"A Framework to Analyze Institutional Systems for Managing and Governing Water Resources"

"Marco Analítico Institucional para Sistemas de Gestión y Gobernanza de Recursos Hídricos"

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Dedication

In the hopes that this work may be a step towards achieving water security, I dedicate it to all those who are currently suffering from its absence.

Dedicatoria

Con la esperanza de que este trabajo pueda ser un paso hacia el logro de la seguridad hídrica, lo dedico a todos aquellos que hoy están sufriendo por su ausencia.

Acknowledgments

"The essence is, in itself, an act"
Paul Gulian Cobben

How to achieve a sustainable water management and governance in Chile? If I was asked this question years ago, my answer would have been that the fundamental thing is to promote local action and strengthen the institutional framework, together with thrusting the adoption of new technologies. Today, my vision continues to maintain these three pillars as fundamental aspects, but the focus has shifted to position people at the center of the work. I consider that the study of people and their relationship with water, their behavior, their interests and their entire decision-making process, is the key to understanding the management of the resource and its problems. It is what gives meaning to the community, it gives perspective to the institutional framework, and it gives functionality to new technologies.

To this extent, a large part of my thesis rests on the shoulders of the Nobel prize winner Elinor Ostrom and the team of academics who have continued their studies. They have shown that it would be possible to achieve a sustainable management of common resources, such as water, by promoting their self-management and local collective action. That is why I want to thank my teacher and mentor, Guillermo Donoso, for having introduced me to Elinor, and for having guided me with patience and generosity throughout this journey.

I perceive that in academic instances the paradigm of achieving consensus has often prevailed; to get approval. Still, I believe that dissent thinking, as well as consensus, is crucial. In disagreement, there can be more dialogue, innovative and creative solutions can be found, and it can give rise to dissimilar thoughts. That is why I want to thank the voice and participation of my informant professors Rodrigo Harrison and Óscar Melo. Thanks to your reflections and opinions, this work has been greatly strengthened.

However, local water management organizations in Chile are far from being easy organizations. There is a lack of understanding of the communities, their people, their norms, their processes and their history. That is why I want to thank the representatives of local organizations who gave me their testimony and trust, and who allowed me to go one step further in understanding their institutional system.

Likewise, I want to thank all the professors, colleagues and administrators of the Agricultural Sciences Faculty at the *Pontificia Universidad Católica de Chile*, and specifically, of the Department of Agricultural Economics, who supported with their creative and innovative reflections. A special thanks is due to the group of emerging researchers, from different universities and contexts, whose free minds have substantially nourished this study.

Finally, I thank my family, my mother, partner and friends, for guiding me and accompanying me on this path always. Without going any further, it is because of you that achieving optimal water management makes sense. It is this recognition of the relevance of people and of recovering their voice, from the individual stage to the communal and social one. My contribution is to recover the value of our essence and turn it into action.

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Agradecimientos

"La esencia es, en sí misma, un acto"
Paul Gulian Cobben

¿Cómo lograr una gestión y gobernanza sostenible del agua en Chile? De contestar esta pregunta hace años atrás, mi respuesta habría sido que lo fundamental es impulsar la acción local y fortalecer el entramado institucional, acompañado de la promoción de la adopción de nuevas tecnologías. Hoy en día, mi visión sigue manteniendo estos tres pilares como aspectos fundamentales, pero el foco se ha desplazado para posicionar en el centro del entramado, a las personas. Considero que el estudio de las personas y su vínculo con el agua, su comportamiento, sus intereses y todo su proceso de toma de decisiones, es la clave para el entendimiento de la gestión del recurso y sus problemáticas. Es lo que le da sentido a lo comunitario, le da perspectiva al entramado institucional y le da funcionalidad a las nuevas tecnologías.

De esta forma gran parte de mi tesis se apoya sobre los hombros de la premio nobel Elinor Ostrom y el equipo de académicos que ha continuado sus estudios. Ellos han demostrado que sería posible lograr un manejo sostenible de los recursos comunes, como las aguas, fomentando su autogestión y la acción local. Es por ello que quiero agradecer a mi profesor y mentor, Guillermo Donoso, por haberme introducido a Elinor, y haberme guiado con paciencia y generosidad a lo largo de este trayecto.

Percibo que en instancias académicas muchas veces ha primado el paradigma de lograr consensos; de lograr aprobación. Aun así, considero que las disidencias, tal como los consensos, son clave. En el desacuerdo, puede haber más diálogo, se pueden encontrar soluciones innovadoras y creativas, y se puede dar pie a pensamientos disímiles. Es por ello que quiero agradecer la voz y participación de mis profesores informantes Rodrigo Harrison y Óscar Melo. Gracias a sus reflexiones y opiniones, este trabajo se ha fortalecido enormemente.

Ahora bien, las organizaciones locales de gestión de aguas en Chile distan mucho de ser organizaciones fáciles. Existe una falta en el entender las comunidades, sus personas, sus normas, sus procesos y su historia. Es por ello que quiero agradecer a los representantes de organizaciones locales que me brindaron su testimonio y su confianza, y que me permitieron ir un paso más allá en el entendimiento de su lógica institucional.

Asimismo, quiero agradecer a todos los profesores, compañeros y administrativos de la Facultad de Agronomía de la Pontificia Universidad Católica de Chile y en específico, del Departamento de Economía Agraria, que apoyaron con sus reflexiones creativas e innovadoras. Un especial agradecimiento merece el grupo de investigadores emergentes, de distintas universidades y contextos, cuyas mentes libres han nutrido de manera sustancial este estudio.

Finalmente, agradezco a mi familia, a mi madre, pareja y amigos, por orientarme y acompañarme en este camino siempre. Sin ir más lejos, es por ustedes que lograr una óptima gestión de las aguas cobra sentido. Es este reconocimiento a la relevancia de las personas en todo el entramado, y a recuperar su voz, desde lo individual hacia lo comunitario y lo social. Mi aporte está en recuperar el valor de nuestra esencia y volverlo acción.

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Contents

General summary

Securing access to water entails more than a matter of availability, but also a matter of management and governance. While some water systems have demonstrated success in managing their scarce resources efficiently, many encounter challenges when it comes to organizing and coordinating the sustainable allocation and management of their resources. To understand natural resources systems, Common Goods Design Principles, the Socio-Ecological Systems (SES), and the Institutional Analysis and Development (IAD) framework have been developed, all rooted in collective action theories. These theories have been employed to understand the ways in which complex institutional systems operate, and the often-intricate decision-making processes that take place within them. At the same time, in order to establish rules and understand the roles within these institutional systems, Mechanism Design theory has been devised. These theories have not yet been fully adapted to incorporate the complexities and fragmentation inherent of water institutional frameworks.

The objective is to develop an analytical framework that can study and better understand water socio-ecological systems in order to improve their institutions and governance. In doing so, this work seeks to offer guidance to a broad audience, including water users, researchers, policymakers, and authorities responsible for designing policies and protecting the sustainability of water resources. Therefore, this thesis aims to contribute to the advancement of knowledge and comprehension regarding water socio-ecological systems management. It aspires to understand, unravel, analyze, and apply these theories, towards the analysis of water systems.

This presents a challenge, since water systems constitute a higher level of complexity, than those usually considered by these theories. Water systems have higher levels of diversity among them, in terms of physical water availability and geo-climatic conditions, cultural background, historical development and regulatory terms, among others. By adapting these frameworks, we seek to incorporate the analysis of critical issues, such as administrative and organizational processes, accounting and monitoring decisions, as well as financial aspects, which are not present in current analytical frameworks.

Multiple instances for the theoretical and empirical testing of this new framework have been carried out. These include an empirical analysis of a Chilean case study, using the tools and frameworks mentioned, identifying their opportunities and limitations towards water socio-ecological systems analysis. With it, a new framework was developed, and the empirical testing was carried out in Chilean water basins from the north and central area. The latter was done to represent different groups of local collective action organizations: private groundwater communities (Copiapó River case) and private surface associations (Aconcagua River case). Also, and to test the new framework more thoroughly, the study includes the analysis and comparison of the Chilean conflict resolution system from colonial times with current times. By adapting these frameworks towards local water communities, it provides a way to unfold these complex systems, so that they can be explored, analyzed and improved, without simplifying or limiting their potential.

The dissertation ends by providing a synopsis of the research chapters, showing and connecting the main findings, delivering several policy implications. The chapter also discusses the limitations regarding the scope of the results, offering a series of future research avenues, complementing and expanding the knowledge of institutional analysis applied to water socio-ecological systems worldwide.

Resumen general

*Garantizar el acceso al agua implica más que una cuestión de disponibilidad, sino también una cuestión de gestión y gobernanza. Si bien algunos sistemas hídricos han demostrado éxito en la gestión eficiente de sus escasos recursos, muchos enfrentan desafíos cuando se trata de organizar y coordinar la asignación y gestión sostenible de sus recursos. Para comprender los sistemas de recursos naturales, se han desarrollado los Principios de Diseño de Bienes Comunes, los Sistemas Socio-ecológicos (SES, por sus siglas en inglés) y el marco de Análisis y Desarrollo Institucional (*Institutional Analysis and Development framework, *IAD), todos ellos arraigados en teorías de acción colectiva. Estas teorías se han empleado para comprender las formas en que operan los sistemas institucionales complejos y los, a menudo, intrincados procesos de toma de decisiones que tienen lugar dentro de ellos. Al mismo tiempo, para establecer reglas y comprender los roles dentro de estos sistemas institucionales, se ha desarrollado la teoría del diseño de mecanismos. Estas teorías aún no se han adaptado completamente para incorporar las complejidades y la fragmentación inherentes a los marcos institucionales del agua.*

Por lo tanto, la presente tesis pretende contribuir al avance del conocimiento y la comprensión sobre la gestión de los sistemas socio-ecológicos hídricos. Aspira a comprender, desentrañar, analizar y aplicar estas teorías, hacia el análisis de los sistemas hídricos. Con ello, el objetivo es desarrollar un marco analítico que pueda estudiar y comprender mejor los sistemas socio-ecológicos del agua para mejorar sus instituciones y gobernanza. Al hacerlo, este trabajo busca ofrecer orientación a una audiencia amplia, incluidos usuarios del agua, investigadores, formuladores de políticas y autoridades responsables de diseñar políticas y proteger la sostenibilidad de los recursos hídricos.

Esto presenta un desafío, ya que los sistemas hídricos constituyen un nivel de complejidad mayor que los habitualmente considerados. Los sistemas hídricos presentan mayores niveles de diversidad entre ellos, en términos de disponibilidad física de agua y condiciones geo-climáticas, antecedentes culturales, desarrollo histórico y términos regulatorios, entre otros. Al adaptar estos marcos, buscamos incorporar el análisis de temas críticos, como procesos administrativos y organizacionales, decisiones contables y de seguimiento, así como aspectos financieros, que no están presentes en los marcos analíticos actuales.

Se han llevado a cabo múltiples instancias para la prueba teórica y empírica de este nuevo marco. Estos incluyen un análisis empírico de un estudio de caso chileno, utilizando las herramientas y marcos mencionados, identificando sus oportunidades y limitaciones hacia el análisis de sistemas socio-ecológicos hídricos. Con ello se desarrolló un nuevo marco y se realizaron las pruebas empíricas en cuencas hidrográficas de la zona norte y centro de Chile. Esto último se hizo para representar a diferentes grupos de organizaciones locales de acción colectiva: comunidades privadas de aguas subterráneas (caso del río Copiapó) y asociaciones privadas de superficie (caso del río Aconcagua). Asimismo, y para probar más a fondo el nuevo marco, el estudio incluye el análisis y comparación del sistema de resolución de conflictos chileno desde la época colonial con la época actual. Al adaptar estos marcos a las comunidades hídricas locales, se proporcionó una manera de desplegar estos sistemas complejos, de modo que puedan explorarse, analizarse y mejorarse, sin simplificar ni limitar su potencial.

La tesis finaliza proporcionando una sinopsis de los capítulos de investigación, mostrando y conectando los principales hallazgos, entregando varias implicaciones políticas. El capítulo también discute las limitaciones en cuanto al alcance de los resultados, ofreciendo una serie de líneas de investigación futuras, complementando y ampliando el conocimiento del análisis institucional aplicado a los sistemas socio-ecológicos hídricos a nivel mundial.

Chapter 1. General introduction and putting it all together

"*If you're gonna try and walk on water*
make sure you wear your comfortable shoes"
Arctic Monkeys

1. Introduction and context

According to a report by the World Resources Institute, currently 17 countries -representing a total of a quarter of the world's population- face "extremely high" water stress (Hofste et al., 2019). Predictions indicate that this situation will only worsen over the years (Martínez-Valderrama et al., 2023; Roy et al., 2018). Given this scenario, together with incorporating new technology, the need to improve water governance and integrated water resources management has been pointed out as a critical measure for achieving water security, together with economic growth, social inclusion and environmental sustainability (OECD, 2018).

Most global water management systems involve public institutions, in charge of the initial allocation of the resource, and a local institution with various levels of public-private coordination (OECD, 2011, 2012). This type of structure with several decision centers, each autonomous, with regulations that offer a limited range of options, is typical of common natural resources and has been called a social-ecological system. (Martínez-Fernández et al., 2020). These systems are generally characterized by a multiplicity of institutions that participate simultaneously, connecting human and natural systems, in a rather complex and disordered structure (Alessa et al., 2009; Folke et al., 2003; Gain et al., 2021). This complexity makes it difficult to analyze, understand and promote potential improvements in water management.

To study these institutional systems, different theories can be helpful. The Design Principles for common-pool resource (CPR) governance, for example, set guidelines for sustainable shared resources management. Also, Social-Ecological Systems (SES) Framework, has been widely used to analyze and consider the biophysical and ecological foundations of institutional systems. Additionally, the Institutional Analysis and Development (IAD) framework was conceived to understand these messy institutional systems. The latter was developed from game theory, that studies how individuals or entities act, considering their outcomes depend on the decisions of others. While studying institutional systems, Mechanism Design theories can also be helpful since they study how to design rules and institutions to achieve predefined socially desirable goals.

Hence, the following dissertation studies these theories, seeking to adapt them towards the analysis of water socio-ecological systems. Thus, these theories are presented ahead, together with the challenges they have for the analysis of water systems. Afterwards, the hypothesis, research questions and goals of the thesis are presented. Finally, the basis for an adapted framework is presented, and the structure of the dissertation.

2. The basis: collective action and mechanism design

The basis of the analytical framework proposed has been developed considering different theoretical tendencies. On the one hand, it considers the Common Goods Design Principles, together with the

underlying theories of Socio-Ecological Systems (SES) and the Institutional Analysis Development (IAD) framework. On the other hand, it also takes components from game theory, and mechanism design and regulation.

2.1. Design principles

In 1968, Hardin published his well-known Tragedy of the Common Goods theory, stating that individuals sharing a common resource will act for their own benefit, obtaining worse results than if they acted collaboratively. As Dawes and Messick (1980) points out, this tragedy may occur in any social situation characterized by the following two elements: i) each individual has a non-cooperative dominant strategy, receiving a higher outcome for it no matter what others do; and ii) the entire community is better off under the cooperation strategy.

However, Nobel Prize Elinor Ostrom (1990, 2000, 2015) observed that the Tragedy and the self-interested attitudes were preventable. She studied several cases where voluntary organizations using collective action were able to manage their resources sustainably. For this to happen, eight design principles were defined as key for successfully governing the commons, including the definition of clear boundaries; that rules are aligned with local needs and that these can be modified by participants; respect from external authorities; the development of a system for monitoring compliance; gradual sanctions; as well as accessible and low-cost solutions to disputes (Ostrom, 2015).

Regarding water resources, the use of these design principles as an analytical tool has been widely used, even at transboundary levels (Heikkila, et al. 2011). For example, while applying these principles, a study carried out by Van Vugt (2002) regarding domestic water demands during droughts, shows that residents' conservation efforts were strongly linked to their trust in the cooperation of other members of the community. It proved that higher levels of trust effectively restrict users in pursuing their immediate self-benefit, protecting the long-term interests of the community (Van Vugt, 2002).

These results are consistent with what was highlighted in non-water-related participation and trust studies carried out by Alesina and La Ferrara (2000, 2002). They also identify that participation in community groups that require direct contact between members is difficult, particularly in heterogeneous communities (Alesina and La Ferrara, 2000). For the rest, they identify that the strongest factors associated with low participation are a recent traumatic history, including long-lasting droughts; be economically unsuccessful; live in a racially mixed community and/or with a high degree of income disparity, among others (Alesina and La Ferrara, 2002).

Moreover, Gambetta (2000) specifies that trust as a precondition of cooperation may be needed to varying degrees, depending on the strength of the mechanisms that motivated the cooperation and on the social arrangements in which those decisions are made. Users may have to trust blindly, not because they do not know how untrustworthy others are, but because the alternatives are way worse (Gambetta, 2000). However, too much cooperation or trust can hinder the development of collective action, since it can encourage free-riding behavior (Gambetta, 2000).

Axelrod and Hamilton (1981) analyzed the evolution of cooperation by computationally replicating situations under different scenarios, finding that in the absence of central authority, cooperation naturally arises among users. In further research, Axelrod studied the dynamics between enemy soldiers, who appear to have learned ways of signaling to the enemy their predisposition to cooperate (Axelrod, 1984, in Gambetta, 2000). Thus, trust and the development of cooperation is a rational option when sharing resources.

Gradually, different countries have implemented, adopted or simply allowed collective action strategies in water management. This, with varying degrees of success and with a diverse range of results. In Spain, for example, a study compared groundwater associations in three watersheds of Almería Province, analyzing the different strategies that naturally emerged to maintain the resilience of the system, all of them carried out in a collective way (Rica, et al. 2011). They identified the materialization of actions towards decreasing the price paid for energy from wells; encouraging the use of alternative sources such as recycled water or desalination; notable leadership skills that were followed by a majority of users; and the use of public funding. In these watersheds, the common goal coincided with the individual interest, and collective action was successful. However, in multi-objective groups where ecosystem resilience was also a goal, the equilibrium was not always stable (Rica, et al. 2011). A similar study was carried out in Jaén Province, Spain, specifically in La Loma basin, showing how informal water associations begun a process of formalization starting by elaborating rules; choosing a representative or president and a board made up of members; hiring an unbiased operator to be in charge of the pump and the irrigation system; and making joint decisions on how and when to distribute water (Rica, et al. 2014). In Mexico, Pacheco-Vega (2014) studied the latest trends in water management research, determining that there is a rising trend towards adopting collective action theories. The study points out that in the literature regarding water resource management, the principles and the attributes proposed by Ostrom (2005 and 1992) have been gradually adopted.

In urban matters, a study carried out in Colombia determined that the communities can provide public drinking water and manage it as a common resource in a sustainable manner (Moncada, et al. 2013). As an example, they refer to the association of aqueducts-communities of the Desquebradas precinct, where they developed their own system of internal rules; all members participate in the management; and a board of directors is responsible for administrative topics that are later solved in general assembly.

These experiences were considered in the development of Bolivia's Irrigation Law and Water Authority (Villarroel and Peredo, 2006). The latter, an assembly composed of representatives of the government and civil society, became a decentralized system with different degrees: traditional local authorities in the base, a department assembly, and finally, a national assembly, with user's participation in all three stages. The users have maintained their commitment to the process and formed a national association of irrigators and community drinking water systems, among other organizations at the departmental level (Villarroel and Peredo, 2006).

Not all case studies present positive experiences. Cobbing and Rose-Innes (2018) studied groundwater management associations in Grootfontein aquifer at Mahikeng, South Africa, where self-regulation has not occurred even though a National Water Act was signed to improve it. The current situation includes the absence of appropriate local conditions -as the attributes described earlier by Ostrom (1992) and Baland and Platteau (1996)- and ineffective institutions. Moreover, as Molle, et al. (2018) indicate in their summary of the article, water users are heterogeneous, lack a shared understanding of the aquifer, organizational experience, leadership, trust and reciprocity, all relevant elements for generating collective action. A similar experience was presented in Mirnezami, et al. (2018) analyzing why Iranian society has been inactive in the conservation of groundwater, despite the existence of qanats, known as effective groundwater community-based management systems. Here, the role of the socio-technological transition of pumping tube wells led to the deterioration of the self-regulated systems, as well as institutional problems and trust, such as high concentration of power in the bureaucracy, corruption, abuse of political power, and a perception of inequity (Mirnezami, et al. 2018). Also, in California, Langridge and Ansell (2018) analyzed two Groundwater Districts where governing authorities are disaggregated in multiple semi-autonomous institutions, all with different objectives, that may overlap sometimes. Even though advances have been made in the sustainability of the aquifer, they conclude that as the local units are more hermetic and private,

the less they engage in wider multi-objective arrangements, such as incorporating water quality considerations or watershed protection (Langridge and Ansell, 2018). Milman, et al. (2018) address the formation of Groundwater Sustainability Agencies (GSAs) dictated by the recent Sustainable Groundwater Management Act (SGMA), and the determinants of the decision between choosing single basin-wide organizations or agencies to coordinate the organizational structure. They show the diversity of the factors involved, such as the weight of agriculture, the number of counties, and racial diversity, among others, in the emergence of particular governance structures (Milman, et al. 2018). Considering groundwater, private water users are relatively reluctant to participate in WUAs, since most of them still consider the aquifer to be an open-access good (Rinaudo, et al. 2012). Thus, groundwater WUAs are perceived as more restrictive in terms of water abstraction than surface associations. Recent research conducted in France and Portugal has managed to increase user's collaboration through prospective participation activities that include i) raising awareness of the long-term benefits associated with the sustainable use of groundwater and ii) facilitating information and shortening existing asymmetries of information (Rinaudo, et al. 2012). In communities with past experiences of failed collective action, whose leaders had been accused of favoring some associates and even of corruption, collective action for self-regulation of the aquifer was viewed as possible only in a critical situation.

Thus, the application and usage of the common-pool resources theoretical tools has been applied to water systems with different levels of success. Also, the formation and promotion of self-governing institutions depends on the existence of certain principles, contextual variables of the resource and of appropriators, and a well-established social capital. However, these theories usually involve general common-pool resources, and not specific water usage and management.

2.2. Collective Action and the Social-Ecological Systems (SES) Framework

The Social-Ecological Systems (SES) Framework was developed to analyze and consider the biophysical and ecological foundations of these institutional systems. The idea was to analyze patterns of interactions and outcomes embedded in these SES, with focus on the variables involved (McGinnis, 2011). The framework assists in organizing these variables regarding specific attributes of i) the resource system, ii) the resource units generated by that system, iii) the users of that system, and iv) the governance system (Ostrom, 2007). The analysis could also encompass v) social, economic, and political settings, integrating the broader context in which the governance system is situated. Additionally, it allows for the consideration of vi) related ecosystems, to provide a more comprehensive understanding of the broader ecological context.

The latter has been applied to a variety of studies regarding the institutional scope of SES, such as forests (Vogt, et al. 2015; Rivero and Hakizimana, 2016; Xie, et al. 2019), fisheries (Blythe, et al. 2017; Botto-Barrios and Saavedra-Díaz, 2020; Partelow, et al. 2021) and water resources (Nagendra and Ostrom, 2014; Baudoin and Arenas, 2020). Nevertheless, when it comes to water institutions, there appears to be a scarcity of research. Here, a study by Ruth Meinzen-Dick can be mentioned, where hypothetical factors that could influence interactions and outcomes regarding irrigation institutional systems are proposed (Meinzen-Dick, 2007).

Rather than setting up rigid institutional models, the overall notion of the framework is to recognize the differences between sites and make specific provisions for each case analyzed (Ostrom, 2007). However, the framework does not consider a deeper analysis on the interactions of users, especially considering a wider administrative unit, such as a whole basin. A step towards it was carried out by Oakerson and Parks regarding multi-level institutional analysis in protected areas (Oakerson and Parks, 2011). Thus, in order to adapt this framework towards water institutions, it becomes essential to incorporate additional theoretical perspectives that can provide a more comprehensive analysis of the issue.

2.3. Game Theory and Water Management

The modeling of situations using Game Theory provides the possibility of predicting the equilibrium state of the game with the analysis of the behaviors and the decisions of the logical players (Myerson 2013). It was first developed by Von Neumann and Morgenstern (1944). The application of this method has significantly helped to identify and analyze water conflicts between different users, with different variations (Dinar and Hogarth, 2015). Models have been developed considering a single period of time, two periods (Wang, et al. 2003; Saak and Peterson, 2007; Ito, 2012), multi-periods (Saleh, et al. 2011) and dynamic models (Azaiez, et al. 2015); two users (Saak and Peterson, 2007) and n-users (Saleh, et al. 2011); identical (Suppala, et al. 2002), different users (Gopalakrishnan, et al. 2005; Saleh, et al. 2011) and different objectives (Raquel, et al. 2007; Lee, 2012); modeling water quality and quantity together (Wei, 2008; Wei, et al. 2010), among others. Wang and Segarra (2011) incorporated and examined the model with varying water demands elasticities. Madani and Dinar (2012a; 2012b) even modeled cooperation and non-cooperation among groundwater public institutions.

In terms of collective water management, even though not many, models that have been developed to incorporate user behavior in the face of the management of a common resource, which could be applied to a country at a national scale are scarce. A simple model is presented in Poteete, *et al.* (2010) where new rules of water extraction are expected to be chosen if the sum of the expected costs of at least one coalition, k, are positive: $D_k > (C1_k + C2_k + C3_k)$, with $C1$ being up-front costs spent agreeing upon new rules, $C2$ being short-term costs of implementing new rules, and $C3$ referring to long-term costs.

The study carried out by Saak and Peterson (2007) adds complexity to the model considering a restricted access aquifer with two identical users over a finite planning horizon (two periods), modeling the hydrological behavior of the return flows and incorporating the possibility that users lack information. The net benefit function considered is $g(u,x) = v(py(u) - c(u,x) - k)$, where p is the per unit price of the crop, y the yield, c the cost of pumping groundwater, k the cost of other farming inputs, and v the utility-of-income function, depending on u, water extraction and x, stocks of groundwater. Thus, the decision of the users varies according to the information they have, as well as their optimum extraction rates, in all cases having superior extraction rates than the social optimum.

Saleh, Gürler and Berk (2011) improve such model considering multiple different users and two types of management, one centralized where water is extracted with the supervision of a social planner, and one decentralized where each user can pump the water they want. The difference in users is established in the net benefit function, since the benefits function now varies for each user i, each period of time t: $y_{it}(u_{i,t}) = a_{i,t}u_{i,t} - 0{,}5b_{i,t}u_{i,t}^2$. The same happens with the quadratic groundwater extraction costs: $\tau_{it}(u_{i,t}, x_{i,t}) = c_{i,t}[(x_{i,0} - x_{i,t})u_{i,t} + 0{,}5u_{i,t}^2]$. The two generate the net utility function: $g_{it}(u_{i,t}, x_{i,t}) = [\rho_{i,t}a_{i,t} - c_{i,t}(x_{i,0} - x_{i,t})]u_{i,t} - 0{,}5(\rho_{i,t}b_{i,t} + c_{i,t})u_{i,t}^2$.

In the equation, differences in the parameters $a_{i,t}$, $b_{i,t}$ and $\rho_{i,t}$ among users represent different cropping and irrigation patterns, whereas the difference in the cost parameter, $c_{i,t}$, represents different technologies and machinery used in pumping groundwater. With these, they identify that the centralized solution dominates the decentralized one, obtaining more benefits in the use of water. The optimum extraction is obtained maximizing the discounted sum of all benefits, for the two-period time, simulation associated with a centralized management.

Another line of research following these studies has been followed by Loáiciga (2004), who estimates sustainable groundwater extraction rates. He demonstrates that for cooperation to yield its benefits, enforcement must be effective, in which case sustainable aquifer mining is possible and economic efficiency

is theoretically demonstrable. The model was also empirically proved with data from a rural aquifer and from an urban coastal aquifer threatened by seawater intrusion in Santa Barbara.

The model is used by Bazargan-Lari, *et al.* (2009) to provide a conjunct surface and groundwater study. It uses a hydrological tool and then applies an integrated conflict-resolution approach, generating coherent results.

Few other studies apply theoretical models to a basin empirically. This is the case of Wei (2008), who develops a theoretical model of cooperative and non-cooperative conflict games and then applies this simulation approach to the water conflicts of the Hanjiang River basin in China. Their results confirm that cooperation models achieve a social optimum, although some players must be in worse conditions to achieve it. Cooperation with other users is the dominant strategy for each player, but the risks come from other players and sub-players. Similar results obtained by Wei, *et al.* (2010) in the water transfer project from north to south of China, where cooperation would make the players improve collectively, although with some players facing losses. On this occasion, however, the users were not willing to cooperate, because they had uncertainty that the large users would cooperate as well.

Ito (2012) model was applied to a group of rural communities in Yunnan, China. It identifies that collective action is carried out in the optimum, with the exception of communities where water scarcity is severe and where wealth is distributed unequally among the members of the community. On the contrary, mutual cooperation will probably occur in communities where there are equal norms in terms of farmers' access to land and water supply; in cases where users participate in other social exchange games and it is likely that mutual cooperation will take place in a community characterized by social homogeneity.

The analysis in Ito (2012) also revealed that the participation of the immediate stakeholders facilitates cooperative behavior, while the intervention of the local government exerts a negative effect. Similar results were obtained by Rinaudo, *et al.* (2012) indicating that these associations need to be a bottom-up creation, since associations created by the state are doomed to fail. In Chile, a study made in a local village of Molinos concluded with similar results, adding that participation could not take place without a comprehensive community consultation, people-centered projects or autonomous organizations (Garande and Dagg, 2005).

As seen, even though several models have been proved to coordinate water users in their intake with game theory, few include elements of social capital or the relevance of trust. An exception is the study carried out by Aoki (2001) with an experimental study on an irrigation community. When the return from social exchange was large enough, players tend to cooperate in maintenance and the irrigation system will be well-maintained. The existence of social capital thus prevents selfish behavior and leads to better resource management. With this information, Aida (2011) estimates the effect of social capital between head-enders and tail-enders on the irrigation water allocation problem.

However, these studies have been based on a centralized management system, without incorporating elements of collective water management and its complexity. In detail, these cases do not consider the high heterogeneity that exists among users and among group sizes, as well as the low public participation, typical of these systems.

2.4. Institutional Analysis and Development (IAD) Framework

The Institutional Analysis and Development (IAD) Framework condenses multiple efforts to understand the ways in which institutions operate and change over time. It was developed from Game Theory, combining it with collective action theories. The framework specifically targets communities without state intervention (McGinnis, 2011). Examples of its use span from the analysis of office microwave sharing to indigenous communities sharing a forest.

It was designed as a tool to simplify the analytical task confronting the study of institutions in their full complexity (Anderies et al., 2004; McGinnis, 2011; Ostrom, 2009b, 2011). For this, the framework assigns all relevant factors and variables of the system into categories, and then locates these categories in a structure of logical relationships (Ostrom, 2009b).

The framework involves the analysis of Exogenous Variables that change the analysis of the case study as they vary; the Action Situation, where the decision-making process takes place; the Interactions and Outcomes of this decision-making process; and specific Evaluation Criteria to provide feedback for adaptive learning. The Exogenous Variables, also known as inputs, include contextual factors such as attributes of the community, nature of the good, also known as biophysical conditions, and rules, that encompass the setting of the Action Situation. The Action Situation, at the IAD's core, is a social space where the actors interact and solve the commons problem (Ostrom, 2007; Ostrom et al., 2007). Here, the framework uses elements of Game Theory, since the "Action Situation" is where *individuals/participants* in specific *positions* take *actions*, considering the information they possess and the *payoffs* they face, regarding different outcomes or results. Thus, it is where the decision-making process takes place. Around the Action Situation, different components and their relations are analyzed, as shown in Figure 1.

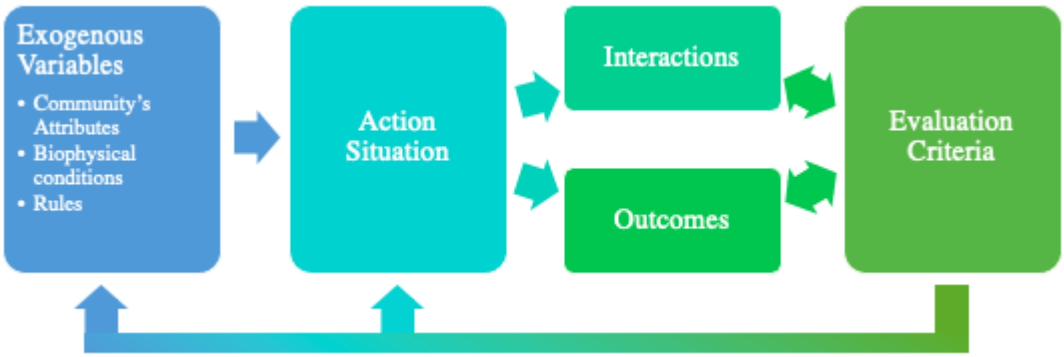


Figure 1. Basic scheme and components of the IAD framework (adapted from Ostrom, 2010).

The strength of the IAD framework is to recognize and acknowledge the complexity of the world, with a systematic theoretical tool that copes with this complexity (Rudd, 2004). It has been considered a well-suited framework for addressing the challenges of analyzing decentralized natural resource governance (Clement, 2010). At the same time, the framework comes from the Game Theory discipline, that analyzes the behavior of individuals or groups in situations of strategic interaction. Game Theory has been used to explain situations where conflicting results are reached, even though a better solution was available (Myerson, 2013). Thus, IAD framework could have a central role modeling and predicting water conflicts (Ostrom, 2015). Finally, the IAD framework was the result of a combination of methods to study complex systems, with Common-Pool Resources being at the center, thus providing an advantage when studying communal resource management such as water, over other methods.

The specific form of the framework has varied over time. Initially developed by Kiser and Ostrom (1982), it was then studied and applied in multiple institutional systems (see e.g. Ostrom, 1986, 1990, 1998, 1999, 2007, 2009a; Ostrom et al., 1994, 2011; Poteete, et al. 2010). In water, Eva Ebenhöh (2007) used the IAD framework to generate an agent-based model for water management regimes, and Yang Zhang (2018, 2019, 2020) has used the framework to analyze different irrigation systems in China. Some elements have

also been used in large-scale social-ecological systems, such as the Great Barrier Reef in Australia and the Rhine River in Western Europe (Fleischman et al., 2014).

2.5. Mechanism design theory

The theory of mechanism design has been used to address how to design rules of the game or institutions to achieve predefined socially desirable goals as equilibrium outcomes. Initially developed by Nobel Prize winners Leonid Hurwicz, Eric Maskin and Roger Myerson, who study the performance of existing economic institutions, how these can be improved, and its theoretical limits. These advances have been the origin of a new normative framework known as the "New Economics of Regulation" (Laffont and Tirole, 1993), which has been used to design regulatory reforms in developed and developing countries.

Recently there has been a recognition that developing countries have specific characteristics that must be taken into account when applying mechanism design literature to institutional design. Laffont (2005) builds a basic model of monopoly regulation to expose the institutional limitations affecting regulation in developing economies, what he refers to as "institutional failures". Estache and Wren-Lewis (2009) use Laffonts' theories organizing institutional limitation in four broad groups: i) limited regulatory capacity, regarding resources and funding; ii) limited commitment, acknowledged through the inability to rely on contracts; iii) limited accountability and thus, where collusion is more likely to occur; and iv) limited fiscal efficiency. With these groups, the expected effect of each institutional limitation can be predicted and addressed.

These theories have been mostly applied towards concessions or public contracts. Here, the theoretical literature commonly assumes that the public authority designs a concession contract in such a way that incentives between the private provider and the authority are aligned (Dewatripont and Legros 2005, Guasch et al. 2006). However, as Carrasco et al. (2018) point out, this situation differs significantly from real-world experience, since we are usually dealing with polycentric institutions rather than a single authority, each one acting as a counterpart to the concessionaire while possessing different objectives. Thus, to successfully solve this problem, all roles should be assigned, and conflicting roles should not fall on the same institution.

Furthermore, this literature has been used to understand high variance performances among concessions, or public contracts. Here, Harrison et al. (2013) argues that an important and often excluded element for the evaluation of the pertinence of a concession process is the institutional framework, mainly because it defines the interaction between its relevant actors, developing an analytical framework useful to evaluate it.

