Review article

The social drivers of cooperation in groundwater management and implications for sustainability

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ABSTRACT

The present article develops a methodical literature review on the social and behavioral dimensions in common-pool resources (CPR) cooperation, especially in groundwater management. It is built upon the revision of ninety-five articles published in peer-reviewed journals related to water, collective goods, common-pool resources, and natural resources economics. The time span covers the published books and articles from 1964 until 2018 and makes special reference to Hume (1898) explanations on how complicated the maintenance of resources used in common is. If sustainability in CPR management programs is pursued, drivers for cooperation should be understood to make it manageable and operationalizable. Suggestions are made in terms of the classification of the drivers for cooperation, namely instruments, conditions, components/strategies, and assumptions. Apart from presenting the literature reviewed, the implications for CPR sustainability are discussed. Aquifers present different hydrogeological characteristics, subject to complex social extraction decisions and physical changing circumstances such as climate change and climate variability. Groundwater conservation and experimental settings should not only reflect the complex physical interrelated elements, but the complex social institutions and rules governing the extraction patterns.

1. Introduction

Although it is tempting to view groundwater management as an infrastructure provision problem, continuing to focus on this issue in such a way, would be to mischaracterize the nature of the resource. In situations of water scarcity, supply enhancement infrastructure to improve water provision is observed in developing countries like Colombia, Brazil, Paraguay, Mexico; Middle East countries (OECD, 2017a). Aquifer recharge, water wells deepening, new boreholes construction and other engineering activities dominate the socio-political setting in groundwater management. Besides infrastructure or supply-side dimensions, the rules and institutions governing the common-pool resources (CPR) play a fundamental role in resource management. The extant groundwater management approaches should no longer overlook social institutions and behavioral dimensions shaping the cooperation in water resources conservation. Infrastructure and institutions might be complementary in searching for aquifers sustainable management approaches and to face aquifers overexploitation at global scale.

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An urgent call is made on the need to find hands-on alternatives to promote sustainable management of aquifers and prevent resource overexploitation. The evidence documents the existence of disseminated groundwater resource overexploitation in dry regions around the world (Barlow and Leake, 2012; Meinzen-Dick et al., 2016; OECD, 2017b). Groundwater plays an increasing role for irrigation in the agricultural sector in semi-arid regions; it has recently reached a 38% of global irrigation use and water from aquifers provides fresh water for around half of the global population (OECD, 2017b; Siebert et al., 2010). Surface water volatility and weather shocks will expand the role of groundwater in current and future irrigated areas. As a result, several regions that do not significantly use groundwater for agriculture, will likely do so in the future and risk facing the same challenges, currently experienced in the regions which already use groundwater intensively (OECD, 2017b).

Part of the problem lies in ascribing the scarcity challenges as a supply-side issue. Conventional responses to scarcity include engineering solutions, which in turn, will not always supply keys to avoid observed overexploitation, since the aquifers cannot be exploited in perpetuity. The top-down hierarchical central environmental authorities’ approach may continue being unfruitful in controlling dispersed borehole construction and groundwater extraction. Balanced supply-enhancement infrastructure and water consumption curbing might go with possible sustainable management of CPR. By definition, in Common-Pool Resources it is costly to exclude potential beneficiaries from obtaining benefits from their use (Gardner et al., 1990) and each person subtracts from the quantity of resource units available to others (E. Ostrom, Gardner and Walker, 1994). Since the aquifers’ overexploitation is clear worldwide, understanding the nature of the resource in consideration is needed.

Groundwater access entails a certain competition for resource system units, the depletiable character of most aquifers demand its conservation. Aquifers’ protection requires that stakeholders cooperate in avoiding overexploitation; cooperation inevitably requires that the interactions of multiple actors lead them to formal or informal agreements. However, this cooperation is at odds due to the free-rider problem and the coordination costs. Consequently, instead of simply finding supply-side solutions, water managers should face the core issue of responding how to increase cooperation towards sustainable groundwater access and consumption.

The access to natural resources used in common such as groundwater, inevitably bring about water users’ interaction and organization (Axelrod, 1984; Knight, 1992; V. O. E. Ostrom, 1977). Access to CPR involves the implementation of formal, informal, and autonomous social rules by communities and usually water authorities play a role in promoting resource conservation and regulating water access. Which are the conditions to avoid CPR overexploitation? Which are the conditions to reach stable cooperative attitudes and actions in conserving water from the ground? In CPR as groundwater, since individuals cannot be prevented from benefiting, cooperators and free-riders use to interact and live in the same communities. While the latter use to lurk at the former to benefit on the effort of others, the temptation to free-rider is present (Ostrom, 2015; Schlager, 2002). Individual cooperation tends to be unstable. This is, there is a latent incentive to detach from a strategy of cooperation and the defects or free-riders, have few incentives to move away from a strategy of non-cooperation (Elster, 1985; E. Ostrom, 1998b); Cooperators may not maintain his/her cooperative attitude in conserving the resource, which implies cooperators not necessarily will follow a steady conservationalist behavior in the long-term. Relevant question with sustainability implications is being a matter of inquiry in the literature.

Scholars have found promising responses to the social problem of managing CPR. Results demonstrate that individuals using CPR deviate from egoistic and selfish behavior predicted by the economic theory (Gardner et al., 1990; Ostrom, 2015; Velez et al., 2009). Economic theory predicts that every individual rush for extracting the most of the resource in the present, because the remaining stock might not be available in the future (Hardin, 1968; Negri, 1989; Ostrom, 2015).

Giving answers to previously suggested questions has long tradition among researchers, who focus the explanations for cooperation on drivers such as reciprocity (Axelrod and William, 1981; Axelrod, 1984; Hamilton, 1964); trust on others (Cox, 2004); ability to communicate (Abrahamse and Steg, 2013; M. A. Janssen, Holahan, Lee and Ostrom, 2010; M. Janssen, Lee and Tyson, 2014; E. Ostrom, Gardner and Walker, 1994; Sally, 1995); capacity of communities to devise their own rules and institutions, to self-manage natural resources (Isaac et al., 1994; Ostrom, 2015; E. Ostrom, 1990); inequity aversion (Cox, 2004; Fehr and Schmidt, 1999; Velez et al., 2009) and other causes that explain cooperation in CPR management.

Based on the criteria of pursuing sustainable aquifer management through applicable and manageable strategies, a claim is made on the need to organize the existing literature on CPR drivers of cooperation. For this aim, the present article develops a methodic literature review on the nature of social and behavioral dimensions in groundwater conservation. It is built upon the review of ninety-five articles published in peer-reviewed journals related to water, collective goods, common-pool resources, and natural resources economics. The time span covers the published books and articles since 1.896 since Hume’s explanations of how complicated is endeavoring in designing and implementing activities to maintain resources used in common such as meadows.

The reminder of this article is organized as follows. Section I includes the present introduction in which the existing gap in literature is presented. The role of social institutions and working rules are discussed in section II, in which the evolution of institutions and its role in reaching sustainability are emphasized; since social, environmental and economic circumstances use to change, similarly, institutions are expected to follow the trends of changes. In section III, the drivers of cooperation are discussed. Fig. 1 is used as a pivotal instrument to describe the social and behavioral drivers for cooperation in CPR management. Apart from presenting the literature reviewed, the implications for CPR sustainability are discussed. Aquifers present different hydrogeological characteristics that become them in renewable or non-renewable resources, subject to complex social extraction decisions and physical changing circumstances such as climate change and climate variability. Most studies dealing with the understanding of social and behavioral dimensions of cooperation in CPR, are based on field, lab and framed experimental settings. Thus, a discussion on the way how empirical work can be improved in incorporating the complex socio-physical interactions that characterize CPR is presented in section IV. In the final sections, discussion and conclusions and future research agenda are briefly described.
Fig. 1. Institutional design for sustainable CPR management and cooperation.
2. Social institutions in groundwater overexploitation

Social institutions are present whenever we work or live together (Knight, 1992) and solutions to CPR problems inevitably involve some form of organization to ensure collective decisions that can be enforced against all users (V. O. E. Ostrom, 1977). The access to water resources used in common, imply making interrelated actions between water users. Economic theory predicts selfish behavior from economic agents pursuing their own benefits. Evidence suggests the existence of cooperative attitudes and a plethora of examples, showing how individuals self-organize in pursuing collective and productive outcomes (Ostrom, 2015). Self-organization reflects a sort of interdependence and true interest on others’ behaviors, since individuals hold expectations about the behavior of others (Runge, 1984).

CPR scholars claim that some communities have successfully reached productive outcomes in managing their commons, while overcoming the temptation to be a free-rider on the contributions of the others (Ostrom, 2015; Schlager, 2002). On the opposite side, many other communities and governments have failed in pursuing productive outcomes (E. Ostrom, 2002; 2008a). In some cases, communities have overtly tried to self-manage, while others have not intended a trial-and-error process of self-organization.

Failures in productively managing the commons, are part of the predicted tragedy of the commons (Hardin, 1968). Different authors, from the assumption that all CPR are overexploited, question how privatization has been agreed as the only solution (Stevenson, 2005) or whether state-owned management is the solution to avoid this result (Ostrom, 2015; Schlager, 2002). Based on such gloomy forecasts, not surprisingly, policies aimed at averting the tragedy of the commons, called for the intervention of external actors, because the acting individuals under rationality assumption, are not able to liberate by own efforts and an external agent does (Ostrom, 2015; Schlager, 2002). Rather a robust centralized authority is essential to protect and enhance the viability of natural resources (J. C. Cárdenas, 2009; Schlager, 2002).

Some dry regions in Western USA, Middle East, China, Latin American countries, and other regions of the world, are experiencing external interventions as prescribed to avoid the so-called tragedy. At the same time we are experiencing clear evidence of overexploitation of groundwater resources (OECD, 2015).

