

Sustainable Groundwater Management Lessons from Practice

Case Profile Collection Number 9**

The Guarani Aquifer Initiative – Towards Realistic Groundwater Management in a Transboundary Context

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This Case Profile first provides a concise scientific overview of the advances in understanding of the Guarani Aquifer System generated by the GEF-supported Guarani Aquifer–Sustainable Development & Environmental Protection Program of the Mercosur Nations of Argentina, Brasil, Paraguay & Uruguay. The Program, undertaken during May 2003–January 2009, was implemented by the Organization of American States (OAS) under the supervision of the World Bank and with detailed advice from GW-MATE, and benefitted from the important contributions of the International Atomic Energy Agency (IAEA) and the BGR through German development cooperation. The scientific overview is followed by a detailed assessment of the main implications for resource management strategy, the progress of practical groundwater management and protection measures at local level through on-going pilot projects (both within and outside the GEF Program), and the status and strengthening of associated institutional and legal provisions. The ‘core reference document’ for this overview assessment is the GEF Program–Strategic Action Plan (Plan Estratégico de Acción/PEA) of 2009, but groundwater resource management dimensions are here the principal focus and their discussion is taken further. GW-MATE acknowledges the major contribution of the OAS Guarani Program Secretariat and Pilot Project Facilitators, together with that of national government agencies and committees, and of the consultants and academics executing various parts of the program under contract.

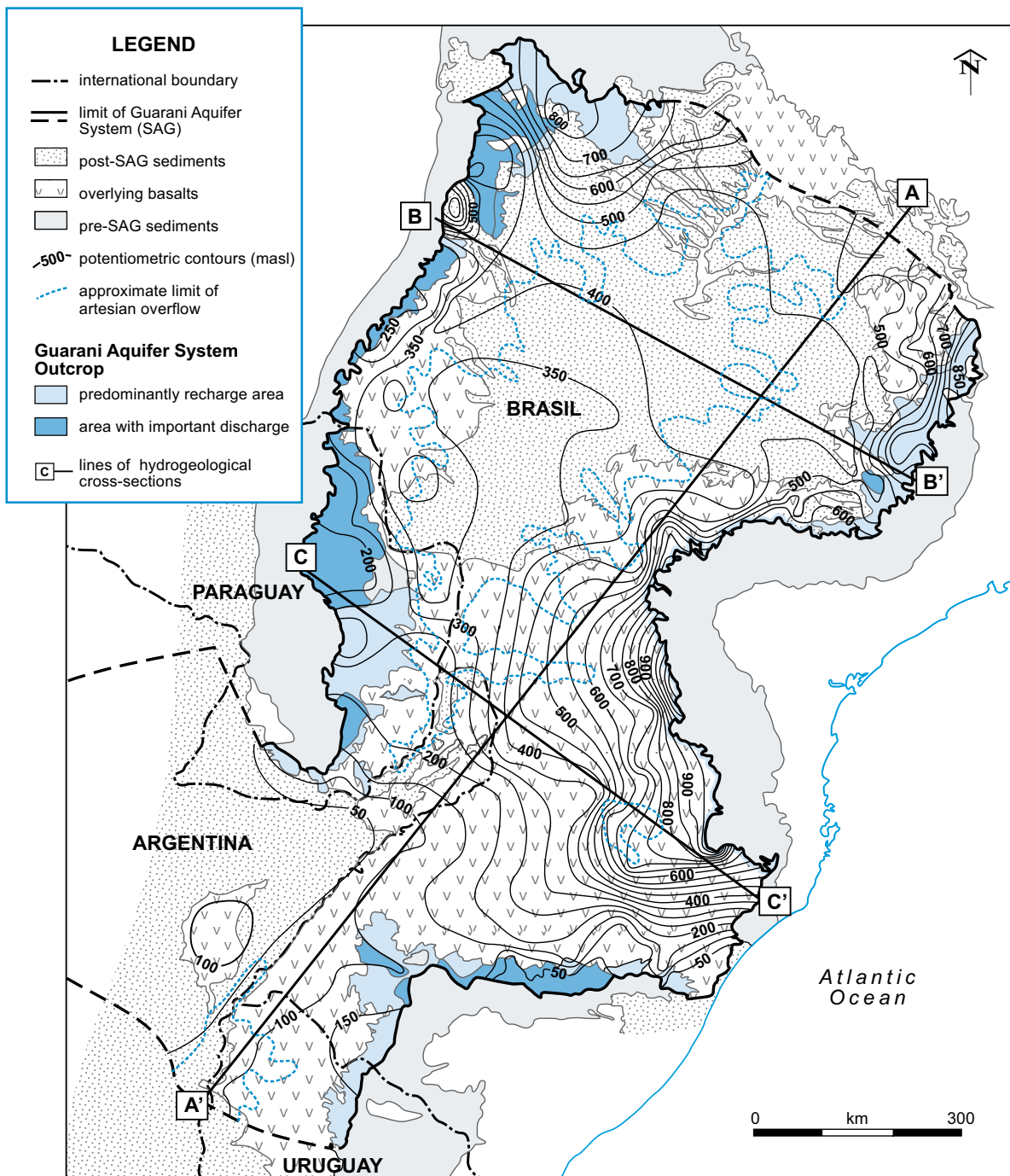
CONSOLIDATION OF SCIENTIFIC UNDERSTANDING OF GUARANI AQUIFER

Hydrogeological Characteristics of Aquifer System

- The Guarani Aquifer is a huge hydrogeological system that underlies an area of about 1,100,000 km² mainly in the Paraná River Basin of Brasil (with about 62% of its known area), Paraguay, Uruguay and Argentina (Figure 1). It has an average thickness of about 250 m (but varying from < 50m to > 600m)

and reaches depths of over 1,000 m (Figure 2). The total volume of freshwater it contains in storage is estimated to be around 30,000 km³ – equivalent to 100 years cumulative flow in the Paraná River. The aquifer extends across a number of international political boundaries, as well as those of many individual states of Brasil and provinces of Argentina, which are federal countries with groundwater resources essentially under state/provincial-level jurisdiction.

Figure 1 : Schematic hydrogeological map of the Guarani Aquifer System



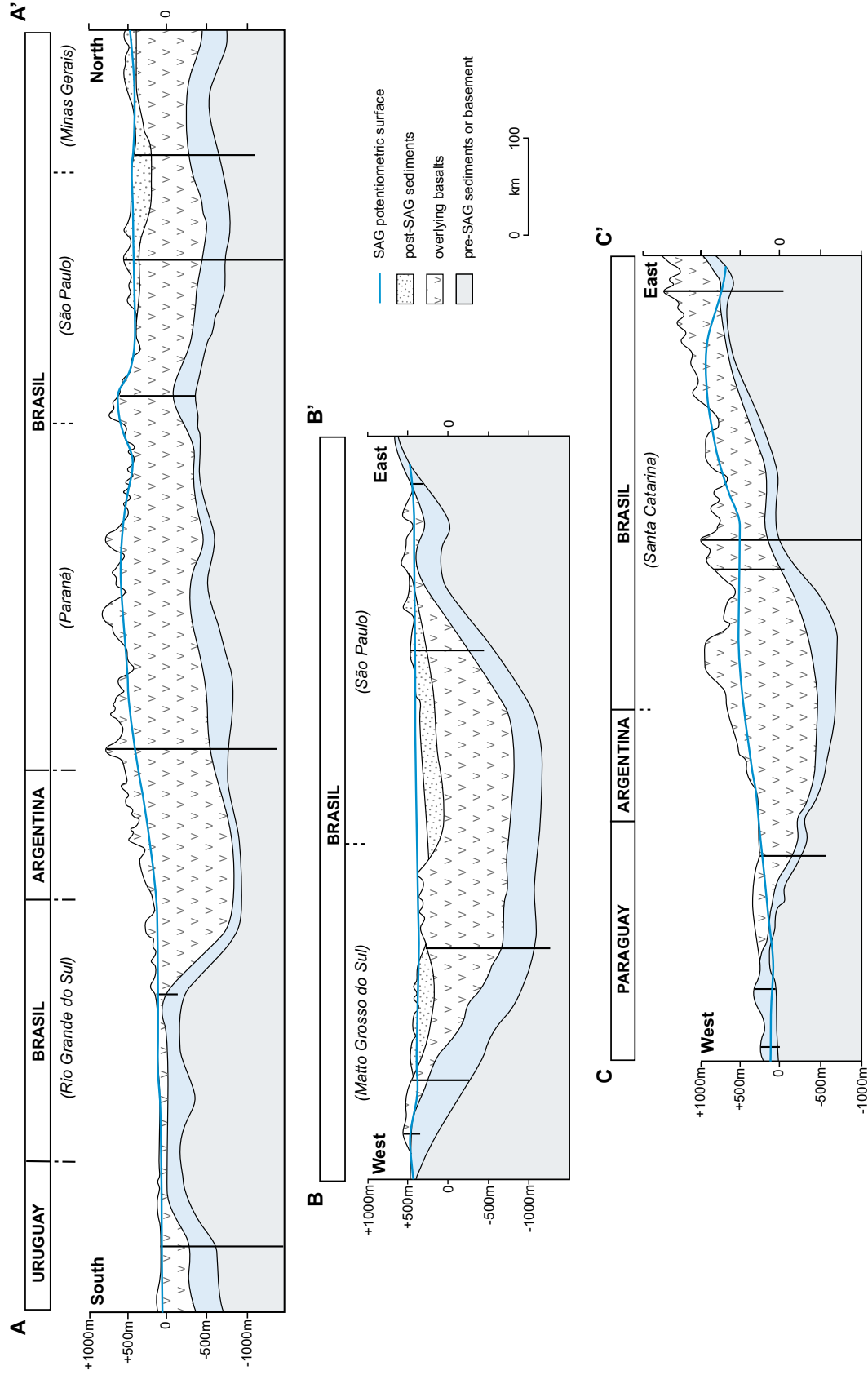


Figure 2 : Selected hydrogeological cross-sections of the Guarani Aquifer System

- The Guarani Aquifer System (SAG from the Spanish and Portuguese abbreviation) comprises a sequence of sandstone beds (mainly weakly-cemented) of Triassic-Jurassic age – they were formed by the (aeolic, fluvial and lacustrine) processes of continental deposition on a Permo-Triassic regional erosion surface (dated at 250 M years BP) and are overlain by Cretaceous basalt flows (dated at 145-130 M years BP), which are almost equally-extensive and exceed 1,000m thickness in some areas.
- The geostatigraphic equivalence of these sandstones was only recognized in the 1990s, following drilling of oil exploration wells and subsequent stratigraphic interpretation by academic researchers, who named the associated aquifer system the ‘Guarani’ in homage to the indigenous population of the area. The geological formations comprising the SAG, whose nomenclature pre-dates this, are thus known by different names in different areas (Table 1).
- The aquifer occurs in three main ‘hydrogeological domains’ delimited by two geological structures that have exerted a control on aquifer thickness and depth, and today influence regional groundwater flow :
 - the Ponta Grossa Arch (in the north of Paraná State-Brasil), which forces groundwater to flow from east to west in São Paulo State-Brasil
 - the Asunción-Rio Grande Arch, which divides the portion south of the Ponta Grossa Arch into two semi-independent sedimentary basins – the Central Paraná and the south-western Chaco-Lower Paraná.