To Promote water users associations formation and participation and encourage users to cooperate, a line of authors have theorized and then empirically developed mechanisms to promote cooperation and participation of users in water management conflicts. For example, Safari, Zarghami and Szidarovszky (2014) compared strategies of two agents (a follower and a leader) in their negotiation process, identifying that those who play the role of leaders have more advantages of achieving the desired objective, and that the existence of a leading user reduces the possibility of stagnation. In a similar study, Mehrparvar, Ahmadi and Safavi (2015) stated that the formation of a grand coalition (full cooperation on the part of all stakeholders) is the best solution for a region with water shortages. Also, the introduction of punishment in different social structures has achieved similar results (Neilson and Wichmann, 2014). In Hipel, Kinsara and Kilgour (2014) conflict resolution mechanisms are developed, demonstrating again, the importance of coalitions and incorporating the intervention of third parties. Although this study is developed considering transnational water conflicts of the Middle East, they highlight the difficulty of achieving impartial agreements when some users are better placed for water supply than others. These results are aligned with what was obtained

by Zanjanian, et al. (2018) who develop a similar study, in the Ilam dam basin, Iran. Oftadeh, et al. (2017) goes one step further, proposing a conflict resolution mechanism based on the ultimatum game, where if the two parties do not reach an agreement, the treaty is canceled, and neither receives water. This case study was tested with positive results in Iran, with the Ministry of Agriculture and Energy acting as players.

A whole other literature branch involves the use of interactive computer programs for conflict resolution using Negotiation Support Systems, NSS (Jelassi and Foroughi, 1989). According to Fisher, et al. (2011), five factors impact the structuring of a negotiation and are then relevant to NSS design: i) separate the people from the problem; ii) provide communication between negotiators; iii) help negotiators identify their real interests; iv) generate options for mutual gain; and v) use objective criteria. The development and use of NSS to facilitate and help guide multi-party negotiations in water matters was initially explored by Thiessen, et al. (1998), and then applied by Hämäläinen, et al. (2001). Carraro, et al. (2005) incorporates Multi-Agent and Agent-Based Systems as well as the status quo analysis illustrated earlier by Li, et al. (2004).

Therefore, theoretically it would be possible to modify the individual's utility function, incorporating a punishment or penalty to their costs. This may equate the balance towards the probability of cooperation and enhance the formation and participation of users in WUAs.

In all the above, the convenience of using the framework to analyze water systems was verified. Despite this, none of these investigations have proposed significant changes to capture the specificities and complexities of the water resource, leaving aside key aspects that could be determining the sustainability and good governance of the water system.

3. Theoretical challenges, research questions and thesis objectives

3.1. Current theories challenges

The above-mentioned theories can all be useful for studying natural resources systems and their institutions. However, they all present challenges, as they have not been adapted to capture the specificities and complexities of water resources. Collective Action and Common Goods leads the theoretical development regarding water resources and local associations. However, it does not consider a deeper analysis on the interactions multi-purpose users, nor the consideration of different administrative units. Also, one of the most relevant and repeated results from these theories is the impossibility of developing a panacea, that is, an institutional solution that can be used in different contexts. Mechanism design theories have been generated on the basis of monopolistic behavior and then expanded to fulfill concessions and conflict among agents. The difficulty here is to analyze its usage considering water institutional systems as the only providers of water, and thus, linking it to its monopolistic behavior. Thus, the usage of this theoretical background presents the challenge of having to expand their results towards multi-purpose and multi-scale cases, without falling into structured solutions. Hence, the usage of any of these theories alone, in specific and complex water systems, could leave aside determinant aspects for a sustainable governance of the water systems themselves.

3.2. Research hypothesis and questions

In this scenario, the most used theories for natural resources governance face a void when understanding water institutional systems and their interactions. Thus, for the research project, the underlying hypothesis is that by gathering elements from these theories, the analysis and understanding of water institutional

systems could be done more comprehensively. This would allow for the identification of spaces for improvement and could lead to sustainable management and governance of water resources.

The question that arises then is if there could be a method that allows for a more comprehensive analysis of these particular socio-ecological systems. Specific questions that derive from this big question are:

a. Can current collective action theories be useful for understanding water socio-ecological systems?
b. Can these theories detect which barriers face users to organize themselves and develop successful water governance.
c. Can these frameworks be adjusted to fit the analysis of delimitated water systems.
d. Could this framework be useful to learn from different contexts and scales of water systems?
e. Could such a framework be useful for analyzing past experiences and historical trends?

3.3. Dissertation objectives

The primary aim of this dissertation is to contribute to the advancement of knowledge and comprehension regarding water socio-ecological systems within the realm of improving their management. It seeks to understand, analyze, and apply theories generally used to study social systems, and bring them together into one framework, to be used in the analysis of water systems.

Thus, considering and narrowing the research towards the above stated questions, this thesis seeks to enlighten the panorama by developing an analytical framework that can analyze water socio-ecological systems for improving their institutions and governance. This, with the aim of providing guidelines for water users, research scholars, policymakers and authorities responsible for designing policies and protecting the sustainability of water resources.

While impossible to address all the potential inquiries around the thematic, this thesis proposes and addresses a set of specific objectives, which are:

a. To analyze current collective action theories in regard to their adaptation potential towards their usage in water social-ecological systems.
b. To develop a theoretical analytical framework to assess water management and governance systems.
c. To empirically test this framework using different case studies.
d. To empirically test the framework in different historical moments.

4. The theoretically adapted IAD framework

As mentioned, the IAD framework defines an arrangement of action situations that can be applied to different political levels, from a nation-wide arrangement to a local process of decision making. The present method has to narrow the analysis towards water systems. Here, the action situations include “operational choice” situations, referred to practical and periodical decisions taken by authorized individuals as a consequence of collective choice processes. In water matters, these are the actions taken by community managers, water watchmen, and other positions hired by the local community to distribute water resources. Also, in water we include “collective choice” situations, where the analysis considers the processes through

which local community decisions are made, by those actors authorized to participate in the collective decisions. These situations include the variety of alternatives that members of a water community have to set their norms and regulations, as well as their duties and obligations towards the community. Here, the organization and decision-making process of the irrigation district, vigilance committees, groundwater or surface water communities or any other water association can be studied. Their decisions are valid and recognized by nation or statewide regulations and norms, also called "constitutional choice processes", and constitute the third action situation arrangement. In the present study, we limit the scope of the analysis to the operational and collective choice situation.

The IAD Framework has its origins in a general system approach to policy processes, where inputs are processed by policymakers into outputs that are later evaluated. For water systems, the components that should be analyzed have been adapted from McGinnis (2011) to answer for water social-ecological systems, and their complexity.

As will be seen, several aspects listed below could be accounted for quantitatively. However, since there are a large number of variables involved and there are significant differences among water systems, multiple studies have reflected on the preferability to carry out these kinds of analysis qualitatively, or using mixed methods (Anderies et al., 2004; Ostrom, 2009b). Through qualitative analysis the complexity of the local social-ecological systems can be accounted for and not over-simplified.

In the following subsections, each component of the adapted framework is described.

4.1. Exogenous Variables

Exogenous variables include the contextual factors that encompass all aspects of the social, cultural, institutional, and physical environment of the action situation. They describe the Community's Attributes, this is, particular aspects of the social and cultural context where an action situation is situated; the Nature of the Good, referring to any biophysical condition of the water resource; and the Rules-In-Use, that is, any formal or informal rule that defines the institutional situation.

Regarding the Community's Attributes, the original framework has been modified to include new variables of analysis, regarding a better description and characterization of the water communities. With the purpose of improving the analysis regarding the causes and understanding of what lead to said attributes, a deeper analysis of the community size, heterogeneity, its leaders, formation mechanism, and financial scheme have been added (Figure 2).

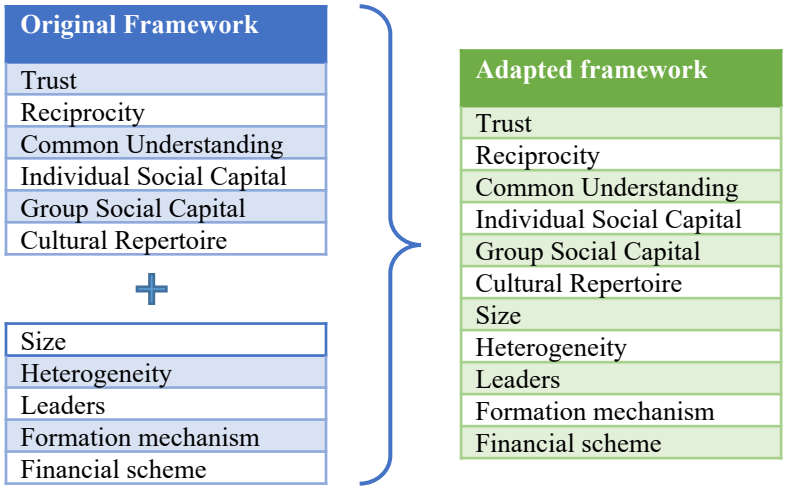


Figure 2. Adapted framework regarding the Attributes of the Community sub-component

The Nature of the Good component expresses the biophysical conditions concerning the resource. One of the particularities of water systems is the complexity of the resource itself, and the difficulties regarding how it can be monitored, understood, distributed, and shared. Thus, to adapt the framework to allow for a deeper analysis of the characteristics and level of conflict of the resource we added scarcity or drought conditions and water quality.

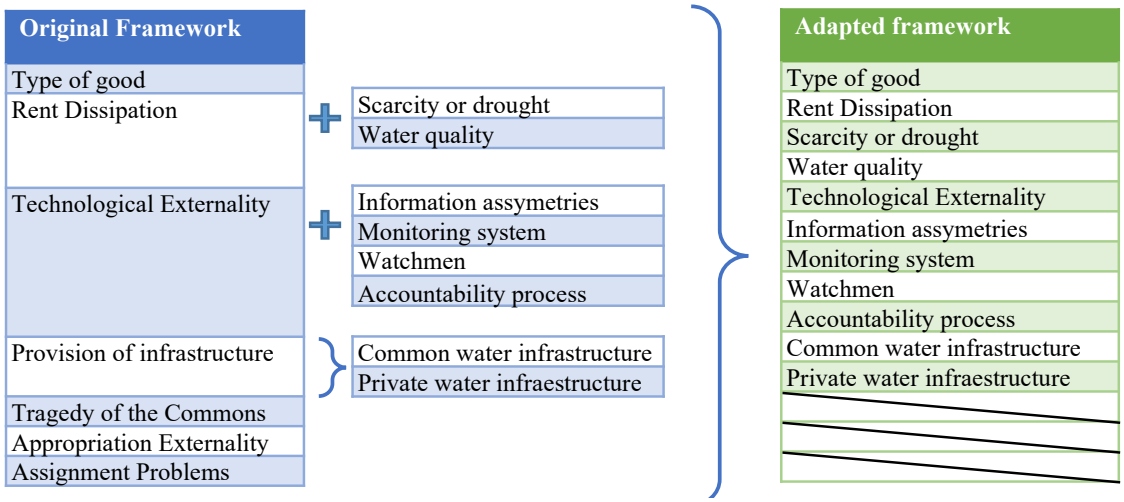


Figure 3. Adapted framework regarding the Nature of the Good sub-component

Also, to capture information regarding the available information and monitoring system, the Technological Externality aspect was broadened by including information asymmetries, monitoring systems, watchmen, and accountability processes. The Provision of Infrastructure was modified to capture and widen its analysis regarding shared and private infrastructure. Finally, following other authors indications, the aspects regarding the Tragedy of the Commons, Appropriation Externality and Assignment Problems where all excluded from the adapted framework, as these are all elements present in every local water system, and thus, do not provide new information or source of analysis. Figure 3 summarizes these proposed changes.

Rules, also known as Rules-in-use identifies all important aspects to define the institutional context within which an action situation is situated. Changes from the original framework have been made to capture the differences of the operational and regular rules of distribution, from the collective rules. On the other hand, the differentiation made in the original framework, regarding separating formal rules, from strategies, norms, and other less formal rulings, was dismissed, allowing for the analysis of the formality of the rules to be carried out within each category. As is presented in Figure 4, they were specified as Collective rules, strategies and norms and Operational rules, strategies and norms.

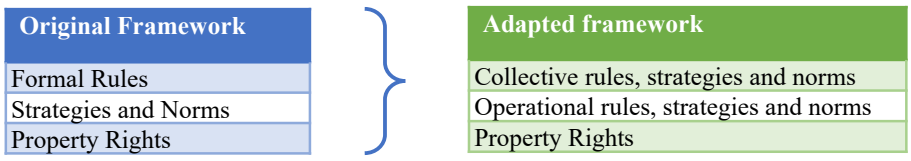


Figure 4. Adapted framework regarding the Rules-in-use sub-component

4.2. Action Situation

The Action Situation is also called the "black box", and it is where policy decisions are made. Changes have been made from the original framework, regarding adding specification to the Participants component (Figure 5).

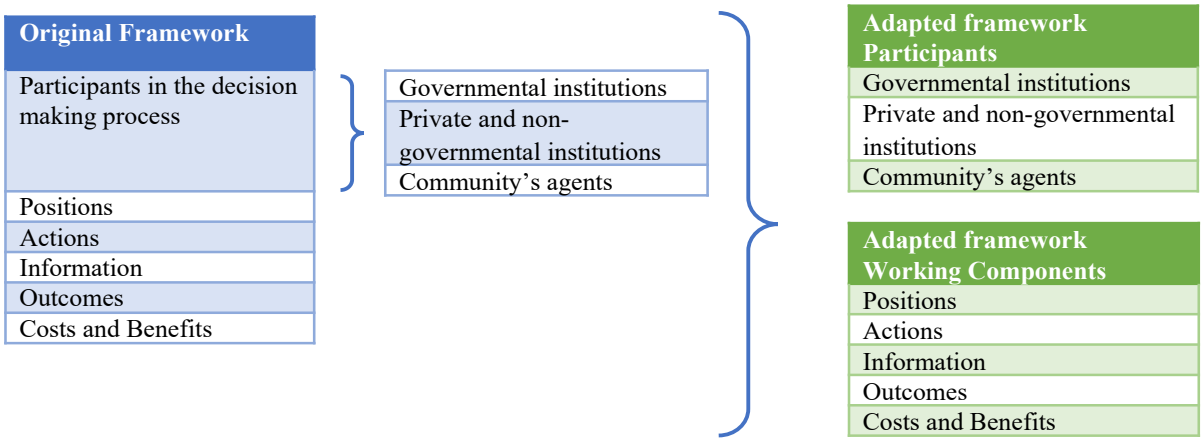


Figure 5. Adapted framework regarding the Action Situation component

In the original framework, the Working Components of the Action Situation specifies the nature of the relevant actors as well as the resources and options they face, and thereby serve as a generalization of the "rules of a game". For the adapted version, the sub-component *Participants*, has been upgraded to be a component by itself, and sub-categories have been included. This allows for a special focus on actors, their interactions and intentions; as a separate element of the institutional structures, following the studies of Hassenforder and Barone (2018).

4.3. Interaction

The component of Interactions reveals the dynamics among participants and the working components of the Action Situation. The original framework does not specify categories that should be studied. However, regarding water user's associations or local water social-ecological systems, this component should be specified in more detail so as to provide a deeper and richer analysis. For this, a number of elements have been included in the framework. These have been considered, following a suggestion of variables of the analysis for the Social-Ecological Systems (SES) framework (Ostrom, 2007) and include water extraction levels, information sharing among users, conflicts among users and management capacity.

4.4. Outcomes

Outcomes are shaped by both the outputs of the action situation and by exogenous factors. The original framework does not consider any specificity or suggest aspects to analyze. For the purpose of allowing a better understanding of local water systems, three aspects were considered here. All three have been used, following a suggestion of variables of the analysis for the SES framework (Ostrom, 2007) and include social and ecological performance, as well as externalities to other SESs.

4.5. Evaluative Criteria

Evaluative Criteria may be used by participants or external observers to determine which aspects are deemed satisfactory and which aspects are in need of improvement. These have been preserved from the original framework, since they are sufficiently general to evaluate different local water systems, but at the

same time, sufficiently specific, to truly assess their success. The components are efficiency, equity, legitimacy, participation, accountability, fiscal equivalence, consistency and adaptability.

4.6. Social, Economic, and Political Settings

This component was added following the SES framework, to incorporate the broader context within which the governance system per se is located. The aspects have been incorporated following a suggestion of variables of the analysis for the SES framework (Ostrom, 2007), as well as applied to water studies (Meinzen Dick, 2007; Zhang, 2020; Blanco and Donoso, 2021). They include economic development, demographic trends (density, settlement pattern), political stability, government water policies and commitment, market incentives and media organization.

4.7. Related Ecosystems

This component has also been added to the original framework to include a broader ecological context following suggestions from the SES framework (Ostrom, 2007). The variables used have been selected from applied SES studies (Meinzen Dick, 2007; Zhang, 2020; Blanco and Donoso, 2021) and include climate patterns, pollution patterns and flows into and out of focal SES.

The complete adapted framework is presented in Figure 6. This version of the IAD framework, adapted to adjust to water social-ecological systems and their complexity, was then tested empirically in different Chilean case studies, where it was analyzed and validated.

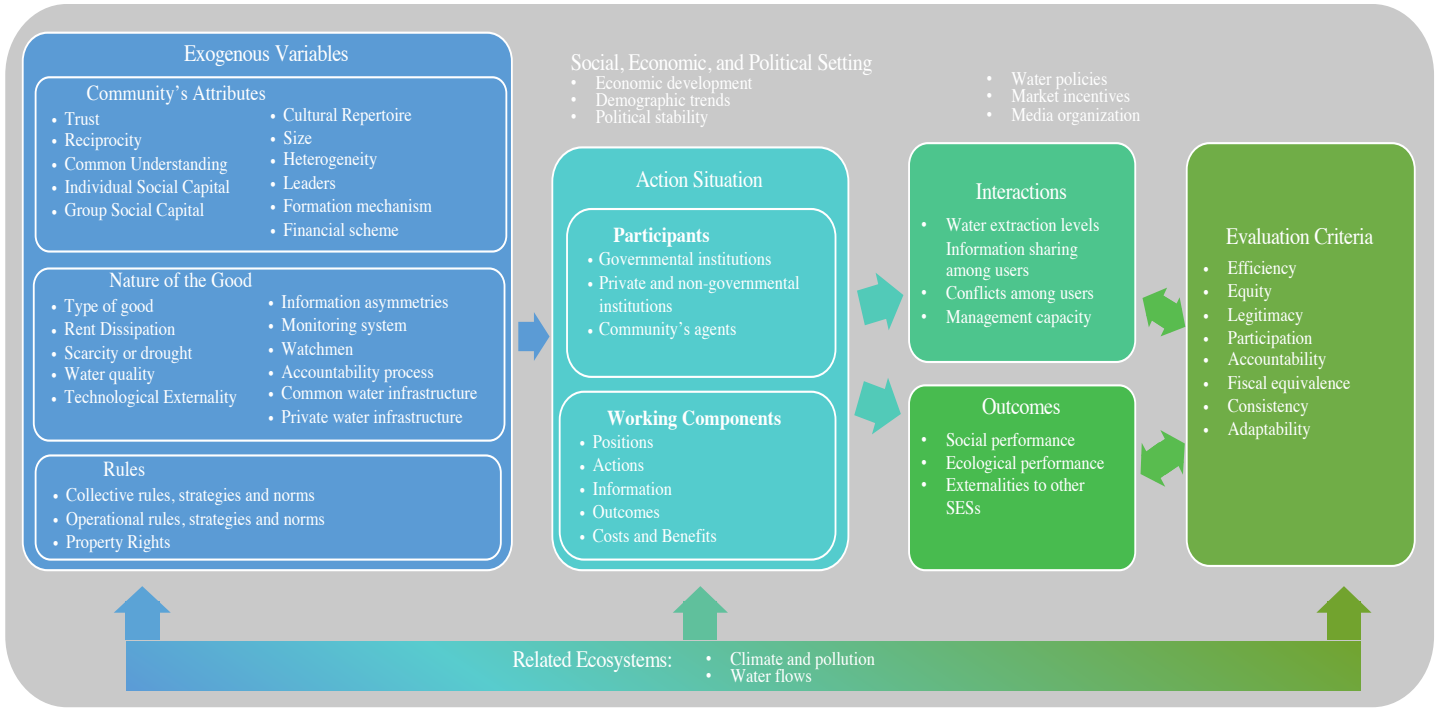


Figure 6. Adapted framework with all its components

5. Structure of the thesis

To test the adapted framework empirically and theoretically, various research instances have been conducted, and are presented ahead. Together, they contributed to solving all the research questions stated above, and collectively they make up the structure of this thesis project.

First, an analysis was made through the application of the Design Principles for Sustainable Management of Common-Pool Resources and the Social-Ecological Systems (SES) framework, both methods based on Elinor Ostrom's theories. These helps explore the institutional structures that support arrangements to manage common resources in a sustainable way. The Chilean Copiapó basin, a highly productive but dry area, characterized by extreme over-extraction and by serious water conflicts was used as a case study. This, since the basin has gone through an institutional reform and now is fully organized into groundwater users' communities with representative boards. By using the existing tools, we were able to analyze the basin and its institutional scheme, identifying the barriers that had to be solved regarding information, trust issues, and a bureaucratic institutional system. In this case, the analysis shows the relevance of the existence of a neutral and technical team that acted as mediators; the identification and empowerment of leaders; and the restrictions of the administrative authority in the community's decisions. All the above were considered successful elements to consider in future institutional empowerment. However, the analysis was also limited to basin-level aspects and did not consider either the history of the institutional scheme, the social components that influence the development of the system, as well as the nation-wide or other basin influences. Thus, it was considered that the framework needed for analyzing water institutional schemes needs to be adjusted towards a broader approach. This analysis is presented in Chapter 2.

The complexity of water socio-ecological systems is explored by the analysis of two Chilean case studies. Here, the Institutional Analysis and Development (IAD) framework is adapted and incorporates socio-ecological framework components and other elements to capture these complexities. The new framework helps understand the ways in which highly complex institutional systems, such as Chilean water systems, operate, distribute, and manage available water resources. Through the empirical work conducted in two Chilean case studies, a way of unwrapping complex water systems has been presented, allowing for their exploration, analysis and improvement, without oversimplification or constriction of their potential. This is all shown in Chapter 3.

Finally, and to test whether the new framework can be used under different settings and water situations, the research analyzed water-related conflicts from the colonial period, comparing them to current conflicts. The study shows how the analysis helps identify factors that supported, as well as elements that hindered these conflicts. It showed, for example, that a strong institutional system surrounding conflict resolution during colonial times, with nested schemes and empowered figures appointed in leading roles were crucial elements towards having a good conflict resolution scheme, and thus, better water management. However, through the use of the framework, a lack of equity and inclusion of all actors was also visible, identifying that these could reduce the legitimacy of the whole system. Thus, with the method, we can even identify learnings from past times about how to empower and improve the institutional water system in present times. This study can be seen in chapter 4.

In the final section of this dissertation, a comprehensive synthesis of the results obtained in each chapter is provided, culminating in a general conclusion. This conclusion encapsulates the conceptual, methodological, and empirical contributions made throughout the research. It also offers a contemplation of the implications arising from the research findings and puts forth policy recommendations. Lastly, the conclusion acknowledges the inherent limitations of the study and suggests potential avenues for future research.

6. References

Aida, T. (2011). Social Capital as an Instrument for Common Pool Resource Management: A Case Study of Irrigation Management in Sri Lanka. Impact Assessment of Infrastructure Projects on Poverty Reduction. JICA-RI working paper 33.

Alesina, A. and La Ferrara, E. (2000). Participation in heterogeneous communities. The quarterly journal of economics, 115(3), 847-904.

Alesina, A. and La Ferrara, E. (2002). Who trusts others?. Journal of public economics, 85(2), 207-234. Alessa, L., Kliskey, A., and Altaweel, M. (2009). Toward a typology for social-ecological systems. *Sustainability: Science, Practice, and Policy*, *5*(1), 31–41

Alessa, L., Kliskey, A., and Altaweel, M. (2009). Toward a typology for social-ecological systems. *Sustainability: Science, Practice, and Policy*, *5*(1).

Anderies, J. M., Janssen, M. A., and Ostrom, E. (2004). A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective. *Ecology and Society*, *9*(1).

Aoki, M. (2001). Community norms and embeddedness: A game-theoretic approach. In Aoki, M. and Hayami, Y. (Eds.) Communities and markets in economic development, 97–125. Oxford University Press.

Axelrod, R., and Hamilton, W. D. (1981). The evolution of cooperation. science, 211(4489), 1390-1396.

Azaiez, M. N., Hariga, M., and Al-Harkan, I. (2005). A chance-constrained multi-period model for a special multi-reservoir system. Computers and operations research, 32(5), 1337-1351.

Baudoin, L., and Arenas, D. (2020). From raindrops to a common stream: using the social-ecological systems framework for research on sustainable water management. Organization and Environment, 33(1), 126-148. Berkes, F., Colding, J., and Folke, C. (2002). *Navigating Social-Ecological Systems Building Resilience for Complexity and Change*. Cambridge: Cambridge university press

Bazargan-Lari, M. R., Kerachian, R., and Mansoori, A. (2009). A conflict-resolution model for the conjunctive use of surface and groundwater resources that considers water-quality issues: a case study. Environmental management, 43(3), 470.

Blanco, E., and Donoso, G. (2021). Drivers for collective groundwater management: The case of Copiapó, Chile. In S. H. Choi, E. Shin, A. K. Makarigakis, O. Sohn, C. Clench, and M. Trudeau (Eds.), *Global Water Security Issues (GWSI) 2020 Theme: The role of sound groundwater resources management and governance to achieve water security.* (pp. 59–75). UNESCO, International Centre for Water Security and Sustainable Management.

Blythe, J., Cohen, P., Eriksson, H., Cinner, J., Boso, D., Schwarz, A. M., and Andrew, N. (2017). Strengthening post-hoc analysis of community-based fisheries management through the social-ecological systems framework. *Marine Policy*, 82, 50-58.

Botto-Barrios, D., and Saavedra-Díaz, L. (2020). Assessment of Ostrom's social-ecological system framework for the comanagement of small-scale marine fisheries in Colombia: from local fishers' perspectives. *Ecology and Society,* 25(1).

Carraro, C., Marchiori, C., and Sgobbi, A. (2005). *Applications of negotiation theory to water issues* (Vol. 3641). World Bank Publications.

Carrasco, J. A., Harrison, R., Munoz, R., and Sánchez, J. M. (2018). Institutional design for concession contracts: A proposed framework and experiences from Chile.

Clement, F. (2010). Analysing decentralised natural resource governance: proposition for a "politicised" institutional analysis and development framework. *Policy Sciences*, *43*, 129–156.

Cobbing, J. and Rose-Innes, C. (2018). Groundwater Governance: The Case of the Grootfontein Aquifer at

Mahikeng, South Africa. Water Alternatives, 11(3).
Dawes, R. M., and Messick, D. M. (2000). Social dilemmas. International journal of psychology, 35(2), 111-116.
Dewatripont, M., and Legros, P. (2005). Public-private partnerships: contract design and risk transfer. EIB papers, 10(1), 120-145.
Dinar, A., and Hogarth, M. (2015). Game theory and water resources: Critical review of its contributions, progress and remaining challenges. Foundations and trends in microeconomics, 11(1–2), 1-139.
Ebenhöh, E. (2007). Designing Agent-based Models of Water Management Regimes using the IAD Framework. *The Challenge of Self-Governance in Complex, Globalizing Economies*
Estache, A., and Wren-Lewis, L. (2009). Toward a theory of regulation for developing countries: Following jean-jacques laffont's lead. *Journal of Economic Literature*, 47(3), 729-770.
Fleischman, F. D., Ban, N. C., Evans, L. S., Epstein, G., Villamayor-Tomas, S., and Garcia-Lopez, G. (2014). Governing large-scale social-ecological systems: Lessons from five cases. *International Journal of the Commons*, *8*(2), 428–456
Folke, C., Colding, J., and Berkes, F. (2003). Synthesis: building resilience and adaptive capacity in social-ecological systems. Navigating social-ecological systems: Building resilience for complexity and change, 9(1), 352-387.
Gain, A. K., Hossain, M. S., Benson, D., Di Baldassarre, G., Giupponi, C., and Huq, N. (2021). Social-ecological system approaches for water resources management. *International Journal of Sustainable Development and World Ecology*, *28*(1), 109–124
Gambetta, D. (2000). Can we trust trust?. Trust: Making and breaking cooperative relations, 13, 213-237.
Garande, T., and Dagg, S. (2005). Public participation and effective water governance at the local level: a case study from a small under-developed area in Chile. Environment, Development and Sustainability, 7(4), 417-431.
Gopalakrishnan, C., Levy, J., Li, K.W. and Hipel, K.W. (2005). Water allocation among multiple stakeholders: conflict analysis of the Waiahole water project, Hawaii. International Journal of Water Resources Development, 21(2), 283-295.
Guasch, J.L., Laffont, J.J., and Straub, S. (2006). Renegotiation of concession contracts: A theoretical approach. *Review of Industrial Organization*, 29, 55–73
Hämäläinen, R., Kettunen, E., Marttunen, M., and Ehtamo, H. (2001). Evaluating a framework for multi-stakeholder decision support in water resources management. Group decision and negotiation, 10(4), 331-353.
Harrison, R., Muñoz, R., and Sánchez, J.M. (2013). Institutional Design for Concessions. *Network Industries Quarterly*.
Hassenforder, E., and Barone, S. (2018). Institutional arrangements for water governance. *International Journal of Water Resources Development*.
Heikkila, T., Schlager, E., and Davis, M. W. (2011). The role of cross-scale institutional linkages in common pool resource management: Assessing interstate river compacts. Policy Studies Journal, 39(1), 121-145.
Hipel, K.W., Kilgour, D.M., and Kinsara, R.A. (2014). Strategic investigations of water conflicts in the middle east. Group Decision and Negotiation 23(3): 355-376.
Hofste, R. W., Reig, P., and Schleifer, L. (2019). 17 Countries, Home to One-Quarter of the World's Population, Face Extremely High Water Stress
Ito, J. (2012). Collective action for local commons management in rural Yunnan, China: Empirical evidence and hypotheses using evolutionary game theory. Land Economics, 88(1), 181-200.
Jelassi, M. T., and Foroughi, A. (1989). Negotiation support systems: An overview of design issues and existing software. *Decision Support Systems*, *5*(2), 167-181.

Kim, O., and Walker, M. (1984). The free rider problem: Experimental evidence. *Public Choice*, *43*(1), 3-24.

Kiser, L. L., and Ostrom, E. (1982). The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches. In *Strategies of Political Inquiry* (pp. 179–222)

Koundouri, P. (2004). Potential for groundwater management: Gisser-Sanchez effect reconsidered. Water Resources Research, 40 (6).

Laffont, J. J. (2005). Regulation and development. Cambridge University Press.

Laffont, J. J., and Tirole, J. (1993). A theory of incentives in procurement and regulation. MIT press.

Langridge, R. and Ansell, C. (2018. Comparative Analysis of Institutions to Govern the Groundwater Commons in California. *Water Alternatives*, 11(3).

Lee, C.S. (2012). Multi-objective game-theory models for conflict analysis in reservoir watershed management. Chemosphere 87(6): 608-613.

Li, K.W., Kilgour, D.M., and Hipel, K.W. (2003). Status quo analysis of an environmental conflict. In *Systems, Man and Cybernetics, 2003. IEEE International Conference* (4): 3700-3705.

Loáiciga, H. A. (2004). Analytic game—theoretic approach to ground-water extraction. Journal of Hydrology, 297(1-4), 22-33.

Madani, K., and Dinar, A. (2012a). Non-cooperative institutions for sustainable common pool resource management: Application to groundwater. Ecological Economics, 74, 34-45.

Madani, K., and Dinar, A. (2012b). Cooperative institutions for sustainable common pool resource management: Application to groundwater. Water Resources Research, 48(9).

Martínez-Fernández, J., Banos-González, I., and Esteve-Selma, M. A. (2020). An Integral Approach to address Socio-Ecological Systems Sustainability and their uncertainties. *Science of the Total Environment*, *762*

Martínez-Valderrama, J., Olcina, J., Delacámara, G., Guirado, E., and Maestre, F. T. (2023). Complex Policy Mixes are needed to cope with Agricultural Water demands under Climate Change. *Water Resources Management*, 37(6-7), 2805-2834.

McGinnis, M. D. (2011). An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. *Policy Studies Journal*

Mehrparvar, M., Ahmadi, A., and Safavi, H.R. (2016). Social resolution of conflicts over water resources allocation in a river basin using cooperative game theory approaches: a case study. International Journal of River Basin Management 14(1): 33-45.

Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.0702296104

Milman, A., Galindo, L., Blomquist, W. and Conrad, E. (2018). Establishment of Agencies for Local Groundwater Governance under California's Sustainable Groundwater Management Act. Water Alternatives, 11(3).

Mirnezami, S.J., Bagheri, A. and Maleki, A. (2018). Inaction of Society on the Drawdown of Groundwater Resources: A Case Study of Rafsanjan Plain in Iran. Water Alternatives, 11(3).

Molle, F., López-Gunn, E. and Van Steenbergen, F. (2018). The Local and National Politics of Groundwater Overexploitation. Water Alternatives, 11(3).

Moncada, J., Pérez, C. and Valencia, G.D. (2013). Comunidades organizadas y el servicio público de agua potable en Colombia: una defensa de la tercera opción económica desde la teoría de recursos de uso común. Ecos de Economía, 17 (37): 125-159.

Myerson, R.B. (2013). Game theory. Harvard university press.

Nagendra, H., and Ostrom, E. (2014). Applying the social-ecological system framework to the diagnosis of urban lake commons in Bangalore, India. *Ecology and Society,* 19(2).

Neilson, W., and Wichmann, B. (2014). Social networks and non-market valuations. Journal of Environmental Economics and Management 67(2): 155-170.

Oakerson, R. J., and Parks, R. B. (2011). The study of local public economies: Multi-organizational, multi-level institutional analysis and development. *Policy Studies Journal*, *39*(1), 147-167.

Oftadeh, E., Shourian, M., and Saghafian, B. (2017). An Ultimatum Game Theory Based Approach for Basin Scale Water Allocation Conflict Resolution. Water Resources Management 31(13): 4293-4308.

Ostrom, E. (1986). An agenda for the study of institutions. *Public Choice*, *48*, 3–25.

Ostrom, E. (1990). The Evolution of Institutions for Collective Action. In *Political Economy of Institutions and Decisions*.

Ostrom, E. (1998). A Behavioral Approach to the Rational Choice Theory of Collective Action. *The American Political Science Review*, *92*(1), 1–22.

Ostrom, E. (1999). Institutional Rational Choice: An Assessment of the Institutional Analysis and Development Framework. In *Theories of the Policy Process* (pp. 21–64).

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187.

Ostrom, E. (2009a). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422

Ostrom, E. (2009b). Understanding institutional diversity. In *Understanding Institutional Diversity*.

Ostrom, E. (2010). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422.

Ostrom, E. (2015). Governing the commons. Cambridge University Press. 294 p.

Ostrom, E., Gardner, R., and Walker, J. (1994). Rules, Games, and Common-Pool Resources. In *Rules, Games, and Common-Pool Resources*. University of Michigan Press.

Ostrom, E., Janssen, M. A., and Anderies, J. M. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(37), 15176–15178.

Ostrom, E., Lam, W. F., Pradhan, P., and Shivakoti, G. P. (2011). Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal. In *Improving Irrigation in Asia: Sustainable Performance of an Innovative Intervention in Nepal*. https://doi.org/10.4337/9780857938022

Pacheco-Vega, R. (2014). Ostrom y la gobernanza del agua en México. Revista mexicana de sociología, 76(SPE), 137-166.

Partelow, S., Jäger, A., and Schlüter, A. (2021). Linking fisher perceptions to social-ecological context: mixed method application of the SES framework in Costa Rica. Human Ecology, 49, 187-203.

Poteete, A. R., Janssen, M. A., and Ostrom, E. (2010). Working together: Collective action, the commons, and multiple methods in practice. In *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*.

Raquel, S., Ferenc, S., Emery Jr, C., and Abraham, R. (2007). Application of game theory for a groundwater conflict in Mexico. Journal of environmental management, 84(4), 560-571.

Rica, M., López-Gunn, E., and Llamas, R. (2011). Institutional Diversity and incentives in collective action: groundwater user groups and their role in SES resilience. In 14th IWRA World Water Congress. Brasil: Porto de Galinhas.

Rica, M., Dumont, A., Villarroya, F., and López-Gunn, E. (2014). Whither collective action? Upscaling collective actions, politics and basin management in the process of 'legitimizing'an informal groundwater economy. Water international, 39(4), 520-533.

