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

Laurence Amblard

Université Clermont Auvergne, AgroParisTech, INRA, Irstea, VetAgro Sup, Territoires, 9 avenue Blaise Pascal, CS 20085, 63178 Aubière, France

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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.

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 (European Environment Agency (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 (Commissariat Général au Développement Durable (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 and Ribaudo, 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 (European Union (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” (European Union (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

E-mail address: laurence.amblard@irstea.fr.

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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; Agence de l’Eau (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, 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 (Fig. 1).

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

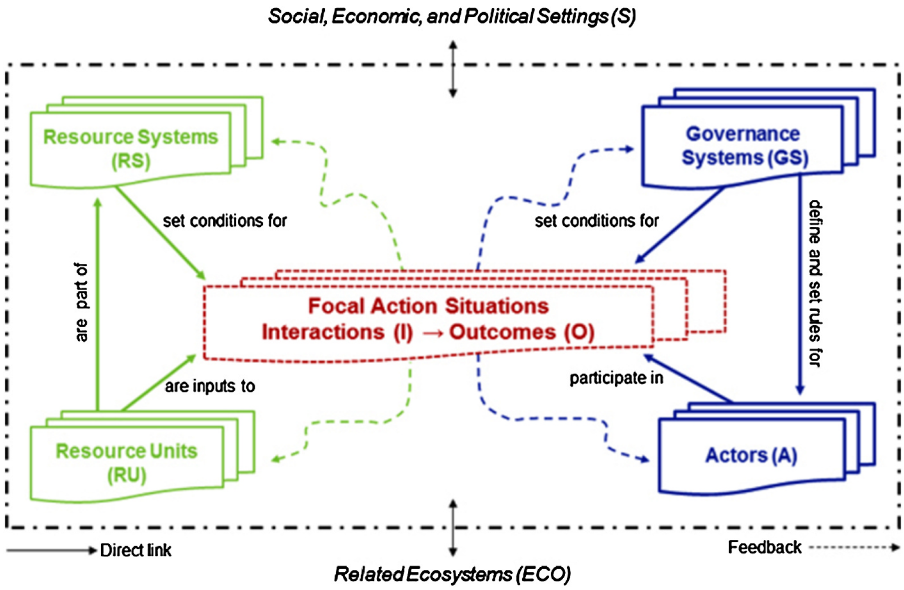


Fig. 1. SES framework (Source: McGinnis and Ostrom, 2014).

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.

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 Fig. 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).

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

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	Seond-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	+

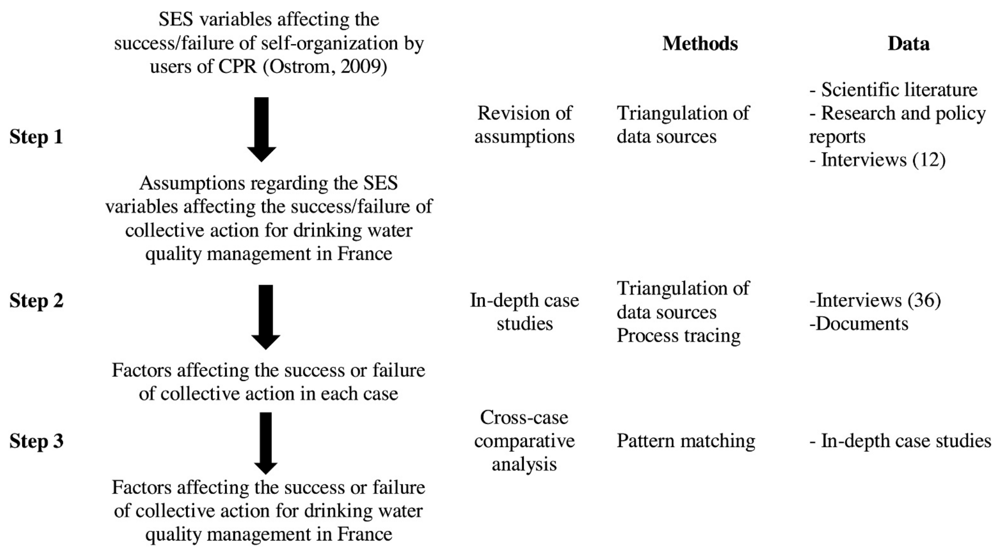


Fig. 2. Multistep research design.

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

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.

