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A Doubly Invisible Aquifer: Hydrogeological Studies and Actors' Strategies in the Pampa del Tamarugal Aquifer, Northern Chile

Elisabeth Lictevout

Universidad de Concepción, Concepción, Chile; and Carpe Science, San Pedro de la Paz, Chile;
elisabeth.lictevout@gmail.com

Nicolas Faysse

G-Eau research unit, Cirad, Montpellier University, Montpellier, France; and Asian Institute of Technology, Bangkok , Thailand; faysse@cirad.fr

ABSTRACT: In northern Chile groundwater resources are used intensively for mining activities, drinking water and agriculture. This article analyses the groundwater management in the Pampa del Tamarugal Aquifer, paying special attention to the links between (a) how information relating to groundwater resources and its uses is applied to management and (b) actors' strategies and discourses on groundwater management. The analysis focuses on two moments: the decision to stop issuing new water rights and the short-lived experience of a regional water resources research centre. Actors never actually discussed an appropriate groundwater pumping rate and some used groundwater resources as a means of pursuing strategies that were not related to water management per se. Many called for a participatory process to allocate water for different uses, although this would entail changes to Chilean legislation. Such a process would help the Pampa del Tamarugal Aquifer become more 'visible' and could trigger genuine discussion about the status and use of groundwater resources.

KEYWORDS: Groundwater management, hydrogeological assessment, Pampa del Tamarugal, Chile

INTRODUCTION

Water resource management in Chile has attracted worldwide interest. It is based on a system of private water rights, and water is considered to be a fully marketable commodity. The legal and institutional framework follows free market principles. It is regulated by the 1981 Water Code, one of the neoliberal reforms introduced by Pinochet's military regime (1973-1990). The state therefore has a limited role in water management (Bauer, 2004; Lajaunie et al., 2011; Budds, 2013) and water rights are managed in the same way as property (Rinaudo and Donoso, 2018).

Groundwater use was insignificant in Chile until the 1990s. However, since then it has increased rapidly as the allocation of surface water rights was discontinued in 'closed basins' (Molle, 2003) and commercial enterprise has developed in areas where there is no access to surface water (Lajaunie et al., 2011; Rinaudo and Donoso, 2018). This is particularly the case in the region of Tarapacá, which is located in the hyper-arid Atacama Desert, northern Chile. In this region, as in the neighbouring regions of Arica-Parinacota and Antofagasta (Far North, Figure 1), the majority of the water resources are underground and non-renewable. The Far North regions have the world's largest deposits of natural nitrate and copper (US Geological Survey, 2017). Since the 1990s, their exploitation has triggered an economic boom and growing demand for water for domestic use and mining activities (Aitken et al., 2016).

In this context, competition and conflict over water use have intensified (Lajaunie et al., 2011; Costumero et al., 2017). The situation is exacerbated by the fact that the administration has stopped delivering new water rights for an increasing number of aquifers and rivers. In order to meet their water requirements, mining companies attempt to buy water rights from holders, especially small-scale farmers (Valdés-Pineda et al., 2014). The use of saline or desalinated water has also been considered, although this involves high energy costs (Oyarzún and Oyarzún, 2011). Despite the growing tensions over water use, there are no clear decision-making processes for allocating groundwater to balance economic, social and environmental objectives (Budds, 2009, 2012; Rinaudo and Donoso, 2018).

The Pampa del Tamarugal (hereafter PdT) aquifer is a major aquifer located in the Tarapacá region. It plays an important role in providing drinking water, as well as water for mining companies and agricultural use. In 2009, the administration deemed the aquifer to be overused and shortly afterwards stopped issuing new water rights. In 2010, in light of concern over excessive water use for mining activities, the regional government in Tarapacá, the Regional University of Arturo Prat and the National Science and Technology Research Commission created a regional research and development centre for water resources (CIDERH) as part of a national programme to decentralise science. However, in 2015 the regional government withdrew its support and funding for the centre for no official reason. As a result, the centre was forced to halt its work on surface and groundwater resources, including studying the PdT aquifer.

This article analyses the groundwater management of the PdT aquifer, paying particular attention to the links between: i) how information relating to groundwater resources and its uses is applied to groundwater management; and ii) the actors' strategies and discourses regarding groundwater management. The article is organised as follows: the first section describes the institutional framework for groundwater management in Chile, followed by a description of the case study and method used. The results section is divided into four themes: the process leading up to the declaration of a restricted area in 2010, the CIDERH's experience, groundwater management practices and actors' claims and discourses. Drawing from the analyses of these themes, the discussion highlights the main obstacles preventing actors from engaging in a joint groundwater management plan for the PdT aquifer and preventing fruitful use of science to support this engagement.

