THE GROUNDWATER RESOURCES OF URUGUAY

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Abstract. Knowledge of the natural resources of a country is essential for the assessment of its development possibilities. This is particularly true for the evaluation of groundwater resources in a country like Uruguay, where less than 5 per cent of the potential is exploited and this in an inefficient way, and where no drastic future increase in demand is predicted.

In the present paper the generalized hydrogeological model of the country was reconstructed, and recharge values, obtained by an approach adapted from nearby areas, were introduced.

Les ressources en eaux souterraines en Uruguay

Résumé. *La connaissance du potentiel des ressources naturelles d'un pays est essentielle pour l'évaluation* de ses possibilités du développement. C'est aussi valable pour l'évaluation des ressources en eaux souterraines dans un pays tel que l'Uruguay, où, moins de 5 pour cent de son potentiel est exploité et en outre, d'une manière inefficace et où on ne prévoit pas d'accroissement vigoureux de la demande à l'avenir.

Dans cet article un modèle hydrogéologique généralisé du pays était reconstruit et les taux de rechargement, obtenus par une méthode adaptée des régions prochaines, étaient introduits.

INTRODUCTION

The Republic of Uruguay, one of the smallest countries in South America, is practically empty. Except for the dense population centred around Montevideo and some limited extensions of plantations along the Rio Uruguay, the lowlands are covered by evergreen pastures. This uneven concentration of urban extensions and economic activities, leads to uneven distribution of water demand. On the one side there are a few urban centres of high water consumption, and on the other, many small dispersed local consumers, like isolated farm houses or watering places for herds. In a country with abundant surface water the demand for groundwater is low and is limited mostly to local supply. To answer these demands more than 10 000 wells, with low daily yields (a few cubic metres), are scattered mainly in the southern part of the country. Except for the Punta del Este area no central water supply scheme was based exclusively on groundwater. Lately the tendency has been to replace the deteriorating waters of the coastal aquifers by surface waters.

Preliminary evaluation of the groundwater resources is the subject of the present paper. For this purpose, the author reconstructed a generalized hydrogeological model of the country covering its different permeable formations and fractured layers. Recharge values obtained for a similar nearby area (Sao Paulo, Brazil) by daily hydrometeorological computations, were imposed on the defined media, to obtain estimated values of the groundwater potential of Uruguay.

GENERAL DESCRIPTION

The structure of Uruguay consists of a stable igneous basement, limited to the north by the large sedimentary Parana basin (Gilboa *et al.*, 1976) and to the south by the coastal plains. The existing structures are dissected by normal faults.

Uruguay, which covers 186 926 km^2, is a low country with 87 per cent of its area occupied by low undulating hills (lower than 200 m), with only one peak of 510 m. It can be divided into three principal geomorphological units:

(1) *Hills*—composed of the Gondwana sedimentary basin in the north and northeast; the crystalline basement, with the highest hills forming the divide between the Atlantic and the interior watersheds, occupies the eastern, central and southern parts of the country; and the basalt sheets that form the elongated hills in the north and northwest extremes.

(2) *Coastal plains*—along the Rio de La Plata and the Atlantic coasts.

(3) *The valley of Rio Uruguay*—which differs from the other units in topography, soils and vegetation.

The mean annual precipitation varies from 1000 mm in the south to 1200 mm in the north (Fig. 1).

Excluding the Uruguay and De la Plata rivers, the mean annual discharge of the Uruguayan rivers is about 1900 m^3/s or some 60×10^9 m^3/year. The rivers are grouped in six major basins: the Rio Negro (the most important river of Uruguay), northern and southern basins of the Rio Uruguay, the Rio de la Plata basin, Atlantic basin and the basin of Laguna Merin (Fig. 1).

THE AQUIFERS

It is estimated that in Uruguay there are 10 000 boreholes with an average depth of 40 m. Of these, more than 50 per cent operate for short periods or for a few hours per day with inefficient and old pumping equipment. The total actual extraction of groundwater, from all the aquifers combined, is about 100×10^6 m^3/year.

The aquifers of Uruguay are divided into two main groups (see Table 2).

(1) Regional with large extensions and/or with importance for water supply.

(2) Local with limited dimensions or with circulation limited to sporadic lines and with low yields, serving only local demands.

Table 1 shows the stratigraphic sequence of the country.

Regional aquifers

Two aquifers, Tacuarembo and the Quaternary of the coast are included in this group (Fig. 1).

