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Community Management of Groundwater under a Private Property Regime: An Example of Institutional Local Adaptation to Overexploitation Problems in the Copiapó Aquifer, Chile

Rodrigo Fuster [1,*], Katherinne Silva-Urrutia [1], Cristian Escobar-Avaria [1], José Miguel Valdés-Negroni [1], Gustavo Abrigo-Cornejo [2] and Hilda Moya-Jofré [1]

[1] Laboratory of Territorial Analysis, Department of Environmental Sciences and Renewable Natural Resources, University of Chile, Av. Santa Rosa 11315, La Pintana, Santiago 8820808, Chile; ksilva@uchile.cl (K.S.-U.); crescobar@uchile.cl (C.E.-A.); jose.valdes@ug.uchile.cl (J.M.V.-N.); hilda.moya@uchile.cl (H.M.-J.)

[2] Department of User Organizations, General Directorate of Water, Morandé 59, Santiago 8340648, Chile; gustavo.abrigo@mop.gov.cl

* Correspondence: rfuster@uchile.cl; Tel.: +56-2-29785926

Abstract: The governance model established in Chilean water law delegates responsibility for groundwater management to private water rights owners. The Copiapó aquifer in the Atacama Region, Chile, has problems of overexploitation resulting from intensive use of the resource. This is explained by the limited information on the water availability in the aquifer and the existence of legally granted water rights whose flows exceed the rate of natural recharge. In this context, water users formed Chile's first groundwater users' community in the Copiapó basin for the collective administration of the aquifer. Although this organization is regulated by Chilean water law, the way in which its members participate in decision-making processes and some self-management mechanisms that they have implemented are local institutional arrangements that go beyond the rules established in the Water Code, showing this organization to be an empirical case of institutional adaptation to the overdepletion of an aquifer. The local institutional arrangements include incorporating environmental protection objectives for aquifers and wetlands, establishing an institutional arrangement that guarantees the participation in the decision-making processes of different water uses and users, developing an internal management model that promotes temporary transfers of partial volumes of a water right and carrying out studies to improve water management.

Keywords: groundwater overexploitation; institutional arrangements; groundwater management; water markets

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1. Introduction

Diverse institutional arrangements have been adopted to address various water management challenges. One approach involves the incorporation of free-market criteria in water resource allocation and reallocation for different uses [1]. This approach treats water as a private and fully tradable commodity, subject to the forces of supply and demand. The free-market approach aims to reallocate water to uses of higher economic value while also considering the cultural, environmental, and social value of water as externalities. The private sector's involvement is believed to increase water use efficiency by triggering innovation and mobilizing action in situations of institutional inertia and lack of governmental capacity [2].

Chile has become the world's leading example of a free-market approach to managing water resources [1]. The approach established in Chile is based on the concept of private rights to use water, aiming to favor the establishment of a water market by strengthening private property rights, making them tradable, and reducing the state's intervention. This institutional structure, along with a water rights market with few regulations [1,3], should prevent the "tragedy of the commons" [4,5] from threatening resource sustainability.

Chilean aquifers, particularly in arid and semiarid regions, have experienced an overexploitation scenario that has caused a severe water crisis in recent years [1,6,7]. This issue is partly a result of inadequate regulatory implementation and an excessively rigid institutional framework, which has allowed little flexibility in responding to changing conditions [8]. This situation prompted the Chilean parliament to consider making significant changes to current legislation, resulting in the enactment of the new Water Law in March 2022.

The issues of overexploitation of aquifers and water scarcity, particularly in the context of uncertain and complex climate change, require immediate adaptation measures. One possible alternative is for existing Water Users' Organizations (WUOs), which in the case of groundwater are called "Groundwater Communities (GCs)", to establish local arrangements that extend beyond their legally mandated authority, thus obviating the need for substantial legal restructuring. The objective of this article is to describe how GCs may make institutional arrangements to deal with the overexploitation of aquifers under a private property regime. This study is based on the experience of CASUB, which was the first GC formed in the country in response to the overexploitation of the aquifer in the Copiapó aquifer, Chile. In this article, the term "local arrangements" refers to the formal and informal regulations and standards that determine the individuals or entities responsible for making decisions regarding a shared resource, such as water, encompassing the specific choices made regarding its utilization, administration, monitoring, and enforcement [9].

1.1. Background

The legislation governing water management in Chile (Water Code) is a unique model that has undergone several reforms since its inception in 1981 [1]. The Water Code was enacted with the primary objective of incorporating market criteria into all procedures for the reallocation of water resources. The market mechanism is believed to be the system that best protects social welfare and the "correct" allocation of resources [10].

The General Directorate of Water (DGA) is the main government agency in charge of water in Chile, and it is obliged to deliver (allocate) water rights to those who request them, provided that they do not affect the water rights of third parties and availability is proven. Chilean water rights have certain features that make this water allocation/reallocation model unique. Private owners of water rights are free to transfer those rights and are protected as fully as other private properties in the Chilean Constitution of 1980 [1]. The main elements of the Water Code are strong private water rights, the creation of favorable conditions for water markets, and the reduction in the role of the state in water management [1]. The resolution of water conflicts is dealt with between the different actors in the courts of law [1].

Water is managed by the users themselves, either individually or in the WUOs that they may form. The powers of the state to oversee the operation of WUOs or to promote the formation of these organizations are limited. The DGA does not participate in decisions about how water is managed or what transactions are carried out and can only act in cases of complaints about problems with financial management or water distribution [6].