The SAG is also affected by many tectonic structures and crossed by numerous volcanic dykes, but despite these important discontinuities at local scale it is considered to be a ‘continuous groundwater body’ across the entire region.

Table 1 : Stratigraphic sub-division of the Guarani Aquifer System

Country	URUGUAY	ARGENTINA	PARAGUAY	BRASIL		
Sedimentary Basin	north	Chaco-Paraná	Paraná	south	Paraná center	north
POST-SAG	Arapey basalts	various formations	Alto Paraná basalts	Serra Geral basalts		
(Lower Cretaceous)	(Sup. Member) Tacuarembo (Inf. Member) Itacumbú	Misiones or Tacuarembó	Misiones	Botucatu		
SAG	<i>Jurassic Inner Basin Unconformity</i>			Guará		
	<i>Permo-Triassic Regional Unconformity</i>			Caturrita	Pirambóia	
(Triassic)				Santa Maria		
PRE-SAG						

PRINCIPAL FEATURES OF GROUNDWATER STORAGE AND FLOW REGIME

The 'Active Flow System' in Recharge Areas

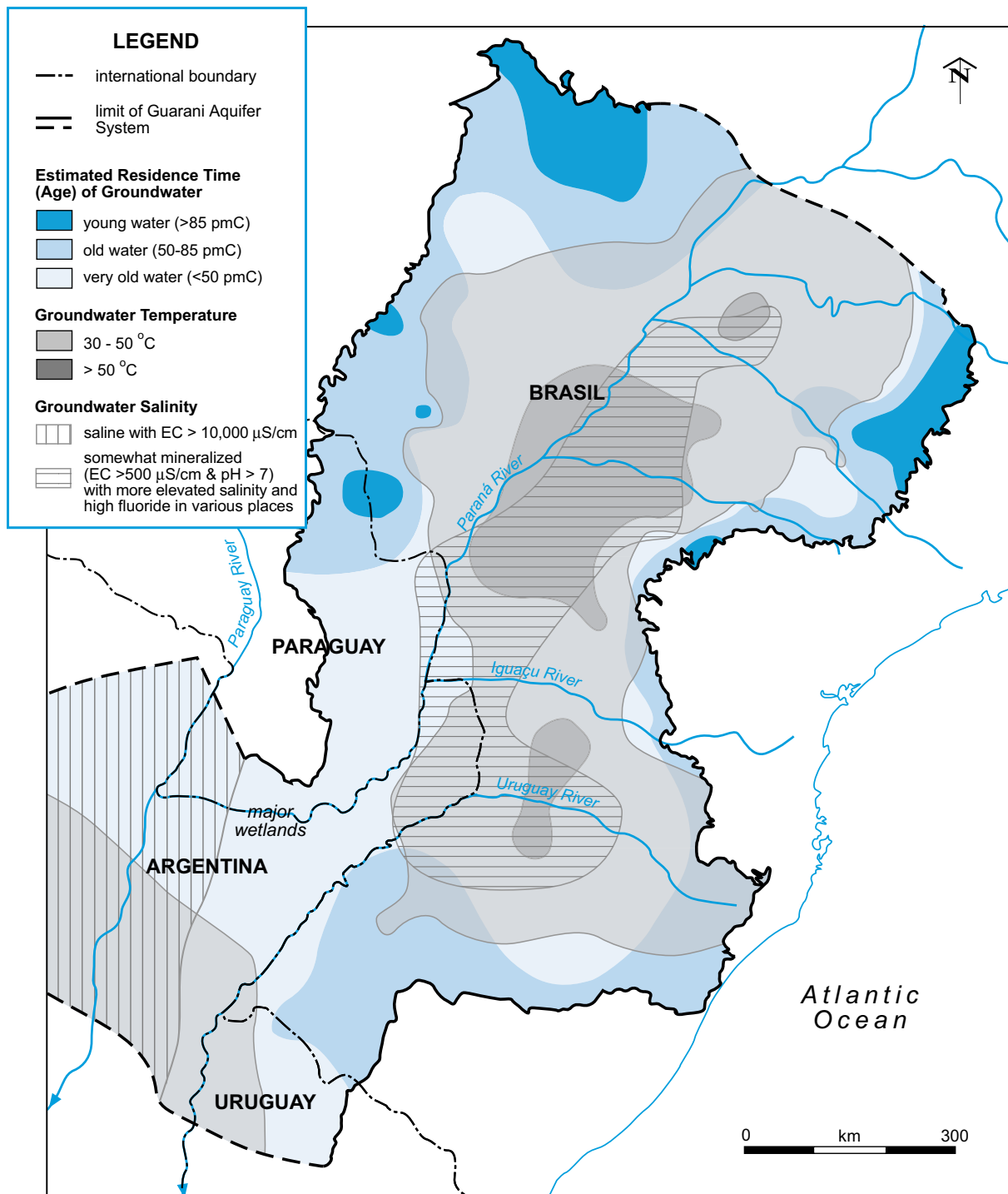
- Replenishment of the SAG occurs by direct infiltration of excess rainfall and streamflow along the length of the aquifer outcrop area (Figure 1), and in adjacent zones with a limited thickness of well-fractured basalt and via 'windows' in the basalt from overlying local groundwater bodies in Tertiary sedimentary formations.
- The high average rainfall across most of the SAG recharge area (1000-2000 mm/a) results in potentially elevated rates of aquifer recharge (300–400 and 500–600 mm/a in the northern and southern regions respectively). Although some may be 'rejected' because of inadequate infiltration capacity or high water-table, most of this potential recharge infiltrates forming local flow cells which discharge nearby as baseflow to rivers crossing the SAG outcrop. In these areas groundwater hydraulic gradients are up to 3-5 m/km and actual flow velocities are over 5 m/a.
- There are, however, substantial differences in detail between the recharge areas (Figure 1) on the 'north-western flank' of the main basin (Paraguay to Mato Grosso do Sul-Brasil) and on the 'northeastern flank' (Santa Catarina to São Paulo State in Brasil), where reduced formation thickness and steeper dip result in a much narrower outcrop area, a smaller zone where recharge through the basalt cover is favoured and much more restricted aquifer discharge areas (Figure 1).
- Estimation of the overall current rate of SAG recharge is not straightforward because of uncertainties not only in the spatial variation of average potential recharge rates but also over the proportion of SAG outcrop area that permits recharge and the extent of recharge in basalt-covered areas. But the total SAG recharge area is only a minor proportion of the known aquifer extension (Figure 1), and using best estimates for the above factors a value in the range 45-55 km³/a appears reasonable – this is less than 0.2% of the estimated freshwater storage. The SAG is thus unquestionably a totally 'storage-dominated' groundwater system, and this reality is reflected widely in the results and conclusions that follow.

The Contrasting Picture of 'Regional Storage'

- The latest groundwater potentiometric map (Figure 1) indicates some regional flow from the main recharge areas into the deeper structural basins, and subsequent southward flow parallel to the general axis of the Paraná Catchment. Towards the centre of structural basins, SAG groundwater becomes progressively more confined by an increasing thickness of overlying basalts and exhibits artesian overflowing head in deep water wells over extensive areas (Figure 1).
- The SAG has a relatively high 'permeability' (K_h of 5-10 m/d) and a mean estimated transmissivity of about 300 m²/d (range 50-1200 m²/d), but the flat terrain and low hydraulic gradients into the confined aquifer (about 0.1-0.3 m/km) imply very low groundwater flow velocities (less than 0.5 m/a). Aquifer numerical modelling suggests that the active groundwater flow into the deep confined aquifer is very limited, probably equivalent to 10-15 mm/a of vertical infiltration in the recharge area (only about 1-2% of the annual rainfall).

- With increasing depth and confinement the groundwater temperature also increases substantially (as a result of normal geothermal gradients), such that it forms a low-enthalpy hydrothermal resource with temperatures widely exceeding 40°C and locally reaching 60°C (Figure 3). It should be noted that the temperature increase will also significantly reduce groundwater viscosity.

Figure 3 : 'Groundwater ages' based on $\delta^{14}\text{C}$ analysis of percent modern Carbon (pmC) for the Guarani Aquifer System and its regional groundwater temperature & salinity variation



- Some natural discharge from the regional flow regime undoubtedly occurs – but is not yet quantified due to difficulty in detecting and measuring small groundwater upwellings in areas with large river flows. But for example, there are often small springs with chemical composition similar to that of confined SAG groundwater in areas with volcanic dykes, and other potential discharge zones (of favorable geological structure, aquifer potentiometric levels and reduced basalt thickness) include sections of the Paraná River (along the Paraguay frontier) and the Uruguay River (in Rio Grande do Sul & Santa Catarina States-Brasil), and the Esteros de Ibera (Argentina) and Ñeembacú (Paraguay) wetlands (Figure 3).
- An extensive study of environmental isotope (^3H , $\delta^{18}\text{O}/\delta^2\text{H}$, $\delta^{14}\text{C}/\delta^{13}\text{C}$) composition of SAG groundwaters has proved very useful for corroboration of this regional flow model. Groundwater associated with the aquifer recharge area generally has $\delta^{18}\text{O}/\delta^2\text{H}$ values matching those of present-day rainfall ($> -7.5\%$ in $\delta^{18}\text{O}$). Moreover, the presence of ^3H up to 3 T.U. and $\delta^{14}\text{C}$ activity close to 100 pmC confirm the presence of recently-recharged water, including below some ‘windows’ in areas with thicker basalts.
- The rapid decline of $\delta^{14}\text{C}$ activity along groundwater flow paths towards the highly-confined SAG is commensurate with extremely slow circulation – with most deep boreholes recording $\delta^{14}\text{C}$ below detection limit (probably water recharged more than 35,000 years BP) (Figure 3). In addition the $\delta^{18}\text{O}$ content of groundwater in some confined SAG areas (eg. in São Paulo State-Brasil) is at first sight anomalous, given more negative stable isotope composition than present-day rainfall ($\delta^{18}\text{O}$ of -8 to -9.5 ‰) – this probably reflects paleo-groundwater recharged under colder climatic conditions, but the same phenomena is not found in the SAG further south.

Natural Groundwater Quality Regime

- Natural groundwater quality in the SAG is generally very good with low mineralization levels in most areas. A hydrogeochemical evolution is seen as recharging waters from outcrop areas flow slowly into the deeper confined aquifer (Table 2) with dissolution of carbonates (confirmed by the $\delta^{13}\text{C}$ content of dissolved inorganic carbon), ion exchange processes (notably Na replacing Ca in solution), rising pH from 6.8 to 9.5 and also marked temperature increases.