After facing the constant extraction by urban communities and farmers living in dry regions, little is known about the social and institutional dynamics leading to aquifer overexploitation. Actually, in developing countries there exist external norms and regulations pretending to ensure sustainable use to avoid exhaustion of groundwater (OECD, 2015). Policy measures include, limited use by allocating water quotas by periods of extraction and the negation of extraction permits, when water authorities consider that certain physical hydrogeological conditions are not met. However, to the extent that the majority of individuals do not request permits or pass over regulations (Foster et al., 2009; Sandoval, 2004; World Bank, 2010), extraction dynamics behave as a no limit to entry. Accordingly, we are facing a heterogeneous common resource, with certain open access characteristics predestined to exhaustion. Simultaneously, we are exhibiting the existence of rules from outside the communities, pretending to avert commons’ tragedies in state – owned resources, through limitation of entry and assignation of quotas. We may say that the property scheme of groundwater is heterogeneous, in the sense that the water users who request the permits to extract the water, treat the resource as a centrally-managed resource, while the “illegal” appropriators treat the groundwater as an open access resource, without any coordinated management.

Social dimensions of overexploitation in different regions are made patent in different circumstances. For instance, the incomplete complies of the external rules (permits to extract); in the perception about the resource value and the materialized extraction (intensive extraction) and, in the perception about the role of environmental authorities dictating norms (top-down hierarchical management). More outstandingly some social dimensions have operated, via communities' own rules and institutions devising. Rules and institutions have been subject of inquiry by scholars, while overexploitation has remained subject to engineering analysis.

Rules from outside approaching from central water authorities are expected to avoid the collapse of natural resources, while promoting its conservation and regulation compliance. We may not necessarily assume that there is a clear and effective delivery process of new regulations to be abided by every single water user. Some proportion of urban and rural water users have a certain lack of knowledge about rules and regulations in place (Ostrom, 2015) and the daily interaction in accessing water resources, entail the device of their own rules. But not certainly the overexploitation of groundwater resources, corresponds to a clear example of failed central regulation from water authorities. Thus, a co-existence of internal/social rules and institutions in combination with external rules, still unable to avoid overexploitation in specific territories, is hypothesized.

Institutions refers to the rules and norms that guide the interactions among us and the environments that sustains us (Anderies and Janssen, 2013), more widely it refers to the set of working rules that are used to determine (...) what actions are allowed or constrained, what procedures must be followed, what information must or must not be provided, and what payoff will be assigned to individuals dependent on their actions (Ostrom, 2015; E. Ostrom, 1986).

Working rules imply social institutions are present during the social interdependence (Knight, 1992) between resource users. In case of institutions are stable, and this stability is of common knowledge by all members of a community or among a group, this condition facilitates the type of attitudes requested to succeed in cooperating (Knight, 1992). Achieving mutual cooperative behavior under stable conditions, rely on the real possibility of continuous interaction among the actors (Axelrod, 1984). Stable institutions are relevant to achieve the benefits of acting together while cooperation is an ideal state in managing common resources. However, the institutions and the cooperation evolve (Axelrod, 1984; Ostrom, 2015).

The evolution of social institutions may have implications in reaching sustainability. Actual overexploitation of groundwater resources in some dry regions in Western USA, Middle East, China, Latin American countries, may reflect a detrimental evolution of social institutions in managing the resource. The social institutions have the capacity to influence the society’s ability to get used to changing circumstances (Spencer, 1969). Changing circumstances include population growth the competition among communities for available
resources (Spencer, 1969),\(^1\) climate change and climate variability generating tensions for water use at local and regional levels (Bates, Kundzewicz, Wu and Palutikof, 2008b; Shen and Wu, 2016; Yang et al., 2016) and increasing group sizes which tend to influence cooperation\(^2\) (P. E. Oliver, 1993; Olson, 1971).

The challenge with the inevitable changing circumstances, rests in how changes influence reaching sustainable outcomes in collective action. Collective action problems relate to situations of social dilemmas. A dilemma is present when an individual each time perceives a greater utility or payoff when he/she chooses a defect strategy instead of a cooperative strategy; however all individuals are in a better situation if all decide to choose the strategy of cooperation than defecting from this (Dawes and Messick, 2000). Social dilemmas exist when individuals interact in decision-making, and they are challenged by options in which the short-term egoistic interest produces outcomes leading all individuals in worse condition than alternative cooperative options (Ostrom, 1998). The challenges with social dilemmas lie in how individuals may adapt to changing circumstances. Thus, evolving changes may impact the social institutions in place and time, which should be a matter of inquiry. One may suggest the need to inquire other ways around also; this is, how social institutions impact the evolving changes, especially the effects of changes.

Population growth spurs the competition for resources by larger groups. Climate change alters hydrogeological variables such as recharges, which in turn affect wells productivity and physical and economic\(^3\) scarcity. Put simply how evolving social institutions alter the stocks and flows of the aquifers through time and space. The first impression we may have about the relationship between institutions and changes, is perceived in the evident overexploitation of aquifers as appointed by (OECD, 2017b; Siebert et al., 2010). Notwithstanding, in this relationship there might not be a straightforward connection and causal relations. In the evolving and dynamic changes looming from climate change, water scarcity and more competition for the resources, the social institutions and rules are not inert.

The working rules in place and time are not static, since some communities endeavor in a trial-and-error process to manage resources (Ostrom, 2015). The devise and implementation of social institutions are not straightforward, especially when physical conditions change. In sustainability challenges, understanding the extent to how social interdependence evolves to create new rules is needed. I refer to productive rules that lead to intended collective action, to achieve sustainable outcomes in managing the groundwater resources. People may access water from different sources; individual access to tap water at private households is different from collective efforts to appropriate water units from a CPR. Devising productive institutions and incentives to conserve the groundwater may differ from institutions in access to tap water (see (Asprilla Echeverría, 2020) and Chapter 2 – Social drivers of urban water consumption).

2.1. Individual and collective incentives for cooperation

The connection to a public water network to access tap water, produce different saving mechanisms (C. Smith, 2013; Ternes, 2018) and diverse conservation incentives to individuals; in comparison to accessing water from aquifers by own efforts. Sparing water use patterns are scarce among people accustomed to fresh running water into household taps, which is seen as “naturally” abundant in many rivers (C. Smith, 2013; Watson, 2017). People are accustomed to water's affordances as a good and fewer are accustomed to water as a scarce and a valued resource (Harlan et al., 2009). Meanwhile, the reliance on limited groundwater supplies likely makes private wells sites of more cautious water usage (Ternes, 2018).

Consumers connected to the grid perceive the water supply as a shared commodity (Basmajian, 2014), while consumers relying on groundwater, manage the water as a common-pool resource (Meinzen-Dick et al., 2016; Ostrom, 2015; E. Ostrom, 2008b). The latter allocate time and effort to collect water, to consume later and the former, just consume and pay tariffs without producing any physical effort to access it.

This difference might be seen as a contrast between accessing and consuming water by public utility provisions and a sort of individual management (Ternes, 2018) to extract water from aquifers, store and consume the resource. The individual management involves investing in equipment and infrastructure and allocating financial resources, which after a costly effort, cautiousness and careful management of the resource would be expected, as appointed by (Ternes, 2018). A cautious management is expected from knowing the limited character of groundwater supply and in turn, the conservation of the resource is expected. This means that investing resources in building wells and extracting limited natural resources from aquifers, would provide the basis for individual conservation incentives. Notwithstanding, water from aquifers brings about a collective character in extraction, involving the action and interaction of different private individuals, households, agricultural and industrial users.

The groundwater extraction by different types of users entails the production of externalities arising from private exploitation. Individuals pursuing to collect water from the ground, generates two causes of non-static inefficiency in managing the property of a common aquifer: an externality arising from the pumping costs and a “strategic externality” that emerges from the race between resource users to hold the groundwater stocks (Negri, 1989). That is, in groundwater ownership a “rule of capture,” disincentives individual groundwater users to overlook the combined consequences of groundwater extraction, and generates incentives to continue using the water from the ground before another party does (Donohew, 2005).

The natural resources economics theory predicts that every individual will rush for extracting the resource and consuming the most of it in the present, because the remaining stock, might not be available to each one in the future (Hardin, 1968; Negri, 1989).
This strategic behavior of competition for groundwater reserves lead to overexploitation of the resource (Negri, 1989). Notwithstanding, one may argue that between strategic behavior and overexploitation, there is not such a straightforward implication. This provoking argument offers the opportunity to do further inquiries on the behavioral regularities stemming from the evolution of rules, the institutions and subsequent overexploitation.

Where resource use is unrestricted and many users are present, overexploitation results as a tragic consequence. This dire prediction was appointed by (Hardin, 1968) in his analysis of grassland use. Hardin concluded that every herder is embedded into a situation that induces him to augment the size of his herd in an unrestricted way, in an environment that is bounded. Hardin’s outstanding result, revealed a clear example of how individual interest overcomes collective interest, in the sense that every herdsman has incentives to add another animal to the open access grassland. This type of incentive is present in spite of the marginal revenue of every animal added is less than not adding it, when sustainable yield has been reached (Stevenson, 2005).