1.2. Use of Groundwater in Chile

In Chile, aquifers have become an essential source of water in arid and semiarid regions of the country. With the increasing demand for water, the number of water rights granted significantly rose by 4350% between 2001 and 2017 [7]. Overuse of groundwater has led to a significant decrease in groundwater levels in aquifers, resulting in several water-related issues and conflicts that have put the sustainability of these water sources at risk [3,7].

The primary reason for the decline in water tables is the overgranting of water rights in many basins, coupled with various management problems [6,8] including a lack of knowledge of the dynamics of aquifers and their interaction with surface water bodies, insufficient information on actual abstractions and sources of pollution, the independent management of surface and groundwater, and the absence of collective management of aquifers in most areas [7].

The lack of knowledge among users and the state regarding the long-term effects of the uncontrolled exploitation of groundwater is another significant obstacle to the collective management of aquifers [3,7]. Furthermore, many groundwater users are unaware of the legal possibilities of establishing restrictions on water use and have difficulties understanding how these mechanisms can be implemented. Consequently, user participation in decision-making processes has been characterized as inadequate, especially among small users who lack a pre-existing organizational social base and voting power proportional to their water rights [11].

Nevertheless, the State's push has been insufficient, as less than 10% of aquifers with overexploitation problems have formed groundwater user organizations [12], despite the issues of overexploitation existing in most of them.

2. Methods

2.1. Case Study: Institutional Arrangement in Copiapó River Basin

Between 2013 and 2021, a series of research projects were carried out that allowed the collection of information on the institutional arrangements made by the Groundwater Community of Sectors 5 and 6 of the Copiapó Aquifer (named CASUB), the first groundwater users' organization in Chile. The methodologies included participant observation, semi-structured interviews, working groups, and a literature review. These activities aimed to identify the actions taken by CASUB to address the overexploitation of the aquifer, actions that exceed the obligations imposed by the Chilean Water Code. These actions are referred to as institutional arrangements in this work.

The gathered information was analyzed based on the functions and attributions of Water User Organizations established by the Chilean Water Code. The information-gathering activities carried out by the study are detailed in Figure 1. This research provides insights into the effectiveness of institutional arrangements implemented by the first groundwater user organization in Chile to address the challenges of groundwater management, which can be useful for other regions facing similar problems.

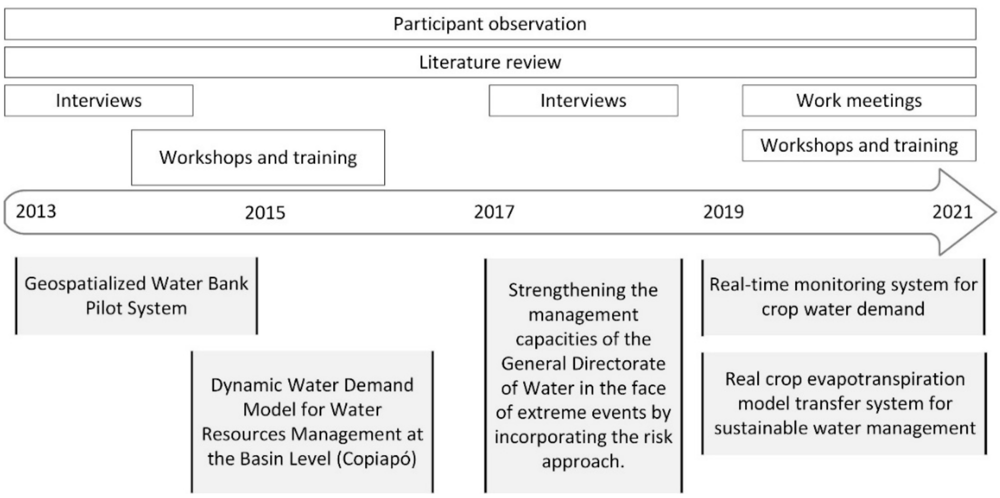

Figure 1. Information-gathering activities carried out by the study. Grey boxes: Research projects developed with CASUB participation. White boxes: Information-gathering activities.

2.1.1. The Copiapó River Basin

The Copiapó River basin, whose surface area is 18,538 km^2, is located between 27° and 29° south latitude in the arid region of Atacama, Chile (Figure 2). The Copiapó basin is in the bioclimatic region of the desert–oceanic Mediterranean [13], presenting a semiarid climate with an average annual precipitation of 28 mm, with a decreasing gradient as the altitude decreases. Copiapó is the main city in the basin with 153,937 inhabitants [14].