GROUNDWATER MANAGEMENT IN CHILE

Institutional setting

The 1981 Water Code was primarily designed to regulate surface water (Rivera, 2015; Rinaudo and Donoso, 2018), but when it became necessary to regulate groundwater extraction the same legislation was applied. The Department of Water (*Dirección General de Aguas*, hereafter DGA) is the state agency in charge of monitoring water resources through the operation of a national hydrometric network and grants water rights, which are registered in the national registry of water rights (*Catastro Público de Aguas*). For groundwater, as for surface water, the DGA grants permanent extraction rights upon request and free of charge. Rights are expressed as a flow (volume of water per unit of time). The maximum extraction flow that is considered sustainable (the 'sustainable flow') is calculated as the natural recharge rate (Valdés-Pineda et al., 2014). In the case of aquifers with a recharge much smaller than the volume stored, i.e. mainly non-renewable groundwater, the calculation for the sustainable extraction flow should take into account the uncertainties relating to the estimates of the recharge. However, they should not exceed 5% of the total volume stored over a 50-year period (DGA, 2008, 2013).

Until 2010 the DGA applied a use coefficient to determine the annual volume pumped (expressed in cubic metres) in relation to water rights (expressed in litres per second). The coefficient depended on the type of use (75% for drinking water, 40% for agriculture, 75% for mining activities and 30% for

industrial use) and reflected the fact that users do not normally pump 24 hours a day throughout the year. The use coefficient was abandoned in 2010 because it failed to reflect the actual extraction rates and may even have underestimated extraction levels (Rinaudo and Donoso, 2018). Since 2010 the sustainable flow has been calculated on the basis that 100% of the water rights are used.

In 2005 a reform of the 1981 Water Code included: i) an obligation to specify the water's end use in any request for a new water right; ii) a change in the characterisation of groundwater rights, specifying both the maximum instantaneous flow and maximum pumped volume per year; iii) a fee for unused water rights; and iv) greater state involvement (Oyarzún and Oyarzún, 2011; Rinaudo and Donoso, 2018). In addition, the reform provisionally authorised the regularisation of unofficial water use (not previously registered). In particular, this measure concerned the pumped flow rates of less than 2 litres per second in the regions situated north of Santiago.

In practice the DGA's role is generally limited to managing crisis situations (Budds, 2009). The Water Code stipulates three legal measures allowing the DGA to intervene in situations of conflict over groundwater use or aquifer over-exploitation. Firstly, the DGA can temporally reduce the allocated groundwater flow if there is proof that extraction rates have a direct impact on groundwater levels or existing water rights (corresponding to a reduction in pumping capacity of 15% or more*).* This measure was used in the case of surface water, but not yet for groundwater (Rivera, 2015; Donoso and Vicuña, 2016). Until recently, it could only be initiated by a groundwater user, which may seem surprising. However, it fitted with the concept of private water rights: a private right should not be challenged as long as it does not negatively affect another one. First introduced in 1981, the measure was modified in early 2018 and can now be activated by the DGA (DGA, 2018a).

Secondly, the DGA can declare an aquifer to be a 'restricted area' (*area de restricción*) or a 'prohibited area' (*area de prohibición*) where at least one of the following conditions is met (DGA, 2008, 2013): i) a general decline in groundwater levels, affecting groundwater uses; ii) groundwater extractions exceeding the recharge rate, reducing groundwater levels and the volume of water stored in the aquifer by more than 5% of the total volume over a period of 50 years; iii) a 10% decrease in the average low flow of springs and surface water, affecting existing water rights; iv) a risk of groundwater contamination from polluted water or saline intrusion; v) an environmental risk in protected areas. The declaration of a restricted or prohibited area can be requested by any water user or the DGA itself. When a restricted or prohibited area is declared, the allocation of new permanent water rights is suspended, although in a restricted area temporary water rights can be allocated. Temporary rights can become permanent water rights if they are used continuously for at least five years, on condition that they do not affect other users. The allocation of, albeit provisional, rights to an aquifer considered to be in a fragile state may be understood as a way to account for uncertainties in hydrogeological studies before a final decision is taken on the appropriate pumping rate. In a prohibited area, no further rights are granted. However, since the code includes no measures for a permanent reduction in water use in restricted or prohibited areas, the DGA is unlikely to be able to decrease groundwater overexploitation in the long term.

The Water Code states that a groundwater user association (*comunidad de aguas subterráneas*) should be set up when an aquifer has been declared a restricted or prohibited area. These associations are responsible for: i) setting limits for each user's pumping rate where necessary to avoid a drawdown of the water table; ii) controlling extractions; iii) monitoring the quality and quantity of groundwater; and iv) reporting to the DGA. When it comes to decision-making, the number of votes allocated to groundwater users in the association is proportional to their groundwater rights. Theoretically, 159 groundwater user associations should have been set up in 2016. However, only 13 were in fact established, mostly in the regions of Copiapó and Ligua-Petorca (DGA, 2016). User participation is poor, and this is particularly true of small-scale users since votes are based on the pro rata allocation of water rights. Additionally, users tend to see the process as state controlled (Rinaudo and Donoso, 2018). A revision of the Water Code (DGA, 2018a) included a new requirement: groundwater users in restricted

or prohibited areas must monitor the volume of water they pump and report this to the DGA, even where there is no groundwater user association.

