THERMAL SPAS: AN ECONOMICAL DEVELOPMENT ALTERNATIVE ALONG BOTH SIDES OF THE URUGUAY RIVER

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INTRODUCTION

The origin of balneology in the region is associated with oil exploration efforts that began about 60 years ago. Deep wells, like the ones at Gaspar, Belén, Arapey, Artigas, Daymán, Guaviyú, Almirón, Paso Ulliestie (Figure 1) were drilled in the Uruguayan sector of the Chaco-Paraná Basin. Some of them brought about the development of thermal spas ("Centros Termales" in Spanish) that are still in operation.

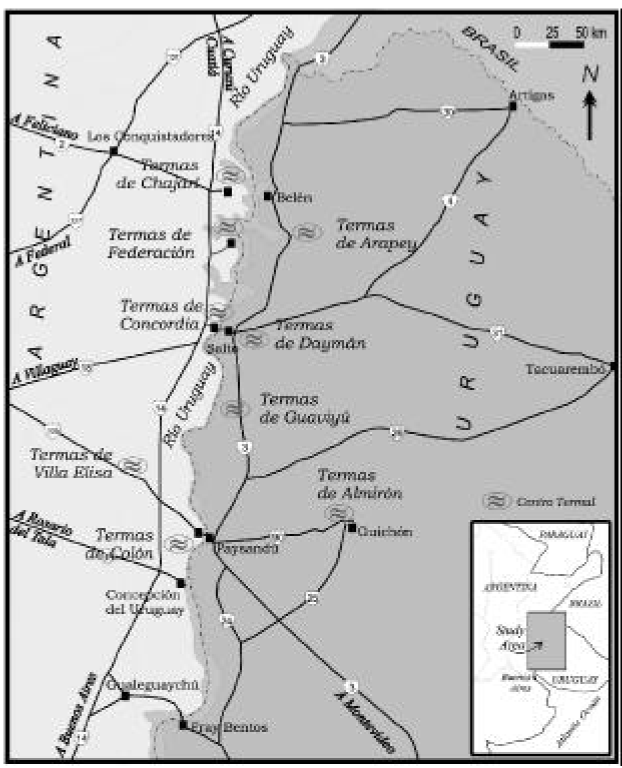

Figure 1. ***Location of the study area and of thermal spas in northeastern Argentina and western Uruguay.***

In the 1960s and 1970s, mainly based on geologic data from the Uruguayan wells, the Argentine part of the Basin was studied. Only one deep well was drilled in the general area, at Nogoyá about 150 km west-northwest of Concepción del Uruguay (Figure 1). It was plugged and abandoned since no evidence of hydrocarbons was found. Recent studies by SEGEMAR (Pesce, et al., 2001) suggest the existence of thermal waters at Nogoyá similar to the ones being produced at Villa Elisa.

These low-temperature geothermal resources are found in a vast volcanic-sedimentary basin hosted in an inter-cratonic region of low-to-normal thermal gradient. Three thermal aquifers with large potential for direct geothermal applications have been identified and characterized (Pesce, 2001). The governments of both countries have recognized the importance of these hot waters and are promoting the development of the spas and tourist centers around the wells tapping them.

The wells supplying thermal water to the spas produce from different levels of the Guaraní Aquifer System (GAS), depending on location (Table 1). The lower aquifer exploited at Almirón in Uruguay and at Villa Elisa in Argentina, is quite saline; it is in Lower Carboniferous-Middle Permian glaciomarine deposits. The middle and most impor-tant thermal aquifer, is in Lower Triassic to Lower Jurassic sedimentary rocks (eolian at the top, fluvial, deltaic and lacust-rian toward the bottom). Generally, this highly productive aquifer is of low salinity, however as it deepens towards the east-southeast its salinity increases. The spas at Chajarí, Federación, Concordia, Arapey, Dayma and Guaviyú tap into this aquifer. The upper aquifer is in Lower Jurassic to Upper Cretacic sedimentary rocks that are interlayered with thick basaltic flows, particularly toward the bottom. The spa at Colón extracts water from this low salinity water-bearing unit.

THE GUARANÍ AQUIFER SYSTEM OF ARGENTINA AND URUGUAY

The GAS has three levels of thermal aquifers that correspond to separate hydrogeologic systems.

