

Research

Hydrosocial power and territorial transformation: a case study of the Longaví River sub-basin in south-central Chile

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ABSTRACT. This article examines the configuration of hydrosocial territories (HST) and hydrosocial power (HSP) in the Longaví River sub-basin of south-central Chile. Drawing on land-use change analysis, documentary review, and interviews with key actors, we characterize how agricultural intensification and forestry expansion have reshaped both landscapes and water governance over the past three decades. The results show that HSP operates through infrastructure, discourses, and institutions that concentrate water rights and decision-making power in the hands of a few dominant actors. These dynamics reinforce historical and colonial configurations of HST, reproducing socio-environmental inequalities and marginalizing small-scale farmers and local communities. Such path-dependent processes not only constrain the emergence of alternative governance arrangements but also undermine the sustainability of water resource management amid increasing scarcity. By tracing socio-spatial dynamics, the study contributes to understanding how power asymmetries are embedded in hydrosocial relations and discusses their implications for advancing more equitable water governance in Chile and similar contexts.

Key Words: *hydrosocial territories; hydrosocial power; territorial transformation; water rights concentration*

INTRODUCTION

Chile is projected to be among the 25 countries facing the most severe water stress globally by 2025 (Kuzma et al. 2023). According to the comprehensive analysis conducted by Escenarios Hídricos 2030 (EH2030) (2018), Chile's nationwide water deficit is estimated at 82.6 m³/s, with projections indicating that will widen to 149 m³/s by 2030. This anticipated increase in water scarcity poses significant challenges for sustainable water resource management in the country. Precipitation rates in central Chile have decreased from 2010 to the present, inducing a mega-drought that is superimposed on a multi-decade trend toward a drier climate between the regions of Coquimbo (30°S) and Aysén (45°S) (Garreaud et al. 2020). In this context, between 2010 and 2020, the combination of water scarcity and rising demand substantially intensified water stress in central Chile (Álvarez-Garretón et al. 2023). In response, a series of water management policies and regulatory measures have been implemented to address water security, one of which is the Climate Change Framework Law (Ministerio de Medio Ambiente (MMA) 2022), which defines water security as:

Possibility of accessing water with sufficient quality and quantity, considering the natural particularities of each watershed, for its support and use over time for human consumption, health, subsistence, socio-economic development, ecosystem conservation and preservation, promoting resilience against threats associated with droughts or rising rivers, and preventing pollution.

In line with the definition provided by the Climate Change Framework Law, the 2022 reform of the Chilean Water Code (Ministerio de Obras Públicas (MOP) 2022) and the Framework

Law itself (MMA 2022) mandate the development of strategic water resource plans covering 101 basins included in the national inventory.

Given persistent scarcity, ongoing regulatory reforms, and mounting socio-environmental conflicts, it is essential to shift the focus from physical water availability to the political and institutional arrangements that shape access, allocation, and control over water. Disputes are less about water itself, or purely technical and material issues, and more fundamentally about who is entitled to influence decision-making processes, the legitimacy of knowledge claims, and the capacity of actors to define governance outcomes and impose their visions of water (Boelens and Doornbos 2001, Godínez-Madrigal et al. 2020, Gumeta-Gómez et al. 2021). Thus, conflicts cannot be reduced to scarcity or demand alone; they are arenas in which authority, legitimacy, and social justice are constantly negotiated, i.e., power.

The reconfiguration of governance exposes the coexistence of diverse actors, competing interests, and asymmetric power relations that overlap and interact in ways that generate tensions, making water struggles more visible and often more contentious. As Boelens and Doornbos (2001) observed, disputes over water are never merely technical or material, but fundamentally about who is entitled to control decision-making processes and whose visions of water prevail. In this sense, conflicts cannot be reduced to scarcity or demand alone; they are arenas where authority, legitimacy, and social justice are constantly negotiated. Likewise, Boelens et al. (2016) show how neoliberal hydrosocial governance reinforces these asymmetries by institutionalizing regimes that privilege certain users, discourses, and practices while marginalizing others. Such processes of legitimation not only

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regulate water flows, but also actively produce and reproduce socio-political orders, shaping territories in ways that naturalize inequality and normalize exclusion.

To examine these dynamics, we draw on the concept of hydrosocial territories (HST), understood as dynamic configurations that articulate the material, cultural, and political dimensions of water and extend beyond administrative boundaries (Baud et al. 2019, Damonte 2015). From this perspective, water is not only a biophysical resource, but also a socio-political construct, embedded in histories, governance arrangements, and cultural meanings (Swyngedouw and Boelens 2018). Territories are thus continuously reconfigured through shifting political priorities, economic pressures, and environmental conditions (Lopez et al. 2019). Within this framework, hydrosocial power (HSP) refers to the capacity of specific actors to secure dominant positions in water governance by controlling water sources and the institutional, technical, and symbolic arrangements through which water is allocated and given meaning. As noted by Damonte et al. (2016), HSP rests on three interrelated capacities (economic, techno-cognitive, and coercive) that enable actors to maintain authority over other users and territories. These capacities are materialized through mechanisms such as the financing, construction, and management of hydraulic infrastructure; the consolidation of formal water rights; the control of decision-making arenas and regulatory instruments; and the circulation of legitimizing narratives (e.g., efficiency and development). In this way, the exercise of HSP reproduces unequal HST, shaped by the interaction of historical trajectories, infrastructure, and institutional arrangements (Damonte 2015).

