

Sustainable Groundwater Management Concepts & Tools

Case Profile Collection Number 9

Brazil, Paraguay, Uruguay, Argentina: The Guarani Aquifer Initiative for Transboundary Groundwater Management

2002-2005

Authors: Stephen Foster, Karin Kemper & Hector Garduño

Task Managers: Abel Mejía & Samuel Taffesse (World Bank - LCR)

Lead Counterpart Organizations: SSRH-Argentina, SRH-Brazil, SEAM-Paraguay,
DNH-Uruguay, OAS Guarani Secretariat

This case profile provides a summary and vision of the GEF-funded Guarani Aquifer Project for groundwater resource sustainability and environmental protection (Proyecto para la Protección Ambiental y Desarrollo Sostenible del Sistema Acuífero Guarani), which is valued at US \$26.7 million with 50% from GEF. The project was launched in May 2003 by the Mercosur nations of Argentina, Brazil, Paraguay & Uruguay under the implementation of the World Bank, execution of the Organization of American States (OAS) and with support of the International Atomic Energy Agency (IAEA) and German technical assistance (BGR). GW•MATE has been involved throughout the detailed project preparation process (which commenced in 2000) and continues to provide services in support of project implementation, with special reference to (a) the evaluation of regional aquifer development and management issues and (b) the promotion of practical groundwater protection measures at local level through 4 pilot aquifer management projects and (c) the definition of an appropriate legal and institutional framework for efficient transboundary groundwater management.

Characteristics of the Guarani Aquifer System

Hydrogeological Structure

- The Guarani Aquifer is a huge hydrogeological system that extends over an area of at least 1,200,000 km² of Brazil (with about 70% of its known area), Paraguay, Uruguay and Argentina (Figure 1). It has an average thickness of 250 m and reaches depths in excess of 1,000 m. The total volume of freshwater in storage is estimated around 40,000 km³ (equivalent to 125 years cumulative Paraná River flow). Most of this is believed to be of potable quality, although at certain depths in some areas it can have excess fluoride or high salinity concentrations.
- The aquifer occurs in two major semi-independent structural basins – the Central Paraná (which is relatively well known) and the south-western Chaco-Lower Paraná (whose geology and freshwater distribution is much less understood). These two basins are separated by the pronounced Asunción-Rio Grande structural high (Figure 1), and this, and other 'structural highs' (such as the Punta Grossa in Brazil-Paraná State), appear likely to affect aquifer structure generally, to control the presence of magmatic intrusions, and thus have a strong influence on the groundwater flow regime.

- The Guarani Aquifer System (known as the Sistema Acuífero Guaraní (SAG) in Spanish and Portuguese) comprises a sequence of aeolian and fluvial weakly-cemented sandstones of Upper Jurassic-Lower Cretaceous age, extensively overlain by Upper Cretaceous sheet basalt flows (Figure 1). The geological continuity of this sandstone was only recognized in the 1990s, following the drilling of some 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 concerned.
- Prior to the identification of the SAG as a system it was known locally by various names:
 - the Tacuarembó Formation in Uruguay and Argentina
 - the Botucatu Formation in Brazil
 - the Misiones Formation in Paraguay.

Some underlying formations (such as the Pirambóia Formation in Brazil-São Paulo State) are sufficiently permeable to form the lower part of the SAG, although being more of lacustrine and fluvial origin tend to be lower yielding and may contain groundwater of unacceptable quality.

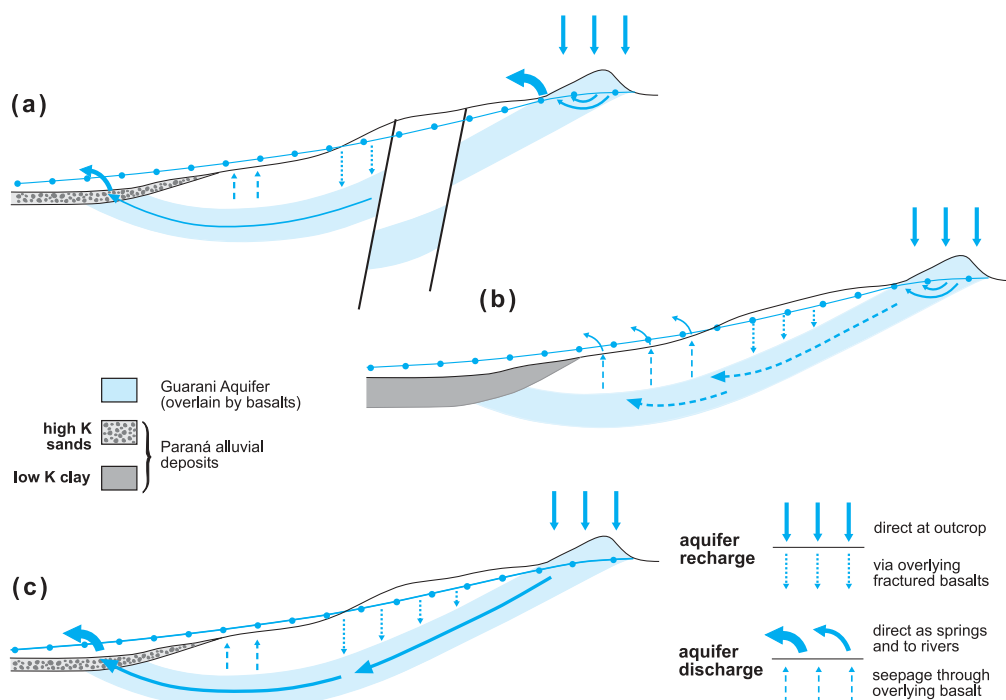
Figure 1: Hydrogeological map of Guarani Aquifer System showing the location of pilot management area