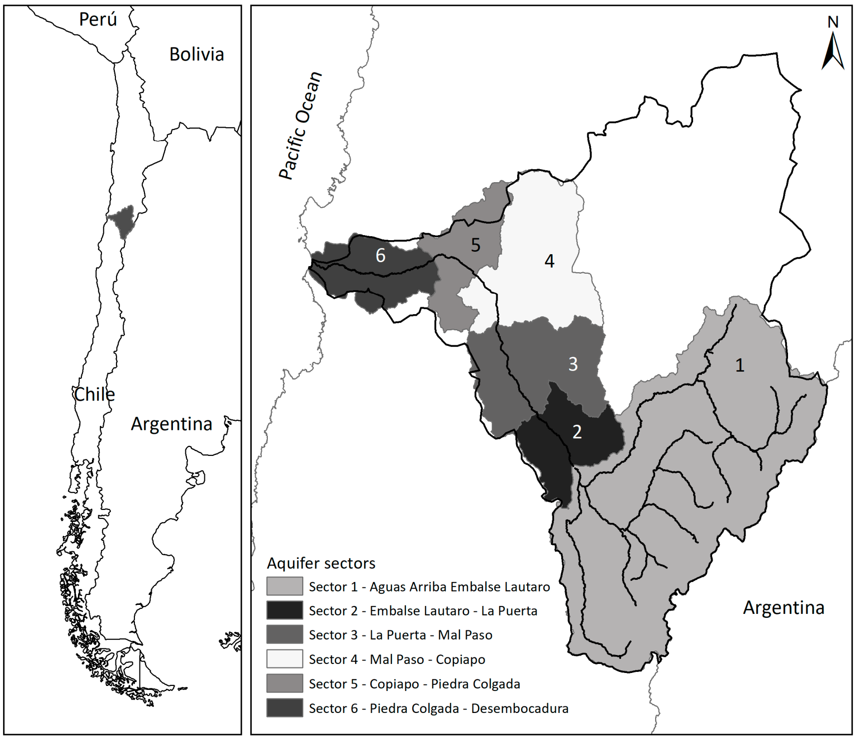

Figure 2. Area of study. Aquifer sectors according to [15].

The Copiapó River has a mixed pluvial glacier regime and is formed by the confluence of the Manflas, Pulido, and Jorquera Rivers, which provide continuous surface flows, though they disappear partially or totally in some areas, mainly due to their use for agricultural irrigation. In addition, the river receives water from lateral gorges that are normally dry and contribute only when high precipitation occurs in the Andes. The Copiapó River is regulated by the Lautaro reservoir, which has a storage capacity of 24.5 million m^3 (equivalent to $\approx$30% of the Copiapo River's average annual flow). This reservoir is one of the main sources of aquifer recharge [15]. Downstream from the city of Copiapó, the river has dried up on the surface, with the exception of sporadic intense rainfall events. In the lower basin near the coast, the river recovers due to a rising water table [15].

The Copiapó River Basin is home to a significant aquifer that is crucial for human use in the region, such as agriculture, mining, and drinking water. Two general types of geological units can be identified in the Copiapó River valley: unconsolidated deposits (UND) and undifferentiated bedrock. These geological formations play a crucial role in facilitating groundwater recharge, storage, and transmission within the valley. The UND encompasses diverse units such as dune deposits, fluvial and lacustrine formations, dejection cones, and alluvial flows [16]. These deposits have permeable and semi-permeable sequences, characterized by intergranular porosity, with varying degrees of stratification, resulting in multi-layered aquifers ranging from free to semi-confined. Among these, gravel and sand deposits stand out for their significant hydrogeological potential, acting as free aquifers in the region [17].

While the aquifer should be viewed as a single integrated unit from a hydrological and physical perspective, it is split into six aquifer sectors for management purposes (Figure 2). These aquifer sectors were defined by the Water Authority in 1997, with the aim of improving aquifer management and promoting sustainable groundwater use [6,18]. The first aquifer sector, coinciding with the sub-basins of the Jorquera, Pulido, and Manflas rivers, supplies the second aquifer sector, where the Lautaro reservoir is located. This second sector, in turn, sustains the third and fourth sectors, directing groundwater flow in the NNW direction, with groundwater flowing parallel to the Copiapó River. In aquifer sectors 5 and 6, the flow direction changes to W [15]. The last two sectors (5 and 6) are the most extensive areas with the lowest precipitation rates in the basin, and as such, they have the lowest recharge rates owing to the exploitation of surface water resources in sectors 3 and 4 [6].

2.1.2. Development and Use of Groundwater in the Copiapó Aquifer

According to a recent groundwater use analysis by [15], the average annual extraction was calculated at 4.9 m^3/s, with agriculture accounting for close to 60% of the usage, mining for 30%, and drinking water supply for 10%.

Unfortunately, the Copiapó Aquifer has suffered severe overexploitation, which has resulted in a severe water crisis in recent years [6,8]. The average annual extraction has exceeded the mean annual rate of natural recharge of the aquifer, estimated at 4.0 m^3/s [19]. As a result of overexploitation, the volume stored in the aquifer has decreased from the 1980s to the present (Figures 3 and 4), especially in sectors 3 and 4, which have greater overuse. Groundwater levels in these sectors decreased by an average of 10 to 150 m between 1998 and 2015, mainly due to mining activities and drinking water supply [6]. In contrast, sector 5 has experienced a gradual decrease in groundwater levels since 1998, with an estimated current rate of decline of 2–6 m per year. However, sector 6 has maintained static groundwater levels close to the surface, and the presence of a large discharge area of the underground layer is common. This phenomenon occurs through the evapotranspiration of the meadows and mainly by the outflow of springs located in the riverbed.