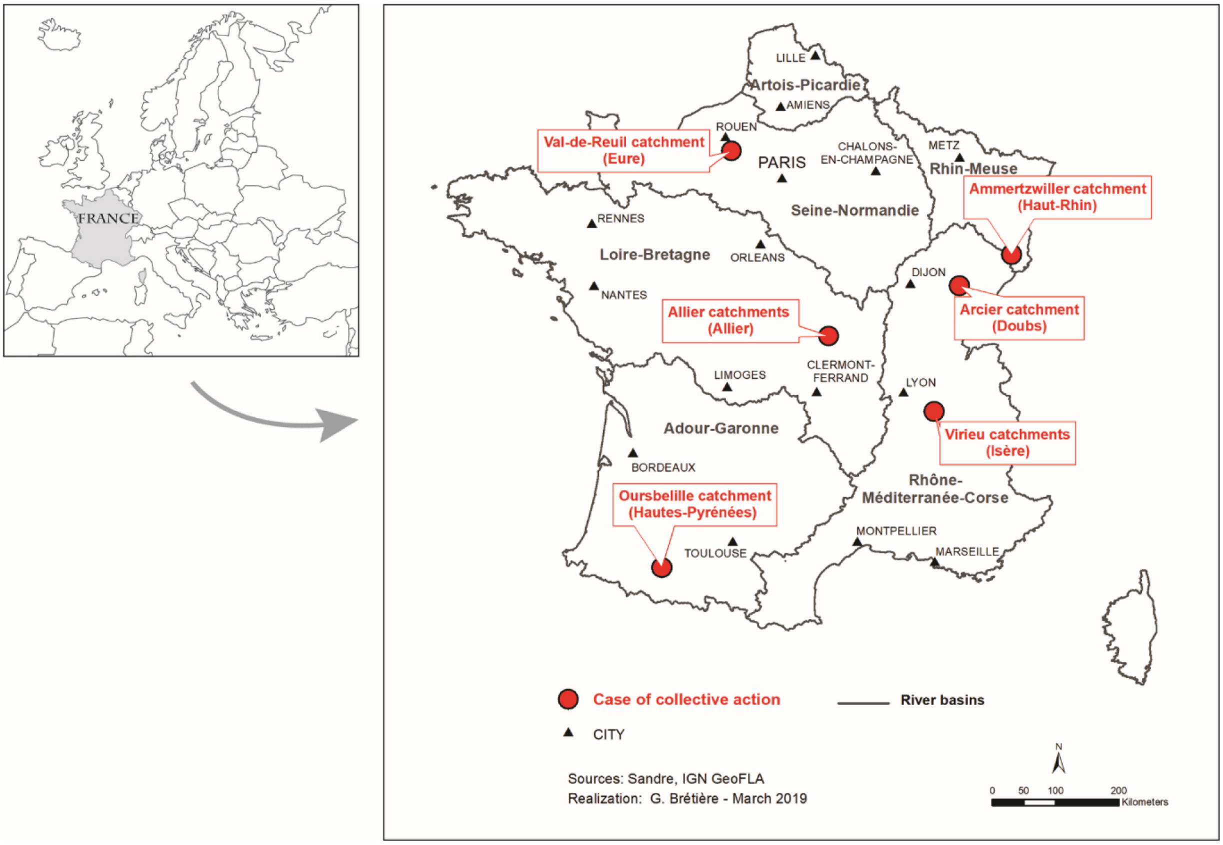
The first step led to a revised set of assumptions regarding the factors likely to affect the benefits, costs and transaction costs associated with collective action for drinking water catchment protection in France. Appendix C presents the revised set of assumptions.

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



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

covered by changes in farming practices in the drinking water catchment.

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

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

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).

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) (Syndicat Mixte des Eaux de l'Allier (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 (Syndicat Mixte des Eaux de l'Allier (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 (Agence de l'Eau (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, 2007Décret n° -882, 2007Décret 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 (Agence de l'Eau (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).

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 (Agence de l'Eau (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

Table 4
Main characteristics of the drinking water catchments in the six cases.
Sources: Allier: *Syndicat Mixte des Eaux de l'Allier (SMEA, 2013; Virieu: *Agence de l'Eau (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, **Bureau de Recherches Géologiques et Minières (BRGM, 2005, ***Agence de l'Eau (AE) Rhône Méditerranée Corse, 2013b; Ammertzwiller: *Chambre d'Agriculture du Haut-Rhin, 2008, **Agence de l'Eau (AE) Rhin-Meuse, 2009; Val-de-Reuil: *Communauté d'Agglomération Seine-Eure (CASE, 2014, **Levinson and Weiss, 2012, ***Safer Haute-Normandie, 2008.

	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%***

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

Table 5
Collective action process and outcomes in the six cases.
Sources: Allier: *Interviews, **Syndicat Mixte des Eaux de l'Allier (SMEA, 2015; Virieu: *Interviews, **Agence de l'Eau (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, **Fédération Nationale d'Agriculture Biologique (FNAB, 2014.

	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**

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 (Communauté d'Agglomération Seine-Eure (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 (Fédération Nationale d'Agriculture Biologique (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.

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 Tables 6 and 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; Agence de l'Eau (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-

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).

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 McCann, 2012). In the Allier

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).

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.

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; Agence de l'Eau (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 (Agence de l'Eau (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; Agence de l'Eau (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 (Agence de l'Eau (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 (European Court of Auditors (ECA, 2011; Kuhfuss 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 (Giovanopoulo 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.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gloenvcha.2019.101970.

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