Rinaudo, J.D., Montginoul, M., Varanda, M., and Bento, S. (2012). Envisioning innovative groundwater regulation policies through scenario workshops in France and Portugal. Irrigation and Drainage, 61, 65-74.

Rinaudo, J.D., and Donoso, G. (2018). State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). International Journal of Water Resources Development, 1-21.

Rivera, D., Godoy-Faúndez, A., Lillo, M., Alvez, A., Delgado, V., Gonzalo-Martin, C., Menasalvas, E., Costumero, R. and Garcia-Pedrero, A. (2016). Legal disputes as a proxy for regional conflicts over water rights in Chile. Journal of Hydrology 535 (2016) 36–45

Rivero, A. L., and Hakizimana, E. (2016). E. Ostrom's SES Framework to Understand the Factors of Successful and Unsuccessful Situation in the SES: A meta-analysis of community forests in Mexico. Fronteiras: *Journal of Social, Technological and Environmental Science*, 5(2), 103-117.

Roy, J., Tschakert, P., Waisman, H., Abdul Halim, S., Antwi-Agyei, P., Dasgupta, P., et al. (2018). Sustainable Development, Poverty Eradication Warming, and Reducing Inequalities

Rudd, M. A. (2004). An institutional framework for designing and monitoring ecosystem-based fisheries management policy experiments. *Ecological Economics*, *48*(1), 109–124.

Ruttan, L.M. (2006). Sociocultural heterogeneity and the commons. Current Anthropology, 47(5), 843-853.

Ruttan, L.M. (2008). Economic heterogeneity and the commons: Effects on collective action and collective goods provisioning. World Development, 36(5), 969-985.

OCDE. (2011). *Water Governance in OECD Countries: A Multi-level Approach*. *OECD Studies on Water*. OECD Publishing

OCDE. (2012). *Gobernabilidad del Agua en América Latina y el Caribe : Un enfoque multinivel*. OECD Studies on Water. Éditions OCDE

OCDE. (2018). *Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices*. *OECD Studies on Water*. OECD Publishing, Paris

Saak, A. E., and Peterson, J.M. (2007). Groundwater use under incomplete information. Journal of Environmental Economics and Management, 54(2), 214-228.

Safari, N., Zarghami, M., and Szidarovszky, F. (2014. Nash bargaining and leader–follower models in water allocation: Application to the Zarrinehrud River basin, Iran. Applied Mathematical Modelling 38(7-8): 1959-1968.

Saleh, Y., Gürler, Ü., and Berk, E. (2011). Centralized and decentralized management of groundwater with multiple users. European Journal of Operational Research, 215(1), 244-256.

Supalla, R., Klaus, B., Yeboah, O., and Bruins, R. (2002). A Game Theory approach to deciding who will supply instream flow water. JAWRA Journal of the American Water Resources Association, 38(4), 959-966.

Thiessen, E. M., Loucks, D. P., and Stedinger, J. R. (1998). Computer-assisted negotiations of water resources conflicts. *Group Decision and Negotiation*, *7*(2), 109-129.

Van Vugt, M. (2002). Central, individual, or collective control? Social dilemma strategies for natural resource management. American Behavioral Scientist, 45(5), 783-800.

Villarroel, E., and Peredo, C. (2006). The struggle for water as a common good: The experience of Andean communities in Bolivia. In IASCP Conference.

Von Neumann, J., and Morgenstern, O. (1944). Game theory and economic behavior. Joh Wiley and Sons, New York.

Vogt, J. M., Epstein, G. B., Mincey, S. K., Fischer, B. C., and McCord, P. (2015). Putting the" E" in SES: unpacking the ecology in the Ostrom sociale-cological system framework. *Ecology and Society*, 20(1).

Wang, L. Z., Fang, L., and Hipel, K.W. (2003). Water resources allocation: a cooperative game theoretic approach. Journal of Environmental Informatics, 2(2), 11-22.

Wei, S. (2008). On the use of game theoretic models for water resources management (Doctoral dissertation, Brandenburg University of Technology).

Wei, S., Yang, H., Abbaspour, K., Mousavi, J., and Gnauck, A. (2010). Game theory based models to analyze water conflicts in the Middle Route of the South-to-North Water Transfer Project in China. Water Research 44(8): 2499-2516.

Wilson, P.N., and Thompson, G.D. (1993). Common Property and Uncertainty: Compensating Coalitions by Mexico's Pastoral "Ejidatarios". Economic Development and Cultural Change, 41(2), 299-318.

Xie, Y., Wen, Y., and Cirella, G. T. (2019). Application of Ostrom's social-ecological systems framework in nature reserves: Hybrid psycho-economic model of collective forest management. *Sustainability,* 11(24), 6929.

Zanjanian, H., Abdolabadi, H., Niksokhan, M.H., and Sarang, A. (2018). Influential third party on water right conflict: A Game Theory approach to achieve the desired equilibrium. Case study: Ilam dam, Iran. Journal of Environmental Management 214: 283-294.

Zhang, Y. (2018). Crossing the divide: an integrated framework of the commons. *Evolutionary and Institutional Economics Review*, *15*, 25–48. https://doi.org/10.1007/s40844-017-0077-2

Zhang, Y. (2019). Governing the water commons in China: from historical oriental despotism to contemporary fragmented hydraulic state. *International Journal of Water Resources Development*, 35(6), 1029–1047.

Zhang, Y. (2020). How did the lost Shangri-La get lost? The tragedy of the groundwater commons in Lijiang, China. *Water*, 12(11).

Chapter 2. Drivers for collective groundwater management: The case of Copiapó, Chile[1]

0. Abstract

The first analysis carried out, was using the existing methodological framework to study a local case in Chile and understand its benefits and limitations. With this purpose, the present study analyzes an exemplar case regarding collective groundwater management in northern Chile. It studies the barriers that limited or delayed the formation of collective action, as well as the solutions that afterwards lead to a fully organized groundwater organization. This focus highlights how to establish multi-stakeholder communities in places with extreme water depletion and water conflict. The approach adopted as a methodology involves the analysis of a case study through the application of the Design Principles for Sustainable Management of Common-Pool Resources, the Social-Ecological Systems (SES) framework and elements from the Institutional Analysis and Development (IAD) framework. All of the above help explore the institutional structures that support arrangements to manage common resources in a sustainable way. The Copiapó basin is located in a highly productive area, with a situation of extreme over-extraction and is characterized by serious water conflicts. Despite the above, the basin is currently fully organized into groundwater users' communities with representative boards. To achieve this, a number of barriers had to be solved regarding information, trust issues, and a bureaucratic institutional system. An external technical team used innovative strategies to establish formal groundwater user associations, considering their legal documents, a consensual users registry, and finally, a monitoring system for wells. The analysis shows the relevance of three elements for the development of self-groundwater governance: the existence of a neutral and technical team that acted as mediators; the identification and empowerment of leaders; and the limitation of the administrative authority in the community's decisions. With these tools, the analysis was confined to basin-level aspects, not considering the historical context of the institutional scheme, social factors influencing system development, and broader national or cross-basin influences. Thus, an adjustment of the framework for water institutional scheme analysis could provide a more comprehensive approach.

1. Introduction and a brief context

Conflict is part of the dynamics of any socio-economic and ecological system that involves multiple stakeholders with varying agendas, understanding, and perceptions. These social systems are typical of common resources, with various decision centers, each with limited and autonomous decisions, all operating under delimited set of rules (Ostrom, 1991). There are usually a multiplicity of institutions participating simultaneously, in a rather complex and messy structure.

[1] This chapter is a modified version of: Blanco, E., and Donoso, G. (2021). Drivers for collective groundwater management: The case of Copiapó, Chile. In: UNESCO and UNESCO i-WSSM. (2021). The Role of Sound Groundwater Resources Management and Governance to Achieve Water Security (Series III). UNESCO Publishing, Paris.

In water matters, the systems are even more complex, given the wide variety of geo-climatic diversities of each area; cultural, historical, and institutional divergencies, as well as having a wider range of purposes for water use. Groundwater resources provide a whole new level of complexity. Since they cannot be seen and are expensive to monitor; a major concern is the general lack of information about groundwater and insufficient knowledge about its dynamics. Most aquifers have gaps in terms of data and models on the interaction of ground and surface waters, seawater intrusion, and groundwater quality levels (Donoso et *al.*, 2020; Gorelick and Zheng, 2015; Kinzelbach et *al.,* 2003). This is particularly worrying when facing higher levels of uncertainty in groundwater recharge, posed by climate change, and increased demands for water use due to economic development.

As for many countries, the Chilean legislation regarding water resources has focused on solving surface water management issues, almost forgetting about groundwater particularities. Here, the government - i.e., the public sector - grants water rights depending on the water available, and the private sector is in charge of its management through the organization of local water users. There are different instances of conflict resolution, but the local community is the first to intervene in resolving them. The non-recognition of groundwater in their initial legal documents has had a diverse range of effects. This non-recognition led to an over-use of aquifers and reservoirs, as well as the increase of several conflicting situations. It also led to the fact that ground and surface waters are managed independent of each other, and the effects on the recharge of aquifers due to the modernization of irrigation are not being considered nor analyzed (Donoso et *al.*, 2020). This regulatory absence has been covered with groundwater guidelines established by the public water authority, the *Dirección General de Aguas* (DGA), through internal administrative acts (Rivera, 2015). While this trend has experienced some variations in recent years, the precariousness of the treatment of groundwater remains and the current Chilean water legislation contains insufficient rules to effectively regulate groundwater resources (Rivera, 2015; 2018). This void regarding groundwater has not impeded the emergence of collective action.

This is the case of Copiapó valley in the dry northern Chilean region, where users adapted themselves to the current institutional and normative system and were able to organize the first groundwater user communities in the country. Twenty years ago, the basin used to be highly conflictive among the different water users, namely mining, agriculture, and urban. The situation led to extreme over-extraction, where not only did the river disappear, but the aquifer started dropping its water level fast (Donoso et *al.*, 2020). In 2004 the first self-managed groundwater user association in Chile was legally formed in the lower part of the basin and, later on, four others followed its steps. Currently the basin is fully organized into groundwater users' communities with representative boards, partially nested in the surface water association and most wells now have monitoring devices. With these institutional, managerial, and technological improvements, the aquifer is now completely self-managed by users.

The main objective of this article is to analyze the barriers that limited or delayed the formation of Copiapó's groundwater associations, as well as the triggers/solutions that afterwards lead to their formal establishment. This case study sheds light on how to enhance the development of self-managed groundwater users' communities; establish multi-stakeholder participation and negotiations in places with extreme depletion and water conflict; and derive lessons for policy makers on the development of groundwater management and governance.

2. Methodology and Conceptual Framework

The study of the Copiapó basin was done by combining empirical work - improved with a literature review - and the application of the Design Principles for Sustainable Management of Common-Pool Resources and

the Social-Ecological Systems (SES) framework, together with elements from the Institutional Analysis and Development (IAD) framework.

Groundwork to directly assess the formation and empower groundwater communities in Copiapó was conducted between the year 2012 and 2015. The work involved different instances of participation with local water users. Among others, the tasks carried out included:

- Monthly field campaigns for the identification of users, potential directives, and finally, the formation of four new groundwater communities in the valley (communities from sub-aquifers 1 to 4). With them, it was possible to develop a model of statutes to be used by the four communities.
- With the existing groundwater community, the team worked directly with the Community Administration and with its Board of Directors, on the proposals for the normative documents. Also, monthly meetings were held for accomplishing this aspect. It involved the modification of their current statutes as well as the development of internal operational regulations and procedures manual.
- Running a training course for community members, where the topics to be addressed were defined collectively. Each training was carried out for the whole community, and in greater detail, for the Board of Directors. A total of fourteen training instances were carried out for users, focused on water terminology, hydrology of the valley, current situation of the resource in the area and the main duties and attributions that involve taking part of a groundwater community.
- Also, six workshops were carried out to discuss the use of public funding for implementing better irrigation technologies at farms, as well as a monitoring system for the communities.
- The team also supported the communities by georeferencing all wells. The work began in sectors 5 and 6 (located in the lower part) of the Copiapó valley, and then began gradually completing the georeferencing of the upper zone, accounting for 100% of the existing wells.
- Finally, two massive seminars were held, open to the whole community, to inform the public about the project, the objectives, the achievements and their importance for the valley.

To support the analysis, a literature review was also carried out, regarding scientific articles and project reports of studies regarding water governance that were conducted in the area.

Finally, to guide the diagnosis and analysis, tools from Design Principles for Sustainable Management of Common-Pool Resources, and the Social-Ecological Systems (SES) framework were used. These tools allow us to explore the institutional structures that support arrangements to manage common resources in a sustainable way. A brief summary of these frameworks is provided below.

2.1. Design Principles for Sustainable Management of Common-Pool Resources

In 1968, Hardin published his well-known Tragedy of the Common Goods theory, stating that individuals sharing a common resource will act for their own benefit, obtaining worse results than if they acted collaboratively (Hardin, 1968). However, Ostrom (1990; 2000; 2015a) observed that the Tragedy and the self-interested attitudes were preventable. She studied several cases where voluntary organizations using collective action were able to manage their resources sustainably. For this to happen, eight design principles were defined as key for successfully governing the commons. These are: 1) the definition of clear boundaries; 2) that rules are aligned with local needs and that 3) these can be modified by participants; 4) respect from external authorities; 5) the development of a system for monitoring compliance; 6) gradual sanctions; 7) accessible and low-cost solutions to disputes; 8) enforced through multiple layers of "nested" organizations (Ostrom, 2015a).

Later, these design principles were reviewed and expanded, while being contrasted with a greater number of case studies (Cox et *al.,* 2010; 2016). For example, the first principle expanded into 1A) Individuals

or households who have rights to withdraw resource units from the common-pool resource (CPR) must be clearly defined; and 1B) The boundaries of the CPR must be well defined (Cox et *al.,* 2010). Thus, for successful collective governance to happen, regarding any common resource, these principles should be present.

These design principles as analytical tools have been widely used in water management and irrigation, including interstate or transnational river basins (Heikkila et *al.,* 2011). Even in Chile, the tools have been used to analyze water users associations as a whole (Donoso, 2018), or case studies from specific basins (Rinaudo and Donoso, 2019). Therefore, these principles are useful for establishing a diagnosis of the Copiapó case study, since they can extend their use towards water resources, and even for groundwater. They can help identify aspects that can allow or impede an effective groundwater collective governance.

2.2. Institutional Analysis and Development (IAD) and Social-Ecological Systems (SES) framework

Together with the Design Principles, the Institutional Analysis and Development (IAD) framework was conceived (Kiser and Ostrom, 1982). The goal of the framework was to understand the ways in which institutions operate and change over time, with focus on communities without state intervention and their governance over common pool resources (McGinnis, 2011). At the IAD's core is the 'action arena', composed of an action situation and actors. The first refers to a social space where the actors interact, solve the commons problem, and exchange goods and services, while the actors are those who participate in the situation (Ostrom, 2007; Ostrom et *al.,* 2007). IAD involves the analysis of the interactions and outcomes of this 'action arena' regarding evaluation criteria, as well as exogenous variables that change the analysis of the case study as they vary (Ostrom, 2011). Regarding water, Ebenhöh (2007) adapted the framework to generate an agent-based model for water management regimes, and Zhang (2018; 2019; 2020) has used the framework to analyze different water regimes in China. In all of the above, the convenience of using the framework to analyze water systems was proven.

In the past decade, the Social-Ecological Systems (SES) Framework was developed as an ongoing effort to revise the IAD framework. This was done in order to give equal attention to the biophysical and ecological foundations of institutional systems. The idea was to analyze patterns of interactions (I) and outcomes (O) imbedded in the SES, called the Focal Action Situation (McGinnis, 2011). The framework assists organizing relevant variables regarding specific attributes of i) the resource system (RS), ii) the resource units (RU) generated by that system, iii) the users (U) of that system, and iv) the governance system (GS) (Ostrom, 2007). The analysis could also include aspects regarding v) social, economic and political settings (S), to incorporate the broader context within which the governance system per se is located, and vi) related ecosystems (ECO) to include a broader ecological context (See Figure 2-1).

Social, Economic, and Political Settings (S)			
S1- Economic development		S4- Government water policies and commitment	
S2- Demographic trends (density, settlement pattern)		S5- Market incentives (distance to market)	
S3- Political stability		S6- Media organization	
Resource system (RS)	**Resource Units (RU)**	**Users (U)**	**Governance System (GS)**
RS1- Sector	RU1- Resource unit mobility	U1- Number of users	GS1- Government organizations
RS2- Clarity boundaries	RU2- Growth or replacement rate	U2- Socioeconomic attributes of users	GS2- Non-government organizations
RS3- Size of resource system	RU3- Interaction among resource units	U3- History of use	
RS4- Human-constructed facilities		U4- Location	
		U5- Leadership	
		U6- Norms/social capital	

RS5- Productivity of system RS6- Equilibrium properties RS7- Predictability of system dynamics RS8- Storage characteristics RS9- Location	RU4- Economic value RU5- Size RU6- Markings RU7- Spatial & temporal distribution	U7- Knowledge of SES models U8- Dependence on resource U9- Technology used	GS3- Network structure GS4- Property-rights GS5- Operational rules GS6- Collective rules GS7- Constitutional rules GS8- Monitoring & sanctioning processes
Interactions (I) I1- Harvesting levels of diverse users I2- Information sharing among users I3- Deliberation processes I4- Conflicts among users I5- Investment activities I6- Lobbying activities		**Outcomes (O)** O1- Social performance measures O2- Ecological performance measures O3- Externalities to other SESs	
Related Ecosystems (ECO) ECO1- Climate patterns ECO2- Pollution patterns		ECO3- Flows into and out of focal SES	

Figure 2-1. Variables of analysis for the Social-Ecological Systems (SES) framework (*source* adapted from Ostrom, 2007).

The latter has been applied to a variety of studies regarding the institutional scope of SES, such as forests, fisheries and water resources. Regarding water institutions, Meinzen-Dick (2007) proposes hypothetical factors that could influence interactions and outcomes regarding irrigation systems. Rather than setting up rigid institutional models, the overall notion of the framework is to recognize the differences among sites and make specific provisions for each case analyzed (Ostrom, 2007). Since the institutional settings are then adjusted to specific requirements, this approach avoids carrying out large or costly investments with no long-term improvements, or without generating dependencies on external help (Lam and Ostrom, 2010; Ostrom et *al.,* 2011).

The framework has only been applied for irrigation and does not consider a deeper analysis of the interactions of users with different purposes. It has not been applied considering different administrative units, such as the analysis of a community, micro-basin, a complete basin, or even the institutional framework of a country or transboundary agreement. A step towards this type of multi-level institutional analysis was carried out by Oakerson and Parks (2011), nevertheless it was limited with respect to protected areas. Thus, the framework can be extended to be used in the analysis of groundwater socio-ecological system, such as the Copiapó case. It can be especially helpful for identifying problems, barriers, and triggers for successful cooperation, and can help detect elements to achieve water security at a basin level.

3. Copiapó case study: context, problems and barriers to their resolution

3.1. Context

The Copiapó basin is located in northern Chile, an extremely dry area. Copiapó only has about 28 mm of rain a year (DICTUC, 2010). At the same time, this is a highly productive area in terms of mining and agriculture. Both activities depend considerably on the existing water resources in the basin, which means that water stress can affect the entire economy of the area. At the same time, water is needed for the cities of Copiapó and Tierra Amarilla, environmental preservation of wetlands, and for the cultural well-

being of indigenous communities (DGA, 2004). Thus, there is a high and diverse demand for water in the area that contrasts with the low precipitation received annually in the valley. At present, agricultural water use accounts for 75% of groundwater withdrawals, while mining and industrial activities account for 15%, and drinking water supply, 10% (PUC, 2014).

The Copiapó aquifer was divided into six administrative sectors[2] from the Andes Mountains until it joins the sea (Figure 3-1).

The melting snow and ice from the mountains is the main contribution to the recharge of the basin, reaching its maximum in the summer months (McFarlane and Norgate, 2012). Surface water is extracted mainly in the upper part of the basin since the river has stopped flowing superficially downstream and groundwater is the only water source in these lower areas. At present, the estimated recharge of the basin equals approximately 3,700 L/s. However, water rights have been granted for a total of nearly 19,600 L/s, more than 5 times its capacity. Even though a significant part of the allocation belongs to farmers, who do not use these resources all year long, the aquifer is still under an extreme overallocation of water rights. As expected, groundwater levels started dropping. A study carried out in 1994 already pinpointed a negative balance between the water that was entering and that being extracted from the basin in the area of the city of Copiapó (DICTUC, 2010). This situation has only worsened since.

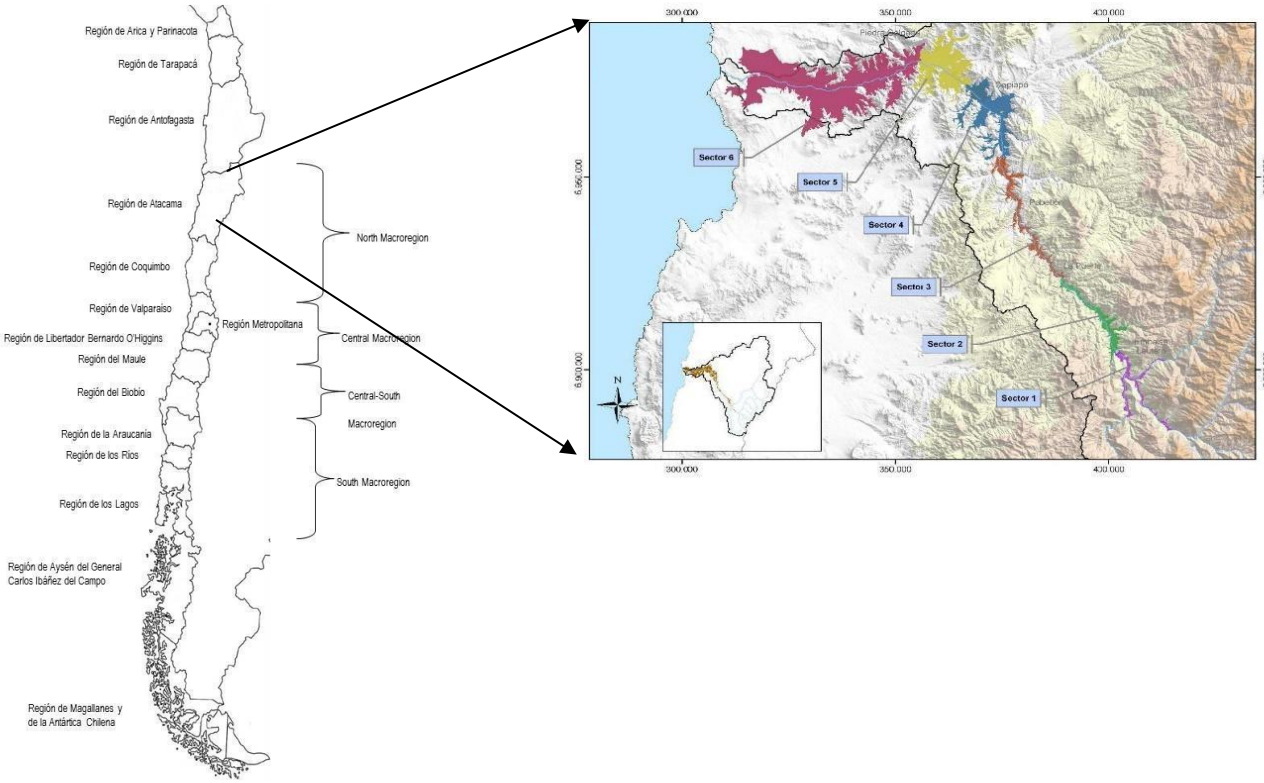


Figure 3-1. Copiapó aquifer divided into six administrative sectors (*source* adapted from DICTUC, 2010).

The river is managed by a Vigilance Committee, a surface water users association. This collective organization is formed by the presidents of the boards of directives of all irrigation districts and other surface water communities. In the year 2004, since the river did not flow in the lower sector of the basin, they did

[2] Sector 1 Upstream of the Lautaro Reservoir; Sector 2 Lautaro Reservoir- La Puerta; Sector 3 La Puerta- Mal paso; Sector 4 Mal Paso-Copiapó; Sector 5 Copiapó-Piedra Colgada; Sector 6 Piedra Colgada-Desembocadura (flows into the ocean).

not consider themselves responsible for managing sectors 5 and 6. With the objective of developing water resources management and to achieve sustainable exploitation of the Copiapó river in these lower sectors, a groundwater user community was organized, the first community of its kind in Chile.

Currently, five groundwater communities are in place: one for each groundwater aquifer sector, with the exception of sectors 5 and 6, that, as has been mentioned, are organized as one. Each one of them has a board of directors, with positions reserved for small farmers, medium farmers, large farmers, the mining sector and the sanitary/urban sector (PUC, 2014). They have hired a manager and have people surveilling the community's wells and the main basin storage infrastructure, the Lautaro Dam. Regarding water usage, almost all wells have monitoring devices that assess their water intake and satellite telemetry that sends the information to the community. Each organization has written bylaws where all their norms are established, including the definition and responsibilities of each member of the community, the number of directors, in what manner they will be assigned, in what way assemblies will be conducted, and how often will they be held, among others[3]. Also, they have rules of operation in place that provide details regarding the use of telemetry, possibility to enter private property to control pumping devices, and a system of sanctions (Donoso et al., 2020; PUC, 2014; Rinaudo and Donoso, 2019).

In general terms, since the organization of the groundwater communities, the basin has advanced in several aspects regarding their self-governance. Considering the Design Principles for Sustainable Management of Common-Pool Resources, Copiapó's groundwater communities have their boundaries well defined and have achieved recognition from the public agency (see Figure 3-2). They have made progress and achieve partial degrees of satisfaction on several other principles; however, they have not been able to truly adapt their rules to their local needs and do not have graduated sanctions.

Principle (according to Cox et al., 2010)	Degree of satisfaction
1A. User boundaries: Clear boundaries between legitimate users and nonusers must be clearly defined	*Satisfied.* Users are defined by a system of well-established water rights, and the official registry is held by each groundwater community.
1B. Resource boundaries: Boundaries that define the resource system are present.	*Satisfied*. The aquifer and its boundaries have been clearly delineated.
2A. Congruence with local conditions: Appropriation and provision rules are congruent with local social and environmental conditions	*Partially satisfied*. The maximum water intake is defined by the system of water rights, and rules of operation are in place regarding monitoring, inspections and sanctions. However, since the groundwater levels are too low, these tools are used for an accountability process more than for a sanctioning one.
2B. Appropriation and provision: The benefits obtained by users from a common-pool resource, as determined by appropriation rules, are proportional to the amount of inputs required	*Not satisfied.* The initial allocation of the resource is given by the State. Even though a specific use has to be initially justified, it can be transferred to any other user. Thus, the water rights system in place is independent on how it is used.
3. Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying the operational rules	*Partially satisfied*. Their bylaws or statutes allow the participation of all users in the modification of their rules. However, since votes are

[3] DGA *Sistema Nacional de Información del Agua*, SNIA (National Water Information System), Files NC-0302-149 (sectors 5 and 6), 150 (sector 4), 151 (sector 3), 152 (sector 2), 153 (sector 1).

	proportional to the size of the water rights, small users feel excluded from the decision process.
4A. Monitoring users: There exists an accountable process of monitoring the appropriation and provision levels of the users.	*Partially satisfied*. Almost all wells are monitored, yet the communities do not have the technical resources to analyze and share the huge amount of data generated. This results in a lack of credibility.
4B. Monitoring the resource: Monitors who are accountable to the users monitor the condition of the resource	*Partially satisfied*. The hydrometric system in place is weak and can be noted by the contradictory results achieved by the different studies that have been conducted on the Copiapó aquifer.
5. Graduated sanctions: Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and the context of the offense).	*Not satisfied*. Even though the rules have been established, in practice, no significant sanction has ever been implemented, although there have been violations.
6. Conflict-resolution mechanisms: Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials	*Partially satisfied*. The boards of directors should arbitrate conflicts. Since the board is mainly composed of large or powerful users, their judgment is not perceived as impartial.
7. Minimal recognition of rights to organize: The right to devise their own institutions is not challenged by external governmental authorities	*Satisfied*. Almost all communities have been formally registered by the public authority, except for sector 1 (paused in the legal department review).
8. Nested enterprises: They are organized in multiple layers of nested enterprises	*Partially satisfied*. The groundwater communities have bought surface water rights to become a part of the surface Vigilance Committee.

Figure 3-2. Groundwater communities in Copiapó analysis of degree of satisfaction of design principles for common resources governance (*source* adapted and expanded from Rinaudo and Donoso, 2019, who analyzed only sectors 5 and 6)

3.2. Analysis of obstacles to sustainable groundwater management in the Copiapó basin

Before the development of groundwater user communities, as Copiapó has today, the basin was struggling with different problems that had led to an extreme management crisis. When the basin was facing a severe drought, surface water users distributed their water rights proportionally, according to the water available, and their intakes continue to be monitored. This is managed by the surface Vigilance Committee at the river level, and, by law, they should be the ones in charge of the groundwater users as well (Rivera, 2018). However, in the Copiapó basin, this has not occurred.

Using the SES framework, we conducted a diagnosis on the basin situation before it was fully organized into groundwater communities; the results are summarized in Figure 3-3. Looking at the Governance Systems (GS) variables analyzed, not only did the surface Vigilance Committee neglect the management of groundwater users, almost all governance elements analyzed failed as well. For example, even though there was a groundwater community in place, it did not develop operational rules, nor collective action norms, nor had the capacity to perform some monitoring or sanctioning processes. This led to a number of negative interactions or problems that could be seen as obstacles to groundwater governance.

Social, Economic, and Political Settings (S)			
S1- High economic development of the mining sector in the area already highly productive			
Resource system (RS)	**Resource Units (RU)**	**Users (U)**	**Governance System (GS)**
RS1- Sector: Water RS2- Clear boundaries RS5- Significant scarcity RS6- Aquifer depleted and scarce hydrometric information	RU2- Seasonal water availability (mostly during spring) RU3- Hydrologic interaction between groundwater aquifers RU4- Costly agricultural and mining production	U1- Total number of wells in the basin was over 600. U2- High heterogeneity of economic sectors involved and wealth of users. U5- No clear leadership U6- No groundwater norms U9- Efficient irrigation technologies in place	GS1- A small public authority's office in place GS2- Only one groundwater community in place (sector 5 and 6) with limited capacity GS5- No operational rules GS6- No collective-choice rules GS8- No monitoring & sanctioning processes
Interactions (I)		**Outcomes (O)**	
I1- Overallocation of water rights and maximum water usage by diverse users I4- Conflicts among users I6-1 Poor management capacity of communities in place I6-2 Surface Vigilance Committee not managing groundwater resources and each aquifer being managed as independent		O1- Lack of equity in water distribution (since big farmers and the mining sector have deeper wells, small farmers and rural communities are left with "hanging wells") O2- Aquifer depletion and salinity problems. O3- Higher energy demands (for deeper wells)	
Related Ecosystems (ECO)			
ECO1- Higher uncertainty of water availability ECO2- Appearance of pollution ECO3- Existence of wetlands at the beginning of the basin			

Figure 3-3. Summary of variables analyzed in the Copiapó groundwater aquifer, using SES Framework.

The main identified problems are described in more detail in what follows.

Problem 1: Over-allocation of water rights. As has already been mentioned, the aquifer was being highly over-extracted, and its groundwater levels were quickly diminishing. In the past years, the aquifer level had started dropping and wells have had to be deepened as much as 200 m in order to get water in some areas (DICTUC, 2010). This generated a number of "hanging" wells, as well as an increase in electricity consumption, and an overall increase in costs to extract groundwater. This over-allocation was due to:

i) The lack of studies that model and project the availability of water and contradictory reports on the effects of exploitation. In 1984, a study concluded that there are groundwater sectors where extraction equals recharge, so some aquifer sectors should close for new water withdrawals (IPLA, 1984). Contradicting such information, in 1993, was another model which estimated that the basin still had a margin for new abstractions, information that was refuted a year later (DGA, 1993; IPLA, 1994). However, in 1995, once again, a study stated that there was no overexploitation in the upper part of the basin (Álamos and Peralta, 1995). This assertion was supported by a study conducted in 2006 (Golder, 2006). Since then, all the studies carried out demonstrated the need for the closure of the basin due to problems of over-extraction (SITAC, 2008; DICTUC, 2010; McFarlane and Norgate, 2012; Fuster et *al.,* 2010).

ii) Lack of planning for the process of granting water rights. From all the studies mentioned earlier, only those done once the basin was closed considered climate change projections and interaction of surface and groundwater. They were not available during the years when most water rights were granted[4].

iii) The use of the "foreseeable use factor" of water for the farming sector. The latter consists of estimating the number of permits that could be granted by taking into account only their intended use. Thus, the approach considers a theoretical use factor of water rights that assumed agriculture would consume 20% of its annual allotment and drinking water supplies and the mining industry would only consume 75% of their allotment (Rinaudo and Donoso, 2019). These assumptions were based on the seasonality and interannual variability of the extractions, as well as extraction efficiency. Due to improvements in water use efficiency, the actual use factor is much higher: closer to 40% for agriculture and 100% for mining and drinking water (Rinaudo and Donoso, 2019). Thus, the total volume actually extracted is much higher than the one estimated when the water rights were granted. The temporary introduction of the concept of foreseeable use value worsened the over-allocation situation (Jouravlev, 2005; Muñoz, 2010; World Bank, 2011).

These factors explain the overallocation: scarce and contradicting information; lack of planning; and the incorporation of the "foreseeable use factor", are shared in Rinaudo and Donoso (2019), as well as in Donoso, Lictevout and Rinaudo (2020). In both studies, the legal complexity of the Chilean system and political pressures, as well as compliance and enforcement problems -considering a lack of monitoring devices- also triggered an over-allocation of the resource.

Problem 2: Independent management of the underground connected aquifer sectors, and between surface and groundwater. The subdivision of the six administrative sectors, carried out after the study of Álamos and Peralta (1987), sought to achieve better administrative management of the resource (Golder, 2006; SITAC, 2008; DICTUC, 2010). However, in all technical studies, the interconnection between the different hydrogeological zones is acknowledged by recognizing that water intakes in the upper sectors of the aquifer affect the aquifer level in the sectors 'downstream' in the aquifer. In all studies, it is emphasized that the six sectors respond to an administrative rather than hydrogeological division. Nonetheless, because the aquifer was administratively sectorized, the public agency, the *Dirección General de Aguas* (DGA), has interpreted each sector as a hydrogeological division, thus endorsing the individual management of each sector (Donoso, 2014). Since the aquifer's water level has been dropping, salinity issues and increasing conflicts have ensued; having independent water management in these aquifers has proven to be suboptimal for the efficient water management of the basin as an integrated unit.

In the Copiapó river, although the Vigilance Committee, should exercise its actions towards surface and groundwater users[5], it only actually manages surface water for irrigation districts and individual river intakes. Furthermore, since the river no longer flows downstream from the city of Copiapó, they justified their governance ending at the city, and not any further.

Other initiatives, such as the establishment in 2006 of a Public-Private Water Table to operate as a binding basin-level agency, and the establishment of a Regional Advisory Council for Water Resources[6] in 2014, have arisen (CSIRO, 2015). Nonetheless, they haven't worked or settled upon long-lasting agreements.

[4] Most water rights were formally registered between 1985 and 1988, reflecting the time when historical rights began to be inscribed in the Real Estate Conservators books.

[5] Due to a legal reform passed in 2005

[6] *Consejo Asesor Regional de Recursos Hídricos* (CARRH)

Problem 3: Poor or no groundwater management. In the lower basin, sectors 5 and 6, the first groundwater user community was organized, the *Comunidad de Aguas Subterráneas* (CASUB). Its main objective was to carry out groundwater management in its area of jurisdiction, which covers from the Copiapó city downstream to the ocean. This management includes seeking the sustainable exploitation of the resource, jointly managing quality and quantity issues, and ecosystem conservation. Even though the community was established in 2004, it only became active in 2008 and its management capacities have been limited due to the lack of rules of operation (Donoso et *al.,* 2020).

Between 2012 and 2015, the authors of the present article conducted field work to strengthen CASUB. The diagnosis was that CASUB lacked the tools and resources to effectively manage the groundwater resource. The community was mainly focused on limiting the acquisition of new water rights, updating their user registry, as well as monitoring upper river flows and a small number of water wells. The situation was even more complicated upstream, since before 2012 there were no groundwater user communities established, nor any groundwater management controls.

