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Diplomatic Advances and Setbacks of the Guarani Aquifer System in South America

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A B S T R A C T

The Guarani Aquifer System (GAS) covers 1,088,000 km^2, 68% of which is in Brazil, 21% in Argentina, 8% in Paraguay, and 3% in Uruguay. It is one of the most important aquifers on the continent and one of the largest transboundary aquifers in the world. More than 15 million people share this resource. Extensive analysis of existing documentation, supported by research questions, resulted in classification of five cooperation phases regarding management of the GAS: (i) 1970–2000, where scattered initiatives tried to grasp the aquifer's geological and hydrogeological features as well as its regional circulation dynamics; (ii) 2000–2003, time needed for developing the project proposal; (iii) 2003–2010, the period marking the beginning of the official launching of the Environmental Protection and Sustainable Integrated Management of the Guarani Aquifer (GASP), funded by the Global Environmental Facility, the implementation of which lasted until 2009. This period was marked by intense cooperation efforts and concrete partnership achievements, including the Strategic Action Plan and, later, the Guarani Aquifer Agreement (GAA); (iv) 2010–2017, marked by a slowdown in transboundary cooperation, limited to sporadic cross-border projects, and some new local/national projects; and (v) 2017–present the benchmark of which is the ratification of the GAA by the four countries, a bright and formal move forward. Water availability in the region is extensive, and the absence of transboundary conflicts within the GAS has created a sense of abundance that is leading, unfortunately, to a lack of proactivity in terms of agreement implementation. The consequences are clear: data and tools developed by the GASP have not been updated; there has been a disruption of cooperation and administrative networks; there has been a loss of momentum generated by the GASP by societies and stakeholders; and there has been a loss of opportunities for detailed assessments to manage the aquifer's heterogeneities and dynamics. Absent any coordinated approach, chances to obtain international funds are diminishing. There is no doubt that the GAA is one of the first examples of groundwater-related hydrodiplomacy—a negotiation process that seeks to simultaneously balance national interests and strengthen regional and local cooperative governance in aquifers shared between countries. Thus, the GAA should be considered a model, both for fulfilling requirements of international treaties and for designing an integrated water resource management approach.

1. Introduction

Study of legally-binding international water documents reveals a preponderance of treaties among countries sharing superficial water bodies such as rivers and lakes, as opposed to international aquifers. Countries in the southern part of South America have long-standing experience collaborating on transboundary water issues, most notably concerning the Plata River basin, which has been covered by a general treaty and an inter-governmental committee since the 1960s. Bilateral projects and specific treaties cover other water systems as well, including the Uruguay River (Uruguay and Argentina), and the Parana River (Brazil and Paraguay). Discussions around so-called hydro-diplomacy have been quite frequent, denoting the importance of the topic for the region.

Since the early 1990s, a vast hydrogeological aquifer shared by Argentina, Brazil, Paraguay, and Uruguay, called the Guarani Aquifer System (GAS), with an area of than 1,088,000 km^2, has been recognized as the largest transboundary aquifer body in the region. The importance of the GAS as an inducer of socio-economic development was initially alluded to by Rebouças (1976). Currently, the GAS is responsible for meeting water demands for various uses by more than 15 million people. As deep-well drilling techniques become more accessible and as infrastructure conditions improve (such as access to electricity), a clear tendency to develop this resource has developed, even in the highly-confined conditions of the GAS.

Collischonn et al. (2020) assessed the impacts of long-term climate change (2081–2100) on water resources in the GAS region using 25 climate models, combined with a hydrological model. Although there was considerable disagreement between the predictions, especially in the magnitude and intensity of rainfall, the authors concluded that: (i) precipitation is expected to increase by 10% in the east and south of the area where the GAS occurs, and to decrease by 5% in the north and northwest; (ii) increase in potential evapotranspiration and reduction of precipitation in the northern region will increase the aridity index by

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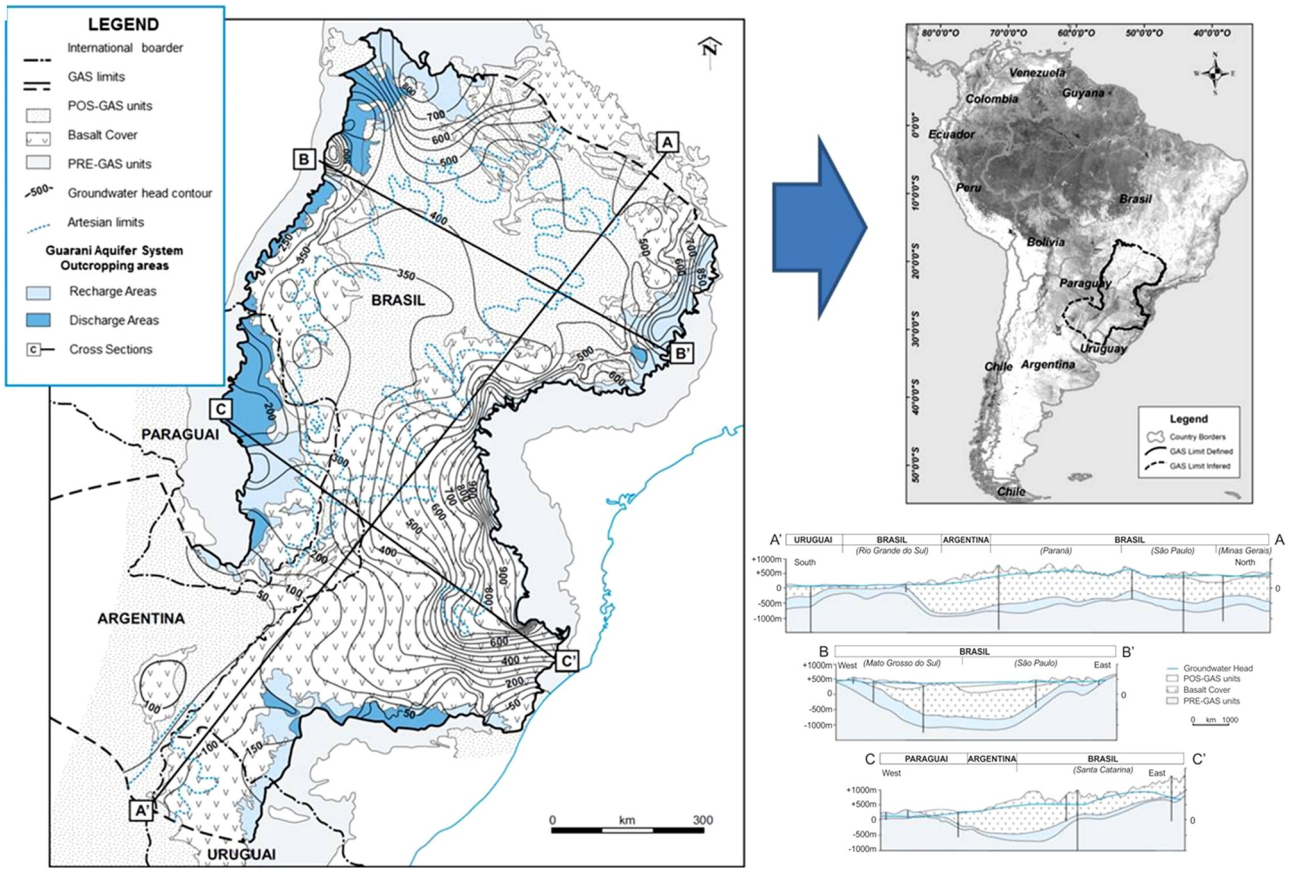