The relationship between HSP and HST has drawn increasing attention in recent academic debates, which emphasize that HSTs are both shaped by and constitutive of power relations over water (Boelens et al. 2016, Swyngedouw 2009). Hydrosocial power operates at multiple spatial and administrative levels (local, regional, and national) and within different arenas (public, private, and civil society), generating inequalities in access to water, control over decision making, and distribution of benefits derived from water use (Hommes et al. 2016). These inequalities shape social relations and landscapes, determining which uses and users are prioritized, as well as how decisions regarding infrastructure and policies are made (Boelens et al. 2019, Duarte Abadía et al. 2019, Hommes and Boelens 2017). These dynamics often result in the concentration of water rights, the marginalization of vulnerable users, primarily smallholder farmers and rural communities with limited access to formal water rights and weak representation in decision-making arenas, and the absence of equitable spaces for participation (Hoogesteger and Verzijl 2015, Romano 2016).

Comparative studies further illustrate these dynamics. For instance, Baud et al. (2019) show how agribusiness expansion and water scarcity in Peruvian valleys reconfigure governance and generate new HSTs marked by inequality. Hommes et al. (2019) document how rural–urban conflicts in Peru and Spain reshape water distribution, and Meehan et al. (2020) highlight that inequalities persist even in contexts of apparent abundance in the global North. Similarly, Swyngedouw and Boelens (2018) demonstrate that centralized water resource policies and infrastructures (e.g., dams, irrigation systems) reconfigured

landscapes and power relations, consolidating state authority within a techno-political project in Spain during the 20th century. In Latin America, Rocha (2021) and Duarte Abadía (2023) report how indigenous and Afro-descendant communities mobilized relational ontologies and epistemologies to resist dispossession and defend water sovereignty. Taken together, these works underscore the relevance of HSP–HST relationships for understanding water governance, struggles for justice, and social-ecological reconfiguration.

Synthesizing the findings across these studies, it becomes clear that HSP–HST relationships are central to analyzing water governance. Yet much of this research has concentrated on metropolitan regions or extractive economies, reflecting contexts where conflicts are highly visible and politically salient (Avanco et al. 2025, Castillo et al. 2023). In Chile, for example, studies have largely focused on the Loa River in the north (Prieto 2016) and the Maipo River in the Metropolitan Region (Budds 2020), whereas intensive agricultural sub-basins in south-central Chile remain comparatively overlooked despite their social-ecological relevance and exposure to export-oriented farming. This study addresses this gap by examining the Longaví River sub-basin in south-central Chile, with the specific objective of analyzing how HSP relations shape territorial configurations and water governance dynamics. It builds upon and complements previous technical analyses of the sub-basin (Lillo-Saavedra et al. 2021) while incorporating local-level dynamics of water users' organizations. In doing so, the study offers both a novel empirical focus and a theoretical contribution to debates on HST and water justice.

METHODOLOGY

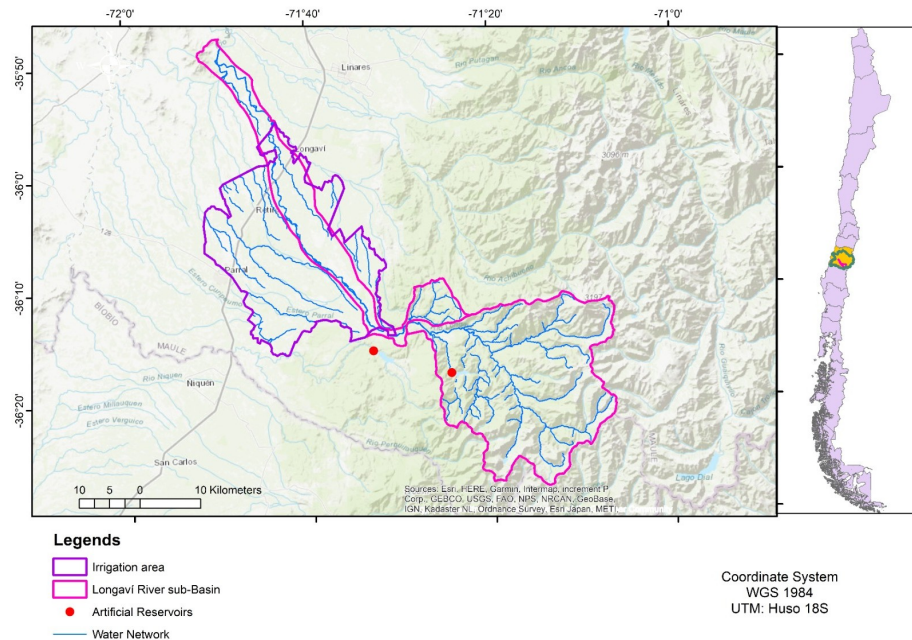
The methodological approach connects the conceptual lens of HSP and HST with the empirical analysis of the Longaví River sub-basin. The study was structured around two complementary dimensions: (i) a hydrosocial characterization of the sub-basin, tracing land use/land cover (LULC) transformations and socio-environmental conditions; and (ii) the construction of the hydrosocial network, identifying key actors and mapping the relations and power asymmetries that shape water governance. We combined cartographic analysis, documentary review, field observations, and semi-structured interviews, linking material changes in land and water use with the organizational and institutional dynamics observed in the basin.