The Tacuarembo aquifer of Triassic age is the most important aquifer of Uruguay, occupying about 42 000 km^2 in the northwestern region, or about 22 per cent of the total area. Composed of fine to medium eolian sandstone, 300-550 m thick, only 3700 km^2 of the aquifer is exposed, the remainder being covered by thick basalt flows of the Arapey group. This aquifer forms part of an untapped continental aquifer extending over the whole of the Parana basin, up to Minas Gerâis state in Brazil (the Botucatu aquifer). The confined parts of the aquifer are presumably saturated, slowing down the deep infiltration in the sandstone and increasing the baseflow of the rivers that cross it (Gilboa *et al.*, 1976). The few wells drilled by ANCAP and for dispersed water supply systems in this section of the aquifer, furnish little information on the direction of the groundwater flow. It is not known whether the groundwater flows towards the visible outlet of the aquifer in the states of Santa Catarina and Rio

TABLE 1

Condensed stratigraphic sequence of Uruguay

Age	Formation	Thickness [m]		Lithology	
Quaternary		20		Alluvium and beach sands	
	Bellaco	?		Clays and gypsum	
	Libertad	15		Grey clays	
	Raigon	35		Sands and clays, pebbles	
Pliocene	Arazati			Loess, somewhat calcareous	
	Salto	?		Red sandstones	
	Camacho			White calcareous sandstones	
Miocene	Fray Bentos	80		Sandy siltstone	
Oligocene	Queguay	40		Silicified limestones	
Upper Cretaceous	Asencio	40		Argillaceous and calcareous sandstones	
	Mercedes	70	*	Conglomerates and sandstones, compact	
	Guichon	100		Argillaceous red sandstones	
	Puerto Gomez	1000		Gabroid extrusives	
Jurassic	Arapey	100-1000		Basalt flows	
Upper Triassic	Tacuarembo	300-550		Sandstone	
Upper Permian	Buena Vista	?		Red sandstone	
	Yaguari	150		Argillaceous sandstone	
Middle Permian	Paso Aguiar	?		Sandy shales	
	Mangrullo	70		Bituminous shales	
	Frayle Muerto	200		Sandy shales, some limestone	†
Lower Permian	Tres Islas	150		Sandstone and shales, carbon	
	San Gregorio	250		Conglomerates and argillaceous sandstones	
Lower Devonian	Las Palmas	35		Sandstone	
	Cordobes	100		Shales	
	Cerrezuelo	150		Arkosic sandstone	
Crystalline basement					

* Up to 2000 m in Santa Lucia.
† Gondwana series.

TABLE 2

Estimated recharge rates of the aquifers

Aquifer		Surface [km²]	Infiltration [%]*	Precipitation [mm/year]	Infiltration [mm]	Total infiltration [10^6 m^3/year]
Tacuarembo		3 700	1 -2	1 200	12-24	44- 88
Libertad		2 400	3 -5	1 000	30-50	72- 120
Laguna Merin		8 000	3 -5	1 100	33-55	264- 440
La Plata (West)	Quaternary	1 000	3 -5	1 000	30-50	30- 50
La Plata (Centre)		500	3 -5	1 000	30-50	15- 25
La Plata (East)		200	3 -5	1 000	30-50	6- 10
Atlantic		1 500	3 -5	1 100	30-50	45- 75
Salto(Pliocene)		1 000	0.1-2.5	1 100	1-27	1- 27
Mercedes (Cretaceous)		15 000	0.1-2.5	1 100	1-27	15- 420
Buena Vista (Upper Permian)		3 000	1.5-4	1 200	18-48	54- 144
Tres Islas		3 000	1.5-4	1 200	18-48	54- 144
Cerrezuelo (Devonian)		1 000	1.5-4	1 100	16-44	16- 44
Arapey (basalts)		49 000	1.2-3.8	1 100	13-42	637-2 058
Crystalline basement		60 000	1.5-4.5	1 000	15-45	900-2 700
						2 153-6 245

* For infiltration rates, see Gilboa *et al.* (1976).

