levels below the regulatory standard (Ditner, 2014b).

5.2. The factors identified as fostering/constraining collective action

5.2.1. The characteristics of the resource system

Due to the threat of activating a ZSCE procedure, the high level of water contamination (RS5.1), with regular peaks of pollutant rates above regulatory standards, was the initial diver of the involvement of both the water supplier and agricultural stakeholders in collective action. The small size of the water catchment (RS3.1) had a positive impact on cooperation because of the small number of farmers in the catchment (A.1.1). The short response time of the unconfined aquifer (RS7) reduced the costs for assessing the impact of actions on water quality, which strengthened the willingness of farmers to participate.

5.2.2. The characteristics of the actors

5.2.2.1. Water supplier

Despite the low-cost access to water dilution for lowering the pollutant rates in drinking water (A8.1), the strong environmental preferences of the members of the board of the intermunicipal water utility (A8.2.1) favored the involvement of the water supplier in collective action for protecting the water at the source. Because of the support provided by the Rhin-Meuse water agency and the Haut-Rhin department council (S4.1.1), the small financial resources available to the water supplier (A2.1) did not constitute a constraint on cooperation. However, the supplier's lack of legal expertise increased the costs of establishing the miscanthus supply contracts with farmers.

5.2.2.2. Agricultural stakeholders

The dominance of intensive field crop farming in the Ammertzwiller catchment (A2.2.1) was a constraint on farmers' participation in collective action because of the high costs potentially induced by changes in such farming systems. However, the involvement of farmers was favored by their pro-environmental attitude (A8.2.2), which had been developed in the framework of the agri-environmental programs previously implemented in the area. The leadership role (A5.1) played by the president of the water utility board, also a farmer and the mayor of Ammertzwiller, also favored farmers' participation in collective action.

5.2.2.3. Norms (trust-reciprocity)/social capital (A6)

The pre-existing social links between the drinking water supplier and farmers reduced the costs of negotiating and enforcing the miscanthus supply contracts.

5.2.2.4. Knowledge of the resource system (A7)

The availability of hydrogeological surveys and pollution source assessments reduced the costs associated with the definition of the relevant actions to be implemented.

5.2.3. The characteristics of the governance system

The financial compensation and the guaranteed outlet offered by the water supplier for growing miscanthus covered the costs borne by farmers (GS5.1). Some of the farmers considered that while no net economic benefits could be expected from their participation in the cooperative agreement, the contract incentives were strengthened by their willingness to contribute to water quality restoration (A8.2.2). The autonomy of local stakeholders (GS6.1) in designing the miscanthus supply contract allowed the consideration of the characteristics of the local farming systems. The low-cost visual control of the planting and maintenance of miscanthus by the water supplier (GS8.1) was effective in reducing the risk of opportunistic behavior of farmers.

5.2.4. The characteristics of the social, economic and political settings

The miscanthus project benefited from the financial support provided by the Rhin-Meuse water agency and the Haut-Rhin departmental council (S4.1.1). Additionally, the experimental project status granted by the water agency allowed the drinking water supplier to cover the miscanthus planting costs incurred by farmers. The threat of activating the ZSCE procedure if water quality further deteriorated beyond the regulatory standards (S4.1.2) favored the voluntary participation of farmers in collective action. The high profitability of intensive cereal farming in the area (S5.1) was not identified as a constraint on the involvement of farmers, as the drinking water supplier offered an alternative outlet for the low-input miscanthus development.

Sources

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Table F5a: The factors identified as fostering/constraining collective action in Ammertzwiller

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	65% (Ditner, 2014b)	Present	+
		Existence of a technical support program at higher levels	Experimental project status (CA Alsace, 2013)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	Yes (CA du Haut-Rhin, 2008)	Yes	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	No (Interviews)	Absent	°
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	363 ha (AE Rhin-Meuse, 2009)	Small	+
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	Noncompliance (pesticide) (2003-2008) Increasing trend (nitrates) (1993-2009) (CA du Haut-Rhin, 2008)	High	+
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Low (CA du Haut-Rhin, 2008)	High	+

Table F5b: The factors identified as fostering/constraining collective action in Ammertzwiller

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	Partial match (Interviews)	Partly	+
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	Supply contract (SIVOM d'Ammertzviller/ Bernwiller, 2011)	High	+
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Monitoring by the water supplier (SIVOM d'Ammertzviller/ Bernwiller, 2011)	Present	+

Table F5c: The factors identified as fostering/constraining collective action in Ammertzwiller