The degradation of natural resources has been attributed to the tragedy of the commons; similarly it has been accepted as the source of dire predictions for natural resources accessed in common (Schlager, 2002; Stevenson, 2005). Different authors, from the assumption that all commonly used resources are overexploited, conclude that privatization is the only solution (Stevenson, 2005) or state-owned management is the solution to avoid this result (Ostrom, 2015; Schlager, 2002). Based on such gloomy forecasts, the intervention of external actors is requested because individuals by themselves are not able to liberate by their own efforts and an external agent does (Ostrom, 2015; Schlager, 2002). To challenge the definitions of natural resources issues and decisions made by individuals, evidence has proved that individuals are able to devise their own mechanisms, institutions and rules to manage commonly used resources (Ostrom, E.; Gardner, 1994; Ostrom, 2015; E. Ostrom, 2008b; Schlager, 2002) as they are not always incapable, confined in tragic situations created by themselves, nor are central governments all the time almighty and all-knowing (Schlager, 2002). Likewise, the models resembling the tragedies of the commons are based on individuals who make independent decisions; consequently these models fall short in not capturing the opportunity of cooperation (Schlager, 2002). Most clearly Hardin’s tragedy argues that without external influence, individuals would not have enough incentives to cooperate and avoid exploitation.

The essential problem of cooperation in managing a CPR, is how to reduce the joint cost of extraction and increase the joint benefit of cooperation (V. O. E. Ostrom, 1977). The overarching commonality across situations of using scarce resources, refers to the need that all beneficiaries should share the long-term gains and the short-term losses (Madani and Dinar, 2012). Institutional facilities must be established to change the structure of incentives and deterrents (V. O. E. Ostrom, 1977) in collective action to manage CPR.

Water resources used in common, have been subject of analysis by scholars aiming at understanding the nature of collective use and collective action. Water resources such as aquifers, canals, lakes and fishing grounds, entails a common interest of individuals. Resource users intrinsically expect that the resources are always available, since the resources are the sources of fresh water, fishing, environmental amenities and other types of benefits. The character of common use encompasses different elements worth to note. There exists a common interest in resource preservation; there is not one but many individuals pursuing its extraction to reap the benefits of using it, and there exists a group concerned to maintain a shared interest. As happens in public goods, the resources are categorized by their jointness of supply and the consumption is made by distinct groups (Runge, 1984). Inside the groups, it is impossible to reject any individual from using or consuming the resource (E. Ostrom et al., 1994; Runge, 1984; Schlager and Ostrom, 1992). A group member can make use of a shared and divisible resource, creating a dilemma that leads to the exhaustion of the resource (Ostrom et al., 1994).

Social scientists generally assumed that there was a straightforward convergence between the interests of individuals and the interest of the groups (P. E. Oliver, 1993) and in case of groundwater, private wells’ owners relying on limited groundwater supplies, are assumed to be cautious of water usage (Ternes, 2018). A careful use of water may result as a conservationist group norm in which all CPR users share a unique common interest. However, being acquainted with group norms and becoming it into a working rule are two distinct issues. More outstandingly, turning it into a stable attitude that matches individual and group interests, that overcomes the egoistic temptation to free-ride on the efforts of others is a complex issue.

Appealing to the traditional economic theory, people, in spending their limited budget, act in their own interest, displaying egoistic behavior. Thus, individuals would not voluntarily contribute to water resources conservation. Individuals would not allocate financial resources to maintain waterways, to recharge aquifers, to let the aquifer static-level recover after sustained extractions and will not implement other necessary investments to guarantee sustainable water sources use. The natural tendency of individuals to reject voluntary contribution to commonly used resources, explains the imposition of coercive taxation (P. E. Oliver, 1993) and the justification of the state, because people would not successfully cooperate in realizing common interest (Hardin, 1968; Taylor, 1976, 1987).

In CPR many users are present and it is hard to reject users or bind the extraction of resource units (E. Ostrom, Burger, Field, Norgaard and Policansky, 1999) in public goods (PG), once it is delivered to one of the members of the group, the resource cannot be withdrawn from another member (Hardin, 1968) or put simply once the good is provided by one member of the group, the others perceive the benefits of provision, no matter whether he/she provided it too. The non-excludability in perceiving the benefits of CPR and PG provision, motivate rational individuals to behave as free-riders on the effort of others (J. C. Cárdenas, 2009; P. E. Oliver, 1993; Ostrom, 2015; Taylor, 1987).

3. Drivers for cooperation in groundwater sustainable management

In case sustainability plans to manage aquifers are pursued, the understanding of the drivers for cooperation is suggested. Some drivers are referring to social capital issues that might be difficult to implement, while others are more practical and tangible which in turn would result in more operationalizable in practice.
The drivers for cooperation elaborated and discussed in the literature can be classified in four categories. The drivers that lead to explain cooperation in CPR management, correspond to different levels of materialization. To design governmental interventions aimed at promoting efficient uses of CPR at local level, an adequate understanding of the incentives and strategies by the users of the resource is required (Velez et al., 2009). For instance, conditions for cooperation such as reciprocity may incentivize a cooperative attitude amidst water users; but if assumptions such as low transaction costs are not met, efforts to coordinate users for cooperative management may gradually disappear.

In Fig. 1, the above classification is made on the drivers in four groups: instruments, conditions, components/strategies and assumptions. Instruments refer to the palpable tools that allow designing and maneuvering a program to promote groundwater conservation. Instruments in place may arise from water authorities, communities and individuals. Conditions make reference to the key cultural patterns and structural characteristics of social relationships. These might be deemed as necessary to sustain cooperation. Assumptions are key sensitive issues which are expected to work for stable cooperative behavior in groundwater use. In some cases, if relevant assumptions are favorable, individuals might not find enough incentives for cooperation and decide to resign. In case of high transaction costs, trust in others is low or the perceived net gains from CPR is lower than others, some actors may avoid getting involved in collective action and the regimes to administer the resource may not be implemented or ill-timed in its adoption. Similarly it could be changed with more binding constraints or the cooperation may erode (Ayres et al., 2018; J. Cárdenas, 2009). Components and strategies correspond to relevant decisions and activities needed to improve the local circumstances, to facilitate or enforce cooperation. Drivers allocated to each four groups, do not prevent the possibility to find some cases in which, for instance a strategy is connected to an instrument; or an assumption is dependent on a condition. Similarly, the drivers and its relationships occur under an institutional setting and a context set by nature.

Nature governs the groundwater balance equation. This equation is influenced by socio-physical interactions. Groundwater as part of the hydrological cycle, depends on recharges to ensure available stock; meanwhile, water tables depend on extractions, the aquifer geological characteristics and the discharges to surface water bodies (see central part in Fig. 1). Social and physical characteristics of water bodies system may change through time. Changing circumstances may arise from climate change, climate variability, army conflicts, technological changes, population growth or migratory events. In this research, special attention is paid to the effects of socio-physical changes. As examples of changing circumstances and its effects, one can mention population growth stimulating the competition for resources by larger groups, which may cause aquifer depletion. Climate change altering aquifer recharges, which in turn affect wells productivity and physical and economic scarcity. Migration to urban areas (Lahariya, 2008; Lucas, 2004; Todaro, 1969) in the developing world will exert more pressures on urban water demand. Technological changes in water extraction may increase extracted volumes; technical changes for water saving at household or agricultural levels, may produce the so-called rebound effect.

Thus, changes and its effects may spark the design of social institutions able to manage the consequences of changes in water stocks, water availability, scarcity, and water flows. The importance of understanding how evolving social institutions alter the stocks and flows of the aquifers through time and space is suggested. Water stocks and flows are the factual realizations of groundwater management systems. These realizations make up the observable effects of the changing circumstances among social institutional settings. In the definition of social institutions, stakeholders determine which actions are allowed or constrained (Ostrom, 2015; E. Ostrom, 1986). However, the undertaking of actions should not be at will exercised if the physical-needed conditions are not met locally in terms of flows and stocks of aquifers. For this reason, the water availability and, so the water balance is central, because it determines water stocks (inflows driven by recharges) and water extractions (outflows). Despite different rules and institutions to sustainably manage aquifers can be designed; the physical limitations of water balance governed by nature, impose binding limits to water extractions.

In summary, for adaptive and stable social institutions that lead to sustainable CPR management, we need to work out an effective combination of the four categories of the drivers of cooperation. Thus, an institutional design configured by assumptions, conditions, strategies and instruments, may be arranged to put to work at local level. Notwithstanding, since social and legal institutions are already in place (see inner rectangle in Fig. 1), the four groups of drivers may help in re-configuring a transition towards a new generation of institutional arrangements focused in sustainable CPR management, centralized in stimulating cooperation.

3.1. A. Sustainability of CPR among existing social institutions

Different scholars have made outstanding contributions to explain the drivers for cooperation and groundwater resource conservation. Drivers to cooperation go further than classical economic theory prescriptions, which states that budget constraints, prices and preferences will lead to resource demand attenuation (Pollitt and Shaorshadze, 2013). Since Hume’s explanations of the human condition, more clues have been found to understand human behavior in resources accessed in common (Hume, 1896). Stated the “difficulty and impossibility that a thousand persons should agree in an action of draining a meadow used in common, it being difficult for them to concert so complicated a design, and still more difficult for them to execute it; while each seeks a pretext to free himself of the trouble and expense, and would lay the whole burden on others”. Hume asserted relevant and contemporarily studied issues such as group size, interests, coordination, free-riding and communication. Hume started from the assertion that men are mostly governed by interest (McMillan, 1979).

Reaching cooperation in groundwater conservation, represents a situation in which individuals abandon the temptation to merely pursue their self-interest, in order to contribute to collective interest in managing aquifers. Accessing water resources used as a CPR, imply making interrelated actions between water users. This interrelation is guided by a set of rules and norms, more specifically by working rules that determine which actions are allowed or constrained and the corresponding payoff depending on actions (Anderies, J.; Janssen, 2013; E. Ostrom, 1986, 2015).
The norms and working rules are called social institutions. We may argue that the actual overexploitation of groundwater resources, occurred between internal institutions devised and evolved inside the communities and external institutions devised by central governments. Since the latter aims at avoiding overexploitation, in the former, actors may have different knowledge and point of view, punishments based on trust may be unmanageable, and the possibility to use conflict mechanisms may not exist (Patterson, 2017). Keeping this business-as-usual non-productive institutional relationship, do not guarantee the hydrological balance of aquifers, especially in dry regions exposed to climate variations. To achieve groundwater sustainable yield and particularly, to avoid causing a permanent state of imbalance in the hydrological budget of an aquifer (California Department of Water Resources, 2003; Gunn, 2012), cooperation and social-institutions inclination for conservation are needed.

