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Publisher: Routledge

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Water International

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/rwin20>

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Published online: 08 Jun 2015.

To cite this article: Zachary P. Sugg, Robert G. Varady, Andrea K. Gerlak & Rafael de Grenade (2015) Transboundary groundwater governance in the Guarani Aquifer System: reflections from a survey of global and regional experts, *Water International*, 40:3, 377-400, DOI: [10.1080/02508060.2015.1052939](https://doi.org/10.1080/02508060.2015.1052939)

To link to this article: <http://dx.doi.org/10.1080/02508060.2015.1052939>

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Transboundary groundwater governance in the Guarani Aquifer System: reflections from a survey of global and regional experts

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(Received 30 January 2014; accepted 12 May 2015)

To understand transboundary groundwater governance in the South American Guarani Aquifer System, we surveyed global and regional experts about the region's groundwater quantity and quality, ownership and rights, and regulation and administration. Respondents (1) perceived groundwater quality and withdrawal as under-regulated, and relevant information and data as inadequate; (2) suggested that contamination and overdrafting remain mostly incipient and localized along international borders; and (3) viewed groundwater as a shared resource administered by the state for the public, rather than as private property. Respondents suggested that while there is progress towards implementing a formal transboundary aquifer agreement, local-to-national-scale governance is important.

Keywords: transboundary groundwater governance; expert survey; Guarani Aquifer System; Brazil; Argentina; Uruguay; Paraguay; South America

Introduction

As much as 98% of the earth's total freshwater that is not in ice caps is in aquifers (Foster & Chilton, 2003). Aquifers around the globe, though invaluable sources of water for humans and ecosystems, have largely escaped scrutiny, integration into legal frameworks, and management. Thousands of aquifers (water-bearing geologic formations) and groundwater basins (systems of one or more aquifers) have been identified, though mapping is recent and incomplete. Some 450 aquifers and basins merit scrutiny because they underlie two or more nations (IGRAC, 2012).

Visibility, transnationality and governance of aquifers

In many regions full allocation (and over-allocation) of surface water has increased pressure on groundwater as an alternative supply. In spite of rising extraction costs – especially for energy used in pumping and conveyance – groundwater may be the sole option available. In some places, growing competition for diminishing and degraded water has turned attention to governance, especially in transboundary and transjurisdictional settings. Where robust institutions are lacking, absence of rules around transboundary waters – along with prevailing uncertainty, indecision and differing agendas – has engendered competition, crisis, and occasionally conflict (Dietz, Ostrom, & Stern, 2003).

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As with international rivers, transboundary groundwater governance is challenged by national sovereignty, upstream–downstream hegemony, quality control and, most significantly, water rights. Uniquely for aquifers, however, the water remains unseen and thus difficult to chart and quantify. Issues of sovereignty, property rights and ownership – already thorny in the case of surface water – are further complicated by this ‘invisibility’ of the resources and their boundaries. Despite the number of transboundary groundwater systems and their importance to human development, international water policy makers, conventions and agreements have paid scarce attention to these resources (Puri & Aureli, 2005).

The invisibility of and lack of attention to transboundary groundwater may be about to change. Propelled by increasing demand for groundwater, there is growing interest in its management and an emerging need for cross-border cooperation (Foster & Chilton, 2003; GEF/TWAP, n.d.; UNESCO, 2009). A notable example is the ambitious multi-year project, Groundwater Governance: A Global Framework for Country Action (2011–2015), funded by the Global Environment Facility (GEF), which seeks to gain a better understanding of groundwater governance and to protect the resource’s sustainability. Accordingly, GEF has commissioned explorations of policies, laws, practices, and other aspects of governance (GEF/FAO/UNESCO/IAH/WB, 2013). This enterprise recognizes explicitly the potential benefits of ‘soft-path’ approaches to water management. For several decades after World War II, development approaches featured infrastructure-intensive, ‘hard-path’ solutions such as dams, reservoirs, water transfers and physical plants (Brandes & Brooks, 2007).

Touting non-infrastructure methods, Eckstein (2011) highlights a number of recently signed transnational agreements and activities relating to groundwater cooperation. International initiatives to map groundwater and to formulate legal frameworks, such as the UN International Law Commission’s Draft Articles on the Law of Transboundary Aquifers (Yamada, 2011), also have emerged. Policy scholars call on the global water community to improve water governance – especially in transboundary settings (Dinar, Dinar, & McCaffrey, 2007; Jarvis, 2014; Linton & Brooks, 2011; Wolf, 2007; Wouters, 2013). In response, the GEF project and other programmes such as the International Groundwater Resources Assessment Centre, UNESCO’s Internationally Shared Aquifer Management initiative, and the United Nations Economic Commission for Europe are creating and enhancing knowledge of the physical, societal, legal and policy aspects of transboundary groundwater governance (IGRAC, 2012; ISARM, <http://www.isarm.org/>; Margat & Van Der Gun, 2013; UNECE, 2014). These initiatives have included informal and formal, or non-diplomatic and diplomatic, arrangements at the state, national and transnational levels (de los Cobos, 2012).

The case of the Guarani Aquifer System

The 2010 Agreement on the Guarani Aquifer System is a notable example of formal regional cooperation between aquifer-sharing nations. One of the world’s largest groundwater bodies, the Guarani Aquifer System (SAG)¹ underlies four countries (Argentina, Brazil, Paraguay and Uruguay) and has benefited from heightened attention, sustained research studies and important development projects. In the Guarani, as in other large transnational aquifers, there exist multiple challenges to effective groundwater governance. As a framework for our analysis – and building on previous research – we highlight three key elements of governance: (1) groundwater quantity and quality issues; (2) ownership and rights; and (3) regulation and administration. Further, we contend that

groundwater governance requires examination at two scales: regional, given the specific geographical settings and geologic heterogeneity of aquifers; and global, to provide context and perspective.

To better understand transboundary groundwater governance in the SAG, we developed a survey questionnaire to elicit the perspectives and experiences of two sets of informants: (1) individuals with knowledge of transboundary issues in the SAG region, i.e. officials, managers and other stakeholders actively involved in SAG groundwater governance or familiar with on-the-ground conditions and practices; and (2) ‘global experts’, i.e. representatives of international and nongovernmental organizations, law and policy scholars, hydrologic professionals and other observers who are broadly conversant with groundwater management and governance, especially in transboundary settings. We supplemented our questionnaire with individual interviews with 10 experts on the 2010 agreement and related political and governance issues. These interviews clarified perceptions of SAG science and policy, and apprised us of recent national and international developments.

Potential application of this study

Ultimately, we hope our empirical data will improve transboundary groundwater governance in three ways.

1. By addressing the knowledge gap that inevitably lags legal and mapping efforts, this study elicits perceptions of stakeholders as a step towards developing a holistic understanding of transboundary groundwater governance, policies and institutions.
2. Consistent with soft-path inquiries and the recent focus on informal shared agreements based on norms and rules (e.g. Blatter & Ingram, 2001), this knowledge can help clarify whether governance improves or worsens in a particular setting.
3. An assessment of formal agreement efficacy in addressing specific transboundary governance challenges will enable better cross-border resources management.