The management of water resources in Chile remains a challenge. Firstly, there is generally little information on the availability of surface water in each catchment and even less on groundwater availability. Hydrogeological processes are still poorly understood – in particular recharge and the interaction between ground and surface water (Lajaunie et al., 2011). Secondly, the registry of water rights is not exhaustive, which means it is difficult to organise controls and estimate discharge accurately. Lajaunie et al. (2011) suggest that the registry only covers 20% of the rights relating to surface and groundwater use because: i) water rights obtained prior to the 1981 Water Code may not have been regularised, and ii) users, law courts and particularly notaries (*conservadores de bienes raíces*), who legally register water rights, do not always inform the DGA, which is responsible for updating the registry, of the final resolutions for the allocation of water rights.[1] Moreover, the 2005 Water Code reform states that a new water right request should specify the water's end use. Yet, once the water right has been granted, the owner can change the use without informing the DGA, or sell the right to a third party, who may use the water for a different purpose. Thirdly, surface and groundwater are managed separately. Finally, few wells or boreholes are monitored. Conflicts are often resolved by the users themselves or by going to court (Lajaunie et al., 2011).

Lessons drawn from other case studies

Few studies have been conducted on the implementation of groundwater management in Chile. In her study of La Ligua Valley, Budds (2009) pointed out that extremely tenuous hydrogeological calculations had been used to justify the declaration of a restriction on the aquifer. She demonstrated that while the official sustainable flow estimates meant no new water rights could be issued, they did not lead to challenge existing water rights and also enabled to validate requests for new water rights that had already been made.

Rinaudo and Donoso (2018) analysed the depletion of the aquifer in Copiapó Valley. Numerous studies had been conducted with contradictory conclusions as to the cause of this depletion, meaning the actors involved were able to push forward the study that best supported their particular strategies. The state was also concerned as it supported large-scale mining projects, which were expected to boost economic growth. Rinaudo and Donoso (2018) proposed several solutions to improve groundwater management, such as allocating water rights in terms of volume rather than flow and adopting a crisis management mechanism. This could involve a series of steps to be taken when the groundwater level reaches a given threshold, for example a temporary reduction in water use.

Usón et al. (2017) studied a case in central Chile, which involved conflicts between industries and community organisations over the assessment of groundwater resources and uses. As a means to secure their investments, industries that already had water rights promoted the declaration of a restricted area to prevent new rights from being granted.

METHODOLOGY

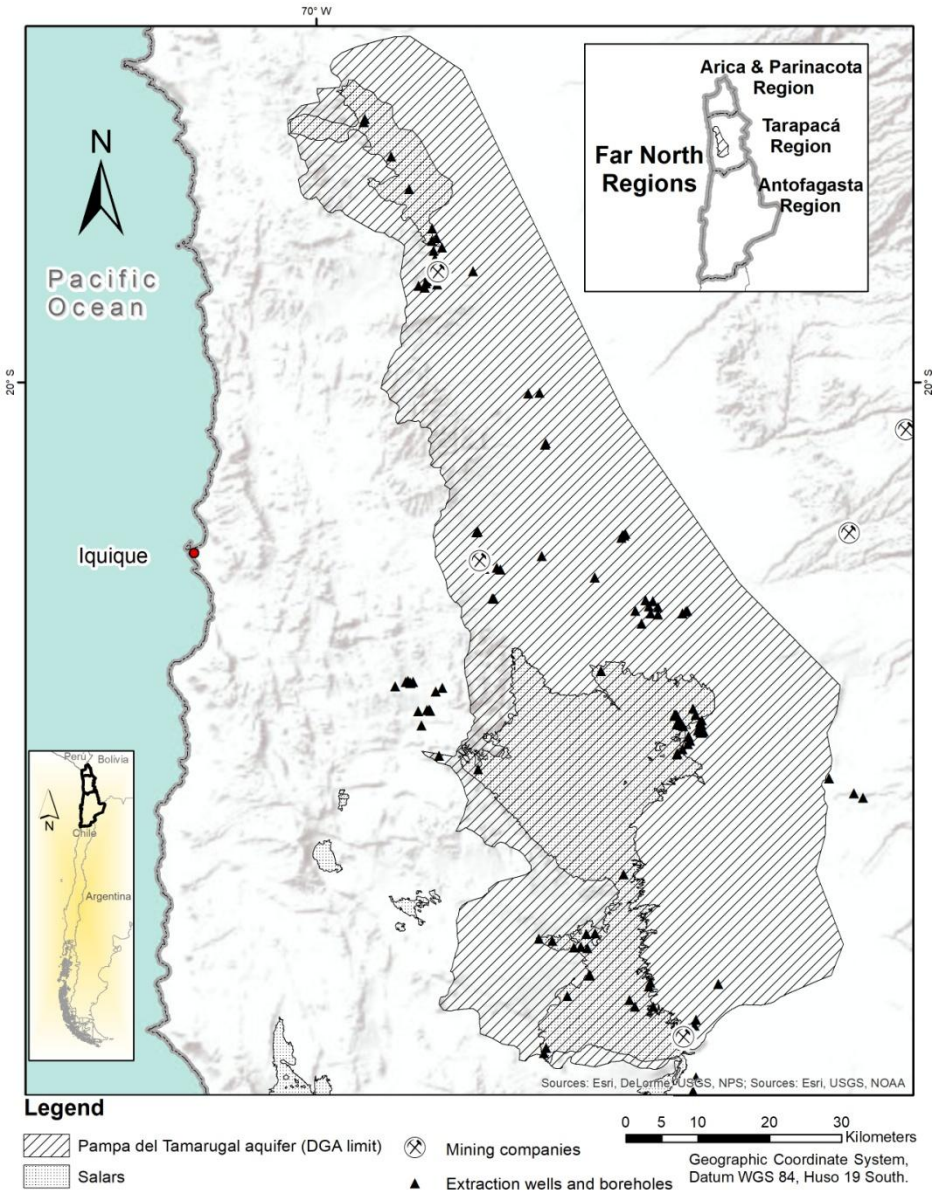
Groundwater resources and uses in the Pampa del Tamarugal