Problem 4: Conflicts and trust issues between users. In Chile, water conflicts are a common issue regarding water management. A majority of these involve large companies, such as corporations operating large-scale mining projects, many of them located in the arid north (Bauer, 2015). According to Rivera, et al. (2016) different conflicts arise as a result of the characteristics of the relationship between companies and communities. They highlight the lack of dialogue and agreements among the different sectors involved (Rivera et al., 2016). A subsequent study identified that, over time, conflicts have evolved to fewer topics that include the protection of property and the environment, and claims regarding the adaptation of water rights towards current legislation processes (Herrera et *al.,* 2019). Although subjects tend to be recurrent, additional demands have been added in recent years, including technical components, and environmental and social issues (Rivera et *al.,* 2020).

Copiapó is not the exception and is one of the provinces with the highest number of water disputes (Rivera et *al.,* 2020). Besides having several legal water disputes, there is a high level of mistrust among water users in the basin. There are trust issues both among users themselves and with the authorities. An analysis carried out in the basin identified distrust of the mining sector, especially by farmers, a lack of credibility of public authorities, and mistrust of the drinking water providers (CSIRO, 2015).

The groundwater crisis that affected Copiapó was triggered by several problems, most of them regarding management issues. These problems are commonly found in other water basins, especially in those areas that depend significantly on groundwater reservoirs. In many cases, collective action has proven to be mutually beneficial for all parties (Lopez-Gunn, 2003; Lopez-Gunn and Martínez, 2006; Martínez and Hernández, 2003; Poteete et *al.,* 2010). Thus, the question that arises is what acted as a barrier for users to organize themselves and develop successful groundwater self-governance.

3.3. Barriers for collective groundwater management

Even though collective management of these groundwater resources could help solve the problems identified previously, we identified specific barriers in the basin that acted as obstacles for the development of said strategy.

Barrier 1: Heterogeneity of the actors involved and no opportunities for conversation. There was difficulty in coordinating different requirements and needs of a diverse range of actors. In Copiapó, the existence of large, medium and small farmers, indigenous communities, mining companies, and the cities having different needs regarding the timing and quantity of the water required, affected their ability to coordinate, and thus, their ability to develop collective management. Multiple research supports our finding,

suggesting that different forms of group heterogeneity affect collective action (Poteete et *al.,* 2010; Ruttan, 2006; 2008). On the matter, Tang (1991) shows that lower variance in the group income can be associated with a higher degree of rule conformance and good maintenance among irrigators. Along these lines, Wang and Segarra (2011) predicted that welfare losses arise in the presence of productivity heterogeneity. Using the SES framework, considering these aspects we conclude that the existence of different actors, in terms of income and production, was a barrier limiting their collective action.

Working with a range of stakeholders, all with different motivations, requires time, patience, and compromise (Powell and Bundhoo, 2019). In Copiapó, the lack of coordinated conversations, or a person/organization acting as a mediator, only worsened the situation. This conclusion is shared with Donoso, Lictevout and Rinaudo (2020), indicating that the absence of a forum where diverse stakeholders could gather to talk and debate about water issues is an important problem for the coordination throughout the basin. This is a regular problem in Chile related to groundwater issues (Abrigo, 2019; Rinaudo and Donoso, 2019).

Barrier 2: Disinformation regarding water available and granted water rights. The level of knowledge regarding granted groundwater rights, as well as the knowledge regarding the physical operation of the resource in Copiapó valley, truncated the emergence of collective management of the resource. First, there are significant gaps in the official water rights registry listed by the public authority, the DGA (Rinaudo and Donoso, 2019; World Bank, 2011; 2013). This is due to the fact that water rights given in the past have not all been adapted to the standards of the current legislation and customary water rights have not formalized their titles. Also, the DGA is not informed of water rights listed in real estate offices (*Conservadores de Bienes Raíces*), as well as several transactions between users. Thus, there was no agreement regarding who has water, when and where. To reduce this barrier, we built a water rights database using historic real estate registry information. This actualized water right registry was delivered to CASUB and became the basis to constitute the groundwater communities in the upper part of the basin.

A second source of disinformation, as mentioned previously, is that even though several studies have been conducted on the Copiapó aquifer over the past few years, they have not shown agreement regarding the groundwater situation. This has been identified by several authors (Donoso et *al.,* 2020; Rinaudo and Donoso, 2019; Troncoso et *al.,* 2012). The disinformation regarding the list of users that should be considered in the water management, as well as the lack of information regarding water dynamics, is a critical issue for self-governing resources, as has been pointed out in numerous research papers (Meinzen-Dick, 2014; E. Ostrom, 2015b; Poteete et *al.,* 2010; Powell and Bundhoo, 2019).

Barrier 3: Government bureaucracy problems. Copiapó's crisis and the lack of collective groundwater governance may also be explained as a consequence of severe governmental failure. Bureaucratic issues regarding a rigid public system can be pinpointed as problematic. As mentioned, despite the fact that the aquifer has proven to be connected in its six administrative sectors, and therefore joint management must be carried out, our proposal to develop a unique groundwater user community was rejected by the public authority, the DGA. Additionally, there was a significant delay in the resolution of regular procedures, poor digital documentation, and long delays due to paperwork requirements, all associated with the DGA, as has been diagnosed by the World Bank (2013). In addition, the extremely rigid regulatory framework that leaves limited space for adjustment to changing conditions, has also been criticized (Bitran et *al.,* 2014). Finally, the lack of understanding of an institutional integrated system has led to isolated interventions from different departments, sometimes duplicating efforts. This has also been considered as a source of conflict and a barrier to collective management (Bitran et *al.,* 2014; World Bank, 2013).

Barrier 4: Trust issues. The evidence shows that there was a lack of trust between water users. This limited the creation of collective water management associations. This barrier was overcome through multiple workshops to bring users together, reflect on the problem, and reach a consensus on the need to jointly manage the aquifer. Additionally, there was distrust between water users and public agencies. For example, the approved statutes and rules of operation for the new groundwater user associations were not registered by the DGA until 4 years later, due to different opinions on the attributions of these associations; this delay limited the association's ability to effectively manage the groundwater. As Powell and Bundhoo (2019), point out, this lack of trust is a barrier to collective action. The existence of trust and trustworthiness of institutions has been linked with successful collective associations (Coleman, 1988; Gambetta, 2000; Ostrom and Ahn, 2009). These results agree with Van Vugt (2002) regarding domestic water demands during droughts where lower levels of trust effectively restrict users from pursuing their collective benefit, i.e. protecting the long-term interests of the community.

Barrier 5: Lack of monitoring techniques and facing financial barriers. The Chilean water code establishes that groundwater user communities are responsible for monitoring and enforcing compliance with water extraction requirements. However, CASUB was formed in 2004 and the remaining associations were only created between 2012 and 2015. Thus, there was no monitoring done by water users, as established in the water code when there were no associations. The DGA tried to fill the gap unsuccessfully, since it did not have the resources to monitor all groundwater extractions (World Bank, 2013), and the State has not had sufficient power to require communities to take action, in particular in terms of data collection, and designing rules to reduce abstraction (Donoso et *al.,* 2020; Rinaudo and Donoso, 2019). Only as of 2018, with the latest reform of the water code, has the DGA had greater powers to monitor and enforce water use; however, the DGA was not allocated additional budget to increase its monitoring activity and, thus, has not acted on the increased powers. Thus, the State lacks the financial, technical and human resources to implement all the provisions of the Chilean water law regarding water management and monitoring. This lack of monitoring contributed to the high levels of distrust creating a critical barrier to collective action.

Overall, a major issue is that these problems, theoretically, should not exist. Leaving aside the space for conversation between heterogenous actors, all other issues already have an established protocol written in the Chilean legal framework. For example, for the lack of information, there are formal registries where all water rights should be written, and deadlines for all water rights to be updated to fit current legislation. However, due to different institutional, technical and financial matters, in practice, they have been left unsolved. As has already been stated, the Chilean law is very sophisticated "on paper" but many of its dispositions are left unimplemented (Donoso et *al.,* 2020). In this case, there are institutional, technical and financial limitations that translate to information asymmetries, delays in procedures, bureaucratic conundrums and conflictive situations. All of the above factors end up limiting the development of collective groundwater management, in spite of having a legal framework that supports it.

4. Solving Groundwater management barriers in Copiapó

Despite all of the barriers mentioned earlier, currently the basin has developed collective groundwater action. For this to happen, formal and informal solutions helped as triggers.

Solution 1: Neutral and technical mediator. The need for a neutral space or forum, where all stakeholders could debate, was solved by the State by hiring an external team. This team was constituted by researchers with the objectives of organizing the groundwater users' communities of the four upper sectors

and empower the existing groundwater community, the CASUB. Some key aspects for the development of spaces for agreements were:

i) The neutrality and technical confidence provided by the team. The researchers were not linked to the government and authorities. Also, it was an interdisciplinary group including agronomists, lawyers, engineers and economists, among others, thus providing strong technical support. With both of these features, the group provided confidence to the variety of stakeholders.
ii) An on terrain/field team. Besides the interdisciplinary group of academics and researchers, a local professional team was established in the area, led by a women agronomist. The insertion of the team in the locality, with members who are regular inhabitants, facilitated encounters and opportunities for dialogue.

Solution 2: Formally establishing common language and spaces in legal documents. A relevant aspect that triggered collective action was having a collective language and formal representation of all stakeholders established. In detail, the drafting of the legal documents for the new groundwater users' associations, as well as the editing of the existing legal documents, was done using a more colloquial language and format following a bottom-up approach. Water users' associations statutes in Chile are complicated to read. They usually copy paragraphs of the water code, incorporate a lot of written information, including a list of all users and details on their water rights. In this case, the statutes were summarized into a shorter document, with less legal jargon, even though it still complies with the normative requirements. The statutes were complemented with a document of procedures that specifies how to put them in practice, and a manual that translates everything into a user's language. This helped develop a common language when discussing water management in the basin. The reformed statutes and rules of operation were approved in a general assembly of CASUB after a series of workshops where they were presented and debated with the users.

Also, to encourage participation, specific seats were established on the board of directors of each community so as to ensure representativity in the main decisions of the association, accounting for the heterogeneity of users. Specific seats were designated for small, medium and large farmers, as well as the mining sector, and the urban uses. Thus, when making regular decisions in the directors' board, small users have voice and a meaningful vote. Nevertheless, small water users pointed out that they still felt excluded from the decision process[7].

Solution 3: Providing information and cross checking it. To clearly delineate the different communities' boundaries and identify their members, a consensus on the list of water users needed to be established. For this step, the research team undertook the extensive work of reviewing all water registries from the real estate offices (*Conservadores de Bienes Raíces*) and comparing them with the information provided by the public agency. At the same time, the information was provided to the users for their review, in order to identify differences with their registries, thus achieving a consensus on the final registry. After this stage was completed, all wells were referenced using a geographic information system (GIS). Currently, all water rights and their users have been clearly identified, and an updated registry is in the possession of each groundwater users' community.

Solution 4: Creativity and openness to all ideas. A key for developing collective action in the basin was to use innovative solutions, considering the institutional context. Two extraordinary examples can be mentioned to illustrate this aspect. First, even though the groundwater users' community that was already in place, the CASUB, manages two administrative sectors, the request for developing a unique community

[7] Even though the legal documents allow for an effective participation of all users, since votes are proportional to the size of water rights, small users feel excluded from the decision process.

for upstream users was denied. Instead, the public authority explicitly indicated the need to develop four separate communities, one for each administrative sector. Complying with this request, four new groundwater users' communities were formed. However, all of them were organized with the same statutes. This allows them to work together, based on goodwill, or at least ensures coherency among the management of the resources in the basin. Currently, sectors 1, 2 and 3 are managed as one community, instead of three different and independent ones.

A second example of the need for creative solutions was the acquisition of surface water rights in the upper section of the basin by the CASUB. The Vigilance Committee did not consider downstream groundwater users when managing the dam's levels. CASUB, as a surface water right holder, now has a say in decisions regarding surface waters which affect their groundwater availability. By buying these surface water rights, they "nested" themselves within the surface water organization.

Solution 5: Building trust. Regaining trust, once it has been lost, is one of the most complicated issues. In Copiapó, the trust among users had to be restored. The triggers for the development of trust among users included:

i) Regular meetings over a period of three years, organized by the research team,
ii) Government not involved in user meetings, allowing users from different economic sectors to moderate their positions while discussing,
iii) Regular meetings with public authorities informing them of the advances in the constitution of groundwater associations,
iv) Establishment of websites for each community with the information available in a transparent way.

Thus, the proactive involvement of users and public agencies in the problem analysis, increased transparency, and improved communication, building trust between users. A similar conclusion is reached by Parag and Timmons Roberts (2009).

Solution 6: Alliances and long-term planning. One of the most problematic issues faced in the development of a groundwater monitoring strategy is the financial aspect. To solve this, an informal alliance was made with the public sector. The groundwater users' associations developed a strategy to establish to gradually install flowmeters connected to telemetry so as to monitor water extraction, and static and dynamic aquifer levels in real time. To help finance the investment required, the groundwater user associations presented this plan to the public forum to stimulate technological improvement in irrigation works[8]. This program has sequentially co-funded this program together with the users, and currently, all important wells have their own monitoring system, and soon all wells will be monitored.

With all the above, currently the basin has groundwater users' communities working actively in all the six administrative sectors. Each community has representatives and trained directors, empowered in their rights, as well as in their obligations. They now have an updated list of their users' information agreed with the community, as well as the geospatial location and monitoring devices installed in almost all wells. There are still aspects that need to be solved in the basin, such as environmental minimum flows, and indigenous communities' rights that have to be formally incorporated. However, in terms of promotion and development of collective action, the basin has proven to be a successful case to study.

Overall, three aspects can be mentioned as key to the formation of groundwater users' communities in the Copiapó basin. First, the development of long-term contracts with technical and neutral parties who

[8] Law N. 18,450, *Ley de Fomento a la Inversión Privada en Obras de Riego y Drenaje* (Law for the Promotion of Private Investment in Irrigation and Drainage) is an instrument to stimulate technological improvement in irrigation works. Over the years, it has incorporated off-farm projects, such as works for the distribution of water in a community, and thus, allows supporting the investment in groundwater monitoring devices with subsidies.

act as mediators has been crucial. The research team was initially set up to last two years but ended up lasting three. This time extension was needed because it was not until the end of the first year that the local information was completely gathered, the users started attending the meetings, and the team started gaining credibility and making a solid impression. It took a second year just to solidify these achievements. The establishment of trust cannot be rushed. Short-term relationships cannot build trust that acts as a cornerstone for everything that comes afterwards.

A second aspect relevant for the development of groundwater collective action was the identification and empowerment of good leaders. Since several meetings were held with different groups and places, those who always participated, those who motivated others, and those who were seen as trustworthy among other users, ended up standing out. It turned out, they also had a vision of the basin and an understanding of the need for self-governance. The suggestion of creating a temporal directive was the opportunity for them to be in those positions and to empower others.

Finally, limiting the participation of the administrative authority in the communities' decisions was fundamental. When public agencies have highly bureaucratic standards, self-governance is restricted. In this case, excluding them from the meetings and overall decision-making process led to users finding their voices, finding innovative solutions, and more empowerment for the community. The overall feeling is that the community was not imposed and that they contributed to the process development. The government through its public agencies should only act as a facilitator, either for information or financial resources.

5. Conclusion and lessons learned

The Copiapó case represents a sound example of a groundwater basin with many conflicts. It shows a situation where different factors have led to extreme over-extraction. At the same time, poor management is in place in terms of a lack of understanding of connected aquifers, disconnection between surface and groundwater administration, and non-existence of monitoring devices. To add challenges to the situation, an environment of major conflicts and distrust had already been established as the norm. Even though collective management of these ground resources could help solve these issues, specific barriers prevented it.

In the case of Copiapó, the barriers included the existence of highly heterogeneous actors, considering representatives of different economic activities, and the lack of spaces for them to gather. Also, a context of general disinformation regarding their water rights and the water dynamics, high government bureaucracy, and severe trust issues, together with a weak or non-existent monitoring system, all acted as barriers for users to gather and organize themselves. These elements are also commonly found in other intra-national water basins that have not been able to organize themselves collectively.

Here, it is clear that even though the legal framework has formal protocols to avoid these problematic situations, in practice, many of them are not implemented. Since there is an established protocol, it is difficult to propose alternatives to replace the institutional or technical void without being considered an illegal practice or without encountering opposition. This gap between the tools, institutional arrangements, and information that should be in place and what is really happening, ends up limiting the development of collective water management.

Regardless of these barriers, the basin has been able to develop groundwater collective action. A diversity of actions, with different levels of formality, have been combined and developed in the basin to help with the formation of groundwater communities. Some of the elements that were used include:

i) The development of a neutral space or forum, where all stakeholders could debate, encouraged by the hiring of an external and technical consultant team.

ii) Having a collective language and representation of all stakeholders established formally in the legal documents.
iii) Clearly identifying all members, their water rights, and establishing a common consensus on this registry.
iv) Searching for solutions "out of the box" to achieve strategies in a given strict and bureaucratic institutional framework.
v) Being consistent and transparent to promote regaining trust between users.
vi) Specific financial alliances with the public sector to implement a monitoring plan.

The analysis shows the relevance of three elements: first, the existence of a neutral and technical team that acted as mediators; second, the identification and empowerment of leaders; and thirdly, the limitation of the administrative authority in the community's decisions.

At present, the basin has groundwater users' communities working actively in all six administrative sectors. There are still aspects that require solutions in the basin, such as the establishment of environmental securities, and indigenous communities' rights that must be formally incorporated. However, in terms of promotion and development of collective action, the basin has proven to be a successful case to study and its lessons can be useful for groundwater basins all over the world, as most of the problems and barriers reviewed for the case study can be found in many other basins. Also, the presented case study contains great divergency regarding the multiplicity and heterogeneity of users that it describes, and a highly fragmented institutional system. The above can also account for users and institutional divergencies across different places, and thus, can be useful for enhancing self-managed groundwater communities in other countries as well.

Finally, the use of tools from the Design Principles for Sustainable Management of Common-Pool Resources and the SES framework was key to organizing the analysis and understanding the real barriers and solutions that exist. This analysis and tool are useful, especially after working for years with the case study, where significant variables could go unnoticed. This study can be viewed as a first step towards adapting and expanding the SES Framework in order to consider water management variables. For example, it could encompass broader dimensions, such as the historical evolution of the institutional scheme, the interplay between social factors that shape the system development, or the potential influences stemming from a nationwide perspective or interactions with other basins. Thus, further research regarding different groundwater case studies should be conducted to strengthen the tool. Nevertheless, key barriers and solutions were identified with the analysis, and these can be useful, not only for improving groundwater governance, but for developing an integrative collective water governance that can hold surface and groundwater as well.

6. References

Abrigo, G. (2019). *Propuesta metodológica para la organización y funcionamiento de comunidades de aguas subterráneas. AFE para optar al Grado de Magíster en Manejo de Suelos y Aguas*. https://doi.org/10.5354/0717-8883.1955.11040

Álamos, F., and Peralta, F. (1987). Análisis y Evaluación de los Recursos Hidrogeológicos del Valle del Río Copiapó. *Dirección General de Aguas (DGA) Del Ministerio de Obras Públicas (MOP)*.

Álamos, F., and Peralta, F. (1995). Análisis y Evaluación de los Recursos Hídricos en el Valle del Río Copiapó. *Dirección General de Aguas (DGA) Del Ministerio de Obras Públicas (MOP)*.

Bauer, C. J. (2015). Water conflicts and entrenched governance problems in chile's market model. *Water Alternatives*.

Bitran, E., Rivera, P., and Villena, M. J. (2014). Water management problems in the Copiapó Basin, Chile: Markets, severe scarcity and the regulator. *Water Policy*, *16*, 844–863. https://doi.org/10.2166/wp.2014.107

Coleman, J. S. (1988). Social Capital in the Creation of Human Capital. *American Journal of Sociology*. https://doi.org/10.1086/228943

Cox, M., Arnold, G., and Villamayor-Tomás, S. (2010). A review of design principles for community-based natural resource management. *Ecology and Society*, *15*(4). https://doi.org/10.5751/ES-03704-150438

Cox, M., Arnold, G., and Villamayor-Tomás, S. (2016). Design principles in commons science: A response to "Ostrom, Hardin and the commons" (Araral). *Environmental Science and Policy*, *61*, 238–242. https://doi.org/10.1016/j.envsci.2016.03.020

CSIRO. (2015). Plan de gestión integrada para la cuenca del Copiapó, Fase 1. *Serie de Informes Técnicos (SIT) Dirección General de Agias (DGA) Del Ministerio de Obras Públicas (MOP) Fundación CSIRO Chile*, 179. Retrieved from http://www.dga.cl/estudiospublicaciones/Series documentales/Informe_Final_para_Empaste_01_10_2015.pdf

DGA, Dirección General de Aguas. (1993). Situación de los Recursos Hídricos III-IV Regiones. *Dirección General de Aguas (DGA) Del Ministerio de Obras Públicas (MOP)*, *Enero-Dici*.

DGA, Dirección General de Aguas. (2004). *Diagnostico y Clasificacion de los cursos y cuerpos de agua segun objetivos de calidad. Cuenca del río Copiapó*. *Dirección General de Aguas (DGA) Ministerio de Obras Publicas, Gobierno de Chile*.

DICTUC. (2010). *Analisis integrado de gestion en cuenca del rio Copiapo, Chile, Informe final tomo 1*.

Donoso, G. (2014). Integrated water management in Chile. In *Integrated Water Resources Management in the 21st Century: Revisiting the paradigm*. https://doi.org/10.1201/b16591-16

Donoso, G. (2018). Overall Assessment of Chile's Water Policy and Its Challenges. In *Water Policy in Chile* (pp. 209–219). https://doi.org/10.1007/978-3-319-76702-4_14

Donoso, G., Lictevout, E., and Rinaudo, J. D. (2020). Groundwater Management Lessons from Chile. *Sustainable Groundwater Management. Global Issues in Water Policy*, *24*, 481–509. https://doi.org/10.1007/978-3-030-32766-8_25

Ebenhöh, E. (2007). Designing Agent-based Models of Water Management Regimes using the IAD Framework. *The Challenge of Self-Governance in Complex, Globalizing Economies*.

Fuster, R., Gonzáles, L., Morales, L., Cerda, C., Hernández, J., Sotomayor, D., … Valdebenito, J. (2010). Gestión Integrada de los recursos hídricos en Chile. *Biblioteca Del Congreso Nacional, a Través de Fondos Del Banco Interamericano Del Desarrollo. Departamento de Ciencias Ambientales y Recursos Naturales Renovables de La Facultad de Ciencias Agronómicas de La Universidad de Chile*, 395.

Gambetta, D. (2000). Unknown - Unknown - aefi-idrv. https://doi.org/10.1.1.24.5695

Golder Associates (2006). Diagnóstico de los recursos hídricos de la cuenca del Río Copiapó y proposición de un modelo de explotación sustentable, 245. Retrieved from https://research.csiro.au/gestion-copiapo/wp-content/uploads/sites/216/2018/01/062-2006-Diagnostico-de-recursos-hidricos-en-Copiapo-Golder.pdf

Gorelick, S. M., and Zheng, C. (2015). Global change and the groundwater management challenge. *Water Resources Research*, *51*, 3031–3051. https://doi.org/10.1002/2014WR016825

Hardin, G. (1968). The Tragedy of Commons. *Science*. https://doi.org/10.1126/science.162.3859.1243

Heikkila, T., Schlager, E., and Davis, M. W. (2011). The Role of Cross-Scale Institutional Linkages in Common Pool Resource Management: Assessing Interstate River Compacts. *Policy Studies Journal*, *39*(1), 121–145. https://doi.org/10.1111/j.1541-0072.2010.00399.x

Herrera, M., Candia, C., Rivera, D., Aitken, D., Brieba, D., Boettiger, C., … Godoy-Faúndez, A. (2019). Understanding water disputes in Chile with text and data mining tools. *Water International*, *44*(3), 302–320. https://doi.org/10.1080/02508060.2019.1599774

IPLA, Ingeniería y Planificación (1984). *Balance Hidrológico Nacional Regiones III y IV*.

IPLA, Ingeniería y Planificación (1994). Análisis de Uso Actual y Futuro de los Recursos Hídricos de Chile, Regiones III-IV. *Dirección General de Aguas (DGA) Del Ministerio de Obras Públicas (MOP)*.

Jouravlev, A. (2005). Integrating Equity, Efficiency and Environment in the Water Allocations Reform. In *Presentation at the International Seminar of Water Rights Development in China. Beijing*.

Kinzelbach, W., Bauer, P., Siegfried, T., and Brunner, P. (2003). Sustainable groundwater management - Problems and scientific tools. *Episodes*, *26*(4), 279–284. https://doi.org/10.18814/epiiugs/2003/v26i4/002

Kiser, L. L., and Ostrom, E. (1982). The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches. In *Strategies of Political Inquiry* (pp. 179–222).

Lam, W. F., and Ostrom, E. (2010). Analyzing the dynamic complexity of development interventions: Lessons from an irrigation experiment in Nepal. *Policy Sciences*, *43*, 1–25. https://doi.org/10.1007/s11077-009-9082-6

Lopez-Gunn, E. (2003). The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. *Water International*, *28*(3), 367–378. https://doi.org/10.1080/02508060308691711

Lopez-Gunn, E., and Martínez, L. (2006). Is self-regulation a myth? Case study on Spanish groundwater user associations and the role of higher-level authorities. *Hydrogeology Journal*. https://doi.org/10.1007/s10040-005-0014-z

Martínez, L., and Hernández, N. (2003). The role of groundwater in Spain's water policy. *Water International*, *28*(3), 313–320. https://doi.org/10.1080/02508060308691704

McFarlane, D., and Norgate, T. (2012). Summary report on Copiapó water yields and demands. A report submitted to AusAID as part of the study: Copiapó River Basin, Chile – analysis study of shortfalls in water rights, industrial usage and social requirements. *CSIRO*, 1–66. Retrieved from https://publications.csiro.au/rpr/download?pid=csiro:EP126400&dsid=DS4

McGinnis, M. D. (2011). An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. *Policy Studies Journal*. https://doi.org/10.1111/j.1541-0072.2010.00401.x

Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.0702296104

Meinzen-Dick, R. (2014). Property rights and sustainable irrigation: A developing country perspective. *Agricultural Water Management*, *145*(0), 23–31. https://doi.org/http://dx.doi.org/10.1016/j.agwat.2014.03.017

Muñoz, J. (2010). Aplicación del concepto de uso previsible en la constitución originaria de derechos. *Revista Vertiente*, *11*(Capítulo Chileno A.G.).

Oakerson, R. J., and Parks, R. B. (2011). The Study of Local Public Economies: Multi-organizational, Multi-level Institutional Analysis and Developmentp. *Policy Studies Journal*, *39*(1), 147–168.

Ostrom, E. (1990). *The Evolution of Institutions for Collective Action*. *Political Economy of Institutions and Decisions*. https://doi.org/10.1017/CBO9780511807763

Ostrom, E. (2000). Collective Action and the Evolution of Social Norms. *The Journal of Economic Perspectives*, *14*(3), 137–158.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.0702288104

Ostrom, E. (2011). Background on the Institutional Analysis and. *Policy Studies Journal*, *39*(1), 7–27. https://doi.org/10.1111/j.1541-0072.2010.00394.x

Ostrom, E. (2015a). *Governing the commons: The evolution of institutions for collective action*. *Governing the Commons: The Evolution of Institutions for Collective Action*. https://doi.org/10.1017/CBO9781316423936

Ostrom, E. (2015b). *Governing the commons*. Cambridge university press.

Ostrom, E., and Ahn, T. K. (2009). The Meaning of Social Capital and Its Link to Collective Action. In G. T. Svendsen and G. L. Svendsen (Eds.), *Handbook on Social Capital* (pp. 17–34). Edward Elgar Publishing.

Ostrom, E., Janssen, M. A., and Anderies, J. M. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(37), 15176–15178. https://doi.org/10.1073/pnas.0701886104

Ostrom, E., Lam, W. F., Pradhan, P., and Shivakoti, G. P. (2011). *Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal*. *Improving Irrigation in Asia: Sustainable Performance of an Innovative Intervention in Nepal*. https://doi.org/10.4337/9780857938022

Ostrom, V. (1991). Polycentricity: The Structural Basis of Self-Governing Systems. In *The Meaning of American Federalism: Constituting a Self-Governing Society [Vincent Ostrom]* (pp. 223–244). San Francisco: ICS Press.

Parag, Y., and Timmons Roberts, J. (2009). A battle against the bottles: Building, claiming, and regaining tap-water trustworthiness. *Society and Natural Resources*, *22*(7), 625–636. https://doi.org/10.1080/08941920802017248

Poteete, A. R., Janssen, M. A., and Ostrom, E. (2010). *Working together: Collective action, the commons, and multiple methods in practice*. *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*.

Powell, J., and Bundhoo, D. (2019). *Negotiating a way towards consilience in managing conflicts over commons: a multi-stakeholder dialogue Report*.

PUC, Pontificia Universidad Católica de Chile. (2014). *Informe Final Programa: Capacitación y Apoyo a Comunidades de Aguas Subterráneas en el Valle de Copiapó*. Santiago.

Rinaudo, J. D., and Donoso, G. (2019). State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile). *International Journal of Water Resources Development*, *35*(2), 283–304. https://doi.org/10.1080/07900627.2017.1417116

Rivera, Daniela. (2015). Diagnóstico jurídico de las aguas subterráneas. *Ius et Praxis*, *21*(2), 225–266.

Rivera, Daniela. (2018). Alumbrando conflictos: disponibilidad y asignación de derechos de aguas subterráneas en la jurisprudencia chilena. *Revista de Derecho (Valdivia)*, *31*(1), 159–183. https://doi.org/10.4067/s0718-09502018000100159

Rivera, Daniela, Del Río, C., Donoso, G., and Molinos-Senante, M. (2020). Conflictividad judicial de aguas en Chile: caracterización y propuestas para mejorar su prevención y resolución. *Propuestas Para Chile 2019. Centro de Políticas Públicas UC*.

Rivera, Diego, Godoy-Faúndez, A., Lillo, M., Alvez, A., Delgado, V., Gonzalo-Martín, C., … García-Pedrero, Á. (2016). Legal disputes as a proxy for regional conflicts over water rights in Chile. *Journal of Hydrology*. https://doi.org/10.1016/j.jhydrol.2016.01.057

Ruttan, L. M. (2006). Sociocultural Heterogeneity and the Commons. *Current Anthropology*, *47*(5), 843–853. https://doi.org/10.1086/653807

Ruttan, L. M. (2008). Economic Heterogeneity and the Commons: Effects on Collective Action and Collective Goods Provisioning. *World Development*, *36*(5), 969–985. https://doi.org/10.1016/j.worlddev.2007.05.005

SITAC (2008). Modelo Hidrogeológico Cuenca Río Copiapó, Sector Ramadillas - La Puerta, Proyecto

Caserones. Servicios de Ingeniería y Construcciones SITAC S.A.

Tang, S. Y. (1991). Institutional Arrangements and the Management of Common-Pool Resources. *Public Administration Review*, 42–51. https://doi.org/10.2307/976635

Troncoso, R., Pérez, Y., Castro, R., Lorca, M. E., Vega, N., and Al., E. (2012). Evaluación hidrogeológica de la cuenca del río Copiapó, con énfasis en cuanti cación, dinámica y calidad química de los recursos hídricos super ciales y subterráneos. *Servicio Nacional de Geología y Minería (SERNAGEOMIN)*.

Van-Vugt, M. (2002). Central, Individual, or Collective Control? *American Behavioral Scientist*. https://doi.org/10.1177/0002764202045005004

Wang, C., and Segarra, E. (2011). The economics of commonly owned groundwater when user demand is perfectly inelastic. *Journal of Agricultural and Resource Economics*, *36*(1), 95–120.

World Bank. (2011). Diagnóstico de la gestión de los recursos hídricos. Chile. *Departamento Del Medio Ambiente y Desarrollo Sostenible*. https://doi.org/10.1029/2001WR000748

World Bank. (2013). Estudio para el mejoramiento del marco institucional para la gestión del agua. Chile. *Departamento Del Medio Ambiente y Desarrollo Sostenible*.

Zhang, Y. (2018). Crossing the divide: an integrated framework of the commons. *Evolutionary and Institutional Economics Review*, *15*, 25–48. https://doi.org/10.1007/s40844-017-0077-2

Zhang, Y. (2019). Governing the water commons in China: from historical oriental despotism to contemporary fragmented hydraulic state. *International Journal of Water Resources Development*, *35*(6), 1029–1047. https://doi.org/10.1080/07900627.2018.1508989

Zhang, Y. (2020). How did the lost Shangri-La get lost? The tragedy of the groundwater commons in Lijiang, China. *Water*, *12*(11). https://doi.org/10.3390/w12113131

Chapter 3: Going with the Flow: Adapting the Institutional Analysis and Development Framework for local water management[9]

0. Abstract

Securing access to water is not only a question of availability but equally a matter of good management. Water management systems are especially difficult to analyze and improve, because of their complexity. Our study adapts the Institutional Analysis and Development (IAD) framework, developed to understand the ways in which complex institutional systems operate, towards local water systems. The adapted framework is tested with two Chilean case studies. With the new framework, a way of unwrapping complex water systems is provided, so that they can be explored, analyzed and improved without oversimplifying nor limiting their potential.

1. Introduction

As a result of population growth and greater world economic development, pressure on water resources has been increasing, generating larger imbalance between supply and demand. Faced with this scenario, the need to improve water governance has been pinpointed as a critical measure for economic growth, social inclusiveness and environmental sustainability (OECD, 2018).

Most water administration systems worldwide involve public institutions, in charge of the planning, initial allocation of the resource, information provision and system surveillance, among other tasks (OECD, 2011, 2012). They also involve a local institution with various levels of public-private coordination (OECD, 2011, 2012). Here, self-governed systems where the community creates its own rules and norms, have been argued to achieve better results and adjust to the community's needs (Ostrom, 1990, 2015a; Poteete, Janssen and Ostrom, 2010). This type of structure with various decision centers, each having limited and autonomous decisions, all operating under delimited set of rules is typical of common natural resources and has been called a social-ecological system (Martínez-Fernández, Banos-González and Esteve-Selma, 2020). These systems are usually characterized by a multiplicity of institutions participating simultaneously, connecting the human and the natural world, in a rather complex and messy structure (Berkes, Colding and Folke, 2002; Alessa, Kliskey and Altaweel, 2009; Gain *et al.*, 2021).

Usually, the success and failure of collective self-management water systems is analyzed using Ostrom's eight design principles (Ostrom, 2015b; Baggio *et al.*, 2016). However, several studies have shown the limitation of this method regarding its social attributes (Choe and Yun, 2017; Zhang, 2018), and its limits to analyze macro-levels and larger social systems (Singleton, 2017).

The Institutional Analysis and Development (IAD) framework was conceived to understand messy institutional systems (Kiser and Ostrom, 1982; Ostrom, 2009b; McGinnis, 2011a). The

[9] Article adapted from a version submitted to the Water Journal.

framework intends to understand the ways in which communities operate and change over time while governing their common resources (McGinnis, 2011a). The framework has been increasingly significant for understanding and improving social-ecological systems worldwide. However, it has not been adapted specifically towards water systems and their unique specificities. Here, relevant aspects regarding their behavior dealing with a common good as well as specificities related to their institutional complexity, are fundamental for the characterization and are not considered in the original framework. The question that arises then is if the IAD framework can be adjusted to characterize water systems, their complexities and identify potential improvements, while tackling Ostrom's design principles critics.

The Chilean system is a of interest because of its high climatic and hydrological diversity, a specific water system was developed where government assigns robust water rights, according to how much water is available on each water basin. To manage and distribute this water rights system, private associations formed by water right's holders are organized. In general terms, the system has had positive results, but still faces challenges that need to be solved.

Thus, the aim of this paper is to study and analyze two Chilean local water systems that have embarked in some form of local collective water management. Both have different public-private structures, allowing us to explore how local water collective action is sustained under different scenarios and challenges. Through this study, besides showing the Chilean system and how local associations distribute their water, it was possible to identify the advantages and deficiencies of the case studies decision-making dynamics in water governance towards fulfilling a sustainable local water management.

The structure of the chapter starts by presenting the original IAD framework in section two. The details of the framework and components are presented in sector three. Afterwards, a description of the validation method and results regarding the analysis of the case studies is exhibited. The article closes with a section of discussions and presents the lessons learnt from the adapted framework.