Groundwater Flow & Quality Regime

- Replenishment of the SAG occurs by infiltration of excess rainfall and stream flows across the ‘recharge area’ – which is considered to comprise both the sandstone outcrop (limited to about 150,000 km²) and the more extensive adjacent zone where sandstone is covered by relatively thin and well fractured basalt (Figure 1) – the overall rate of recharge has been variously estimated at 50-160 km³/yr
- When traced towards the center of the structural basins, SAG groundwater becomes progressively more confined by the thickening overlying basalts and exhibits an artesian overflowing head over large areas (Figure 1). With increasing depth and confinement the groundwater temperature also increases substantially (Table 1), such that it widely exceeds 400C, and in some localities reaches 600C, although the controlling mechanisms are not yet fully understood. There will also be a marked temperature effect on the aquifer’s hydraulic conductivity (permeability) as a result of changing kinematic viscosity.

Figure 2: Hypothetical cross-sections of Guarani Aquifer System to show potential significance of tectonic disturbance and characteristics of Paraná alluvial cover in controlling discharge regime



- The natural discharge of the SAG is still also very poorly understood. In the ‘undeveloped condition’ a considerable amount of ‘locally rejected recharge’ appears to occur in many locations adjacent to the aquifer recharge area, with the component of natural deep groundwater flow into the confined aquifer section being limited by the geological structure (compare Figure 2a-b to 2c). However, some areas of ‘regional aquifer discharge’ may possibly exist (Figure 1), especially as base flow to the middle sections of the Uruguay River (in southern Brazil) and as up flow to the Esteros de Ibera wetland (in extreme northeastern Argentina), but the groundwater flow lines into these features are not yet confirmed.

- Natural groundwater chemistry shows marked changes when traced downdip from the aquifer outcrop (Table 1) including:
 - cation exchange reactions with Na replacing Ca in solution
 - some increases in F and/or overall salinity, probably associated with upward seepage or diffusion from the basal SAG formation
 - increasing d13C due to dissolution of CO₂ and under closed conditions
 - much lighter d2H and d18O suggesting the presence of palaeo-groundwater recharged under colder wetter climatic conditions.

The apparent presence of a marked modern recharge ‘cut-off’, with much older water at only modest distances down dip, suggests either a long (arid and/or cold) period with little recharge or absence of flow in the deep aquifer with rejection of recharge.

Table 1: Typical chemical and isotopic changes in Guarani Aquifer groundwater when traced westwards down-dip from Ribeirao Preto (São Paulo) – Brazil

PARAMETER (units)		OUTCROP BOREHOLES	DOWNDIP BOREHOLES (distance from outcrop) 30km 150km	
<i>Chemical Characteristics</i>				
T (0C)	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
<i>Isotopic Indicators</i>				
D 2H (0/00)	deuterium	- 50	- 70	- 65
D 18° (0/00)	oxygen-18	- 7	- 9	- 10
D 13C (0/00)	carbon-13	18	- 10	- 8
14C (pmc)	carbon-14	> 80	30	< 5

(data selected from Silva, 1983; Kimmelman et al, 1989; Sracek & Hirata, 2002; Silva et al, 2002)

- There are also some concerns that the deep confined groundwater might contain significant levels of the soluble U isotopes, radium and radon gas, and in general the trace element hydrogeochemistry merits more detailed investigation.

Current Exploitation & Development Potential

- Although a comprehensive waterwell inventory does not yet exist, the current level of SAG exploitation is relatively modest. There are estimated to be around 1,000 operating deep production wells, although the number may reach 3,000 or more if wells in the overlying basalts that may just reach the sandstone are included. Most production wells are capable of producing at least 1,000 m³/hr if pumped, but less than 500 m³/hr where overflowing.

- The total groundwater production has been estimated to be in the range 1-3,000 Mm³/yr and mainly concentrated in Brazil – with 80% of this for public water supply (500 Brazilian towns being wholly or partly supplied from the SAG), 15% for industry and 5% for spa tourist use.
- The population of the extensive area overlying the SAG is in the order of 15 million, and this increases to more than 70 million if adjacent areas are included. This is a largely sub-tropical area of abundant, but often polluted, surface water resources, which experiences a significant dry season and occasional drought. Thus the need for reliable potable water-supply sources (of low-treatment cost) could grow considerably, if demand for high-value agricultural and industrial uses increases substantially.
- The SAG also represents a major, widely-distributed, low-enthalpy, geothermal resource (often with overflowing artesian head) of numerous potential applications. These include:
 - expansion of spa facilities in northwestern Uruguay and neighboring parts of Argentina, and possibly also further north in the Iguazu international tourist area
 - numerous agricultural and industrial applications
 - low-enthalpy energy generation.