How to devise stable social institutions to promote sustainable groundwater management? Responses are not simple and may depend on the management model under consideration. Three theoretical models named private property, central planning and CPR self-governance of water resources, have been subject of theoretical, conceptual and empirical analysis. Central planning for water management assumes the rationality of economic agents. This theoretical model is based on water demand functions and calculation of optimal extraction rates. Since individuals’ compliance is not straightforward, the main challenges for sustainability, refer to the need to develop a better understanding of the transmission mechanism, between extraction rates calculated or prescribed by environmental authorities and the actual extraction by water users. The private property model for water management does not reflect some relevant variables. Environmental externalities, social consequences of pumping externalities for low-income users, the effects of possible market power of some private agents, changes in water distribution and the capability to equitably adapt to climate variability, are quite relevant for sustainable water management as well. The CPR self-management approach has demonstrated that the temptation to free-ride can be reduced or overcome; a Social-Ecological System exists in which agents self-manage the System Resources and productive outcomes are achieved. Notwithstanding, not all communities are prone to self-organize and cooperation tends to be unstable. Thus, alternative models to manage the CPR and avoid its exhaustion are demanded.

The discussion whether implementing centrally managed instead of private property regime, may change according to hydrogeological conditions. It seems that the need to create a private regime of property rights for the groundwater resources, only appears when a water basin has reached a stage of steady overdraft (Donohew, 2005). Sustainability of groundwater brings about avoiding the unwanted condition of overdrafts. Under private property regimes, the value of scarcity of water from aquifers is highlighted; which is reflected in the market prices and allocations of water to its highest-valued uses as stated by Donohew. Anyhow, societies should ponder whether resigning to wait until aquifers are over-drafted or not, to start valuing groundwater and water scarcity.

In this section, the four categories of the drivers for cooperation are described. All drivers are needed since all of them correspond to interconnected elements having distinct functions and implications. This applies in case an aquifer sustainability program was planned and implemented. If instruments to promote cooperation were implemented in isolation, crucial intangible dimensions belonging to the social capital arena or external factors influencing decision-making would be missing. So, the intended social institutions about to be built would skip indispensable foundations. More importantly hidden social and cultural values shaping communities’ actions and decisions in water management, may work in favor or may impose hurdles to participation in program implementation (Meinzen-Dick et al., 2016; T. Van Der Voorn, 2008). Thus, donors’ attempts of technology transfer cannot assume communities are passive actors when external values are transferred to them (T. Van Der Voorn, 2008). Similarly, if a water management sustainability program focused only on cultural and social dimensions, it would miss the tangible elements aimed at making cooperation a workable stage in resource management. This is, tangible and intangible dimensions are similarly proper for a new generation of water management programs, and social aspects and institutions cannot longer be overlooked. As stated above, the access to common-pool resources inevitably brings about water users’ interaction and organization (Axelrod, 1984; Knight, 1992; V. O. E. Ostrom, 1977) and social institutions are present amidst these interactions (Knight, 1992). More suggestively, the formal and informal institutions consist of cognitive, normative, and regulative pillars that provide firmness to social behavior (Scott, 2014). However, most water management programs put emphasis on regulatory aspects only, which in turn make it inefficient because people ignore regulations, and regulatory systems are hindered due to complex legal procedures to control scattered water extractions (Sandoval, 2004; World Bank, 2010). Rules and laws as part of regulative pillars, are symbolic systems carried; but other carriers such as relational systems, activities and artifacts, configure regulative, cultural-cognitive and normative pillars as well (Scott, 2014). Thus, in the cross-tabulation between three pillars and four carriers, more than twelve management aspects appear and rules are only one of them (see (Scott, 2014)).

Table 1, Table 2, Table 3 and Table 4, summarize the existing empirical and theoretical work related to CPR management and cooperation towards conservation. The practical implications for sustainability are shortly described and simultaneously, some critiques are presented and key elements to take into consideration to discuss how feasible the drivers for cooperation are.

3.2. Instruments to stimulate cooperation

Provision of information and especially providing feedback has found to be a relevant driver for water conservation (Abrahamse and Steg, 2013; Liu et al., 2015; Seyranian et al., 2015). Thus, feedback provision tends to show the adoption of similar behaviors by others. For instance a higher consumption by other individuals influences the adoption of high consumption by the participant, and feedback representing economical consumption led to curb consumption also (Van Dijk, De Cremer, Mulder and Stouten, 2008). These findings may be interpreted as being suggestive of group members to take on the “correct” action (Van Dijk et al., 2008).

When referring to correct strategy and normative feedback used by participants to define his/her own strategy, there exist some risks in how convenient the numbers in consideration are. The level of others’ water consumption might send a misleading signal about the optimal levels of consumption. This is, the consumptions of others as a reference number to guide consumption, not neces-
Table 1

| Instruments as drivers for cooperation in groundwater management and implications for sustainability. |
|--------------------------------------------------------------------------------------------------|
| **Drivers influencing cooperation**                     | **Authors**                     | **Practical implications for groundwater management and sustainability**                                                                 | **Critiques and suggestions to drive towards cooperation** |
| Communication and Face-to-face communication            | Sally                           | Individuals able to follow an institutionalized and costless-communication, can create spoken agreement to implement rent improving approaches and manage non-conforming players (Walker and Ostrom, 1989). Communication enhances the likelihood of individuals shifting from relatively self-interested decisions to more group-oriented ones (Cardenas et al., 2000). → Communication among participants involved in CPR management should not be overlooked. | Communication need some effort and time to be maintained (Walker and Ostrom, 1989). Creating and reinforcing norms and exchanging mutual commitment, are significant processes that allow communication to be more effective (E. Ostrom, 1998a). |
| Learning how to cooperate and trial and error process   | (E. Ostrom, 1990)               | In case of extremely erratic situations, a time-consuming trial and error process is desirable before individuals are able to devise their own rules aimed at producing considerable positive net revenues over a sufficiently long time horizon (Ostrom, 2015; E. Ostrom, 1998b). → Sustainable management of CPR should not expect straightforward achievements after first attempts in program implementation: failures are part of learning process. | To reach sustainability, the lessons learnt in successful and failed attempts to conservation should be documented or transmitted between generations. In endeavoring to try to devise ways to cooperate, we need for example an individual willing to ignite collective action. |
| Group identity and group size                           | Dawes et al. (1990)             | In some circumstances, the size of the group affects positive or negatively⁴. The greater the group size, the amount of collective benefits provided will become increasingly suboptimal and the absolute amount of collective benefits provided will decline (Olson, 1971). → The size of the groups with whom negotiations/agreements are made should be arranged properly. | The difficulty to concert to agree with thousand people on maintaining a resource used in common, and even more complicated for them to accomplish it; while each individual strives to avoid the concern and cost, and would prefer to place the entire problem on others (Hume, 1896). |

⁴ Previous to know how the size of the group will affect the collective action, it is suggested to get acquainted of the characteristics of a specific case (P. E. Oliver, 1993).

sarily correspond to the socially optimal level of water consumption, especially when the reference of consumption levels by others is higher than optimal.

Consequently, a simple feedback on others’ water consumption without meeting each other, would not result in sufficient opportunities to communicate. People might communicate to reach certain agreements on how to coordinate efforts to cooperate in managing aquifers among the existing limits of the resource.

Allowing communication among individuals and especially face-to-face communication is one of the most clear drivers for CPR conservation and channel for promoting cooperation. Communication boosts the prospects of individuals to shift from quite self-interested choices towards group-oriented decisions (Cardenas et al., 2000). Individuals can contrive spoken covenants to implement rent improving tactics and manage non-conforming individuals (Walker and Ostrom, 1989). The main challenge to ensure sustainable management of groundwater, when allowing the ability to communicate between individuals, arises from the fact that communication needs some effort and time to be maintained (Walker and Ostrom, 1989). The format, framing and timing of communication is similarly a matter of careful design since what operates in some communities does not necessarily work in others.