The PdT aquifer lies in the Atacama Desert and within the Pampa del Tamarugal Basin – a hyper-arid and relatively flat sedimentary basin bounded in the east by the Precordillera Mountains and the Chilean Altiplano and in the west by the Coastal Range (Figure 1). As the precipitation in the area is

[1] Regarding the regularisation of water rights, the DGA is responsible only for producing a technical report recommending the allocation of a water right. It is the court that ultimately decides whether to allocate it.

almost nil, aquifer recharge comes from lateral groundwater transfer, which originates from the ephemeral runoff that occurs on the western flank of the Andes (Jayne et al., 2016; Scheihing et al., 2017), where the average annual precipitation ranges between 150 and 180 mm (Lictevout et al., 2013). Until recently, little was known about the aquifer's limits, structure and recharge (Lictevout et al., 2013). The exploited aquifer is made of one unconfined layer with a total estimated saturated thickness of 100 to 300 m (Rojas and Dassargues, 2007). The recharge was estimated to be approximately 1,180 l/s. The main natural discharge occurs through evaporation of the western and southern parts of the aquifer (145 l/s) and evapotranspiration of the tamarugo trees (900 l/s) (Pacific Consultant International, 1995). There is also an outflow to other aquifers estimated at 135 l/s (DICTUC, 2008). The DGA manages the regional hydrometric network, which has many failings. It provides insufficient coverage (for example, some watersheds do not have rainfall or streamflow gauges) and is often unrepresentative (for example, stations are in unsuitable locations) (Lictevout and Gocht, 2017).

Figure 1. Map of the Pampa del Tamarugal Aquifer.



In the early 19th century, nitrate was extracted in the Pampa del Tamarugal Region and exported worldwide. The industry began to decline with the invention of synthetic nitrate during World War II. By 1974 all the mines in the region had been closed. However, since the 1990s a revived interest in natural nitrate and its derivatives has regenerated the industry. Nitrate and iodine are mainly extracted by SQM Company – the world leader in this sector. Other mining companies are also present in the PdT, including Cosayach and ACF, although they manage smaller-scale operations. They all require water to transform nitrate. A private company also pumps groundwater to supply domestic water to neighbouring cities. In the Tarapacá Region the growth in mining activities triggered a 51% population increase between 1992 and 2017, which was seen in the major towns. The corresponding rise in demand for drinking water was met with groundwater from the PdT Aquifer. Small-scale farmers also pump water for irrigation purposes. The water rights granted for agricultural use derived from the aquifer increased from 529 l/s to 1021 l/s in 2009, following the regularisation of groundwater usage as permitted by the 2005 reform of the Water Code.

Table 1 presents the distribution of water rights according to the national Water Rights Registry but may not reflect the true situation due to the possibility of transactions between users and incomplete information handled by the DGA.

Table 1. Registered water users pumping water from the Pampa del Tamarugal Aquifer according to the national Water Rights Registry (data from 2017).

Types	Number of users	Pumping rights (l/s)	Percentage of granted rights
Drinking water	26	2080	58
Industry	2	19	1
Mining	68	639	14
Agriculture	305	1020	27
Total	401	3758	100

Method and data collection

The analysis is structured around four issues: i) the DGA's decision to declare the PdT Aquifer a restricted area in 2010; ii) the work of the CIDERH, how it disseminated information and the crisis it faced; iii) how groundwater resources and their use are monitored and managed in practice; and iv) actors' discourses regarding the current status and sustainable use of the aquifer.

Firstly, the four issues were analysed on the basis of published information (technical reports from public organisations, data on water use, laws, decrees, diverse policy documents and newspapers). Secondly, 27 key actors were selected and contacted for interview based on their knowledge of or involvement in managing the PdT Aquifer: farmers, Native American communities, mining companies, the regional water supply company, public institutions and a regional university. Of the 14 who accepted and were interviewed in July 2017 there was one from a mining company, eight from communities located in the PdT area, one from a local municipality, one from an industrial union, one from the Office of Forestry, one from a public-private body responsible for promoting sustainable economic practices and one from the regional university. The water supply company, the DGA regional office and two mining companies that extract water from the aquifer did not respond to our request.

In order to avoid possible bias due to the first author's former position as director of the CIDERH from 2011 to 2015, interviews were conducted and recorded by a third party. Finally, the analysis presented here draws on the first author's experience.