REGIONAL OBJECTIVES OF THE INITIATIVE

Scope & Structure of Project

- The Guarani Aquifer Project is not just a scientific investigation, but more the development of a comprehensive management framework, where sustainability and environmental concerns figure prominently, especially those with transboundary repercussions.
- During the preparation phase a list of key issues and concerns were identified:
 - insufficient baseline information on SAG groundwater, and its users and uses, due to disperse and incomplete data, and inadequate data compilation and dissemination
 - potential conflict due to localized excessive or indiscriminate pumping, and lack of pollution protection in aquifer recharge areas
 - concern about the possibility of extensive but subtle pumping interference effects in the highly-confined aquifer system threatening reductions in artesian head and overflow, reductions in dry-weather river base flows and groundwater discharge-dependent wetlands
 - general absence of transboundary and national groundwater development and management policy, especially in terms of 'operating rules' and 'decision-making protocols' at local level
 - no enforced code of practice for well design, construction and operation
 - inadequate legal framework for groundwater governance, with unclear procedures for groundwater allocation and use licensing
 - no experience of addressing transboundary aquifers, with only outline draft legal codes for transboundary groundwater management to draw upon
 - diverging standpoints (between national/federal and provincial governments) as to the required character of a 'water resource authority', and thus to identification of appropriate organizations to be responsible for transboundary groundwater management (in part because Argentina and Brazil are federal countries in which groundwater is primarily a state/provincial responsibility with variation between states/provinces)
 - despite well-developed and widely-distributed scientific expertise in groundwater, a lack of capacity in practical resource management and protection, socio-political risk assessment and conflict resolution
 - little public awareness of groundwater in general and of the SAG in particular, and insufficient stakeholder participation in resource management and environmental protection.

Table 2: Summary of Principal Guarani Aquifer Project Components

COMPONENT	PROP. OF TOTAL COST	OUTPUTS
Expansion & Consolidation of Scientific Knowledge	33%	<ul style="list-style-type: none"> · definition of aquifer geometry and properties · evaluation of aquifer structural compartmentalization · groundwater quality / isotopic signature / pollution risks · evaluation of aquifer recharge mechanisms and rates · survey of aquifer discharge mechanisms and functions · regional/local aquifer numerical management modelling · specification of norms for well design and construction · evaluation of hydrogeothermal resources and applications
Development of Legal & Institutional Framework	12%	<ul style="list-style-type: none"> · review of existing legal/institutional framework · assessment of future legal/institutional requirements · negotiation of coordinated management framework · identification/implementation of priority management actions
Stakeholder Participation & Public Awareness	8%	<ul style="list-style-type: none"> · development of a strategic plan for participation · initiation of participatory management process · development of a plan for public education · initiation of school, society and media campaigns
Groundwater Pilot Management & Protection Projects	41%	<ul style="list-style-type: none"> · critical component in terms of overall program objective (described in detail in subsequent section)
Program Administration, Monitoring & Dissemination	6%	<ul style="list-style-type: none"> · normal program management arrangements (not specified in detail here)

- The Project (which will be of 4 years duration) is designed to address the above deficiencies, and the project components, together with 4 pilot groundwater management and protection projects, will provide the foundation and vehicle for an appropriate level of local and regional groundwater resource administration.

Scales & Levels of Aquifer Management Needs

- The process of project preparation and initiation revealed widespread misconceptions about the SAG – and in particular the character of its groundwater resources, the scale of problems with which it could be affected and the most appropriate level of management for resolution of these problems. Because of this an indicative framework has been elaborated (Table 3) to provide a realistic and balanced summary in this regard, which can be used for:
 - communication at national level in debates on water and environment politics
 - dissemination to the various international agencies involved or interested.
- This framework, which has been carefully drawn up and critically reviewed, shows clearly that :
 - the SAG Project (SAG-P) is ‘preventive’ in character – there being no major ‘crisis issues’ to resolve and many benefits potentially accruing from cooperation
 - current transboundary groundwater issues do not have major ‘upstream-downstream implications’, but are strictly limited in distribution and essentially local in character, requiring resolution through agreement and action at the corresponding scale
 - only with extensive change in agricultural land use and/or intensive groundwater use for irrigation – and under a specific combination of hydrogeological conditions (which are not yet proven) – are any potential transfrontier effects on groundwater likely to grow from local to catchment scale.

Table 3: Framework of groundwater management needs for the Guarani Aquifer System and their appropriate scales of resolution

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 contamination (F, U, Rd, Rn) affecting use for potable water supply 	<ul style="list-style-type: none"> contamination of potable waterwells due to inadequate urban sanitation and uncontrolled urban land-use 	
<ul style="list-style-type: none"> 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"> wetland impact and river baseflow reduction as a consequence of potential intensive groundwater resource development for agricultural irrigation deterioration in the quality and rate of aquifer recharge as a result of extensive changes in agricultural land use and crop cultivation 	<p>the adjacent problems could grow if regional agricultural policies and markets favour the intensive and extensive use of local soils and/ or groundwater resources — but only if current field investigations confirm (a) the present ecological role of aquifer discharge and (b) the hydraulic continuity of the aquifer system in the corresponding areas</p>
<ul style="list-style-type: none"> evaluation of economic and efficient options for the use of the aquifer's geothermal resources 	<ul style="list-style-type: none"> reductions in the artesian and geothermal characteristics of the aquifer due to uncontrolled exploitation by geothermal wells 	
<i>Appropriate Level of Resolution</i>		
SAG-P and CSDP in service of the national and state organizations involved	SAG-P through intervention of CSDP with the countries and local institutions involved	CSDP in consultation with supra-national organizations and with support of the SAG-P

* principally the Esteros de Ibera (Argentina) and Niembucu (Paraguay), and the Rio Uruguay respectively

- An interrelated issue is that of selection of an acceptable physical model on which to base further development of an appropriate transboundary legal framework for aquifer management. Various analogues are from time-to-time referred to:
 - an 'underground river' in the guise of 'water flowing to a common terminus', with by implication limited residence time since flow dominates over storage
 - a 'hydrocarbon reservoir', which is completely isolated from surface processes and without resource replenishment
 - an 'underground lake', which storage dominated but with immediate propagation of physical perturbations.
- But none of these is really appropriate to many aquifers, and certainly not to the SAG—which possesses huge storage (compared to its annual replenishment) and very long residence times, and whose natural flow directions can be modified, at least locally, as a result of groundwater extraction. Like all 'granular aquifers' it also tends to localize the impacts of abstraction and pollution, and in addition has a significant (but not well understood) degree of compartmentalization with uncertainty about groundwater flow paths and discharge regime. It is much more appropriate to identify 'groundwater bodies' (as used in the EU Water Framework Directive -1999) as sub-units of the SAG for groundwater management purposes, and these can be better defined once the 'basic study component' has advanced understanding of the groundwater flow and storage regime.