Our study may help other researchers and professionals interpret and assess transnational groundwater agreements. Prospective drafters of such instruments may benefit from more in-depth knowledge of a prominent transboundary aquifer. Our case, built on the perspectives of regional and international experts on shared governance challenges, can inform management of other transboundary aquifers.

Transboundary groundwater governance

Groundwater governance has gradually pervaded the literature on resources management policy over the last decade (see e.g. Conca, 2005; Kemper, 2004; Moench, Dixit, Janakarajan, Rathore, & Mudrakartha, 2003; Mukherji & Shah, 2005; Rogers & Hall, 2003; Shah, 2008; UNDP, 2004; Varady, Meehan, & McGovern, 2009). Its application to international transboundary situations also has emerged. Efforts such as UNESCO’s Internationally Shared Aquifer Resources Management project (ISARM, <http://www.isarm.org/>) – to identify, situate and assess aquifers – have helped draw attention to transboundary groundwater governance as an issue of international consequence (Aureli

& Eckstein, 2011; Aureli et al., *in press*; Linton & Brooks, 2011; Margat & Van Der Gun, 2013; Puri & Aureli, 2009).

Notwithstanding rising attention, functional definitions of groundwater governance have remained elusive. Megdal, Gerlak, Varady, and Huang (2014, p. 2) define groundwater governance as “the overarching framework of groundwater use laws, regulations, and customs, as well as the processes of engaging the public sector, the private sector, and civil society” that “shapes how groundwater resources are managed and how aquifers are used”. This framework operates among multiple jurisdictional levels. *Transboundary* groundwater governance may be seen as the subset of groundwater governance that applies to aquifers that underlie and cross political boundaries (Figure 1).

Transboundary groundwater governance often faces legal and cultural constraints, and practical limitations such as ineffective organizations and insufficient human and financial resources (Varady et al., 2013). Effective water governance is characterized by institutions that operate accountably, efficiently, responsively and sustainably (Rogers & Hall, 2003). Overall, effective governance of transboundary aquifers can be pursued by establishing appropriate scales-of-interest articulation and decision making, and by involving assorted non-state actors, as well as state agencies (Linton & Brooks, 2011). Yet, stakeholder participation demands good, symmetric, transparent and reliable information to facilitate cooperation (Mukherji & Shah, 2005; Puri, 2001). Groundwater governance is intimately linked to the development and implementation of norms and principles that promote change in actor behaviour across management scales (Pahl-Wostl, Gupta, & Petry, 2008). In addition to more formal processes and institutions, informal rules, institutions and practices may be key elements of effective governance (e.g. Blatter & Ingram, 2001; Sehring, 2009). Further, interplay between formal and informal institutions – across and within scales – is an important institutional and political element of governance (Lebel, Garden, & Imamura, 2005; Young, 2002).

Although innovative insights into groundwater governance are emerging (e.g. de Gooijer et al., 2009; Kemper, 2007; Theesfeld, 2010), gaps remain in understanding of the workings of more contextual and cross-scalar arrangements. Further, the existing literature generally lacks instructive examples of transboundary groundwater situations in which such arrangements are pursued (but see e.g. Eckstein & Hardberger, 2007; Eckstein, 2013). Especially lacking are views and opinions concerning some important elements of transboundary groundwater governance, such as availability of sufficient quantities of acceptable-quality water, types of ownership

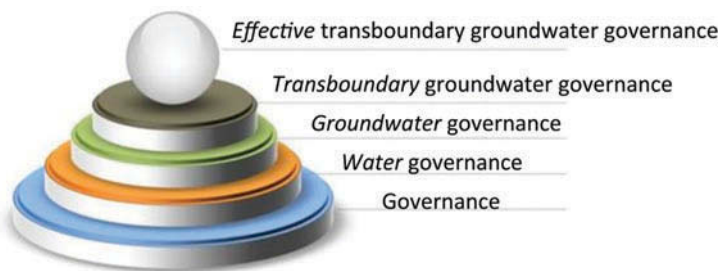


Figure 1. Transboundary groundwater governance as a set of nested concepts.

regimes, and questions of regulation and administration type. For example, results from the first multinational survey of socio-economic dimensions of groundwater use were reported only as recently as 2006 in a study that solicited information from tube-well owners in various South Asian countries (Shah, Singh, & Mukherji, 2006), though this study did not identify transnational issues. And while the international and comparative study by Sagala and Smith (2008) addressed questions of legal ownership and control of groundwater, it similarly did not address transboundary groundwater governance.

These governance questions merit consideration because of the relative infancy and unknown effectiveness of formal and informal transboundary groundwater agreements and other multilateral instruments. As indicated earlier, we examined three basic elements of transboundary groundwater governance in the SAG and globally: (1) groundwater quantity and quality; (2) ownership and water rights; and (3) regulation and administration.

Groundwater quantity and quality

Aquifer depletion has remained geographically uneven; that is, in some places around the globe, only a small fraction of the estimated total fresh groundwater resources has been tapped for human uses, while in other cases there has been a 'revolution' in groundwater use, especially for agricultural purposes (Giordano & Villholth, 2007; Llamas & Martínez-Santos, 2005). The severity of groundwater depletion in a region may reflect access to aquifers, rising water demand driven by population growth and urbanization, availability of financing and infrastructure, and full allocation of existing surface-water supplies. The rapid and severe exploitation of groundwater in basins around the world creates management challenges, including controlling overdraft and water-quality problems (Giordano, 2009).

Governance and management of groundwater present special challenges. Few would contest the need for responsiveness to local and regional conditions, problems, constituencies, perspectives and interests. When such considerations are disregarded, tensions are exacerbated and solutions become more elusive (Ingram, Milich, & Varady, 1994). When resources cross (above or beneath) national boundaries, national interests necessarily come into play and often dominate resource governance.

Identifying salient cross-border groundwater issues, however, is far more daunting than doing so for surface water, partly because of the immense cost and inherent difficulty of quantifying the resource's physical parameters. As importantly, data and information essential to effective decision making and implementation may be inadequate. Furthermore, crafting rules specifying who can and should collect such information, to whom to distribute it and how is not trivial – especially when entangled with transnational politics.

Ownership and rights

In most nations, groundwater has been considered as either government or state property; or a communally owned resource; or private property that may be owned by individuals or private-sector entities. In both civil law and common law countries, groundwater may be considered the private property of individual landowners (Burchi & Nanni, 2003). In such cases, active or collective governance, management

and regulation may be minimal. Users may perceive groundwater as property that can be owned or exploited without deference to neighbouring users. In contrast, groundwater can be viewed as a shared resource, where individuals see it not as ownable but as legally trust-held by the state. Then, in some places, groundwater is owned collectively by civil society and subject to regulation, as per South Africa's 1998 Water Act, Argentina's Civil Code, and by Islamic law and tradition in Islamic countries (Burchi, 1999; Burchi & Nanni, 2003).