Geospatial processing and qualitative data analysis produced cartographic outputs of land use in the sub-basin, along with maps of water rights, infrastructure distribution, demographic dynamics, and actor networks. Interview data were triangulated with field observations, documentary sources (e.g., Junta de Vigilancia Río Longaví (JVRL) annual reports), and official cartographic data sets. This triangulation enhanced the validity of the findings by integrating multiple layers of evidence, both narrative and visual, thus reducing interpretive bias and strengthening the robustness of the analysis of hydrosocial configurations and power asymmetries.

Study area

The Longaví River sub-basin extends over 965.5 km² (36°08'S, 71°40'W) and constitutes a tributary of the Maule basin, representing approximately 5% of its total area. The river

Fig. 1. Study area and river network within Longaví River sub-basin. Source: authors, based on data from DGA (2023).



originates in the Andes, at around 2000 m.a.s.l., and flows north–south for nearly 120 km across the Central Valley of Chile (Fig. 1). Its hydrography is shaped by the Longaví River and its tributaries, particularly the Blanco River, as well as by artificial reservoirs such as Bullileo and Digua, which play a central role in irrigation. Hydrologically, it is characterized by a pluvio-nival flow regime, as both rainfall and snowmelt contribute significantly to seasonal streamflow. At the Quiriquina gauging station, the mean daily streamflow is estimated at 42.8 m³/s, with peak flows occurring during winter (rainfall) and spring (snowmelt) (Centro de Ciencias del Clima y la Resiliencia (CR2) 2025).

The Longaví River sub-basin has a Mediterranean climate, with warm, dry summers and cold, wet winters. Mean annual precipitation, measured at the Quiriquina meteorological station, reaches 1273 mm (CR2 2025), with most rainfall concentrated between May and July. In the Andean headwaters, conditions are colder and semi-arid, with glaciers, snow packs, and pronounced daily thermal oscillations. Geomorphologically, the sub-basin spans three units: the Andean cordillera (1000–3200 m), the precordillera or foothills (250–1000 m), and the Central Valley (100–350 m), the latter concentrating most agricultural and urban activities.

A mosaic of irrigated agriculture, forestry, and natural vegetation characterizes the LULC. The valley floor is dominated by intensive fruit production, including walnuts, apples, cherries, hazelnuts, and blueberries, among others. Forestry plantations of pine and eucalyptus have expanded on the hillsides, frequently replacing scrubland and secondary native forest. Remnants of native vegetation, dominated by *Nothofagus* species such as hualo and roble, persist mainly in the precordillera and cordillera. Urban areas are concentrated in the towns of Longaví, Retiro,

and Parral. This configuration highlights the competing pressures between agricultural intensification, forestry expansion, and conservation, shaping the hydrosocial dynamics of the basin.

The irrigation zone (631 km²) influenced by the Longaví River sub-basin encompasses the three municipalities of Parral, Retiro, and Longaví, with a combined population of 92,140 inhabitants, Parral being the most populous. Approximately 49% of this population lives in rural areas, primarily within the municipality of Longaví (Instituto Nacional de Estadística (INE) 2017). The sub-basin itself is home to 45,798 inhabitants, most of whom fall within the 40–59 and 0–19 age ranges. This distribution reflects an aging demographic profile, where younger cohorts tend to migrate to other regions of the country. Between 1992 and 2017, the rural population declined by 12% in Longaví, 20% in Retiro, and 11% in Parral (INE 2017). In 2017, the demographic dependency index, defined as the ratio of dependents (under 15 and over 65 yrs of age) to the working-age population, stood at 54% in Parral, 49% in Longaví, and 51% in Retiro, all above the regional (48%) and national (46%) averages. In 2020, the income-based poverty index was also higher than the national (11%) and regional (12%) averages, ranging from 14% to 17% across the three municipalities (Ministerio de Desarrollo Social y Familia 2022). Average educational attainment in the area is 7.6 yrs of schooling, below the national mean (12.1). Collectively, these indicators suggest that local communities face a substantial social burden and socioeconomic disadvantage, factors that may increase their vulnerability to water scarcity and governance conflicts.

The local economy is predominantly based on primary sector activities, particularly agriculture. Approximately 30% of the population are employed in farming, livestock production, forestry, and fishing, and 58% work in tertiary sector activities (INE 2017). The sub-basin accounts for about 20% of the country's agricultural production and 15% of national exports.

Water scarcity has been a persistent issue in the area since 2010. At least five official water shortage declarations were issued (2014, 2017, 2018, 2021, 2022). As a result, 477 households in rural areas of the three municipalities relied on water delivered by tanker trucks; 4578 obtained supplies from wells or norias; and 250 depended on springs, streams, canals, or reservoirs (INE 2017, Dirección general de aguas (DGA) 2023).

Since 1957, the Longaví irrigation system has been governed by the “Junta de Vigilancia del Río Longaví y sus Afluentes” (JVRL), a non-profit users’ organization that holds formal authority over the administration and allocation of water rights within the sub-basin. Beyond water distribution, the JVRL plays a central role in coordinating collective decision making, overseeing irrigation projects, and strengthening the governance capacities of its member water communities (JVRL 2022).

The Longaví irrigation system administers water rights equivalent to around 38,520 L/s to supply water to 32 communities that bring together around 5000 agricultural producers (large, medium, and small), where 80% are small farmers with lots under 12 ha. All the producers combined irrigate around 50,000 ha through 20 intakes, which is the second highest number of hectares under irrigation out of all Water Boards within the Maule federation. It should be mentioned that beyond the area of the water board and the watershed is the Digua reservoir, which is fed from the Longaví River (JVRL 2022).