From Project Implementation to Transboundary Aquifer Management

- There is a long-standing history of Mercosur cooperation on international waters with a complex web of multilateral and bilateral treaties in existence, and these impinge upon and could help to underpin the present initiative on SAG groundwater resource management.
- The formation of a semi-independent 'transboundary aquifer commission' was not favored from the outset, because of the implied high transaction costs and danger of losing contact with national and state groundwater management issues, capabilities and procedures. The preferred initial institutional model was the creation of a Guarani Aquifer Project Steering Council (CSDP in Spanish and Portuguese), supported by a 'slimline project secretariat' (developed through the vehicle of the present project) and involving the persons nationally responsible for groundwater resources (or their representatives) directly.
- One possibility could be for the CSDP could evolve into a more permanent structure and provide a mechanism to:
 - consult upon, co-evaluate and negotiate 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, and promote subsidiary local action through appropriate management interventions and day-to-day management procedures.
- It would thus hopefully tend towards making resource-allocation decisions by a pragmatic risk assessment and impact based approach, rather than more arbitrary approaches such as force majeure, aerial extension, etc. The key to developing a 'shared vision' and the foundation for cooperative management will be the development of a common knowledge base, shared information systems and agreed (target-oriented) monitoring protocols, underpinning aquifer numerical modelling at different scales (but with compatible boundary conditions) to evaluate actual linkages, present dependencies and potential impacts, and to predict development and management scenarios.

Management in Practice – Role of the Pilot Projects

- Four groundwater management pilot projects have been defined and prepared, which are aimed at identifying and promoting local agreements and actions on specific 'type problems' of SAG groundwater management and protection – two of these are transboundary in character and the other two restricted to a single country and state. The organizational structure for the interaction between the 'pilot projects' and the overall project is given in Figure 3.

Ribeirão Preto–Brazil

- The Ribeirão Preto (RP) Pilot Project is centred upon this municipality in the northeastern part of São Paulo State and has a population of some 505,000. It comprises an area of 651 km² including 137 km² of the Guarani Aquifer outcrop, but spreading mainly across the overlying Serra Geral Basalts (Figure 4).
- Infiltration across the sandstone outcrop occurs during November-March and is believed to amount to 135 mm/yr, but the recharge area of the Guarani Aquifer extends considerably beyond its outcrop since where the overlying Serra Geral Basalts are thin, they are densely fractured and allow downward seepage from their phreatic zone (Figure 4) at rates of less than 50 mm/yr since their soils reject much of the high-intensity rainfall.

The flowchart is divided into two main sections: **PILOT PROJECT** and **NATIONAL AND REGIONAL LEVEL**.

PILOT PROJECT:

- LOCAL MANAGEMENT PLAN (PAL)** leads to **institutional/legal framework**.
- institutional/legal framework** leads to **- institutional agreements/arrangements** and **- action plan**.
- LOCAL MANAGEMENT PLAN (PAL)** leads directly to **implementation**.
- implementation** leads to **selected adjustments**.
- selected adjustments** leads back to **implementation** via a dashed feedback loop.
- selected adjustments** also leads to **impediment analysis**.
- impediment analysis** leads to **capacity building**.
- capacity building** leads to **communication and education**.
- communication and education** leads back to **implementation** via a dashed feedback loop.

NATIONAL AND REGIONAL LEVEL:

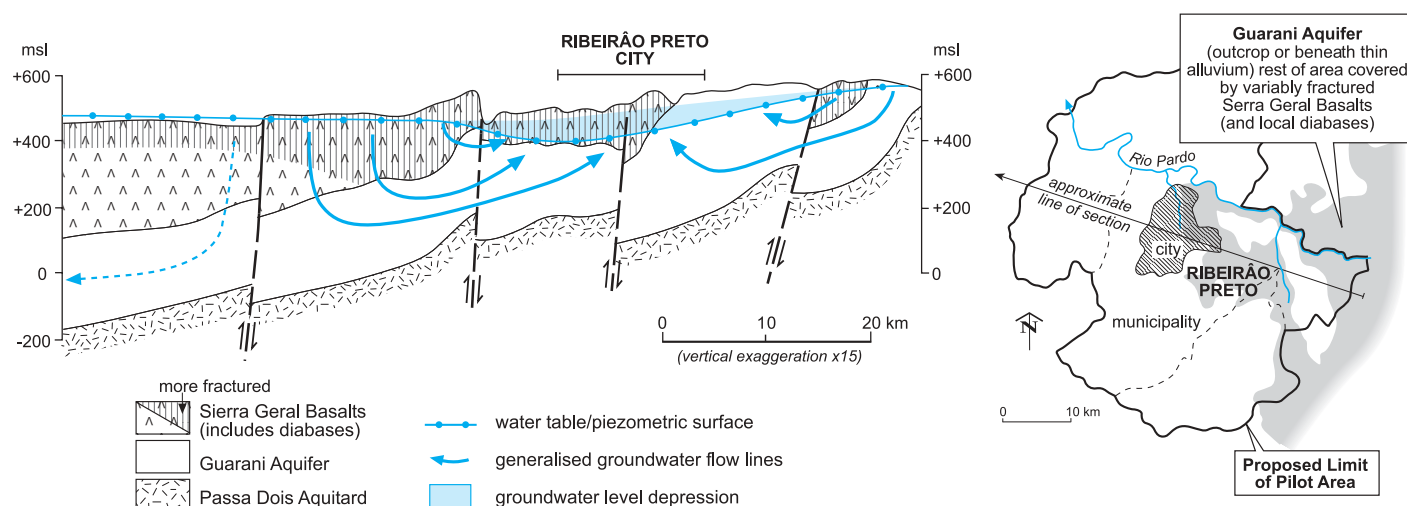
- project population identification** leads to **national and regional implementation needs**.
- national and regional implementation needs** leads to **STRATEGIC ACTION PLAN (PEA)**.
- STRATEGIC ACTION PLAN (PEA)** leads to **transboundary diagnosis**.
- transboundary diagnosis** leads to **gradual implementation**.
- gradual implementation** leads to **legal institutional framework - proposal for improvement**.
- legal institutional framework - proposal for improvement** leads back to **gradual implementation** via a dashed feedback loop.
- STRATEGIC ACTION PLAN (PEA)** leads to **legal/institutional framework**.
- legal/institutional framework** leads to **minimum indispensable improvements**.
- minimum indispensable improvements** leads back to **project population identification** via a dashed feedback loop.
- STRATEGIC ACTION PLAN (PEA)** also leads to **impediment analysis** (via a dashed line) and **capacity building** (via a dashed line).