Table 2 : Typical chemical changes in groundwaters of Guarani Aquifer System when traced westwards down-dip from Ribeirão Preto (São Paulo) – Brasil

PARAMETER (units)		OUTCROP BOREHOLES	DOWNDIP BOREHOLES (distance from outcrop)	
			30km	150km
Chemical Characteristics				
T (°C)	temperature	24	26	42
pH	acidity	6.5	8.5	9.5
Ca (mg/l)	calcium	30	20	2
Na (mg/l)	sodium	1	5	90
HCO ₃ (mg/l)	bicarbonate	15	75	160
Cl (mg/l)	chloride	1	2	10
F (mg/l)	fluoride	< 0.1	0.2	> 1.0
SiO ₂ (mg/l)	silica	15	20	30

(data selected from Sracek & Hirata, 2002)

- The hydrochemical and isotopic data show that formations underlying parts of the SAG (mostly saline aquitards) contribute to observed salinity and significant trace element increases (especially F and more locally As) in certain areas, but that this contribution is not significant in terms of associated groundwater flow volumes. There are also much more marked and general down-dip increases in groundwater salinity in the extreme southwest of the SAG in Argentina (Figure 3), which effectively mark the limit of the potentially useful aquifer system. There have also been some concerns that the deep confined groundwater might locally contain significant levels of the soluble U isotopes, radium and radon gas.

FRAMEWORK FOR GROUNDWATER DEVELOPMENT AND MANAGEMENT

Current Status and Future Drivers of Resource Utilisation

- The recent Guarani Aquifer Program has completed a full inventory of production boreholes in the SAG which indicates current resource exploitation to total 1.04 km³/a, with 94% in Brasil (of which about 80% is in São Paulo State), 3% in Uruguay, 2% in Paraguay and 1% in Argentina. Some 80% of the total is used for public water-supply, 15% for industrial processes and 5% by geothermal spas.
- There are estimated to be around 2,000 operating deep production boreholes. Some are capable of producing more than 500 m³/hr but less when only the 'overflow yield' is utilized – and as regards actual average abstraction less than 20% of the total are producing more than 100 m³/hr.
- The extensive area underlain by the SAG has a present population of about 15 million (although including large cities in its proximity this figure increases to about 90 million), a mainly sub-tropical climate, and abundant (but often polluted) surface water resources which experience occasional droughts. Thus the need for reliable potable water-supply sources and industrial supplies (of low-treatment cost) is likely to grow significantly, especially in some climate-change scenarios (which imply increased water demand due to ambient temperature increase and more frequent and intense surface-water droughts).
- The increasing importance of the SAG for the potable water-supply of many towns with populations of 50,000-250,000 must be emphasized – examples include Tacuarembó and Rivera in Uruguay, Caaguazú and Ciudad del Este in Paraguay, and (in Brasil) Santana do Livramento and Caxias do Sul in Rio Grande do Sul, Londrina in Paraná, Uberaba and Uberlândia in Minas Gerais, and Campo Grande in Mato Grosso do Sul.
- Importantly the SAG also represents a major low-enthalpy geothermal resource (often with overflowing artesian head) of very extensive distribution (Figures 1 & 3), with potential for future expansion of :
 - spa facilities in northwestern Uruguay, neighboring parts of Argentina, and further north in the Iguazu international tourist area
 - numerous industrial applications and potential agro-industrial processes
 but groundwater temperatures are too low for conventional electric-power generation.
- The question of whether demands will arise for the extensive and/or intensive use of SAG groundwater for agricultural irrigation, especially in some climate-change scenarios and with increasing trends

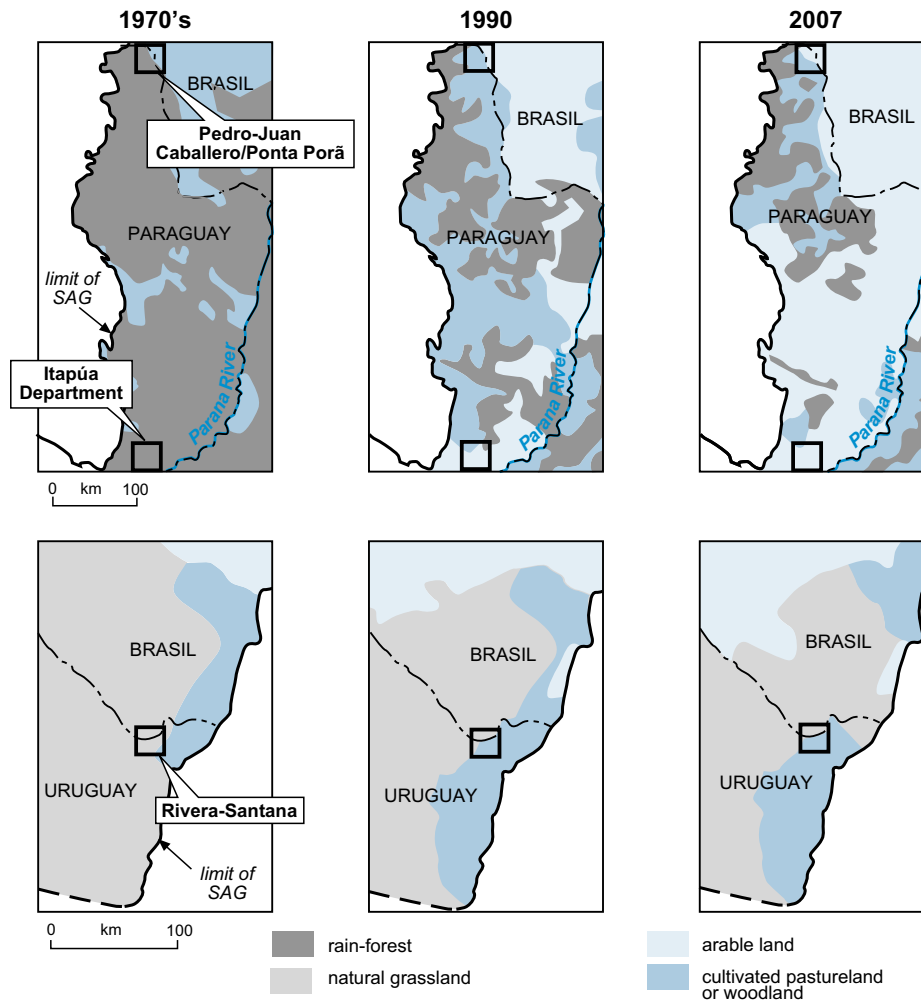
in crop prices, is especially critical in terms of future groundwater management needs. Preliminary agro-economic assessment suggests that the use of SAG groundwater for supplementary irrigation, as an insurance against crop yield reduction caused by short-duration drought during soya-bean cultivation, is not yet generally economic – except in recharge areas with shallow water-table.

Aquifer Pollution Vulnerability and Land-Use Issues

- The only parts of the SAG which exhibit significant vulnerability to groundwater pollution from anthropogenic activities on the land-surface are the main recharge area – comprising the aquifer outcrop and adjacent areas where the basalts are highly-fractured or ‘windows’ through the basalt exist. The degree of groundwater pollution vulnerability here will vary with water-table depth, and the degree of consolidation of the sandstone units or fracturing of the overlying basalts, and although not ‘extreme’ is likely to be in the ‘moderate to high range’.
- At some distance from the SAG outcrop below the basalt cover, the ‘relatively old groundwater ages’ deduced from isotopic analyses (Figure 3) indicate minimal pollution vulnerability, except perhaps from low levels of any highly persistent and mobile groundwater contaminants in the very long term.
- Potential threats to the naturally-excellent groundwater quality of the SAG in its recharge areas include:
 - urbanization and the disposal of domestic urban wastewaters
 - industrial premises, and their potentially inadequate storage and handling of hazardous chemicals, and disposal of liquid and solid effluents
 - intensification of agricultural crop cultivation and forestry.
- As a result of the latter, rural land-use in parts of the SAG recharge area has witnessed enormous changes over the past 30 years or so (Figure 4) including :
 - clearing of humid sub-tropical forests to exploit their timber resources and make way for cattle-ranching pastures (in Brasil and Paraguay)
 - ploughing-in pastureland for introduction of intensive agriculture – soya-sunflower/soya-maize rotations and sugar-cane (in Brasil, Paraguay & Argentina), in part for biofuel production, and citrus fruits (Brasil)
 - forestation of some natural rough pastureland with eucalyptus for paper-pulp or pines for timber production (in Uruguay).

Since much better soil profiles are developed on the basalts than the sandstones, the introduction of intensive soya-bean rotations within the SAG recharge zone tends to be concentrated in the areas with thin basalt cover. The impact of these major large-scale changes on the quality and rate of SAG recharge has not yet been adequately researched and requires further attention in the future.

Figure 4 : Evolution of agricultural land-use in selected parts of the SAG recharge area