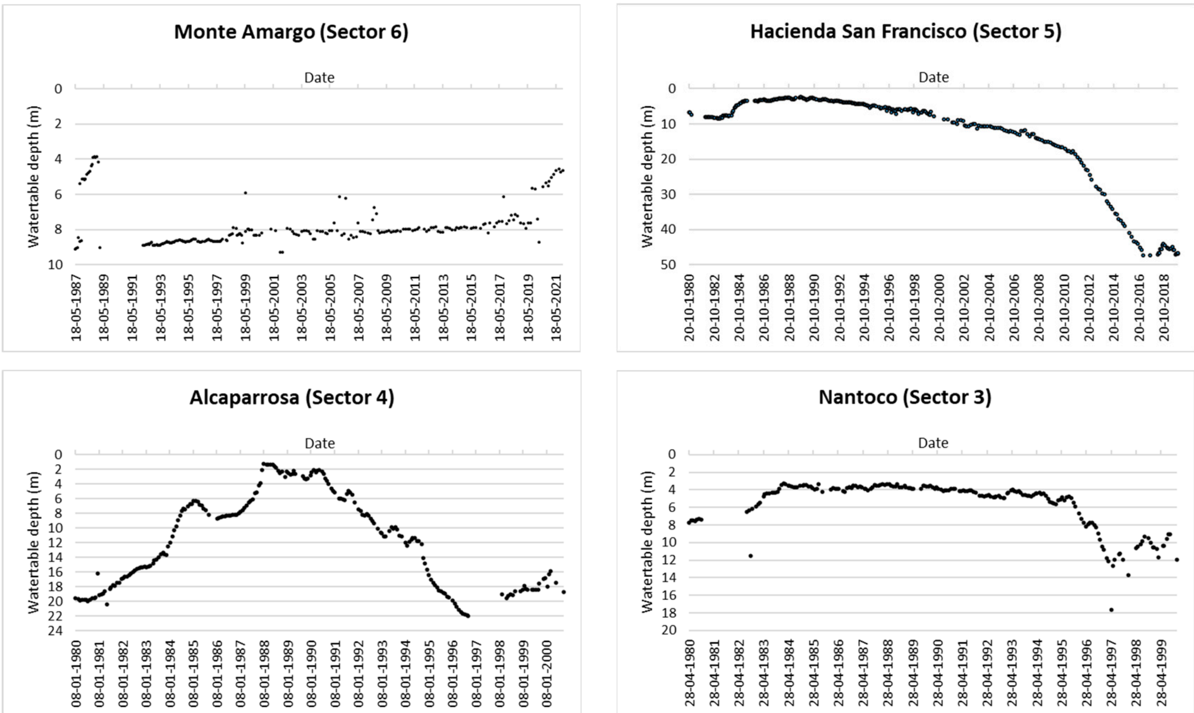

Figure 3. *Cont.*

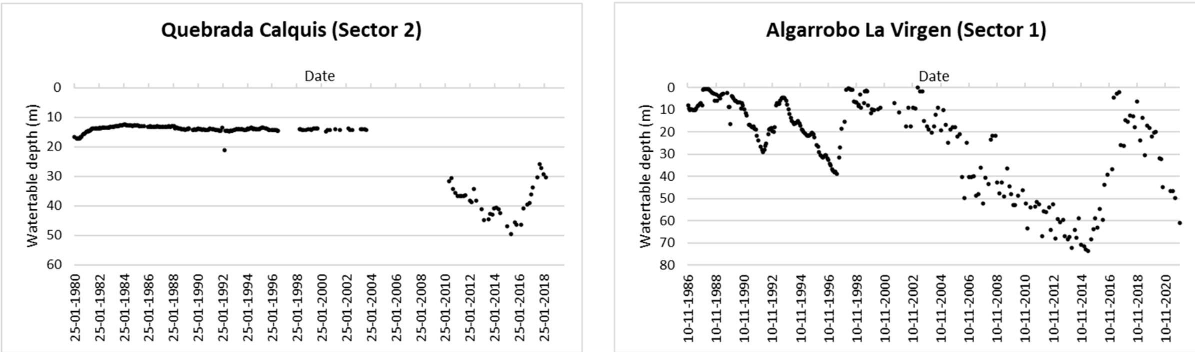

Figure 3. Water table behavior in each hydrological management sector of Copiapó Aquifer. Source: [20].

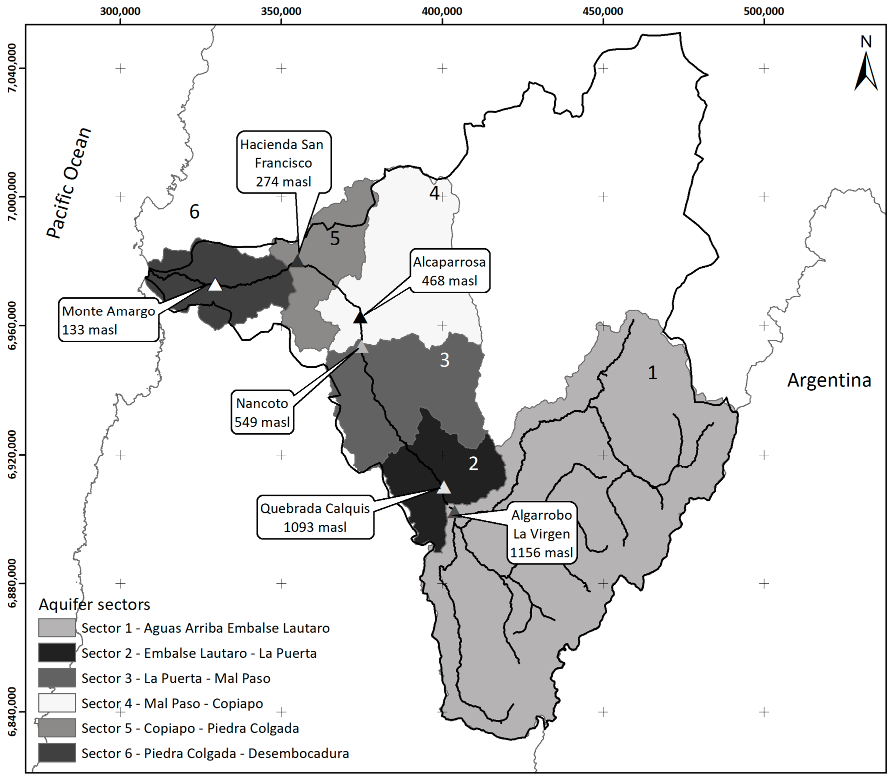

Figure 4. Location of measured wells in the aquifer sectors. Source: own elaboration based on [20].