2. The Chilean Water system and its particularities

Chile is 4,329 km. long, which turns it into the longest country in the world, and thus it encounters high hydroclimatic diversity, along with varying needs and challenges. For example, with an average water runoff of 53,000m3/person/year, a value considered high in terms of the world's average of 6,600 m3, there are areas in the north characterized by constant droughts where it rains less than 8mm a year (Donoso et al. 2015).

Regarding the groundwater resources, urban, industrial and agricultural growth have led to a high extraction of groundwater, and increases in the depth of wells, with overexploitation of water and its consequent high energy requirements (DIRECOM, 2018). A diagnosis carried out by the World Bank, estimated that the average annual recharge of the aquifers from the Metropolitan Region to the north is approximately 55m3/s, while the effective use of groundwater reaches, on average, 88m3/s (World Bank, 2011). Therefore, in most of the northern regions of the country, there is an unsustainable use of groundwater.

Studies on the possible impacts of climate change show that there is high probability that rainfall will decrease in most of the Country (20-30% reduction), together with a temperature increase (Donoso and Vicuña, 2019). Thus, a reduction in the area covered by glaciers is expected, with an added pressure on the snow-based hydrological regimes and a reduction of groundwater recharge.

Consistent with the above, since the beginning of the 2010s, Chile has been experiencing a situation of unprecedented drought. The conjunction of several years in a row with extremely low rainfall has characterized it as a "mega-drought" (CR2, 2019). Studies conclude that a quarter of the

phenomenon would be associated with the impact of global climate change and the rest with historical climate variability. In addition, the projections made from global climate models warn that, although droughts with these characteristics had a return period of 100 years in the past, in the new climate conditions they would present return periods of 20 years.

The Chilean economy is mainly concentrated on exports based on non-renewable natural resources (mining) and renewable (agriculture, aquaculture, fishing and forest plantations), which depend heavily on water resources. Therefore, the set of goods whose production and competitiveness in the markets that depend on adequate water management is extremely relevant for the country's economy. They reach a value of USD 58,000 million, which represented 83% of national exports in 2019 (Banco Central de Chile, 2021)

2.1. Chilean Water System

The Chilean Water System is considered to have a dual structure. On the one hand, the Government grants Water Rights according to how much water there is available in each basin. On the other hand, users, organized in Water Users Associations, are in charge of the management and distribution of these Rights. The system is surrounded by a highly fragmented institutional framework, complemented by ordinary courts to deal with conflict resolution.

2.1.1. Water Rights

Chile's water legislation is mainly established in the Water Code of 1981. This regulation had the purpose of incorporating market criteria in the reallocation of water (Fuster, 2013). For this reason, a fundamental aspect was to guarantee the legal certainty of the ownership of the water right to be traded, developing strong Water Rights.

Thus, the Water Code established that to use water from natural sources it is necessary to be a holder of a Water Right -except for the use of underground flows that are destined for domestic use[10]. In all other possible cases, users require a Water Right, which must be requested from the General Water Directorate (DGA) under the Ministry of Public Works (MOP).

The last Water Code reform of 2022 limited this aspect, and new water rights are given in the form of 30-year concessions. Previous water rights cannot expire, which gives great strength to its owner. In addition, they can be sold and transferred, rented, inherited, and use as mortgage, presenting the same protection characteristics as housing property rights or any other asset (Peña, 2004).

The recent reform also established priority of use, benefiting domestic or subsistence uses, together with ecosystem preservation on top of other uses, such as industrial or agriculture. This contradicts the earlier principle that suggested that by subjecting each user to compete for the resource, the market would re-assign the water rights towards the most efficient use. Water rights are defined by the following characteristics:

- A volume per unit of time
- Surface or Groundwater
- Non-Consumptive or Consumptive, depending on whether the water is returned to the stream (for example, used for hydroelectric purposes), or not.
- Continuous, Discontinuous or Alternating mode refers to weather the water is used all

[10] The other exception for the request of a Water Right, is for using water from a source or water canal that are born and die within the property of user.

year round, only during the farming season, or, through specific shifts.

- Permanent or Contingent (Eventual), depending on whether the right can be used all year round, or just when there are surpluses.

The DGA is obliged to deliver water rights to whoever requests it, provided that it is available[11]. Once a water source is declared depleted, to obtain water from that supply source, the reallocation of existing water rights is required, through water markets. This implies that it is expected that rights will be mobilized towards those uses of greater economic benefit. Water transactions have indeed developed, with more frequency during relative dry years (Donoso, Montero and Vicuña, 2001; Donoso *et al.*, 2010; Donoso, 2018a). Studies conclude that water rights markets have allowed for the expansion of mining, agriculture, and growing cities without the need to invest in alternative sources such as major water infrastructures or desalinization (Alevy, Cristi and Melo, 2010; Hearne and Donoso, 2014; Hearne, 2018). However, many transactions have been for relatively small amounts of water and for low transactions amounts. This implies that transactions costs have often not been prohibitive (Hearne, 2018). However, prices have been highly variable, with more experienced buyers and sellers negotiating favorable prices (Donoso, 2018a). This is mainly due to the lack of an efficient price revealing mechanism.

2.1.2. Water User's Associations

Water is managed by water users themselves through water users' associations. These organizations are formed solely by water right's holders and are in charge of distributing the resource in accordance with the water rights that each one has. These are established within each water basin and can either be: i) Water Communities or ii) River Canal Associations, in the case of waters that are distributed through artificial cannals; and iii) Vigilance Boards (JV) in the case of natural rivers or other natural source and iv) Groundwater Communities, for managing water extraction of a groundwater aquifer (Peña *et al.*, 2011).

If established, each association must form a board of directors that will be responsible for enforcing the law and making decisions regarding water management. The powers of the State to influence the operation of the water users' associations are limited. Thus, it does not participate in decisions about how water is managed or in water transactions carried out between users and can only act in cases of complaints about financial management or water distribution problems that do not respect established rights.

This management system is organized in river sections and not at the basin level. Each water users' association manages water from its natural or artificial source, independently of the other associations in the basin. This generates a situation of competition and not integration between associations. However, in those areas of the country characterized by water scarcity, and even more so, when irrigation water uses have significant economic productivity, user organizations have been established and operated "reasonably well" (Cristi, et al., 2000; Brown, 2004). They have assumed a more comprehensive role in water management in hydrographic basins.

Water users' associations do not incorporate uses that do not have water rights, such as ecological (maintenance of ecosystems), environmental (recharge of aquifers, transport of materials, landscape, or others) or non-traditional (informal tourism, ancestral, cultural, to name a few). Also, in a large part of the country, water rights are characterized by not being regularized, that is, many water

[11] That is, that this request does not affect the rights of third parties, and that the body of water where the right is requested is not legally exhausted.

users have not registered their right in the Real Estate Registrar (Rivera, 2013). This happens either due to ignorance, due to the cost that this means, or due to other factors, such as remoteness to populated centers, legal situations such as unresolved inheritances, or due to non-existent documentation (ancestral uses). These elements imply that, in most of the basins, water users association distributes the water among those who have been their historical users, some of them with regularized formal rights and others without regularization. The recent reform aims to address this information gap by imposing a deadline for registering water use rights until April 6, 2025. Rights not registered by this date will be deemed expired.

2.2. Institutional framework

Water management institutional system in Chile is broad and complex and comprises very diverse organisms. Multiple institutions from the public administration must complement the job that private organizations in the form of water user associations do. The State is responsible for and promotes the legal framework for its administration, it maintains functions of promotion and supervision of water users associations and, through different public institutions, fulfills a wide range of functions regarding the resource.

In a World Bank study, 43 institutional actors were identified that are involved in the management of the water resources (World Bank, 2013). Public and private actors in the form of agencies, management units and stakeholders composed the system. In the center of them all, the General Directorate of Water or DGA (from Dirección General de Aguas) is located.

The system is dependent on the judicial branch to resolve multiple procedures and conflicts. Even though water users associations are a first step in water conflict resolutions, the Judicial Power, through the Courts of Justice, is in charge of resolving conflicts that were not resolved in this first private instance. The Legislative Power is also involved since it constitutes the channel for discussing the modifications or regulations that the State promotes in the system. This generates a highly fragmented system that requires significant organization and coordination.

2.3. History of the current water system

In 1981, Chile was under a totalitarian military regime that had been adopting, for almost a decade, a series of policies that sought to regulate the agricultural sector in accordance with the new ideological and economic model of free markets and strong private property rights. These policies included strengthening the agricultural land market and reducing the role of the State in the production and marketing of this productive activity (Budds, 2004; 2010).

Until that moment, waters were governed by the 1969 Water Code, which attributed to the State the administration and management of water in a centralized manner, a condition that was incompatible with the foundations of the new economic model. This situation forced the development of a profound transformation that made water management compatible with the new agricultural policies.

This reform was entrusted to neoliberal economist advisers to the military government known as “Chicago Boys” for their professional training at the University of Chicago, which was recognized for its favorable position on the free market (Bauer, 1998). These economists argued that water needed greater protection as private property and that a system based on the free market would promote the economic efficiency of its use, as well as its conservation, by encouraging owners to see

this resource as an economic good. In this way, the 1981 Water Code was created, in a political context that prevented the discussion of interested parties in the process prior to the enactment of the law, resulting in legislation recognized as the most liberal in the world (Bauer, 2004b; Baillat, 2010).

The result was a system where the government's ability to regulate the country's water resources was profoundly reduced in favor of a purely economic approach (Andreen, 2011).

In 2019, after a period of multiple social events and disputes, the political and social discussion for a new Constitution has been fostered. Said tensions and social conflict have, among several of their expressions and reasons, the demand for access to water, equitable distribution among its users, and consideration of the environment.

2.4. Challenges of the Water System

Regarding challenges of the system itself, several aspects regarding water rights definition and the formation of associations remain, that are reviewed ahead. A great pending challenge is the existence of a significant number of historic uses and old water rights, that are not registered. Even though some of them are considered in the distribution made by water users' associations, they are not considered in public registries, and cannot be protected (or managed).

Also, there are issues regarding return flows. The problem arises given that the water rights do not include specifications of type of use. Thus, their owners can increase their real water consumption, for example, from an agricultural towards an industrial use (that requires water all year long), and therefore reduce the return flows on which others can depend. This situation is worse because of the issue with over-granting of water rights. Even though users have to distribute the water available, once the water income decreases, the overallocation of rights has left no room for environmental uses and has caused over-extraction of groundwater aquifers.

Multiple basins have not succeeded in organizing water users' associations, also, putting pressure on the system. Regarding surface water, in central Chile nearly 37% are not formally organized (Fuster, 2019). Regarding groundwater, only 17 of the mandatory 159 aquifers facing scarcity have been organized (DGA, 2021). Also, of those that are organized, not all users participate (especially small farmers or vulnerable users), and there is a general lack of information and funding.

In relation to the aspects that the system doesn't solve, there are still challenges to incorporate the protection of water for human consumption and the protection of water requirements for ecosystems and associated services. This is the system's largest criticism, not including social nor environmental concerns, that the water markets leave aside (Bauer, 2004, 2010a; Fuster *et al.*, 2010; Fuster, 2013).

2.5. Case studies analyzed

To analyze water resources' self-management in Chile, two cases have been studied. They have both embarked in local collective water management, with different structures and results.

The Copiapó basin is an interesting case study since it represents groundwater conflicted basins. It is located in a highly productive area in northern Chile, with a situation of extreme over-extraction and serious water conflicts. Also, it presents high heterogeneity of the actors involved, including representatives of different economic activities, a context of high government bureaucracy and trust issues. All these elements are commonly found in other intra-national water basins that are under water scarcity. In Copiapó, the first groundwater self-managed user's community of the country was created in the year 2004, and, over time, other four communities followed. Currently, the entire

groundwater aquifer of the basin is collectively managed by these communities.

Regarding surface waters, the Aconcagua basin is an interesting positive experience. It crosses from east to west the Valparaíso Region, in north central Chile. Its main economic activities are agriculture, mining and industry. They compete for water for urban uses, supplying Valparaíso and other important cities of the region; rural communities; and with environmental uses, to fulfill the water needs of areas under official protection and biodiversity conservation. They have also been subject to conflict, regarding distributing of water among different uses, water contamination, disagreements regarding water infrastructure, among others. The Aconcagua Plan emerged under a Water Emergency situation declared in September 2018. It included the formation of a technical committee between representatives of the four surface self-managed Vigilance Committees of the river, and the Public Works Ministry (Ministerio de Obras Públicas, MOP). They have been continuously meeting, organizing and formulating short, medium and long-term actions for the basin.

3. Methodology: the adapted IAD Framework towards water systems

To analyze these cases, an adapted version of the Institutional Analysis and Development (IAD) Framework has been used. The framework condenses multiple efforts to understand the ways in which institutions operate and change over time. It specifically targets communities without state intervention (McGinnis, 2011a). Examples of its use span from the analysis of office microwave sharing to indigenous communities distributing the forest resources.

It was designed as a tool to simplify the analytical task confronting research trying to understand institutions in their full complexity (Anderies, Janssen and Ostrom, 2004; Ostrom, 2009b, 2011; McGinnis, 2011a). For this, the framework assigns all relevant factors and variables of the system into categories, and then locates these categories in a structure of logical relationships (Ostrom, 2009b)

The framework involves the analysis of Exogenous Variables that change the analysis of the case study as they vary; the Action Situation, where the decision-making process takes place; the Interactions and Outcomes of this decision-making process; and specific Evaluation Criteria to provide feedback for adaptive learning. The Exogenous Variables, also known as inputs, include contextual factors such as attributes of the community, nature of the good, also known as biophysical conditions, and rules, that encompass the setting of the Action Situation. The Action Situation, at the IAD's core, is a social space where the actors interact and solve the commons problem (Ostrom, 2007; Ostrom, Janssen and Anderies, 2007). Here, the framework uses elements of Game Theory, since the "Action Situation" is where individuals/participants in specific positions take actions, in light of the information they possess and the payoffs they face, regarding different outcomes or results. Thus, it is where the decision-making process takes place. Around the Action Situation, different components and their relations are analyzed.

The strength of the IAD framework is to recognize and acknowledge the complexity of the world, with a systematic theoretical tool that copes with this complexity (Rudd, 2004). It has been considered a well suited framework to address the challenges of analyzing decentralized natural resource governance systems and how they evolve (Clement, 2010). Finally, the IAD framework is a combination of methods to study complex systems, with Common-Pool Resources at the center, thus providing an advantage when studying communal resource management, over other methods.

The specific form of the framework has varied over time. Initially developed by Kiser and Ostrom (1982), it was then studied and applied in multiple institutional systems (see e.g. (Ostrom, 1986, 1990, 1998, 1999, 2007, 2009a; Ostrom, Gardner and Walker, 1994; Poteete, Janssen and Ostrom, 2010; Ostrom *et al.*, 2011)).

Regarding water, Ebenhöh (Ebenhöh, 2007) used the framework to generate an agent-based

model for water management regimes, and Zhang (Zhang, 2020) has used a combined method, including components of the Social-Ecological Systems framework, to analyze groundwater management in Lijiang, China. Some elements have also been used in large scale social-ecological systems, such as the Great Barrier Reef in Australia and the Rhine River in western Europe (Fleischman *et al.*, 2014). In all the above, the convenience of using the framework to analyze water systems became clear.

However, these studies all lack the analysis of specific attributes that characterize water systems. For example, the particular nature of the good and its characterization as a common good, such as difficulties to access, monitor, distribute and store water, together with the existence of high social, environmental and productive conflicts, coming from its multiple and valuable uses. Thus, previous analysis leaves out these aspects that are determinant for the water system's sustainability and good governance. At the same time, no previous research has proposed significant changes to the framework to capture these specificities and complexities.

Thus, to analyze more complex systems, such as those involving water, we developed an adapted IAD framework. Adding water-specific attributes and dynamics to the analysis in order to reveal and provide advantages when studying these systems. The latter can be especially helpful to identify problems and barriers limiting sustainable management of bounded water social-ecological systems and detect elements to achieve water security at a basin level.

3.1. Adapted IAD framework

The IAD framework defines an arrangement of action situations that can be applied to different political levels, from a nation-wide arrangement to a local process of decision making. The present research focuses the analysis on local water communities. Here, the action situations include "operational choice" situations, referred to practical and periodical decisions taken by authorized individuals as a consequence of collective choice processes. In water matters, these are the actions taken by community managers, water watchmen, and other positions hired by the local community to distribute water resources. Also, in water we include "collective choice" situations, where the analysis considers the processes through which local community decisions are made, by those actors authorized to participate in collective decisions. These situations include the variety of alternatives that members of a water community have, when setting their norms and regulations, as well as their duties and obligations towards the community. Here, the organization and decision-making process of the irrigation district, vigilance committees, groundwater or surface water communities or any other water association can be studied. Their decisions are valid and recognized by nation or statewide regulations and norms, which is also called "constitutional choice processes", and constitutes the third action situation arrangement. In the present study, we limit the scope of the analysis to the operational and collective choice situation and how they change over time.

The IAD Framework has its origins in a general system approach to policy processes, where inputs are processed by policymakers into outputs that are later evaluated. For water systems, the components that should be analyzed have been adapted from McGinnis (2011a) to answer for local water social-ecological systems and their complexity.

Several aspects could be accounted for quantitatively. However, since there are a large number of variables involved and there are significant differences among water systems, multiple studies have reflected on the preferability to carry out these kinds of analysis qualitatively, or using mixed methods (Anderies, Janssen and Ostrom, 2004; Ostrom, 2009b). Through qualitative analysis the complexity of the local social-ecological systems can be accounted for and not over-simplified. This version of the IAD framework, adapted to adjust to water social-ecological systems and their

complexity, was then tested on Chilean case studies, where it was analyzed and validated.

4. Results

As mentioned, the validation was carried out in two Chilean basins, representing different institutional schemes and situational issues. These were selected since they represent multiple problems a water social-ecological system faces, namely: scarcity issues, summer floods, distributing water between multiple users, conflicts between users, groundwater measurement and enforcement, among others. Both cases have applied some form of local collective water management, with different structures, that allowed us to test the framework under different institutional schemes.

4.1. Groundwater communities in the Copiapó basin

The Copiapó basin represents a highly conflicted groundwater basin, located in a productive area in northern Chile, with a situation of extreme over-extraction (Rinaudo and Donoso, 2019). Here, groundwork to directly assess the formation and empower groundwater communities was conducted between the year 2012 and 2015. The work involved different instances of participation with local water users, including the development of their written operational rules. For any missing information and to verify the whole case study, the manager was contacted and interviewed.

Overall, when applying the adapted IAD framework to the Copiapó case, what can be seen is that on several occasions, users have decided to go beyond the norm, adapting their rules and mechanisms towards their needs. This can be seen when developing a monitoring plan with a public agency's agreement to partially fund it (CNR, 2019). Also, when establishing alliances with other groundwater communities.

The private alliance between users has worked, since their gatherings have been periodical, with a valid user's participation and the associations have remained active over the years. This, even though there are issues of trust, social justice and transparency still pending. The alliance between groundwater communities has been harder to sustain since there are no legal options for establishing supra-organizations. The communities have creatively solved this issue, by establishing the same set of rules and naming the same manager and technical team to perform periodical operations. This led to the joint management of three upstream communities. These communities also had similar users -for example, a majority of them are farmers-, and a smaller number of users than downstream communities. The two other downstream communities, even though they have different boards and managers, continuously coordinate. A creative solution towards the river's full alliance was done by the downstream groundwater community, since they bought surface water rights to become part of the surface Vigilance Committee, the community that controls and operates the upstream water dam, that affects groundwater aquifers significantly. Once again, this was a solution taken by groundwater users not adapting the established norm but going beyond it.

The major issues for coordination are related to the high heterogeneity encountered, regarding the different purposes and situation of users involved, the technology used and the information they possess. The continuity of the community can be attributed to the fact that leaders are aware of the situation and come from different backgrounds, a common understanding of local priorities, that they have official rules in place, and due to the fact that the formation of the community was conducted by an external and neutral party.

The community faces the challenge of managing a depleted aquifer, with high variability regarding monitoring standards, on top of the fact that it distributes groundwater, a resource difficult

to monitor. The communities developed monitoring plans to gradually establish monitoring devices in all wells and created an alliance with a public agency to partially fund this monitoring system. Also, they developed a set of official rules, written and known by everybody. Here, they specified all duties and obligations of users, as well as the fines for non-compliance. The communities also focused their efforts on bringing clarity to all granted water rights in the basin, and the registry of users is continuously being updated.

With regards to the action situation, even though the users are the ones that make all decisions, they have developed alliances with the regional offices of specific public agencies when needed. Also, they have hired staff to support with the operational aspects, and generally hire technical advisers for particular topics. They coordinate between each other for voting and regular decisions, and these are seen as valid processes, inside the community and out. Small communities have raised complaints regarding not-being considered, even though mechanisms and special dispositions have been developed for their support.

As lessons learned from this case study, the relevance of developing transparent accounting methods, both for the monitoring of water flows and individual extractions, as well as for the decisions made in meetings can be identified. This also applies towards formal conflict resolution processes. The need to formally support creative solutions taken by local communities should also be derived as a lesson from this case study. The latter since the creative solutions that the local communities come up for their specific situation, could perfectly fit in other scenarios. As an example, following the development of their own monitoring plan by Copiapó's groundwater communities, the State not only endorsed but also sought to promote this initiative in other regions. Subsequently, a policy was formulated to install well monitoring systems in other valleys as well. Thus, national institutional schemes should adapt towards allowing creative solutions and efforts done by local communities and not the other way around. Finally, special attention should be placed on the funding scheme, from the community's origin, regarding the neutrality of the organizing agent, up to their operations and monitoring funding. Even though public support is needed, public agencies should have limited power, to allow the local organization and decision-making process.

In Copiapó, the adapted framework allowed to explicitly analyze a monitoring plan partially funded by a public agency. A positive dynamic between the monitoring system developed -aspect analyzed under the Nature of the Good component- and the operational rules, from the Rules component was identified. Both involve different participants and their decision-making process, resulting in a better Management Capacity (Interactions tier) and Social Performance (Outcomes). Altogether they are generating an accounting process and providing legitimacy to the whole system (Evaluation Criteria). In this case study, the different attributes associated to the community were also explored and derived regarding the number of users required for this agreement to happen, and how the leaders where crucial in this achievement[12].

4.2. Surface vigilance committee alliance at the Aconcagua basin

The second case study refers to the Aconcagua basin, where activities such as agriculture, mining and industry compete for water with urban uses, supplying Valparaíso and other important cities of the area, rural communities and environmental uses. They have also been subject to conflict regarding water distribution among different uses, water pollution, and disagreements regarding water infrastructure, among others. The information to support this case study comes from the analysis of the almost 90 community meeting minutes, complemented with an interview to a local vigilance

[12] The full analysis of the two cases using the adapted framework is available in the Anex.

committee manager.

Due to the extraordinary situation of water scarcity in 2018, representatives of the Surveillance Boards of the four sections of the Aconcagua River signed an agreement to redistribute water. In 2019, due to the prolonged drought, a new agreement was made that included the formation of an Executive Committee to monitor and ensure the execution of the agreement, propose modifications if necessary and manage conflicts for an adequate solution (DGA, 2019). The Ministry of Public Works identified three work groups for water management in the development of the "Aconcagua Plan" (DGA, 2020 Plan). The Aconcagua Roundtable, made up of the surveillance boards of each of the sections of the river and the public sector, was created to monitor and ensure the execution of the agreement, manage conflicts and propose measures for compliance with the terms of the Protocol. Another panel was created to manage the drought emergency and a third panel was established to work on improving water management practices in the region. Below is a review of the operation of this local surface water management system.

From an economic point of view, the Aconcagua River basin is important for agricultural activity, especially in the production of fruits and vegetables, producing approximately 41% of the country's total avocados, 29.7% of grapes and 30% peaches (GORE, 2020). The drought has had a negative impact on this activity, reducing the amount of water available for irrigation and affecting farmers' production and income. Also, from a political point of view, water management in the Aconcagua River basin has been the subject of controversy, with judicial resolutions from the public authority, the DGA, in the years 1878 and 1916, setting five hydrological sections (CNR, 2016a), in such a way that there should be a monitoring board for each of them. This has been criticized for "dividing" the resource and laying the foundations for future conflicts (CNR, 2016; DGA, 2020b).

Representatives of three main sections were present at each meeting of the Aconcagua Roundtable, occasionally accompanied by the drinking water and sanitation company, the main user of the fourth section, and by the XXX, representative of the fifth and final section (DGA, 2020). Likewise, the presence of the public sector, through the DGA, was permanent throughout the meetings, supervising the compliance of the agreement, in addition to contributing to the role of mediator (DGA, 2020). Thus, within the meetings, the DGA itself commits actions, resources, and even acts as a mediator with other key actors. An example of this are the actions of the DGA on monitoring issues, committing to expedite the calibration of monitoring stations, as well as supervision on that users carry out distribution agreements (Meetings 1-3). In addition, the meetings are attended by other public actors (SEREMI Public Works, SEREMI Agriculture, DOH, CNR, among others) and private actors (ESVAL, APR, etc.) depending on the topics discussed in each session (DGA, 2020). However, the Roundtable does not include other private entities such as mining companies or other producer associations, nor does it include members of civil society (indigenous communities, environmental organizations, tourism), so it has been indicated that this body would not be part of a process of effective integrated participation and collaboration (DGA, 2020).

Regarding interactions, in the meetings held, an extension of requests to other actors and sectors involved is also carried out. One case worth mentioning is that during one of the meetings, a letter was written addressed to the Minister of Public Works and the Minister of Agriculture, inviting them to be part of the Board (Minutes 2 and 3). Sometimes, some hierarchy between relevant topics can be highlighted, and the Roundtable's interests have been placed above local political decisions. An example of this is that the users were against decisions made by the municipality, arguing that the mayor did not have the legal power to stop the operation of the wells and they asked the MOP to use its authority to start them up again (Meeting 15).

Regarding outputs, from the initial meetings, it is mentioned that the spirit of the agreement is to be able to deliver water to those who do not have it (Meeting 2). Also, in a later meeting, it is

stated that the main ideas that should be promoted are that (Meeting 15):

- Water for human consumption is guaranteed,
- Water is available to all farmers, whether large, medium or small,
- The committee's purpose is also to address actions that will address drought in the medium and long term.

The decision-making process is fast and flexible. For example, in a meeting held in August, prior to the beginning of the irrigation season, comments on the complicated water situation and the poor projections were made for the upcoming summer. The attendees agree that a new distribution agreement must be placed early this year, as well as push forward the operation of supplementary wells (Meeting 32). The agreement was already drawn up in the following session (Meeting 33) and practically signed in the subsequent one (Meeting 34).

Also, in a period of drought, a complete cut-off of water use was carried out in upstream sections, with the aim of allowing the river to recover in downstream sections and to deliver water to those who were not receiving it. This agreement, although it is formal and very rigorous, has to the possibility to be modified and become more lax, always with the approval and consensus of the rest. An example of this is the rule of maintaining the water cutoff for 36 hours, despite the fact that due to the flow figures, it was only appropriate to open them for 24 hours, since the value was very close to the cutoff figure (Meeting 9). Another solution taken quickly throughout the meetings was the initiative for the surveillance boards to be in charge of monitoring and cleaning the channels that lead to the river, from a battery of wells installed during the emergency (Meeting 13).

In each meeting, in addition to reviewing short-term issues, such as the river operation agreements for that week, medium and long-term issues are also reviewed. It is included as one more point in the minutes of the meeting and as the main objectives it promotes (Meeting 15, when they define the objectives to be communicated). An example of this is the review of major infrastructure works projects that involve the entire section of the river, and the establishment of monitoring systems (Meetings 1-14, DGA, 2019); strategy of holding meetings and leaflets and other strategies to inform the rest of the community about the meetings extensively (Meetings 3 and 6). Communication is also relevant, and for it, MOP proposed and promoted a Strategic Communication Plan, to maintain coordination and disseminate the same communication messages through the media, social networks and direct contact with all actors linked to the Aconcagua Plan (Meeting 24).

As an evaluation, there are statements that show that the alliance led to better coordination, improvements in distribution efficiency with the consequent greater availability of water, reduction of conflicts and developed long-term planning. For example, in a meeting, it is pointed out that the season has been better than the previous one in terms of water management, even though this season has brought less available water (Meeting 18). The attendees agree that the operation of the agreement and this committee is carried out in an environment of trust. In another gathering, it is stated that the main value of the agreement and water table formation was its own existence, since it has been a space to debate long-term issues, as well as the distribution of water on a voluntary and consensual basis (Meeting 14). The peace agreement is so relevant that it is interesting to note that the user representatives of each section even issue apologies, for statements made by members of their communities, that could affect harmony (Meeting 5).

Lessons learned from the Aconcagua case are specially interesting regarding the Action Situation, where all actors -users, public agencies, and water services agencies- have clear positions with respect to the decision-making process and do not interfere between them. The case shows the relevance of allowing flexible rules, as long as there are funded reasons, unanimity, transparency, monitoring of the measure and the possibility of complaint from those affected. The allegiance invested in gaining trustful data and information towards quantifying the outputs of different actions.

This is a key element that has led to reaching an unpresented agreement on water distribution which should be strengthened, or at least secured.

4.3. Lessons learned towards local self-managed water resources associations

Overall, applying the adapted IAD framework to the case studies allowed for an exploration and analysis of complex and varied water systems dynamics, and how they have evolved in time. This was done, even with the added complexity of involving groundwater particularities, in the case of Copiapó Basin, and involving public-private alliances, as in the case of Aconcagua Basin.

These results align with Ostrom's design principles regarding the need for an accountable process of monitoring the appropriation of users, the relevance of collective-choice arrangements and its formal recognition (Ostrom, 2015b; Cox, Arnold and Villamayor-Tomás, 2016). It also supports previous studies regarding groundwater communities and their need for self-adapted local rulings, as well as the need for coherence between public and private involvement (Taher *et al.*, 2012; Meinzen-Dick *et al.*, 2018; Molle, López-Gunn and Van Steenbergen, 2018). It aligns with studies done in the area by applying Ostrom's design principles in Copiapó (Rinaudo and Donoso, 2019; Blanco and Donoso, 2021) and in the characterization of water user's associations in Chile (Engler *et al.*, 2021). Therefore, the framework allowed for a coherent characterization and analysis of the case study, its multiple components and their linkages. It even goes one step further, by identifying how each of these parameters has evolved in time, providing for a dynamic picture, instead of a static one, used in previous studies.

Regarding the variables added, the results are consistent with studies that associate the community's size and members who know each other, with the capacity and management of socio-ecological systems (Agrawal and Goyal, 2001; Esteban and Ray, 2001; Poteete and Ostrom, 2004; Palerm-Viqueira, 2010). They are also coherent regarding the heterogeneity of its members and how it affects the development and sustainability of communities (Alesina and La Ferrara, 2000; Ito, 2012); the characterization and performance of leaders (Von Rueden *et al.*, 2014; Glowacki and von Rueden, 2015; Xu and Yao, 2015), the formation mechanism and what triggered their organization (Powell and Bundhoo, 2019); and the financial stability of the community (Brunner and Starkl, 2012). With the original framework, these specificities and their overall impact on the system's performance would have been omitted. By adding these elements, the study involves the analysis of all these as well as their linkages to the variables of the traditional IAD framework. Thus, it allows to better elucidate the complexity of the dynamics involved in these systems and support their positive results while trying to improve harmful habits.

All the elements incorporated were used in the analysis and enriched the results. However, the Evaluation Criteria was the tier where information was harder to obtain, and the interviews carried out were crucial for its completeness.

The adapted framework was also applied to analyze the alliances between communities occurring in both Copiapó and Aconcagua Basin. For example, in the Aconcagua Basin, the adapted framework allowed for a greater understanding of the process that allowed the communities to reach an agreement on important water investments that are desired in the Valley, such as major water dams, implementing groundwater recharge pools, and groundwater well monitoring systems. Each one of these agreements has been explored by studying the particularities and linkages between all elements mentioned above, and how the situation has changed over time. Thus, the framework allows for a multiplicity of analysis, with different scopes and for diverse purposes.

Therefore, by using the adapted framework, the study was improved with respect to previous works, since it integrates elements and their linkages that were previously analyzed separately. It

allowed for the identification of elements that are supporting each community's water management, and those that are hampering it. These methods are also similar to those used when adapting the IAD framework for similar contexts, such as in water conservation projects (Oñate-Valdivieso *et al.*, 2021) and in programs to deal with flood risks (Molenveld and van Buuren, 2019).

Combining both case studies, the analysis identified some key aspects for assuring successful local water systems. These include the development of conflict resolution mechanisms and coordination regimes, capacity to develop technological and innovative solutions, the information devices for water accountability used, and the existence of financial strategies for the sustainability of these associations. Once again, even though these elements were identified from the case studies and can be helpful when analyzing other contexts, each system has its own particularities, and these conclusions cannot be blindly extended to other water basins.

Most of the lessons identified would not have been recognized under the original IAD framework, since it lacked the water specificities that explained most of the dynamics and their results. This, especially regarding the community's characterization, the monitoring and accounting process and thanks to exploring collective and operational rulings separately.

5. Discussion

The adapted IAD framework allowed us to explore and analyze complex local groundwater management systems and how they vary over time in more detail, identifying the enabling factors and those that have hindered collective action. It proved able to disentangle the complexities of these specific social-ecological systems and allow for their understanding, for sorting out negative aspects and for identifying their positive dynamics.

Both case studies have developed different institutional solutions schemes to deal with their issues. They have embarked on different structures of local collective water management, going beyond official norms to fulfill their purposes. Furthermore, given the high institutional fragmentation, Chile offers a more complex case than that of similar countries. Hence, the analysis of these complex governance structures can be studied under our adapted framework. The framework captures their complexity, rather than limit it.

The adaptability of the framework towards different local organizations, water systems and overall water management structures was also validated. Thus, the framework is applicable to fully study and analyze local water communities elsewhere. This, due to the fact that both cases encompassed a variety of water problems typically found in other countries and regions as well. However, both cases come from the same Country, and thus, some similarities can be found. This study then constitutes a first attempt to test the adapted IAD framework, but further research is required.

For example, the framework was applied to the analysis of local water systems, and thus, proven at a local level. Nevertheless, the tool has the potential of explaining complex dynamics that occur with water management at higher levels as well. Since it has great adaptability capacity, its usefulness can also be explored under sub-national and national water systems. Furthermore, the case studies represent relatively medium size water basins, with areas of less than 20.000 km^2. In this context, it proved to be a helpful tool. Future research could encompass the application of this adapted framework towards transboundary basins, to analyze and test its applicability.

The overall purpose of this adapted framework is broad. On the one hand, its use helps to clearly identify miss-management situations regarding the interactions of local communities themselves and analyze processes that could be modified. It considers each case study and its evolution as unique, where all elements and how they have evolved are relevant for how the water system is

currently working, and they cannot be ignored or simplified. Thus, an improvement or solution detected for one water basin, could not be useful for other water contexts, that have been formed and developed under different parameters. Thus, while applying this framework in each water system, it allows for the development of unique solutions for each water context and specificities.

On the other hand, this tool is useful to capture the larger picture of the dynamics of a water socio-ecological system. It can be used to identify higher institutional failures, as well as resolve internal communities' conflicts. It does not, however, intend to serve as a panacea for managing water resources at a basin level. Instead, it is intended to be used for analyzing, evaluating or comparing situations on a case-by-case basis.

Altogether, the article shows that we can improve the understanding of local water system's complexity, than would have been reached without the adapted framework. It can only be achieved by considering where the failures come from and solving these dynamics, within their context. With this tool, cooperation can be facilitated, formation can be enhanced, and participation of users in different local water regimes can be promoted. Also, it can empower these local associations to work collectively. By reaching this milestone, despite all difficulties, these local communities can achieve an efficient, fair, and sustainable water management.

Therefore, the main lesson learnt is that the proposed adapted framework allows the understanding of a community's needs and supports them to successfully manage their local water systems. By improving our current water systems, empowering the development of efficient, sustainable, and socially validated institutions, this can be achieved. It requires to be done from the smallest local water association to upper sub-national and national contexts. Thus, altogether, this is a necessary first step towards achieving the desired sustainable water management, strong enough to adapt to future needs and changes.

6. References

Adler, R.A. *et al.* (2007) 'Water, mining, and waste: An historical and economic perspective on conflict management in South Africa', *The Economics of Peace and Security Journal*, 2(2). Available at: https://doi.org/10.15355/epsj.2.2.33.