Interactions between Pilot Project and National and Regional Level:

- implementation** (Pilot Project) leads to **national and regional implementation needs** (National and Regional Level).
- national and regional implementation needs** (National and Regional Level) leads to **implementation** (Pilot Project).

- The Ribeirão Preto area is one of major agricultural production, with sugarcane (for alcohol distillation), coffee and oranges (for fruit juice production) being the dominant crops. The city is also a major industrial center – with fuel-alcohol distilling, agro-industrial products and services, and a wide variety of manufacturing enterprises being very active.
- The SAG is exploited by more than 1,000 wells in the general area – DAERP (Departamento de Águas e Esgotos) have 97 that are currently in active operation with a potential yield of about 3,700 l/s and an estimated actual production of around 65 Mm³/yr. However, there is a significant degree of uncertainty about the total level of actual groundwater abstraction, which is estimated to have grown from 45 Mm³/yr in 1976 to 96 Mm³/yr in 1996.
- The process of groundwater resource development and water-table lowering has reduced and largely eliminated natural groundwater discharge to streamflow (and replaced it in large measure by wastewater discharges). Contemporary groundwater recharge is exceeded by abstraction since, over a large area across the city, groundwater levels appear to have fallen since the 1970s by an estimated 15-25m. Amongst the side effects experienced have been:
 - Increase in operational water-supply costs, due to falling water level and decreasing well efficiency with loss of upper well-screen sections
 - loss of groundwater confinement in some boreholes
 - previously effluent watercourses becoming influent and increasing groundwater pollution risks.

Figure 4: Hydrogeological sketch map and section of the Ribeirão Preto Pilot Project Area



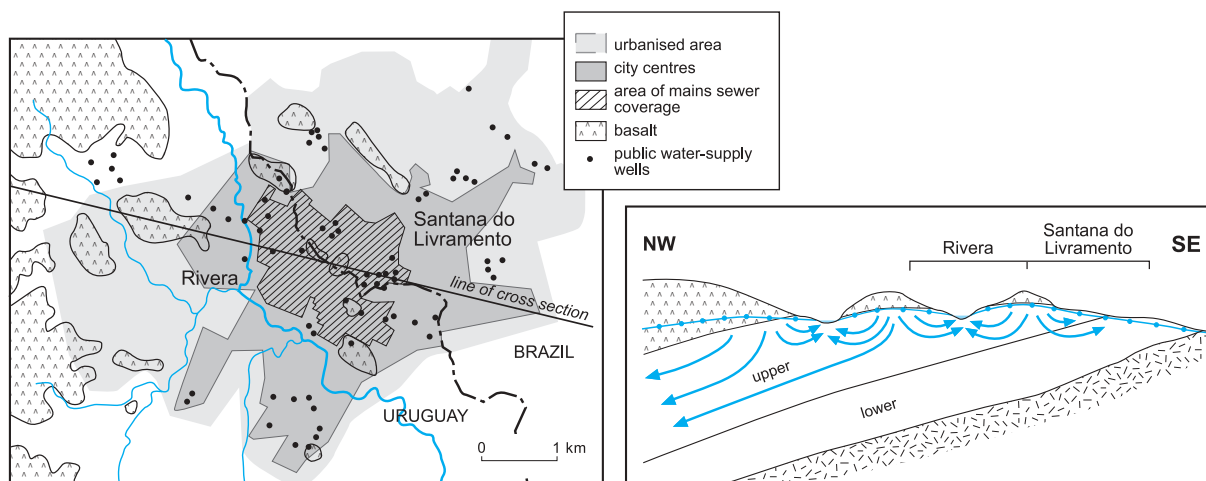
- Groundwater quality is reported to be good, with excellent microbiological results, exceptionally low total salinity, slightly acidic pH (6.0-6.5) and nitrate concentrations not exceeding 10 mg/l in DAERP waterwells. Mobile herbicides (such as tebuthiuron, diuron, ametrine, etc) widely-applied to sugarcane, have not yet been detected in groundwater samples. But the vadose zone is thick (often 30-60m) and these waterwells also have deep screen intakes, thus groundwater pollution by persistent contaminants from sanitation practices, industrial effluents and agricultural cultivation would take many decades to reach such depths, and the need to take some timely preventive measures must be assessed.
- 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 towards developing a more holistic vision for the future:
 - the CBHP (Comite da Bacia Hidrografica do Pardo) is promoting actions to constrain water demand in the urban population
 - the IGSP, (Instituto Geologico de São Paulo), with German technical cooperation, have undertaken aquifer vulnerability mapping, groundwater pollution risk assessment and source protection zone delineation at pilot level.
- The pressing issues that must be addressed by the RP Pilot Project are:
 - first and foremost, to promote land-use planning on the Guarani Aquifer 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
 - second, to appraise 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 serious or significant risks identified and confirmed – in particular the urban water cycle needs to be better understood and managed from supply sources to wastewater reuse