The imbalance between the sustaining capacity of the water system and the human pressures that are placed on it stems from the implementation of economic policies during the 1980s, which triggered an explosive increase in agriculture's cultivated surface area, especially with fruit species (e.g., table grapes). This agricultural boom was accompanied by an increase in investments in the mining sector in the 1990s and the 2000s, driven by high copper prices [6]. The regional economic growth associated with the development of agriculture and mining has produced an increase in population growth and, therefore, in drinking water demand, which has been satisfied by groundwater pumping. These historical events resulted in a large number of water rights being granted to different actors in the basin, equivalent to several times more groundwater than is recharged annually. According to [15,21], the total groundwater rights delivered in the Copiapó aquifer corresponds to 386 rights for a flow of 19,492 L/s (19.5 m^3/s; Table 1). This potential demand is approximately four times greater than the estimated annual average aquifer recharge. Bauer [1] argued that the Copiapó aquifer crisis illustrates critical structural failures of

Chilean water management, emphasizing weak administration by the state regulatory agency (DGA), partly explained by a political and legal context that pressured the agency to overgrant groundwater rights.

Table 1. Total groundwater users and total granted flow by aquifer sector in Copiapó River Basin.

Total Groundwater Users (n°)						
Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Total
14	45	39	43	120	156	417
3%	11%	9%	10%	29%	38%	100%
Flow Granted (L/s)						
Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Total
2201	3341	4182	4024	3668	2076	19,492
11%	17%	21%	21%	19%	11%	100%

Note: Source: [21].

Rinaudo and Donoso [6] identified several factors that contributed to the water crisis in the region, including limited knowledge of the aquifer dynamics, political pressure and legal complexity, poorly defined water rights, and the inability of GCs to effectively monitor and limit extractions. Additionally, the management of surface water and groundwater was inconsistent due to improvements in water technology, which increased irrigation efficiency and reduced aquifer recharge. The crisis was exacerbated by a severe drought that occurred between 2010 and 2014, which had no precedent in the region's local records [22].

2.1.3. The Copiapó Groundwater Community "Copiapó–Piedra Colgada; Piedra Colgada–Desembocadura" (CASUB)

The first groundwater user organization in Chile—the Comunidad de Aguas Subterráneas Copiapó–Piedra Colgada and Piedra Colgada–Desembocadura (CASUB)—was created in the Copiapó River basin. The First Civil Court of Copiapó constituted the CASUB on 29 April 2004. As shown in Figure 2, the jurisdiction of CASUB covers sectors 5 and 6 of the aquifer, the two farthest downstream, where water use depends almost entirely on groundwater due to the lack of surface water, except for the final part of the river where underground waters emerge.

Members of the CASUB, as established in the Water Code, hold rights to the groundwater. The CASUB administers 5744 L/s in groundwater rights, which are distributed in 218 wells and 276 water rights owners, belonging to different uses (Table 2; [23]). The water demand for agriculture, which has the largest use, varies according to the different months and water sectors.

Table 2. Flow granted by the economic sector in CASUB's jurisdiction zone.

Use	**Sector 5**	**Sector 6**	**Total**
		Flow (L/s)	
Sanitation	438	--	438
Mining	518	173	691
Agriculture	2403	1847	4250
Industry	220	50	270
Rural domestic	1	3	4
Other	88	3	91
Total	3668	2076	5744

Note: Source: [23].

3. Results

The origin of CASUB as an organization is explained by the problems of depletion of groundwater resources. In 2001, the DGA declared the Copiapó aquifer a restricted zone and stopped granting definitive water rights, while continuing to grant provisional water rights [6]. This was an administrative measure to try to avoid overexploitation of the aquifers.

There was a legal provision to start up the water community, and that legal process was started when the provisional rights were given. The small farmers of the lower sector did not have water rights; we were given provisional rights so that we could have water rights (Participant 2, focus group).

CASUB was initiated to defend rights and to give water a good use (Participant 4, focus group).

Although the regulatory framework, specifically the Water Code, establishes the administrative functions that WUO should have, the territorial reality of the study area meant that CASUB, from the beginning and over the years, has incorporated functions in its own regulations (statutes) that transcend what is defined in the Water Code. These internal regulations reflect an effort to adapt the institutions defined for groundwater management to the territorial reality of this area.

According to the CASUB standards, many of the organization's functions are defined by the Water Code, such as controlling the extraction of water according to water rights, implementing and maintaining well measurement devices, coordinating agreements and actions among members, and requiring its members to maintain and replace their extraction control devices. However, the statutes also define institutional arrangements that the Code does not include, which reflects the need for the formal adaptation of this organization to the territorial reality. These additional institutional arrangements include (ii) regulating the exploitation of the aquifer, (iii) seeking the participation of all users/uses, and (iv) carrying out studies to implement measures to restrict exploitation.