Agrawal, A. and Goyal, S. (2001) 'Group size and collective action: Third-party monitoring in common-pool resources', *Comparative Political Studies* [Preprint]. Available at: https://doi.org/10.1177/0010414001034001003.

Alesina, A. and La Ferrara, E. (2000) 'Participation in heterogeneous communities', *Quarterly Journal of Economics*, 115(3), pp. 847–904. Available at: https://doi.org/10.1162/003355300554935.

Alessa, L., Kliskey, A. and Altaweel, M. (2009) 'Toward a typology for social-ecological systems', *Sustainability: Science, Practice, and Policy*, 5(1), pp. 31–41. Available at: https://doi.org/10.1080/15487733.2009.11908026.

Alevy, J.E., Cristi, O. and Melo, O. (2010) 'Right-to-choose auctions: A field study of water markets in the Limari Valley of Chile', *Agricultural and Resource Economics Review*, 39(2), pp. 213–226. Available at: https://doi.org/10.1017/S1068280500007255.

Anderies, J.M., Janssen, M.A. and Ostrom, E. (2004) 'A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective', *Ecology and Society*, 9(1). Available at: https://doi.org/10.5751/es-00610-090118.

Angelakis, A.N. *et al.* (2021) 'Water conflicts: From ancient to modern times and in the future', *Sustainability (Switzerland)*, 13(8). Available at: https://doi.org/10.3390/SU13084237.

Arévalo, G. (2013) 'Comunidades de aguas subterráneas: dificultades en su organización y ejercicio', *Actas de Derecho de Aguas*, (3), pp. 185–194. Available at: http://derechoadministrativoeconomico.uc.cl/images/stories/ADAG/ADAG3/14. comunidades de aguas.pdf (Accessed: 6 December 2018).

Arroyo, D.I. (2009) *Las Asociaciones de Usuarios de Agua en Chile durante el siglo XIX y primera mitad del siglo XX: 1800-1950*. Facultad de Derecho, Universidad de Chile.

Baggio, J.A. *et al.* (2016) 'Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles', *International Journal of the Commons*, 10(2), pp. 417–439. Available at: https://doi.org/10.18352/IJC.634/METRICS/.

Banco Central de Chile (2021) 'Base de Datos Estadísticos (BDE)'.

Bauer, C.J. (2004) 'Results of Chilean water markets: Empirical research since 1990', *Water Resources Research*, 40(9). Available at: https://doi.org/10.1029/2003WR002838.

Bauer, C.J. (2010a) *Siren song: Chilean water law as a model for international reform*, *Siren Song: Chilean Water Law as a Model for International Reform*. Available at: https://doi.org/10.4324/9781936331062.

Bauer, C.J. (2010b) *Siren song: Chilean water law as a model for international reform*, *Siren Song: Chilean Water Law as a Model for International Reform*. Routledge. Available at: https://doi.org/10.4324/9781936331062.

Bauer, C.J. (2015) 'Water conflicts and entrenched governance problems in chile's market model', *Water Alternatives* [Preprint].

Berkes, F., Colding, J. and Folke, C. (2002) *Navigating Social-Ecological Systems Building Resilience for Complexity and Change*. Cambridge: Cambridge university press. Available at: https://doi.org/https://doi.org/10.1017/CBO9780511541957.

Blanco, E. and Donoso, G. (2021) 'Drivers for collective groundwater management: The case of Copiapó, Chile', in S.H. Choi et al. (eds) *Global Water Security Issues (GWSI) 2020 Theme: The role of sound groundwater resources management and governance to achieve water security.* UNESCO, International Centre for Water Security and Sustainable Management , pp. 59–75.

Bravo, G. and Moor, T. De (2008) 'The commons in Europe: from past to future', *International Journal of the Commons*, 2(2). Available at: https://doi.org/10.18352/ijc.98.

Brunner, N. and Starkl, M. (2012) 'Financial and economic determinants of collective action: The case of wastewater management', *Environmental Impact Assessment Review* [Preprint]. Available at: https://doi.org/10.1016/j.eiar.2011.07.001.

del Campo García, M.E. and Sánchez Reinón, M. (2021) 'The Decade of Contentious Politics: The Rise of Social Movements Around Water in Post-transitional Chile', in B. Navarrete and V. Tricot (eds) *The Social Outburst and Political Representation in Chile*. Latin American Societies, Springer, pp. 151–172. Available at: https://doi.org/10.1007/978-3-030-70320-2_9.

Camus, P., Castillo, S. and Muñoz, E. (2019) 'Mecanismos de Apropiación, sistema de administración y resolución de conflictos por el uso de los sistemas de riego en una sociedad colonial', *Revista de Historia y Geografía Universidad Católica Silva Henriquez*, 24.

Carranza, D.M. *et al.* (2020) 'Socio-environmental conflicts: An underestimated threat to biodiversity conservation in Chile', *Environmental Science and Policy*, 110, pp. 46–59. Available at: https://doi.org/10.1016/J.ENVSCI.2020.04.006.

Castillo, S. (2014) *El río mapocho y sus riberas. Espacio público e intervención urbana en santiago de chile (1885-1918)*, *Ediciones Universidad Alberto Hurtado*. Available at: https://doi.org/10.4067/S0250-71612014000300014.

Choe, H. and Yun, S.-J. (2017) 'Commons in East Asia View project Social Movements in South Korea View project'. Available at: https://doi.org/10.21588/dns/2017.46.1.005.

Clement, F. (2010) 'Analysing decentralised natural resource governance: proposition for a "politicised" institutional analysis and development framework', *Policy Sciences*, 43, pp. 129–156.

Cox, M., Arnold, G. and Villamayor-Tomás, S. (2016) 'Design principles in commons science: A response to "Ostrom, Hardin and the commons" (Araral)', *Environmental Science and Policy*, 61, pp. 238–242. Available at: https://doi.org/10.1016/j.envsci.2016.03.020.

CR2 (2019) *Informe a la Nación: La megasequía en Chile La megasequía 2010-2019: Una lección para el futuro*, *Informe a la Nación*. Available at: http://www.cr2.cl/megasequia/.

DGA (2017) 'Actualización del Balance Hídrico Nacional', *Ministerio de Obras Públicas, Dirección General de Aguas, División de Estudios y Planificación, Santiago, Chile, Realizado por: Universidad de Chile y Pontificia Universidad Católica de Chile*, SIT N° 417, p. 378. Available at: https://snia.mop.gob.cl/sad/REH5796v1.pdf.

Dipierri, A.A. and Zikos, D. (2020) 'The role of common-pool resources' institutional robustness in a collective action dilemma under environmental variations', *Sustainability (Switzerland)*, 12(24), pp. 1–21. Available at: https://doi.org/10.3390/SU122410526.

DIRECOM (2018) *Comercio Exterior de Chile enero-septiembre 2018*.

Donoso, G. *et al.* (2010) 'Análisis del Mercado del Agua de Riego en Chile: Una Revisión Crítica a través del caso de la Región de Valparaíso'. Santiago, Chile: ODEPA, Ministerio de Agricultura de Chile.

Donoso, G. (2018a) 'Water Policy in Chile', in *Water Policy in Chile*. Available at: https://doi.org/10.1007/978-3-319-76702-4.

Donoso, G. (2018b) *Water Policy in Chile*. Springer.

Donoso, G., Montero, J.P. and Vicuña, S. (2001) 'Análisis de los mercados de derechos de aprovechamiento de agua en las cuencas del Maipo y el sistema Paloma en Chile: efectos de la variabilidad de la oferta hídrica y de los costos de transacción', *Revista Derecho Administrativo Económico*, 6, pp. 367–387.

Dougnac, A. (1994) 'Manual de historia del Derecho Indiano', in. México: Instituto de Investigaciones Jurídicas, UNAM.

Dougnac, A. and Barrientos, J. (1991) 'El Derecho de Aguas a través de la Jurisprudencia Chilena de los siglos XVII y XVIII', *Revista de Estudios Histórico-Jurídicos*, XIV, pp. 101–136. Available at: http://rehj.cl/index.php/rehj/article/viewFile/188/179 (Accessed: 6 December 2018).

Ebenhöh, E. (2007) 'Designing Agent-based Models of Water Management Regimes using the IAD Framework', *The Challenge of Self-Governance in Complex, Globalizing Economies* [Preprint].

Engler, A. *et al.* (2021) 'Governing Water Resource Allocation: Water User Association Characteristics and the Role of the State', *Water 2021, Vol. 13, Page 2436*, 13(17), p. 2436. Available at: https://doi.org/10.3390/W13172436.

Escenarios Hídricos 2030 (2018) *Radiografía del Agua: Brecha y Riesgo Hídrico en Chile.* Santiago, Chile.

Esteban, J. and Ray, D. (2001) 'Collective action and the group size paradox', *American Political Science Review* [Preprint]. Available at: https://doi.org/10.1017/S0003055401003124.

Fleischman, F.D. *et al.* (2014) 'Governing large-scale social-ecological systems: Lessons from five cases', *International Journal of the Commons*, 8(2), pp. 428–456. Available at: https://doi.org/10.18352/ijc.416.

Fuster, R. *et al.* (2010) 'Gestión Integrada de los recursos hídricos en Chile', *Biblioteca del Congreso Nacional, a través de fondos del Banco Interamericano del Desarrollo. Departamento de Ciencias Ambientales y Recursos Naturales Renovables de la Facultad de Ciencias Agronómicas de la Universidad de Chile*, p. 395.

Fuster, R. (2013) *El estado de la gestión integrada de los recursos hídricos en chile: estudio de casos en la cuenca del río Limarí. Tesis Doctoral*.

Gain, A.K. *et al.* (2021) 'Social-ecological system approaches for water resources management', *International Journal of Sustainable Development and World Ecology*, 28(1), pp. 109–124.

Ganoulis, J. (2022) 'Water Security in the Anthropocene: A Dialectical Water–Man Interaction Model', *Sustainability (Switzerland)*, 14(12). Available at: https://doi.org/10.3390/SU14126955.

Gleick, P.H. and Heberger, M. (2014) 'Water Conflict Chronology', in *The World's Water*. Available at: https://doi.org/10.5822/978-1-61091-483-3_11.

Gleick, P.H. and Shimabuku, M. (2023) 'Water-related conflicts: definitions, data, and trends from the water conflict chronology', *Environmental Research Letters*, 18(3). Available at: https://doi.org/10.1088/1748-9326/acbb8f.

Glowacki, L. and von Rueden, C. (2015) 'Leadership solves collective action problems in small-scale societies', *Philosophical Transactions of the Royal Society B: Biological Sciences* [Preprint]. Available at: https://doi.org/10.1098/rstb.2015.0010.

González, C. (2012) 'El abogado y el procurador de pobres: la representación de esclavos y esclavas a fines de la Colonia y principios de la República 1 The lawyer and solicitor of the poors: the representation of slaves in the late Colonial and Republican periods', *SudHistoria*, 5, pp. 81–98.

Grech-Madin, C. *et al.* (2018) 'Negotiating water across levels: A peace and conflict "Toolbox" for water diplomacy', *Journal of Hydrology*, 559. Available at: https://doi.org/10.1016/j.jhydrol.2018.02.008.

Hearne, R.R. (2018) 'Water Markets', in *Water Policy in Chile*, pp. 117–127. Available at: https://doi.org/10.1007/978-3-319-76702-4_8.

Hearne, R.R. and Donoso, G. (2014) 'Water markets in Chile: Are they meeting needs?', in *Easter K., Huang Q. (eds) Water Markets for the 21st Century. Global Issues in Water Policy, vol 11. Springer, Dordrecht*. Available at: https://doi.org/10.1007/978-94-017-9081-9_6.

Hernández, M. (2021) *65% de causas de Primer Tribunal Ambiental por temas agua*, *Actualidad Minera*. Available at: https://www.mch.cl/2021/03/23/65-de-causas-de-primer-tribunal-ambiental-han-estado-asociadas-a-problematicas-de-agua/# (Accessed: 11 October 2022).

Herrera, M. *et al.* (2019) 'Understanding water disputes in Chile with text and data mining tools', *Water International*, 44(3), pp. 302–320. Available at: https://doi.org/10.1080/02508060.2019.1599774.

Ito, J. (2012) 'Collective action for local commons management in rural Yunnan, China: Empirical evidence and hypotheses using evolutionary game theory', *Land Economics*, 88(1), pp. 181–200. Available at: https://doi.org/10.3368/le.88.1.181.

Kiser, L.L. and Ostrom, E. (1982) 'The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches', in *Strategies of Political Inquiry*, pp. 179–222.

Klare, M.T. (2001) 'Resource wars: The new landscape of global conflict', *Issues in Science and Technology*. Available at: https://doi.org/10.2307/3093336.

Klimes, M. *et al.* (2019) 'Water diplomacy: The intersect of science, policy and practice', *Journal of Hydrology*. Available at: https://doi.org/10.1016/j.jhydrol.2019.02.049.

Klubock, T.M. (2021) 'The early history of water wars in Chile: Rivers, ecological disaster and multinational mining companies', *Environment and History*, 27(3). Available at: https://doi.org/10.3197/096734019X15463432087008.

Larrain, S. and Poo, Pamela (2010) *Conflictos por el agua en Chile: Entre los derechos humanos y las reglas del mercado*, *Chile Sustentable*. Edited by S. Larraín and P Poo. Chile Sustentable.

Lira, P. and Maza, L. (1940) *Régimen legal de las aguas en Chile*. Santiago: Editorial Nascimento. Available at: https://snia.mop.gob.cl/repositoriodga/handle/20.500.13000/4121 (Accessed: 29 November 2022).

Lozano Parra, J., Pulido Fernández, M. and Garrido Velarde, J. (2021) 'The Availability of Water in Chile: A Regional View from a Geographical Perspective', in *Resources of Water*. Available at: https://doi.org/10.5772/intechopen.92169.

MacQuarrie, P.R., Viriyasakultorn, V. and Wolf, A.T. (2008) 'Promoting cooperation in the Mekong region through water conflict management, regional collaboration, and capacity building', *GMSARN International Journal*, 2.

Martín, L. and Justo, J.B. (2015) 'Análisis, prevención y resolución de conflictos por el agua en América Latina y el Caribe', *Serie Recursos Naturales y Desarrollo, CEPAL*, 171, p. 62.

Martínez-Fernández, J., Banos-González, I. and Esteve-Selma, M.A. (2020) 'An Integral Approach to address Socio-Ecological Systems Sustainability and their uncertainties', *Science of the Total Environment*, 762.

McGinnis, M.D. (2011a) 'An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework', *Policy Studies Journal* [Preprint]. Available at: https://doi.org/10.1111/j.1541-0072.2010.00401.x.

McGinnis, M.D. (2011b) 'Networks of Adjacent Action Situations in Polycentric Governance', *Policy Studies Journal*, 39(1), pp. 51–78. Available at: https://doi.org/10.1111/J.1541-0072.2010.00396.X.

Meinzen-Dick, R. (2007) 'Beyond panaceas in water institutions', *Proceedings of the National Academy of Sciences of the United States of America* [Preprint]. Available at: https://doi.org/10.1073/pnas.0702296104.

Meinzen-Dick, R. *et al.* (2018) 'Playing games to save water: Collective action games for groundwater management in Andhra Pradesh, India', *World Development*, 107, pp. 40–53. Available at: https://doi.org/10.1016/J.WORLDDEV.2018.02.006.

Molenveld, A. and van Buuren, A. (2019) 'Flood Risk and Resilience in the Netherlands: In Search of an Adaptive Governance Approach', *Water 2019, Vol. 11, Page 2563*, 11(12), p. 2563. Available at: https://doi.org/10.3390/W11122563.

Molle, F., López-Gunn, E. and Van Steenbergen, F. (2018) 'The local and national politics of groundwater overexploitation', *Water Alternatives*, 11(3), pp. 445–457.

De Moor, T. (2008) 'The silent revolution: A new perspective on the emergence of commons, guilds, and other forms of corporate collective action in Western Europe', *International Review of Social History*, 53(SUPPL. 16). Available at: https://doi.org/10.1017/S0020859008003660.

OECD (2011) *Water Governance in OECD Countries: A Multi-level Approach*, *OECD Studies on Water*. OECD Publishing. Available at: https://doi.org/10.1787/22245081.

OECD (2012) *Gobernabilidad del Agua en América Latina y el Caribe : Un enfoque multinivel*, *OECD Studies on Water*. Éditions OCDE.

OECD (2018) *Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices*, *OECD Studies on Water*. OECD Publishing, Paris. Available at: https://doi.org/https://doi.org/http://dx.doi.org/10.1787/9789264292659-en.

Oñate-Valdivieso, F. *et al.* (2021) 'Application of Ostrom's Institutional Analysis and Development Framework in River Water Conservation in Southern Ecuador. Case Study: The Zamora River', *Water 2021, Vol. 13, Page 3536*, 13(24), p. 3536. Available at: https://doi.org/10.3390/W13243536.

Ostrom, E. (1986) 'An agenda for the study of institutions', *Public Choice*, 48, pp. 3–25. Available at: https://doi.org/10.1007/BF00239556.

Ostrom, E. (1990) *The Evolution of Institutions for Collective Action*, *Political Economy of Institutions and Decisions*. Available at: https://doi.org/10.1017/CBO9780511807763.

Ostrom, E. (1998) 'A Behavioral Approach to the Rational Choice Theory of Collective Action', *The American Political Science Review*, 92(1), pp. 1–22.

Ostrom, E. (1999) 'Institutional Rational Choice: An Assessment of the Institutional Analysis and Development Framework', in *Theories of the Policy Process*, pp. 21–64.

Ostrom, E. (2007) 'A diagnostic approach for going beyond panaceas', *Proceedings of the National Academy of Sciences of the United States of America*, 104(39), pp. 15181–15187. Available at: https://doi.org/10.1073/pnas.0702288104.

Ostrom, E. (2009a) 'A general framework for analyzing sustainability of social-ecological systems', *Science*, 325(5939), pp. 419–422. Available at: https://doi.org/10.1126/science.1172133.

Ostrom, E. (2009b) *Understanding institutional diversity*, *Understanding Institutional Diversity*. Available at: https://doi.org/10.1093/oso/9780190672492.003.0008.

Ostrom, E. (2011) 'Background on the Institutional Analysis and', *Policy Studies Journal*, 39(1), pp. 7–27. Available at: https://doi.org/10.1111/j.1541-0072.2010.00394.x.

Ostrom, E. *et al.* (2011) *Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal*, *Improving Irrigation in Asia: Sustainable Performance of an Innovative Intervention in Nepal*. Available at: https://doi.org/10.4337/9780857938022.

Ostrom, E. (2015a) *Governing the commons*. Cambridge university press.

Ostrom, E. (2015b) *Governing the commons: The evolution of institutions for collective action*, *Governing the Commons: The Evolution of Institutions for Collective Action*. Available at: https://doi.org/10.1017/CBO9781316423936.

Ostrom, E., Gardner, R. and Walker, J. (1994) 'Rules, Games, and Common-Pool Resources', *Rules, Games, and Common-Pool Resources* [Preprint]. Ann Arbor: University of Michigan Press. Available at: https://doi.org/10.2307/2083092.

Ostrom, E., Janssen, M.A. and Anderies, J.M. (2007) 'Going beyond panaceas', *Proceedings of the National Academy of Sciences of the United States of America*, 104(37), pp. 15176–15178. Available at: https://doi.org/10.1073/pnas.0701886104.

Palerm-Viqueira, J. (2010) 'A comparative history, from the 16th to 20th centuries, of irrigation water management in Spain, Mexico, Chile, Mendoza (Argentina) and Peru', *Water Policy* [Preprint]. Available at: https://doi.org/10.2166/wp.2010.110.

Peña, H. *et al.* (2011) *Temas Prioritarios para una Política Nacional de Recursos Hídricos.* Comisión de Aguas, Instituto de Ingenieros de Chile.

Piwonka, G. (1999) *Las aguas de Santiago de Chile, 1541-1999*. Editorial Universitaria. Available at: https://books.google.com/books/about/Las_aguas_de_Santiago_de_Chile_1541_1999.html?id=CyqWILXMW2kC (Accessed: 29 November 2022).

Piwonka, G. (2000) 'Regulación cuántica y jurídica de las aguas en Chile: el debate en torno al regador chileno.', *Revista Derecho Administrativo Económico*, (6), pp. 433–450. Available at: http://redae.uc.cl/index.php/redae/article/view/120 (Accessed: 6 December 2018).

Popovici, R. *et al.* (2022) 'Maladaptive learning in Peru's integrated water resources management', *Environmental Science and Policy*, 127, pp. 209–217. Available at: https://doi.org/10.1016/J.ENVSCI.2021.09.012.

Poteete, A.R., Janssen, M.A. and Ostrom, E. (2010) *Working together: Collective action, the commons, and multiple methods in practice*, *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*.

Poteete, A.R. and Ostrom, E. (2004) 'Heterogeneity, group size and collective action: The role of institutions in forest management', *Development and Change* [Preprint]. Available at: https://doi.org/10.1111/j.1467-7660.2004.00360.x.

Powell, J. and Bundhoo, D. (2019) *Negotiating a way towards consilience in managing conflicts over commons: a multi-stakeholder dialogue Report*.

Puig, A. (1999) *El Fortalecimiento de las Organizaciones de Usuarios para una Gestión Integrada de los Recursos Hídricos*.

Rinaudo, J.D. and Donoso, G. (2019) 'State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile)', *International Journal of Water Resources Development*, 35(2), pp. 283–304. Available at: https://doi.org/10.1080/07900627.2017.1417116.

Rivera, D. (2013) *Usos y derechos consuetudinarios de aguas. Su reconocimiento, subsistencia y ajuste*. Thompson Reuters.

Rivera, D. *et al.* (2016) 'Legal disputes as a proxy for regional conflicts over water rights in Chile', *Journal of Hydrology* [Preprint]. Available at: https://doi.org/10.1016/j.jhydrol.2016.01.057.

Rivera, D. *et al.* (2020) 'Conflictividad judicial de aguas en Chile: caracterización y propuestas para mejorar su prevención y resolución', *Propuestas para Chile 2019. Centro de Políticas Públicas UC* [Preprint].

Rojas, C. (2014) 'Autogestión y Autorregulación regulada de las aguas: Organizaciones de usuario de aguas (OUA) y Juntas de Vigilancia de Ríos', *Ius et Praxis*, 20(1), pp. 123–162. Available at: https://doi.org/10.4067/s0718-00122014000100006.

Rudd, M.A. (2004) 'An Institutional Framework for Designing and Monitoring Ecosystem-Based Fisheries Management Policy Experiments', *Ecological Economics*, 48, pp. 109–124.

Von Rueden, C. *et al.* (2014) 'Leadership in an Egalitarian Society', *Human Nature* [Preprint]. Available at: https://doi.org/10.1007/s12110-014-9213-4.

Saravia Matus, S. *et al.* (2020) 'Desafíos hídricos en Chile y recomendaciones para el cumplimiento del ODS 6 en América Latina y el Caribe', *Serie Recursos Naturales y Desarrollo, CEPAL*, 198, p. 77. Available at: https://www.cepal.org/sites/default/files/publication/files/46503/S2000726_es.pdf.

Singleton, B.E. (2017) 'What's missing from Ostrom? Combining design principles with the theory of sociocultural viability', *https://doi.org/10.1080/09644016.2017.1364150*, 26(6), pp. 994–1014. Available at: https://doi.org/10.1080/09644016.2017.1364150.

Skarbek, D. (2020) 'Qualitative research methods for institutional analysis', *Journal of Institutional Economics*, 16(4). Available at: https://doi.org/10.1017/S174413741900078X.

Sridhar, S. (2008) 'Kashmir and Water: Conflict and Cooperation', *Swords and Ploughshares, winter 2007-8*, Winter 2007-2008. Available at: https://hdl.handle.net/2142/15473 (Accessed: 14 August 2023).

Stewart, D. (1970) *El Derecho de Aguas en Chile*. Santiago, Chile: Editorial Jurídica de Chile.

Taher, T. *et al.* (2012) 'Local groundwater governance in Yemen: building on traditions and enabling communities to craft new rules', *Hydrogeology Journal 2012 20:6*, 20(6), pp. 1177–1188. Available at: https://doi.org/10.1007/S10040-012-0863-1.

Vergara, A. (2017) 'Las aguas como bien público (no estatal) y lo privado en el derecho chileno: evolución legislativa y su proyecto de reforma', *Revista Derecho Administrativo Económico*, (8), pp. 63–79. Available at: http://redae.uc.cl/index.php/redae/article/view/312 (Accessed: 6 December 2018).

Villamayor-Tomas, S. *et al.* (2015) 'The Water-Energy-Food Security Nexus through the Lenses of the Value Chain and the Institutional Analysis and Development Frameworks', *Water Alternatives*, 8(1), pp. 735–755. Available at: www.water-alternatives.org (Accessed: 2 May 2022).

Wobeser, G. von (1989) 'Surgimiento y Consolidación de la Hacienda', in *La formación de la hacienda en la época colonial. El uso de la tierra y el agua*.

Wolf, A.T. (1998) 'Conflict and cooperation along international waterways', *Water Policy*, 1(2). Available at: https://doi.org/10.1016/S1366-7017(98)00019-1.

World Bank (2011) 'Diagnóstico de la gestión de los recursos hídricos. Chile', *Departamento del Medio Ambiente y Desarrollo Sostenible* [Preprint]. Available at: https://doi.org/10.1029/2001WR000748.

World Bank (2013) 'Estudio para el mejoramiento del marco institucional para la gestión del agua. Chile', *Departamento del Medio Ambiente y Desarrollo Sostenible* [Preprint].

Xu, Y. and Yao, Y. (2015) 'Informal institutions, collective action, and public investment in rural China', *American Political Science Review* [Preprint]. Available at: https://doi.org/10.1017/S0003055415000155.

Yoffe, S., Giordano, M. and Wolf, A.T. (2003) 'CONFLICT AND COOPERATION OVER INTERNATIONAL FRESHWATER RESOURCES: INDICATORS OF BASINS AT RISR1', *Journal of the American Water Resources Association*, 39(5).

Zamora y Camino, J.M. (1844) *Biblioteca de legislación ultramarina en forma de diccionario alfabético*. Madrid: Imprenta de Alegría y Charlain.

Zhang, Y. (2018) 'Crossing the divide: an integrated framework of the commons', *Evolutionary and Institutional Economics Review*, 15, pp. 25–48. Available at: https://doi.org/10.1007/s40844-017-0077-2.

Zhang, Y. (2019) 'Governing the water commons in China: from historical oriental despotism to contemporary fragmented hydraulic state', *International Journal of Water Resources Development*, 35(6), pp. 1029–1047. Available at: https://doi.org/10.1080/07900627.2018.1508989.

Zhang, Y. (2020) 'How did the lost Shangri-La get lost? The tragedy of the groundwater commons in Lijiang, China', *Water*, 12(11). Available at: https://doi.org/10.3390/w12113131.

Chapter 4. Water Conflicts in Chile: Have we learned anything from colonial times?[13]

0. Abstract

The number of disputes related to water that reach courts in Chile has increased in the last decades, the topics of these disputes have become more complex, and the current conflict resolution system has not been able to adjust to this situation. This study analyses colonial texts from water-related conflicts that were addressed at the Royal Hearings in Santiago (1691-1800) and from the Cabildo gatherings (1541-1802), using an adaptation of the Institutional Analysis and Development framework. The research shows a strong institutional system surrounding conflict resolution during colonial times, with nested schemes and empowered figures appointed in leading roles. However, a lack of equity and inclusion of all actors is also visible, reducing its legitimacy. At present, the increasing value of water and a sense of distrust in the institutional system have led to longer and more complex conflict resolution processes. Here, learning from past times about the empowerment of the institutional system for solving water disputes could be useful. An increased support towards initial conflict resolution mechanisms, giving space for local knowledge and generating stronger participation in these initial steps, is a lesson for the future.

Keywords: Institutional Analysis and Development Framework (IADF); Hydropolitics; Water management; Water governance; Colonial period; Water conflicts

1. Introduction to Chilean water conflict resolution and its origin, a big uncertainty

Water conflicts and tensions have been increasing worldwide (Klare, 2001; Grech-Madin *et al.*, 2018). Even though this can be associated with higher levels of scarcity, flood events and water uncertainty, in general, the root of the controversy comes from a wider range of factors that include poor water management, water pollution, monopolization of access, negative externalities, threats to sustainability or limitation of future development opportunities, inability to manage and insufficient regulation and investment in exploitation infrastructure (Martín and Justo, 2015). Due to the above, tensions over water are increasing, and in some cases becoming more violent (Klare, 2001; Klimes *et al.*, 2019; Gleick and Shimabuku, 2023). Thus, these conflicts have political, social, environmental, cultural and economic implications, with all the complexity that this implies to arbitrate and coordinate the multiple interests that are in dispute. Correctly managing these kinds of conflicts can reinforce water resilience, water security, and environmental sustainability (Ganoulis, 2022).

1.1. Relevance of water conflicts and their resolution in Chile

[13] This chapter is a modified version of: Blanco, E., Donoso, G., and Camus, P. (2023). Water Conflicts in Chile: Have We Learned Anything from Colonial Times?. *Sustainability*, 15(19), 14205.

In Latin America and the Caribbean region, Chile is considered a country from which valuable lessons can be learned because it has been successful in advancing the UN's 2030 Agenda for Sustainable Development, Goal 6: clean water and sanitation. At the same time, the Chilean water system has been studied because of its strong market-based water rights system, complemented with self-governed water user associations (WUAs). It has been considered to have one of the most liberal water systems of the world (Herrera *et al.*, 2019). Besides its progress in these areas, Chile also has challenges regarding water availability. Even though the Country stores a significant amount of water (in global terms) of 695 mm/y, there is a great imbalance between where the people and the industries reside, and where the water is located, having highly productive areas with less than 2mm/y of rain (Lozano Parra, Pulido Fernández and Garrido Velarde, 2021). These challenges add up to those associated with being a developing country, including growing water demand, together with a significant lack of institutional coordination, all further aggravated by climate change (Donoso, 2018b). Climatic projections point towards a significant increase in the aridity of the Country, especially in central areas, where the most important cities are located (Lozano Parra, Pulido Fernández and Garrido Velarde, 2021). Collectively, as with many other countries in a similar situation, there is a pressing challenge of rising conflicts between users, that have led, in past years, towards the emergence of a number of regulatory reforms involving water (del Campo García and Sánchez Reinón, 2021). In addition to this situation, the demand to secure access of water in rural areas, the equitable distribution among its users and the consideration of the environment, have been one of the reasons behind the political and social process for a new Constitution (del Campo García and Sánchez Reinón, 2021). These processes, if not handled correctly, can scale up, such as the water wars seen in Cochabamba, Bolivia (Angelakis *et al.*, 2021).

Indeed, the amount of water conflict is increasing and imposing pressure on the judicial system. This diagnosis is supported in a study carried out mapping multiple legal disputes in water matters in Chile (2016) and in one that used data and text mining tools (2019). Also, an analysis of conflicts solved by judicial courts in Chile between 2009 and 2018 identified an upward trend in these disputes, as well as an increase in cases that reach the Supreme Court, the final judicial venue for conflict resolution (Rivera *et al.*, 2020). Thus, disputes involving water are rising and are not being settled in previous conflict resolution stages.

The first step of the Chilean water conflict resolution system is a collective one. WUAs themselves are allowed to solve conflicts between their members (Water Code, 1981). However, this approach is rarely used. When individuals consider themselves affected by a particular situation, they usually bring it to the attention of the public authority, the *Dirección General de Aguas* (DGA), or the competent court of law (Rivera *et al.*, 2020; Engler *et al.*, 2021). This explains why numerous conflicts end up in the hands of the justice system. The courts may ask the DGA or WUAs for their expert opinion, but they have no obligation to do so. Wider conflicts over water, such as between non-agricultural users or between private users and the DGA, are generally seen in the regional Courts of Appeal. As mentioned previously, these decisions may only be appealed to the national Supreme Court.

Even though, several legal and normative reforms have occurred, there may be elements of the current Chilean water system, that come from previous official documents. For example, the first national set of regulations governing water use – an executive decree from 1819 that set the size of an irrigation unit, the form of trading it, and the parties responsible for the water canals – to some extent defined our current allocation and reallocation system (Bauer, 2010b). Thus, some aspects regarding water

conflict resolution in present times may come from historical conflict resolution mechanisms, similar to what studies have shown regarding collective action associations in Europe (Bravo and Moor, 2008; De Moor, 2008). However, prior to 1819, water conflict resolution in Chile was not as clear and thus, this thesis has not been proved from the true origins of the water system in the Country.

1.2. What we know about water conflict resolution during colonial times

During colonial times (i.e., 1600 to 1810), the fights surrounding water in the region were between competing water consumption activities, like demand to access water sources to develop urban settlements, water-powered industries, fishing, mining, and irrigation **(Angelakis *et al.*, 2021)**. For these issues, the country's water management was guided by the Castilian law through the *Fuero Juzgo* (Jurisdiction Forum), the *Fuero de Castilla* (Castilla Forum), the *Fuero Real* (Royal Forum), and the *Código de las Siete Partidas* (Code of the Seven Parties) (Camus, Castillo and Muñoz, 2019). These legal provisions strengthened monarchical control of water at the expense of the local power – represented by municipalities – by declaring that certain uses of fresh water were monarchical royalties (Stewart, 1970). However, following the Conquest of Chile, the colonies generated their own forms of management and control in relation to water use and resolution of conflicts. As Spanish law contained some contradictory and entangled rules, especially in the absence of competent jurists, the colonies were able to generate their own jurisprudence (Camus, Castillo and Muñoz, 2019). At the same time, the Spanish tradition favored custom over written law, so in the use and distribution of water it was common to proceed casuistically (Wobeser, 1989). For example, according to the Castilian legal tradition, the Indian Law established that the pastures, mountains, and waters common in the Indias were common to all their neighbors (Zamora y Camino, 1844). According to the Spanish colonies, the neighbors were members of their own colonies, they established the limits of their own properties and granted themselves volumes of water (merced) as rights of use, ignoring previous settlers (Camus, Castillo and Muñoz, 2019). Thus, even though the colonies were subject to Spanish law, in practice, the subjective implementation of the norms led to a unique colonial governance system. Yet, little is known about how water conflicts were treated and solved during colonial times, how the conflict resolution system evolved during that period, or which elements influenced Chile's actual system.

1.3. What can we learn from looking into the past of water conflict resolution in Chile

The question that arises, then, is what can we learn from the past, and understanding how certain elements, present in the current legislation, came to be. Side questions of this project include how water conflicts were treated and solved during colonial times. Is it possible that water conflict resolution from Chilean colonial times (pre-1819) influenced the current Chilean system? Also, is it possible that, at present, we are facing problems that were solved more efficiently in the past? Answering these research questions can help us unveil where the current problems of the system are, to consider this knowledge in current regulatory processes, and avoid making the same mistakes. An effective conflict resolution scheme for water issues, besides supporting a more peaceful environment, provides for better decision-making and promotes an overall recognition of the legitimacy of the water system. Unsolved, these water conflicts impact economies, political arenas, social stability, populations and the environment (Martín and Justo, 2015).

Despite this relevance, most of the discussion and analysis of the history of water conflicts focuses on transnational, or interstate, disputes (Gleick and Heberger, 2014). These have focused on general

international water conflict and its history (Wolf, 1998), transboundary water management conflicts (Yoffe, S., Giordano and Wolf, 2003), or particular case studies, such as the history of water sharing between India and Pakistan (Sridhar, 2008). Also, historical assessment of conflict resolution sheds light on the effectiveness of different mechanisms of solving water conflicts (Adler *et al.*, 2007). For example, historical evidence demonstrates that water tensions often become catalysts for cooperation (MacQuarrie, Viriyasakultorn and Wolf, 2008). Few studies analyze historical water conflicts and their resolution mechanisms in Chile (Palerm-Viqueira, 2010; Klubock, 2021). Historical water related studies have focused on the analysis of the legal regime of water and the evolution of its legislation (Lira and Maza, 1940; Dougnac and Barrientos, 1991; Dougnac, 1994; Palerm-Viqueira, 2010; Arévalo, 2013; Vergara, 2017; Klubock, 2021) or works about potable water supply to Santiago (Piwonka, 1999, 2000; Castillo, 2014). However, the evolution of water conflicts during colonial times, as well as its current influences, has not been studied. Thus, history shows that better mechanisms and far greater efforts are needed to address water conflicts and their resolution mechanisms, and there is a clear need for advancing in this research stream.