<u>Lower GAS Level</u>. Montaño and Collazo (1998) described the lower level of the GAS in Uruguay where it is found in glacial and fluvioglacial units corresponding to the Lower Permian San Gregorio Formation which correlates to the Sachajoy and Charata Formations of Argentina (Figure 2). The sedimentary rocks, consisting of fine to medium sandstones and conglomerates of the Tres Islas Formation (similar to the Chacabuco Formation of Argentina), were

Table 1. Guaraní Aquifer System. Thermal Well Data.

Well	Latitude (S)			Longitude (W)			Approx. Elev. (m.a.s.l.)	Top Serra Geral Fm. (r.n.m.)	Top Rivera - Tacuarembó Fms. (r.n.m.)	Top Carbonif.-Permian Fms. (r.n.m.)	Top of Basement (m.a.s.l.)	Total Depth (m.b.b.p.)	Temp. (º C)	Flow Rate (L/min)
	Deg.	Min.	Sec.	Deg.	Min.	Sec.								
Colón	32	12	31	58	8	50	25	-209	-	-	-765	1500	33	2250
Arapey	30	57	36	57	31	48	60	60	-477	-	-	?	41	5800
Chajarí	30	44	46	58	0	46	55	-57	-611	-	-	811	38	6100
Federación	30	58	32	57	55	41	35	-7	-776	-	-	1301	41	7500
Concordia	31	17	41	58	0	16	48	-20	-935	-	-	1175	43	4400
Daymán	31	32	24	57	53	24	20	20	-935	-2000	-2155	2206	45	5166
Guaviyú	31	51	36	57	53	24	33	33	-642	-	-	958	38	6800
Paso Ullestie	32	27	0	57	58	48	25	-235	-	-875	-950	?	-	-
Almirón	32	39	36	57	11	24	68	10	-	-568	-860	?	34	312
Villa Elisa	32	7	40	58	27	18	50	-309	-	-898	-	1032	41	216

deposited in continental to littoral environments. In Argentina, in the western part of the basin, the lower level is represented by the Chacabuco, Charata and Sachajoy Formations. At the bottom of this level there are sedimentary rocks deposited during a marine transgression. The top corresponds to an Early Permian regression period (Chacabuco and Charata Formations). The Chacabuco Formation (Padula, 1972), and Charata and Sachayoj Formations (Padula and Mingramm, 1969) present hard, micaceous, gray-to-dark-gray clays and sometimes bituminous shales, as well as gray limestone and medium-to-fine sandstone interlayers. The Charata Formation, representing Upper Carboniferous glacial and fluvioglacial environments, is formed by silty, gray clays; tillite intercalations are abundant near the base of the formation.

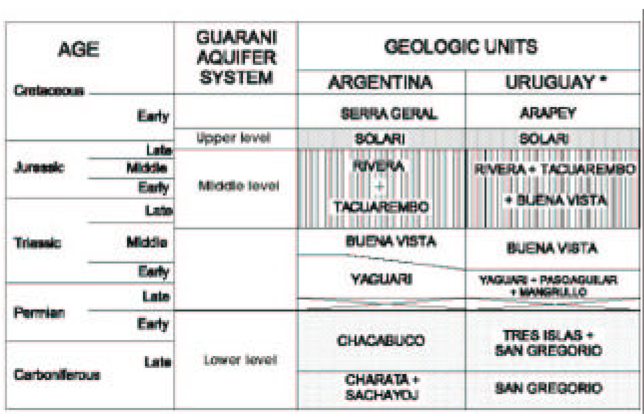

Figure 2. Stratigraphy of the Guaraní Aquifer System.

The thickness of the lower GAS level varies between 292 m in the southeastern part of the basin (i.e., in the Almidón well; Figure 3) and 95 m toward the south (i.e., in the Paso Ullestie well). Near the Uruguay River this level was not deposited because of a basement high in that region. It is not encountered in the wells at Colón and Concepción del Uruguay, but it is found to the west in the Villa Elisa well.