Fig. 1. The Guarani Aquifer System (GAS).

0.5. These forecasts will have little effect on GAS hydraulics; however, there will be new land-use arrangements. Activities such as agriculture and animal production will be severely affected by possibly drier conditions. Thus, following the current trend the agricultural use of the GAS is expected to intensify.

The GAS was the subject of a regional cooperation initiative financed by the Global Environmental Facility (GEF) within its operational program dedicated to international waters. The World Bank (WB) acted as the implementing agency for these resources, with the Organization of American States (OAS) acting as the executing agency for actions carried out jointly among the four countries. This paper analyzes the various phases of cooperation among the four countries sharing the GAS. Five specific periods since the ratification of the Guarani Aquifer Agreement (GAA) were identified, from the period that preceded the preparation of the Guarani Aquifer System Project (GASP) until the present.

The contribution of this manuscript is to provide not only the necessary historical background on the process that led to the GAA's ratification, but also to classify the actions that have worked and those that have not, so as to better understand integrated management of a transboundary aquifer. This article also outlines some ways to overcome the identified barriers to allow other initiatives to benefit from the GAS experience. The analysis also seeks to enrich the global discussion around the challenges and dilemmas involving water and diplomacy. When discussing these processes, the institutional arrangements, and the particular idiosyncrasies of each country, we sought to determine, after great efforts and expenditures of capital, why there remains no implementation of integrated management measures among the four countries, despite the fact that the GASP created cutting edge tools for the management of transboundary groundwater.

2. Methodology

This study was guided by some motivating research questions: (i) what are the scenarios and pathways that inspired countries to develop a transboundary groundwater project? (ii) was the central motivation for developing GASP on the countries' priority agendas concerning their water resources? (iii) how effective are the cooperation mechanisms established during the various phases of GASP? and (iv) what were the reasons for the gradual exhaustion of the project and the complete lack of formal and institutional articulation among countries after the end of GASP?

The insights derived by exploring these questions have contributed to the analysis of the rich sources of information available: (i) an extensive review of the entire set of official and formal documents developed by the international organizations, the participating countries, and the technical execution report of the various stages of the project, including the documents necessary for the GEF submission and assessments, the aide memoirs of the high level board summits, and national representatives meetings, including the Transboundary Analysis (AT) and Strategic Action Plan (SAP); (ii) interviews with interested parties and qualified actors during the SAP development phase (2007-2008), individually or in workshops. Part of these interviews contained a formal and structured script, composed of questions about the institutional, legal diagnosis, perception of the results obtained, and expectations of continued cooperation. Individual interviews were informal and unstructured. In total, around 150 people were heard, including representatives of international organizations, national project coordinators, representatives of governmental institutions involved in the implementation and/or monitoring of specific thematic activities, civic leaders, water management technicians and national political representatives and international; (iii) evaluation of the scientific and technical references developed after the end of the GASP, including

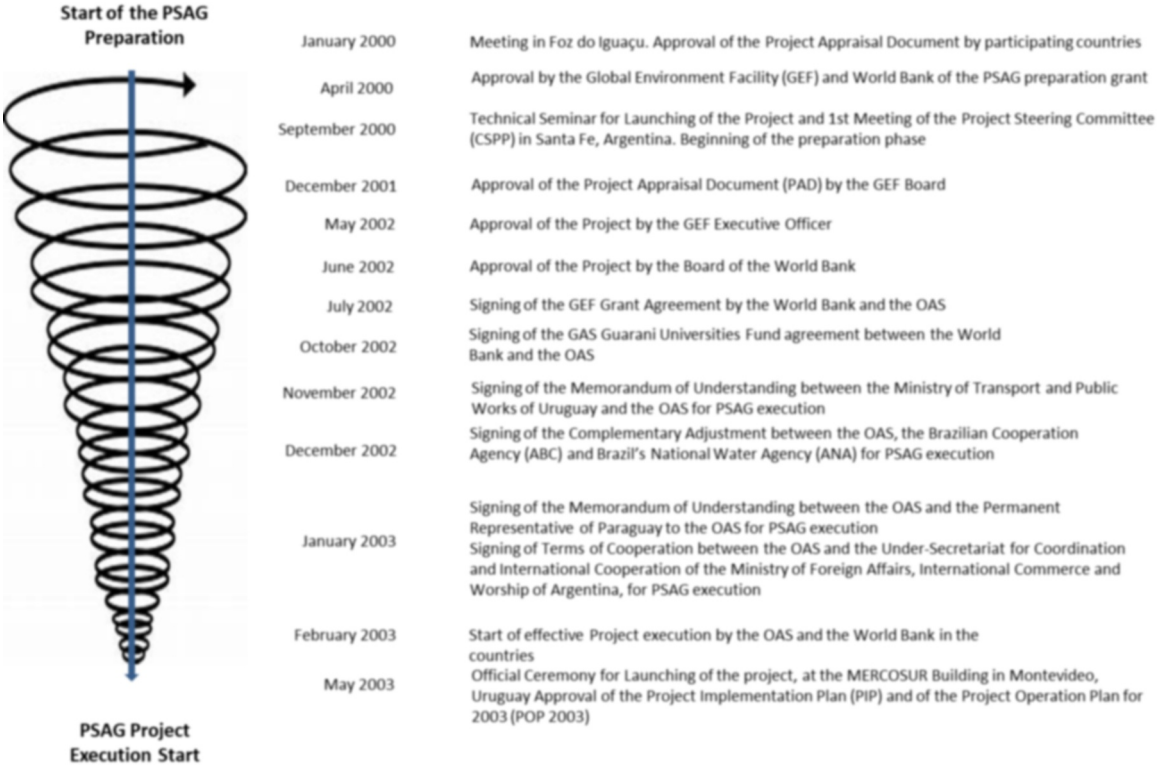

Fig. 2. Time chart of the events elapsed during the GASP preparation period (modified from OAS, 2009; Strategic Action Plan - SAP).

academic papers as well as reports from projects developed by national governments related to the expansion of the GAS data, its monitoring, and how the results have been incorporated into public water resource management policies at the national and subnational levels; and (iv) the authors' personal experiences as actors participating in the process during practically the entire period of GASP.