Overall, as described by Lillo-Saavedra et al. (2021), the conditions of heavy fragmentation for land lots, technological asymmetries, and high crop sensitivity to extreme climate events in the context of climate change make the Longaví River sub-basin quite representative of farming basins in south-central Chile.

Land use/land cover change analysis

To analyze landscape transformations in the Longaví River sub-basin, we used official LULC data sets provided by the National Forest Service for the years 1986, 1999, 2009, and 2016 (Corporación Nacional Forestal (CONAF) 2024). The LULC data set offers consistent temporal benchmarks for assessing long-term trends over a 30-yr period as shapefiles. The data sets were clipped to the Longaví River sub-basin boundaries, and the original categories were reclassified into seven groups to ensure comparability across periods: scrubland, native forest, forestry plantations, agriculture, urban areas, industrial areas, and other LULC. Geospatial processing was conducted in ArcGIS 10.4.1, including raster-to-polygon conversion, clipping, and reclassification. For each year, the total surface area of each LULC class was calculated, expressed both in hectares and as percentages of the study area.

Change detection analysis was performed using cross-tabulation of land cover classes for consecutive periods (1986–1999, 1999–2009, 2009–2016), allowing the identification of net changes in surface area and specific transitions, such as the conversion of native forest and scrubland into forestry plantations or agricultural land. Land use/land cover transitions were quantified in both absolute terms (ha) and relative share of the total sub-basin, providing a quantitative basis to interpret socio-environmental implications.

Field work and interviews

Field work was conducted in two campaigns during 2023, including guided field tours with key actors to identify areas of interest, with the Bullileo Reservoir standing out as a key infrastructure element for supplying water users, mainly farmers under the administration of the JVRL. Other participant observations (Döring et al. 2024) took place during territorial visits, where the research team observed organizational dynamics in the JVRL, such as decision making, approval of the annual budget, and the dissemination of information to water users regarding the requirements of the new Chilean Water Code (MOP 2022).

Semi-structured interviews were conducted with water-related actors at three levels: three at the national level (public sector institutions), three at the sub-basin level (linked to water management and governance), and three at the canal level (water users). Six interviews were conducted in person and three online, each lasting an average of 2 h. Actor selection was based on their geographical location within the sub-basin (except for those at the national level), their connection to the evolving national water regulation framework, and their role in water management and administration at community and canal levels.

Interviews continued until reaching data saturation; after the ninth interview, responses across levels converged around recurring categories such as water infrastructure, institutional governance, distribution of rights, and narratives of scarcity. At this point, no new insights emerged, and the information became repetitive, confirming that the principal analytical dimensions of interest had been adequately captured. Data saturation was applied as a principle to ensure analytical depth while avoiding unnecessary data collection (Guest et al. 2006).

Document analysis

A bibliographical review of journal articles on HST, HSP, and water governance was carried out, consulting databases such as Scopus and Web of Science for publications from 2011 to 2025. Secondary sources included historical documents (annual JVRL records) about water management in the territory under the Water Board from 1998 to 2023. All bibliographical material, together with the transcripts of the semi-structured interviews, was analyzed through content analysis using Atlas.ti 23.

The coding process combined deductive and inductive strategies. Deductive codes were derived from the theoretical framework, focusing on concepts such as HST, hydrosocial relations, governance, and power asymmetries. Inductive codes emerged directly from the empirical material, capturing specific themes raised by interviewees and documents, such as conflicts over water distribution, organizational dynamics within the JVRL, and changing land use practices. Codes were progressively refined into analytical categories through constant comparison across data sources, allowing us to identify convergences, divergences, and emergent patterns. This systematic approach provided a robust basis for interpreting how discourses and practices around water governance contribute to the production of HSTs in the Longaví River sub-basin.

Hydrosocial network

To analyze the interactions among actors, the hydrosocial network of the Longaví River sub-basin was constructed. Following Wester (2008), HST are composed of networks of ties in which water and

the societies it sustains maintain a reciprocal relationship, each influencing and reshaping the other (Budds et al. 2014). From this perspective, hydrosocial networks encompass three dimensions: the physical (rivers and streams), the technological (the means through which societies appropriate and manage water), and the socio-political (the ways in which human–water relations are understood, regulated, and contested) (Tvedt 2010). To classify relations between actors, two key characteristics were considered: scope and durability. Following Bolding (2004), scope refers to the social, material, and institutional reach of hydrosocial networks, which may extend from a single canal association to the scale of an entire watershed. Durability refers to the stability and persistence of these networks over time, depending on the strength of their heterogeneous components; without water, the network literally dissolves. This conceptual framework provided the analytical basis for mapping and interpreting the multi-scalar relations that underpin water governance in the study area.

We used the concept of socio-spatial scales instead of purely administrative or hydrological levels, as it better captures the interplay between social organization and spatial reach in water governance. From a relational perspective, scales are not neutral or fixed but rather socially produced, fluid, and temporal, as they emerge from social relations in and with space (Muñetón Santa 2016). Thus, scales are continuously redefined through the practices and power relations that shape water management.