Middle GAS Level. Because of its productivity, the middle level is the most important one in the GAS. Montaño and Collazo (1998) mention that the aquifer outcrops in some areas. It is found in the Rivera and Tacuarembó Formations (Falconer, 1931; Ferrando and Andreis, 1986) which form the largest known eolian deposit that may extend over a 1.5 million square kilometer area (Sprechmann et al., 1981). The outcrops, restricted to Uruguay, occur along a north-south band that starts east of the city of Rivera, and ends at the Negro River to the south, passing through the city of Tacuarembó. These large outcrops are the main recharge areas of the middle GAS which is exploited on both sides of the Uruguay River.

The wells drilled at Arapey, Belén, Federación, Charají and Concordia show that the Rivera and Tacuarembó Formations extend toward the west into Argentina (Pesce, 2001). The southern limit of the middle level is north of the Almirón, Colón and Villa Elisa wells. The total thickness of this level could only be determined in the Belén well (i.e., 526 m) that had been drilled looking for oil. All the other wells which were exploring for thermal waters only penetrated the upper few meters of the two units.

The lithologic and sedimentary characteristic of the Early-to-Lower Jurassic Rivera Formation (e.g., sandy dunes, eolian and ephemeral torrential fluvial deposits) indicate that it was deposited in a desert environment. It is composed mainly by fine-to-medium, well-sorted, cross-bedded quartzitic sandstones of eolian origin. Drill cuttings from the Chajarí wells show that they have no or little cement, and a porosity of about 30%.

The sedimentary rocks of the Middle Triassic-to-Early Jurassic Tacuarembó Formation are mainly of fluvial type (i.e., river bed, alluvial plain, and overflow deposits). It is composed by very fine-to-medium grained, well-to-regularly sorted, feldspar, quartz and micaceous (mainly muscovite) sandstones with clay cement, and by green, redish siltstones and mudstones, friable muscovite shales, and intraformational conglomerates.

Upper GAS Level. The upper aquifer of the GAS is hosted in continental sandstones of the Solari Formation (Herbst, 1971) interstratified with the lower basalts of the Serra Geral Formation (White, 1908). At present, this thermal aquifer is only being penetrated by the Colón well, west of the Uruguay River, at 795 m below sea level (Figure 3). In this part of the basin the basement presents a structural high, the Colón- Concepción del Uruguay Horst, that did not allow the deposition of the formations corresponding to the lower and medium GAS levels. Fine and medium grained quartz sandstones and some coarse psammitic interlayers predominate the lithology of the upper GAS level. Some basalt flows are also found. There is evidence of alternating basaltic effusions, and erosion and deposition events occurring under arid conditions. Sediments are predominantly eolian, with smaller amounts of deposits.

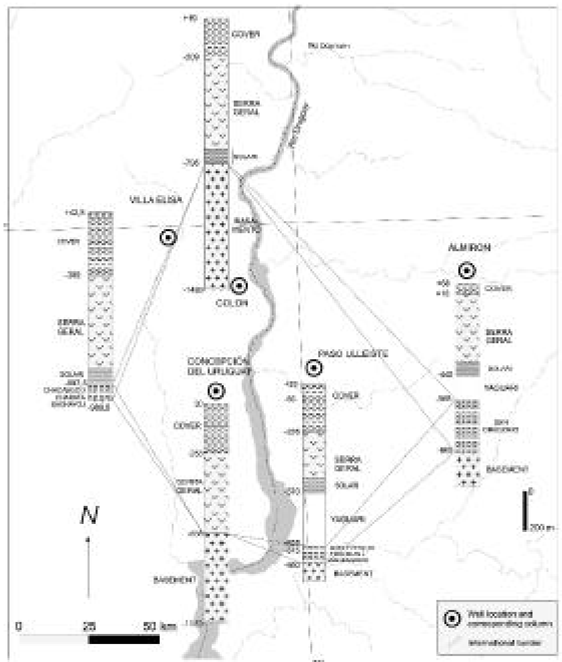

Figure 3. ***Lower level of the Guaraní Aquifer System. Correlation between wells in the southern part of the study area.***

The north-south profile along the Uruguay River (Figure 4) was prepared using the information from the Chajarí, Federación, Concordia, Colón, Concepción del Uruguay and Gualeguaychú wells. The Colón-Concepción del Uruguay Horst that had an important effect on sedimentation, is clearly discernable. Its highest part (at 686 m below sea level) was encountered by the Concepción del Uruguay well. Toward the north and south where the basin becomes deeper, the lower and medium GAS levels are found in the wells. The lower level occurs south of the horst (i.e., at Gualeguaychú).