The analysis was discretized in five phases, organized in chronological order. These time intervals are defined by striking facts that express changes in institutional attitudes as well as changes in the intensity of cooperation interactions among countries. Simultaneously, they guide readers toward understanding of the concatenation of the facts during the period.

3. The GAS Knowledge Evolution

The GAS, lying on the eastern edge of South America (lat. 16° to 32 °S, long. 47° to 60 °W), is the most important aquifer on the continent and one of the largest transboundary aquifers in the world. The location of the GAS, as well as its main features, geological framework, and some cross sections are shown in Fig. 1. According to the UNESCO-IHP ISARM Program (2009) and Rivera and Candela, (2018), in addition to the GAS, there other large transboundary aquifers in the world, include the Nubian Aquifer System, the North-Western Sahara Aquifer System, the Northern High Plains Aquifer System, the Amazonas Basin, the Northern China Aquifer System, and the Artesian Grand Basin, to cite only a few.

The GAS is described as a 10-600 m package of clastic detrital sedimentary sequences of the Mesozoic age, deposited over the Permo-Eotriassic regional unconformity and at the top by lava flows of the Serra Geral Formation. In the early stages of cooperation among countries, the heterogeneity and dispersion of aquifer information in each country and its various official nomenclatures presented obstacles to a common understanding (Sracek and Hirata, 2002; Hirata et al., 2011; Gastmans et al., 2017; Kirchheim et al., 2019).

Aquifer recharge occurs in outcrop areas located at the eastern, northern, and southern borders of the GAS, giving rise to intermediate to local flow lines, with markedly different hydrochemical evolution compared with the old deep flow paths (Fig. 1). The GAS hydrogeological features evolved from a large homogeneous groundwater structure to a more complex and heterogeneous system, where its geological structural framework controls regional flows according to the central axis of the large Paraná Basin. According to Manzano and Guimaraens (2012), who conducted an extensive hydrochemical assessment, the great majority of the water was found to be of very good quality and suitable for domestic consumption and agricultural use. Anthropogenic contamination has been detected only at a few of the GAS outcrops and adjacent semi-confined areas.

A regional numerical model of the GAS was proposed (Vives et al., 2008; OAS, 2009), the water balance of which showed inflows varying between 0.2 and 1.6 km^3/year, whereas discharge ranges from 0.2 to 0.8 km^3/year in the outcrop areas; these differences may indicate ascending GAS flow into the basalt cover. According to these authors, the total amount of water stored within the GAS ranges between 29,550 ± 4,000 km^3 and 32,830 ± 4,400 km^3. Despite this apparently huge water volume, not all of it is available for use. Considering a drawdown limit depth of 400 m for regular pumping equipment, available GAS volume decreases to 2,000 km^3 (Foster et al., 2009; OAS, 2009) and a large portion of the GAS would carry nonrenewable groundwater (Foster et al., 2009; Kirchheim et al., 2019). The GAS has a huge storage capacity (compared to the annual recharge), and very long residence times. Using isotope techniques, it was possible to confirm very low groundwater flow (0.7–0.3 m/y), and high residence times (834 ± 91 × 10^3 years) in some of the GAS confined areas in the west of the State of São Paulo (Aggarwal et al., 2014).

Despite the fact that there have been significant developments in understanding of the GAS in recent years, there remain pending issues related to the role played by large structures and how they act as flow barriers to regional fluxes. Some of these issues may even have cross-border implications. Transboundary aquifer management demands active mechanisms against overexploitation in confined and storage-

Table 1
The GAS management zonation (Foster et al., 2009).

Zone I Unconfined	Zone II Basalt-covered recharge	Zone III Intermediate confined	Zone IV Deep confined	Zone V Confined saline water
Outcrop area, Recent water, Direct recharge from rainfall Renewable resource.	Closely-ZI adjacent zone with important vertical recharge through fractured basalts.	No significant recharge occurs, Old waters; Mined exploitation.	Same of ZIII, Exploitation limited up to 400mbs of dynamic level in wells.	Saline, no potable water.

controlled areas and recharge areas where there is river base flow. The planned use of water from a fossil aquifer should also be incorporated in a sound management program.

GASP assessments led to the identification of five broad and general domains concerning groundwater management strategies (Fig. 2) (i) outcropping recharge zone; (ii) basalt-covered recharge zone; (iii) intermediate confined zone; (iv) deep confined; and (v) confined saline water (Table 1).

4. The Starting Scenario

According to Martin (2013), “in stark contrast to other international waters such as shared rivers or lakes, transboundary aquifers are rarely co-managed.” Groundwater became subject to international law only in 1966, with the Helsinki Rules on the Uses of Waters of International Rivers, which mentioned groundwater fluxes in the context of a river basin. Subsequently, the International Law Association set rules on international groundwater in 1986 (Seoul Rules), but again with no rights or obligations of States with respect to the governance and protection of transboundary aquifers (Hanasz, 2015). According to this author, the 1989 Bellagio Model Agreement (Hayton and Utton, 1989) concerning the use of transboundary groundwater “has built the concept of equitable utilization by encouraging the protection and control of groundwater, establishing a joint commission between signatory States for deciding issues relating to shared aquifers. Despite these apparent advances, provisions so far were in true merely recommendations for best practices rather than ratified law instruments”. The 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses (McCaffrey, 1997) understood that the same rules (including the principle of equitable and reasonable utilization) should be applied to surface and groundwater, assuming that both could be considered international watercourses. Nevertheless, it was only in 2008 when the UN International Law Commission finally proposed a groundwater-specific legal instrument, known as the Draft Articles on Transboundary Aquifers (Hanasz, 2015). According to this instrument, States should use transboundary aquifers in equitable and reasonable ways, maximizing their benefits in the long term. According to the Model Provisions on Groundwater Resources established by the United Nations Economic Commission for Europe (UNECE, 2012), the aquifer recharge rates were also considered to preserve ecosystems. International instruments have difficultly encapsulating the complex groundwater dynamic circulation patterns in transboundary aquifers. Reflecting this fact, there is a tendency for instruments to be restricted to general principles without clarity regarding regulatory mechanisms. A chronological record on agreements regarding transboundary aquifers has been offered in Burchi (2018).