The need for governance mechanisms to establish transboundary management processes underlines the importance of who 'owns' or *ought to own* groundwater. State and regional jurisdictions, as well as nations, may apply varying legal doctrines of usufruct and resource-ownership rights. Yet researchers and policy makers may not know whether stakeholders in transboundary settings know which of these regimes might be in effect or most appropriate. Questions of sovereignty, differences in views about ownership, and laws and policies determining ownership rights are part of the groundwater governance process.

Regulation and administration

Groundwater quantity and quality and ownership-regime heterogeneity of groundwater basins are often connected to our third significant element of transboundary groundwater governance: cross-border administration and regulation. Boundaries – whether international or interjurisdictional – complicate natural resources management. Administrative procedures, legal statutes and regulatory mechanisms all are artefacts of the societies and political units within which they are embedded and function. Transnational settings can render issues of ownership and sovereignty even more byzantine than intra-national settings by introducing an additional web of institutions, obligations, rights, neighbours' rivalries, and other complications. Some sharing countries may have undeveloped or unenforced regulatory regimes for groundwater within their borders, complicating transnational coordination and agreements.

In regard to water resources, concerns over sovereignty, national security, budgetary resources and other central-government prerogatives strongly favour the predominance of national agencies. But water management typically responds to local issues and concerns that may transcend or contradict national interests. This disjuncture is also reflected in data collection and control – data are typically hard to come by, considered valuable, and commonly sought by national agencies.

As Moench (2004) argues, provision of the information that matters most to users should include local-scale measurements rather than regional-scale assessments. Schlager (2007) further emphasizes that groundwater information promotes management solutions more effectively when it involves active (i.e. local) user participation. When users are on opposite sides of an international border, however, sovereignty and security concerns can hamper coordination.

Groundwater – like surface water – is a flowing resource that ignores political boundaries, and this complicates transboundary groundwater governance, administration, allocation and regulation. With transboundary aquifers, a common question is: Who does or should perform these critical functions? We seek to provide new empirical evidence to examine stakeholders' views on administration in a transboundary context.



Figure 2. The Guarani Aquifer region. Map credit: Lily House-Peters.

The Guarani Aquifer System: description and context

Our research focuses on the Guarani Aquifer System (SAG, Figure 2). The SAG is one of the most spatially extensive groundwater reserves in the world, covering 1.1 million km² and underlying parts of four nations in the mid-eastern region of South America.² The SAG's freshwater storage volume is approximately 30,000 km³ (Foster, Hirata, Vidal, Schmidt, & Garduño, 2009), qualifying it as one of the world's largest aquifers by volume.

The SAG comprises Mesozoic sandstones ranging in thickness from less than 50 m to more than 800 m (Kemper, Mestre, & Amore, 2003). The aquifer is mostly confined by basalt layers (Tujchneider, Perez, Paris, & D'Elia, 2007), although there is approximately 125,000 km² of outcrop zones around the periphery that contain areas of both recharge and discharge (Amore & Tröger, 2010). The system includes two sub-basins: the Central Paraná and the south-western Chaco–Lower Paraná.

Natural groundwater quality is generally considered very good; approximately 90% is estimated to be potable (Kemper et al., 2003). The system is 'storage dominated', with the estimated 45–55 km³ of yearly natural recharge being less than 0.2% of the SAG's total freshwater storage (Foster et al., 2009). Current withdrawal rates are approximately 1.04 km³ per year, with around 94% used in Brazil, 3% in Uruguay, 2% in Paraguay and 1% in Argentina (Foster et al., 2009). SAG groundwater use is primarily urban, with the major uses being 66% for public water supplies, 16% for industrial, and 13% for recreation and tourism (Amore & Tröger, 2010).

The SAG has been the target of well-funded efforts to formulate and adopt a multi-national protocol for information sharing, management, and conflict resolution. Gerring (2007) refers to the SAG as an “extreme” case in terms of attention and resources devoted and extent of transboundary cooperation.³ In turn, this prominence has facilitated the implementation of transnational agreements for sustainable management and dispute resolution. As a result, the SAG has been studied hydrologically, legally and socio-economically – work that has been funded by the GEF, World Bank, Organization of American States, and Mercosur (Foster et al., 2009).

The SAG’s significance owes much to its location in a densely populated, rapidly developing area of south-central South America. Some 15–24 million inhabitants live within the area delimited by the Guarani Basin, and 70–90 million people live in areas influenced by the aquifer (Foster et al., 2009; OAS, 2005). Because of the enormous stores of surface water and groundwater, the area not only supplies irrigation water but also holds major potential for municipal and industrial use and for generation of additional hydro-geothermal energy (the Itaipu hydroelectric facility, near SAG’s centre, is the world’s second-largest hydropower plant). The area is rapidly urbanizing and faces intensive land-use-change pressures, principally the conversion of naturally forested lands to soybean cultivation. These land-use changes contaminate the runoff that recharges the aquifer, and affect groundwater quality (Hirata & Vidal, 2012).

Since at least the late 1980s to early 1990s, observers of world water consumption have noted a rising demand for finite supplies of freshwater (e.g. Falkenmark, 1990). Not far from the SAG, São Paulo’s 2015 drought and water-shortage crisis demonstrates the intensity of population-related need for ever-growing supplies of water (Romero, 2015). In the SAG, localized areas of pollution and overexploitation evoked concern from communities, researchers and institutions in the four countries. This concern – leveraged with the support and leadership of scientists and stakeholders – prompted transnational cooperation towards an aquifer-management strategy. That effort led to serious multinational water-management negotiations amongst the water officials of the four nations. The framework for this collaborative process built on the 1969 La Plata Basin Treaty to establish principles for governance, conflict resolution and information exchange for the basin’s surface waters (del Castillo Laborde, 1996; Walter, 2013a).

In 2003, with GEF and World Bank support, the four SAG countries began discussions and negotiations on joint management and protection of the aquifer’s groundwater resources. The initiative aimed towards sustainable management and use of the SAG via a management framework based on “appropriate technical, scientific, institutional, legal, economical and environmental guidance” (OAS, 2005, p. 2). These negotiations took place in an atmosphere of water-management decentralization and democratization that featured scientific research and involvement of stakeholders at various levels in the four countries (Villar & Ribeiro, 2011; Walter, 2013a).

The 2003–2009 Project for the Protection and Sustainable Development of the Guarani Aquifer System aimed to: (1) increase scientific knowledge about the SAG; (2) establish a permanent monitoring system for the groundwater resources; (3) create a transboundary diagnostic analysis and a strategic action plan; and (4) identify basic guidelines for a framework for integrated management of the resources. The scientific outcomes included regional hydrogeological assessments and maps, hydrodynamic models of the aquifer system, surveys and geo-referencing of water-wells, and a piezometric monitoring system to identify ‘hotspots’ (OAS, 2005; Walter, 2013a). The countries also

developed science-based, local-level operational arrangements. The cities of Salto, Uruguay, and Concordia, Argentina, for example, adopted common drilling practices and regulation of waste disposal and minimum distances between wells, and the Riberão Preto municipality implemented groundwater regulations to protect recharge areas. The project increased awareness of the SAG and stimulated discussion and cooperative groundwater management within the four countries at national, provincial and community levels (Villar & Ribeiro, 2011).