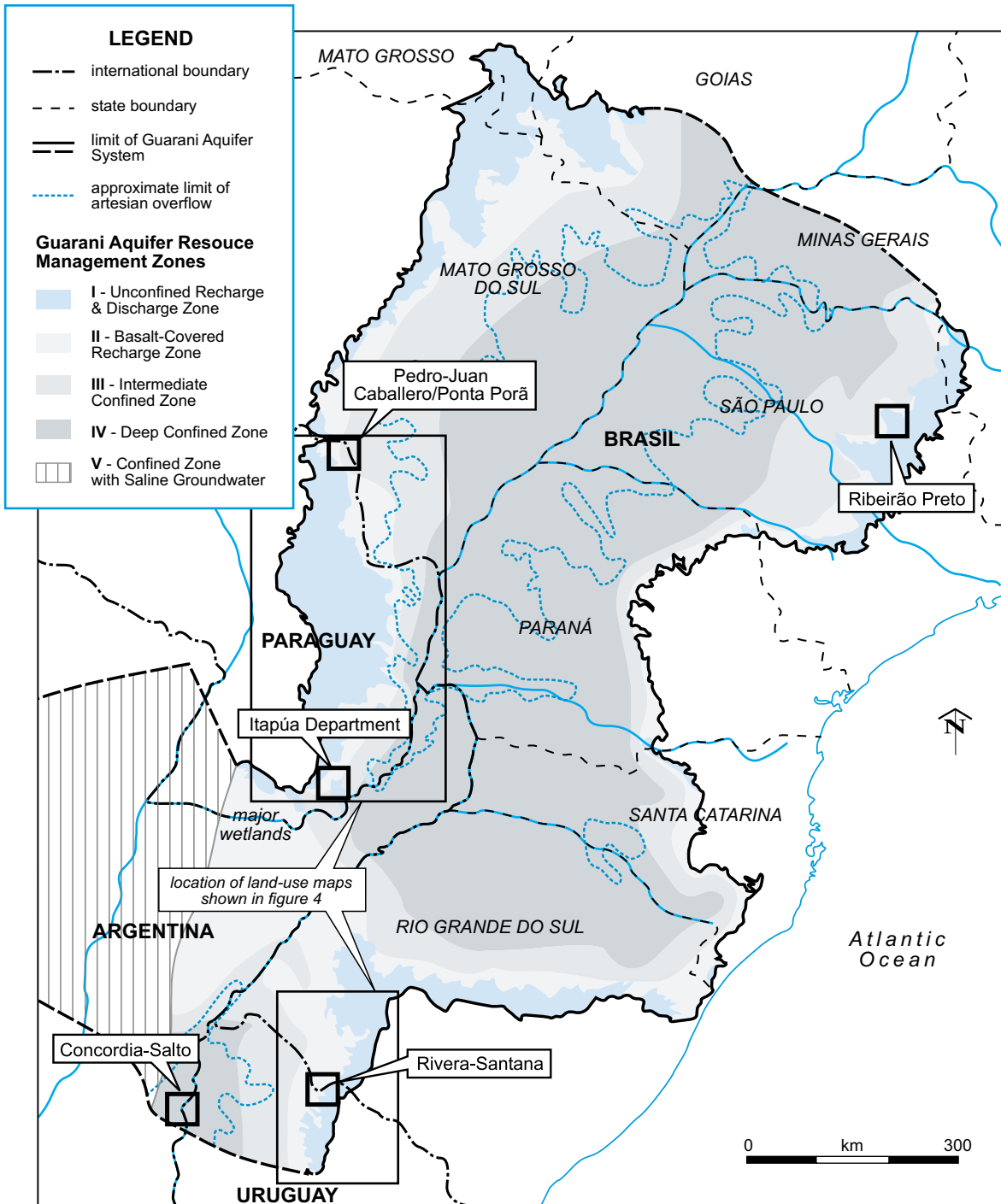


Scientific Basis for Resource Management

- The revised conceptual model of SAG hydrogeology has important implications in terms of the definition of an efficient and sustainable strategy for the managed development of groundwater resources. Five distinct ‘resource management zones’ can be usefully defined (Figure 5), whose characteristics are discussed below.
- **I – Unconfined Recharge & Discharge Zone**
 - Groundwater resources extracted from this zone will be fully renewable up to a level equivalent to somewhere in the range 300-600 mm/a natural recharge over the local area concerned (depending on location) – and indeed there may be potential to induce additional recharge as the water-table becomes depressed.
 - However, the aquifer is significantly vulnerable to pollution from land-surface activities, and for potable and other supplies where quality is a premium, a focused campaign of aquifer or source protection measures should be implemented.

- The main impact of intensive groundwater abstraction will be reducing the baseflow of local rivers. For this reason it may be convenient to regard only a proportion of the total recharge as ‘available for extraction’ – although if groundwater use is not significantly consumptive the baseflow reduction can be compensated by effluent returns (albeit with some river-water quality implications).

Figure 5 : General delineation of resource management zones for the Guarani Aquifer System



- **II – Basalt-Covered Recharge Zone**

- In this closely adjacent zone, where the sandstone is covered by relatively thin and well fractured basalt (typically < 100m thick), the SAG exhibits a ‘semi-confined’ condition and important vertical recharge can be expected to occur or to be induced by pumping (in addition to horizontal groundwater flow from the main outcrop/recharge area).
- The criteria for groundwater resource development and management in this zone are in many ways similar to Zone I, but the overall rate of long-term recharge will be significantly less.

- **III – Intermediate Confined Zone**

- In this zone no significant recharge occurs (aquifer residence times being >10,000 years), and pumped groundwater will in effect be ‘mined’ from aquifer storage with continuously (but very gradually) falling potentiometric surface. As such the resource is almost entirely ‘non-renewable’, although a small volume of regional groundwater flow will be intercepted and additional flow induced in the very long term. Groundwater is completely protected from anthropogenic pollution and widely of potable quality (although some local problems might be encountered).
- There are large amounts of groundwater in confined storage in this zone – and the total amount exploitable is estimated to be about 10 km³. In practice the amount and spread of drawdown in response to groundwater abstraction will be controlled by the aquifer storage coefficient – and in areas where the top of the SAG is not too deep the rate of water well drawdown will greatly reduce on reaching and dewatering the topmost horizons of the aquifer (where the available groundwater storage is orders of magnitude higher).
- Given the continuously-falling dynamic water well levels until the top of the SAG is reached, the limit of this zone is (somewhat arbitrarily) defined as that where the top of the confined SAG is less than 400 m bgl, because this depth corresponds to the current limiting economic head for conventional water well pumps – albeit that many water wells have been drilled to 1000 m in total depth.

- **IV – Deep Confined Zone**

- Most of the considerations discussed above in relation to Zone III also apply to Zone IV, but in this zone the top of the SAG is more than 400 m bgl and the only exploitable groundwater is thus from confined storage. Below this level, the exploitation is unlikely to be economic except for hydrogeothermal applications, although the total amount of confined storage is about 40 km³.
- In this zone also groundwater is completely protected and generally of good quality, although in some areas it presents troublesome and/or trace-element concentrations.

- **V – Confined Zone with Saline Groundwater**

- There is an extensive area in Argentina where the confined SAG contains groundwater of high salinity. In this zone groundwater can be used in spas, and other hydrogeothermal applications, or for other purposes after treatment where this is economically feasible.

General Institutional and Legal Advances for Resource Management

- In most respects an adequate legal basis (at national and/or sub-national level) exists for the management and protection of groundwater resources in the ‘Guarani countries’, with the notable exception of clearly-specified powers for groundwater protection in recharge areas by exerting influence over :

- agricultural policy as a key driver of rural land-use
- municipal decision-making on urban land-use.

There were, however, widespread deficiencies in the regulation, tools and capacity for implementation and enforcement of groundwater management measures.

- Throughout implementation of the GEF-Program there was consensus among countries on developing a coordinated legal framework and harmonizing their laws regarding groundwater resource management, whilst recognizing national differences and peculiarities.
- Both Paraguay and Uruguay are unitary states with responsibility for groundwater resources resting wholly with the respective national governments, and :
 - in Uruguay there is a clearly stated ‘water resource code’ and a specific decree dealing with hydrogeothermal energy and establishing an advisory committee – the competent authority is the Dirección Nacional de Aguas y Saneamiento (DINASA) although they have no jurisdiction over pollution
 - in Paraguay the national water law has some relevant issues still pending regulation – the Secretaria del Ambiente (SEAM) having responsibility for water resources and the Empresa Reguladora de Servicios de Saneamiento (ERSSAN) for the regulation of water services.

In contrast, both Brasil and Argentina are federal countries in which the administration of groundwater resources has been largely delegated to state or provincial government – but various states/provinces (including some large ones) have not yet evolved adequate institutional capacity and/or are not very active on implementation.

- Significant efforts were made by the GEF-Program to remedy deficiencies in groundwater regulations and/or tools, such that all four ‘Guarani countries’ have shown important advances (Table 3). In addition, 7 Brazilian States and 3 Argentinian Provinces have made specific Guarani Aquifer management provisions, and resolutions on SAG protection by the Rio Pardo Basin Committee (CBRP) in Brasil have prompted deliberations on groundwater restriction areas by the São Paulo State Water Resources Council. However, significant concerns remain quite widely about the institutional capacity for enforcement. The GEF-Program also strengthened institutional capacity through staff training and attachment, and at academic centres through deployment of a ‘special university fund’ (supported by World Bank-BNWPP).
- At international level an important legal outcome of the GEF-Program is the agreement for continuing regional cooperation on SAG management and protection through :
 - assuming direct responsibility for continuation of the main activities, with each country responsible for providing (in coordination with the others) the necessary tools and resources – SISAG database management (Argentina), groundwater monitoring and modelling (Brasil), capacity building and dissemination (Paraguay) and coordination of activities and office-base (Uruguay)
 - continuation of the activities initiated in the pilot projects – with Concordia/Salto being coordinated by Argentina, Rivera/Santana by Uruguay, Riberao Preto by Brasil and Itapúa by Paraguay – although there has been reluctance or difficulty to retain the services of the Pilot Project Facilitators critical to continuity and effectiveness, and an option here (which needs urgent consideration) would be to appoint someone accountable from within (as opposed to outside) existing line agencies.

Table 3 : Strengthening of groundwater legal provisions and regulatory tools

COUNTRY	PROVISION	SCOPE
Argentina	Federal Groundwater Plan (2009)	<ul style="list-style-type: none"> • all provinces involved in SAG agreed on planning and coordinating groundwater management • regulatory framework for hydrogeothermal resources
	Thermal Water Act of Entre Rios (2006)	
	Guarani Aquifer Act of Chaco, Corrientes & Misiones (2004, 2004 & 2006)	<ul style="list-style-type: none"> • provisions on use and protection of SAG through declaration as provincial public domain
Brasil	CONAMA Regulations (2005 & 2008)	<ul style="list-style-type: none"> • provisions for waterbody classification • waterwell protection areas and potential pollution control
	CERH Deliberation Sao Paulo (2005)	<ul style="list-style-type: none"> • restriction areas and control of abstraction and use of groundwater
Paraguay	National Water Act (2007)	<ul style="list-style-type: none"> • management and protection of water resources • guidelines for borehole drilling for groundwater abstraction • regulation of water councils • national register of water rights
	SEAM Resolutions (2005, 2006 & 2007)	
Uruguay	Constitutional Amendment (2004)	<ul style="list-style-type: none"> • public domain and management principles for groundwater • possibility of creating local 'groundwater management committees'
	Water Policy Act (2009)	
	National Decrees (2004 & 2006)	<ul style="list-style-type: none"> • technical guidelines for deep borehole drilling • National Commission of Water & Sanitation set-up

Scale of Transboundary Aquifer Management Needs

- The GEF-Program confirmed that most actual and potential groundwater resource management and protection needs of the SAG fundamentally do not have an ‘international transboundary character’ – albeit that there exist some local ‘transboundary hotspots’ both between nations, and indeed between individual states of Brasil, that share the aquifer. The predominant need for international and federal cooperation arises from the benefits of sharing advances in scientific understanding and positive management experiences – thus a clear commitment from the countries involved would help to continue developing research and spreading knowledge.
- Widespread misperceptions about the SAG were revealed amongst the public administration and community itself – in particular over the character of its groundwater resources, the scale of problems which might affect it and the most appropriate level of management for their resolution. An indicative framework (Table 4) was thus drawn-up showing that :
 - current transboundary groundwater issues are strictly limited in distribution and essentially local in character, and do not have major ‘upstream-downstream’ implications – they thus require resolution through agreement and action at the corresponding local scale
 - only with extensive intensification of groundwater use for supplementary irrigation are any potential transfrontier effects on groundwater likely to expand from local to catchment scale, and preliminary assessment suggests that this is not yet economic except in recharge areas with shallow water-table.

The GEF-Program is thus essentially ‘preventative’ in character and cooperative in nature – there being no major ‘crisis issues’ to resolve and many benefits potentially accruing from cooperation.