Actors were defined as individuals, organizations, or institutions with a recognized role in water use, management, or decision making within the sub-basin. Their identification drew on documentary analysis (e.g., statutes of the JVRL, official records of the DGA), field observations, and semi-structured interviews with key stakeholders. Once identified, actors were classified according to two main criteria: (i) socio-spatial scale of action (national, basin/regional, sub-basin, and local) and (ii) type of relation with other actors. The latter was categorized as membership (M), user (U), member-user (MU), coordination (Coor), or collaboration (Col), depending on the role and intensity of their interactions in water governance. In the network representation, arrows indicate the direction of interaction and can represent either unilateral or bilateral relations. Their thickness reflects the strength and stability of these interactions: thicker lines denote stronger and more stable ties, whereas dotted lines indicate weak and/or unstable connections. Through this coding, actors, links, and arrows were used to operationalize the construction of the hydrosocial network and to analyze the structural position and influence of each actor across different socio-spatial scales of water management.

RESULTS

The results are presented in two sections. The first addresses the hydrosocial characterization of the Longaví River sub-basin, focusing on LULC change, water infrastructure, and the distribution of water rights. The second examines the hydrosocial network, highlighting the actors involved and the interactions that shape water governance.

Hydrosocial characterization of the Longaví River sub-basin

Land use/land cover changes, 1986–2016

Table 1 summarizes LULC changes in the Longaví River sub-basin between 1986 and 2016. Agriculture remained the dominant activity, reflecting a long-standing trajectory of development

Table 1. Land use/land cover (LULC) in the Longaví River sub-basin, 1986–2016. Source: authors, based on data from CONAF (2024); Echeverría et al. (2006).

Land cover	1986 (ha)	1999 (ha)	2009 (ha)	2016 (ha)
Agriculture	52,214 (70%)	57,090 (76%)	56,754 (75%)	53,231 (72%)
Scrubland	14,248 (19%)	10,876 (14%)	9800 (13%)	5500 (8%)
Native forest	5948 (8%)	2600 (3%)	2400 (3%)	2200 (3%)
Forestry plantations	3756 (5%)	7092 (9%)	7800 (10%)	12,056 (16%)
Urban/industrial	<1%	<1%	<1%	<1%

documented since the 19th century (Valladares 1979). Agricultural land peaked in 1999 (76%) but subsequently declined to 72% in 2016, partly replaced by forestry plantations, which expanded from 5% to 16% of the sub-basin. During the same period, scrubland decreased by nearly 8700 ha, and native forest contracted to less than 3%. These transformations align with local accounts of land sales to forestry companies, contributing to the concentration of irrigated hectares and water rights.

These quantitative changes are consistent with local narratives collected during interviews, which emphasize how small and medium-sized farmers increasingly sold their land to forestry companies. According to these accounts, the process has reinforced the concentration of irrigated hectares and water rights, thereby reshaping the socio-environmental configuration of the sub-basin. In this way, land use transitions are not only biophysical transformations but also expressions of HSP relations, where economic pressures, environmental stress, and governance structures converge to redefine access, control, and territorial dynamics.

Water infrastructure

For the Longaví River sub-basin, hydraulic infrastructure has a central role in water allocation and governance. The Bullileo reservoir, located in the upper basin, has a storage capacity of approximately 60 million m³ and is the main contributor to the 20 intakes that distribute water along a network of 854.3 km of canals. This system sustains irrigation over nearly 50,000 ha and supplies 32 canal communities with around 5000 agricultural producers, of which 80% are smallholders farming less than 12 ha. In addition to sustaining this local irrigation system, the sub-basin also contributes water to the Digua reservoir, on the Cato stream. Digua, with a storage capacity of about 220 million m³, receives part of its supply from the Longaví River through a 6.5 km feeder canal (25 m³/s capacity), as well as contributions from the Perquilauquén River via a 12 km canal (20 m³/s). This means that the Longaví River sub-basin not only regulates and distributes water internally through Bullileo but also supports inter-basin transfers to Digua, extending its influence beyond its own territory and adding pressure on local water resources (Sandoval Jeria 2003:65-66).

According to the Public Water Cadaster (DGA-Catastro público de aguas (CPA) 2024), the Maule River basin contains a total of 2160 groundwater rights, of which 1773 include georeferenced coordinates. These rights are associated with wells, norias, and drains, and are allocated for diverse uses, including irrigation, industry, and urban as well as rural drinking water. In 2011, the region registered 810 wells, with 172 located in the municipality of Longaví and 161 in the municipality of Retiro. Interviews with

canal presidents and operators suggest that these numbers have nearly tripled over the past two decades as a response to surface water shortages. This trend is consistent with the 2017 census, which reported that 4221 households within the irrigation area relied on wells for their water supply, representing 22.5% of local homes (INE 2017).

No, it's not working, now that we've made, lots of us have dug wells, because since we've changed crops, I need to water my hazelnuts and walnuts in March, and we don't have any water left in March anymore, so I had to dig a well. (Interview #8, 2023)

....I think there'll be a lot deeper wells and bringing up groundwater and all that. And there's already deep wells. Lots of them. There are people who take a chance and run half their irrigation from wells... Yes, overall, the larger fields have more different products, more things sown and grown, so they've started using deep wells. (Interview #4, 2023)

Water infrastructure is a component that manifests and gives shape to HST. In turn, it is one of the main mechanisms by which HSP operates. For instance, within the study area, a museum for this infrastructure at the heart of the JVRL has been created, reinforcing the central role of this infrastructure in water management.

Well, the reservoir is the main project, it's the heart of the system. It goes back to '47; they started building it around 1927 or '30, and it was finished in '47, and ever since then it's helped with regulation... The State built it, and handed it over to the water board in '78... that's the basis for the regulation, the heart of the system, so that's how we regulate and distribute water availability. (Interview #5, 2023)

The reservoir, it's fundamental for us, it regulates the river and if it's short on water, they put water in the reservoir. (Interview #8, 2023)

Given the water shortage situation and the uncertainty that this generates among water users, discourse has been updated to reinforce the need to improve and deploy water infrastructure.