In the southern and central parts of the area under study the upper and medium levels of the GAS produce the thermal fluids. The western and eastern edges of the horst and the southern limits of the medium and lower levels have been established by correlating the Almirón, Colón, Paso Ullestie, Concepción del Uruguayand Villa Elisa wells (Figure 3).

HYDROLOGY

The GAS is confined over 90% of its area. In the remaining 10%, where the aquifer is unconfined, most of the recharge occurs (Campos, 2000). The chemical characteristics of the GAS waters are given in Table 2.

Montaño and Collazo (1998) mentioned that the waters in the Rivera and Tacuarembó Formations are potable everywhere. The waters are of calcium chloride and calcium bicarbonate type. The concentration of calcium is higher than that of sodium which could be related to the poor cementation of the Tacuarembó Formation that some times is calcareous (Montaño and Collazo, 1998). The mean total hardness, expressed as $CaCO_3$, is 45 mg/L; the average dry residue is 120 mg/L.

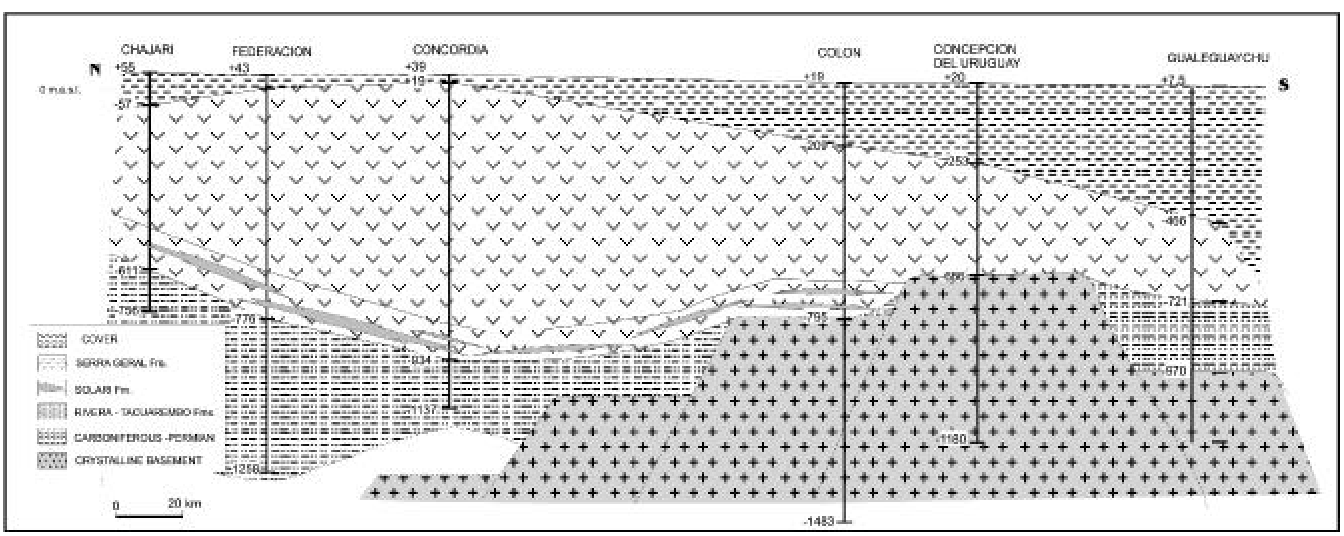

Figure 4. ***North-south geologic section along the Uruguay River showing the Colón-Concepción de Uruguay Horst. Elevation given in meters.***

Table 2. Chemical Analysis of Waters From the Three Levels of the Guaraní Aquifer System.