3.1. Promoting Integrated and Sustainable Water Management

The CASUB has acted to jointly manage the quality and quantity of water to maintain good-quality surface water flow in the riverbed (organization's statutes, article 4; [24]). The objective was to recharge the aquifer and sustain the ecological functions of the wetland areas. The CASUB has been actively involved in environmental assessment processes, particularly in cases related to mining and industrial projects that affect water resources. In 2018, CASUB reported that a mining company (CODELCO-CHILE) was drying up a large area of vegetation between the Salar of Pedernales and Maricunga (upper basin). This report was accepted by DGA on 8 March 2018 [25]. This is an example of CASUB's actions to promote sustainable management at the basin level.

In 2019, the CASUB filed a complaint against the Copiapó River Surveillance Board for serious faults committed in the distribution of surface water, which may affect aquifer recharge [26,27]. After two years of investigation, the DGA applied a fine and ordered the Surveillance Board to adopt corrective measures to update its operational water distribution model. This case represents the first experience in Chile in which a groundwater community influenced the management and distribution of surface water by a Surveillance Board, indicating a first level of integration between the roles of surface/groundwater user organizations.

Another example is the purchase of surface water rights in the middle section of the Copiapó River Basin. These rights were purchased to maintain the ecological flow of the river. By doing so, the water recharge is increased, which helps protect the aquifer environment and reduce overexploitation [23]. The original Copiapó River Surveillance Board did not consider downstream groundwater users when managing the dam level. However, by purchasing these surface water rights, the CASUB has established itself within the surface water organization. The institutional arrangement now seeks to ensure that during wet periods, users who would normally use groundwater switch to surface water related to those water rights. By maximizing the use of surface water, users will be able to lower pumping rates, thereby reducing the pressure on the aquifer [23]. As a complementary action, CASUB has planned to take advantage of rare wet periods by diverting excess flows to sites for artificial recharge of the aquifer. The CASUB has utilized its legal status to negotiate the use of private land for infiltration pools. Although the specific results of these actions are not yet known, they serve as examples of the adaptation measures undertaken by groundwater communities under the private property regimen.

3.2. Water Bank as a Way to Regulate the Exploitation of the Aquifer

Legally, the CASUB Board of Directors has the power to adopt pumping agreements that restrict the water use of community members, but this would affect economic activities that rely on adequate water supplies. To address this issue, CASUB developed a model that allows the short-term transfer of water volumes currently in use to maintain extractions at current levels and reduce pumping in the future. The CASUB worked with the Atacama regional office of the DGA to develop a water bank model that promotes the temporary lease of water volumes rather than permanent sales of water rights. CASUB serves as an intermediary guarantor of transactions and closely monitors water use and information with the DGA to comply with legal requirements. The water bank focuses on the temporary transfer of volumes of water, all of which are pumped underground. The rules of the water bank require that a water rights owner who rents water to another user must reduce their own use by the same volume. The water bank encourages transactions to be made for the volume used and not for the volume associated with the water right, that is, for "wet water" rather than "paper water". This applies to rentals within agriculture and across sectors. CASUB implemented a program for monitoring and controlling extractions with 90 agricultural wells and 30 nonagricultural wells to regulate the extractions according to water rights and monitor the volumes extracted in the community and the behavior of the aquifer. The water bank is a management tool that adapts to the current overexploitation of aquifers in the CASUB jurisdiction. Some examples of the water bank's operation with the participation of CASUB as guarantor are the following (CASUB Administration; personal communication):

Temporary water lease between agriculture and a drinking water company. There exists documentation of transfers of water volumes between six farmers and the company Aguas Chañar that provides drinking water to the population of the cities of Copiapó and Chañaral. In one case, a farmer stopped cultivating around 225 ha of crops to transfer the 2,835,000 m^3/year of water to the drinking water company.

Temporary water lease between agriculture and mining. In one example, a farmer stopped irrigating about 125 ha and transferred 1,575,000 m^3/year of water to the mining company Cerro Negro for 1.5 years.

This management model has promoted an agile and transparent way of transferring water volumes that has been applied beyond the CASUB's area of jurisdiction. In the case of the Huasco River valley, south of Copiapó, the drinking water company that supplies the city of Vallenar was faced with water depletion from its wells in August 2015 [28]. To resolve this situation, as advised by CASUB, a lease of water volumes was developed between the farmers of the area and the company, addressing the problem of supply in the short term.

3.3. Seeking the Participation of All Users: Breaking the Asymmetry of Power

The Water Code establishes the rules governing who can participate in water management and in what ways [3]. Each water user organization must hold an annual meeting at which members elect their board of directors, and the board reports on the organization's management. The decisions are made by a vote of the CASUB members, weighting the vote according to the amount of water that each member owns, as established in each water right. Thus, whoever has more water has a greater influence on decisions. Through this system, decisions are made, including the choices of board members. The board then appoints its president from among its members.

Although CASUB could not change the general voting rules, its members approved internal rules that specified additional requirements for the composition of the Board of

Directors. The board must include representatives of each of the major types of water use in the basin: small, medium, and large farmers; mining companies; and urban water supply companies. The principle is that managing the regional aquifer requires all relevant stakeholders, that is, the owners of water rights who use them for different economic purposes [24,29]. This principle reflects the territorial reality of a common resource, rather than the neoliberalist logic of the Water Code.