As dependence on groundwater resources has increased globally, a host of new questions and problems arose relating to ownership, use, access, protection, and development of groundwater resources, especially in areas where such water resources traverse international political boundaries (Hayton and Utton, 1989). These issues have become increasingly important in the context of hydrodiplomacy, primarily because there is scarcely a country in the world (except for most island nations) not linked hydrologically to another country (Teclaff and Teclaff, 1979; Almássy and Buzás, 1999).

It must be acknowledged that there has always been a productive process of cooperation in Latin America as well as institutional arenas for meetings of technicians and government representatives. Nevertheless, according to Martin (2013) “water resources shared by the riparian countries of La Plata River Basin were proxies for the geopolitical competition existing between countries”. National stakeholders and scientists were familiar with their neighbor pairs, a fact that has enabled convergence in the shared task of preparing and executing transboundary projects such as the GASP. Nevertheless, it is remarkable that the international understanding of the use and protection of transboundary groundwater systems remained in an embryonic stage.

Relevant research groups for groundwater studies hosted at universities in the region, led by the Federal University of Paraná, the University of Uruguay, and the University of Mar del Plata, underlined the need to develop a regional research project for government institutions, proposing them to international cooperation agencies such as the World Bank (WB) and the Organization of American States (OAS). However, the perception among government representatives of the necessity for such an international cooperation program occurred only during a bilateral meeting between representatives from Brazil and Uruguay, organized to negotiate the water resource management challenges posed by transboundary Quaraí-Cuareim River Basin in 1999.

There is no doubt about the role played by the academic community in carrying out the initial studies, spreading its cross-border nature, and requesting funding for a regional project. Researchers established connections with international organizations and searched for financing. Nevertheless, Martin (2013) and Villar (2016) tend to overestimate this role, assuming that, without this mobilization, States would have ignored the fact that they share this aquifer. The promotion of a regional GAS initiative, just as GASP emerged, was promoted by the research community and by representatives of the countries’ governments simultaneously. The project, prepared by academics, emphasized the expansion of hydrogeological knowledge of the GAS and did not consider the involvement and leadership of national institutions responsible for the management of water resources, nor diplomatic representatives.

On the other hand, it is important to highlight the leading role and impetus that international organizations had in proposing and creating the financial and structural conditions for the preparation of the GASP. It should be remembered that, within the GEF financed initiatives, this was the first proposal dealing with transboundary management of groundwater resources worldwide. There was a clear perception of opportunity from the GEF, materialized by the WB as the implementing agency and OAS as the executing agency for the development of a consensual regional project proposal (GEF Proposal for Project Development Funds PDF Block B Grant, 2000).

An essential issue to be considered is the fact that an international legal framework for the management of transboundary groundwater resources had not been available at that time. Neither did the WB have a specific policy regarding this type of water resource. The issue began to be addressed with the evaluation of the WB’s Water Resources Policy Paper of 1993. It was generally recognized that transboundary groundwater issues needed to be addressed, because projects were often

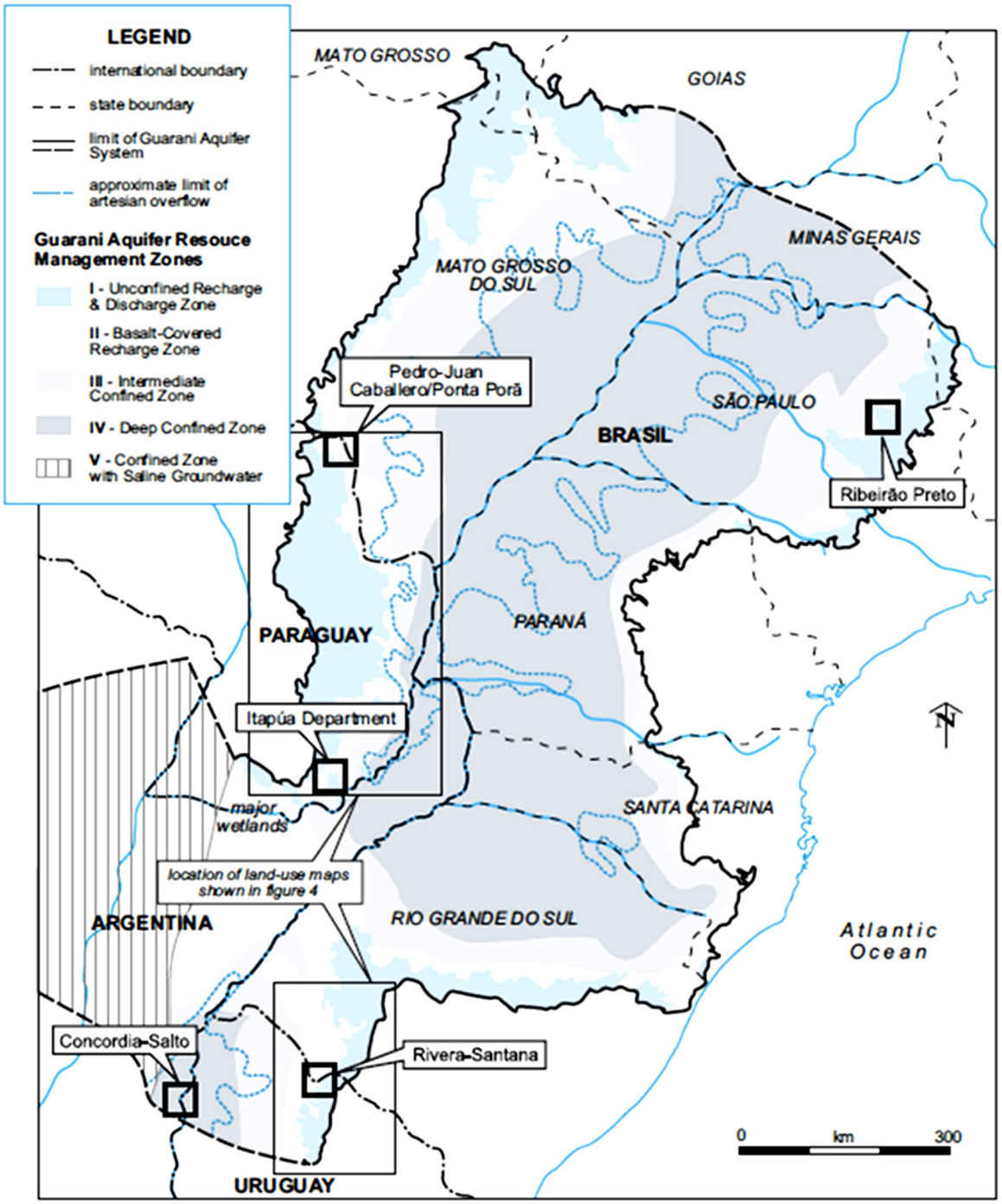

Fig. 3. Guarani resouce management zones and location of the Pilot projects (Foster et al., 2008).

proposed and implemented in areas where a situation of scarcity and competition already existed (e.g. North Africa and the Middle East). In the case of the GAS, the WB/GEF could contribute by helping to shape an institutional framework regarding transboundary groundwater, which could serve as a replicable model for other countries and regions. Both the WB and the OAS invested resources in maintaining preparatory activities until the start of the project in 2003, ending in early 2009 (Fig. 3).