The project culminated in the development of the transnational Guarani Aquifer Agreement, signed in August 2010. The agreement is a cooperative-governance model that functions at diverse scales. It is considered the world's first such agreement covering a major transboundary aquifer (Sindico, 2011). Furthermore, it is the first such accord encouraged by the UN Convention on the Laws of Transboundary Aquifers – a document presented to the UN General Assembly in 2008 and submitted for ratification in 2011 (Sindico, 2011; Villar & Ribeiro, 2011) – and the first that directly incorporates some of the principles contained in the Draft Articles (Eckstein & Sindico, 2014). The agreement is characterized as a “more general cooperative regime” (Eckstein & Sindico, 2014, p. 32); it does not prescribe specific regulatory duties but leaves them open to future development (Cassuto & Sampaio, 2011). Our survey results and detailed expert interviews include recent updates on the agreement's implementation within the four nations.

Methods: a survey and interviews of experts

Our case-study survey methodology distinguished two kinds of experts: global and regional. Global experts, drawn from around the world, are persons with broad professional experience studying and working on groundwater. The focus of their responses was not the SAG but rather transboundary groundwater governance in general. Our second set of informants, regional experts, drew primarily from the SAG region. Although our general objective was to survey SAG experts, the survey instruments allowed us to see whether and how regional experts' understanding of SAG governance diverged from the global experts' views.

To identify respondents, the sampling methodology combined respondent-driven (snowballing) recruitment with literature searches for authors of relevant publications. The survey was administered online between June and December 2011. Tailored (yet broadly similar) versions of the survey were created, one for each respondent group. Questions for the global experts were worded so as to extract academic, experiential and comparative knowledge from a broader context; targeted and case-specific questions were presented to the regional experts. The survey questions – structured questions (dichotomous and Likert-scale, including filter/contingency questions) and unstructured or open-ended, short-answer-text-response questions – elicited respondents' perceptions on groundwater quantity and quality issues, ownership and rights, and regulation and administration. Text responses were coded using qualitative-data-analysis software and frequencies were analyzed with statistical analysis software. As a follow-up procedure, short, detailed interviews were conducted via email or videoconference with 10 SAG experts in August 2014 to clarify survey responses and update the status of the multinational 2010 agreement.

Results

Although the sample sizes of the two groups (global and regional experts) were comparable, and the overall response rate of 30% was favourable (Table 1), the methodology encountered constraints. Sample sizes were limited by the volume of

Table 1. Overall respondent totals and response rates.

Respondent group	Received survey	Returned survey
Global experts	143	54 (38%)
Guarani regional respondents	186	43 (23%)
Total	329	97 (30%)

published literature, reliance on authors' personal networks, and availability of print- and Internet-based contact information. We were thus able to query only a partial, not fully representative sample of stakeholders and experts – typically men, with post-graduate degrees, working in research or government. Researchers and physical scientists together made up the majority of respondents in both groups (58% of global experts and 60% of regional experts). Other professions included engineers, lawyers, managers and planners. Vocational-sector proportions were similar for both groups, with the two most common categories being academic/research organization (50% of global experts, 38% of regional experts) and government (20% of global experts, 41% of regional experts). The third-largest category included NGO and intergovernmental-organization workers (18% of global experts, 12% of regional experts). The majority (58%) of the 43 SAG regional experts were from Brazil, with 12% in Argentina, 5% in Paraguay and 7% in Uruguay. This distribution roughly corresponds with the geographical distribution of the aquifer, of which, as noted above, approximately 70% lies within Brazil. Sixteen per cent of the regional experts were located outside the four sharing countries.

The following sections report results from questions related to the three elements of transboundary groundwater governance identified earlier: groundwater quantity and quality; ownership and rights; and regulation and administration.

Groundwater quantity and quality

Global experts were asked to identify whether contamination, well interference and drawdown, and several other issues (Table 2) were prevalent in the transboundary groundwater systems in their areas of experience and expertise. Regional experts were asked to indicate which of the same set of issues had occurred within the last decade in the SAG. Groundwater contamination and well interference/drawdown were the two issues most frequently cited by both groups of respondents.

In text responses, several SAG respondents characterized the problems of contamination and depletion as localized, emergent phenomena. An especially illustrative statement was, “The contentious issues have been circumscribed to urban centres located on the borders between countries. There has been no conflict at the level of the entire aquifer.” Another regional expert indicated that drawdown resulting from intensive pumping was limited to municipal boundaries and did not extend to the level of transboundary conflict. One respondent described competition between wells, and local pollution in border areas, as “emerging” rather than “existing” problems.

Table 2. Frequencies and percentages of group respondents' responses indicating the occurrence of several transboundary groundwater issues.

Transboundary groundwater issue	Occurrence reported by global experts ($n = 51$)	Occurrence reported by Guarani regional respondents ($n = 34$)
Contamination	37 (73%)	21 (62%)
Well interference/ drawdown	38 (75%)	19 (56%)
Quantification of water rights	31 (61%)	11 (32%)
Access	21 (41%)	9 (27%)
Inter-agency jurisdictional conflict	22 (43%)	16 (47%)
Regulatory disputes	23 (45%)	12 (35%)
No contentious issues	5 (10%)	10 (29%)

Note. Values in bold are significantly greater at $p < .05$ in a two-sided test of equality for column proportions.

Ownership and rights

To better understand the extent to which groundwater is perceived as private property or as a shared resource, both global experts and SAG respondents were provided the statement, "Groundwater can be viewed as private property or a shared resource." The global experts were asked to indicate how strongly they agree or disagree with the statement, "In my experience, groundwater is generally viewed as a shared resource" (which could be based on any of a wide variety of countries and locations, depending on the respondent's experience). SAG respondents were asked how strongly they personally agree with the statement, "I view groundwater as a shared resource."

The agreement and disagreement of the two groups with these statements are reported in the net stacked distribution shown in Figure 3. Views of regional respondents diverge in two ways from those of the global experts. First, a higher proportion of global experts disagreed that groundwater has been generally viewed as a shared resource (a score of -21) compared with SAG respondents (a score of -3). Second, a strong majority of SAG respondents (82%) agreed or strongly agreed that they view groundwater as a shared resource rather than private property (data not shown). However, this view is not expressed as frequently by global experts, as shown in Figure 3, where SAG respondents were twice as likely to select 'strongly agree' than the global experts (66 compared to 30). This proportion of SAG respondents who selected 'strongly agree' was significantly larger ($p < .05$) than in the global experts (data not shown).