3.4. Carrying out Studies to Implement Measures to Restrict Exploitation

Although this action is not an institutional arrangement, it is important to mention that in the last decade, CASUB has collaborated with several academic and research institutions to address the gaps in scientific and technological knowledge. Figure 5 shows a conceptual model of water management, which aims to expose the actions carried out by the organization associated with different elements of this ideal model of water management (identified with the nomenclature Px), and thus, showing the areas in which CASUB has generated research and knowledge. Specifically, studies and research projects have been conducted to comprehend the behavior of local groundwater, evaluate the actual water demand by its members, and establish management models to regulate groundwater pumping towards sustainable use of the aquifer (as shown in Figure 5, P1, P2, P3). Moreover, CASUB has actively pursued funding to enhance the monitoring of well withdrawals and the real-time transmission of information (as shown in Figure 5, P7).

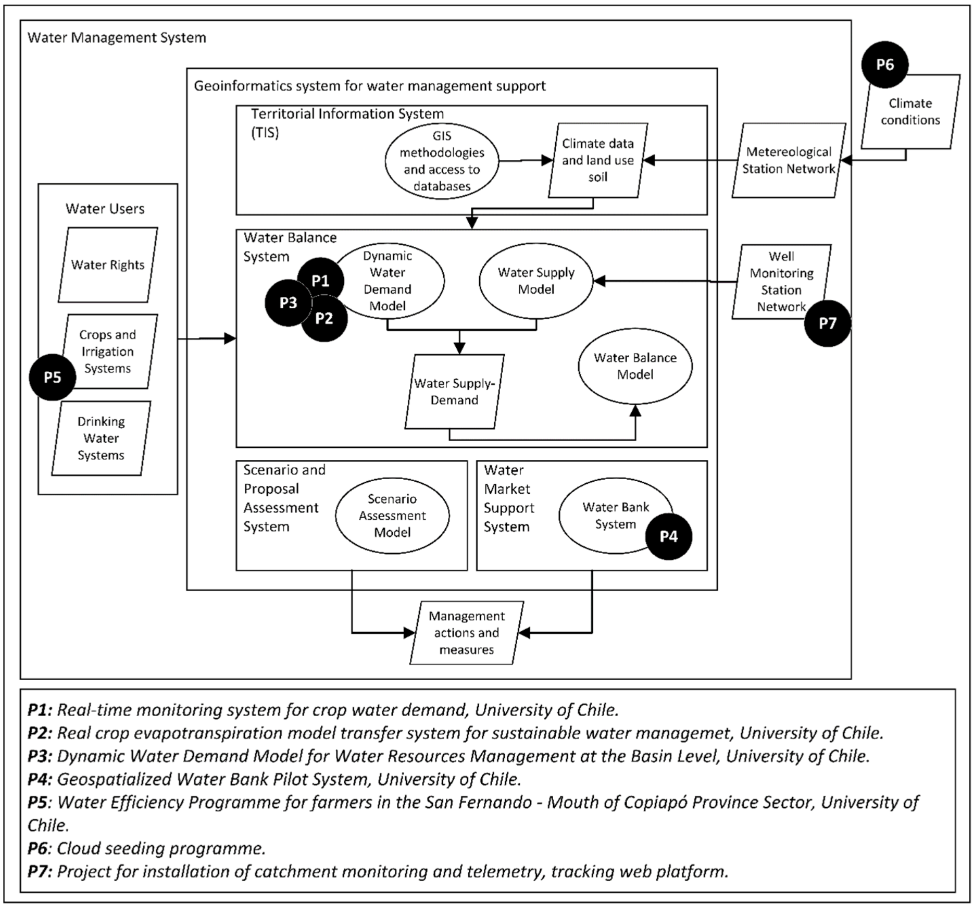

Figure 5. CASUB-driven projects outlined in a simple conceptualization of the water management system.

4. Discussion

The case study presented in this article shows that the private water management regime, as seen in Chile, has not been able to address the problems of groundwater scarcity and overexploitation. Faced with this situation, CASUB has opted to adapt by defining its own local rules or institutional arrangements on the premise that it complies with the legal framework.

CASUB has implemented institutional arrangements and actions to deal with water scarcity in the Copiapó aquifer that go beyond what is required by law. Although the impact of these arrangements and actions has not yet been assessed in terms of a significant reduction in abstractions, the scientific literature suggests that these contribute to a more sustainable use of the aquifer. For example, in the case of water banks, various experiences around the world support their effectiveness in reducing pressure on groundwater [30,31]. In the case of implementing institutional arrangements that promote integrated and sustainable water management at the basin level, such as managed aquifer recharge and the purchase of water rights from surface water user organizations to maintain a constant flow in the river, in part to increase aquifer recharge using the "rules of the model", are actions that are consistent with the rationale underlying IWRM as well as with various research recommendations [32–34]. The purchase of surface water rights is the result of CASUB's active engagement with surface water user organizations to reconcile management objectives aimed at avoiding further overexploitation of the aquifer. In the case of this institutional arrangement, it is important to note that CASUB has been able to take advantage of the existing rules to achieve a benefit in terms of the sustainability of its water sectors. In other words, CASUB uses existing rules, which give water a tradable market value in its favor to maintain a constant flow in the river.

Although CASUB has demonstrated the ability to implement institutional arrangements and actions that go beyond what is required by law, the current water regulation regime (Water Code) renders the agreements underpinning them fragile, with a lack of legal validity [1]. This is due to the prioritization of water right holders (except for human consumption, which is a priority), which weakens the nature of the agreements and subjects them to the influence of actors holding the most water within the aquifer [1,11].