Table 4 : Scale of potential transboundary groundwater management needs for the Guarani Aquifer System

COOPERATIVE ACTIONS OF LOCAL APPLICATION WITH MUTUAL BENEFITS	ACTUAL & POTENTIAL SITUATIONS WITH LOCAL TRANSBOUNDARY EFFECTS	POSSIBLE SITUATIONS WITH SIGNIFICANT IMPACTS AT CATCHMENT SCALE
<ul style="list-style-type: none"> • evaluation of incidence/control of natural groundwater quality problems (F, As, etc.) affecting use for potable water supply • definition of strategies for efficient groundwater resource development and sustainable management • assessment of aquifer pollution vulnerability and appropriate protection measures for aquifer recharge areas 	<ul style="list-style-type: none"> • contamination of potable water wells due to inadequate urban sanitation and uncontrolled urban land-use • wetland impact and river baseflow reduction as a consequence of potential intensive groundwater resource development for agricultural irrigation • deterioration in quality and rate of aquifer recharge as a result of extensive changes in agricultural land-use, crop cultivation and eucalyptus forestation 	<ul style="list-style-type: none"> • adjacent problems could grow if agricultural policies and markets favour intensive and extensive use of local soils and/or groundwater resources – but even then unlikely to result in major transboundary environmental impact unless a critical ecological role for SAG groundwater is confirmed
<ul style="list-style-type: none"> • evaluation of economic and efficient options for the use of aquifer geothermal resources 	<ul style="list-style-type: none"> • reductions in artesian and geothermal characteristics of aquifer due to uncontrolled exploitation by geothermal wells 	

GROUNDWATER MANAGEMENT IN PRACTICE – THE PILOT PROJECTS

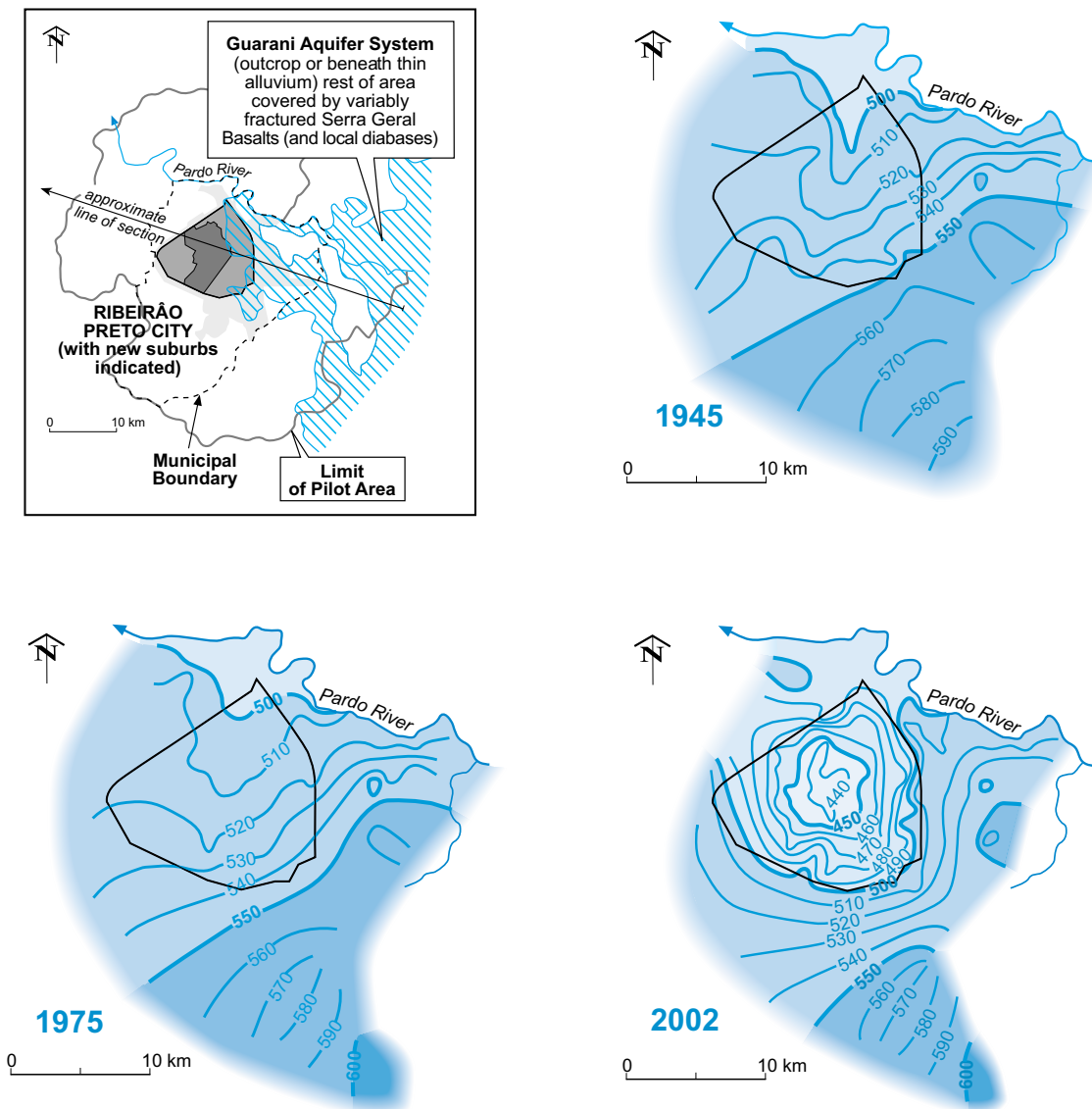
Identification of Measures Required in Different Settings

- Five pilot experiences of advancing SAG groundwater management and protection are reported on here whose locations are given on Figure 5 :
 - four promoted under the GEF-Program through Local Project Facilitators or ‘Champions’ – two of which are of international transboundary incidence
 - one involving international cooperation (Paraguay-Brazil) facilitated by German technical support.
 Of the five pilot projects four are sited within SAG Groundwater Resource Management Zones I & II and one in Zone IV.
- These pilot groundwater management projects cover a representative range of resource management and quality protection issues, and are attempting to identify problem-specific and scale-specific solutions, capable of being implemented by appropriate local institutional agreements.

Ribeirão Preto (Brasil)

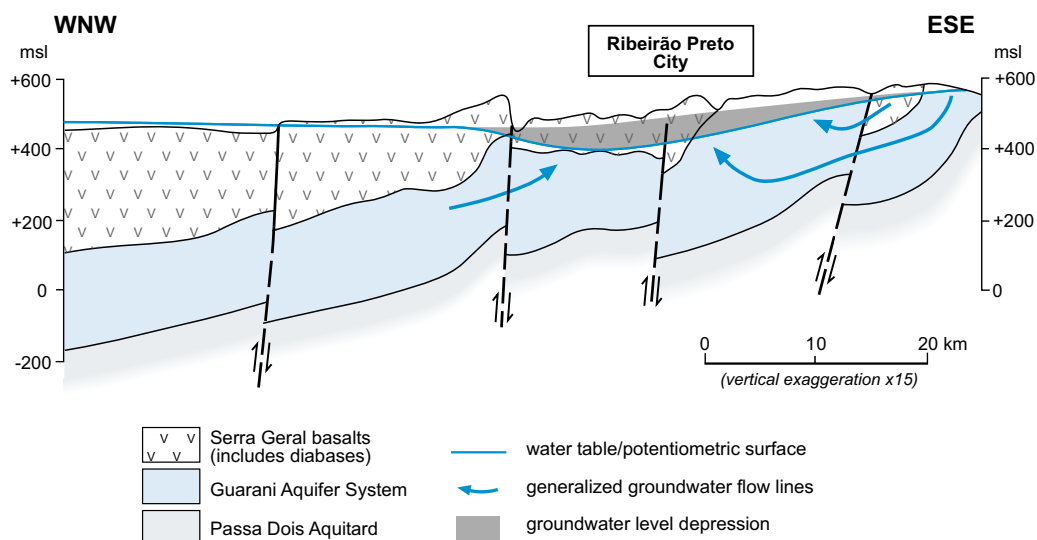
- The Ribeirão Preto Pilot Project is centred around the municipality and city of the same name in the northeastern part of São Paulo State-Brasil, which has a population of some 547,000 and an area of 652 km², including 137 km² of SAG outcrop but spreading mainly across the overlying Serra Geral Basalts (Figure 6), and includes territory falling under jurisdiction of various neighboring municipalities. In total, the pilot-project area is about 2,920 km² and has a population of 766,000 inhabitants (2007), which according to government projections will double by the year 2045.
- The area is one of major agricultural production, with sugarcane (for sugar refining and alcohol distillation), coffee and oranges (for fruit juice production) being the dominant crops. The city is also a major industrial centre – with important fuel-alcohol distilling, agro-industrial products and services, and a wide variety of manufacturing enterprises.

Figure 6 : Evolution of groundwater table decline in Ribeirão Ribeirao Preto Municipality



- Groundwater recharge occurs when rainfall excess to plant requirements on the sandstone outcrop infiltrates during November-March at average rates believed to be around 250 mm/a. Very detailed and comprehensive studies conducted in this area concluded that little recharge to the SAG occurs through the Serra Geral Basalt aquitard, once there is a continuous overlying basalt lava-flow (generally <30 m thickness).
- The SAG is exploited by more than 1,000 wells – Departamento de Águas e Esgotos (DAERP) has about 95 currently in active operation with an estimated actual production of around 127 Mm³/a. However, there is a significant uncertainty about the total level of groundwater abstraction, which is estimated to have grown from 45 Mm³/a in 1976, to 96 Mm³/a in 1996 and to 133 Mm³/a in 2007. For the whole pilot area (including the other municipalities) the total amount of water extracted reached 186 Mm³/a in 2007.
- Groundwater development and water-table lowering have reduced, and largely eliminated, natural groundwater discharge to stream flow (and replaced it by wastewater discharge). Contemporary groundwater recharge is exceeded by abstraction since, over a large area across the city, groundwater levels have fallen by an estimated 30-40 m since 1970 (Figure 7), with the following side-effects :
 - increases in operational water-supply costs, due to falling water level and decreasing well efficiency consequent upon loss of upper well-screen sections
 - previously effluent watercourses becoming influent with increasing groundwater pollution risks.
- Groundwater quality from the deeper (DAERP) water wells is reported to be good, with excellent microbiological results, exceptionally low total salinity (60 μ S/cm), slightly acidic pH (5.5-7.0) and nitrate concentrations not exceeding 10 mg/l NO₃-N. Mobile herbicides (such as tebuthiuron, diuron, ametrine, etc) widely-applied to sugarcane have not yet been detected in groundwater samples, nor any of the chlorinated solvents used in some industries. But the majority of DAERP water wells are located where the SAG is partly protected by basalt aquitard cover. Elsewhere, in the much more vulnerable outcrop zone, the vadose zone is generally thick (often 30-60 m) and has increased as a result of falling

Figure 7 : Hydrogeological cross-section of the Ribeirão Preto Pilot Project area



water-tables – thus groundwater pollution by persistent contaminants from sanitation practices, industrial effluents and agricultural cultivation may not yet have percolated down to the deep screen intakes of these water wells (since this could take various decades).

- The pressing issues that need to be addressed are :
 - promotion of land-use planning on the SAG recharge zone compatible with its primary function as a low-cost, high-quality, source of potable municipal water supply – this should be based rationally on aquifer vulnerability mapping and groundwater supply protection area delineation
 - appraisal of the risks to existing municipal groundwater sources posed by current urban sanitation measures, industrial activities and agricultural practices, and to promote action to manage any significant risks identified and confirmed – in particular the urban water cycle needs to be better understood and managed from supply source to wastewater reuse
 - constraint on the demand for groundwater abstraction – current average water production is very high (350 l/d/cap) and total municipal demand is predicted to rise by a further 187 Mm³/a in 2030 as a result of population growth to 867,000 – thus measures need to be taken to relieve pressure on aquifer resources and keep to a sensible minimum the land area that will need to be specially protected in the interest of municipal potable water supply
 - consideration of possible development of some municipal groundwater production capacity from wellfields situated in the most protected SAG confined area, in part to replace any existing sources found to be at great risk of pollution and also to reduce the intense hydraulic interference in the downtown area of the city.