To better understand the existing systems of groundwater ownership, we asked respondents to identify what kinds of users possess legal rights to groundwater as property. Global experts were asked, "If you have observed cases where groundwater is individually owned, what types of users tend to possess it?" Respondents mostly cited individual users and landowners, and the farming/agriculture sector (Figure 4). Industrial and non-farm commercial users made up the third-largest category of 'owners.'

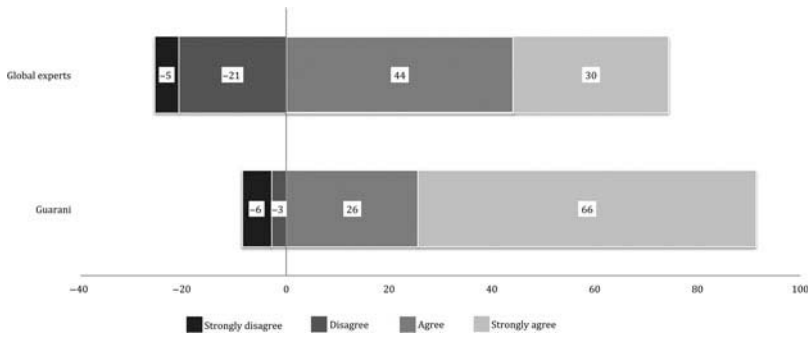


Figure 3. Net stacked distribution showing agreement or disagreement with the view of groundwater as a shared resource rather than private property. Global experts’ responses reflect individual impressions of how groundwater is generally viewed based upon their personal experience. Guarani respondents’ responses express their personal views. Positive (agree or strongly agree) and negative (disagree or strongly disagree) responses are shown as a percentage of total non-neutral responses (neutral responses are omitted).

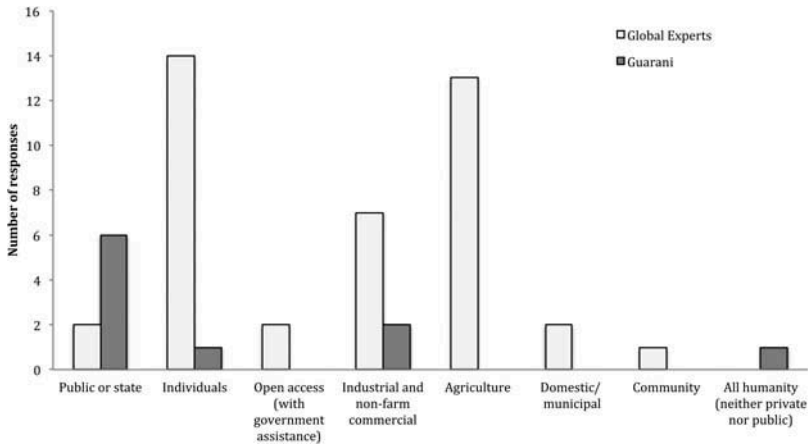


Figure 4. Varieties of groundwater rights owners reported by respondents. Guarani experts’ responses pertain only to the Guarani aquifer system, while global experts reflect property rights regimes outside the Guarani. Respondents were allowed to cite more than one kind of user.

Drawing on the informants’ open-ended responses, these owners are most commonly associated with Roman law-based countries, where groundwater is a property right attached to land ownership, especially in the case of irrigation farmers and commercial users. Some respondents observed that sometimes the state officially owns the resource but exercises little regulation or oversight – especially where the resource is plentiful. One global expert remarked that, in general, the notion of groundwater as a shared resource is “not yet widely perceived.”

SAG respondents were asked, “If you view groundwater as property, please identify who possesses it.” Two respondents mentioned that companies doing explorative work to develop water for human consumption may have ownership rights to groundwater, but the

rest of the comments (6 of 10 total) were mostly to the effect that the aquifer “is a public good of four countries, according to the national constitutions [of] the states”.

Regulation and administration

We asked respondents to report their perceptions of transboundary groundwater regulation (of production and quality) and administration (including data and information collection and availability). Overwhelmingly, both global experts and regional respondents indicated that there is not enough regulation of either quality or quantity (Table 3).

Additionally, strong majorities of respondents in both groups indicated that not enough information exists on groundwater quality or quantity. In fact, the strongest point of agreement overall for this question was that technical information and data sharing on transboundary aquifers are inadequate, an opinion shared by over 90% of global experts and 81% of SAG respondents.

Of the 27 global experts who offered ‘additional’ issues, 9 mentioned ones related to transboundary groundwater information, citing information gaps, lack of expertise, and/or a lack of shared understanding of physical aspects of transboundary aquifers. SAG respondents also expressed concerns about an overall lack or inadequacy of information. In their open-ended responses, they noted the need for better information and coordinated management; lack of laws and regulations; and existence of physical problems being contingent on local settings.

To better understand the relevance of institutions at different jurisdictional levels, we asked respondents to rate the relative importance of those institutions in regulating groundwater quality and extraction. Global experts were asked to appraise the importance of several levels of government jurisdictions in terms of each one’s role in regulating groundwater quality and use. SAG respondents were asked to identify the institutions

Table 3. Respondents’ perspectives on transboundary groundwater regulation, information and access.

		Respondent group	
		Global experts (<i>n</i> = 53)	Guarani regional respondents (<i>n</i> = 36)
Transboundary groundwater issue			
Quality	Not enough regulation	38 (76%)	27 (77%)
	Too much regulation	1 (2%)	2 (6%)
	Groundwater quality not a major issue	11 (22%)	6 (17%)
Quantity	Not enough regulation	43 (90%)	24 (77%)
	Too much regulation	2 (4%)	0 (0%)
	Groundwater quantity not a major issue	3 (6%)	7 (23%)
Information	Inadequate data sharing and technical info.	48 (91%)	25 (81%)
	Availability of information not an issue	5 (9%)	6 (19%)
Access	Access to groundwater is an issue	31 (66%)	14 (50%)
	Access to groundwater not a major issue	16 (34%)	14 (50%)

Note: Value in bold is significantly greater at $p < .05$ in a two-sided test of equality for column proportions.

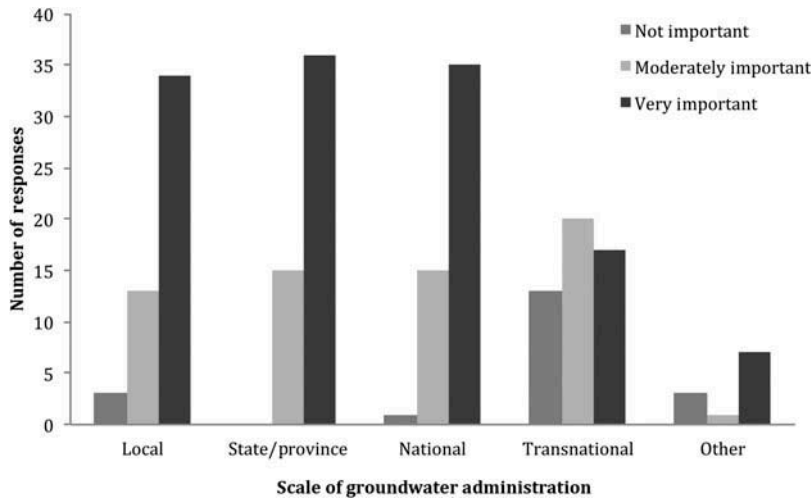


Figure 5. Views of global experts on the importance of different jurisdictional and administrative levels for groundwater regulation. Responses are not mutually exclusive; respondents could rate the importance of any or all administrative levels.

involved, and to then name the one with the most influential role in regulating quality and use of groundwater in the system.