First-tier variable	**Second, third and fourth-tier variables**	**Indicators**	**Indicator values (Sources)**	**Variable assessment**	**Impact on collective action**
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	30 (CA du Haut-Rhin, 2008)	Small	+
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	28 000 € (2009-2010) (Interviews)	Small	-
		Skills-preventive approaches to water pollution control	Lacking (Interviews)		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	6% (CA du Haut-Rhin, 2008)	Intensive	-
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	1 Field crops (CA du Haut-Rhin, 2008)	Low	°
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of “farm leaders” in collective action	Yes (Interviews)	Yes	+

Table F5d: The factors identified as fostering/constraining collective action in Ammertzwiller

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	Yes (Interviews)	Present	+
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	Yes (CA du Haut-Rhin, 2008)	Available	+
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	Yes (CA du Haut-Rhin, 2008)	Low	°
	A8.2 – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at the source	High (Interviews)	High	+
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	Yes (Interviews)	High	+
		Previous involvement in eco-friendly supply chains	No (CA du Haut-Rhin, 2008)		

6. The case of Val-de-Reuil

6.1. Description

The four wells located in the **Val-de-Reuil** catchment are used to supply two-thirds of the population of the metropolitan area Seine-Eure (40 000 inhabitants). The pollution rates of the water resource are well below the regulatory standards (CASE, 2014). However, the metropolitan authority responsible for drinking water production and supply initiated a collaborative process with agricultural stakeholders to limit the risk of diffuse pollution from agriculture in the catchment. In 2008, intensive cereal cropping was the main farming system in the area, with seven farmers renting land from a regional public land development agency (Safer Haute-Normandie, 2008). Between 2009 and 2011, the metropolitan authority became the owner of the rented land, which covered 110 ha in the catchment (FNAB, 2014). Through partnerships with multiple local stakeholders involved in organic farming supply chains, including producers' groups and potential public and private consumers, environmental land leases were established with farmers. Based on the conversion of part of the cereal area and the development of organic produce production, collective action led to the effective development of organic farming in the Val-de-Reuil catchment.

6.2. The factors identified as fostering/constraining collective action

6.2.1. The characteristics of the resource system

The small size of the catchment (RS3.1) limited the negotiation and enforcement costs of environmental land leases with farmers. The good quality of the water resource (RS5.1) appeared to be an obstacle to the participation of some farmers who questioned the legitimacy of undertaking costly changes in their farming system for preventing diffuse pollution. The short response time of the aquifer (RS7) reduced the costs of assessing the impact of actions on water quality.

6.2.2. The characteristics of the actors

6.2.2.1. Water supplier

The decision of the drinking water supplier to initiate cooperation with agricultural stakeholders for maintaining the good quality of the resource was driven by the high costs of investing in a water treatment unit (A8.1). The pro-environmental political stance of the elected representatives leading the metropolitan water service (A8.2.1) was also an important factor for the initiation of collective action. The large financial resources available to the Seine-Eure metropolitan area authority (A2.1) favored the cooperation process, which involved a costly farmland acquisition operation.

6.2.2.2. Agricultural stakeholders

The low level of concern of some farmers for the protection of the water at the source (A8.2.2) constituted an initial barrier to their involvement in collective action. A well-respected cereal producer in the catchment played a leadership role (A5.1) in convincing most farmers to participate in the cooperation process. The homogeneity of farming systems in the catchment (A2.2.2) decreased the costs for defining and enforcing the environmental land lease contracts.

6.2.2.3. Norms (trust-reciprocity)/social capital (A6)

The absence of previous interactions between the water supplier and farmers was identified as a constraint for the development of collective action.

6.2.2.4. Knowledge of the resource system (A7)

The completion of a hydrogeological survey at the beginning of the collaborative process was useful for identifying the vulnerable areas in the catchment, thereby reducing the costs of defining relevant actions to prevent potential diffuse pollutions.

6.2.3. The characteristics of the governance system

The autonomy of local stakeholders in designing the environmental land lease contracts (GS6.1) was found to have a positive effect on cooperation. The duration of the contracts (9 years) and the lower level of land rent were considered by farmers as benefits outweighing the extra costs associated with the change in farming systems (GS5.1). The public organic certification agency is in charge of monitoring farming practices (GS8.1); therefore, the water supplier does not bear any control costs.