The institutional prestige offered through the role of the GEF/WB and the OAS and the possibility of having GEF donation resources had an important stimulatory role during the earlier stages. Despite criticisms and misunderstandings regarding the WB's bidding rules and its own involvement (giving rise to unnecessary geopolitical conspiracy theories in some segments of the society), a proactive spirit was noted in the countries' technical scientific communities.

The initiative produced a knowledge base for the development of policies aimed at the protection and sustainable management of the aquifer system. The international cooperation project produced a strategic action plan (SAP) characterized by concrete management policies at the local, regional, and national levels. The SAP also led to the signing of a multi-lateral framework agreement in 2010, the so-called Guarani Aquifer Agreement (GAA), which outlined general non-binding principles for future transboundary groundwater governance in the region and a new benchmark in the context of hydrodiplomacy. The agreement emphasized the countries' inalienable sovereignty over the resource and enshrined reciprocal no-harm and sustainability as

guiding principles for the future exploitation of the resources (Sindico et al., 2018).

5. Limited Cross-Border SAG Problems

Groundwater is usually part of more significant hydrologic systems, and sometimes it is shared between countries. Transboundary problems may be, in large part, a function of pumping rates (Eckstein and Eckstein, 2005). Any excessive pumping on the part of one or both countries could have serious implications for the section of the aquifer along the border. Extensive contamination associated with agricultural activities can also affect transboundary aquifers, because this degrades large areas.

As the GASP was being executed and new results were reported, it became apparent that the initiative was preventive in nature, because there were no critical transboundary issues to tackle. Potential transboundary effects are still restricted to a narrow strip of territory of no more than a few dozen kilometers, depending upon locally specific hydrodynamic conditions (OAS, 2009). Essential changes in land-use are occurring rapidly in many parts of the aquifer recharge area (deforestation, intensification of grazing of cattle, conversion of grasslands to intense soybean and corn cultivation, and reforestation with eucalyptus). Therefore, changing land-use scenarios could trigger cross-border conflicts. The potential transboundary effects on groundwater could only evolve from local to basin-level, even if substantial changes in agricultural land-use occurred and/or if the use of groundwater for irrigation intensified in combination with specific hydrological conditions. These conditions have not yet been met. The GAS transboundary issues did not have substantial upstream-downstream implications; however, their scope of influence is strictly delimited because they are primarily local. This means that their solution can be arrived at through agreements and actions at the local or basin scale. The extensive amount of data systematized in the countries, including studies in GASP cross-border pilot areas (Santana do Livramento-Rivera, Salto-Concordia, during the GASP) and (Quaraí-Artigas in the Project for the Management of the La Plata Basin), allow assessment of the actual dimension of transboundary effects. The areas with potential risk of conflicts coincide with the recharge areas located on the borders, especially in the region of Mato Grosso do Sul (Brazil) and Paraguay, and the southwest of Rio Grande do Sul (Brazil) and Uruguay. Deep confined areas with intensive use of the thermal potential of the GAS are also subject to potential conflicts, mainly between Uruguay and Argentina. A discussion on how vast regional freshwater storage contrasts sharply with localized active flow systems of recharge areas, which are strongly impacted by land-use change can be found in Hirata and Foster (2020).

Nevertheless, at the first stages of GAS cooperation among countries, the existence of transboundary issues such as pollution risks had been clearly overestimated and became the primary drivers underpinning the need for the GASP.

6. Phases of Cooperation: A Bumpy Road Towards an Agreement

In an attempt to assess in more detail the rich process of cooperation that has occurred in the region, this study identifies five phases for the GAS cooperation process among countries.

(i) Before the preparation of the GASP (1970–2000); this phase is marked by scattered initiatives, predominantly related to the geological and hydrogeological knowledge of the GAS and the dynamics of regional circulation. The need to prepare the GASP project arose from a group of researchers from local universities and the interest of government institutions responsible for the management of water resources in the four countries. At the end of 1999, there was a fortuitous coincidence of factors that allowed the construction of the GASP. There were no previous agreements, except at the academic level, and regional institutions were not prepared for a deal with the objective of GASP.

The GEF approved the funds requested by the countries to prepare the GASP in 2000. As it was clearly stated in the Project Appraisal Document (PAD, 2001), “the GAS was a clear example of an international water body threatened by environmental degradation through pollution as defined and included in the GEF Operational Program Number 8. The primary rationale behind the initiative assumed that in the absence of a strategic intervention supported by the GEF, business-as-usual would prevail in the four countries. At the aquifer’s current use rate, and considering the growing use of groundwater for human consumption, it was easy to foresee the increasing threat of pollution in the not too distant future”.

The GEF was financing several projects in the GAS area that primarily dealt with surface water resources, including the Bermejo River and the Pantanal water management projects, both of which were executed by United Nations Program for Environment (UNEP) and the OAS. A wider GEF strategic approach for the Plata Basin under the framework of the Intergovernmental Coordination Committee for the countries sharing the La Plata Basin (CIC-Plata) was also being envisioned. While the former projects had no direct linkages with the proposed GASP project, the GEF activities relating to the Plata Basin project focused on roughly the same geographic area. Project activities would consider ongoing activities in the Plata basin to achieve synergies where appropriate. From a management and hydrological point of view, however, the GAS was considered a distinct system and different treatment should be postulated.

The fact that groundwater and GAS issues became placed on a higher level of national policy agenda was due to the manner in which the GAS project proposal was forwarded, with the close engagement of government institutions directly involved with water resources management. Furthermore, the capacity-building and institutional strengthening tested by these institutions resulted in a broad harmonization of central groundwater concepts leading to an enhanced willingness to cooperate. This achievement would never be reached in the context of a pure academic research project. It is striking to note the degree of diffusion to which GAS issues have achieved among civil society in the four countries during project preparation and execution.