Look, years ago there was the idea to make a reservoir, but like 25–30 years ago. Since then, I've dreamed that I'll have lots of water, but it's nothing but a dream. And now we're with another reservoir and another one, and it's going on 30 years talking about a new reservoir... (Interview #8, 2023)

...Reservoirs don't increase hectares, they improve irrigation security. The main difference is that instead of irrigating wheat, you start irrigating cherry or fruit trees, or beets or inulins or some annual crop, which doesn't depend on nature, and with another reservoir this irrigation rate could be more steady or even higher. Making it steady or higher improves the conditions for the people there, and they have better investment and business conditions. So instead of making 300 lucas (300,000 CLP) selling wheat, they make 2 million (CLP) from the fruit. That's the key. (Interview #5, 2023)

Water rights

The JVRL administers a total of 20,920 consumptive water rights, equivalent to 38,520 L/s, distributed across the 32 canals of the irrigation system. Each water right, defined as a proportion of the actual or expected streamflow, corresponds to 1.5 L/s, a value established in the statutes of the JVRL without explicit hydrological or technical justification. The El Álamo Forestry Company concentrates the largest water rights, holding approximately 3000 L/s. The bylaws of the JVRL grant the largest rights holder preferential authority, including the presidency of the boards of directors for two canals (Copihue and El Molino) and influence over six additional canals. Furthermore, this actor secures direct representation on the JVRL's board of directors. As emphasized by one interviewee, this institutional arrangement reinforces the capacity of large-scale users to shape decision-making processes within local water communities:

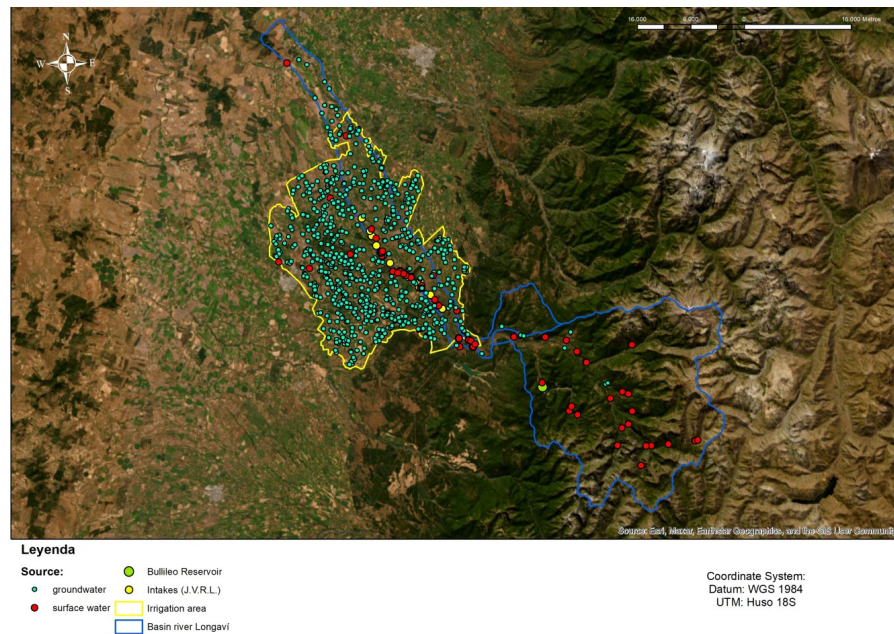
... There are water communities with 10 people, and they elect one person from amongst themselves to be the representative. There're others that are 100 people or 1000. There's a lot of variety in this, so whether it's 10, 100, or 1000 people, the votes are by share, and usually the largest one has a good proportion of the shares in the group... so that's usually who runs the decisions in that small organization... and then that person carries the whole bag of votes from their community. (Interview #5, 2023)

Although there are surface water rights, there is also a growing use of groundwater, which currently lacks specific regulation or a representative organization. According to the Public Water Cadaster (DGA-CPA 2024), groundwater rights already outnumber surface rights in the area, as shown in Fig. 2.

This expansion of wells, which according to our interviews has tripled since 2006 in response to the mega-drought, suggests that in the future the Longaví River sub-basin could increase water availability by complementing surface flows with groundwater extraction. However, decreasing precipitation has led to less groundwater recharge and less streamflow. Thus, putting pressure on groundwater use may create new disputes among those users with economic power to drill deep wells and those relying on surface water. Moreover, even though current regulation fosters conjunctive administration of groundwater and surface water, in practice, users tend to see both systems as non-connected water systems. Emerging patterns in the Longaví River sub-basin include the concentration of water rights, the marginalization of vulnerable users, and the absence of equitable spaces for participation and decision making (Hoogesteger and Verzijl 2015, Romano 2016).

These patterns show how power asymmetries in water governance are reproduced through two key mechanisms: the deployment of water infrastructure and the consolidation of hydrosocial networks, which reinforce the dominance of powerful actors while undermining the position of local communities and ecosystems (Romano 2017). At the same time, demographic processes, such as migration, population aging, and rising dependency ratios, intensify pressures on smallholder farmers, deepening trajectories of exclusion and reinforcing these emergent patterns.

Fig. 2. Distribution of surface and groundwater rights. Source: authors, based on data from DGA-CPA (2024).