- third, current average domestic water use is very high at 350 l/cap/d, with total municipal demand predicted to rise 65% to 105 Mm³/yr by 2020 as a result of population growth to 830,000 – measures need to be identified and taken to bring down this demand by 20-30% 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
- fourth, at the planning level consideration will need to be given to developing municipal groundwater production capacity from the more protected (confined) sections of the aquifer system, in part to replace any existing sources found to be at greatest risk of pollution and in part to meet the increasing water demand
- Despite calibration limitations and potential difficulties of defining boundary positions/conditions, the construction of a numerical aquifer model will serve as a rigorous tool to integrate all existing data and challenge the existing conceptual model. It could then be used to identify key groundwater investigation and monitoring needs and to evaluate possible aquifer development and management scenarios and to facilitate dialogue with stakeholders and municipal authorities. A corollary to this type of aquifer modeling will be its application to improve the definition of capture and flow zones around individual municipal wells and wellfields needed as an input to land-use planning.

Rivera-Uruguay / Santana do Livramento-Brazil

- The Rivera / Santana do Livramento (R-SL) Pilot (Figure 5) is an area of 750 km², straddling the frontier of Uruguay (Departamento de Rivera) and Brazil (Estado de Rio Grande do Sul), occupied by the outcrop of the Guarani Aquifer with the groundwater table at shallow depth. Groundwater flow is more concentrated in the most permeable aquifer horizons in the depth range 40-80 m, and is naturally in a north-easterly direction but modified by abstraction which has depressed groundwater levels by about 5 m in the last 10 years.
- The towns of Rivera and Santana do Livramento have a combined population of about 170,000, divided almost equally and growing rapidly and they live and interact almost as one. The principal economic activity is based upon agriculture (cattle and sheep for wool, leather and meat production, grapes, maize and increasingly soy cultivation – and on the Uruguayan side forestry and wood production). There are some potentially-polluting facilities such as livestock slaughterhouses and timber yards.
- Both towns have somewhat fragmented urbanization as a result of the undulating topography and presence of stream gulleys, with some more central areas quite densely populated, and while the coverage of mains water supply is high (above 95%) that of mains sewerage is much more limited at about 30% in Rivera and 40% in Santana do Livramento.
- The SAG is the principal source of water supply there being in the order of 170 water wells, including those of Obras Sanitarias del Estado (OSE) in Rivera and the Departamento de Agua y Esgoto (DAE) in Santana do Livramento (Figure 5), which provides up to 5.1 and 8.7 Mm³/yr (about 70% and 100% of the total public water supply) respectively.

Figure 5: Sketch map of water infrastructure and hydrogeological section of the Rivera – Santana do Livramento Pilot Project Area



- In general terms the groundwater quality is good with a low level of CaHCO_3 mineralization, but low pH (less than 6.0) and elevated NO_3 concentrations (over 50 mg/l) have been reported on the Uruguayan side. The main groundwater management problem relates to the lack of mains sewerage, which results in a substantial load of wastewater to an aquifer of relatively high pollution vulnerability either directly from cesspits or indirectly from polluted streams. The past history of land tipping of solid municipal waste, the infiltration of a variety of industrial effluents and the presence of a substantial number of poorly-maintained gas stations represent further hazards to groundwater quality.
- A Guarani Aquifer Transboundary Commission (COTRAGUA) has been formed to promote the pilot project with representatives of 5 local stakeholder organizations on each side – including some local government offices, water utilities (OSE and DAE), water well drillers, NGOs, agricultural, hydrological and public health organizations. Its functions will comprise:
 - assisting in the collation of relevant technical, economic and legal materials, and in the dissemination of information to the community
 - functioning as the focal point for required social surveys and promotion of community participation in groundwater management decision-making, especially monitoring and denouncing illegal well construction and enforcing regulations on polluting discharges
 - coordinate local efforts for capacity building amongst stakeholders.

Some international legal agreements already exist locally, most notably the 'Acuerdo sobre Cooperación Brasil-Uruguay en Materia Ambiental de 1992', and these, along with the long-standing cooperative environment between the two cities, should provide an excellent starting point for the present initiative.

- The main outcomes desired of the R-SL Pilot Project are to:
 - plan the improved coverage of mains sewerage and other pollution prevention measures in vulnerable aquifer zones in the communal interest of conserving groundwater quality
 - establish 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 number of specific management tools will need to be developed for this purpose (Table 4).