- Some important advances that have already been promoted include :
 - strong time-based constraint on water well drilling and/or replacement within Ribeirão Preto Municipality until definition of a resource management policy – under an agreement reached between DAEE (Departamento de Águas e Energia Elétrica - São Paulo State) and Municipal Government
 - setting-up an observation borehole network (through conversion of old water wells) by DAERP.

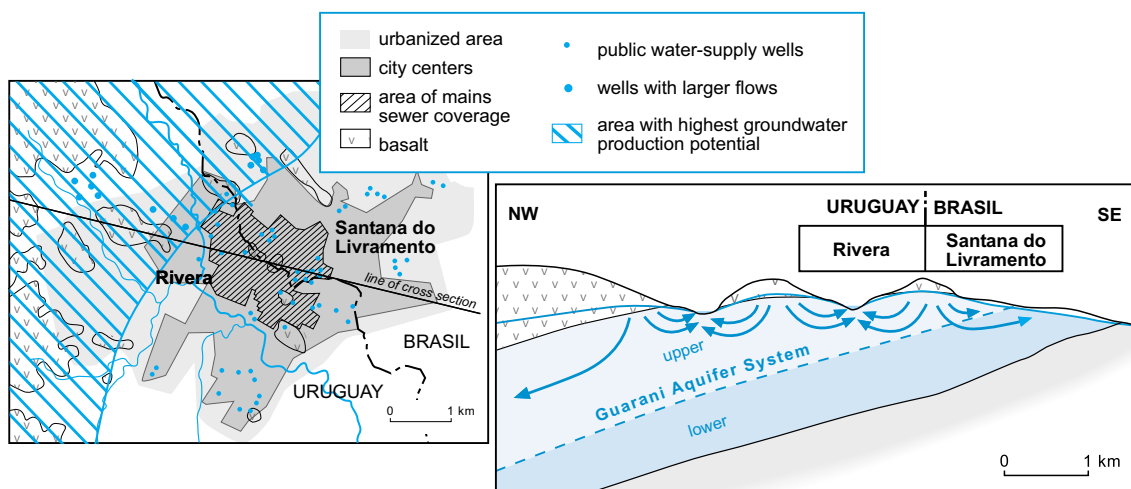
- São Paulo State Law and Ribeirão Preto Municipal Decrees make various provisions for groundwater resource management and protection, which are at least partially enacted but require more integration, application and enforcement through institutional cooperation and stakeholder involvement. In addition various local initiatives are contributing to the development of a more holistic vision for the future :
 - Comitê da Bacia Hidrográfica do Pardo (CBHP) is promoting actions to constrain water demand in the urban population
 - Instituto Geológico de São Paulo (IGSP), with German technical support, has undertaken aquifer vulnerability mapping, pollution risk assessment and source protection zone definition at pilot level.

Rivera (Uruguay)-Santana do Livramento (Brasil)

- The Rivera/Santana do Livramento Pilot Project (Figure 8) straddles the Uruguay-Brasil (Rio Grande do Sul State) border and covers the environs of the frontier towns of Rivera and Santana do Livramento, which have a combined and growing population of about 162,000 and in many ways act as a continuous urban area (eg. single electricity supply and emergency services). Economic activity is based largely upon agriculture – with cattle and sheep for leather, meat and wool production, maize and increasingly soya-bean cultivation, and on the Uruguayan side forestation for wood and pulp production.

- The SAG outcrops across much of the area, and elsewhere is covered by a thin capping of basalts, with the frontier following a low but hilly surface water-divide. The groundwater table occurs at shallow depth, with the natural groundwater flow occurring in a north-easterly direction and being concentrated at 40-80 m depth in the most permeable aquifer horizons – but this has been modified by abstraction depressing groundwater levels by 5-10 m in the last 10 years (Figure 8).
- The SAG is the principal source of water-supply – there being in the order of 300 water wells including those of Obras Sanitarias del Estado (OSE) in Rivera and the Departamento de Aguas e Esgotos (DAE) in Santana do Livramento (Figure 8), which provided some 7.3 and 8.7 Mm³/a (70% and 100% of the corresponding total) respectively in 2002. Mains water-supply coverage is more than 95% by population, but multi-residential buildings and larger family residences also operate private boreholes to mitigate against discontinuity of mains service and/or to reduce the overall cost of water-supply. Such practice was in fact prohibited in Rio Grande do Sul State by a Sanitary Declaration (1974) and reinforced by Federal Law (2005), because it was feared that use of shallow groundwater from inadequately constructed water wells could present a serious health hazard – but the ban has proved to be of arguable legal foundation (with the law having been judicially questioned) and will not be implemented until there is a final pronouncement.
- Natural groundwater quality is excellent and of low CaHCO₃ (80 mg/l) mineralization with average values of Cl = 33 mg/l, SO₄ = 4 mg/l and Na = 6 mg/l – but low pH (less than 6.0) and elevated NO₃ concentrations (some over 10 mg/l NO₃-N). The main groundwater management problem relates to the lack of mains sewerage, which results in a substantial load of wastewater to an aquifer of significant pollution vulnerability either directly from cesspits or indirectly from polluted streams – and thus potential problems with nitrate, chloride and persistent organic compounds must be expected in the longer run with continuing wastewater infiltration. The past history of land tipping of solid municipal waste, the infiltration of some industrial effluents (from timber-processing yards and livestock slaughterhouses) and the presence of a substantial number of poorly-maintained gasoline filling stations represent further hazards to groundwater quality.

Figure 8 : Sketch map of water infrastructure and hydrogeological section of the Rivera (Uruguay)-Santana do Livramento (Brazil) Pilot Project area



- Main sewerage coverage is restricted to 30% and 40% of the Rivera and Santana do Livramento populations respectively, with the implication of substantial subsurface loading of wastewater from in-situ sanitation units over extensive urban areas. There is also overflow of numerous in-situ sanitation units in certain areas (due to improper construction, insufficient space for soakaway construction and locally inadequate soil infiltration capacity) leading to insanitary conditions at street level. Both towns are striving to amplify their mains sewerage system (with OSE in the process of increasing coverage from 30% to 50%) – but the process is complicated by a number of factors :
 - very hummocky terrain which necessitates many local sub-stations for pumping sewage and causes escalating capital cost and operational problems
 - low population density in outer urban areas considerably increasing the unit cost of sewerage provision
 - unwillingness of part of population to meet the capital cost of linking properties to the main sewer when provided and/or to pay the annual charge for mains sewerage provision once connected
 - illegal connections of roof and patio drainage from residential properties to the main sewers, causing system overload, heavy sediment load and treatment plant by-pass during frequent episodes of intense rainfall.
 It is thus uncertain whether increased investment will result in better aquifer protection.

- Both OSE and DAE have high-yielding (>100 m³/hr) SAG water wells in restricted areas west of the city, close to the main basalt escarpment where the full thickness and most permeable horizons of the SAG are present. The supply derived from these areas already appears to represent more than 30% of the total – and these locations, which are at or beyond the current limit of urbanization, are suited to construction of public water-supply well fields and the establishment of special groundwater protection areas. This approach would provide a more secure urban water-supply, reducing dependence on the numerous wells dispersed throughout the urban area which are at greater risk of pollution irrespective of decisions on extension of the coverage of mains sewerage. A question arises as to where the legal and institutional powers lie for possible declaration of potable groundwater supply protection areas (of various km² extension) for which significant land-use constraints would apply – and it is likely that such action would have to be taken through petition to municipal or local government.

- The principal desired outcomes of the Pilot Project in the longer run are :
 - establishment of protection zones/perimeters around the more important sources of public water-supply, with appropriate land-use planning controls (both urban and rural), to ensure their sustainability and protect investments in the sources themselves and their associated infrastructure
 - a joint investment action plan to improve urban sanitation both as regards wastewater and solid waste elimination – including where appropriate improved coverage of mains sewerage and other control measures in vulnerable aquifer areas in the communal interest of conserving groundwater quality.

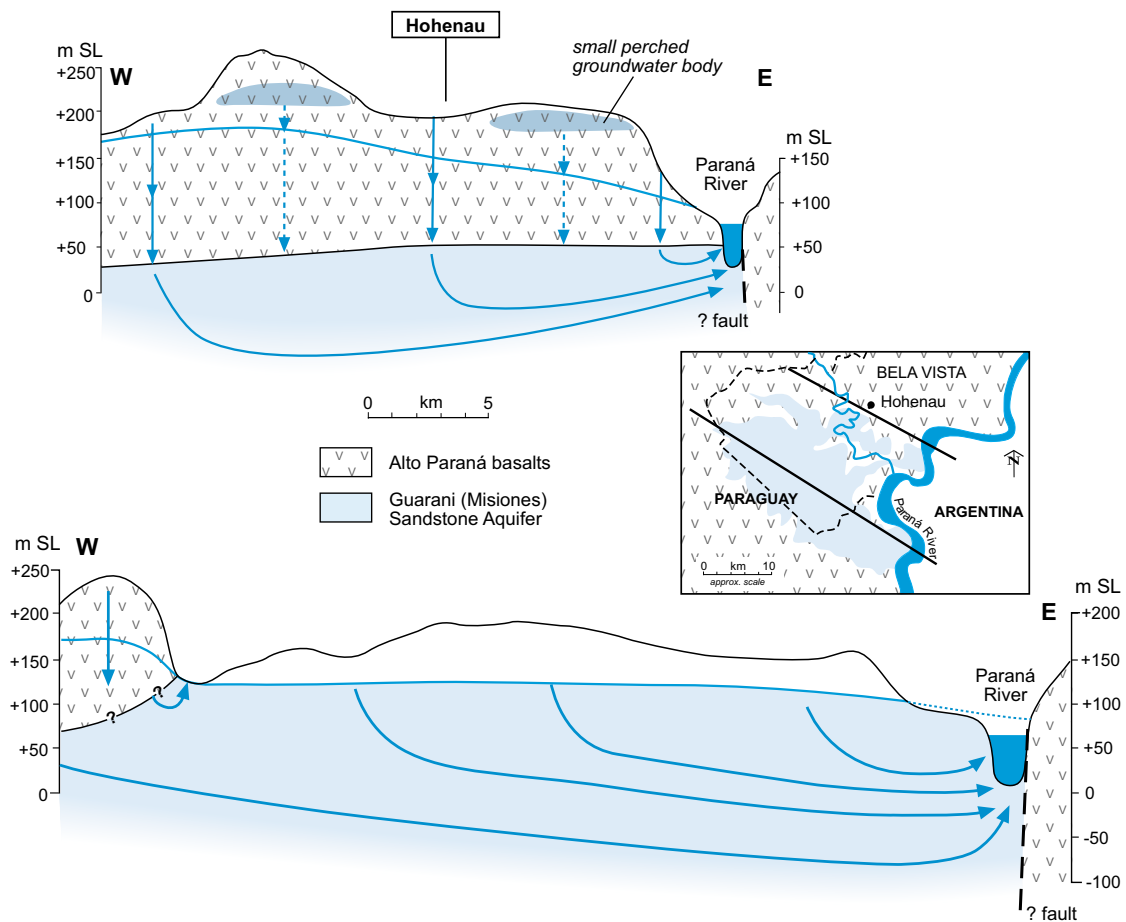
- Against a background of past international agreement ('Acuerdo sobre Cooperación Brasil-Uruguay en Materia Ambiental de 1992'), the Comisión Transfronteriza del Acuífero Guaraní (COTRAGUA), with representation of 5 stakeholder organizations on each side (including local government offices, corresponding water utilities (OSE and DAE), water well drillers, NGOs, agricultural, hydrological and public health organizations), was formed with the functions of :
 - assisting in collation of relevant technical, economic and legal materials
 - a focal point for social survey and participation in groundwater management, such as denouncing illegal well construction and polluting discharges
 - coordinating local efforts for capacity building amongst stakeholders.