Global experts indicated that local, state, and national agencies are of about equal importance, with a majority rating each as being ‘very important’ and very few rating any of them as ‘not important’ (Figure 5). In contrast, only 33% rated transnational institutions as ‘very important’. ‘Other’ institutions rated as ‘very important’ by global experts included user groups and associations, NGOs, market parties, individual users and civil society, and aboriginal authorities, where relevant.

SAG respondents most commonly identified ‘municipalities and local governments’ as the most influential in regulating groundwater quality and use at the local level, accounting for 52% of the responses for local agencies. The second-most frequent response was ‘state or provincial agencies or authorities’, at 22%. At the state/provincial level, 90% of Guarani respondents cited state-level agencies as having the largest regulatory role for groundwater. At the national level, most respondents named the respective national water agencies (e.g. the Brazilian Agência Nacional de Águas), though other agencies also were mentioned (e.g. Corposana, Paraguay’s state water company, and Brazil’s mining agency).

At the transnational jurisdictional scale, 6 out of 14 respondents (43%) stated that no transnational body has a role in groundwater regulation. Three informants mentioned interstate commissions (especially the Intergovernmental Coordinating Committee of the Countries of the Plata Watershed), and two named the multilateral commission authorized by the agreement (though not yet formed).

Discussion

Groundwater quantity and quality issues

One aim of our research was to identify and characterize common problems associated with groundwater development in transboundary areas. The open-ended responses from

survey respondents, coupled with our expert interviews, allow us to more effectively contextualize quality and quantity issues in transboundary areas.

Survey responses and interviews generally agreed that while localized quantity and quality issues do exist in transboundary areas of the system, these problems are not yet perceived as urgent or severe. Almost one-third of regional respondents felt that there were no *contentious* problems (Table 2). Legal scholar Gabriel Eckstein (personal communication, 11 August 2014) points out that only recently have experts appreciated the SAG's massive spatial extent and volume, and that exploitation of groundwater remains at a relatively low level in most of the aquifer. Interviewees agreed that relatively little information exists on the aquifer's physical characteristics, and, consonant with the regional respondents, concerns over quantity and quality (contamination and well interference/drawdown, for instance) are not widespread but limited to local, especially urban areas.

The absence of serious or high-profile transboundary groundwater quantity and quality issues in the SAG prompt the question: What led to the Guarani Aquifer Agreement? The agreement is notable because it came about not because of intra-national or international conflict over water contamination or scarcity but out of localized concern over *future* conflicts among the countries. Villar and Ribeiro (2013) describe the role of scientists as critical in the cooperation process. Researchers in the region, mindful of the aquifer system's extensive nature and of the potential of future conflicts, promoted awareness and organized the first international meetings concerning the SAG's transboundary nature. These efforts attracted the attention of national governments and international institutions, including the World Bank and the Organization of American States, two of the agreement's central facilitators. Grass-roots movements, building on experiences of prior international cooperative agreements, and the buy-in of respected and powerful international institutions, facilitated the treaty process.

While the SAG lacks major high-profile problems, groundwater resource challenges have the potential to worsen in the future. Some SAG respondents suggested that these dormant challenges are mainly localized and urban, and not yet transboundary. This response reflects the nearly universal tendency to respond to problems only after they become crises. Yet identifying incipient and emerging *transboundary* groundwater-resource challenges within the SAG, as well as globally, is critical because the impacts of drawdown on human and natural systems may happen far in advance of major threats to the resource (Giordano, 2009). Thus, advance understanding of conditions and accurate diagnostic information can help avert problems. Because of groundwater's inherently unseen nature, problems may not be detected until the aquifers are in advanced stages of depletion.

Seen in this light, the Guarani Aquifer Agreement is a notable culmination of a movement that began with local concern over local water problems. These local concerns were leveraged through a network of informed scientists, mobilization of stakeholders, support and funding by international institutions, prior cooperative-agreement experience by national governments, successful realization of the Project for the Protection and Sustainable Development of the Guarani Aquifer System, and approval of the United Nations Law of Transboundary Aquifers.

These effective cooperative processes created the momentum needed to sign the agreement (Villar & Ribeiro, 2013; M. Walter, personal communication, 28 August 2014). The participating nations have had the opportunity to discuss the challenges, agree on a basis for decision making, negotiate use rights and conflict-resolution strategies, and craft guidelines before major problems arise. The agreement is also evidence of rare recognition of the need to develop accords *before* transboundary groundwater challenges become severe – even if

the effectiveness of this agreement in the event of future conflict has been called into question (F. Sindico, personal communication, 14 August 2014).

Ownership and rights

Our results indicate that the prevailing view amongst regional and global informants is that groundwater is considered a shared resource rather than private property (at least within countries). Perhaps because global experts reflected a highly diverse array of experiences in different parts of the world, they reported much more frequently than did the SAG respondents that groundwater is not viewed as a shared resource. SAG respondents emphatically viewed groundwater as a shared resource rather than private property (Figure 3), and most of those who saw groundwater as property indicated that the state or public is the owner, rather than individuals (Figure 4). This contrasts with the experiences of many global experts, who primarily identified individuals, industrial users and agriculture as by far the most common individual groundwater owners. While regional respondents clearly affirmed that groundwater in SAG countries is owned by the public or the state, there is still some disagreement about transboundary-scale ownership.

Even if all parties involved have a common knowledge of the aquifer's physical attributes, variations in each country's prevailing legal regimes may not be readily amenable to international arrangements. For example, Cassuto and Sampaio (2011, p. 668) argue that "Brazil's constitutional predicament with respect to transboundary groundwater, as well as other domestic legal hurdles, further complicates an already difficult multilateral management process." Domestic laws and rules are therefore not immaterial at the multinational level of discussion, and in fact, according to one Brazilian government official (personal communication, 15 August 2014), can make or break international agreements.

Further, even if two sharing countries apply identical ownership laws – a rare situation – differences in hydrogeology suggest there is no guarantee that an existing doctrine will facilitate more effective governance. In the western US states, for instance, a particular ownership doctrine (e.g. prior appropriation) can have very different effects depending on whether the groundwater in question is tributary or non-tributary (Schlager, 2006). Sharing agreements at the international level must be able to overcome this sort of conundrum.