Table 4: Summary of desired outcomes and corresponding management tool for the Rivera – Santana do Livramento Area

TARGET OUTCOMES	MANAGEMENT TOOLS DEVELOPED
Coordinated Groundwater Resource Management : – avoiding conflicts – reducing groundwater pollution – protecting public water supplies – controlling hydraulic interference	<ul style="list-style-type: none"> • detailed local hydrogeological database and maps through local node of aquifer geographical information system (SISAG) • adequate conceptual/numerical aquifer model for evaluating resource management scenarios and defining source protection areas • diagnostic study of transfrontier groundwater issues, such as hydraulic interference effects and pollution origin/transport
Mobilization of Investment for Joint Action Plan for Improvements in Urban Sanitation and Land-Use Planning	<ul style="list-style-type: none"> • a system for coordinated aquifer management with agreed rules on land-use planning controls, wellhead protection areas, well spacing, design, construction and operation
Groundwater Production for Public Water Supply Concentrated in Wellfields Protected from Indiscriminate Urban Expansion and Intensive Agricultural Practices	<ul style="list-style-type: none"> • institutional mechanism for consultation and agreement of future resource development proposals and protection measures
Optimization of Socioeconomic & Environmental Benefits from Sustainable Use of Groundwater Resources	<ul style="list-style-type: none"> • a joint action plan for priority improvements in the coverage of main sewerage and the final disposition of wastewater • a coordinated network for monitoring groundwater level, temperature, quality and use, with establishment of a joint information system

Itapúa Department - Paraguay

- The Itapúa Department (ID) Pilot involves a predominantly agricultural and livestock-rearing area of 800 km² in the extreme south-east of Paraguay, including the districts of Bella Vista, Jesus, Trinidad, Hohenau and Obligado. The outcrop of the Guaraní Aquifer forms about 50% of the area and in the rest it is covered by a variable thickness of volcanic basalt flows. Some 50 water wells have been registered by the Servicio Nacional de Agua y Saneamiento (SENASA), and inspected by an on-going German technical assistance project with the Secretaria del Ambiente (SEAM). These mainly vary between 70-120 m in depth but reaching to over 300m in areas of thick basalt cover, a few of the shallower wells show signs of incipient nitrate contamination.
- The area was originally populated by indigenous Guaraní, and includes important Spanish colonial sites (ruined Jesuit missions), but today has a cosmopolitan population of 45,000 with immigrants from more than 20 countries.
- The main aims of this pilot project are to:
 - review the socio-economic and agricultural evolution of the area and establish its impact on SAG groundwater
 - predict future trends and identify needs for management action to ensure groundwater resource sustainability and environmental protection
 - establish the potential of the SAG to support agricultural irrigation
 - develop local institutional and stakeholder capacity to manage soil and groundwater resources.

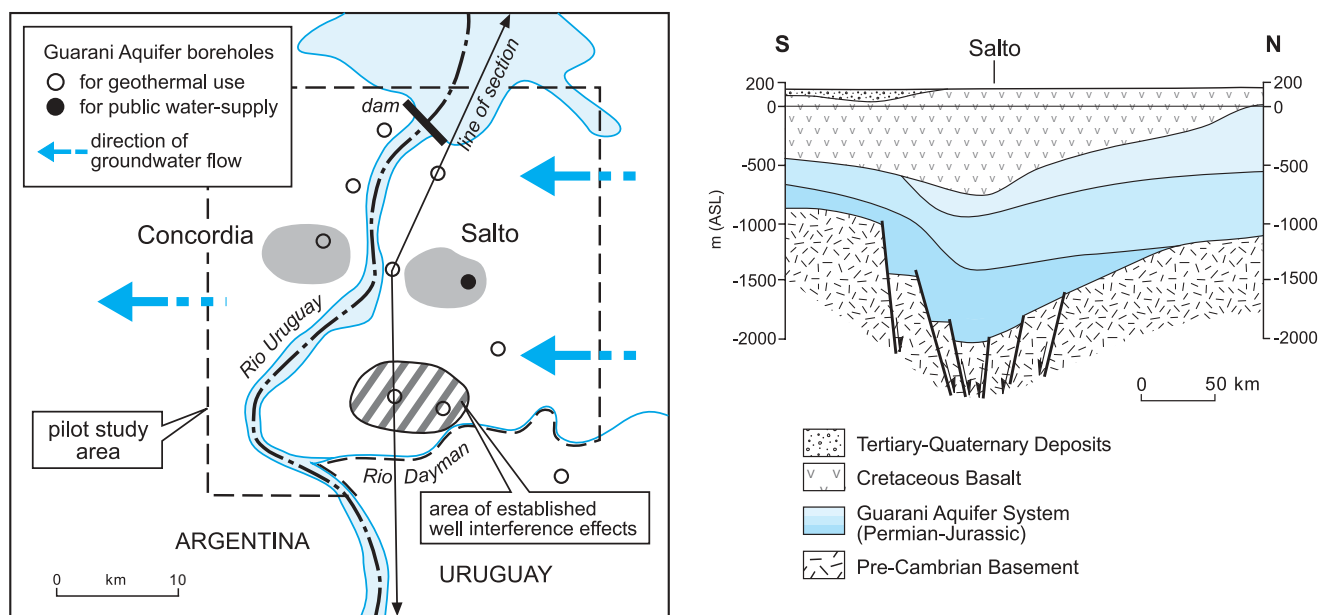
It is clear that it will be necessary to mobilize the participation of ‘key actors’ from both the agricultural and water sectors, together with representatives of local government and community leaders, for the project to be a success.

- Points of particular interest, which are of much broader relevance to SAG groundwater protection, are:
 - the effect of deforestation of the SAG recharge area and its conversion to pastureland
 - the effect of conversion of ‘permanent pasture’ to more intensive crop cultivation (for example, maize and soy) using larger fertilizer and pesticide applications
 - relative significance of these ‘development processes’ in areas with different soil characteristics – most notably the contrast between zones with outcrop sandstone and outcrop basalt
 - relative pollution vulnerability of the SAG below sandstone outcrop and varying thicknesses of sandstone cover.
- The ID Pilot Project will also provide the types of general groundwater management tools described for the R-S Pilot (Table 4) and these are not repeated again here. It will also develop an integrated model for sustainable groundwater resource development, soil and land use for provincial government and the various municipalities of the area.