Geothermal Area	pH	EC [µS/cm]	TDS [mg/L]	Na+ [mg/L]	Ca++ [mg/L]	Mg++ [mg/L]	Cl- [mg/L]	SO4= [mg/L]	HCO3- [mg/L]	CO3= [mg/L]	SiO2 [mg/L]	K+ [mg/L]	Fe++ [mg/L]	F- [mg/L]	B [mg/L]	NO3- [mg/L]	Li+ [mg/L]	Al+++ [mg/L]	Mn++ [mg/L]	As+++ [mg/L]	Water Type
UPPER LEVEL																					
Colón	8.5	1180	620	235	1.4	0.5	105	74	318	12	22	0.7	0	3.1	1.4	n.d.	0.03	<1	0	0.01	Sodium Bicarbonate-Sodium Chloride
MIDDLE LEVEL																					
Arapey *	8.2	416	297	98	19	10	33	20	175	49		6.3	0	0.2		0.1			0		Sodium Bicarbonate
Chajarí	8.2	918	569	175	11	5	120	40	238 *	< 5	----	5	0.01	0.6	0.17	n.d.	< 0.1	0.017	< 0.005	0.021	Sodium Bicarbonate-Sodium Chloride
Federación	8.5	1250	698	240	16	5.8	199	92	236	2.6	7.9	4.3	0.2	0.5	0.23	4	0.04	0	< 0.05	0.03	Sodium Bicarbonate-Sodium Chloride
Concordia	8.5	554	326	118	4.6	1.8	21	8.4	290	3.8	9.6	2.5	< 0.2	0.7	0.17	3.1	0	0	0	0.06	Sodium Bicarbonate
Daymán *	7.8	806	455	140	7	2	32	28	295.24	0		2	0	0		0			0		Sodium Bicarbonate
Guaviyú *	8.7	997	712	245	1.8	0.4	80.97	70	302	88		2	0	1		0.1			0		Sodium Bicarbonate
LOWER LEVEL																					
Paso Ullestie *		3000	2803	900	41.5	5.8	911.68	602	129.32	0		10	0	0		0			0		Sodium Chloride
Almirón*	7.2	8000	8044	2000	233	2.9	2933.95	1215	37	0		15.01	0	0		0			2.9		Sodium Chloride
Villa Elisa	7.7	18900	14500	4900	191	70	5070	4800	98	0	15	13	0.4	1.1	4.1	n.d.	0.47	<1	<0.05	0	Sodium Sulfate-Sodium Chloride

The GAS presents three confined aquifer levels. The top of the system corresponds to the upper and mid-parts of the Serra Geral Formation; in some areas and because it presents fractures, the formation behaves as an aquitard (Araujo et al., 1999).

As indicated earlier, the GAS deepens toward the east-southeast where it presents a remarkable number of reactivated regional faults (Aráujo et al., 1995) that permits the infiltration of waters from overlying units. Since in the western part of the basin these units are Tertiary marine formations, there is an increase in total dissolved solids toward the west (Pesce, 2001).

The lower level of the GAS is exploited in the extreme southern part of the basin where three wells have been drilled (i.e., at Almirón, Paso Ullestie and Villa Elisa). The Almirón well reaches the San Gregorio Formation at less that 568 m depth; at Paso Ullestie, at less than 855 m; and at Villa Elisa (Argentina), the Chacabuco Formation is found at less than 897 m depth, indicating that the lower GAS level deepens toward the west. The waters are of sodium sulfate-chloride type. The amount of total dissolved solids (TDS) increases toward the west (i.e., the average TDS is 5423 mg/L in the east and 14,500 mg/L in the west. The amount of magnesium in the waters also increases in that direction. The average pH of the waters is 7.5. The electrical conductivity varies between an average of 5500 FS/cm in Uruguay to 18,900 FS/cm in Argentina.

The middle level is being produced in the south-central part of the region under study, where the Rivera-Tacuarembó can be found (i.e., in the Guaviyú, Daymán, Concordia, Arapey, Federación and Chajarí wells). The major ions in the thermal waters of this level are mainly of sodium bicarbonate type. The wells in Federación and Chajarí produce high chloride content waters. This can be explained by the hydrogeologic model for this aquifer that shows the groundwaters moving from east to west.

The temperatures in the middle level vary between 38º and 46ºC; the pH (i.e., 8.3) is almost constant throughout this level. The average TDS is 509 mg/L; it varies between 455 mg/L (Arapey) and 712 mg/L (Guaviyú).

The waters in the upper GAS level (only produced at Colón) have a temperature of 33ºC, a pH of 8.5 and TDS of 620 mg/L; they are mainly of sodium bicarbonate-chloride type. Sodium and potassium concentrations are higher than that of calcium and magnesium, and the fluor content is high. The waters' electrical conductivity is 1180 FS/cm.