The following study presents the results of a review of nearly 40 judicial files with water-related conflicts from the years 1691 to 1804 of the *Real Audiencia de Santiago* (Royal Hearing of Santiago), the court of law that ruled during the colonial period, as well as gatherings of the *Cabildo*, where neighbors discussed administrative, economic and political problems. Also, a review of complementary bibliography was used to support the analysis. The goal is to understand how conflicts associated with a common good, such as water, were managed during the colonial period, and obtain lessons from this historical knowledge. A secondary objective is to compare past and present water conflict resolution mechanisms to provide insights into how current water systems could be improved.

2. Conceptual Framework, Data and Methodology

To understand the ways in which water conflict resolution worked in colonial times, an adapted version of the Institutional Analysis and Development (IAD) framework was used. The framework, derived from institutional economics, was conceived to analyze how institutions operate and change over time (Kiser and Ostrom, 1982). It is targeted towards social ecological systems and communities without state intervention and their governance over common resources (McGinnis, 2011a).

The IAD framework involves the analysis of the interactions and outcomes of an "action arena" formed by the action situation, a social space where the actors interact, solve the commons problem, and exchange goods and services, together with actors that participate in the situation. This action arena depends on exogenous variables that change the analysis of the case study as they vary and leads to interactions that generate outcomes that can be evaluated afterwards (Ostrom, 2011). The components and their relationships are presented in Figure 1.

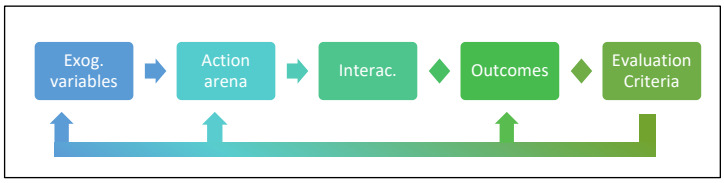


Figure 1. Main components of the IAD Framework. Source: Authors' own illustration based on (Ostrom, 2007, 2011; Ostrom, Janssen and Anderies, 2007; McGinnis, 2011a).

With regards to natural resources, the framework has been used to study conflict resolution (McGinnis, 2011b). In this context, a similar research (2015) used the framework to study the need for coordination and cooperation of different environmental groups [31], and later on, it was used to study the role and capacity of governments to facilitate local collective action [32], both studies regarding environmental conflicts.

In the current study, the framework has been adapted to facilitate understanding of how water conflicts were solved during colonial times, specifically regarding which institutions were in place and what were their main roles. Thus, for this particular study, the "actors" of the "action arena" were sub-categorized into judges and those who support their participation, that is, public authorities and stakeholders, all being an important part of the actions and decisions taken in water conflict resolution during Chilean colonial times. A similar modification was done, adapting the framework to the local context, in (2015). Also, the "exogenous variables (EV)" component was subdivided, to capture different contextual elements in the analysis, considering water availability, referring to the water biophysical situation, such as precipitation trends, scarcity or drought situation, floods, or water quality problems, and rules, considering the regulatory context, including formal rules, property rights and historical considerations, as well as any exception or deviation from them. This follows a similar classification made in (Zhang, 2019). A "broader setting" component was included to highlight any social, economic, and political broader contexts affecting the conflict resolution system in place, following a suggestion of variables in analyses from water studies (Meinzen-Dick, 2007; Zhang, 2020) applying the related Socio-Ecological Systems (SES) framework (Ostrom, 2007). Finally, the "outcomes" was replaced with trial results, to consider any recollection of the jury's final decision, especially regarding innovative solutions, social consideration, ecological performance and externalities, and "evaluation criteria" was replaced with any data or information regarding post-trial analysis. The final version of the framework and its components are illustrated in Figure 2.

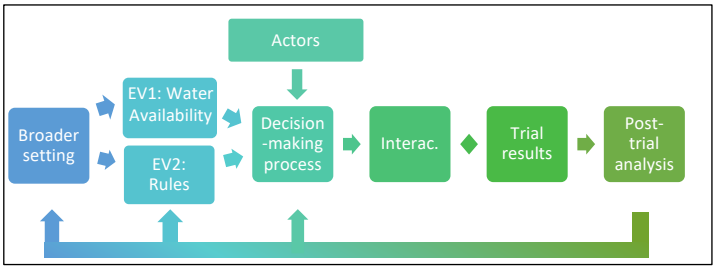


Figure 2. Adapted IAD Framework for analyzing water conflict resolution in colonial times. Source: Authors' own illustration.

For the analysis, the review of the transcripts of nearly 40 judicial files with water-related conflicts was used as primary data. These transcripts come from proceedings of the Royal Hearing of Santiago, from 1691 to the early 1800 and from the *Cabildo* sessions carried out in Santiago between 1541 and 1802. These have been transcribed from old hand-written Spanish into digital spreadsheets. To narrow down water conflicts from other type of disputes, key concepts have been used, selecting water cases from the full digital library of trials. Afterwards, a review was done on these cases to corroborate the selection. Given the inexistence of a categorized archive system, we cannot state that the water trials compiled are all those that occurred between the years analyzed, but we are confident that we captured most of the cases. Also, to complement these transcripts, secondary information was

retrieved from a bibliographic review carried out regarding articles focused on explaining the social, economic, and political context during a similar time period.

A qualitative content analysis was carried out, considering a codebook. The codebook contains a list of the adapted IAD framework components, used as codes for this qualitative data analysis research. It included a definition of each of these components, along with examples of what was considered in each of them. Translated summaries of the files and text analysis can be found in supplementary material, together with the codebook used.

The proposed method provides for more detailed insights and deeper discussion, since it has a qualitative core. However, it has the limitation of having risk of bias, in the selection of cases, and in the analysis (Skarbek, 2020). Also, because of the number and location of the case studies analyzed, there could also be bias from the source of the information. Thus, any conclusion and recommendation have to account for these limitations.

3. Results and what do the trials reveal regarding water conflict resolution during colonial times

3.1. Actors, the decision-making process and their interactions

The Judges or Deliberative bodies

The *Real Audiencia* (Royal Hearings) contain the lawsuits between private parties that disputed the use of a water source, as well as the motives, arguments, and interests that substantiated the demands for water rights. The judges or hearers were the ones who delivered and made proclamations on the different conflicts at these Hearings. They were the last step for conflict resolution in the colonial lands, so they were highly efficient in the sense that most trials were solved within the first hearing. There are specific cases where the trial lasted for longer, but the majority lasted two years. There is one outlier case that lasted 24 years because it included several sub-sequent trials (*Comuneros de acequia de Aedo*, Domingo Santiago, Pedro Jose de Prado, Royal Hearing 1804-1828, Vol. 1879, page 172), but in general, it was a highly efficient and resolutive process.

There are indications of the creation of a "nested" conflict resolution system over the course of the colonial period, because later trials consider and mention previous local trials and judicial resolutions. Also, in the judicial branch, below the Royal Hearings and local Judges, the *Juez de Aguas* (Water Judge) would initially review initial cases regarding water distribution and management (*Cabildo* session 1772, Vol. 34). At first, the functions of this Water Judge were more operational than regulatory, and with time the position came to acquire a remarkable stability (Piwonka, 1999). This institution even continued after colonial times, surviving the uncertainties that accompanied the independence process and all the political, economic and social changes that came with it (Arroyo, 2009). The judges of the Royal Hearings then settled disputes that were not solved by the Water Judge, as well as received the appeals from local judges decisions (Camus, Castillo and Muñoz, 2019).

An interesting figure, and an element that appears in several trials, is the *Alarife*. This person oversaw the water distribution among users and monitored the compliance with local rulings (Camus, Castillo and Muñoz, 2019). For example, the *Alarife* was in charge of monitoring the obligation of urban water users to clean the ditches (Piwonka, 1999; Arroyo, 2009). Each neighbor and resident of the city was supposed to contribute a worker with a shovel or hoe on a designated day, and the *Alarife* would be in charge of following the cleaning process (Arroyo, 2009). This person, as the "eyes" of the water

community, would be later used as the means of proof during water trials that would stand out above all other evidence, and would support the work done by the Water Judge (Arroyo, 2009). Thus, not only were there local institutions "nested" in higher forms of conflict resolution institutions, but there was also an operational branch, for surveilling and assuring the regulations are accomplished on-site, thereby strengthening the institutional system surrounding water conflict resolution.

The Cabildo as representative of the People

Any issue regarding water also reached the *Cabildos*. The *Cabildos* were municipal corporations created by the Spanish kingdom for the administration of the cities. They were legal representatives of the city, similar to the City Council, that is, the municipal body through which neighbors discussed judicial, administrative, economic and military problems. From the first years of the colony these institutions constituted an effective representation mechanism for the local elites against the Spanish royalty and its bureaucracy (Camus, Castillo and Muñoz, 2019). With the evolution of the water management system, the *Cabildos* positioned themselves as the first step for solving water disputes between neighbors, and they annually chose the Water Judge.

Although the *Cabildo* was the institution that should have defended and acted as a representative of the people, it appears that at least at the beginning of colonial times, it played a weak role. First, the *Cabildo* did not consider the land's original water users, usually called natives or Indians, during trials; moreover, several times, the *Cabildo* not only favored the Spaniards, but protected the elite of the colony (Camus, Castillo and Muñoz, 2019). Also, participating in trials or hearings of the *Cabildo* was expensive, and few could afford it at the time, meaning that it was exclusive (Arroyo, 2009). However, the *Cabildo* was the one who brought to light water matters and proposed solutions at a city level, so it was involved in issues that concern the whole city as a community. In the *Cabildo*, the discussions to bring water from the Maipo River started only once the main source for the city was proven uncertain (*Cabildo* session 1729, Vol. 19, page 29; a map of the city of Santiago surrounded by the Mapocho and the Maipo Rivers can be seen in Annex 1). Here, the figure of the *Corregidor*, appears for the first time as a figure bringing voice and support to the people.

Also, civil society was considered in trials, at times, as witnesses. For example, in an early trial, the Royal Hearing proposed the creation of a structured interview that the parties should administer to neighbors (Juan Baptista de las Cuevas against Manuel Ramírez, Royal Hearing 1774-1777). It must be noted that neighbors were usually considered and mentioned throughout the reviewed cases.

Other public authorities

In different cases, the work done by the *Cabildo* was respected and even supported by other political figures. For example, during a drought that occurred in 1729, communal institutions such as the *Corregidor* facilitated the work done by the *Cabildo* by taking a vigilance role. In this case, it even hired guards to keep a safe eye over the city canals (*Cabildo* session 1729, Vol. 19). On a second occasion, the *Corregidor* helped the *Cabildo* by evaluating the supply and distribution of water in the city, as well as executing action plans based on their diagnoses. Also, in other sessions, the figure of the *Corregidor* is seen endorsing previous settlements (*Cabildo* session 1742, Vol. 31). In a second example, in 1763, there was a debate to bring water to Santiago from a parallel river, Estero de Ramón, and the Governor himself proposed that prisoners under his watch could be used for building the canals (*Cabildo* session 1763, Vol. 33). Thus, the function of the *Cabildo*, as well as the other

communal authorities, was respected by the rulings of the Royal Hearing, as well as supported by the *Corregidor* and the Governor.

3.2. The broader setting of trials reveal value for social issues

Against a background of economic instability and marked social classes, trials reveal a specific consideration for the most vulnerable. For instance, the mention of a "poor-people" litigator appears in the documents. In a trial involving a recent widow who had been deprived of her water allowance, this specific kind of lawyer was the one in charge of representing her, because of her poor economic and social position (Josefa Maldonado against Juan Infante, Royal Hearing 1820-1822, Vol. 1690). Even though this appears mentioned only in one case, it seems that it was not rare and, according to a study done for the end of the colonial period in Chile (2012), the poor had the right to represent themselves at these courts without paying.

Even though contact with the Spanish kingdom is scarce in the documents, when it appears, it shows a sense of care towards the new colonies. For example, despite the fact that water was scarce and already considered valuable, Indigenous communities were protected and prioritized in using it, at least under the Royal Hearing trials. This is demonstrated throughout the case of 1705, where Luisa Parras was in charge of a group of "Indians", but was deprived of water (Melchora Mena against Luisa Parras, Royal Hearing 1705, Vol. 1690). Relevance to these Indigenous group and their importance for the kingdom was stated, and thus, their caregiver was given a secured water provision. Here, the care for the Indigenous communities can be contextualized as a patrimonial consideration, and not because of cultural recognition. For example, although Castilian Law established that waters are common goods and, thus, they should be treated as common to all the neighbors, these neighbors were *Indian hosts* and not natives themselves (Camus, Castillo and Muñoz, 2019). Thus, the trials show that social aspects were relevant and considered by judges during colonial times, notwithstanding the fact that Indigenous communities were not directly included as such.

3.3. In a context of water scarcity, conflicts for water were becoming violent

Drought is a relevant issue considered throughout the trials. During colonial times, water stress led to conflict as well as economic impacts and, therefore, was generating more awareness and even violence between users. According to one of the *Cabildo* sessions, sometimes the conflicts were such that people required weapons to protect themselves while extracting water (*Cabildo* session 1778, Vol. 34, pages 133-134). Also, there were vigils of farmers in place to prevent the theft of water, and some farmers had been financially ruined because they were not able to irrigate enough (Cabildo session 1778, Vol. 34, pages 133-134). Thus, the value of water and the costs of water conflicts were already evident at this time and had even led to a violent scenario.

3.4. Rulings adapted towards local and social needs

The rules were broad and adapted to fit local and social needs. For example, there are rulings favoring local issues, such as social matters in terms of food production. The example of the trial between José de Ureta and Juan Antonio Araos, favored local needs by approving the construction of a wheat mill near Araos's vineyard estate affecting his harvest, justified on the basis that bread was a more important asset for Santiago than wine (Royal Hearing 1768, Vol. 1275). Also, there are several decrees

in the *Cabildo* sessions that were instated for the City's needs. Examples of these are rulings regarding water scarcity measures (*Cabildo* session 1742, Vol. 31; and 1772, Vol. 24) and sanitation matters (*Cabildo* session 1729, Vol. 19; 1761, Vol. 33; and 1778, Vol. 34). In all of them, specific rulings are made favoring giving water to the cities and towards a better sanitary management.

The search for a new water source for the main city of Santiago, as well as for having water intakes in the cities for human use, are a constant preoccupation. In the *Cabildo* discussions, arguments towards building water canals and improving current infrastructure invoke a lack of drinking water for certain areas and potential fatalities expected from drinking poor quality water (*Cabildo* sessions 1742, Vol. 31, page 38). In one of the trials, the main argument of the session was the potential demise of a whole neighborhood because of water uncertainty (*Cabildo* session 1729, Vol. 19, page 29). Here, the relevance towards safe and secure drinking water is evident and prioritized. In the Royal Hearings, the same argument is used in a case of dispossession of water (Josefa Maldonado against Juan Infante, Royal Hearing 1820-1822, Vol. 1690). Even in privately held trials, the social worry of the population´s heath due to their access to water was present, and the rulings favored this sector.

3.5. Trial results reveal contradictions, innovations and sanctions

In most trials, the results follow the previous stated rules, giving high priority to traditional uses as well as food production and social concerns. However, there are some cases where contradictions appear. In one case, even though historical use was generally upheld in trials, judges prioritized that the water source was located in the property of the one using it regardless proving it was used historically (Juan Baptista de las Cuevas against Manuel Ramírez, Royal Hearing 1774-1777). As a second example, the judges decided towards equal distribution of water among parties in the case of Magdalena Negrete versus Antonio de Carvajal, Vicente Carrión, and Gonzalo de Córdova (Royal Hearing 1694, Vol. 755, pages 113-191). However, in another similar situation, the trial concluded towards the distribution of the water, not equally, but according to how much each of them farm (Josefa Maldonado against Juan Infante, Royal Hearing 1820-1822, Vol. 1690).

Regarding innovative solutions, in different trials, workers are used by the parties involved as a surveillance mechanism. Even though for a more proper monitoring system to be implemented these elements would need to be permanent, it worked in eventual situations. In 1729, for example, a drought hit Santiago city, and guards were hired to look out for neighbors manipulating the river flow (*Cabildo* session 1729, Vol. 19). In the same drought, there was a proposal for hiring guards for a year. However, the idea was abandoned as soon as the drought was over. Thus, they developed a monitoring system carried out by users. These systems did not work permanently and just appeared sporadically as a response to droughts.

Also, creative and low-cost solutions were put in place for conflict resolution. Often, the use of field laborers is chosen for the surveillance or construction of projects, as well as other solutions where costs are shared. The aforementioned case of prisoners being used to build a water canal for the city of Santiago provides an example (*Cabildo* session 1763, Vol. 33). Using prison labor in this way was justified by the fact that there was a proportionally high population of criminals who committed minor crimes and were not able to be sent to Spain to serve their sentence. These prisoners were seen as "idle" and could help for free. This reason was also used in 1772, to build a water passage to the main square of San Isidro village, in Santiago (*Cabildo* session, 1772, Vol. 34).

Regarding sanctions, many times high or very strict sanctions were used in response to a first offense. There is just one identified case when a warning is mentioned, but the warning came together with a fine. The case sought to demand that residents clean their own irrigation ditches because canals had filled with dirt during a serious drought that affected the city of Santiago (*Cabildo* session 1748, Vol. 32). More commonly, sentences found in these transcripts are the opposite, and misdemeanors such as being disrespectful were sanctioned with jail time. Such is the case of Domingo Frías, who was found guilty after members of the *Cabildo* noted that he had not complied with a mandate, and when hitting the table with rage, he was sent immediately to prison (Royal Hearing 1775, Vol. 1044).

3.6. In post-trial analysis a lack of evaluation was found

There are no perceived instances of post-trial reflections or a formal process for evaluating the performance of the conflict resolution system. Across all documents reviewed, the modifications that took place, such as the incorporation of new actors for the strengthening of the institutional framework, came from sustained petitions from organized sectorial groups (mainly farmers) at the *Cabildo* meetings.

Thus, as a general reflection, resolutions of colonial conflicts started out as small village trials, where the judges knew the people in question and settled issues accordingly. These institutions could take action supporting specific areas of interest for the city, such as food and water security, and could provide assistance in areas of social concern. Over time, the colonies' water problems became more complex because cities started growing and water scarcity issues became more serious. Here, contextual factors were crucial in forming the institutional scheme that developed during colonial times. The appearance of the *Alarife* and the empowerment of the Water Judges as a primary conflict solver shows a response to the need of a more solid institutional system. This evolved into a "nested" conflict resolution scheme, allowing these roles to continue to manage conflict at small and local trials. The same happened with the role of the *Governador* and the *Corregidor*, as supporters of the *Cabildo* rulings. Both gained strength and became more active members of trials and discussions, as the colonial process developed. With a stronger institutional system and with local roles supporting higher level conflict resolution, despite the fact that colonial norms had room for interpretation, the judges and their rulings were respected, sanctions were imposed, and different members of the citizenry participated in them. Altogether, generally, this was a socially validated conflict resolution system and a robust model. These results, together with the study of each of the components reviewed under the adapted IAD, can be seen briefly in Figure 3.

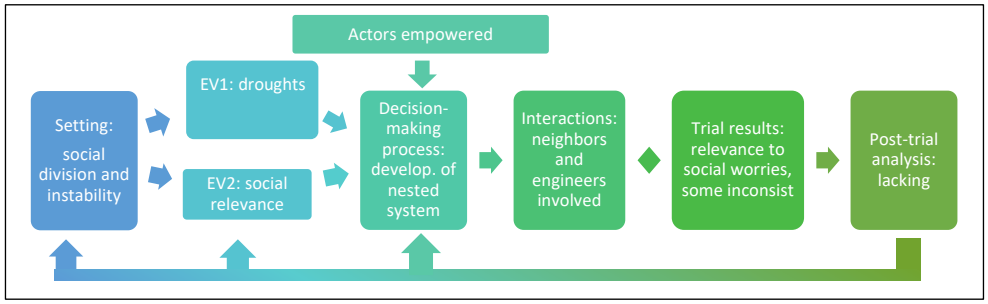


Figure 3. Adapted IAD Framework for water conflict resolution in colonial times. Source: Authors' own illustration based on (McGinnis, 2011a; Ostrom, 2011)

Here, it must be stated that this analysis did not consider the conflicts between the Spanish colony and local Indigenous communities. Even though there are cases where these communities were protected, the Spaniards in charge of them benefited most. Original Indigenous communities were not directly represented and were not included in the colonial system.

4. Discussion: Have we learned anything from colonial times?

4.1. Comparing past and present

Actors: fragmentation has led to discoordination and disparity in the treatment and resolution of water conflicts and trust issues

Currently, there is an issue regarding coordination between institutions. Even though the formation of WUAs involves a judge's resolution and a complex procedure where the public institution is consulted, the DGA acts as a second reviewer, since WUAs must again request registration (Rojas, 2014; Donoso, 2018b). This has led to a number of cases where communities are already organized and operating, yet their registrations are pending and thus they cannot access public funding opportunities (World Bank, 2011, 2013). Thus, a discoordination between authorities limits the work done by judges and generates a sense of mistrust towards the system (Popovici *et al.*, 2022). These types of situations were present, yet being solved, during colonial times. Then, any major decisions involving water went through the *Cabildo*, and at the same time, the *Governador* or the Water Judge would be present and participate (Camus, Castillo and Muñoz, 2019). Thus, the validity of any decision was aligned among all users.

In modern water trials, there is a disparity in the criteria used for the resolution of conflicts that generates meandering or incoherent trial results. Here, the same types of cases are resolved on the basis of different criteria, affecting equality and people's trust in the law and in courts (Rivera *et al.*, 2020). Even though during colonial times some contradictions in the trials resolutions were seen, these usually responded to adapting rulings towards social needs. Currently, these contradictions have generated, once again, a sense of injustice and mistrust in the courts' resolution, thereby jeopardizing the system.

Environmental issues have risen, while social ones persist

Water stress in central Chile has increased in terms of temporality, territorial scale, and intensity, generating a structural deficit of surface water available to cover the water demands (DGA, 2017; Escenarios Hídricos 2030, 2018). The surface water deficit has been partially covered by groundwater extraction, threatening the sustainability of aquifers. This has contributed to the conflict in different areas of the country between water for agriculture and for human consumption (CR2, 2019). As mentioned earlier, this conflict has increased significantly and has become alarmingly violent, especially in dry years (Larrain and Poo, 2010). More so, water is a part of most socio-environmental conflicts, the majority of them related to mining or energy projects (Carranza *et al.*, 2020). Thus, water matters are still pressing issues and we still have not developed an effective system for dealing with these conflicts.

Moreover, after a period of social movements and demonstrations that began in Chile in October 2019, the country has been going through a Constitutional reform. Many of the complaints are related to social and environmental topics, and water and the way it is managed is one of them (Saravia Matus *et*

al., 2020). For example, the difficulties in correctly assessing the social and environmental outcomes of water trading schemes, and the ethics of applying economic principles to a resource such as water, have raised concerns regarding the fairness of the current market-based system (Herrera *et al.*, 2019). Thus, the distribution of scarce water has been a source of conflict, even since colonial times, but nowadays environmental concerns have risen and are adding more pressure to the conflict resolution system.

A space for incorporating social concerns from non-water rightsholders has been through the protection action established in the Constitution of Chile. For environmental claims, specific courts were developed in 2012[14]. These institutions have been used to resolve specific cases that are increasing in frequency. The protection action, for example, receives cases related to water quality, access to drinking water, claims regarding modification of riverbeds and effects on the free runoff of water, irregular extraction of these, as well as conflicts between user organizations and their members, among others (Rivera *et al.*, 2020). Regarding environmental courts, they specialize in resolving environmental disputes, where 65% of them have involved water topics (Hernández, 2021). Thus, social and environmental conflicts have a space to be considered and treated as special cases.

More complex topics are now in place

Regarding the topics in conflict, the relevant focal points are watershed conflicts among users, groundwater overexploitation, social and environmental conflicts, and conflicts of a political and regulatory nature (Bauer, 2015; Carranza *et al.*, 2020). These have become more complex and harder to manage. Even technical aspects, such as defining water availability, has become harder to do in a generalized scenario of drought and climatic uncertainty (Rivera *et al.*, 2020). The same goes for treating environmental and social components that have also become more conflictive, since there are more cases regarding impacts on water quality and its role as an ecosystem sustainer and considering everything related to the human right to water (Rivera *et al.*, 2020; Engler *et al.*, 2021). Thus, water conflicts in Chile have been increasing and have become more complex, and the current system has not been able to cope with them.

New variables and additional demands in water security contexts have been added in recent years. For example, a nationwide report by the association *Chile Sustentable* (Larrain and Poo, 2010) conducted a case-by-case examination of sub-national conflicts and found increased violence in the parties' actions. These studies also state that judges are often not specialized in the complexities of water or in the treatment of these new pressing disputes (Rivera *et al.*, 2020; Engler *et al.*, 2021). This suggests a lack of what is typically a cornerstone of achieving a successful legal system and implies that courts face great challenges when handling cases of water security.

The length of trials of the judicial system has increased

The majority of conflicts, especially in recent years, have been settled by the final stage of the judicial system, the Supreme Court. The trend can be explained by a greater awareness of the litigants about their rights and possibilities of action, together with a greater sense of injustice in rulings and resolutions pronounced by previous judicial stages (Rivera *et al.*, 2020). However, for conflict resolution, WUAs act as the first step[15]. Thus, the Board of Directors of each WUA should arbitrate in

[14] Law 20,600, published on June 28, 2012.
[15] Water Code 1981, Art. 244

cases of conflict arising between users. This would be more effective than utilizing the regular legal process. However, the judgement of WUAs is not always considered as impartial and the procedures are not always clear, leading users to invest money and time in pursuing a more seemingly fair resolution.

Studies also agree that an additional unsolved issue is the duration of the judicial processing of water conflicts, some of them lasting an average of 2.5-7 years (Rivera *et al.*, 2020). This was also identified in a study that interviewed local water associations, which responded that legal processes take too long and do not solve conflicts quickly enough (Engler *et al.*, 2021). Considering the current urgency of water needs, entering these trials implies a significant time investment. This brings into question whether the initial stages in the legal system (e.g., WUAs) stopped offering a more local view, such as the one offered by the Water Judge during colonial times. Moreso, these institutions went through a maladaptive development, using the concept provided by Popovici *et al.* (2022). If initial steps of the conflict resolution process would provide more confidence towards the system, fewer cases would reach the Supreme Court, and would take less time.

Changes in the ones doing the claims

In the past, most claims were between farmers. Even though agriculture is currently still the main consumer of water, at present times, most conflicts over water take place between individuals and the public authority, the DGA (Rivera *et al.*, 2016, 2020; Herrera *et al.*, 2019). This is because the administrative system for constituting and modifying a water use right involves going through courts. This was already present but only eventually used during colonial times, since only the *Governador* or the *Cabildo* could issue or validate a water permit in an official session (Camus, Castillo and Muñoz, 2019). However, in recent years this trend has started to rise, since individuals and WUAs modifying water rights have been watching and increasingly opposing these claims (Rivera *et al.*, 2020). This may also be explained by the increased awareness and greater appreciation of water as a resource.

Conflicts between individuals are still the leading causes of protection actions in Chile, although a significant number of these happen between individuals and WUAs (Rivera *et al.*, 2020). This is due to WUAs becoming stronger and because of their duties regarding distributing water, controlling and enforcing this distribution, keeping records, and as a first step in conflict resolution among users, they act as representatives of their users' needs (Rojas, 2014; Donoso, 2018b). So far, researchers indicate that WUAs have been very much aware of performing these administrative functions and that they have the normative and administrative tools for good management of them, despite the fact that many still operate in precarious conditions (Puig, 1999; Bauer, 2010b; World Bank, 2013). Here, WUAs members, together with the group dynamic in place, has become a crucial element in their capacity to respond to external disturbances, such as environmental variations, as a study carried out (Dipierri and Zikos, 2020) determined. In theory, these associations should involve all users of the watershed, including agricultural, mining, urban, hydroelectric, tourism, environmental and industrial users, as well as anyone else who uses those waters. However, there are few instances of integration with electric companies that operate hydroelectric plants. Hydroelectric plants have, on occasion, generated conflicts between farmers and generators (Larrain and Poo, 2010). A step in the right direction occurred in the north of the country, where electric generating companies and WUAs have developed agreements to share water resources[16]. Even though during colonial times the figure of the *Cabildo* was supposed to represent the people, in reality it was focused more on local elites it did not

[16] Huasco River Hydroelectric Power Plant: https://www.riohuasco.cl/hidroelectrica-rio-huasco-s-a/

truly represent all water users (Camus, Castillo and Muñoz, 2019). Thus, greater involvement of communal organizations in conflict resolution could be considered a modern trend, but not a trend present during colonial times.

Post-trial analysis is still lacking

The current judicial system is now wider, and besides the Ordinary Courts of Justice, water cases can also go to the Free Competition Court (*Tribunal de Defensa a la Libre Competencia*); Arbitrage Courts (*Tribunales Arbitrales*) and Environmental Courts. Any instance where disagreement still holds, generally is seen in Courts of Appeal. These decisions may only be appealed to the national Supreme Court, which provides for yet another process to review the conflict. However, there is still no perceived instance where an official process for evaluating the performance of the conflict resolution system is in place.

In conclusion, there has been a clear evolution in all components of the IAD framework investigated. Since colonial times, water conflicts and their resolutions have been challenging. Due to the fact that water issues evolve, some elements of the system have also evolved, but the main ideas have been present since colonial times. The social worries during colonial times also exist in the present, but environmental and climatic challenges additionally exist in contemporary trials. During the Royal Hearing trials, as well as in the *Cabildo* sessions, the rulings were community or socially focused, and they were adapted to address local needs. The needs, in this case, being the sustainable and clean provision of water and food for cities. Thus, there is an aspiration for the current system to accomplish the same. Even though the current system includes specialized courts, it is still not able to carry out water distribution while also taking care of local social and environmental claims. Thus, in current water policy reforms, there is not only the pressure to generate an efficient system to distribute water throughout basins, acknowledging the diverse water scenario of Chile, but there is also the added demand of addressing economic, social and environmental needs.

The analysis of the trend from colonial to modern times is presented in Figure 4.

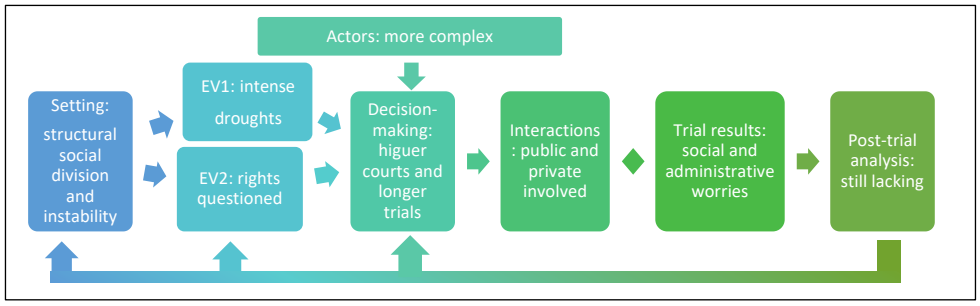


Figure 4. Adapted IAD Framework for Chilean water system trend: from colonial to present times. Source: Authors' own illustration.

4.2. The need for effective water conflict resolution schemes

As can be seen from this analysis, the system for treating and solving water issues has evolved since its development during colonial times. From the cases surveyed here, the development towards a transparent conflict resolution system for treating these particular matters was evident.

Successful conflict resolution mechanisms involve the presence of trustworthy and well-defined institutions, aspects which were present in colonial texts. Indeed, in the past, the function of each actor was clearly defined and there was a tendency towards their empowerment during the colonial process. This led to some institutions, such as Water Judges, *Alarifes* and *Cabildos* persisting beyond the colonial period. However, even though the *Cabildos* were the figure responsible for representing all actors, they had issues with misrepresenting some, affecting the legitimacy of the process that could have caused their later disappearance.

During colonial times, trials concluded quickly and they could address specific political concerns in their resolution mechanisms. More so, the relevance of the economic and social context in which the cases developed is something that has lasted until present times. Currently, environmental concerns are an added layer of context to the specific water issues that must be dealt with. Even though spaces have now been opened to resolve these particular claims, these places allow for less public and political intervention than they did during the colonial era. However, this space for permissive and more independent action also meant that the system was not equitable or coherent, at least regarding water matters. At the same time, the system did not integrate all actors, ignoring native communities and their pre-established system.

It seems that some aspects of colonial times, such as the nested schemes and the strong institutions are no longer present. On the other hand, some problems are persistent in the current system, apparently as if nothing was learned. Historical conflicts over water reveal the social reality of a country, together with the way in which the legal norms are being applied. Thus, past experiences should be considered in any review or possible reform of the regulatory model, as well as in current policies.

The adapted IAD framework was useful for identifying the dynamics and changes of the conflict resolution system analyzed here. It permitted an understanding of the social and political context, together with relevant cultural aspects, and an exploration of all actors, their interactions, and their changes over time. However, even though this study uses transcripts of water trials together with secondary information and is strengthened by a literature review, further studies are required to solidify the results. For example, the same analysis could be done looking at the Peruvian conflict resolution cases and institutional system, since it is a neighboring country to Chile and has gone through a similar colonial process, which could help clarify the results of this study.

5. Conclusion and recommendations

The main conclusion of this papers points to the need to review past documents and experiences to understand the current system and to avoid making the same mistakes. This, since the conflicts reviewed reveal practices that have lasted until present days, longstanding multiple legal and normative reforms. It also shows the relevance of reviewing conflict resolution cases, more than the legal framework itself, since the jurisprudence and practice may sometimes be more official than the formal law.

Thus, following the Chilean case study, we propose some recommendations on the resolution of water conflicts, based on the lessons drawn from the events that occurred during colonial times. These recommendations can also be applicable to other countries and regions with similar characteristics, in terms of water availability and water institutional schemes. Firstly, to identify and understand where, when, and why the identifying elements of the legal and institutional water system of each country were developed. Secondly, to support and strengthen the institutional framework of the Country, considering a structure or figure that can adapt to future challenges and demands. Third, to align present and future normative reforms towards this knowledge.

Overall, the study also points out general conclusions and recommendations regarding the treatment of conflict over water resources. First, all users and actors, at all scales and locations, should be considered and be able to have a voice in the conflict resolution system. Second, nested schemes should be promoted in conflict resolution systems, empowering local water judges. Third, a strong institutional system should be promoted to support this nested scheme, with independent voices and secured resources. Altogether, water conflict may be a constant, but its treatment and resolution may help towards a more peaceful, just, sustainable and inclusive system.

6. References

Adler, R.A. *et al.* (2007) 'Water, mining, and waste: An historical and economic perspective on conflict management in South Africa', *The Economics of Peace and Security Journal*, 2(2). Available at: https://doi.org/10.15355/epsj.2.2.33.

Agrawal, A. and Goyal, S. (2001) 'Group size and collective action: Third-party monitoring in common-pool resources', *Comparative Political Studies* [Preprint]. Available at: https://doi.org/10.1177/0010414001034001003.

Alesina, A. and La Ferrara, E. (2000) 'Participation in heterogeneous communities', *Quarterly Journal of Economics*, 115(3), pp. 847–904. Available at: https://doi.org/10.1162/003355300554935.

Alessa, L., Kliskey, A. and Altaweel, M. (2009) 'Toward a typology for social-ecological systems', *Sustainability: Science, Practice, and Policy*, 5(1), pp. 31–41. Available at: https://doi.org/10.1080/15487733.2009.11908026.

Alevy, J.E., Cristi, O. and Melo, O. (2010) 'Right-to-choose auctions: A field study of water markets in the Limari Valley of Chile', *Agricultural and Resource Economics Review*, 39(2), pp. 213–226. Available at: https://doi.org/10.1017/S1068280500007255.

Anderies, J.M., Janssen, M.A. and Ostrom, E. (2004) 'A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective', *Ecology and Society*, 9(1). Available at: https://doi.org/10.5751/es-00610-090118.

Angelakis, A.N. *et al.* (2021) 'Water conflicts: From ancient to modern times and in the future', *Sustainability (Switzerland)*, 13(8). Available at: https://doi.org/10.3390/SU13084237.

Arévalo, G. (2013) 'Comunidades de aguas subterráneas: dificultades en su organización y ejercicio', *Actas de Derecho de Aguas*, (3), pp. 185–194. Available at: http://derechoadministrativoeconomico.uc.cl/images/stories/ADAG/ADAG3/14. comunidades de aguas.pdf (Accessed: 6 December 2018).