RESULTS

The declaration of a restricted area

In 2004 a farmer holding a groundwater right in the Pampa del Tamarugal asked the DGA to declare the PdT Aquifer a restricted area. The request was based on the following arguments: groundwater levels were decreasing at a rate of 12-20 cm/year in the wells monitored by the DGA; the granting of further groundwater rights would increase the imbalance between the recharge and use, thus represented a threat to existing water rights and protected areas. Four groundwater users objected to the request: one farmer and three mining companies in the PdT – Cosayach, ACF and SQM. No follow up was given to the request. In 2006 SQM withdrew its opposition.

In 2009 the DGA issued a report (DGA, 2009), which confirmed the arguments expressed in the 2004 request and rejected all those upheld by its opponents. The analysis was based on a previous report (DGA, 1996), which used data from Pacific Consultant International (1995). In its 1996 report the DGA considered that it was acceptable to extract 5% of the stored volume (26,908 Mm^3) over a period of 20 years, based on the Water Code provision that uncertainties should be taken into account in aquifers with limited recharge. This corresponded to a sustainable flow of 2060 l/s (the correct figure is actually 2133 l/s and was changed in a later report). The water rights calculated in 1996 amounted to 912 l/s, which meant that an additional 1152 l/s could be allocated. In the 2009 DGA report the sustainable extraction flow of 2060 l/s (taken from the 1996 report) was compared to the demand for groundwater in June 2009 (including new requests for water rights), estimated at 2145 l/s. This figure is significantly lower than the 2009 total pumping rights because the calculation included the use coefficient (Table 1 shows 2017 data of pumping rights, which are very close to 2009 data). The DGA's 2009 report demonstrated that the existing extraction rates would cause a continuous decline in groundwater levels and that the PdT Aquifer was at serious risk of depletion, which in turn would have a negative impact on existing groundwater use. The report also described the evolution of groundwater levels in the 11 wells monitored by the DGA in the PdT Aquifer. The graphs showed decreasing levels in seven wells, four of which showed a constant decrease since 1997 of between 0.05 cm/year and 0.15 cm/year. This led the DGA to declare the PdT Aquifer a restricted area at the beginning of 2010.

The report has three major shortcomings, however. Firstly, the studies used to support the analyses, which were conducted by consultants hired by the DGA, provided little data and were undertaken rapidly. Secondly, the 1996 and 2009 DGA reports calculated a pumping rate equivalent to 5% of the stored volume over a 20-year period rather than a 50-year period as officially required. If a 50-year period had been taken into account, the maximum acceptable pumping flow would have been 853 l/s. In other words, no additional water rights should have been granted in 1996 and many of the existing rights may have been reduced in 2009, if an existing water user had called for the reduction of extraction rates as scheduled in the 1981 Water Code. Using a 20-year period meant that existing rights would not be challenged, although no additional water rights would be granted. Thirdly, the DGA did not consider recharge. They argued that there was a balance between the recharge and the rate of evapotranspiration in order to justify the calculation having only taken stored volume into account (Discharge flows to other aquifers were ignored). In addition, the natural discharge rate decreases as groundwater levels drop. If the PdT Aquifer is overused, as the decreasing groundwater levels suggest, then the natural discharge will also decrease. Thus, at least some of the recharge should be included in the calculation. Finally, a decrease of 0.05 to 0.15 cm/year of the groundwater level in a few wells may be considered limited for an aquifer whose total saturated thickness is estimated at between 100 and 300 m. Therefore, it seems the report was heavily biased in order to 'force' a calculation that would lead to the establishment of a restricted area while maintaining existing water use and granting new entitlements to those who had already submitted their requests.

In 2011 the DGA published a new estimate of groundwater demand and sustainable flow in the PdT Aquifer following a decision to abandon the use of coefficients (DGA, 2011a). This time the calculations included 100% of the granted flow, which amounted to 130.6 Mm^3 per year (i.e. 4141 l/s), and the following parameters were modified: the aquifer's groundwater volume was increased (by 645 Mm^3); its boundary was extended; and the 5% of stored volume was estimated over 50 years as opposed to 20 years. The calculation led to a revised sustainable flow of 27.5 Mm^3 per year (i.e. 872 l/s). The report concluded that existing demand far exceeded the sustainable flow. Therefore, while the aquifer was not declared a prohibited area, the report stated that no provisional groundwater rights would be allocated in the future. However, it stopped short of calling for a reduction in existing water rights.

The CIDERH's work, influence and crisis

The CIDERH was originally funded jointly by the National Science and Technology Research Commission and the regional government for a preliminary 5-year phase (January 2010-December 2014). Its primary objectives were: i) to study the surface and groundwater resources in arid zones for the development of an integrated approach to water resource management; and ii) to develop technological innovations in water processes in order to increase water supply from natural sources and promote water reuse. The CIDERH faced several challenges from the start, particularly when it came to attracting highly qualified professionals to a remote area. Nonetheless, it received a positive international evaluation at the end of its first five years and was granted funding for a further five years from the National Science and Technology Research Commission.