Moreover, it is important to note that groundwater right holders often lack a history of common relationships, represent different economic sectors with different objectives regarding water use, and are geographically dispersed. In fact, due to their nature, groundwater management has not led to social agreements related to their distribution, unlike what is observed in the case of surface waters. Groundwater has generally been used individually and in isolation through wells distributed throughout an aquifer [35], without the need for extensive coordination with other users to agree on issues such as extraction volumes and methods. Furthermore, the common source that delimits the extent of a GC's jurisdiction is not obvious and may differ significantly from the boundaries that users may wish to establish socially (e.g., established boundaries as a function of localities or areas with which there are higher levels of social interaction and, consequently, higher levels of trust and proximity). This key difference from surface water makes it difficult to build trust between users and limits the ability of these organizations to develop collective action in response to rapid, complex, and uncertain change [11,36].

Given the constraints imposed externally by the regulatory framework, an alternative for collective action by GCs is to develop internal organizational capacities that give them autonomy to make decisions and act independently [11,36,37]. From what we have observed in our work with CASUB over a decade, the implementation of the actions identified in the results depended on the existence of leadership within the organization with high human and technical capacity to address the challenges of water management. Leaders play a crucial role in setting common goals, coordinating activities, monitoring cooperation, resolving conflicts, and implementing reward and punishment mechanisms within water user organizations [36,38–41]. Effective leadership is essential to ensure compliance with collective agreements and to represent the interests of all stakeholders.

The analysis of CASUB's experience shows that in addition to the crucial role of leadership, other factors have played an important role in the successful implementation of institutional arrangements. These factors include (1) the generation of reliable information and the democratization of access to such information and (2) the reduction in power asymmetries in the decision-making processes.

The generation of reliable information and the democratization of access to such information enables water users to better understand, for example, the dynamics of the aquifer, the level of extractions, and changes in ownership of water rights in an informed manner. In this context, information on transfers of water rights and changes in ownership are sensitive issues for users; therefore, its transparency would favor self-regulation at the organizational level, help dispel unfounded distrust, and, in turn, grant the administration and management greater credibility [11,41–43]. In this sense, a key aspect of good management of common pool resources such as groundwater is knowledge of the physical system [44]. Understanding the dynamics of aquifers and continuously monitoring their conditions are key elements for the success of any management strategy. In general, CASUB has fulfilled these requirements in an outstanding way and has become a model at the national level, with several investigations and studies in this area.

The reduction in the power asymmetries in the decision-making processes ensures that water users have equitable participation in decision making (in the case of CASUB, at the Board level), fostering a climate of increased trust, leading to the adoption of collective actions within WUOs and GCs [9,39,45]. Recognizing the critical nature of fair representation that encompasses the diverse array of interests impacted by the Board's decisions is essential to ensuring an unhindered pursuit of equitable distribution of the costs and benefits inherent in these determinations [41]. Together, both the generation of reliable information and the reduction in the power asymmetries in the decision-making process act as crucial incentives for the organization of water users, and they are fundamental factors that drive the successful implementation of collective actions in the context of sustainable water resource management [40,43].

The Chilean water management system stands out due to its reliance on private property and market mechanisms for reallocating water rights, making it challenging to find comparable international experiences. The latter is important because this unique approach significantly complicates the identification of analogous cases in other parts of the world. In water management systems similar to Chile's, it is possible to identify institutional arrangements that go beyond what is required by law (e.g., [41,46–48]), but they do not have to deal with the constraints/opportunities imposed by private property.

In order to promote the self-organization of GCs and enhance their capacity to implement collective actions to adapt and transform their resource systems, the academic literature highlights the importance of adopting a polycentric and adaptative approach to governance, involving multiple centers of decision making [2,39,49–51]. In private property regimes such as Chile's, the adoption of such a governance system may face significant constraints. This is because these regulatory frameworks are rigid and designed for stable and unchanging conditions, with multiple entry restrictions and barriers to the participation and inclusion of all water users [1,50]. Transforming rigid systems of governance, such as the Chilean regime, into more participatory, bottom-up, and decentralized approaches requires pushing for structural and legislative change [52], processes that are often inherently slow. However, the CASUB case offers a guiding light toward progress. From its experience, it can be shown that within a private property regime for water management, the collective action and adaptive capacity of GCs depends heavily on internal attributes within the organization itself, such as strong leadership, the generation of transparent information, fair representation in the decision-making processes, and the promotion of transparency in its use. Despite systemic barriers, CASUB's experience suggests that specific strategies can be applied in a context such as Chile's. By focusing on the internal strengthening of organizations, it becomes possible to promote adaptability and effective collective decision making in water resource management.

5. Conclusions

The case study described in this article shows that a legal framework based on private property rights and characterized by rigid structures, as is the case in Chile, encourages individual use of groundwater, which has led to overexploitation of aquifers. Faced with this situation, GCs have had to make institutional arrangements, in addition to legal provisions, to move towards the sustainability of water resources.

CASUB's experience shows that in the face of external constraints imposed by the regulatory structure, an alternative path for collective action emerges in the cultivation of internal organizational capacities to grant autonomy to GCs. Leadership, combined with reliable information and reduced power imbalances, plays a key role in facilitating these efforts. While challenges remain, the CASUB experience suggests adaptable strategies for Chile's unique circumstances, prioritizing internal organizational strengthening to enhance adaptability and collective decision making.

The adoption of a more participatory and decentralized approach, such as a polycentric governance system, is crucial for the self-organization of user organizations and their capacity to adapt to uncertainty and possible changes caused by climate change. However, in Chile's private property regime, the transition to such a model is not without obstacles, given the rigid regulatory structure. Nevertheless, the case of CASUB is a beacon of progress.

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