The COTRAGUA has ceased activities since the GEF-Program ended – the lack of local facilitators and national coordinators being one of the alleged reasons. Thus, interaction and exchange of information amongst DAE and DINASA are not taking place at the moment.

Itapúa (Paraguay)

- The Itapúa Department Pilot Project involves a predominantly agricultural cropping and livestock-rearing area in the extreme south-east of Paraguay, with an average rainfall of about 1,600 mm/a. The area was originally populated by indigenous Guarani, and includes important Spanish colonial sites (ruined Jesuit missions), but today has a cosmopolitan population of 45,000 including two small towns, Hohenau and Trinidad.
- The Guarani Aquifer outcrop forms about 40% of the ‘pilot area’ (of 800 km²) and in the rest it is covered by a variable thickness of basalt flows (Figure 9). Some 60 water wells have been registered by the Servicio Nacional de Agua y Saneamiento (SENASA) with support of German technical cooperation, which mainly vary between 70-120 m in depth but reach to 300+m in areas of thick basalt cover. The water wells, including some for public water supply, show signs of nitrate contamination.
- The area has witnessed major changes of rural land-use in the last 30 years :
 - 1975-80 : rapid deforestation for timber production and cattle ranching, facilitated by construction of the first road-bridge over the Paraná River allowing exportation
 - 1990s : rapid expansion of area under arable cultivation due to widespread introduction of soya-bean and sunflower/maize rotations providing much higher farmer incomes than ranching (especially on the excellent lateritic soils above basalts where rural land prices have risen steeply to around US\$ 4.0 k/ha recently)
 - 2000s : widespread introduction on arable fields of seed-sowing by direct drilling to reduce soil erosion, requiring heavy applications of herbicides such as glyphosate.
 These changes have caused important hydrological impacts (as registered by macro-monitoring of surface water systems), but their effect on groundwater is not yet known.
- The Pilot Project is of potential relevance to land-use planning, agricultural production and water resource management in large tracts of the Mercosur – and had as its principal objectives to :
 - review the agro-economic evolution of the area since 1960, including mapping of land-use and agricultural cropping changes, to confirm the intensification of soya-bean cultivation and its relation with hydrogeologic and pedologic conditions
 - classify the more heavily-applied pesticides on the basis of their water solubility and soil mobility, and then evaluate (using data on typical rainfall intensities at their time of application) the likelihood of their being leached to groundwater in the typical soil profiles developed on the sandstone outcrop and on the basalt cover
 - establish a network of relatively shallow groundwater monitoring piezometers and water wells in the sandstone aquifer and overlying basalts, and undertake analyses to determine the extent of past and current agrochemical leaching to groundwater
 - assess the procedures used to develop and protect groundwater sources for public water-supply, and the design and operation of sanitation systems in small towns.

Figure 9 : Hydrogeological cross-sections of the Itapúa-Paraguay Pilot Project area



- The participation of ‘key actors’ both nationally and locally from both the agricultural and water sectors, together with representatives of local government and community leaders, is necessary to achieve these ambitious objectives – and at the time of completion of the GEF-Program they had only partially been completed. However, the Pilot Project Commission is participating within the Consejo de Aguas de Capibarii, as a technical unit for groundwater issues – and activities continue through involvement of other institutions such as Gobernación de Itapúa.

Pedro-Juan Caballero (Paraguay)/ Ponta Porã (Brazil)

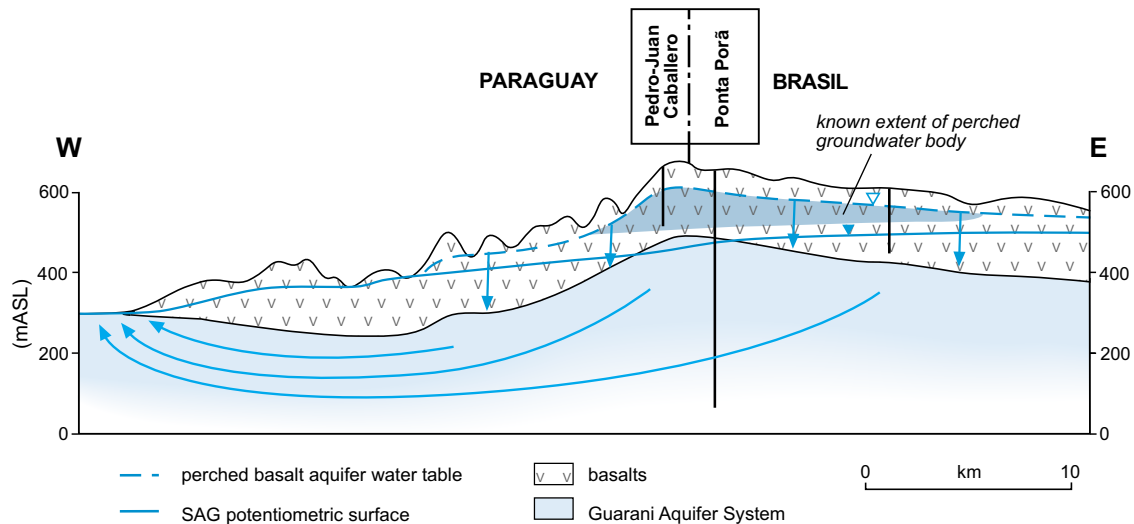
- The Pedro-Juan Caballero/Ponta Porã Pilot straddles the border of Paraguay and Brasil and covers the environs of these frontier towns, which have a combined population of about 135,000 growing at over 1%/a and about 2%/a respectively. The urban ‘frontier economy’ is dominated by the trade and service sector, which has good potential for further development, set in a flourishing agricultural region of good soils and an annual rainfall averaging about 1,200 mm/a. On the Brazilian side, the land-use and agricultural production of Mato Grosso do Sul State is already dominated by intensive soya bean-cereal rotations coupled with livestock rearing, whilst on the Paraguayan side deforestation for these purpose has come later and is still occurring (Figure 4).

- Over most of the area the SAG is covered by 100 m or more of basalts (and outcrops only in the extreme west), and its groundwater exhibits a confined (but not artesian overflowing) condition (Figure 10) – with the frontier following the surface-water divide of the Serra/Sierra de Amambai. The top part of the basalt is sufficiently fractured and weathered to form a semi-independent aquifer across much of the area, which provides recharge through leakage to the SAG with groundwater flow westwards from Brasil to Paraguay under hydraulic gradients of 6-7 m/km.
- Groundwater from the basalts is currently the main source of urban water-supply with over 100 water wells (mainly 70-120 m deep), including those of the Empresa de Servicios Sanitarios del Paraguay (ESSAP) and Servicio Nacional de Agua y Saneamiento (SENASA) around Pedro-Juan Caballero and the Empresa de Saneamento de Mato Grosso do Sul (SANESUL) in Ponta Porã, which can produce a total of 1,200 m³/hr or more. However, there is no main sewerage system in Pedro-Juan Caballero/Ponta Porã, with all urban wastewater disposal to the ground via in-situ sanitation units, and the basalt aquifer is showing signs of pollution with the abandonment of some water wells.
- The most satisfactory solution would be to develop a small number of soundly-constructed water wells into the semi-confined SAG and protect their wellhead areas carefully against contamination – SANESUL have recently completed the construction of the first deep (750 m) borehole which alone can produce an additional 260 m³/hr.
- The first transboundary workshop on water and environmental management was held in February 2009 and attended by groundwater specialists and stakeholder representatives from both sides of the frontier in which it was concluded that :
 - completion of the water well inventory and hydrogeological database is required, with establishment of a conceptual and numerical model of the local SAG and an improved monitoring network for groundwater levels, quality and use
 - further development of SAG resources for public water-supply will require a feasibility study and water well siting plans, and a common policy approach is needed to rationalize such development
 - measures are needed to reduce the contaminant load on the basalt aquifer, especially in those parts of the urban area where it is likely to continue as the 'sole source' of water-supply
 - public information and awareness campaigns were required to gain support for stricter application of relevant existing environmental laws and regulations, and to facilitate the implementation of future groundwater protection measures.

Concordia (Argentina) – Salto (Uruguay)

- The Concordia/Salto Pilot Project occupies an extensive area (500 km²) on either side of the Uruguay River, which forms the Argentina-Uruguay frontier, and where the SAG is found beneath 800-1000 m of basalt flows (Figure 11) with its groundwater exhibiting overflowing artesian heads and marked geothermal potential (temperatures of 44-48 degC). Hydrogeothermal borehole yields are normally in range 100-300 m³/hr with drilling depths up to 1,400 m. In this area the SAG is not significantly developed for public water supply – with treatment plants on the Uruguay River providing the bulk supply, supplemented by shallow waterwells in the thin Tertiary/Quaternary deposits and fractured top of the Sierra General Basalts for public supply and small-scale irrigation.

Figure 10 : Hydrogeological section of the Pedro-Juan Caballero (Paraguay) - Ponta Porã (Brasil) Pilot Project area



- This is the most populated part of this frontier with about 256,000 inhabitants, split between Salto (99,100) and Concordia (157,000). The major sources of income are an expanding citriculture and horticulture industry, together with hydrogeothermal tourism. Salto (Uruguay) is the most developed base of thermal spa tourism in the Mercosur with a history of more than 10 years. By the late 1990s tourist numbers reached 368,000/a generating an income of US\$ 58 million/a and producing employment (directly and indirectly) for 3,500 – in contrast Concordia (Argentina) only recently initiated the same type of activity.
- The Pilot Project aims to provide the foundation for the sustainable and efficient use of SAG hydrogeothermal resources and the principal problems being confronted are :
 - hydraulic interference between neighboring hydrothermal wells (already 8 boreholes in a relatively restricted area, extracting together 2.9 Mm³/a), which may reduce (and eventually eliminate) overflowing artesian heads which are a special tourist attraction
 - some numerical simulation based on the scarce hydrogeological data has demonstrated that any incremental extraction by drilling new wells could provoke serious hydraulic head reduction and any plan to increase the exploitation should be done based on a very careful study
 - a risk of increasing salinity by up-coning (in the Termas de Dayman an increment of Na and Cl from 135 to 205 mg/l and 100 to 200 mg/l respectively has been observed during 1992-2000) and/or intrusion from the south-east (where the SAG contains thermal groundwater of high natural salinity). It is important to point out that the SAG water presents naturally high concentrations of As (20-40 µg/l) exceeding the drinking water standards
 - inadequate water demand and use management in many spas – with need to disseminate more efficient geothermal water-use practices (including water recycling for garden cultivation, space-heating of hotel installations and greenhouses, and fish farming) and to ensure safe discharge of effluents.