The research conducted by the CIDERH improved the understanding of the PdT aquifer's structure, its recharge processes and its evolution over several decades (Lictevout et al., 2014; Moya et al., 2015; Viguier, 2016; Scheihing et al., 2017; Viguier et al., 2018). The CIDERH redefined the aquifer limits on its eastern margin far beyond the previously estimated limits (Viguier et al., 2018), involving a much larger volume of groundwater – at least two or three times that reported by the DGA in 2009. Piezometric measurements taken in 2012, 2013 and 2014 showed that groundwater levels had decreased by an average of 5.6 cm/year since the 1980s, reaching 12-17 cm/year in some places. Thus, water levels dropped by 1-2 metres over two decades (1993-2014), reaching a maximum of 3-5 m in some areas (Lictevout et al., 2014). In other areas the level remained stable, while in several boreholes groundwater levels actually rose over the same period.

The CIDERH established close relationships with the main water actors in the region: mining companies, regional authorities, the Regional University of Arturo Prat, the water supply company, the DGA, farmers and Native American (*indígenas*) communities. Most mining companies readily granted the CIDERH access to their wells. The CIDERH also worked closely with the DGA on research activities.

The findings of CIDERH studies were presented at seminars where, in general, communities were well represented, as were private companies and public institutions. Farmers, Native American communities and other rural inhabitants expressed a strong interest in obtaining information on the aquifer. The water supply company, which owns the largest volume of water rights in the PdT Aquifer, was interested in getting information about the aquifer's current and future evolution, in case it was necessary to consider a shift to desalinated water. However, the company did not consider the situation to be urgent, since its water requirements did not exceed its rights and the levels in the company's wells and their capacity were stable.

The CIDERH also reported all of its results to the regional and national offices of the DGA, although these never officially endorsed the findings. In fact, the DGA and mining companies showed little interest in the CIDERH's research. They were satisfied with the information they had obtained by hiring consultants from Chile and abroad. Nonetheless, mining companies generally sent representatives to listen to the discussions held during the meetings organised by the CIDERH.

The research centre's relationship with the regional authorities was ambivalent and evolved over time. The authorities requested information on the PdT Aquifer based on claims of water scarcity, yet showed surprisingly little interest in the scientific information generated by the centre. Indeed, they rarely attended workshops and seldom engaged in discussion with the CIDERH. Although the CIDERH received support from the regional government until 2014, this gradually declined and eventually disappeared in 2015. No official reason was given.

The actors interviewed recognised the importance of a research centre specialising in water resources. With the exception of one community representative, they were all aware of the CIDERH and considered that it had produced important information about the PdT Aquifer. Eight interviewees said that more information was required to inform decision making. By contrast, three community representatives claimed that further studies would be useless without greater control of groundwater pumping. Four of the interviewees pointed out that the scientific format in which the information was presented made it inaccessible to public institutions and communities. Overall, the actors felt that although significant information had been generated, research results lacked concrete conclusions that could help the authorities and communities manage water resources more effectively.

Two of the community leaders interviewed stated that the CIDERH initially paid insufficient attention to capacity building, which community representatives needed in order to understand and use the information that the centre provided. The leaders also acknowledged that the CIDERH gradually began to take this into account between 2011 and 2015, as a consequence of which collaborative research with farmers and Native American communities was able to develop. For the first time communities were invited to participate in a study on drinking water quality, and, as the results were shared, the local communities gained greater confidence in their relationship with scientific organisations.

The actors interviewed (from public institutions, as well as communities) acknowledged that they used the information produced by the CIDERH to support their arguments for or against a project. For example, in 2012 a national infrastructure programme included a plan to construct three dams in the Tarapacá Region. Two were scheduled to be built in the recharge area of the PdT Aquifer, in the Aroma and Tarapacá Gorges (*quebradas*). The National Irrigation Commission and the regional government called on the CIDERH to present recommendations to aid the regional government's decision whether to allocate the funds for the pre-feasibility study. The CIDERH's brief report provided a summary of the sparse data and information available on the gorges' hydrological characteristics and processes. It highlighted a lack of data, stating that additional information was required to fully understand the hydrological processes, the high spatial and temporal (inter-annual) heterogeneity of the hydro-meteorological variables and the high sediment load, produced by sporadic and intense flash floods. The communities located in these gorges opposed the project, as they feared the dam would benefit mining and hydroelectric activities and not farming. They used the CIDERH report to back up their arguments.

In 2014 some of the regional authorities and communities in the Tarapacá Gorge used a CIDERH study showing that the Tarapacá Gorge played a key role in the recharge processes of the PdT Aquifer, in order to oppose the project involving the installation of a mining company in the catchment head of the gorge.

'Fuzzy' aquifer management

The DGA's official role is to monitor water use and water rights (used and unused). Every year users must declare the volume of water rights left unused, for which a fee is paid to the DGA. Table 2 shows that the total water rights declared as unused decreased between 2010 and 2016. Although this volume is officially not pumped, the DGA consider it to be pumped in the groundwater balance. Table 2 also shows that in the same period SQM company chose to declare its unused water rights rather than sell them. This was probably in order to maintain a 'water right reserve' for future use. In addition, a total of

2080 l/s was allocated for drinking water (Table 1), but the used extraction flow for the purpose was 973 l/s in 2011 (Superintendencia de Servicios Sanitarios, 2013). In the same year the company declared only 145 l/s of unused rights (Table 2). However, no official information is available on the remaining flow allocated, i.e. whether it was extracted and, if so, for what purpose.

Table 2. Unused water rights subject to tax in the PdT Aquifer (l/s) (adapted from DGA, 2018b).