GEOTHERMAL DEVELOPMENT

In the mid-1990s a number of people, witnessing the successful spa industry in Uruguay, proposed similar developments on the Argentine side of the Uruguay River. This led to the drilling of the 1260 m deep Federación well which produced 43ºC waters and the opening of the first thermal spa in northeastern Argentina in January 1997.

After that successful well, others were drilled at Concordia, Colón, Villa Elisa, Concepción del Uruguay and Gualeguaychú. Unfortunately because of lack of appropriate exploration data and bad completion, some did not encountered thermal waters, like the ones at Concepción del Uruguay and Gualeguaychú, and others were drilled too deep (e.g. the 1502-m deep Colón well than penetrated more than 600 m of crystalline basement). Note that all the thermal wells on both sides of the Uruguay River are flowing artesian wells.

The integrated study of the basin and the economic success of the spas is resulting in the rapid development of the region's low-temperature geothermal resources. Five additional wells and associated spas are being planned in Argentina and two new ones in Uruguay. This shows the important role of these developments in the economy of the region.

The growth of economic activity is made obvious by the fast increase in the number of hotel beds in towns having spas. For example, at Federación that number went from 182 in 1994 to 2150 in 2001 (Figure 5). The opening of a spa tends to be reflected by a jump in the number of beds in town.

Statistics collected by the government of the Province of Entre Ríos where for all of the thermal spas located in northeastern Argentina, show a constant growth in the number of tourists visiting the spas; a record number visited during Easter 2002. In the case of Federación the increase of tourist activity is surprisingly high; during the January-June 2002 period more than 210,000 people visited the spa, compared to 150,840 for the twelve months of 2001 (Figure 6). Part of this increase is related to the recent devaluation of the

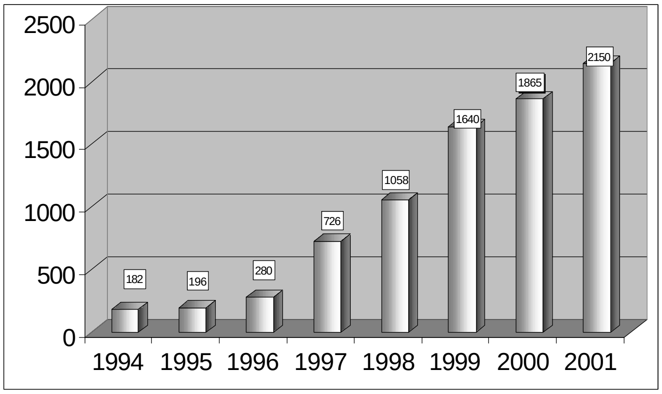

Figure 5. Growth in the number of hotel beds at Federación Thermal Spa.

Argentine peso which lowers the costs for visitors from neighboring countries. It is estimated that only 10% of the visitors are locals, the rest are from other parts of Argentina and from abroad.

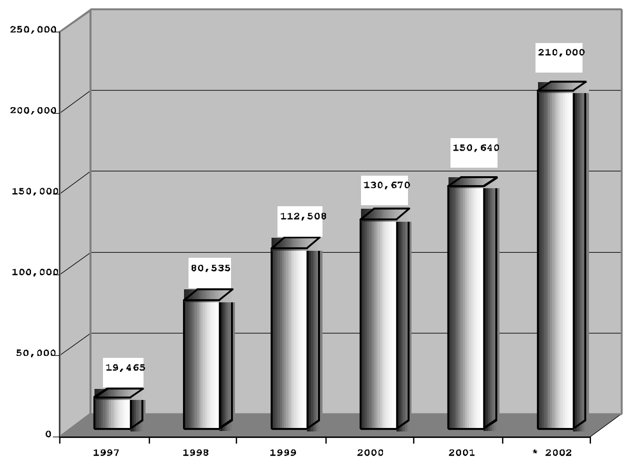

Figure 6. Number of tourist visiting the Federación Thermal Spa.

Figure 7. Colón Spa, Argentina.

The drop in unemployment from 25% to 7% reflects the importance of these centers on the economy of the region over a four-year period. Main characteristics of the thermal spas using waters from the GAS are given in Table 3.

Figure 8. Concordia Spa, Argentina.

Figure 9. Chajari Spa, Argentina.