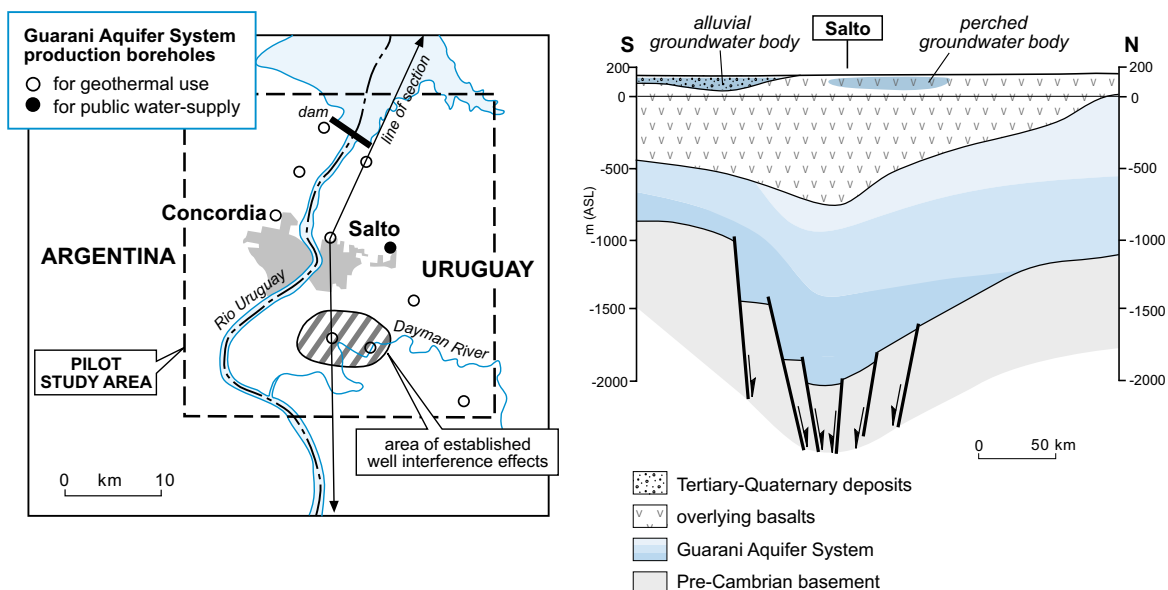
- But important progress has already been made in respect of the joint adoption of :
 - appropriate standards for geothermal well design, construction and operation so as to avoid unnecessary loss of geothermal water or artesian pressure, and ingress of shallow low-temperature groundwater
 - an interim minimum separation for hydrogeothermal wells of 2 km.

- A Pilot Project Committee, comprising representatives of local government and the municipalities, the national/federal and provincial agencies for water resources, geothermal water-users associations and academic centres, was set-up with the following functions :
 - assist in the collation of relevant technical, economic and legal materials, their dissemination to the community and capacity building amongst stakeholders
 - focal point for required social surveys and promotion of community participation in groundwater management decision-making, including denouncing illegal well construction.

- The present institutional arrangements for groundwater management are distinct on either side of the international frontier – in Argentina responsibility is with the Secretaria de Recursos Hidricos-Entre Rios and the federal departments, and in Uruguay with the Direcciones Nacionales de Aguas y Saneamiento & Medio Ambiente (DINASA & DINAMA). But the respective legal provisions have many points in common and could readily be the platform for the development of a ‘set of parallel legal regulations’.

- Since the GEF-Program ended the local committee has suspended transboundary interaction – with the the lack of a facilitator being the alleged reason. In Argentina local government (Municipio de Concordia), with technical support from provincial government, strongly supports local activities and has created a unit with an office and technical staff assigned. In Uruguay, local government (Municipalidad de Salto) has similar intentions and national authorities have manifested that a Guarani Aquifer Unit could be created within the provisions of the new Water Policy Act.

Figure 11 : Hydrogeological sketch map and section of Concordia/Salto Pilot Project area



Institutional and Legal Provisions for Pilot Project Continuity

- The main institutional advances generated by the GEF-Program in respect of groundwater management at local level, together with recommendations for their follow-up within the existing framework, are summarized in Table 5. The legal basis for ‘local commission work’ emanates from state or provincial responsibility for water management in general, and groundwater management in particular.
- The GEF-Program has demonstrated, through its pilot projects, how local management should be set-up, and also provided several useful management tools (such as information systems, practical guidelines, etc). It has also helped to strengthen the institutional nucleus for future local management and it is now in the countries own interest to build upon this. Moreover, as seen in Concordia-Salto, Rivera-Santana do Livramento, Ribeirão Preto and Itapúa, the involvement of national and state/provincial governments has been essential to achieve progress.

Table 5 : Institutional advances of the GEF-Program for improved local-level groundwater management

PILOT PROJECT	ADVANCES	RECOMMENDATIONS
Concordia-Salto (Argentina-Uruguay)	<ul style="list-style-type: none"> • local transboundary committee (with branch in each country) set-up to support Pilot Project activities (CLAP) – although inactive since GEF-Program ended • municipalities agreed registration of deep borehole drilling and quality control for water re-use and effluent discharge 	<ul style="list-style-type: none"> • agreement between municipalities needs to be implemented by specific actions (eg. sampling, analysis, monitoring, etc) • technical guidelines on deep borehole drilling should be reinforced by incorporation in provincial regulations of Entre Ríos • consider tariff collection to support strengthening management at local level
Itapúa (Paraguay)	<ul style="list-style-type: none"> • local committee set-up to support Pilot Project activities (CLAP) • relevant interaction developed amongst local government, stakeholders, academics, municipalities, etc • CLAP interaction with Comisión Aguas del Arroyo Capiibary 	<ul style="list-style-type: none"> • control of activities should be delegated by municipalities to CLAP technical support • agreement between university (FUCAI) and national government (SEAM) could be implemented for monitoring, etc • divulgation of new Water Law regulations amongst stakeholders with CLAP support
Ribeirão Preto (Brasil)	<ul style="list-style-type: none"> • federal and state regulations have been implemented at local level, in parallel with development of specific protection and control measures with support from Comitê de Bacia do Rio Pardo (CBRP) 	<ul style="list-style-type: none"> • involve authorities at all levels in CBRP to articulate groundwater management needs in respect of municipal land-use controls • strengthen regulatory control through dissemination fora with support of CBRP • institution strengthening and capacity building in land, environment and water resources management
Rivera-Santana do Livramento (Uruguay-Brasil)	<ul style="list-style-type: none"> • local transboundary commission was set-up to support Pilot Project activities (COTRAGUA) – although inactive since GEF-Project ended • international agreement to cover shared water resources and environmental management issues 	<ul style="list-style-type: none"> • international cooperation agreement could be implemented for specific actions, such as information exchange on waterwell abstraction • COTRAGUA could articulate modifications to land and water use plans based on information generated by GEF-Program

- At national and provincial/state level each country has the necessary regulations and competent institutions to mobilise on groundwater management and protection, and cooperation between countries is contemplated through existing international treaties. But at local level, current pilot-project agreements, institutional capacity and stakeholder participation in Concordia-Salto and Rivera-Santana do Livramento will need to be further strengthened for effective implementation of required groundwater management and protection measures.

FINAL REMARKS : PRIORITIES FOR INTERNATIONAL COOPERATION

- The fundamental character of the GEF-Program is that it has been in essence preventative and in spirit cooperative. Three aspects warrant special recapitulation :
 - the importance of having addressed the lack of adequate common understanding, since that represented a threat to cooperative conservation, protection and sustainable use of groundwater and hydrogeothermal resources
 - the value of promoting concrete management actions at the relevant local scale, with appropriate transboundary integration, so as to generate best-practice experience which can be replicated in other areas as necessary
 - the feasibility of taking action based upon existing information under current legal and institutional frameworks, whilst in parallel improving the scientific information base and identifying weaknesses that merit improvement through pilot implementation.
- Future priorities for international cooperation should focus upon :
 - finding practical mechanisms and financial means to continue the Pilot Projects in as much as these not only deal with 'hotspot' issues but provide very practical insights about managing SAG groundwater resources in general
 - continuing the further development and operation of the SAG database (SISAG) and the regular exchange of scientific data and management experiences
 - promoting a 'research forum' and initiating further collaborative research projects on key topics on which there remains significant scientific uncertainty including the following (in order of decreasing importance) :
 - the impact of major land-use changes in the SAG recharge areas (described above) on groundwater recharge quality and rates
 - the vertical variation of groundwater quality in SAG recharge areas under both urbanization and intensive agriculture pressures
 - the geographical variation in the rates of, and controls on, SAG recharge in weakly-confined basalt-covered areas
 - the monitoring and modelling of SAG response to major groundwater abstraction from the highly-confined zone of the aquifer, and any localized natural discharge from this zone.
- In the 'Guarani Aquifer' countries there is a long-standing history of environmental cooperation within a complex web of multilateral and bilateral treaties :
 - CIC–Treaty of La Plata Basin (1969) in which the governments of Argentina, Bolivia, Brasil, Paraguay and Uruguay agreed to carry out a long-term, integrated and joint studies of the catchment area

- Mercosur Environmental Framework (2002) in which the same governments agreed to pursue ‘the protection of the environment and sustainable development through the articulation of the economic, social and environmental dimensions’ with common policies on environmental protection, natural resource conservation and sustainable development with harmonization of environmental legislation and information interchange.

Additionally, and most significantly, on 30 November 2009 the Mercosur Parliament (PARLASUR) approved the creation of a 'regional groundwater institute' (INRA-Mercosur — Instituto Regional de Investigacion y Desarrollo del Agua Subterranea y de Proteccion Ambiental de Acuiferos del Mercosur), including specific reference to the shared management of the Guarani Aquifer System. All of this should help to promote and underpin future SAG groundwater initiatives, including the priority activities listed above.

- The formation of a semi-independent ‘Transboundary Guarani Aquifer Commission’ has not been favoured, because of its implied high transaction costs and the risk of its losing contact with national and state groundwater issues, capabilities and procedures. The preferred transboundary institutional model was the creation of a Guarani Aquifer Steering Council (CSDP), developed through the vehicle of the GEF-Program, involving those nationally responsible for groundwater resources (or their representatives) directly. The CSDP could evolve into a more permanent structure to :
 - consult and negotiate on major aquifer development with potential transfrontier effects
 - mobilize investment for local groundwater development and management institutions
 - develop a ‘shared vision’ of resource status, aquifer potential and management needs
 - promote appropriate subsidiary action through local management interventions and procedures.

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