The hydrosocial network analysis of the Longavi River sub-basin (Fig. 3) underscores the pivotal role of the JVRL, which holds the highest number of connections with other actors and maintains diverse types of relations that vary in both intensity and directionality. This centrality illustrates the JVRL's authority in coordinating and mediating water governance across multiple domains and socio-spatial scales.

The hydrosocial network underscores the influence of a key user-member actor, simultaneously linked to the forestry sector, the JVRL directorate, and several canal associations. This individual not only presides over two canal associations and maintains influence in six others, but also holds national-level positions, such as chairing the FSC Chile and participating in the Maule forestry board and Longavi Water Resource Administration Society (SARHAL). This multilevel involvement illustrates how individual actors can bridge scales and concentrate power across institutional arenas.

Overall, the network makes visible how asymmetries of power and overlapping roles enable certain actors and organizations to sustain the hydrosocial configuration of the Longavi River sub-basin, reinforcing its durability through the interplay of local, sub-basin, regional, and national relations.

DISCUSSION

The hydrosocial characterization of the sub-basin reveals significant changes in the distribution of agricultural, forestry, and native vegetation land uses during the 1986–2016 period.

The maps show how agricultural and forestry practices dominated the area over the study period, and how water infrastructure was developed primarily to support productive activities—consolidating control in the hands of actors with greater technical knowledge and economic influence over water.

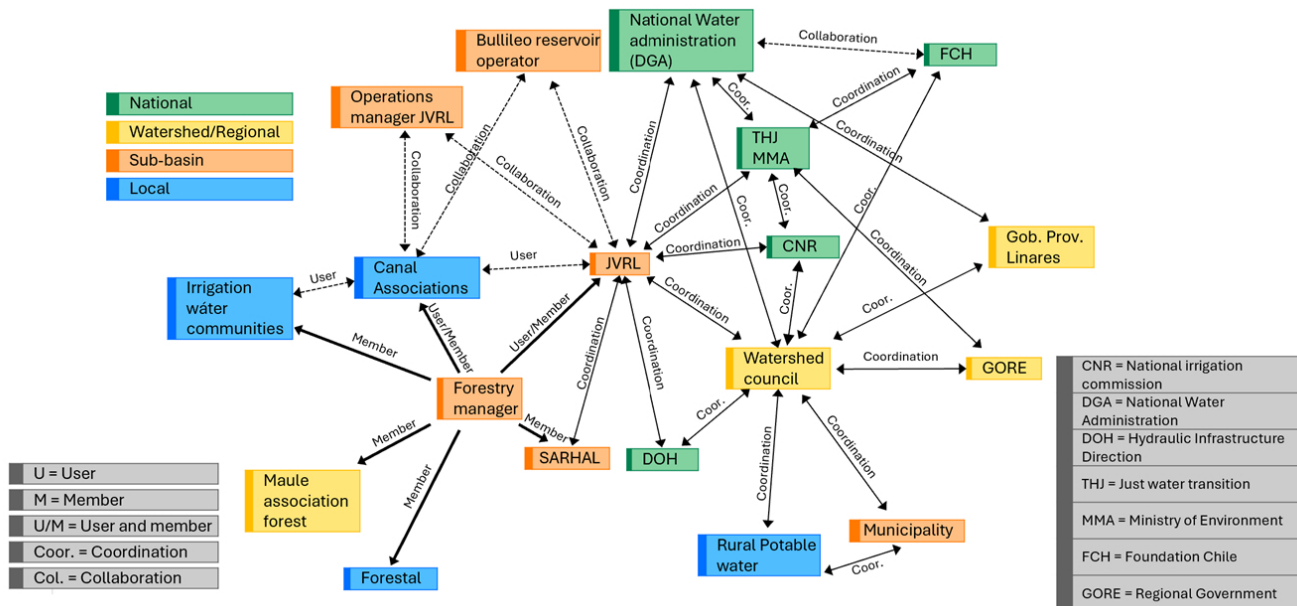
Cascao (2009) uses the concept of water hegemony to refer to the ability of certain actors to dominate and control water resources, imposing their will on others. This phenomenon underscores the importance of critically analyzing the narratives that shape water management policies and practices. As Jerez and Torres (2023) point out, the creation and consolidation of powers have historically been materialized through the deployment of water infrastructure since colonial times. In this sense, the geohistorical analysis of the basin has enabled us to identify the origins of the current hydrosocial network, through which HSP are exercised in the study area.

The transformation of the territory into a zone of continuous expansion of agriculture and forestry plantations has involved the development of irrigation technologies and infrastructure, such as reservoirs, dams, intakes, and canals. Simultaneously, the hegemonic discourse has positioned the reservoir as the “heart” of the watershed and the canals as the “veins” feeding various communities. This historical legacy has shaped current power structures and water management practices in the region.

The cartographic analysis demonstrates a marked transformation of the landscape between 1986 and 2016. Agricultural land expanded significantly until the late 1990s (57,090 ha), but subsequently decreased (53,231 ha), giving way to forestry plantations. At the same time, scrubland vegetation decreased by approximately 8700 ha, equivalent to 11% of the study area. These figures confirm an intensification of productive land uses, particularly forestry, at the expense of native vegetation and small-scale agricultural practices.

Quantitative results of LULC, they also resonate with the social narratives collected during fieldwork. Local interviewees emphasized that the expansion of forestry was linked to the progressive concentration of land and water rights, often through

Fig. 3. Hydrosocial network representing multi-scalar interactions between diverse agents in the Longaví River sub-basin. Source: authors.



the incorporation of small and medium-sized farms into the plantation borders. In this sense, LULC change cannot be understood solely as an ecological or economic process, but as one deeply embedded in power relations around water and territory.