Figure 10. Federación Spa,, Argentina.

Table 3. Guaraní Aquifer System. Main Characteristics of the Thermal Spas.

Location (City)	Hotel Beds	Name of the Site	Therapeutic Applications	Facilities
Colón	1033	Complejo Termal Colón	Topical applications: neutralize gastric acidity, help stomach secretion and evacuation, stimulate pancreatic and bile secretions, increase carbohydrate tolerance and facilitate insulin action. Baths: to reduce stress and nervous exhaustion	Outside and covered swimming pools, hydromassage, jet baths, water fountains
Concordia	1098	Vertientes de la Concordia	Baths: Arthrosis, rheumatism, arthritis, skin, digestive and respiratory systems, relaxation, esthetics.	Five swimming pools (two are covered), jet baths, massage salon, camping facilities.
Chajarí	544	Complejo Termal Chajarí	Topical applications: digestive system, stimulation of chlorohydric secretion, bile activity, gastric and intestinal motility. Baths: activation of metabolic changes, helps with muscular contraction and hypertonia. Chronic rheumatism, vertebral arthrosis, traumatisms and skin diseases.	Five swimming pools with hydrojets, bungalows, camping facilities.
Federación	2150	Complejo Termal Municipal Federación	Topical applications: digestive and respiratory systems, bile and intestinal motility stimulant. Baths: Chronic rheumatism, vertebral arthosis, locomotive apparatus, skin, relaxation.	Outside and covered swimming pools, immersion bathtubs, hydromassage, ozonizer, showers, steam cabins, masotherapy and kinesiotherapy cabins.
Villa Elisa	1245	Termas de Villa Elisa	Baths: Stimulant of cellular functions, cellular trophysm, metabolic secretions. Improve skin and mucose defenses. Antiflogistic and antiseptic actions. Stimulant of respiratory, digestive, vegetative nervous and female genital systems. Recovery from respiratory chronic affections.	Outside and covered swimming pools, hydromassage, jet baths, showers, masotherapy, kinesiotherapy and phyisiatric cabins
Arapey	450	Termas de Arapey	Topical applications: stomach, diuretic and digestive system sedative related to stress symptoms. Baths: stimulant and disensitizing baths. To treat general rheumatism.	Outside and covered swimming pools. Thermal bath cabins, jets.
Salto	2360	Termas de Daymán	Baths: Treatment of stress, rheumatism, traumas, neuralgic, muscular and skeletal affections.	Saunas, hydrojets, jacuzzis, ozone pools, Scottish and Swedish showers, musculation areas, individual and communal swimming pools, physiotherapy areas, aquatic park.
Paysandú	1632	Termas de Guaviyú	Topical applications: digestive, urologic, pulmonar and cardiovascular systems. Detoxification and physiological dehydration. Renal and vesicular stones and filtration affections. Metabolic regulation, diabetes. Baths: Non-inflammatory rheumatism, arthrosis and spondiarthoris, musculatory affections. Skin allergies and asthma.	Four immersion swimming pools, jets for hydromassages.
Guichón	1034	Termas del Almirón	Baths: Salty waters for therapeutic treatments, rheumatism, psoriasis, chronic excemas, and skin diseases in general. Metabolic problems. Chronic bronchitis, detoxification, analgesic and anti-inflammatory treatments.	Two covered swimming pools, jets systems, three immersion pools, motels, camping facilities.

FINAL REMARKS

The data collected from wells drilled during the development of the low-temperature geothermal resources of northeastern Argentina and western Uruguay has allowed a better understanding of the Guaraní Aquifer System, reducing the risks associated with drilling new wells and developing new spas in the region. The popularity of the thermal centers along both sides of the Uruguay River will lead to a further development of these geothermal resources and the construction of new tourist centers, contributing to the growth of the regional economy.

The rapid expansion and importance of the spa industry led to the creation of business and government associations in Argentina and Uruguay and to a regional integration of activities. Strategies have been developed to inform the general public of the benefits of thermal waters and further popularize balneotherapy. Efforts to integrate development and business plans and guidelines have also been conceived. These include holding technical meetings, tourism fairs, developing Websites (Corredor Turístico del Río Uruguay, Mercotur or Todoturismo), all geared toward linking people, organizations and tourist agents.

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