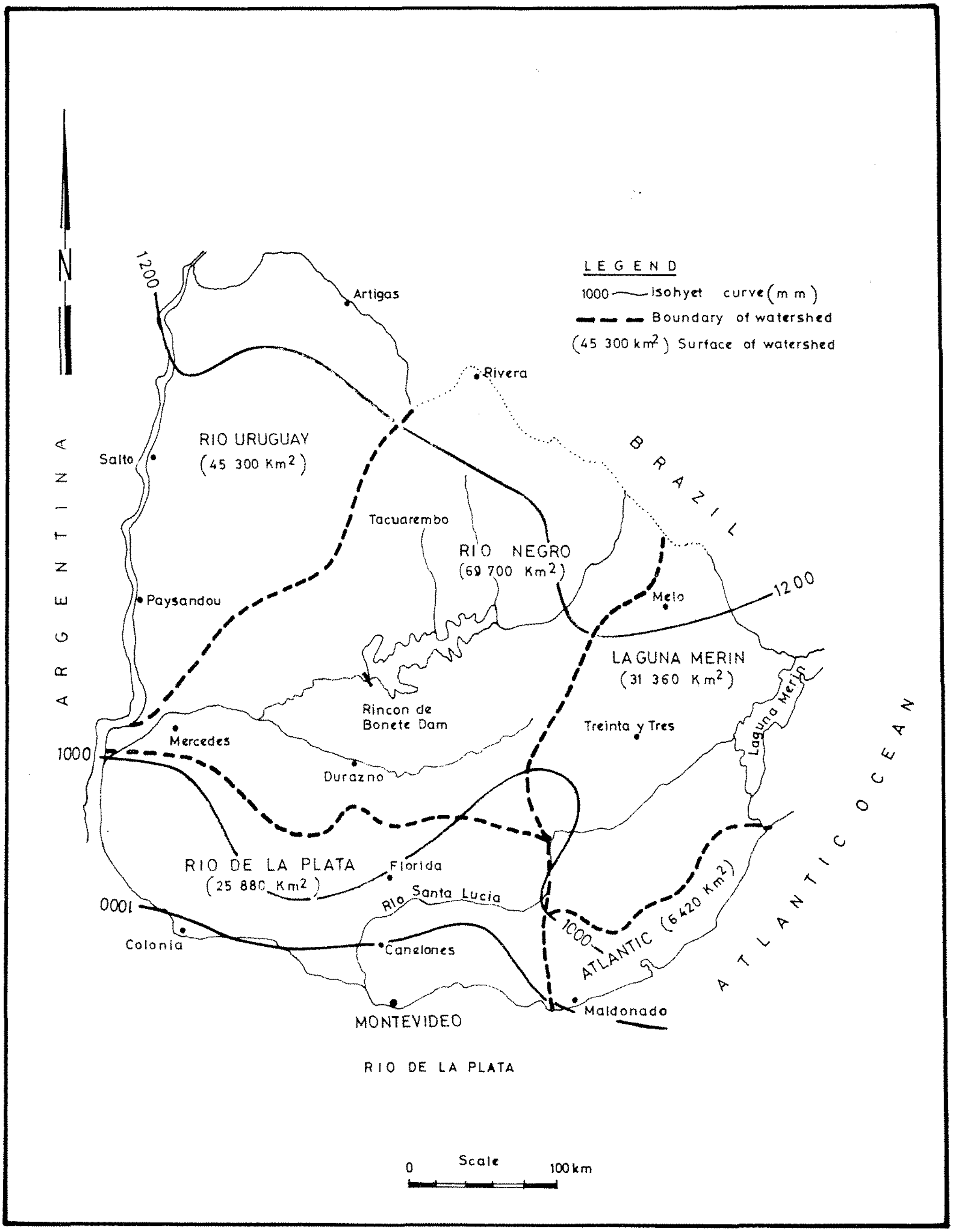

Fig. 1 – Isohyetal map of Uruguay