This reading aligns with Damonte (2015), who highlights the relational nature of water, encompassing both its material and immaterial dimensions. In the Longaví River sub-basin, the observed transformations illustrate how water is simultaneously a biophysical resource and a socio-political object, shaped by historical struggles, economic incentives, and institutional asymmetries. The emergence of multi-scalar conflicts around water governance thus appears not as an external outcome of land-use change, but as a constitutive dimension of the same process.

Forestry companies emerge as central agents in the hydrosocial network, particularly regarding the creation and operational mechanisms of HSP, due to their spatial expansion within the sub-basin and their participation in various regional, national, and local platforms, along with other organizations such as the FSC Chile certification agency. In this regard, the study shows a significant concentration of water rights in the hands of dominant actors, including the forestry company El Álamo. This concentration has generated power asymmetries in decision-making processes within water users' organizations, marginalizing small farmers and altering local water governance dynamics.

Goswami and Mehta (2007) warn how powerful actors may use water scarcity narratives to justify and legitimize interventions that reinforce their control over water resources. The "hydrosocial cycle" proposed by Swyngedouw (2009) provides a useful

framework to analyze the multiple and complex interactions surrounding water, demonstrating how its control can transform both natural landscapes and social structures by recognizing water as a socio-natural hybrid. These findings also confirm those of previous studies that reveal how power asymmetries influence the prioritization of certain water users and uses, as well as decision making regarding water infrastructure and management policies (Hommes and Boelens 2017, Boelens et al. 2018, Duarte Abadía et al. 2019).

Water justice emerges as a critical response to conventional water management practices, advocating for an approach that places social and environmental dimensions at the center of the agenda (Servat and Mesa 2020). It seeks to expose and challenge the ways in which power dynamics, exclusion, and inequality shape access to and control over water resources (Boelens et al. 2012, Romero and Ulloa 2018). In a context marked by climate change and growing socio-environmental conflicts, water justice presents itself as both a theoretical and practical proposal aimed at achieving inclusive and equitable water governance (Servat and Mesa 2020).

Current HSP relations in the Longaví River sub-basin are not a rupture but rather a deepening of historical and colonial HST configurations. The network analysis shows how land and water rights remain concentrated in a few actors, particularly forestry and agroindustrial companies, whereas small-scale and community-based users occupy peripheral positions. This configuration has direct implications for sustainable water resource management. By reinforcing patterns of exclusion and privileging large-scale, extractive land uses, current HSP relations reduce social-ecological resilience and limit the possibilities for more equitable and diversified governance arrangements.

The persistence of colonial HST mindsets compromises sustainable water resource management in two ways. First, it consolidates a trajectory of intensification (forestry and industrial agriculture) that comes at the expense of native ecosystems and small-scale farming. Second, it forecloses alternative HST configurations that might support sustainable management, such as community irrigation organizations, ecosystem-based practices, or multi-scalar governance arrangements that acknowledge local knowledge. Thus, what is at stake is not only the recognition of historical continuities, but also how these continuities actively shape, and constrain, the range of possible futures for water governance in the Longaví River sub-basin.

CONCLUSIONS

This case study illustrates how HSP shapes the configuration of HST through the interaction of actors, infrastructure, and resource distribution in the Longaví River sub-basin. By tracing land use transformations, water rights concentration, and the structure of hydrosocial networks, the analysis underscores the need to explicitly address political and power dimensions in water management, alongside promoting more inclusive and equitable approaches to governance in contexts of climate variability and scarcity.

Quantitative and qualitative data allow us to conclude that landscape transformations in the Longaví River sub-basin are inseparable from broader dynamics of resource governance. Rather than a neutral trajectory of agricultural and forestry expansion, these processes reflect the uneven distribution of power and the capacity of certain actors to redefine access to both land and water.

The current configuration of the Longaví River sub-basin HST reflects the consolidation of power by agribusiness and forestry actors, mediated through the JVRL. Powerful actors have leveraged strategic participation across decision-making levels, from the local to the national, to strengthen their influence over water allocation. Water infrastructure plays a key role in this process: the Bullileo reservoir underpins the internal irrigation system, and at the same time, the sub-basin contributes water to the Digua reservoir, extending its influence beyond its territorial limits and reinforcing existing power asymmetries.

More broadly, these results highlight how historical trajectories of infrastructure development and land use change reproduce unequal access to water, thereby limiting alternative configurations of HST. Addressing these asymmetries requires not only technical solutions but also governance frameworks that recognize power imbalances and incorporate the perspectives of small-scale farmers and marginalized users. In this way, the Longaví River sub-basin case provides insights of wider relevance for debates on sustainable and socially just water governance in Chile and beyond.

Author Contributions:

Marcela Salgado: conceptualization, methodology, investigation, writing - original draft, writing - review and editing, supervision. Fabián Sanhueza: conceptualization, software, investigation, writing - original draft. Mario Lillo-Saavedra: conceptualization, methodology, investigation, writing - original draft, writing - review

and editing, project administration, funding acquisition. Valentina Cisterna-Roa: conceptualization, methodology, writing - original draft. Diego Rivera: formal analysis, writing - review. Marcelo Somos-Valenzuela: formal analysis, writing - review.

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Data Availability:

All data sets used in the study are publicly accessible through the websites indicated in the paper, and no specific repository was generated for this study.

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