Another issue raised by Eckstein (personal communication, 11 August 2014) is that even when a nation's constitution deems groundwater a public good and not real property, in a legal sense, countries might not apply that general principle of ownership at the international level. Instead, they may assert and defend their sovereign ownership over the groundwater within their national boundaries. McCaffrey (2011) has strongly criticized the principle of national sovereignty over shared aquifers as codified in Article 3 of the United Nations International Law Commission Draft Articles on the Law of Transboundary Aquifers and Article 2 of the Guarani Agreement, arguing that it can lead to adoption of what he calls a "drill first and ask questions later" strategy by individual sharing countries. In his view, "A state simply cannot have the exclusive ownership that sovereignty implies in something that is shared with another state" (p. 570). The Guarani Agreement addresses sovereignty directly, as a (purported) safeguard for the aquifer (Villar & Ribeiro, 2013). Sindico (personal communication, 14 August 2014) believes that "protection" of the resource from interests outside the aquifer's physical borders (e.g. transnational corporations, other countries) is as important to the Guarani Aquifer countries as sovereignty among them; in other words, these countries are as concerned about pressure from without as they are about trouble from within.

Regulation and administration

Overall, both regional and global respondents report that the quality and quantity of transboundary groundwater resources are *under*-regulated. There was also strong agreement in the surveys and interviews that availability of technical information on transboundary groundwater and data sharing are inadequate, complicating determination of how much and what kind of regulation is appropriate to a given setting. This raises questions about who can and should regulate and collect information. These issues become especially problematic at the transboundary level because of differing ownership regimes and administrative procedures, and the complications of delineating the roles of agencies at various jurisdictional levels. Further, cross-border collaborative management can be stymied if water managers on the two sides cannot agree on characterization of an aquifer, have different priorities, or pursue unilateral national policies (Milman & Ray, 2011).

Like data collection, most groundwater regulation is the responsibility of national, not subnational, agencies. With some exceptions, e.g. in Brazil, regional experts most frequently cited federal institutions as having primacy over regulation, relative to local and provincial ones. With the SAG, although there are numerous national regulatory organizations and actors, capacity is quite low. Thus, there are few institutions tasked with regulating groundwater extraction and quality across national borders. Such institutions may be unnecessary if the level of exploitation is low and there are no contentious transboundary groundwater problems (personal communications from G. Eckstein, 11 August 2014; F. Sindico, 14 August 2014). To address transboundary groundwater regulation, some global experts highlight the need for regulation at multiple levels – local, state or provincial, national, and even transnational.

This multi-scalar approach to regulation conforms to recent thinking about multilevel governance that involves cross-jurisdictional coordination of policies to address gaps in funding, accountability, and policy, and to reduce institutional fragmentation (Akhmouch, 2012; Charbit, 2011). It also fits well with research on international rivers that calls for collective solutions to public problems. For instance, joint efforts by institutions, states, civil society and business – from the local to the global level – hold promise for achieving cross-border and cross-jurisdictional solutions to resource management issues (Finger, Tamiotti, & Allouche, 2006).

Because respondents identified a need for greater information (data) availability and sharing, they were asked for information about any such SAG transboundary groundwater-related activities since the agreement's adoption. Although the agreement promotes cooperation around the aquifer – e.g. information and data sharing – no such initiative has been implemented.⁴ Further, a Web-based SAG database network has not been developed, and the original agreement-process files remain unavailable to universities and government agencies (R. Hirata, personal communication, 18 August 2014). Despite these perceived limitations in implementation, there are indications that information sharing among country experts occurs informally (M. Walter, personal communication, 28 August 2014). In addition, because the agreement frames SAG management within the 1969 La Plata River Basin Treaty framework, it could provide a mechanism for data sharing and conflict resolution (personal communications from G. Eckstein, 11 August 2014; F. Sindico, 14 August 2014; M. Walter, 28 August 2014; A. Pastori, 3 September 2014).

Since survey respondents indicated a need for more regulation of groundwater quantity and quality, we also asked about the (post-agreement) development of new regulations that might affect the Guarani Aquifer at a transboundary level. We found little indication that the four countries have worked to formally 'harmonize' their legislation. Ricardo

Hirata, director of the Groundwater Research Centre at the University of São Paulo, Brazil, maintains that since the signing, no change in any legislation or specific regulation has been implemented in any Brazilian state within the SAG (personal communication, 18 August 2014). Yet, in São Paulo State, a draft proposal is under consideration for protecting the active recharge (outcrop) zone, a vulnerable, unconfined region of the aquifer. And Brazil's National Water Agency is finalizing a pollution-vulnerability study in the outcrop zone, which might prompt other states to take analogous action (R. Hirata, personal communication, 18 August 2014).

Likewise, regulation has remained a local, regional and state matter. According to Eckstein (personal communication, 11 August 2014), "In South America, local and national governance rather than international agreements are preferred." For one Brazilian official (anonymous, personal communication, 15 August 2014), the local scale also seems most appropriate: "The Guarani shows that the most appropriate scale to address most groundwater issues is at the local level." A consultant for the Infrastructure and Environment Department at the Inter-American Development Bank, Martin Walter (personal communication, 28 August 2014), articulates the relation of local to international governance:

Concrete problems need to be solved at the local level, and they give rise to formal and informal arrangements. However, local problems, especially when they occur near national borders, can require international support. These are often places removed from [financial and administrative] resources and decision-making centres. The internationalization of issues is a way of mobilizing support and resources functional to local-level resolution, though it can also be a problem. When you escalate the issue, [financial and human] resources can be diluted. The international agreement can serve to motivate state- and local-level policy changes, but it can also have a life of its own.

Finally, while Article 15 of the agreement called for establishment of a multilateral commission, such a commission has yet to be created (Villar & Ribeiro, 2013; Walter, 2013b). Lilian del Castillo Laborde (personal communication, 17 April 2015), professor of law at the University of Buenos Aires, explained that although Argentina and Uruguay both passed statutes approving the agreement in 2012, it is still not in force due to lack of internal approval by Brazil and Paraguay; consequently, the proposed intergovernmental commission has not been established. In the absence of any real controversies or threats, the countries have no motive to act further (personal communications from anonymous Brazilian government official, 15 August 2014; G. Eckstein, 11 August 2014; F. Sindico, 14 August 2014). International legal scholar Francesco Sindico suggests that the current deadlock in transboundary cooperative efforts may be due to at least three factors: the lack of urgency because of the aquifer's plentiful reserves; tensions between Paraguay and Brazil that have influenced Paraguay's decision not to ratify the agreement; and other internal priorities within Brazil, a country with many pressing natural resource challenges (personal communication, 14 August 2014).

In synthesis, Sindico (personal communication, 14 August 2014) explained,

As a trajectory, the Guarani tells a story of local concern, spurred by the GEF international project, with four-country interest. This is important because it brought diverse interest groups together, including the four nations' legal and political communities, which eventually led to the Agreement's signing. Provisions 13–14 contain legal grounds for the commission to adopt specific measures in so-called critical areas. This implies an acknowledgment that something as huge as the Guarani Aquifer would require differential treatment across its extent. Any 'real' issues will likely happen on the borders. I think that this has led to the

realization that there will need to be legal grounds for these critical areas. The agreement provided an umbrella structure, but left many things open; it has a loose and general framework. If and when challenges are faced, the countries will have a document in place.