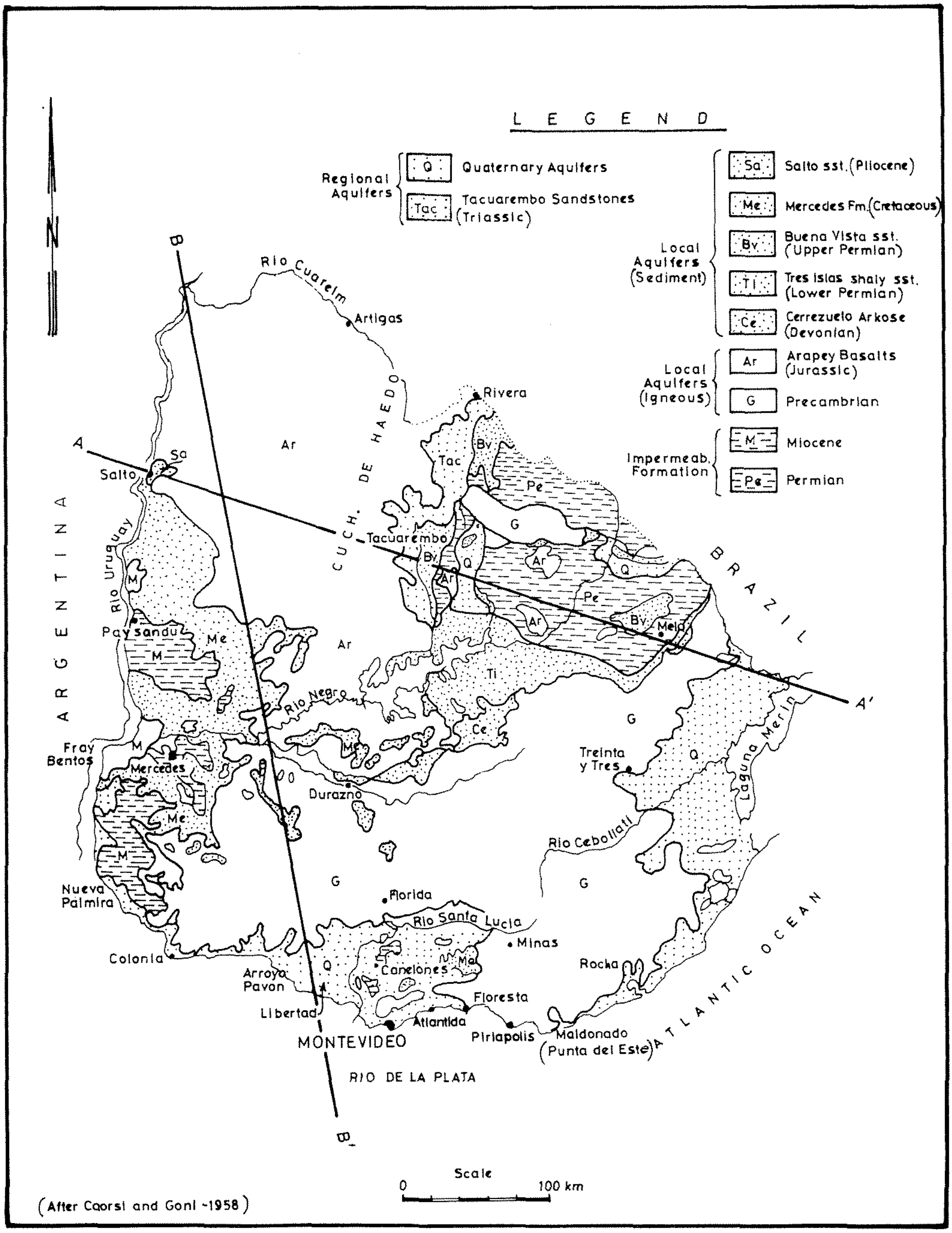

Fig. 2 – The aquifers of Uruguay (after Caorsi and Goni, 1958).