6.2.4. The characteristics of the social, economic and political settings

Covering 54% of the total cost of the project, the financial support provided by the Seine-Normandie water agency, the Haute-Normandie region and the Eure department (S4.1.1) facilitated the cooperative process. The project also benefited from the experimental project status granted by the Seine-Normandie water agency. The absence of a regulatory threat (S4.1.2.) was identified as having a positive impact on the farmers' voluntary involvement in collective action. Finally, the presence of the largest French organic agricultural cooperative in the area (S5.1) facilitated the conversion of cereal producers in the catchment.

Sources

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Table F6a: The factors identified as fostering/constraining collective action in Val-de-Reuil

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Social, economic and political settings (S)	S4 – Other governance systems				
	S4.1 – Larger scale governance systems				
	S4.1.1 – External support from public agencies	Share of total cost funded by public agencies	54% (FNAB, 2014)	Present	+
		Existence of a technical support program at higher levels	Experimental project status (Interviews)		
	S4.1.2 – Regulatory threat	Use of the ZSCE procedure or threat of activating it	No (Interviews)	No	+
	S5 – Markets				
	S5.1 – Market conditions for agricultural products	Presence of agro-food operators offering outlets for low-input/organic products	Organic cereal cooperative (Interviews)	Present	+
Resource system (S)	RS3 – Size of resource system				
	RS3.1 – Size of the water catchment	Drinking water catchment area (ha)	127 ha (Safer, 2008)	Small	+
	RS5 – Productivity of system				
	RS5.1 – Level of water contamination	Pollutant rates in the water used for drinking water production (mg/l)	No pollution by nitrates/pesticides (CASE, 2014)	Low	-
	RS7 – Predictability of system dynamics	Hydrogeological system's response time to measures targeting diffuse pollution	Short (Safer, 2008)	High	+

Table F6b: The factors identified as fostering/constraining collective action in Val-de-Reuil

First-tier variable	**Second-tier, third-tier and fourth-tier variables**	**Indicators**	**Indicator values (Sources)**	**Variable assessment**	**Impact on collective action**
Governance system (GS)	GS5 – Operational rules				
	GS5.1 – Contract incentives	Perception of a match between compensation and costs of changing farming practices	Match (Interviews)	Yes	+
	GS6 – Collective-choice rules				
	GS6.1 – Autonomy at the collective-choice level	Type of contract	Environmental land leases (CASE and GRAB Haute-Normandie, 2013)	High	+
	GS8 – Monitoring and sanctioning rules				
	GS8.1 – Contract enforcement	Implementation of a system for monitoring farming practices	Organic farming label monitoring system (CASE and GRAB Haute Normandie, 2013)	Present	°

Table F6c: The factors identified as fostering/constraining collective action in Val-de-Reuil

First-tier variable	Second-tier, third-tier and fourth-tier variables	Indicators	Indicator values (Sources)	Variable assessment	Impact on collective action
Actors (A)	A1 – Number of relevant actors				
	A1.1 – Number of farmers	Number of farmers with land in the drinking water catchment	7 (Safer, 2008)	Small	+
	A2 – Socioeconomic attributes				
	A2.1 – Resources available to water suppliers	Budget devoted to catchment protection (€)	1 200 000 € (2008-2014) (Interviews)	Large	+
		Skills-preventive approaches to water pollution control	Yes (FNAB, 2004)		
	A2.2 – Farming systems				
	A2.2.1 – Type of farming systems	Share of grassland in agricultural area in the catchment	9% (Safer, 2008)	Intensive	°
	A2.2.2 – Heterogeneity of farming systems	Number of different types of farming systems	Mostly corn single-cropping (Safer, 2008)	Low	+
	A5 – Leadership-entrepreneurship				
	A5.1. – Leadership in the farming community	Involvement of "farm leaders" in collective action	Yes (Interviews)	Yes	+
	A6 – Norms (trust-reciprocity)/social capital	Pre-existing links between water suppliers and farmers	No (Interviews)	Absent	-
	A7 – Knowledge of SES	Existence of hydrogeological studies/pollution source assessments	Yes (Safer, 2008)	Available	+
	A8 – Importance of the resource				
	A8.1 – Economic importance for water suppliers	Access to palliative/curative options	No (CASE, 2014)	High	+
	A8.2 – Environmental preferences of stakeholders				
	A8.2.1 – Environmental preferences of water suppliers	Level of concern for the protection of water at source	High (Interviews)	High	+
	A8.2.2 – Environmental preferences of farmers	Previous implementation of agri-environmental programs	No (Interviews)	Low	-
		Previous involvement in eco-friendly supply chains	No (Interviews)		