At this stage, important issues that affected countries' postures in the phases after the end of GASP help to explain the lack of continuity in the impetus for cooperation: (i) in the early stages of collaboration between countries, the existence of cross-border issues such as risks of pollution and overexploitation had been overestimated, although they remained the main factors that sustained the need for GASP; (ii) the interest in expanding knowledge about the GAS, demonstrated by the countries, did not necessarily reflect their institutional maturity to implement groundwater management actions; and (iii) despite the interest shown and having generated a dynamic and awareness surrounding groundwater, GASP could not be considered a bottom-up initiative. To the contrary, it was strongly induced by international actors and their financial mechanisms.

(ii) GASP Preparation – The institutional heterogeneities related to water resource management became evident shortly after the launching seminar in Argentina. Argentina and Brazil have federal structures, in which provinces or states are the legal authority over the water, while Paraguay and Uruguay have centralized structures.

The four countries made significant efforts in creating National Project Preparation Units (NPPUs) under the direction of the Project Preparation Coordinating Unit (PPCU). In the case of Brazil, State Project Preparation Units (SPPUs) were also established. Internal consensus in each country to define the scope and content of the GASP paved the way for joint decisions and further agreements.

The countries, provinces, and states financed all these internal efforts as counterpart funding, complementary to the preparation grant. The PPCU was responsible for proceeding with technical baseline studies needed and for preparing a proper, and mutually agreed proposal, through a collection of data, revision of material prepared by

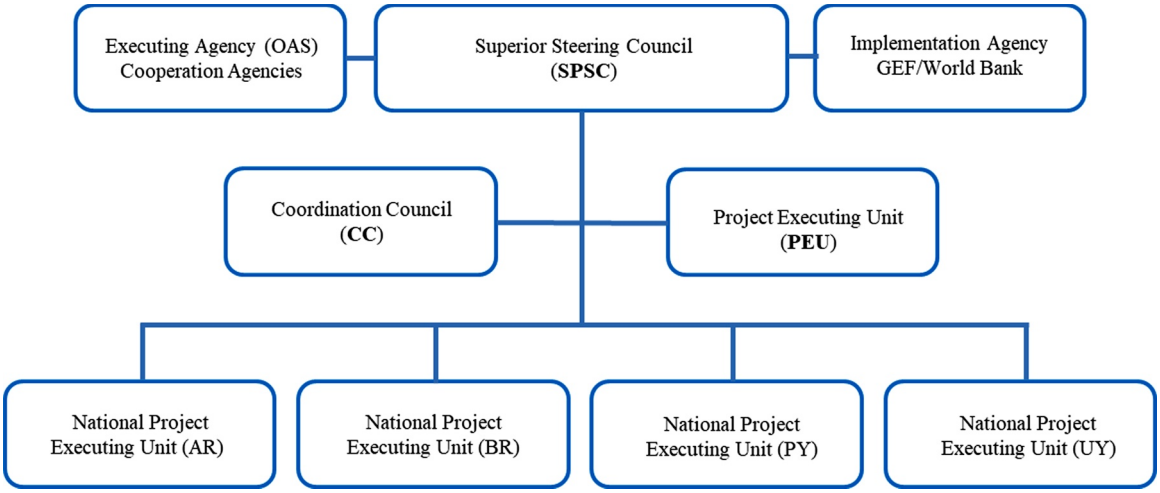

Fig. 4. Operating arrangement of the Guarani Aquifer System Project (GASP).

consultants, and definition of project activities.

Stakeholders from various segments of society, including academia and NGOs, took part in the national units. The Preparation Steering Committee (PSC) was made up of executive representatives from water resources, environmental, and foreign affairs national institutions. Countless opportunities for interaction between countries have led to a unique homogenization of the technical language and a common conceptual understanding of the aquifer. The preparation phase had initially been designed to last a few months but ended up lasting two years. The PAD, as the ultimate result of this join preparation, was formally approved by the GEF Board in the end of 2001. The time elapsed during this preparation phase became a key factor. Having enough time to accommodate countries' expectations was one of the most important lessons learned from this period. Similarly, the financial resources initially designated to support countries in preparation were entirely undersized. There was a need for financial complementation, a fact that also indicates the enormous willingness of foreign organisms to support the continuity of the process. The OAS and the WB, in consultation with, and with the approval of the PSCs of the four countries, prepared key documents for the beginning of the executive phase.

The GAS was recognized by the PAD as a transboundary aquifer that covered three sectorial areas: sustainable water management (of groundwater in particular); transboundary water management; and energy-thermal use. The project had to be designed to deal with the water resources and environmental issues in an integrated manner, targeting pollution as well as over-exploitation of the GAS throughout: (i) recognition of groundwater as a resource in need of far more attention than it has been given to date; (ii) integration of groundwater management concerns into overall water resources legislation (which tends to focus on surface water); (iii) groundwater availability assessment (related to quantification and modeling of the resource, including availability and demand scenarios); and (iv) groundwater protection measures (water rights, well design, construction, extraction, and pollution controls).

All four countries signed the Kyoto Protocol for Global Warming. In this context, according to the PAD, a careful assessment of the potential for the use of the GAS water for low-enthalpy energy could provide alternatives to fossil fuel-based energy sources, and opportunities for local energy savings for industry, irrigation, and/or residence.

Despite the dependence on financial resources for holding meetings and carrying out consultancies, there were substantial counterpart contributions, which in the course of the initiative, ended up never being systematically measured. The formally organized SPPUs hosted fruitful discussions that serve as outstanding models of how to follow up projects on the subnational level. Even so, the expectation of receiving funds for investment for their own projects was noticeable and directly proportional to the frustration perceived by public research institutions in the face of this impossibility.

(iii) GASP execution (2003-2009): This comprises the period that began with the official launching of the transboundary GEF funded project (GASP), whose execution lasted until 2009. It was marked by intense cooperation efforts and concrete partnership achievements such as the SAP and, later, the Guarani Aquifer Agreement (GAA). The GASP received cooperation from the International Atomic Energy Agency (IAEA), the Federal Institute for Geosciences and Natural Resources (BGR), and the Bank Netherlands Water Partnership Program (BNWPP). Funding was distributed and invested in accordance with components and activities foreseen.