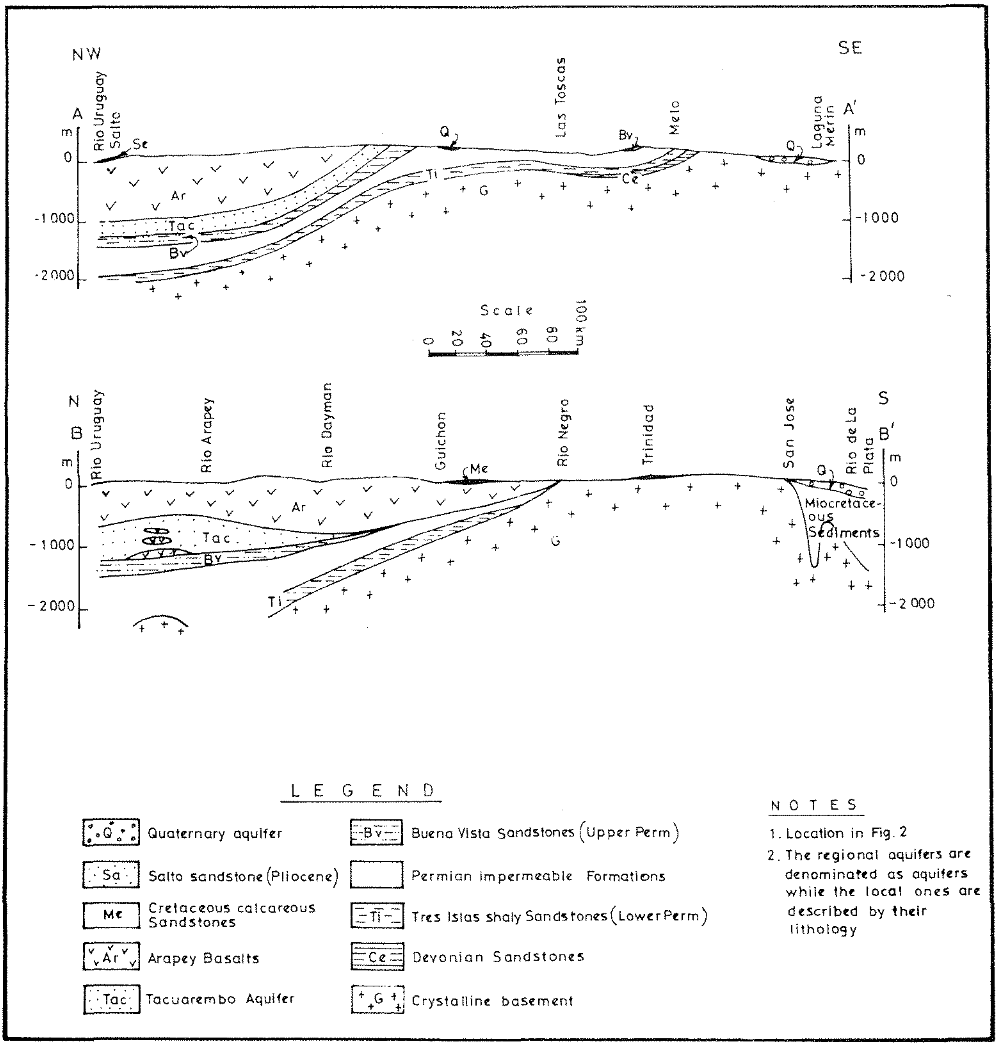

Fig. 3 – Schematic geological cross sections.

Grande do sul or through undetected outlets towards the La Plata basin. Presumably, the water from this part flows towards Argentina. However, as in Brazil, the wells in the western confined parts (Arapey, Salto) yield artesian flows of 100-1000 m^3/h, with temperatures above 39°C. Considerable amounts of water are stored within this huge aquifer.

Quaternary aquifers of the coast

Included in this group are the alluvial deposits along the coast which have a certain importance for water supply or are areas with promising potential. Areas like the upper reaches of the Santa Lucia River and Quaternary region along the Uruguay River are not included. The most important aquifers in this group are the Libertad and the Laguna Merin (Figs. 2 and 3).

Libertad aquifer
Located west of the Santa Lucia River, this aquifer consists of 35 m of sand and siltstone of the Raigon formation. The aquifer overlies the siltstone of the Fray Bentos formation or is directly over the crystalline basement, and it is covered by recent clays that practically confine it. Extending over some 2400 km^2 the aquifer is encountered at a depth of 10-50 m. Most of the wells are less than 40 m deep, and 70 per cent yield less than 10 m^3/h, while a few yield more than 90 m^3/h. Generally the water quality is good, deteriorating only near the Santa Lucia River due to saline water intrusion.

Laguna Merin aquifer
The plain that bounds the western side of the Laguna Merin is composed of up to 100 m of alluvial deposits (sandy clays and pebbles). This immense aquifer, extending about 8000 km^2, covers Tertiary shales and basement rocks. Being mainly phreatic the aquifer is recharged by rainfall and drains into the rivers or through the length of the 140-km shore of the lagoon. Due to lack of demand the number of drilled wells is small; indicating possible good yields (as high as 80 m^3/h) of good quality water.

Quaternary aquifers of Rio de la Plata
West (Nueva Palmira to Arroyo Pavon)
A strip of sandy argillaceous sediments (Raigon formation) and alluvium, 5-10 km wide, extending 120 km along the coast of Rio de la Plata between Nueva Palmira and Arroyo Pavon, is interrupted eventually by outcrops of crystalline basement rocks. The strip has a maximum elevation of 50 m and is drained by tributaries of the Rio de la Plata. A small scale exploration is concentrated in the sandy clays of the Raigon formation. The quality of the water ranges from good to acceptable, except for certain areas of saline water intrusion such as at Juan Lacaze.

Centre (Floresta-Atlantida)
In a 50-km long and 10-km wide strip, between Carrasco Creek and Santa Lucia del Este some 650 wells are concentrated. In this 500-km^2 area, with maximum elevation of 50 m, two aquifers are encountered; the phreatic recent alluvial and sand beds and the confined sands of the Raigon formation that overlie clays of the Fray Bentos formation directly over the basement.

The depth of the Raigon formation varies between 10 and 45 m, but to date no study has been carried out in order to distinguish between the phreatic and confined components.

In this sector, O.S.E. (the state sanitary works organization) extracted in 1968 some 11×10^6 $m^3/year$, with very low instantaneous yields (1-10 m^3/h) per well (O.S.E., 1970). Only in Floresta were better yields (35 m^3/h) registered. Together with the private pumping it is assumed that the exploitation of the aquifers in the area is about to reach the estimated safe yield. The quality of water is good, except for some iron in the upper beds and fluctuations in salt content near the shore. Due to poor yields, O.S.E. intends to change the source of water supply, importing water from the system of Santa Lucia and other surface water sources (lagoons). Therefore, the importance of the aquifer has been reduced and it will serve only as a standby source of supply.