Appendix G: The variables affecting collective action for drinking water catchment protection

Table G.1: The characteristics of the resource system (RS)

Variable	Definition	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Size of the water catchment (RS3.1)	Size of the water catchment	Large	Small	Small	Large	Small	Small
		(-)	(+)	(+)	(-)	(+)	(+)
Level of water contamination (RS5.1)	Level of water contamination	Moderate	High	High	Moderate	High	Low
		(+)	(+)	(+)	(+)	(+)	(-)
Predictability of system dynamics (RS7)	Degree to which stakeholders are able to assess the impact of farming practices on water quality	High	Low	Low	Low	High	High
		(+)	(-)	(-)	(-)	(+)	(+)

(-) Negative influence on collective action; (+) Positive influence on collective action; (o) No influence on collective action

Table G.2: The characteristics of the actors (A)

Variable	Definition	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Number of farmers (A1.1)	Number of farmers with land in the drinking water catchment	Large (-)	Small (+)	Small (+)	Large (-)	Small (+)	Small (+)
Resources available to water suppliers (A2.1)	Financial and human resources available to water suppliers	Moderate (-)	Small (-)	Small (-)	Large (+)	Small (-)	Large (+)
Type of farming systems (A2.2.1)	Dominance of intensive/extensive farming systems	Intensive (-)	Extensive (+)	Intensive (-)	Extensive (+)	Intensive (-)	Intensive (o)
Heterogeneity of farming systems (A2.2.2)	Diversity of types of farming systems in the catchment area	Low (+)	Moderate (+)	Low (-)	Low (o)	Low (o)	Low (+)
Leadership in the farming community (A5.1)	Involvement of "farm leaders" in collective action	No (o)	Yes (+)	Yes (+)	Yes (+)	Yes (+)	Yes (+)
Norms (trust-reciprocity)/social capital (A6)	Existence of trust/norms of reciprocity between drinking water suppliers and farmers	Absent (-)	Present (+)	Absent (-)	Absent (-)	Present (+)	Absent (-)
Knowledge of SES (A7)	Shared knowledge of hydrological system dynamics	Available (o)	Available (o)	Lacking (-)	Available (+)	Available (+)	Available (+)
Economic importance of the resource for water suppliers (A8.1)	Cost of alternative approaches to water catchment protection	Low (-)	High (+)	High (+)	High (+)	Low (o)	High (+)
Environmental preferences of water suppliers (A8.2.1)	Level of concern for the protection of water at the source	Low (-)	High (+)	High (+)	High (+)	High (+)	High (+)
Environmental preferences of farmers (A8.2.2)	Level of concern for the protection of water at the source	Low (-)	High (+)	Low (-)	High (+)	High (+)	Low (-)

(-) Negative influence on collective action; (+) Positive influence on collective action; (o) No influence on collective action

Table G.3: The characteristics of the governance system (GS)

Variable	Definition	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
Incentives (GS5.1)	Match between compensation and costs of changing farming practices	No	Yes	No	Yes	Partly	Yes
		(-)	(+)	(-)	(+)	(+)	(+)
Autonomy at the collective-choice level (GS6.1)	Autonomy in contract design	Low	High	Low	Low	High	High
		(-)	(+)	(-)	(o)	(+)	(+)
Contract enforcement (GS8.1)	Procedures for limiting the risk of opportunistic behavior by farmers	Present	Present	Present	Present	Present	Present
		(o)	(+)	(+)	(+)	(+)	(o)

(-) Negative influence on collective action; (+) Positive influence on collective action; (o) No influence on collective action

Table G.4: The characteristics of the social, economic and political settings (S)

Variable	Definition	Allier	Virieu	Oursbellile	Arcier	Ammertzwiller	Val-de-Reuil
External support from public agencies (S4.1.1)	Existence of financial/technical support from public agencies at a higher level	Present	Present	Present	Present	Present	Present
		(+)	(+)	(-/+)	(+)	(+)	(+)
Regulatory threat (S4.1.2)	Perspective of application of regulatory measures in case of collective action failure	No	Yes	Yes	No	Yes	No
		(+)	(+)	(+)	(+)	(+)	(+)
Market conditions for agricultural products (S5.1)	Presence of eco-friendly agro-food supply chains	Absent	Present	Absent	Present	Absent	Present
		(-)	(+)	(-)	(+)	(o)	(+)

(-) Negative influence on collective action; (+) Positive influence on collective action; (o) No influence on collective action