User	2010	2011	2012	2013	2014	2015
ACF Mining Company		5	5	5		
Water supply company	505	145				
Chilean army	80					
Oceano Hotel and Tourism	73	73	73	73	73	73
Lo Aguirre (estate agents)	52	112	112	112	112	112
National real estate and building company				10	10	10
HMC (mining company)	43					
Planta Tarapacá (mining company)	10	10	10	10		
SQM (mining company)	464	464	398	398	269	229
Total	1228	810	599	609	465	425

In the Taparacá Region users with groundwater rights exceeding 20 l/s are required to install measuring equipment and report the volume pumped, average flow and groundwater level to the DGA (DGA, 2011b). Between 2014 and 2017 the DGA conducted 58 checks to determine the amount of water actually pumped from the PdT Aquifer. The majority of these were carried out following denunciations, although only one led to a penalty for illegal extraction (DGA, 2018a). In practice, small-scale users are not subject to control. The flow officially granted to agriculture in 2009 (1021 l/s) may be used to irrigate approximately 1000 ha. However, the total area of cultivated land in the Tarapacá Region (which is around eight times larger than the area of the PdT Aquifer) is 1047 ha (Oficina de Estudios y Políticas Agrarias, 2017), meaning the area of irrigated land in the aquifer is probably much smaller than 1000 ha. Thus, it is likely that the water rights granted far exceeded the amount actually pumped for irrigation in the aquifer area. There is no official information on transactions involving water rights. However, some of those obtained for agricultural use between 2005 and 2009 may have been transferred to other uses, such as mining, or left unused (for example, waiting to sell for a profit).

Large-scale users, such as mining companies, need to be more cautious, since it is possible, if unlikely, that their actual pumping rates are monitored. In 2008 SQM brought a lawsuit against its main rival, Cosayach, accusing the company of using illegal wells in the PdT Aquifer. In 2011 a court ordered the closure of the illegal wells used by Cosayach. Subsequently, the mine was forbidden from using any more than the volume specified in its water rights (28 l/s were legally granted before the closure of the aquifer). Due to the risk of large-scale users being controlled, these large-scale users would generally make sure they had water rights corresponding to their actual water use. If needed they would buy water from other users, and a water right of one litre per second was sold in 2017 for around US$80,000. The farmers interviewed also mentioned that people continue to extract water even after selling their rights to a mining company. They also suggested that the same situation could arise when a well has been built: the owner can extract groundwater illegally, even if the DGA refuses to allocate a water right. Therefore, the DGA had limited information on water resources, as well as on water use, official rights and actual pumping rates.

In 2015 the DGA attempted to establish a groundwater user association for the PdT Aquifer (as required, once it had been declared a restricted area). However, they met with strong opposition from farmers. The main complaint was that no farmers were on the board of directors. There was also a concern that the association would be controlled by SQM mining company and the water supply company as both of them own the majority of the water rights in the aquifer (according to the Water Rights Registry).

Actors' claims, discourses and opportunities for action

The interviewees all agreed that the state of the PdT Aquifer as reported by the CIDERH was unacceptable. For example, the community leaders pointed to the negative impact of overuse, including the drying up of some salt flats (*salars*) and the deaths of trees. They also agreed that placing a restriction on the PdT Aquifer was the correct decision. However, in 2017 a group of PdT farmers and Native American representatives filed a lawsuit against the DGA in an attempt to reverse the restriction. They claimed that the decision denied their ancestral access to groundwater, but the claim was ultimately rejected (Court of appeal of Iquique, 2017).

None of the actors interviewed were aware of the decision-making process that led to the declaration of a restricted area or of the data used to justify it. The farmers complained that, during the process, the remaining water rights had been divided between the mining companies, the water supply company and some well-connected farmers, who, they claimed, obtained theirs for speculation rather than agricultural use. One farmer stated that the DGA generally "handed over the water to the [mining] companies. They never managed water; they just restricted its use". In addition, many of the actors interviewed expressed the opinion that the restriction failed to improve the situation, for two reasons: i) public organisations lacked the capacity to control extractions, and ii) the water rights already allocated exceeded the aquifer's capacity, which meant that continued over-extraction was inevitable.

The community leaders interviewed suggested that the problem went further and originated with governmental bias towards private companies. One stated, "water and land used to be together; now they have been divided in order to give water to large companies". In their view, people at the grass roots lose out in the process: "the mining sector only harms; the people are condemned to die". The community leaders also claimed that insufficient water rights limited agricultural activities and the possibility of obtaining public subsidies. However, these claims are problematic for two reasons. Firstly, as mentioned above, the water rights registered for agricultural purposes in the national Water Rights Registry are greater than actual irrigation requirements in the PdT area. Therefore, if the water rights owned by actors in the agricultural sector fall short of their requirements, it is because the water rights have been sold to other users. Secondly, the DGA does not control small-scale farmers.