Developing a communication design entails the need to understand the local contexts and the purpose of communicating the purpose of sustainable management. Sustainability of aquifers management may have different meanings in terms of socioeconomic context, weather conditions, storage equipment, extraction technologies used by community members. For instance, for low-income water users, there might be hidden institutions in water allocation because of alleged connivance of politics and economic sectors, so, they might conceive sustainability as a fair water allocation; if migration inflows frequently occur, already living households may per-
Table 2

| Conditions as drivers for cooperation in groundwater management and implications for sustainability. |
|---|---|---|
| **Drivers influencing cooperation** | **Authors** | **Practical implications for groundwater management and sustainability** | **Critiques and suggestions to drive towards cooperation** |
| Reciprocity | (Axelrod and William, 1981) McCabe et al. (1996) Hamilton (1964) Axelrod (1984) | An individual with the intention to pursue an approach of conditional cooperation, is pursuing an approach of reciprocal behavior (Velez et al., 2009). → reciprocal behavior is critical in designing CPR sustainability programs. | Attitudes such as reciprocity might not be enforced or easily incorporated/promoted to be put into practice. |
| Fairness and inequity aversion | Ostmann & Meinhardt (2007) Fehr & Schmidt (1999) Falk et al. (2002) Ahn et al. (2003). Fischbacher et al. (2001) Frey & Meier (2004) Chaudhuri et al. (2016) de Oliveira et al. (2015) Rustagi et al. (2010) (M. A. Janssen, 2013) Nikiforakis (2010) Villena & Zecchetto (2011) (M. Janssen et al., 2014) Sell & Wilson (1991) Runge (1984) | People resist inequitable outcomes (Fehr and Schmidt, 1999). → the underlying perception of inequity may ruin CPR management programs. | Attitudes such as fairness and inequity aversion might not be enforced or easily incorporated/promoted to be set into practice. |
| Conditional cooperation, Social expectations and Information about other actions | | Conditional cooperators adapt their behavior to the group they belong to. If some individuals decide to shirk, the others decide to shirk as well; if others cooperate, individuals will cooperate as well (Gächter, 2007). A conditional cooperator is able to decide on a small harvest if the person believes others likewise will conserve the resource and decide on harvesting a greater amount if he/she presumes others to do the same (Velez et al., 2009). → Sustainability would imply allowing individuals to know how other individuals have contributed to the provision of the collective good. | How to promote positive conditional cooperation in groundwater consumption? How to make sure that cooperators become a reference point for others’ behavior? |

Receives sustainability as forcing migrants to abide to working rules and to formal and informal institutions. If hydrological or meteorological droughts are persistent and rainfall are scanty, sustainability strategy aimed at balancing groundwater extractions to aquifer natural recharge would not make sense for farmers or households. If storage kits and technological tools are rudimentary, implementing a sustainability program based on measurement of data might result not applicable or unfeasible. Since physical and social circumstances tend to change, the designing of communication mechanism, should similarly adapt to the changes if the organization of the communities is expected towards CPR productive outcomes.

In case of extremely erratic situations, a time-consuming trial and error process is desirable before individuals are able to devise their own rules aimed at producing considerable positive net revenues over a sufficiently long time horizon (Ostrom, 2015; E. Ostrom, 1998b). The attempts to promote social institutions based on community self-organization, would fit into the category of instruments, because it may imply the need to disseminate a purpose through different communication strategies. The ones endeavoring in promoting the organization, may come from inside the communities or from external actors who dare to make a change.
Table 3

Assumptions as drivers for cooperation in groundwater management and implications for sustainability.

| Drivers influencing cooperation | Authors | Practical implications for groundwater management and sustainability | Critiques and suggestions to drive towards cooperation |
|--------------------------------|---------|--------------------------------------------------------------------|------------------------------------------------------|
| Transaction costs              | Coase (1960) and Libecap (1982) Ayres et al. (2018) | The reorganization of rights to solve the problem in assignation of property rights, will only be carried out, once the incremental value of production consequent upon the reorganization is higher than the costs that the rearrangement brings (Coase, 1960). → the costs of negotiations to reach mutual agreements should be monitored and managed in favor of sustainability management. | In the negotiation process to reach agreements, aggregate revenues do not exclusively explain this; instead individual benefits and costs and transaction costs do matter as well (Ayres et al., 2018). |

3.3. Conditions to reach stable cooperation

Individuals in situations of interdependence of outcomes are concerned with both their outcomes and the outcomes of others (Gallucci and Perugini, 2000; Runge, 1984), and reciprocity may reflect an array of conjointly contingent interchange of gratifications (Gouldner, 1960). The sustainability goals to avoid groundwater overdrafts, would benefit from reciprocal behavior of the water users who overtly express their preferences for conservation. The key tasks for the same water users belonging to communities relying on this resource, and key challenges for water facilities and water authorities, lay in promoting reciprocity in water consumption behavior. Reaching massive social transformation towards reciprocal behavior might be a fruitless mission or might take a long time, since this type of values are rooted in cultural patterns socially channeled and intrinsic reciprocity characterize preferences of individuals (Sobel, 2005). The same arguments might work for drivers such as fairness and inequity aversion, since these are part of the social and economic characteristics which might not be straightforwardly modified through conservation programs. Conceivably, drivers of this dimension works better as conditions for cooperation and not as instruments for reaching sustainable groundwater and common-pool resources use.

An individual with the intention to pursue an approach of conditional cooperation, is pursuing an approach of reciprocal behavior (Velez et al., 2009). Conditional cooperators, refers to individuals who are disposed to make more contributions to a public good when they perceive the others are contributing more (Fischbacher et al., 2001). In a CPR game, a conditional cooperater is able to decide on a small harvest if she believes others likewise will conserve the resource and decide on harvesting a greater amount if she presumes others to do the same (Velez et al., 2009). How to promote positive conditional cooperation in groundwater consumption? Allowing individuals to know how other individuals have contributed to the setting up of the good used in common, might be a productive way to disseminate cooperative behavior among individuals. This is, searching for individuals exhibiting cooperative behavior and reference them as massive cooperation disseminators, might work in promoting sustainable groundwater use.

Conditions for cooperative behavior might operate as prerequisites aimed at setting the scene for stable contributions to aquifers' conservation. Cooperation demands cooperation from others, because human behavior is not inert to what the others do in using a CPR. This is specially the case in situations of scarcity; if water is scarce and is used more intensively and wastefully by some individuals, chaotic events may result. In case of a prolonged drought persisting, a personal dilemma may crop up in terms, for instance, between the capacity to irrigate crops and avoid economic losses and the awareness of the need to reduce irrigation and put crops under risk of water stress. However, to some extent, climate variability and uncertainty, rainfall shocks and scarcer groundwater resources exert pressure on water users to implement adaptation strategies; consequently, pervasive groundwater scarcity trends might force water users to build adaptive social institutions and rules to persist under scarcity conditions. However, needed adaptive institutions from water users and other stakeholders, would require an adaptive management approach as well. The (re)design of adaptive institutions to climate change and its effects, is a key step; but an effective administration of changing conditions is crucial to make it long-lasting. Physical and social circumstances in water management tend to change and uncertainty prevails (Bates, Kundzewicz, Wu and Palutikof, 2008a; Colvin and Saifyman, 2007). Thus, adaptive management is capable of improving management of Social-Ecological Systems (SES), under unpredictable future conditions (Tom Van Der Voorn, Pahl-Wostl and Quidst, 2011). The adaptive feature lies in a cyclic and iterative policy development and implementation process able to sustain the changes (Tom Van Der Voorn et al., 2011).

3.4. Assumptions in support of cooperation

Adaptive social institutions may arise if some external factors work in favor of cooperation. Said this, a reference is made on the assumptions or positive expectations on key factors shaping stable cooperative behavior. If assumptions are not realized, cooperation might be at odds since daily life issues such as the existence of transaction costs, social and climatic uncertainty, climate variability and trust on others, are borne in mind before or after decisions are made on water allocations. People might adopt cooperative attitudes for a certain time, but if expectations on low transaction costs, trustworthy relationships and low rainfall shocks are not made patent, cooperative behavior towards water conservation might be abandoned.

Reaching stable cooperation levels in sustainably managing groundwater extractions entails the need to coordinate water users towards this purpose. This coordination, despite being costly as well, would reduce the transaction cost of reaching cooperation. Attaining groundwater management cooperation requires water users to renounce the lure to purely pursue self-interest, to contribute to collective interest in managing their aquifers. The essential problem of cooperation in managing a CPR has to do with reducing the joint
| Drivers influencing cooperation | Authors                  | Practical implications for groundwater management and sustainability                                                                 | Critiques and suggestions to drive towards cooperation |
|---------------------------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Graduated sanctions Monitoring rules | (E. Ostrom et al., 1994) (P. Oliver, 1980) | Rules for managing the resource include the imposition of penalties to individuals who defect from cooperative behavior. Sanctions may arise from the communities who agree and monitor it or from external agents. | Sanctions for adopting non-cooperative behavior based on trust and social interactions could be complicated to apply (Patterson, 2017). The existence of a controller coming from outside, crowded out behavior relative to others, which in turn lead to higher self-interest (Cardenas et al., 2000). |
| Pumping restrictions and timing in extractions | Stevenson (2005) Ayres et al. (2018) | Restrictions to water pumping and aquifer conservation, imply the definition of goals. Sustainability of groundwater resources is tied to calculation of aquifer safe yields (Donohew, 2005). The quantification of optimal extraction levels from the CPR system deserves special attention and more importantly, how to abide by these extraction caps. | Water users are more likely to come to an agreement on extraction limits where aggregate benefits exceed transaction and implementation costs (Ayres et al., 2018). It is obvious that the costs of reaching such an agreement will not be zero. What is not obvious is just how large these costs may be (Demetz, 2009). Negotiating costs will be large, especially when each hold-out has the right to work the land as fast as he pleases (Demetz, 2009). |
| Mutual agreements/commitments | (Leonard and Libecap, 2015) (E. Ostrom, 1998a) Demetz (2009) | Each community member is able to come to an agreement and restrict the level at which the land is treated, in case the costs of negotiation and policing are zero (Demetz, 2009). The costs of negotiations to reach mutual agreements might be rarely zero; consequently it should be monitored and managed in favor of sustainability management. | |
| Property rights, Groundwater rights and markets | Gordon (1954). Lin Lawell (2016) Donohew (2005) Hardin (1968) Kuwayama & Brozović (2013) Provencher & Burt (1994) | The tragedy of the commons is averted by setting a private regime in property combined with legal heritage (Hardin, 1968). The definition of property rights might work better during a state of sustained overdraft. Private owners recognize the value of scarcity of water from aquifers; which is exhibited over the market prices and allocations to its highest-valued uses (Donohew, 2005). Complete, measured, enforceable, and enforced property rights that consider the physical properties of the resource will induce the socially optimal rate of extraction in many cases (Lin Lawell, 2016). Property rights and water markets are weakly defined in developing countries and the cost of this definition may result in high and problematic to be digested. | Sustainability of groundwater brings about avoiding the unwanted condition of overdrafts. Societies should not resign to wait until aquifers are over-drafted to value groundwater and water scarcity. |
cost of extraction and increasing the joint benefit of cooperation (V. O. E. Ostrom, 1977). However, a sustainable CPR management rearrangement depends on balancing its own costs with the productive value increase that it likely entails (Coase, 1960). Such an arrangement demands a coordination process among resource users focused on groundwater sustainable management. Based on the socio-physical contexts of groundwater overexploitation, it implies moving from an uncoordinated, independent, and selfish water units appropriation, to a system of new social rules and institutions aimed at reaching stable productive outcomes. The purpose of the coordination is therefore, focused on comprehensive rules and social institutions capable of adapting water extraction decision making to scarcity conditions.