East (Piriapolis-Punta del Este)
The Quaternary aquifers, specially the Raigon formation in Punta del Este, had a major role in the development of the most important beaches of the country. Until recent years the major town in this sector, Maldonado, and the important beach resorts were supplied exclusively from groundwater sources. Such an extensive extraction resulted in serious saline encroachment problems. Even though the instantaneous yield was relatively good (20 wells with more than 20 m^3/h each), the dispersion of such a supply system between numerous

small wells and the deterioration of the water quality complicated and increased the costs of such an operation. This lead to a costly integrated solution of obtaining water supplies from the Sauce Lagoon. In the near future these aquifers, which are similar to the others along the coast, will recover their natural regime by pushing back the saline interface and so improving the water quality.

Quaternary aquifer of the Atlantic (lagoons of Rocha)
As in La Plata coastal aquifers, this low coastal strip, about 120 km long and 10-20 km wide, is covered by Quaternary deposits and contains phreatic dunes and alluvium and confined aquifers (Raigon formation). Due to insignificant water demand the wells are scarce. However, the concentration of lagoons in this strip may indicate low permeabilities of the aquifer beds or basement rock obstacles.

Local aquifers
In this category are included: (1) aquifers with limited extensions (like lenses) in sedimentary formations. In most of these yields are low and in others salinization with confinement is observed. (2) faults and joints in igneous rocks, like granites and basalts. Circulation of water is limited to these lines and yields are relatively low.

The name 'local' adapted here to these hardly permeable beds signifies their unimportant role, limiting their exploitation to solution of local water supply problems.

Local sedimentary aquifers
In this group are included five formations with some possibilities for groundwater exploitation, of these the two most recent (Salto of Pliocene age and the Cretaceous formations) are located at the western part of the country while the Palaeozoic aquifers are located in the northeast (Fig. 2).

Salto (Pliocene)
The red conglomerate sandstones that constitute the Salto formation overlie the Arapey basalts in numerous separated outcrops, north of the town of Salto. Covering in total less than 0.5 per cent of the country, the fine sandstone beds have a thickness less than 40 m. The average instantaneous yield of the wells is 15-30 m^3/h.

Cretaceous aquifer
The Cretaceous sandstones, somewhat argillaceous, and specially the conglomerates and sandstones of the Mercedes formation, attaining a total thickness of 200 m, might serve eventually as a source of water for local consumption. Overlying the crystalline basement and the Arapey basalts in the western part of the country and covered partially by Miocene sediments, the Cretaceous formations are exposed over more than 16 000 km^2. Affected by calcareous cementation and frequent argillaceous intercalations, the permeability of the detritic beds is very low. Generally, the expected yields are low (5-20 m^3/h), the same as in the equivalent aquifer in Brazil (Bauru).

Buena Vista sandstone (Upper Permian)
The characteristics of the Buena Vista sandstone are not known, since they underlie unconformably the important aquifer of Tacuarembo, almost unknown itself. The outcrops of the Buena Vista sandstone cover less than 3000 km^2 north of Melo and east of Route 5, in the northern part of the country. There is no interest in exploiting its confined section, since the overlying Tacuarembo aquifer offers large amounts of less expensive water. On the other hand its phreatic part might offer interesting instantaneous yields.

Tres Islas sandstone (Lower Permian)
The Tres Islas sandstones (formerly Rio Bonito sandstones) appear as lenses alternating and passing into fine clastics (shales). This fact is well known also in the equivalent Tubarao formation (Brazil), resulting in low instantaneous yields (5-10 m^3/h), and only rarely yields of 30 m^3/h are reached. In addition to the 150 m of the formation, the underlying conglomerates of the San Gregorio formation might contribute small amounts of water. The quality of water is bad, especially in its confined sections, and high contents of chloride, sulphates and sometimes fluoride are measured. The deterioration of water quality is due to the confinement of sandstone lenses within shaly masses where deep infiltration is reduced and the percolation is preferentially lateral.

Cerrezuelo sandstone (Devonian)
The lightly cemented feldspathic sandstones of the Cerrezuelo formation with yields of 35-70 m^3/h offer interesting possibilities for extraction. In the same way as the equivalent Furnas formation in Brazil its extension is reduced due to intensive erosion or changes of facies into the Cordobes shales. It outcrops over less than 0.5 per cent of the national territory, between Durazno and Carmen, unconformably overlying the crystalline basement. Towards the northwest, in the middle of the sedimentary basin, the formation is truncated and the younger formations directly cover the basement.