Analogous to the operating arrangement that had been tested during the preparation period, a Superior Project Steering Council (SPSC), supported by a Coordinating Council (CC), oversaw project activities. A Project Executive Unit (PEU) was created, fully financed with project resources with headquarters at the Mercosur Building (Montevideo, Uruguay). The SPSC consisted of representatives of water resources, foreign affairs, and the environment; the CC was composed of National Coordinators (CN) appointed by the executing agencies. Intense and active national participation took place through the National Project Execution Units (NPEUs), with areas for deliberative and consultative inter-ministerial, and public involvement on GAS-related topics in each country (Fig. 4). In Argentina and Brazil, the NPEUs reflected the federal structure and included participation of representatives at the subnational level. During this period, the SPSC met 12 times, whereas the CC another 21 times, a consistent indication of the magnitude of country-level involvement in implementation of GASP.

According to the SAP, the following specific approaches were pursued during execution of the GASP: (i) technical and scientific studies in support of management of the GAS, including diagnostic analyses, generation of new information, and creation of an information system and a database; (ii) evaluation of institutional and normative frameworks relating to the theme "groundwater" at the national, sub-national, and local levels; (iii) execution of local groundwater management measures for the GAS in Pilot-Project areas; (iv) strengthening of technical capacities on groundwater related-themes; and (v) dissemination of information on groundwater and on the GAS at all levels of society.

Considering the dimension that the GASP has reached, it can be said that the theme "groundwater" was definitively placed on the agendas of the four countries. A large number of people and organizations were involved in its execution. News of the existence of the GAS reached a television audience of 2.6 million people and activities financed by the

Guarani Citizenship Fund (meant for supporting selected NGO proposals) reached an additional 5 million people (booklets, radio programs, and other communication strategies). It was presented in various regional and international forums on water and environment, as a pioneer transboundary groundwater management GEF project. There have been clear advances in the hydrogeological knowledge of GAS. Nevertheless, little or no progress has been made in relation to the advances in hydrothermal energy. Similarly, the PAD activities related to the indigenous issues have had no impact either. In fact, it is a classic example of decoupling external and internal expectations.

The SAP development process involved consultation steps, and the participation by the main institutional actors in the countries was considered positive. The document suggests institutional arrangements to guarantee both institutional and economic sustainability for the implementation of strategic actions upon which there was a consensus. The late completion of some of the main technical products as well as the impossibility of delivering them accompanied by capacity-building seminars contributed to the loss of momentum at the end of the GASP. Even with the wide dissemination and robust technical products, the institutional foundations for coordinated cooperation turned out to be fragile. This fact would be even more noticeable in the subsequent phases in the midst of a scenario without external financial support. Despite the clear efforts to raise awareness of GAS issues at the national level and of the benefits of cooperation with neighboring countries, the coordinated governance development process has largely stalled out. Much of this discontinuity was due to incipient institutionalization, characterized by (i) an asymmetry between transboundary groundwater management expectations set by the international institutional actors and the concrete management practices carried on by the respective countries; (ii) weak institutional capacities, basically in the sense of institutional attributions that were/are still in full configuration, in terms of the lack of perception of the institutional role to be played and in the lack of continuity of strategic public policies beyond executive mandates; and (iii) lack of adequate financial support. Beyond criticism, much of the progress achieved was due to the effort and commitment of highly committed individual actors within the institutions or “champions.”

In 2004, Mercosur created an Ad Hoc High-Level Group, whose goal was to formulate a draft agreement on GAS among the States. The Mercosur proposals did not turn into reality, and finally, countries decided to follow a more traditional approach and establish an international agreement aiming to trigger greater cooperation for scientific knowledge and responsible GAS management. Countries decided to recognize the La Plata Basin Treaty as the legal basis for their future actions in the GAS. In 2010, the four countries signed the GAS Agreement (the Guarani Aquifer Treaty) that was inspired by the Declaration of the 1972 United Nations Conference on the Environment, Rio 92, Agenda 21, the United Nations Assembly on Transboundary Aquifer Law, Rio + 10, and the Mercosur Framework for Environment.

According to Tinker and Kirchheim (2016), two unique circumstances led to the creation of the Guarani Aquifer Treaty in 2010: (i) the studies developed during the GASP and the consensus over the SAP; and (ii) the advances in the codification of international law on transboundary aquifers through the United Nations, with the adoption of a broad aspirational 2015–2030 global policy agenda that includes goals on water and sanitation. Since 2012 at the Rio + 20 conferences on sustainable development, the United Nations has been involved in the formulation of new Sustainable Development Goals with one that refers explicitly to aquifers (Sugg et al., 2015). These circumstances created favorable conditions for the development of an agreement. Nevertheless, it remains essential to remember that the treaty has always been considered a high priority objective of GASP. As soon as SAP preparation began, PEU acted as a contract advocate at SPSC.

(iv) The post-GASP execution (2010–2017) period was marked by a slowdown in cross-border cooperation, limited to sporadic cross-border projects linked to the past, some local/national projects, and existing international projects (Sindico et al., 2018). After the completion of GASP, SPSC agreed to continue mutual regional cooperation, assuming direct responsibility for the implementation and continuity of GASP actions. Thus, the first stage of SAP was a transition period, with two main objectives: (i) maintaining articulation and coordination among the four countries; and (ii) assimilate the scientific and technical knowledge produced. During this stage, countries should establish an agreement on a future institutional framework for medium and long-term actions on a regional scale. No drastic changes were expected, and any movement would depend on the countries' abilities to generate the technical and financial resources for the continuity of SAP work. The main logic was to focus on the dissemination of such knowledge among institutions and participants in the country.

Country SPSCs did not accept the World Bank's offer of bridge financing for the transition period after the end of GASP. This decision again reflected what was previously called "incipient institutionalization." National representatives made highly strategic choices subjectively without considering the institutional expectations. The instruments created and negotiated by GASP for cross-border management have never been implemented, including the creation of regional technical committees (Information Systems Committee, Monitoring and Modeling Committee, and Training and Dissemination Committee) and actions to support the continuity of the Pilot Projects.

Again, the institutional disconnection around priorities appeared to be clear. Countries did not promote actions designed to give support to the GAA, but at the same time, they committed themselves to a consensual agreement, having approved it. Five years after the signing of the GAA, only Argentina and Uruguay had ratified it. Remarkable positive news was the creation of a Regional Center for Groundwater Management for Latin America and the Caribbean (CeReGAS) in Uruguay, as a partnership between that country and the IHP/UNESCO. CeReGAS has been acting as the official repository host of all PSAG documents. In addition, the center has been given the mission of coordinating the process of formulating new proposals for the GAS (https://www.ceregas.org).

There have been internal advances in each country, whether in the technical, legal, or institutional context, including the installation and operation of a network of aquifer monitoring wells (RIMAS project, operated by the Geological Survey of Brazil-CPRM) and mapping of the outcropping GAS vulnerability to contamination conducted by the Brazilian Water Agency-ANA (2016). Although these projects generated information about the GAS, they were national projects and were developed outside a cooperation framework.