Social institutions may include but not limited to:

- Following the mandatory groundwater extraction permit.
- Restricting the number of wells on own lands.
- Limiting pumping extraction timing.
- Limiting pumping extraction rates.
- Devising mechanisms to resolve conflicts.
- Defining, monitoring and enforcing rules.

Issuing (new) rules and implementing and keeping institutional work takes time and demands role assignment, individual and collective efforts, and expenses. It entails the need to decipher the complex challenge of keeping individuals as steady cooperators. Cooperation should, indeed, be the unique route towards climate change adaptation and to its effects on water resources. Therefore, a new generation of adaptive social institutions should be an intended purpose and not a result of a sheer coincidence.

If groundwater systems, are about to continue exposed to shocks affecting water stocks and flows, we might say that this system demands iterative and adaptive social institutions to changing circumstances. This is, no matter how deep the water table is, we can inquire whether social institutions and rules adapt to changing water availability levels or not. Since changes in water availability may impact physical scarcity, the social dimensions of the groundwater extraction problem need to focus on socio-economic scarcity as well. Physical and socioeconomic scarcity are interrelated but dissimilar. The former refers to observed declination of water tables heading to exhaustion; the latter results from the relationship between the marginal extraction costs and the marginal benefits of consuming water units extracted; similarly, it refers to the cost of improving groundwater quality due to contamination with agricultural chemical inputs, salt-water intrusion and other sources that reduce water quality. So, the groundwater table might be close to the surface; but it may result in a socially scarcity due to the costs of purification. In summary, the need to understand social institutions and rules definitions under scarcity conditions is suggested. Conceivably, the changes or evolution of social institutions in time and place, might result as alternative adaptation strategies to climate change and climate variability.

In the social institutions’ adaptation to scarcity conditions, each water user may differently perceive alluded assumptions. Some caveats in terms of individual and collective decision making, should be expressed amidst discussed assumptions for cooperation in CPR management. In case social and physical expectations are not met, resigning from cooperation would not essentially rely on others’ behavior. If people observe that what affects their life and decision-making is not working in favor of them, they probably make a decision in isolation; this is, an individual perspective may operate without any organization or coordination with others. However, since the decisions made by water users might be observed through the time, some reactions may be provoked onto others as well. The expected increased pressures of climate change would force individuals to devise wise and evolved social institutions of water use rules towards climate adaptation. Right there is where the real challenge of adaptation lies. Adaptive and cooperative behavior to the inevitable changing circumstances, may be sparked when individuals realize that the unmet assumptions on climate variability result not being episodic, but long-lasting.

Consequently, if climate variations exert more pressures on the need to adapt to its effects in water flows and stocks; changes in status-quo practices on water extractions are similarly needed. New generation of groundwater management plans should work under an old lesson of nature, which refers to working within the limits of the aquifers resource systems. Aquifer recharge is limited, infiltration as well; reserves and water table are not unlimited, and indeed, groundwater resources are overexploited (Barlow and Leake, 2012; OECD, 2017a). If interrelated elements of aquifer resources are limited, water extraction should likewise be limited and congruent with the urgent need to define extraction caps as a concrete strategy to promote CPR sustainable management.

3.5. e. Strategies or components as building blocks aimed at structuring cooperation

Preventing aquifers over-exploitation and overdraft entails the definition of limits to withdrawals. The definition of limits might be possible in centrally managed aquifers and self-managed common-pool aquifers. In private property, depending on whether rights are demarcated as fixed quantities or a portion of a groundwater resource reserve or flow (Donohew, 2005), it may be conceivable to designate limits. Notwithstanding, converting extraction caps as pivots or cores of aquifer sustainable management is not a straightforward task. It might be a disruptive scheme to promote sustainability of aquifer resources. Centrally managed or private management might result irrelevant when it comes to humans characterized by multiple incentives, customs, knowledge, life principles and beliefs. This is especially the case when in contexts of scarcity, to some extent, individuals are/were accustomed to extracting higher-than-needed water quantities, and turning towards extraction caps entails breaking routines of water consumption patterns to which people are accustomed to.

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4 Changes may arise from population size, climate change, climate variability, variations in social preferences; which all seem to be inevitable.
Consequently, issuing extraction caps stands for a new social institution, that despite being well-intentioned in any aquifer sustainability plan; it demands an entire process to become it as a working rule. When existing working rules have been under operation for a long time, the promotion of new institutions delimiting extraction volumes, would demand a long time to be incorporated in users’ mental maps. This is not a minor issue since aquifer resource systems are limited and demand careful management. So, institutions should work under the limits of nature. Embedding extraction caps amidst already-existing rules and institutions in the communities, demands a smooth transition process, and strategies and components acting as building blocks to structure cooperation, are vital to sustain cooperative behavior.

If water extraction exists, monitoring mechanisms are vital to record objective measurements of inflows and outflows; sanctioning rules are useful to avert free-riding proliferation. Since conflicts may arise due to deviations from agreed extraction paths, some formal and informal mechanisms would be needed to avoid chaotic situations and anarchy. Consequently, mutual agreements and commitment towards cooperation shall be requested as part of cooperative efforts. It is obvious that the costs of reaching such an agreement will not be zero; what is not obvious is just how large these costs may be (Demsetz, 2009). In addition to this, since water users own their land plots and are in conditions to make autonomous decisions, the definition of pumping restrictions would be enforced or negotiated and for this aim the definition of property rights are important to make sure the interactions and political transactions are kept formally. Negotiating costs will be large, especially when each hold-out has the right to work the land as fast as he pleases (Demsetz, 2009). Consequently, there exists a challenge in matching or merging the right to extract water from own lands with the duty of abiding to an extraction cap due to the public interest of CPR.

Therefore, if a basin’s sustainable yield is the reference point for limiting groundwater extraction, it would entail that the rights to exert the pumping activity should not be greater than under unrestricted pumping situations (Donohew, 2005). Collective action is essential to effectively apply restrictions to groups of groundwater users, because pumps in summation are in better condition if following the restrictions to pump, however no water user perceives an one-sided incentive to diminish extractions (Ayers et al., 2018).

Notwithstanding most cases of water conservation policies in water savings, specific targets are not borne in mind (Olmstead and Stavins, 2009) and restrictions to water pumping and aquifer conservation, imply the definition of goals. Sustainability of groundwater resources is tied to calculation of safe yield. There is feasible hydrological information that can be assessed, for instance annual natural replenishment of aquifers and the groundwater reserves too (Donohew, 2005) and it is assumed this type of technical information, costly to assess, might be provided by water authorities instead of individuals and communities.

Finally, the drivers for cooperation presented in Table 1, Table 2, Tables 3 and 4, cropped out from different theoretical frameworks and methods. Notwithstanding, most studies dealing with the understanding of social and behavioral dimensions of cooperation in CPR, are based on field, lab and framed experimental settings. Implementing lab experiments benefit economic analysis due to different reasons such as comparing environments; find empirical uniformities as a foundation for new theory and use the laboratory as a setting for institutional design (V. Smith, 1992; V. L. Smith, 1976). In an experiment, the experimenter controls the environment using reward procedures, and controls the institution by means of the experimental instructions describing the rules of interaction of the participants (Cassar and Friedman, 2004; V. Smith, 1992). Subjects are free to make whatever choices they wish; these choices make up the behavior observed by the experimenter.

4. Water stocks and flows and experimental settings

Results and insights presented in Table 1, mostly arise from experimental settings. Some studies were performed in the field and others in lab environments. The suitability or the ability of laboratory experiments to resemble the real-life situations in managing the commons will not be discussed. The key point is the capacity of some lab experiments to closely represent action situations in groundwater management and cooperation for conservation. Experimental tools pose opportunities to comprehend properly the interrelationships between behaviors, institutions, and ecosystems (J. Cárdenas, 2009).

In allusion to hydrological information, it is important to emphasize that water is a natural resource governed by natural cycles. Although stocks and flows of water are influenced by human behavior, water continues falling and replenishing water bodies in accordance with hydro-meteorological conditions. Human decisions influence water stocks and flows in diverse ways. Public sector agencies entitled to provide water to water users, usually develop and authorize investments aiming at enhancing water supply (Griffin, 2006). Dams, river deviation, land use changes and agricultural and public utility infrastructures all have an impact on water stocks and flows.

The water stocks and flows in specific regions need to be understood and analyzed in their complex interrelationships between natural and social elements. The existing evidence explaining the determinants and drivers of cooperation in CPR, has done a partial analysis of the decision-making of individuals sharing a resource. Groundwater wells sourcing water for domestic and agricultural purposes have different physical properties (J Bear and Levin, 1967; Jacob Bear, 1979; Koundouri, P. y Xepapadeas, 2003). Well-depth, extraction costs, water quality, aquifer recharges, water flow and static level; are key variables governing aquifers productivity. The incorporation of this kind of variables and conventional issues in the water extraction practice, may ease the decision making in a more realistic way. Hydrological variables govern the economic and physical feasibility of water extraction through the time.