Status of the Guarani Aquifer Agreement

The 2010 agreement may be seen as a progressive negotiation amongst four member countries to collaborate on information sharing, regulation and administration of groundwater resources. Since its signing, Argentina and Uruguay have internally ratified the agreement. However, Brazil has taken little action, and Paraguay has refused to ratify, citing perceived limits to national sovereignty (personal communications from L. del Castillo Laborde, 8 August 2014; G. Eckstein, 11 August 2014; M. L. Lins Brzezinski, 16 August 2014) – though several of the informants agreed that political tension between Brazil and Mercosur also influenced the decision. In Brazil, the agreement is under consideration at the Ministry of the Environment, where, according to an informant, parliamentary discussion typically “proceeds slowly”. As an international treaty, this accord is subject to the rules of the Vienna Convention on the Law of Treaties, which states that if a country signs a treaty, it is bound to not defeat the treaty’s objectives. Paraguay’s refusal to ratify could negate its signature and its position on the agreement.

A Brazilian official with foreign affairs expertise argues that Paraguay’s refusal has created challenges in the process (personal communication, 15 August 2014). Some Paraguayan stakeholders are calling for the terms of the agreement to be re-evaluated by all four countries, but Argentina and Uruguay are unwilling to revisit the matter because they have already ratified. Brazil has yet to make an internal ratification decision. In sum, conflict between the countries and questions over resource sovereignty may have inhibited the internal ratification of the agreement in two of the four SAG countries.

Conclusions

Groundwater governance needs to address a number of issues, including lack of physical data and technical understanding of aquifer mechanics, varying administrative jurisdictions, insufficient regulation of quantity and quality, and disagreements over access or allocation. However, in the case of transboundary groundwater governance, few agreements exist, and the literature has relatively little to say about the perceptions of stakeholders on important institutional aspects of governance. This article has reported on responses by global experts and regional Guarani Aquifer System specialists, focusing on issues of quantity and quality, ownership and rights, and regulation and administration. We found that:

1. Contamination and overdrafting in the SAG remain mostly incipient and limited to local areas and municipalities situated on international borders.
2. SAG respondents strongly view groundwater as a shared resource administered by the state on behalf of the public, rather than as private property. Although this principle is reflected in the constitutions of the four basin countries, it does not extend in the same way to the international level in the context of the Guarani Aquifer Agreement; that is, the agreement affirms and protects individual states’ sovereignty over the portions of the SAG within their boundaries.
3. There is a general perception that groundwater quality and extraction are in need of greater regulation, and that availability and sharing of information and data are

insufficient. Local, provincial and national governing entities such as government agencies are perceived as important regulators of groundwater, but despite the agreement, transnational entities and agreements are not.

The agreement illustrates an attempt at a governance architecture intended to harmonize multinational interests, while allowing for locally specific institutional arrangements. Based on evidence collected in this study, we find that one of the agreement's most important features is that it provides foundational principles and a means for resolving conflicts, should the need arise. Importantly, the existence of such an agreement does not preclude the adoption of other local and regional arrangements between countries.

Indeed, Article 13 of the Guarani Aquifer Agreement provides clear legal grounds for the adoption of specific, local-level management measures. By including such a provision, future multinational groundwater agreements afford a legal basis for addressing problems at the appropriate geographic scales. As the SAG case demonstrates, informal local and regional governance mechanisms are most likely to be appropriate in transboundary settings where groundwater resource challenges are few and remain geographically discrete.

But the gathered momentum leading up to the signing of an international treaty could diminish rapidly, according to the regional and international experts we interviewed. The activities conducted under the auspices of the agreement, should it succeed in overcoming current obstacles, will be illustrative. To be functional, the agreement will need to develop rules and regulations to avoid and resolve transboundary groundwater conflict, while respecting national sovereignty. So long as the agreement remains inactive, however, transboundary groundwater within the aquifer's multinational extent will be regulated according to individual national practices.

Significantly, the SAG case can help clarify the role of governance by highlighting specific challenges in local/regional contexts. Are such issues addressed effectively through multilateral agreements? This sort of approach can facilitate comparative investigations and provide examples from which to draw. Information derived from such studies should prove helpful, given the early stage of development of transnational groundwater agreements in general.

Further explorations of groundwater governance in the SAG and in other important basins should poll water users from all relevant sectors, at multiple levels (Puri & Aureli, 2005). One template is the type of survey deployed by Shah et al. (2006) for South Asia. International spearhead organizations like UNESCO-IHP may be able to lend support and coordination for such exercises. Additionally, given the proliferation of conferences, workshops and forums, a high degree of communication exists in the world's groundwater epistemic community. As these professionals and stakeholders discuss mutual interests and incorporate salient ideas from the literature, we may anticipate promising strategies for multinational governance of transboundary groundwater resources.

Acknowledgements

This work could not have been accomplished without the strong cooperation of UNESCO's International Hydrological Programme, especially by Dr Alice Aureli, the chief of UNESCO's Groundwater Systems and Human Settlements Section. We are very much indebted to the 100 or so experts, officials, stakeholders and other informants who generously consented to personal interviews or participated in our survey. Finally, we would like to acknowledge Robert Merideth and Christopher Scott of the Udall Center, and Lily House-Peters, a PhD candidate at the School of Geography and Development, University of Arizona, for their insightful critiques of and suggestions for improvements to the article; Emily McGovern, who assisted in editing an early version of the

manuscript; and Lynn Massey, a University of Arizona undergraduate intern, who early in the process helped assemble baseline information.

Funding

This work was partially supported by the Inter-American Institute for Global Change Research [SGP-CRA #005], supported by the National Science Foundation [GEO-1138881]; the National Oceanic and Atmospheric Administration Climate-Society Interactions Program [NA11OAR4310143]; a grant from Lloyd's Register Foundation for research as part of the International Water Security Network; and annual workplan support from the Morris K. Udall and Stewart L. Udall Foundation. The authors confirm that they have no conflict of interest with any individuals or institutions, nor any financial interests in or potential benefits from any of the findings or outcomes of this article or from any direct application of the research therein.

Notes

1. This article uses the Spanish and Portuguese acronym for Guarani Aquifer System.
2. In Brazil 850,000 km², in Paraguay 70,000 km², in Argentina 225,000 km², and in Uruguay 45,000 km² (Foster et al., 2009; OAS, 2005).
3. Gerring's (2007) typology of cases is most appropriate when quantitative indicators of the characteristics of the full population of interest are available. Research on transboundary-governance arrangements does not yet offer such indicators.
4. Transboundary-aquifer data-sharing agreements have been successfully initiated elsewhere, including in the Nubian Sandstone Aquifer System and the North-Western Sahara Aquifer System (G. Eckstein, personal communication, 11 August 2014; FAO, n.d.)

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