Local aquifers in igneous rocks
The extraction of groundwater from the impermeable intrusive or extrusive rocks is possible due mainly to the porosity that results from tectonic activities like faults, fractures and joints. Additional amounts of water are obtained from altered shallow granites and gneisses. According to definition, these rocks are not aquifers since they are not able to transmit water, and water circulates only along lines that have nothing to do with the characteristics of the aquifer. The crystalline basement and the Arapey basalts are exposed over more than 58 per cent of Uruguay, but the chances of encountering water are limited to fracture lines, at shallow depths (Fig. 2).

The Arapey basalts (Jurassic)
The basalt sheets are exposed over 49 000 km^2 occupying in total some 62 000 km^2 of Uruguay. The basalt sheets, overlying the Tacuarembo formation and more ancient formations, are covered in some places by Cretaceous and Tertiary sediments. Known yields are generally less than 5 m^3/h, and scarcely above 35 m^3/h. The depth of wells is less than 100 m, since below this level the faults are clogged. In addition to recharge by rainfall, the fault lines are recharged and/or drained by the rivers.

Precambrian basement
The Precambrian basement, composed of igneous (granite) and metamorphic rocks (gneiss, schists, quartzites, marble etc.) is practically impermeable. It was found that water circulation is possible only in fractured zones down to a depth of 100 m. The yields of the wells are low (1-20 m^3/h), mostly less than 5 m^3/h. Generally the quality of the water is good.

Numerous wells, drilled in the basement, are concentrated in the Montevideo area and south of Canelones, answering private local demands.

REPLENISHMENT POSSIBILITIES AND RECHARGE ESTIMATES

The aquifers in Uruguay are replenished mainly by direct precipitation. As indicated by Mero and Gilboa (1974), the infiltration rates in the Parana basin depend on various factors such as rainfall, evapotranspiration, type and thickness of soils, vegetation and depth of water table. Due to lack of pertinent subsurface data in the Parana basin no conventional method can be applied to estimate the recharge rates. It was observed that, depending on local conditions, a major part of the infiltrating waters escapes from the aquifers to feed the water courses as baseflow. Therefore the rapid evaluation introduced in Sao Paolo (Mero 1969; Mero and Gilboa 1974) is based on the baseflow of rivers that reflects the dynamic equilibrium between the geometry and characteristics of the aquifers and the rate of infiltration. This is done by separating pre-recharge discharges and stored volumes from the post recharge discharges of the system. The technique adapted there, based on the principle of continuity, consists of simultaneous daily hydrometeorological sequential functions in single cells and simulated reconstruction of the actual daily recharge, taking into account the transient components (Gilboa *et al.*, 1976).

Unfortunately, the absence of pertinent data of any kind (subsurface and surface)—impedes for the moment a similar method of calculation being used in Uruguay. However, due to topographic, morphological, lithostratigraphic and pluviometric conditions similar to those in Sao Paolo, the same reasoning was adapted as a starting point for Uruguay. Uruguay is located in the southernmost extreme of the Parana basin while the Sao Paolo state, Brazil is located in its northernmost part. In both areas a stable igneous belt surrounds the sedimentary basin that extends over its area: this has a uniform lithostratigraphic structure and is characterized by low undulating hills, 200 m high in Uruguay and 400-500 m high in Sao Paolo. In the Ribeirao Preto region of Sao Paolo where the infiltration rates were computed from daily hydrometeorological balances, the annual rainfall varies between 1100 and 1400 mm, while in Uruguay it varies between 1000 and 1200 mm (Gilboa *et al.*, 1976). Both areas have a perennial cover of vegetation, but in Sao Paolo the cover is extensive crops and plantations and in Uruguay it is merely pasture. With lower average temperatures and vegetation comprised totally of low natural pastures, it seems that the infiltration rates in Uruguay might be somewhat higher than for similar regions in Sao Paolo. The estimations are based on one approach with constraints which are well known, and therefore call for verification by other techniques whenever the required data become available. The total runoff amounts to some 30 per cent of the average annual rainfall. Adapting from the Sao Paolo computations (Gilboa *et al.*, 1976)—the deep infiltration is estimated to vary between <1 and 5 per cent of total precipitation—as shown in Table 2. It seems that the rate of penetration is more or less the same for most of the rock formations.

By comparing the results summarized in Table 2, it is shown that more than 70 per cent of the total deep recharge in Uruguay enters into the igneous rocks (crystalline basement and the Arapey basalt). This is due mainly to the fact that these rocks cover more than two-thirds of the area that is considered to contain water. Actually, these rocks are impervious, and presumably are drained through faulted zones, into Rio Uruguay, Rio de la Plata and the Atlantic Ocean. This process enables a deeper circulation of groundwater without the water reappearing in the rivers that cross the area. Artificial drainage, through intensive pumping, is not practical due to the poor performance of the wells and the high percentage of failure in the drilling operations.