Given that hydrological components influence feasible and observable water extraction levels, promoting groundwater sustainability, demands the definition of extraction caps congruent with hydrological conditions. From another side, in most economic studies for groundwater optimal management, spatial location of boreholes is overlooked, and any water unit of water abstracted from the aquifers, provokes a similar marginal effect at all points of the aquifer, which is incorrect (Brozović et al., 2010). All these socio-physical issues should not be unnoticed in the decisions made on water extractions volumes. This is, limits of hydrogeological vari-
ables can be put to work for social decision-making on extractions. Bearing this in mind, experimental settings in which participants are asked to make decisions should be able to resemble these socio-physical issues.

The understanding of groundwater extraction should incorporate key missing variables in economic and social institutional analysis. Hydrogeological variables, spatial location of wells and the marginally differentiated impact of water extraction should be carefully incorporated in the socio-physical experimental settings for water conservation analysis. Recent evidence has intended to partially fill the complex socio-physical water resource use perspective gaps. Different scholars designed experiments to analyze the socio-physical interrelationships between the users of water resources, infrastructure and the cooperative behavior of water users (Anderies et al., 2013). Focus on situations in which actors share asymmetric locations compared to the CPR, such as irrigation systems. Since head-enders and tail-enders of irrigation canals produce asymmetric right to use to the water, in the interdependence on the resource, each actor has incentives to cooperate and reach favorable outcomes. The interdependence of incentives varies under environmental unpredictability that provokes uncertainty about resource availability.

The irrigation game is one of the most usual experimental settings where contribution to watershed is tested. In (Cardenas et al., 2011) four treatments are incorporated: baseline situation, communication allowed, high penalty imposed, and low penalty. The games explore the provision and appropriation decisions under asymmetric or sequential appropriation, complemented by a voluntary contribution mechanism experiment. The scholars follow the strong evidence reflecting how the opportunity to communicate influences cooperation and coordination (Cardenas and Carpenter, 2008; E. Ostrom, 1998a). The results indicate that in contrast to an imperfectly enforced regulation from outside, the most effective treatment corresponds to face-to-face communication.

As a means to provoke further discussion about the treatments in (Anderies et al., 2013; Cardenas et al., 2011) games, one might indicate the need to incorporate subtle variations in the treatments. Issues such as the scarcity of the water resource, the possible power relationships between actors, the differentiated cost of delivering the water to crops, the irrigation technology, and the possible social practices such as water sharing between neighbor producers, among other variables might influence the complex socio-physical dynamics in water accessed in common.

(Cardenas et al., 2000) designed and conducted different experiments aimed at studying the consequences of external regulation to control the quality of the environment at local level. The participants in the experiments were tested to choose the quantity of time (in months) they would employ in gathering firewood from a neighboring forest land. Individuals were able to recognize that firewood extraction would adversely affect the quality of adjacent water bodies due to looming soil erosion. Each group of individuals acting in the game, plays a series of rounds in two contexts: without any regulation imposed on them, and without the possibility to communicate with the other players.

In deciding whether to assign a certain amount of time to collect the common firewood, which is related to fresh water quality5 individuals may take into consideration another key variable such as precipitation forecasts, backstop sources of domestic energy, different provisioning and wood endowment preferences and other variables. If individuals are aware that precipitation may increase, they might care less for water quality, because of the practice of collecting stormwater for domestic needs. If individuals have backstop sources of domestic energy, in the case that they choose to extract a few quantities of wood during the years, it may send a false message in terms of their cooperation for forest conservation. Individuals with different provisioning and firewood preferences might choose to spend a few months collecting firewood in comparison to others, but perhaps in this short time might collect larger amounts of wood to be better endowed and manage the risk of forest depletion.

However, the changes in experimental settings, in the treatments tested with participants during every round, should be overtly captured through added variables or controls resembling real situations in decision-making for contribution to the commons. There is opportunity to replicate (Cardenas et al., 2000) work by incorporating central features of the setting of the naturally arising location in regard to the goods, assignment, stakes, and information set of the subjects (Levitt and List, 2009) which correspond to the type of framed field experiments.

Several academic contributions have reported social and ecological dynamics in games. Recent evidence has been aimed at apprehending the social and biophysical background factors that could help elucidate the choices made by individuals, using the elements that influence groundwater use in the real setting (Meinzen-Dick et al., 2016). The games allow participants to make explicit connections between crop choice – income perceived – water extracted – water table. The games were contextualized with the announcement of upcoming dry seasons, which characterized the study area.

(Suter et al., 2012) designed experimental treatments to estimate how the effect of modifications in the hydrogeological model, impact the perceived pumping rates, the strategic behavior, and the outcomes in terms of social efficiency. Results confirmed that dissimilarities in hydrological treatments through the treatments lead to substantial differences in extraction rates. This outstanding work explicitly considers physical variables governing the movement and evolution of water tables, also incorporates future extraction costs and certain levels of interaction between participants. The experiments explicitly use complex settings aiming at reflecting socio-physical dimensions of groundwater exploitation. Notwithstanding, key social dimensions related to the problems of collective action such as coordination, rules from external authorities and conditional cooperation, remain uncovered in this relevant contribution.

In line with the observed complexity in experimental designs, (Cárdenas et al., 2013), incorporated a set of ecological complexities regarding a social dilemma in the use of a CPR such as resource dynamics in forestry. In these experiments, participants were exposed to penalties and scheduling in harvest. In fishery games the design considered resource dynamics, fishers decide how much effort to allocate to different fishing spots and tried to test (among other things) opportunistic behavior. In water irrigation games, par-

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5 In some communities, water is drawn from local rivers and residents are aware that extracting forest products can lead to lower water quality (Cardenas et al., 2000).
participants were located in asymmetric locations to harvest from a public good; participants located upstream, faced the temptation to exhaust the resource used in common and decide whether to reserve remaining volumes of water for participants located downstream.

As revealed in this section, in decision-making, individuals are exposed to various sources of information, pressures and drivers leading to exploitation of resources. Special attention should be paid to the stress produced by climate variations in water allocation at local and regional levels (Bates et al., 2008b; Shen and Wu, 2016; Yang et al., 2016). Some experimental designs to study decision-making, test conservation incentives in the field and in labs, but these might be limited to reflect the complex reality of collective action challenges. More studies such as (Cardenas et al., 2000; Meinzen-Dick et al., 2016; Suter et al., 2012), are needed to incorporate sound quantity of subcomponents in experimental settings, reflecting the variables and interconnections in a groundwater Socio/Ecological System.

5. Discussion

Achieving cooperation in managing aquifers and other CPR is complex, but efforts should continuously be made to reach sustainable management of depletable resources. The present management paradigm to face aquifers overexploitation, is focused on water supply improvements and regulation of water access, issuing mandatory extraction allowances and restrictions to extractions. Notwithstanding, water supply is limited, and regulatory practices tend to be unsuccessful. Meanwhile farmers and industrial sector entrepreneurs located in areas exposed to droughts, continue to plan their investments assuming that the water utility agency will issue the extraction permits (Donohew, 2005). Notwithstanding regularly, one or the other, for political or other reasons, such permissions are not in reality requested or groundwater users tend to pass-over regulations (Donohew, 2005; World Bank, 2010) and legal procedures against illegal groundwater users, are continuously hindered because of the complexity to administer these measures (Sandoval, 2004). Consequently, shifting the top-down approach to manage groundwater is suggested. Policy-makers and water managers should make a halt in the inertial style of aquifers management and acknowledge the socio-physical nature of aquifers as CPR. The CPR are subject to competition and free-riding; a collective action problem exists, instead of a simple individual issue. Consequently, informal and formal institutions may be devised by communities. The essence of shifting the management approach consists of understanding the need for cooperation in managing the aquifer systems.

There exists a vast literature on the understanding of cooperation in CPR management and its drivers. Although there are outstanding findings that explain cooperation, difficulties arise when sustainable management plans are put in place. A further discussion on the ability of the drivers for cooperation to make aquifers sustainability plans materializable in the field is presented. Some drivers might be easy to implement during short periods of time, meanwhile others simply need a long time to make it happen (if possible). Designing communication strategies by setting the scene for face-to-face communication (E. Ostrom et al., 1994; Sally, 1995; Walker and Ostrom, 1989) and feedback provision (Liu et al., 2016; Novak et al., 2016; Schultz et al., 2014), might be implemented in different occasions; and this activity may incentive cooperation. Similarly, strategies such as pumping restrictions (Ayres et al., 2018; Stevenson, 2005), monitoring extractions and promoting mutual agreements (Demsetz, 2009; Leonard, B; and Libecap, 2015; E. Ostrom, 1998a), despite of being difficult and takes time as well, are materializable in the practice. However, other types of drivers are not straightforwardly operationalizable but are an ideal asset to sustain cooperation. Trust on others, inequity aversion and reciprocity result in fundamental social capital assets to withstand cooperative behavior of water users. Thus, any management plan aimed at promoting conservation of CPR resources should not leave these cooperation determinants overlooked. Some efforts can be made in measuring it and some strategies to improve it are suggested.