Arroyo, D.I. (2009) *Las Asociaciones de Usuarios de Agua en Chile durante el siglo XIX y primera mitad del siglo XX: 1800-1950*. Facultad de Derecho, Universidad de Chile.

Baggio, J.A. *et al.* (2016) 'Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles', *International Journal of the Commons*, 10(2), pp. 417–439. Available at: https://doi.org/10.18352/IJC.634/METRICS/.

Banco Central de Chile (2021) 'Base de Datos Estadísticos (BDE)'.

Bauer, C.J. (2004) 'Results of Chilean water markets: Empirical research since 1990', *Water Resources Research*, 40(9). Available at: https://doi.org/10.1029/2003WR002838.

Bauer, C.J. (2010a) *Siren song: Chilean water law as a model for international reform*, *Siren Song: Chilean Water Law as a Model for International Reform*. Available at: https://doi.org/10.4324/9781936331062.

Bauer, C.J. (2010b) *Siren song: Chilean water law as a model for international reform*, *Siren Song: Chilean Water Law as a Model for International Reform*. Routledge. Available at: https://doi.org/10.4324/9781936331062.

Bauer, C.J. (2015) 'Water conflicts and entrenched governance problems in chile's market model', *Water Alternatives* [Preprint].

Berkes, F., Colding, J. and Folke, C. (2002) *Navigating Social-Ecological Systems Building Resilience for Complexity and Change*. Cambridge: Cambridge university press. Available at: https://doi.org/https://doi.org/10.1017/CBO9780511541957.

Blanco, E. and Donoso, G. (2021) 'Drivers for collective groundwater management: The case of Copiapó, Chile', in S.H. Choi et al. (eds) *Global Water Security Issues (GWSI) 2020 Theme: The role of sound groundwater resources management and governance to achieve water security.* UNESCO, International Centre for Water Security and Sustainable Management , pp. 59–75.

Bravo, G. and Moor, T. De (2008) 'The commons in Europe: from past to future', *International Journal of the Commons*, 2(2). Available at: https://doi.org/10.18352/ijc.98.

Brunner, N. and Starkl, M. (2012) 'Financial and economic determinants of collective action: The case of wastewater management', *Environmental Impact Assessment Review* [Preprint]. Available at: https://doi.org/10.1016/j.eiar.2011.07.001.

del Campo García, M.E. and Sánchez Reinón, M. (2021) 'The Decade of Contentious Politics: The Rise of Social Movements Around Water in Post-transitional Chile', in B. Navarrete and V. Tricot (eds) *The Social Outburst and Political Representation in Chile*. Latin American Societies, Springer, pp. 151–172. Available at: https://doi.org/10.1007/978-3-030-70320-2_9.

Camus, P., Castillo, S. and Muñoz, E. (2019) 'Mecanismos de Apropiación, sistema de administración y resolución de conflictos por el uso de los sistemas de riego en una sociedad colonial', *Revista de Historia y Geografía Universidad Católica Silva Henriquez*, 24.

Carranza, D.M. *et al.* (2020) 'Socio-environmental conflicts: An underestimated threat to biodiversity conservation in Chile', *Environmental Science and Policy*, 110, pp. 46–59. Available at: https://doi.org/10.1016/J.ENVSCI.2020.04.006.

Castillo, S. (2014) *El río mapocho y sus riberas. Espacio público e intervención urbana en santiago de chile (1885-1918)*, *Ediciones Universidad Alberto Hurtado*. Available at: https://doi.org/10.4067/S0250-71612014000300014.

Choe, H. and Yun, S.-J. (2017) 'Commons in East Asia View project Social Movements in South Korea View project'. Available at: https://doi.org/10.21588/dns/2017.46.1.005.

Clement, F. (2010) 'Analysing decentralised natural resource governance: proposition for a "politicised" institutional analysis and development framework', *Policy Sciences*, 43, pp. 129–156.

Cox, M., Arnold, G. and Villamayor-Tomás, S. (2016) 'Design principles in commons science: A response to "Ostrom, Hardin and the commons" (Araral)', *Environmental Science and Policy*, 61, pp. 238–242. Available at: https://doi.org/10.1016/j.envsci.2016.03.020.

CR2 (2019) *Informe a la Nación: La megasequía en Chile La megasequía 2010-2019: Una lección para el futuro*, *Informe a la Nación*. Available at: http://www.cr2.cl/megasequia/.

DGA (2017) 'Actualización del Balance Hídrico Nacional', *Ministerio de Obras Públicas, Dirección General de Aguas, División de Estudios y Planificación, Santiago, Chile, Realizado por: Universidad de Chile y Pontificia Universidad Católica de Chile*, SIT N° 417, p. 378. Available at: https://snia.mop.gob.cl/sad/REH5796v1.pdf.

Dipierri, A.A. and Zikos, D. (2020) 'The role of common-pool resources' institutional robustness in a collective action dilemma under environmental variations', *Sustainability (Switzerland)*, 12(24), pp. 1–21. Available at: https://doi.org/10.3390/SU122410526.

DIRECOM (2018) *Comercio Exterior de Chile enero-septiembre 2018*.

Donoso, G. *et al.* (2010) 'Análisis del Mercado del Agua de Riego en Chile: Una Revisión Crítica a través del caso de la Región de Valparaíso'. Santiago, Chile: ODEPA, Ministerio de Agricultura de Chile.

Donoso, G. (2018a) 'Water Policy in Chile', in *Water Policy in Chile*. Available at: https://doi.org/10.1007/978-3-319-76702-4.

Donoso, G. (2018b) *Water Policy in Chile*. Springer.

Donoso, G., Montero, J.P. and Vicuña, S. (2001) 'Análisis de los mercados de derechos de aprovechamiento de agua en las cuencas del Maipo y el sistema Paloma en Chile: efectos de la variabilidad de la oferta hídrica y de los costos de transacción', *Revista Derecho Administrativo Económico*, 6, pp. 367–387.

Dougnac, A. (1994) 'Manual de historia del Derecho Indiano', in. México: Instituto de Investigaciones Jurídicas, UNAM.

Dougnac, A. and Barrientos, J. (1991) 'El Derecho de Aguas a través de la Jurisprudencia Chilena de los siglos XVII y XVIII', *Revista de Estudios Histórico-Jurídicos*, XIV, pp. 101–136. Available at: http://rehj.cl/index.php/rehj/article/viewFile/188/179 (Accessed: 6 December 2018).

Ebenhöh, E. (2007) 'Designing Agent-based Models of Water Management Regimes using the IAD Framework', *The Challenge of Self-Governance in Complex, Globalizing Economies* [Preprint].

Engler, A. *et al.* (2021) 'Governing Water Resource Allocation: Water User Association Characteristics and the Role of the State', *Water 2021, Vol. 13, Page 2436*, 13(17), p. 2436. Available at: https://doi.org/10.3390/W13172436.

Escenarios Hídricos 2030 (2018) *Radiografía del Agua: Brecha y Riesgo Hídrico en Chile.* Santiago, Chile.

Esteban, J. and Ray, D. (2001) 'Collective action and the group size paradox', *American Political Science Review* [Preprint]. Available at: https://doi.org/10.1017/S0003055401003124.

Fleischman, F.D. *et al.* (2014) 'Governing large-scale social-ecological systems: Lessons from five cases', *International Journal of the Commons*, 8(2), pp. 428–456. Available at: https://doi.org/10.18352/ijc.416.

Fuster, R. *et al.* (2010) 'Gestión Integrada de los recursos hídricos en Chile', *Biblioteca del Congreso Nacional, a través de fondos del Banco Interamericano del Desarrollo. Departamento de Ciencias Ambientales y Recursos Naturales Renovables de la Facultad de Ciencias Agronómicas de la Universidad de Chile*, p. 395.

Fuster, R. (2013) *El estado de la gestión integrada de los recursos hídricos en chile: estudio de casos en la cuenca del río Limarí. Tesis Doctoral*.

Gain, A.K. *et al.* (2021) 'Social-ecological system approaches for water resources management', *International Journal of Sustainable Development and World Ecology*, 28(1), pp. 109–124.

Ganoulis, J. (2022) 'Water Security in the Anthropocene: A Dialectical Water–Man Interaction Model', *Sustainability (Switzerland)*, 14(12). Available at: https://doi.org/10.3390/SU14126955.

Gleick, P.H. and Heberger, M. (2014) 'Water Conflict Chronology', in *The World's Water*. Available at: https://doi.org/10.5822/978-1-61091-483-3_11.

Gleick, P.H. and Shimabuku, M. (2023) 'Water-related conflicts: definitions, data, and trends from the water conflict chronology', *Environmental Research Letters*, 18(3). Available at: https://doi.org/10.1088/1748-9326/acbb8f.

Glowacki, L. and von Rueden, C. (2015) 'Leadership solves collective action problems in small-scale societies', *Philosophical Transactions of the Royal Society B: Biological Sciences* [Preprint]. Available at: https://doi.org/10.1098/rstb.2015.0010.

González, C. (2012) 'El abogado y el procurador de pobres: la representación de esclavos y esclavas a fines de la Colonia y principios de la República 1 The lawyer and solicitor of the poors: the representation of slaves in the late Colonial and Republican periods', *SudHistoria*, 5, pp. 81–98.

Grech-Madin, C. *et al.* (2018) 'Negotiating water across levels: A peace and conflict "Toolbox" for water diplomacy', *Journal of Hydrology*, 559. Available at: https://doi.org/10.1016/j.jhydrol.2018.02.008.

Hearne, R.R. (2018) 'Water Markets', in *Water Policy in Chile*, pp. 117–127. Available at: https://doi.org/10.1007/978-3-319-76702-4_8.

Hearne, R.R. and Donoso, G. (2014) 'Water markets in Chile: Are they meeting needs?', in *Easter K., Huang Q. (eds) Water Markets for the 21st Century. Global Issues in Water Policy, vol 11. Springer, Dordrecht*. Available at: https://doi.org/10.1007/978-94-017-9081-9_6.

Hernández, M. (2021) *65% de causas de Primer Tribunal Ambiental por temas agua*, *Actualidad Minera*. Available at: https://www.mch.cl/2021/03/23/65-de-causas-de-primer-tribunal-ambiental-han-estado-asociadas-a-problematicas-de-agua/# (Accessed: 11 October 2022).

Herrera, M. *et al.* (2019) 'Understanding water disputes in Chile with text and data mining tools', *Water International*, 44(3), pp. 302–320. Available at: https://doi.org/10.1080/02508060.2019.1599774.

Ito, J. (2012) 'Collective action for local commons management in rural Yunnan, China: Empirical evidence and hypotheses using evolutionary game theory', *Land Economics*, 88(1), pp. 181–200. Available at: https://doi.org/10.3368/le.88.1.181.

Kiser, L.L. and Ostrom, E. (1982) 'The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches', in *Strategies of Political Inquiry*, pp. 179–222.

Klare, M.T. (2001) 'Resource wars: The new landscape of global conflict', *Issues in Science and Technology*. Available at: https://doi.org/10.2307/3093336.

Klimes, M. *et al.* (2019) 'Water diplomacy: The intersect of science, policy and practice', *Journal of Hydrology*. Available at: https://doi.org/10.1016/j.jhydrol.2019.02.049.

Klubock, T.M. (2021) 'The early history of water wars in Chile: Rivers, ecological disaster and multinational mining companies', *Environment and History*, 27(3). Available at: https://doi.org/10.3197/096734019X15463432087008.

Larrain, S. and Poo, Pamela (2010) *Conflictos por el agua en Chile: Entre los derechos humanos y las reglas del mercado*, *Chile Sustentable*. Edited by S. Larraín and P Poo. Chile Sustentable.

Lira, P. and Maza, L. (1940) *Régimen legal de las aguas en Chile*. Santiago: Editorial Nascimento. Available at: https://snia.mop.gob.cl/repositoriodga/handle/20.500.13000/4121 (Accessed: 29 November 2022).

Lozano Parra, J., Pulido Fernández, M. and Garrido Velarde, J. (2021) 'The Availability of Water in Chile: A Regional View from a Geographical Perspective', in *Resources of Water*. Available at: https://doi.org/10.5772/intechopen.92169.

MacQuarrie, P.R., Viriyasakultorn, V. and Wolf, A.T. (2008) 'Promoting cooperation in the Mekong region through water conflict management, regional collaboration, and capacity building', *GMSARN International Journal*, 2.

Martín, L. and Justo, J.B. (2015) 'Análisis, prevención y resolución de conflictos por el agua en América Latina y el Caribe', *Serie Recursos Naturales y Desarrollo, CEPAL*, 171, p. 62.

Martínez-Fernández, J., Banos-González, I. and Esteve-Selma, M.A. (2020) 'An Integral Approach to address Socio-Ecological Systems Sustainability and their uncertainties', *Science of the Total Environment*, 762.

McGinnis, M.D. (2011a) 'An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework', *Policy Studies Journal* [Preprint]. Available at: https://doi.org/10.1111/j.1541-0072.2010.00401.x.

McGinnis, M.D. (2011b) 'Networks of Adjacent Action Situations in Polycentric Governance', *Policy Studies Journal*, 39(1), pp. 51–78. Available at: https://doi.org/10.1111/J.1541-0072.2010.00396.X.

Meinzen-Dick, R. (2007) 'Beyond panaceas in water institutions', *Proceedings of the National Academy of Sciences of the United States of America* [Preprint]. Available at: https://doi.org/10.1073/pnas.0702296104.

Meinzen-Dick, R. *et al.* (2018) 'Playing games to save water: Collective action games for groundwater management in Andhra Pradesh, India', *World Development*, 107, pp. 40–53. Available at: https://doi.org/10.1016/J.WORLDDEV.2018.02.006.

Molenveld, A. and van Buuren, A. (2019) 'Flood Risk and Resilience in the Netherlands: In Search of an Adaptive Governance Approach', *Water 2019, Vol. 11, Page 2563*, 11(12), p. 2563. Available at: https://doi.org/10.3390/W11122563.

Molle, F., López-Gunn, E. and Van Steenbergen, F. (2018) 'The local and national politics of groundwater overexploitation', *Water Alternatives*, 11(3), pp. 445–457.

De Moor, T. (2008) 'The silent revolution: A new perspective on the emergence of commons, guilds, and other forms of corporate collective action in Western Europe', *International Review of Social History*, 53(SUPPL. 16). Available at: https://doi.org/10.1017/S0020859008003660.

OECD (2011) *Water Governance in OECD Countries: A Multi-level Approach*, *OECD Studies on Water*. OECD Publishing. Available at: https://doi.org/10.1787/22245081.

OECD (2012) *Gobernabilidad del Agua en América Latina y el Caribe : Un enfoque multinivel*, *OECD Studies on Water*. Éditions OCDE.

OECD (2018) *Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices*, *OECD Studies on Water*. OECD Publishing, Paris. Available at: https://doi.org/https://doi.org/http://dx.doi.org/10.1787/9789264292659-en.

Oñate-Valdivieso, F. *et al.* (2021) 'Application of Ostrom's Institutional Analysis and Development Framework in River Water Conservation in Southern Ecuador. Case Study: The Zamora River', *Water 2021, Vol. 13, Page 3536*, 13(24), p. 3536. Available at: https://doi.org/10.3390/W13243536.

Ostrom, E. (1986) 'An agenda for the study of institutions', *Public Choice*, 48, pp. 3–25. Available at: https://doi.org/10.1007/BF00239556.

Ostrom, E. (1990) *The Evolution of Institutions for Collective Action*, *Political Economy of Institutions and Decisions*. Available at: https://doi.org/10.1017/CBO9780511807763.

Ostrom, E. (1998) 'A Behavioral Approach to the Rational Choice Theory of Collective Action', *The American Political Science Review*, 92(1), pp. 1–22.

Ostrom, E. (1999) 'Institutional Rational Choice: An Assessment of the Institutional Analysis and Development Framework', in *Theories of the Policy Process*, pp. 21–64.

Ostrom, E. (2007) 'A diagnostic approach for going beyond panaceas', *Proceedings of the National Academy of Sciences of the United States of America*, 104(39), pp. 15181–15187. Available at: https://doi.org/10.1073/pnas.0702288104.

Ostrom, E. (2009a) 'A general framework for analyzing sustainability of social-ecological systems', *Science*, 325(5939), pp. 419–422. Available at: https://doi.org/10.1126/science.1172133.

Ostrom, E. (2009b) *Understanding institutional diversity*, *Understanding Institutional Diversity*. Available at: https://doi.org/10.1093/oso/9780190672492.003.0008.

Ostrom, E. (2011) 'Background on the Institutional Analysis and', *Policy Studies Journal*, 39(1), pp. 7–27. Available at: https://doi.org/10.1111/j.1541-0072.2010.00394.x.

Ostrom, E. *et al.* (2011) *Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal*, *Improving Irrigation in Asia: Sustainable Performance of an Innovative Intervention in Nepal*. Available at: https://doi.org/10.4337/9780857938022.

Ostrom, E. (2015a) *Governing the commons*. Cambridge university press.

Ostrom, E. (2015b) *Governing the commons: The evolution of institutions for collective action*, *Governing the Commons: The Evolution of Institutions for Collective Action*. Available at: https://doi.org/10.1017/CBO9781316423936.

Ostrom, E., Gardner, R. and Walker, J. (1994) 'Rules, Games, and Common-Pool Resources', *Rules, Games, and Common-Pool Resources* [Preprint]. Ann Arbor: University of Michigan Press. Available at: https://doi.org/10.2307/2083092.

Ostrom, E., Janssen, M.A. and Anderies, J.M. (2007) 'Going beyond panaceas', *Proceedings of the National Academy of Sciences of the United States of America*, 104(37), pp. 15176–15178. Available at: https://doi.org/10.1073/pnas.0701886104.

Palerm-Viqueira, J. (2010) 'A comparative history, from the 16th to 20th centuries, of irrigation water management in Spain, Mexico, Chile, Mendoza (Argentina) and Peru', *Water Policy* [Preprint]. Available at: https://doi.org/10.2166/wp.2010.110.

Peña, H. *et al.* (2011) *Temas Prioritarios para una Política Nacional de Recursos Hídricos.* Comisión de Aguas, Instituto de Ingenieros de Chile.

Piwonka, G. (1999) *Las aguas de Santiago de Chile, 1541-1999*. Editorial Universitaria. Available at: https://books.google.com/books/about/Las_aguas_de_Santiago_de_Chile_1541_1999.html?id=CyqWILXMW2kC (Accessed: 29 November 2022).

Piwonka, G. (2000) 'Regulación cuántica y jurídica de las aguas en Chile: el debate en torno al regador chileno.', *Revista Derecho Administrativo Económico*, (6), pp. 433–450. Available at: http://redae.uc.cl/index.php/redae/article/view/120 (Accessed: 6 December 2018).

Popovici, R. *et al.* (2022) 'Maladaptive learning in Peru's integrated water resources management', *Environmental Science and Policy*, 127, pp. 209–217. Available at: https://doi.org/10.1016/J.ENVSCI.2021.09.012.

Poteete, A.R., Janssen, M.A. and Ostrom, E. (2010) *Working together: Collective action, the commons, and multiple methods in practice*, *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*.

Poteete, A.R. and Ostrom, E. (2004) 'Heterogeneity, group size and collective action: The role of institutions in forest management', *Development and Change* [Preprint]. Available at: https://doi.org/10.1111/j.1467-7660.2004.00360.x.

Powell, J. and Bundhoo, D. (2019) *Negotiating a way towards consilience in managing conflicts over commons: a multi-stakeholder dialogue Report*.

Puig, A. (1999) *El Fortalecimiento de las Organizaciones de Usuarios para una Gestión Integrada de los Recursos Hídricos*.

Rinaudo, J.D. and Donoso, G. (2019) 'State, market or community failure? Untangling the determinants of groundwater depletion in Copiapó (Chile)', *International Journal of Water Resources Development*, 35(2), pp. 283–304. Available at: https://doi.org/10.1080/07900627.2017.1417116.

Rivera, D. (2013) *Usos y derechos consuetudinarios de aguas. Su reconocimiento, subsistencia y ajuste*. Thompson Reuters.

Rivera, D. *et al.* (2016) 'Legal disputes as a proxy for regional conflicts over water rights in Chile', *Journal of Hydrology* [Preprint]. Available at: https://doi.org/10.1016/j.jhydrol.2016.01.057.

Rivera, D. *et al.* (2020) 'Conflictividad judicial de aguas en Chile: caracterización y propuestas para mejorar su prevención y resolución', *Propuestas para Chile 2019. Centro de Políticas Públicas UC* [Preprint].

Rojas, C. (2014) 'Autogestión y Autorregulación regulada de las aguas: Organizaciones de usuario de aguas (OUA) y Juntas de Vigilancia de Ríos', *Ius et Praxis*, 20(1), pp. 123–162. Available at: https://doi.org/10.4067/s0718-00122014000100006.

Rudd, M.A. (2004) 'An Institutional Framework for Designing and Monitoring Ecosystem-Based Fisheries Management Policy Experiments', *Ecological Economics*, 48, pp. 109–124.

Von Rueden, C. *et al.* (2014) 'Leadership in an Egalitarian Society', *Human Nature* [Preprint]. Available at: https://doi.org/10.1007/s12110-014-9213-4.

Saravia Matus, S. *et al.* (2020) 'Desafíos hídricos en Chile y recomendaciones para el cumplimiento del ODS 6 en América Latina y el Caribe', *Serie Recursos Naturales y Desarrollo, CEPAL*, 198, p. 77. Available at: https://www.cepal.org/sites/default/files/publication/files/46503/S2000726_es.pdf.

Singleton, B.E. (2017) 'What's missing from Ostrom? Combining design principles with the theory of sociocultural viability', *https://doi.org/10.1080/09644016.2017.1364150*, 26(6), pp. 994–1014. Available at: https://doi.org/10.1080/09644016.2017.1364150.

Skarbek, D. (2020) 'Qualitative research methods for institutional analysis', *Journal of Institutional Economics*, 16(4). Available at: https://doi.org/10.1017/S174413741900078X.

Sridhar, S. (2008) 'Kashmir and Water: Conflict and Cooperation', *Swords and Ploughshares, winter 2007-8*, Winter 2007-2008. Available at: https://hdl.handle.net/2142/15473 (Accessed: 14 August 2023).

Stewart, D. (1970) *El Derecho de Aguas en Chile*. Santiago, Chile: Editorial Jurídica de Chile.

Taher, T. *et al.* (2012) 'Local groundwater governance in Yemen: building on traditions and enabling communities to craft new rules', *Hydrogeology Journal 2012 20:6*, 20(6), pp. 1177–1188. Available at: https://doi.org/10.1007/S10040-012-0863-1.

Vergara, A. (2017) 'Las aguas como bien público (no estatal) y lo privado en el derecho chileno: evolución legislativa y su proyecto de reforma', *Revista Derecho Administrativo Económico*, (8), pp. 63–79. Available at: http://redae.uc.cl/index.php/redae/article/view/312 (Accessed: 6 December 2018).

Villamayor-Tomas, S. *et al.* (2015) 'The Water-Energy-Food Security Nexus through the Lenses of the Value Chain and the Institutional Analysis and Development Frameworks', *Water Alternatives*, 8(1), pp. 735–755. Available at: www.water-alternatives.org (Accessed: 2 May 2022).

Wobeser, G. von (1989) 'Surgimiento y Consolidación de la Hacienda', in *La formación de la hacienda en la época colonial. El uso de la tierra y el agua*.

Wolf, A.T. (1998) 'Conflict and cooperation along international waterways', *Water Policy*, 1(2). Available at: https://doi.org/10.1016/S1366-7017(98)00019-1.

World Bank (2011) 'Diagnóstico de la gestión de los recursos hídricos. Chile', *Departamento del Medio Ambiente y Desarrollo Sostenible* [Preprint]. Available at: https://doi.org/10.1029/2001WR000748.

World Bank (2013) 'Estudio para el mejoramiento del marco institucional para la gestión del agua. Chile', *Departamento del Medio Ambiente y Desarrollo Sostenible* [Preprint].

Xu, Y. and Yao, Y. (2015) 'Informal institutions, collective action, and public investment in rural China', *American Political Science Review* [Preprint]. Available at: https://doi.org/10.1017/S0003055415000155.

Yoffe, S., Giordano, M. and Wolf, A.T. (2003) 'CONFLICT AND COOPERATION OVER INTERNATIONAL FRESHWATER RESOURCES: INDICATORS OF BASINS AT RISR1', *Journal of the American Water Resources Association*, 39(5).

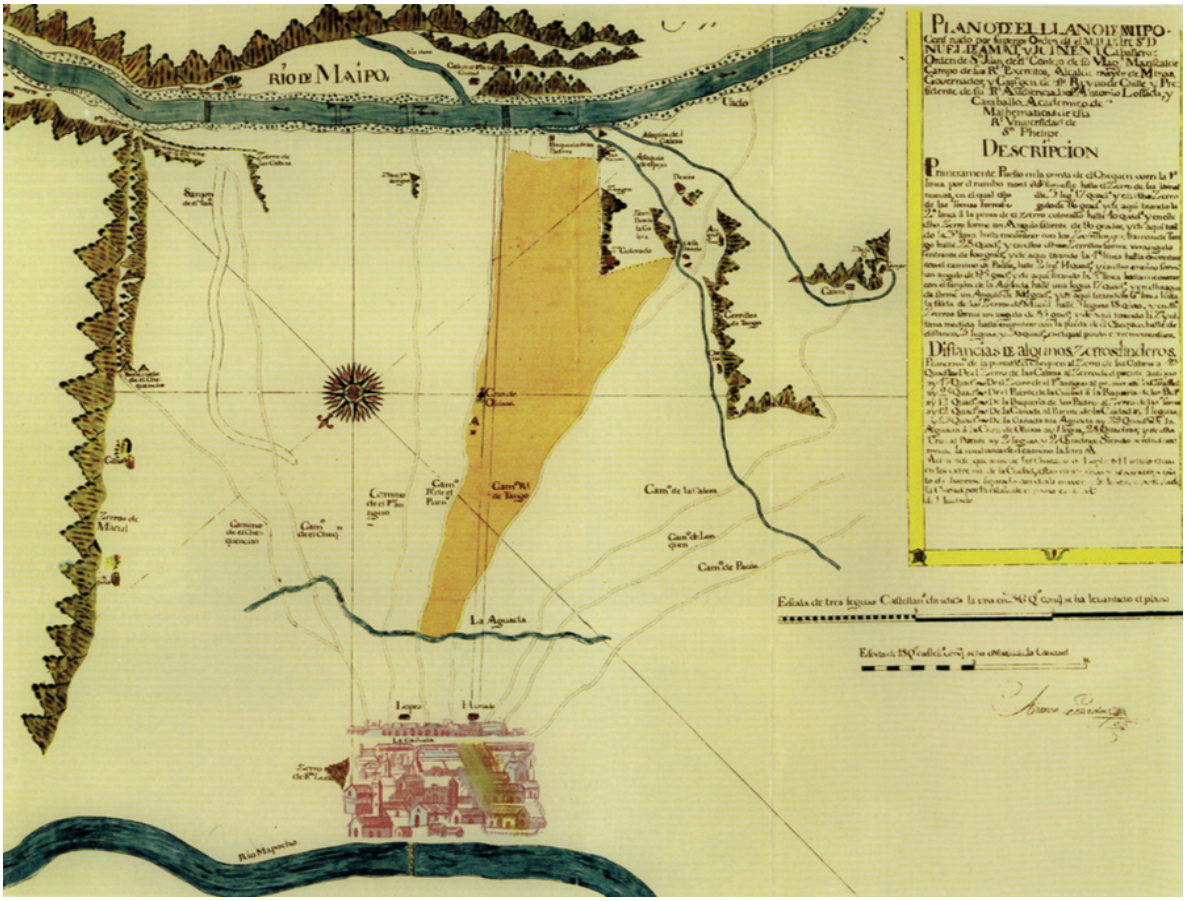
Zamora y Camino, J.M. (1844) *Biblioteca de legislación ultramarina en forma de diccionario alfabético*. Madrid: Imprenta de Alegría y Charlain.

Zhang, Y. (2018) 'Crossing the divide: an integrated framework of the commons', *Evolutionary and Institutional Economics Review*, 15, pp. 25–48. Available at: https://doi.org/10.1007/s40844-017-0077-2.

Zhang, Y. (2019) 'Governing the water commons in China: from historical oriental despotism to contemporary fragmented hydraulic state', *International Journal of Water Resources Development*, 35(6), pp. 1029–1047. Available at: https://doi.org/10.1080/07900627.2018.1508989.

Zhang, Y. (2020) 'How did the lost Shangri-La get lost? The tragedy of the groundwater commons in Lijiang, China', *Water*, 12(11). Available at: https://doi.org/10.3390/w12113131.

Appendix A. Map of colonial Santiago (around 1755-1761) by Antonio Lozada. This historical map shows the Maipo River and, at the bottom, the city of Santiago capturing waters from the Mapocho River.



Chapter 5: Closing remarks and future research

Water management isn't rocket science; it's actually far more complex.

1. Overview

The present dissertation has studied different theories generally used for the study of socio-ecological systems or institutional schemes, analyzed their potential use in water systems, and bring them together into one framework, to be used in the analysis of these systems.

Thus, in the first chapter, a review of the different theories that could be helpful was carried out, together with the study of their application in water matters. The results show that the mentioned theories offer valuable insights for the study of natural resource systems and their institutions, but they face challenges when applied to water resources due to their specificity and complexity. The chapter then explores the initial research question regarding whether current collective action theories could be useful for understanding water socio-ecological systems. It presents the adapted framework, and all its components, created by using elements of the different theories and studies reviewed. It also opens more questions than those solved, since it leaves the application of this theoretical adapted framework for the following chapters.

In chapter 2, a detailed study was carried out using tools from the Design Principles for Sustainable Management of Common-Pool Resources, the SES framework and some elements of the IAD framework, analyzing and understanding the barriers and solutions for organizing groundwater associations (using the Copiapó basin as a case study). The study offered insights, not only for improving groundwater governance, but for developing an integrative collective water governance that can hold surface and groundwater as well. This was a first step towards adapting and expanding the SES Framework in order to consider water management variables, and thus, towards solving the question regarding whether these theories detect triggers and challenges towards sustainably managing local water associations. It also revealed that the consideration of broader dimensions, such as history, social dynamics, and national-scale influences, could provide for an added robustness of the analysis. Thus, it suggests that further research regarding different groundwater case studies should be conducted to strengthen the tool, and for supporting an integrative collective water governance that can hold surface and groundwater as well.

An adapted framework was developed with these insights and was studied in chapter 3 and 4. In the first, it was applied towards two case studies, to prove its flexibility and analysis capacity. It proved to be valuable for exploring complex water management systems, such as a groundwater example (the same Copiapó case, studied previously), while also allowing the examination of complex governance structures (such as the Aconcagua case). Although it has demonstrated its utility at the local level, its versatility allows for potential applications to higher levels of water management, including sub-national and national systems. Thus, chapter 3 proved the framework aids in understanding the dynamics of water socio-ecological systems, revealing institutional failures and promoting cooperation. By empowering local associations and improving water systems at all levels, this framework contributes to efficient, fair, and sustainable water management. Here, the research question concerning the framework's utility for analyzing diverse contexts and scales of water systems

was addressed. However, it also underscores the importance of treating each case individually, as even instances within the same country and governed by the same national laws could have entirely different institutional schemes.

The adapted framework was once again used in chapter 4, this time, analyzing water-related conflicts that were addressed in the past, specifically during Chilean colonial times. This examination underscored the importance of reviewing historical contexts to comprehend the contemporary water system. This, since the conflicts reviewed reveal enduring practices that have lasted until present days, longstanding multiple legal and normative reforms. It also shows the relevance of reviewing conflict resolution cases, more than the legal framework itself, since the jurisprudence and practice may sometimes be more official than the formal law. In essence, the key takeaway is that the adapted framework facilitates the understanding of a community's needs, empowering them to effectively manage their local water systems. By improving current water systems, empowering the development of efficient, sustainable, and socially validated institutions, this can be achieved. This approach requires to be done from the smallest local water association to upper sub-national and national contexts. It then answered the research question of the usefulness of the framework in the analysis of past experiences and historical trends.

Thus, this research project embarked on a critical exploration of existing theories for natural resource governance, particularly in the context of water institutional systems. The overarching hypothesis driving this research was based on the belief that merging elements of these theories could facilitate a more comprehensive analysis and ultimately pave the way for better water resources management and governance. Specific questions posed throughout this study delved into the adaptability of current collective action theories, their ability to identify barriers users face in organizing for effective water governance, and their applicability to limited water systems and contexts, under varying scales, historical trends, and experiences.

The overall findings and insights derived from these studies have made significant strides toward the analysis and identification of elements required for having sustainable water management in a case by case scenario. By shedding light on intricate governance structures, uncovering the dynamics of local water systems, and proposing adaptable frameworks, these studies contribute essential building blocks for the broader objective of sustainable water resource management. The comprehensive understanding gained from these investigations not only allows to address current challenges but also equips stakeholders with the knowledge and tools necessary to navigate and adapt to the evolving demands and changes that the future may bring. Thus, the cumulative impact of these studies extends beyond the immediate context, fostering a foundation for resilient, flexible, and sustainable water management practices on a broader scale.

2. Theoretical contribution

The central objective of this thesis was to contribute to the understanding and improvement of the management of socio-ecological water systems. Drawing on theories commonly employed in the study of social systems, the thesis strove to synthesize them and condense elements of each one, into a unified analytical framework designed for the analysis of water systems. The main objective was to shed light on the potential of current theories towards analyzing and clearing institutional failure interactions, address gaps and propose a practical framework capable of guiding water users, academics, policymakers and authorities in designing effective policies for sustainable and peaceful water resources management.

The developed analytical framework responds to the goal, by being able to evaluate and identify positive elements and potential conflicting situations, at a basin level, for the case studied. The studies undertaken show that comprehensive study of different components, from broad contextual ones to details regarding participants and their responsibilities, the goal can be achieved. A number of improvements can be pointed out, as well as an outline of what is being done correctly in each case. Thus, the analysis of water socio-ecological systems can be achieved, at least at a level that provides for institutional improvements. The method provides a way of analyzing complex polycentric institutions, something that has been avoided or oversimplified in past research. It shows that, even though the process can be messier, and the information required may be more extensive, it achieves a more comprehensive and holistic view of the dynamics and interactions among the different components of the framework. Also, since most of the analytical framework components are flexible, it provides a key feature that can be implemented in multiple scenarios and at different administrative units or scales. This structured approach aimed to not only improve the theoretical foundation but also provide practical insights for real-world applications.

The purpose of this framework remains broad. Even though its usage may help identify miss-management situations regarding the interactions of water institutions and communities themselves, and analyze processes that could be modified, it does not intend to stay there. This tool may be useful for identifying higher institutional failures, as well as solving internal communities' conflicts. It does not, however, intend to serve as a panacea for managing water resources at a basin level. Instead, it is intended to be used for analyzing, evaluating or comparing situations on a case-by-case basis.

In essence, this thesis highlights the critical need for a tailored analytical framework to decipher the complexities of socio-ecological water systems. By addressing the specified objectives, it strives to lay the foundation for informed decision making, sustainable practices and effective policies in the dynamic and intricate field of water resources management. The research journey, guided by a commitment to closing theoretical gaps and offering pragmatic solutions, sets the stage for continued exploration and refinement in this crucial field.

3. Limitations and opportunities for future research

Regarding using theoretical models, the study has shown there is a void regarding group formation and user's participation models in water self-governing institutions when there is no government involvement, such as the Chilean case. Although the review showed the existence of multiple models and mechanisms for boosting water user's cooperation, the development of the specific methodology that will be used to achieve the proposed objectives is still pending. This includes, for example, the development of a specific model for the Chilean case, considering the interaction of two users, between a number of users, or between one water user and the WUA; groundwater users or surface water users, or the interactions between both; together with trust variables and how are they going to be included.

WUAs are currently a key tool in the sustainable management of this scarce resource, taking charge of the information gaps, availability and scarcity of the resource, and have successfully contributed to a successful collective management.

Regarding the study of the developed method, there is still more analysis and testing to be done. In this case, adding more case studies to the analysis, since each basin has a particular scheme and institutional structure, and could provide new insights for the existing method. More studies could also compare water systems from different sizes, for example, analyzing small isolated rural areas, or

huge transboundary water basins. The more case studies are analyzed, the more robust the tool will get.

Thus, even though the goals of the study were met, this is just a starting point to address the problems associated with water management, and it opens new lines of research for focusing the weight on the institutions and their decision making. Altogether, we are one step closer to achieving good water management and governance, towards the final goal of ensuring water security for all.