Concordia-Argentina / Salto-Uruguay

- The Concordia / Salto (C-S) Pilot occupies an area of 500 km² on either side of the Rio Uruguay (Figure 6), which forms the international frontier between Argentina and Uruguay. In marked contrast to the other ‘pilot management areas’, the Guaraní Aquifer is here found beneath 800-1000 m of volcanic basalt flows (Figure 6) and its groundwater exhibits overflowing artesian heads and marked geothermal potential (temperatures of 44-48 °C). Geothermal borehole yields are normally in the range of 100-300 m³/hr with drilling depths up to 1400 m. The fractured upper part of the basalts, together locally with overlying Tertiary / Quaternary sands form a complementary ‘cold water’ source, used for public supply and small-scale irrigation.
- The C-S Pilot also comprises the most populated area of the Argentina-Uruguay frontier region with a total population of around 200,000, split approximately equally on either side of the border. The major source of income in the area is an expanding citriculture and horticulture industry. Salto (Uruguay) is the most developed area of thermal spa tourism in the Mercosur with a history of more than 10 years development – in the late 1990s the annual number of tourists reached 368,000 generating an income of about US\$ 58 million/a and producing (directly and indirectly) 3,500 employment jobs. In contrast Concordia (Argentina) has only recently initiated its first thermal tourist complex. In this area the SAG is not significantly developed for public water supply – with treatment plants on the Rio Uruguay providing the bulk of the supply supplemented by mainly shallow waterwells in the thin Tertiary / Quaternary deposits.
- Environmentally the SAG is well protected by the thick cover of overlying basalts and its high degree of confinement, and the main potential groundwater problems are:
 - hydraulic interference between neighbouring wells (already 8 geothermal boreholes exist in a relatively restricted area), which reduce (and may even eliminate) the overflowing artesian heads which are a special tourist attraction and might also reduce groundwater temperatures
 - a risk of saline intrusion from the south-south-east, where the SAG contains thermal groundwater of high natural salinity.

Figure 6: Hydrogeological sketch map and section of Concordia-Salto Pilot Project Area



Generally SAG groundwater is of the Na-HCO₃ (sodium bicarbonate) type, and an increment in Na from 135 to 205 mg/l has been observed during the period 1992-2000 in the Termas de Dayman. Increased sodium and chloride are observed in wells which draw groundwater from the greatest depths, with increases of chloride from below 100 to above 200 mg/l in some instances.

- Many thermal spas do not yet have adequate water demand and use management, and there is community need to develop and disseminate more efficient geothermal water-use practices, including water recycling, cultivation of more exotic gardens, space heating of hotel installations, final reuse and safe discharge of effluents (especially if their salinity is elevated), and to combine this resource as appropriate with shallow groundwater for 'non-spa uses'. There is also an urgent need for the definition and application of an appropriate standard for geothermal well design, construction and operation – to avoid unnecessary ingress of shallower groundwater of low temperature and/or the loss of artesian pressure – and more generally for capacity building in water and geothermal resource management.
- A local committee (Comité Local de Apoyo al SAG – Proyecto Piloto Concordia/Salto) has been constituted comprising representatives of local government and the municipalities, the provincial and federal agency for water resources respectively for Argentina and Uruguay, geothermal water users associations and universities with the following functions:
 - assist in the collation of relevant technical, economic and legal materials, and in the dissemination of information to the community
 - focal point for required social surveys and promotion of community participation in groundwater management decision-making, including preventing illegal well construction
 - coordinate local efforts for capacity building amongst stakeholders.

- The present institutional arrangements for groundwater management are distinct on either side of the international frontier – with the Secretaría de Recursos Hídricos-Entre Ríos and the federal departments Departamentos Nacionales de Hidrografía & de Medio Ambiente (DNH & DENAMA) being respectively responsible in Argentina and Uruguay. But the respective legal provisions have many points in common (although some significant differences) and could readily be the platform for the development of a ‘set of parallel legal regulations’.
- The C-S Pilot has the aim of laying the scientific and institutional foundation for the sustainable and efficient use of SAG hydrogeothermal resources in an area of the highly-confined aquifer, and will do so through the development of a ‘suite of management tools’ (Table 5).

Table 5: Summary of desired outcomes and corresponding management tools for the Concordia-Salto Pilot Area

TARGET OUTCOMES	MANAGEMENT TOOLS DEVELOPED
Coordinated Groundwater Resource Management : – avoiding conflicts – preserving artesian overflow – conserving water temperature – minimizing salinization Optimization of Socioeconomic & Environmental Benefits from Use of Hydrogeothermal Resources	<ul style="list-style-type: none"> • detailed local hydrogeological database and maps through local node of aquifer geographical information system (SISAG) • adequate conceptual and numerical aquifer model for evaluating groundwater resource management scenarios • diagnostic study of transfrontier geothermal potential • a system for coordinated local aquifer management with agreed rules on well spacing, design, construction, operation and water use • institutional mechanism for consultation and agreement of future resource development proposals and protection measures • a coordinated network for monitoring groundwater level, temperature, quality and use, with information exchange

Publication Arrangements

The GW•MATE Case Profile Collection is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

The findings, interpretations, and conclusions expressed in this document are entirely those of the authors and should not be attributed in any manner to the World Bank, to its affiliated organizations, or to members of its Board of Executive Directors, or the countries they represent.

Funding Support



GW•MATE (Groundwater Management Advisory Team) is a component of the Bank-Netherlands Water Partnership Program (BNWPP) using trust funds from the Dutch and British governments.