Notwithstanding, configuring capital domain assets is complex, takes time and cannot be built in the short term. It depends on the social and psychological profile of individuals that constitute a community of water users. The key question refers to whether trust on others, preferences for equity and reciprocity can be improved as part of a program intervention of external actors or not, or it is a lengthy process arising from the daily interaction of individuals who shares principles, culture, beliefs and many other intangible attributes. Ignoring the roots of social assets may result inconvenient in pursuing sustained efforts to increase cooperation towards sustainable aquifer management. Cooperative behavior results crucial to deter CPR overexploitation until its exhaustion. The evidence suggests that the second option on the sources of social capital assets is more feasible because, for sustainable management of this kind of resources, neither the state nor the market is uniformly successful in enabling individuals to sustain long term use of natural resources (Ostrom, 2015). Undoubtedly, central governments play a role as well in incentivizing cooperation via social capital consolidation. Since there exists a positive and direct effect of trust on governments and the acceptance of climate policies (Adaman et al., 2011; Hammar and Jagers, 2006), governmental accountability, transparency and performance, definitely influence the possibilities to make social capital increased inside the local communities.

Opportunely an immense number of cases of communities’ self-organizing for CPR sustainable management have been observed around the world. Some communities endeavor to reach productive outcomes in managing their commons, while overcoming the temptation to free ride on the effort of others (Ostrom, 2015; Schlager, 2002). Productive outcomes are the resulting outcomes of successful institutions that enable individuals to overcome temptations to free-ride and shirking (Ostrom, 2015). Institutions are not certainly automatically designed and expert entrepreneurs who take community members by hand to lead them to productive outcomes may not exist. Devising productive institutions takes time and demands a trial and error and learning process heading to self-organization (Isaac et al., 1994; E. Ostrom, 2002).

Despite the abundance of relevant cases of self-organization for CPR management worth to note, recent questioning arguments arise. In Social Ecological Systems, problem boundaries may be unclear, actors may have different knowledge and points of view, punishments based on trust may be demanding or unmanageable to apply, and the possibility to use conflict mechanisms may not ex-
ist (Patterson, 2017). Since successful principle design implementations in CPR management have been documented, evident widespread overexploitation groundwater basins, calls the attention to the further understanding of social institutions shaping complex CPR overexploitation and cooperation.

Researchers on CPR have mostly used lab and field experiments to gain knowledge on contributions to cooperation. However, the groundwater management setting differs from deciding whether contributing or not contributing to resource conservation. Many problems of collective action in field settings involve choices from a range of strategies rather than a choice between dichotomous strategies (Walker and Ostrom, 1989), such as whether to contribute or not to contribute to CPR. The key argument showed, refers to the need to incorporate more elements in the collective action contribution analysis. In the reviewed literature, we perceive fragmented experimental settings pretending to investigate the way how individuals make decisions and make a contribution, which is in the middle of the free-rider situation and the efficient level (J. C. Cárdenas, 2009; Iturbe-Ormaetxe et al., 2011) in facing social dilemmas.

Individuals and farmers taking part in field and lab experiments may meet the experimental designs, its questions, and commands for filling out forms, simpler and more abstract than the complex real situations faced in daily decision – making. Since lab and field experiments are recommended to be simple to avoid confusion among participants (Cassar and Friedman, 2004), the need to add complexity to the experimental settings, making sure to not confuse participants and cram them with information in experiments is suggested.

As indicated, households, farmers and other types of water users (demand-side) not only react to the possibility to communicate with others, to afford more environmental information or to respond to relevant drivers such as trust, reciprocity and commitment. Water users are continuously exposed to more sources of information and pressure. Some cases watershed actors have power to influence water management institutional arrangements (Cardenas et al., 2011). The way how water consumption patterns are aligned with a state of balance in the hydrological budget of an aquifer; how farmers and industrial business expect being issued with permits while others proceed to illegally extract water, how the detection of free-riders results practically in vain; are part of the real-life context of groundwater extraction settings. Similarly, extant field and lab experiments research methods, do not fully incorporate the limits of nature in terms of real decreasing water availability conditions. Since water resources tend to be limited, participants in experiments should be challenged to reveal their preferences on how they adapt to reduced water stocks and flows. Rooms for improvements exist for a new generation of experiments able to resemble the limits of nature in terms of quantities of water and in timing before aquifers get exhausted. In doing so, social and behavioral regularities may arise in terms of how people react when exposed to limits of nature and restricted extractions.

In summary, the analysis of social dimensions of groundwater overexploitation offers an opportunity to delve into the intricacies of behavioral and social dimensions of water use. These dimensions may include, i. the drivers of individual decisions to cooperatively extract the water, ii. the inhibitors of collective action towards sustainable extraction, iii. the perception about the asymmetric neighbors’ ability to collect water (Anderies et al., 2013), iv. the competition for the resource units (Negri, 1989; Ostrom, 2015), v. the interaction and reactions to external rules, vi. the creation of autonomous rules and its evolution and embeddedness inside the communities, vii. the dynamic of choice in public goods provision and individual preferences (Taylor, 1987) viii. how social institutions evolve when individuals experience stress due to declining precipitation, more extended drought periods and other evidence of climate change and climate variability in the region are similarly relevant.

After performing this literature review new questions arise. How internal social rules have coexisted with legal or external rules in the subsequent overexploitation of groundwater in dry regions? To what extent the contributions to the commons preservation by rules compliant are enough to avoid overexploitation? This is, which is the trade-off between the benefits arising from the water users abiding by the regulations and the cost of sustained extraction from free riders? Sustainability and groundwater conservation deserve a further analysis and understanding to better advise policy instruments.

6. Conclusions

In this article a literature review on the social and behavioral dimensions of CPR has been presented. A reorganization of the drivers for cooperation is proposed as a means to promote aquifer sustainable management. This proposal is especially relevant to achieve Sustainable Development Goals (SGD) referred to water use efficiency. For this aim, a classical supply-enhancement approach of environmental and water authorities may fall short in succeeding in curbing water extractions and water consumption.

The understanding of the complexities of cooperative behavior would support the need to persist on the sustainability of aquifer resources and another CPR. In CPR management coordination efforts demanded among individuals belonging to the resource governance structure; if cooperative attitudes are achieved in managing the CPR, it does not entail that cooperation would last endlessly. So, reaching cooperation and keeping it for a long time, requires that the proper incentives need to be devised and implemented in a collective action setting instead of a top-down regulation setting.

Scholars are still pursuing rigorous answers to the problem of collective action. Different researchers have found promising responses to the social problem of managing resources used as CPR. Economic theory predicts that every individual will rush for extracting the most of the resource in the present, because the remaining stock might not be available in the future (Hardin, 1968; Negri, 1989; Ostrom, 2015). For the benefit of natural resources used in commons, the evidence indicates that individuals using common-pool resources deviate from egoistic and selfish behavior predicted by the economic theory (Gardner et al., 1990; Ostrom, 2015; Velez et al., 2009).

In searching for answers to the problem of collective action, researchers have focus the explanations for cooperation on drivers such as reciprocity (Axelrod and William, 1981; Axelrod, 1984; Hamilton, 1964); trust on others (Cox, 2004); ability to communicate
(Abrahamse and Steg, 2013; M. A. Janssen et al., 2010; M. Janssen et al., 2014; E. Ostrom et al., 1994; Sally, 1995); capacity of communities to devise their own rules and institutions, to self-manage natural resources (Isaac et al., 1994; Ostrom, 2015; E. Ostrom, 1990); inequity aversion (Cox, 2004; Fehr and Schmidt, 1999; Velez et al., 2009) and other causes.

A discussion is presented on the possibilities and feasibility of implementing a CPR conservation plan aimed at pursuing sustainable aquifer management. To make it possible, applicable and manageable strategies are needed. In support of putting the drivers of cooperation to work, a contribution in organizing the existing literature on CPR cooperation is made in four groups namely: instruments to stimulate cooperation, conditions to reach and sustain stable cooperative behavior, assumptions and positive expectations in support of cooperation and strategies and components as building blocks aimed at constructing cooperative behavior.

Since groundwater are relevant sources for agricultural and domestic affairs around the world, there are still different issues to understand, especially because of the clear overexploitation suffered by this natural resource. Water users, water authorities, communities and other actors interact in managing the resource used as CPR. In this interaction there is still more to study on the behavioral dimensions of attitudes heading to overexploitation and attitudes heading to cooperation in contexts of scarcity and climate variability.

The interaction of actors entails the design of formal and informal rules called institutions. Working rules imply social institutions are present during the social interdependence (Knight, 1992) between resource users. However, the challenge in understanding the institutions rests in how to promote stable institutions adaptive to climate change and other changing circumstances. Stable institutions are relevant to achieve the benefits of acting together while cooperating, an ideal state in managing common pool resources. However, the institutions and the cooperation evolve (Axelrod, 1984; Ostrom, 2015). The evolution of social institutions may have implications in reaching sustainability and social institutions have the capacity to influence the society’s ability to get used to changing circumstances (Spencer, 1969). The challenge with the inevitable changing circumstances, rests in how changes influence reaching sustainable outcomes in collective action. Collective action problems relate to situations of social dilemmas. A dilemma is present when an individual each time perceives a greater utility when he/she chooses a defect strategy instead of a cooperative strategy; however all individuals are in a better situation if all decide to choose the strategy of cooperation than defecting from this (Dawes and Messick, 2000).

The hydrological status and aquifer balance are important variables to consider achieving groundwater sustainable yield, cooperation and social-institutions inclination for conservation are needed. Based on this argument there are old questions still under discussion such as which are the conditions to avoid common resources overexploitation? Which are the conditions to reach stable cooperative attitudes and actions in conserving water from the ground? Which are the behavioral dimensions of water consumption in contexts of scarcity and climate change? In line with earlier statements, there is still more to discover about what drivers work better in promoting cooperation for groundwater conservation, especially the behavioral side of institutions. Finally, adaptive, and cooperative behavior to the inevitable changing circumstances, may be sparked when individuals realize that the unmet assumptions on climate variability result not being episodic, but long-lasting.

Uncited references

Cádenas, 2009, Ostrom et al., 1994

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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