All the actors interviewed said that they had never discussed the question of how much water should actually be pumped from the aquifer. A local researcher commented, "as there is no general development policy for the PdT Aquifer, we do not know what we want to do with this aquifer". Community representatives and the representative from the Forestry Department stated that, firstly, far greater capacity was required to monitor actual use. Secondly, they proposed a participatory process to give all the actors a 'fair vote', i.e. the users' share of water rights would not determine the number of votes. One actor stated: "this is our right to decide about our development priorities". In their view, a participatory process would lead to a shift in the allocation of water rights and prioritise certain uses (e.g. drinking water and agriculture). The actors interviewed also insisted that information on the aquifer should be provided by an independent organisation, i.e. not the private consultants hired by the mining companies when they need an environmental impact assessment.

DISCUSSION

Information used to establish rather than challenge the status quo

Just like in the case of the Copiapó Valley analysed by Rinaudo and Donoso (2018), the poor groundwater management in the PdT aquifer stems from serious loopholes in the national organisation of groundwater management. The high level of uncertainty in all terms of groundwater balance (in particular, outflows and actual water pumping) and the lack of an updated registry of water rights seriously compromise the implementation of a management system based on water rights. This also opens the way to opportunistic use of data. This high level of uncertainty arises both from the legal setting and from insufficient financial and human resources dedicated to water resource management.

However, the issue of poor water management was never discussed further. The key decision taken on aquifer management was to restrict use in 2010, which has led to the status quo. The calculations presented in support of the decision meant that existing water use, and any pending request, were unaffected. Within the framework of the present study it was not possible to prove intentionality regarding the calculations. However, a strong 'coincidence' between the figures presented and the maintenance of a status quo in terms of water rights was also observed in the La Ligua Aquifer (Budds, 2009). Community representatives complained that they had not been part of the decision to establish a status quo.

Some actors used the information produced by the CIDERH at local level to strengthen their arguments on specific issues. However, neither public nor private actors discussed the current or desired status of the PdT Aquifer, despite being informed of the CIDERH's research results. One possible explanation for the withdrawal of regional governmental support for the centre is that its studies often challenged their projects and weakened the DGA's monopoly on technical assessments, which were used to inform (and justify) decision making. In particular, the CIDERH's analyses challenged the calculations made by the DGA in 2010 and 2011. For example, the results of the CIDERH analysis of the volume of water stored in the PdT Aquifer differed from the DGA's figures. Yet the dissemination of its research findings failed to break the status quo, which emerged as a result of the governance framework and actor strategies.

Ulterior motives for actions and discourses relating to groundwater management

Actors had very different views on water resources and their use but lacked a forum for discussion. This is a recurrent problem in Chile for issues relating to groundwater (Usón et al., 2017) and surface water (Palomino-Schalscha et al., 2016).

With regard to the PdT Aquifer, some actors avoided discussion for strategic reasons. Several were driven by an ulterior motive and not by groundwater management itself. Usón et al. (2017) describe a case where key economic actors were in favour of restricting groundwater use. Although the groundwater level drawdown of the PdT Aquifer was limited, the main mining company in the PdT area supported a restriction. The likelihood is that they wanted to prevent their competitors from operating in the area. In addition, local community leaders raised the issue of groundwater overuse in order to: express their opposition to the general development model designed to promote mining, complain about the failure to share the benefits derived from mining activities and improve their visibility with regard to the local authorities. The actors did not appear to want a genuine discussion on the actual and desired status of the aquifer. Together, these strategies served to reinforce the status quo.

CONCLUSION

As this article shows, the Pampa del Tamarugal Aquifer appears to be the locus of several paradoxes, including: a legal setting that provides detailed indications of how to manage groundwater, yet little

genuine power in the field; a major economic actor that favours a restriction of groundwater use, despite the fact that there are signs of limited drawdown of groundwater level in several parts of the aquifer; the local government actively supporting a groundwater research centre and then disregarding its findings. The analysis presented here helps to understand some of these paradoxes; although, because in particular of a status quo situation – no water rights granted and no discussion taking place with regard to the management of the aquifer since it was declared a restricted area –, some actors managed to have covered strategies that they did not have to justify.

The situation that emerged as the outcome of the institutional setting and of actor strategies is not one of free access but one that is characterised by this status quo and a lack of stewardship of the aquifer. A key reason for this is that the procedures to implement sustainable groundwater management have mostly been used by local actors as a means rather than an end; thus, scientific reports failed to trigger genuine discussion between actors. The Pampa del Tamarugal Aquifer therefore seems to be doubly invisible: physically and in the discussions between the actors involved.

Closing the loopholes in the current groundwater management system would be helpful – following the proposals made by Rinaudo and Donoso (2018), for example. However, breaking the status quo partly depends on a genuine discussion between local actors, based on sound data on groundwater resources and their use. A well-informed participatory discussion could lead to a joint decision on future aquifer management regarding the following question: should the amount of water pumped be reduced to ensure that groundwater levels remain stable or should it be increased to enhance economic development? It is worth noting that groundwater circulation in the aquifer is slow. Less water could be extracted in some areas (e.g. around *salars*) and more in areas of limited ecological interest. A participatory process as proposed by community representatives (whereby the decision-making power is not proportional to the water rights held) may provide the opportunity for discussion between local actors. However, this calls for a radical change in the legal organisation of groundwater user associations. Such a participatory decision-making process for the management of the Pampa del Tamarugal Aquifer might make it 'visible' in the eyes of local and regional actors.

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