(v) Post GAA Ratification – The Paraguayan parliament ratified the GAA only in 2018 and Brazil did so a year earlier. This agreement represented an essential move towards international cooperation on groundwater because it reaffirmed the applicability of international water law principles to aquifers and was the first agreement for transboundary groundwater developed under the influence of the UN Resolution 63/124 (2008) (Villar 2015; Sindico et al., 2018). It is also an example of preventive diplomacy (Villar and Ribeiro, 2009), which is "a concept based on the premise that is easier and cheaper to prevent disputes before they begin," making it clear that “transboundary water cooperation usually occurs in a context of water crises or conflicts or even during floods and droughts” (Priscoli and Wolf, 2008). Due to the lack of monitoring networks, when groundwater conflicts are finally noticed, it can be assumed that these are drastic and economically irreversible situations.

GAS has no concrete cross-border conflicts. After the euphoria surrounding GASP money passed, and despite the irrefutable importance of GAS resources, the groundwater issue did not attract public opinion, nor governments.

The GAA represents "a flexible cooperation structure" (Sindico and Hawkins, 2015) that is committed to stimulate cooperation as follows: (i) states must manage the aquifer in their territories by their

constitutional and legal provisions and applicable international law; (ii) a transboundary groundwater organization must be created; (iii) countries must establish an arbitration procedure to resolve disputes; (iv) states must implement groundwater cooperation programs; and (v) states must identify critical areas, especially in border regions (Villar and Ribeiro, 2011). Despite the emphasis on the principle of sovereignty, this is balanced by the principles of international water law (Sindico and Hawkins, 2015). Although the four countries have not signed the UN Watercourses Convention, the agreement includes its main principles and central obligations.

In response, countries developed a new GAS project proposal for GEF and by the end of 2019, received funding approval. This new project is expected to be launched in the second half of 2020 and will undoubtedly generate new institutional dynamics in the GAS region. The initiative and conduction of this proposal was assumed by CeReGAS and had the financial support of the Development Bank of Latin America (CAF) for the development of a concept document to be approved by the four countries.

7. Outcomes and Lessons Learned

Perhaps no other transboundary aquifer in the world has achieved the degree of harmonization, and joint technical advances as the GAS has achieved. This success was a direct result of cooperation efforts between countries, which overcame their technical and institutional differences, as well as the existence of a centralized decision-making system with specific funding. Without this cooperation, the achievements at each location would not have been so significant. It is a process where hydrodiplomacy has materialized.

With the conclusion of GASP, there was a period of few actions and initiatives for the cross-border GAS management. The entire mobilization force of society is gradually being lost, and its causes are as follows: (i) no relevant transboundary conflicts have been identified that could compromise the use of groundwater or threaten the environment; (ii) national water resources management institutions have faced difficulties in meeting their agendas due to budget cuts, deficiencies in human resources, and the troubled internal political environment. Likewise, these institutions, despite the great publicity of the GAS importance, have not yet equated groundwater with surface water. Historically, water management institutions have always paid little attention to groundwater resources; (iii) the large occurrence of GAS resulted in a dispersion of national management efforts. Anticipating this problem, GASP implemented pilot studies across borders and in locations with evidence of overexploitation (Ribeirão Preto, Brazil). However, there was not enough articulation to guarantee local action sustainability, either through the engagement of public water services or by local governments. Thus, pilot projects were gradually abandoned after the end of GASP financing; (iv) the lack of a digital repository of information and technical memory from PSAG helped to fragment the technical knowledge generated by the project. Its inexistence has reduced the chance of academic institutions using data in scientific and academic works. This problem was solved in 2016 when CeReGAS uploaded all GAS documentation on its website; and (v) the national institutions were unable to take responsibility for implementing the management tools developed by the project.

The idea of a transboundary regional project was triggered by the convergence of academic and national government initiatives. These expectations were then welcomed and encouraged by multilateral organizations, which glimpsed an opportunity to develop the first international groundwater cooperation funded by GEF, and advance aspects of water diplomacy. Although cooperation mechanisms established during GASP preparation and execution phases proved to be effective, after project conclusion, the cross-border management instruments created and negotiated could not be implemented. There was no adequate financial support and institutional maturity to implement them, and the project could not develop bottom-up mechanisms, which could force national institutions to pursue the proposed goals.

The experience of the entire GASP left lessons learned with potential for replication in other projects, notably: (a) the problems surrounding groundwater are generally local, and communication must also be locally focused. However, a broader communication strategy is needed to reach central institutions, which are responsible for regional or national aquifer management. Traditional mainstream media has a fundamental role and a plan that involves the different scales of communication has to be established; (b) the PEU, formed by renowned technicians from the four countries, was fundamental to the success of GASP, proving to be essential to support the decision-making processes and to execute them according to the agreed time terms and scope; (c) GEF financial support was instrumental in the success of GASP, which was able to induce other national and multilateral agencies to provide mutual support. One of the significant failures was the national governments' rejection of the bridge financing offered by the WB after the end of the project, which would have allowed the implementation of GAS management tools, as defined in the SAP. Thus, it is understood that the end of the project must occur after the implementation of such actions and not before it; (d) the academic community played an essential role in GASP, facilitating the exchange of knowledge and information. GASP created specific funds for the academy; however, they should have been more substantial and aimed at establishing research networks and training researchers with scholarships and internships at international institutions. GASP showed that the technical capacity for projects in hydrogeology is found in universities and government research centers; (e) an informal network of technicians and administrators was created during the GASP (the “Guarani family”), and this allowed solutions to many operational problems; and (f) the assessment of the legal and institutional framework of the countries in the initial stages of GASP execution should have been broader and more assertive, a fact that could have triggered different executive directions later on.

The overall GAS experience offered countries and institutions a unique opportunity for capacity building and institutional strengthening; nevertheless, this was insufficient to reverse the incipient institutionally faced by the water resources management sector in these countries. The recent the GAA ratification should put pressure on countries to create a common agenda towards groundwater management and the challenges imposed by the GAS hydrogeological framework.

Finally, the GAA should be seen as an inducing tool for countries to comply with the requirements of international treaties in the light of the precepts of good governance and Integrated Water Resources Management (IWRM), and making the involved countries stand at the forefront of hydrodiplomacy.

CRediT authorship contribution statement

Ricardo Hirata: Conceptualization, Supervision, Investigation, Writing - review & editing. **Roberto Eduardo Kirchheim:** Conceptualization, Investigation, Writing - original draft. **Alberto Manganelli:** Formal analysis, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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