About 10 per cent of the infiltrating waters find their way into the local sedimentary aquifers. As indicated by Fig. 1, these aquifers are drained either downstream into Rio Negro (Buena Vista, Tres Islas and Cerrezuelo) or into Rio Uruguay (Salto and Mercedes). Various factors make it unfeasible to extract this substantial amount of infiltrating water: very low permeability reflected by low instantaneous yield (Salto and Mercedes aquifers), irregular development of permeable sequences combined with rather poor quality water (Tres Islas and probably Buena Vista aquifers), limited extension in remote places (Cerrezuelo aquifer) etc.

Some 15 per cent of the infiltrating water recharges the Quaternary aquifers, and of this more than three-quarters percolates into two aquifers (Libertad and Laguna Merin). The aquifers drain into Rio de la Plata, the Atlantic Ocean or the Laguna Merin.

The huge Tacuarembo aquifer is replenished by precipitation over its outcrops (less than 10 per cent of its extent is in Uruguay) and probably by a certain subsurface inflow from Rio-Grande-do-sul state, Brazil (Gilboa *et al.,* 1976). The circulation within this permeable aquifer is slowed down due to the 'back water' conditions formed by the limited capacity of its outlet southwestwards. This effect almost impedes the infiltration into the totally saturated aquifer, decreasing its rates below those of the less pervious formations (like the shaly Mercedes aquifer and the impervious igneous rocks). The water circulation in the Uruguayan section of the Tacuarembo aquifer is insignificant compared to the huge amounts stored. By increasing the pumping, the water table might be lowered to enable percolation of additional amounts of water. Therefore, this water potential has a guaranteed source of replenishment, which might even be increased to more than 200×10^6 m^3/year or 5 per cent of total precipitation (Gilboa *et al.,* 1976).

DISCUSSION

The major aquifers of Uruguay, regarding available amounts, instantaneous yields and stored volumes are the Tacuarembo aquifer in the northwest, the Quaternary aquifer of the Laguna Merin basin in the east and the Quaternary aquifer of Libertad in the south. The water quality is good in all three aquifers.

The Tacuarembo aquifer enjoys several advantages: large stored volumes of water, the possibility to increase replenishment by the intensification of water extraction and great instantaneous, sometimes artesian, yields (up to 1000 m^3/h). Located in an area crossed by small intermittent creeks the relatively hot groundwater (39°C), encountered abundantly near potential agricultural land might help to overcome the deficiency of surface water and accelerate the introduction of intensive and sophisticated crops.

Large amounts of water are replenishing the largest Quaternary aquifer, Laguna Merin, which also enjoys a huge operational storage capacity. Although it is far from centres of consumption the acceptable instantaneous yields (more than 100 m^3/h) make it attractive for irrigation purposes. Recent irrigation schemes ignore this important source, employing only surface water resources. It is believed that the shallow piezometric table might create drainage problems, until extraction of groundwater will be imperative to save the terrain. Therefore, it is expected that when the need comes, the aquifer will serve two purposes simultaneously: drainage and irrigation. The Quaternary aquifer of Libertad is characterized by acceptable instantaneous yields and is recharged by considerable amounts. Its major advantage is its closeness to centres of consumption.

The actual exploitation is divided between the numerous poor wells in the crystalline basement around Montevideo and in the Quaternary coastal aquifers (excluding that of the Atlantic). Except for the Libertad section, safe yields were surpassed in most of the coastal aquifers, endangering the aquifers by sea water encroachment as happened in the Punta del Este area. There, until the inauguration of the Sauce surface water supply scheme, overpumping resulted in serious deterioration of groundwater quality.

The following guidelines are suggested for the integration of the groundwater resources into the general water system of Uruguay:

The local aquifers, especially in the south of the country, will continue to supply scattered small consumers, such as farms or industrial consumption nuclei, as is the case in Sao Paulo, Brazil. The nearby large aquifer of Libertad, might replace deteriorating surface water in the case of rapid industrialization in urban water supply systems. The two large untapped aquifers, the Triassic Tacuarembo sandstone and the Quaternary alluvium of Laguna Merin, are potential resources for intensive irrigation, complementing the consumption needs, met only partially by rainfall.

The estimates presented are of a most preliminary nature, only hinting at the relative importance of the main aquifers and the possibilities of utilizing the groundwater potential. A planned exploitation calls for the implementation of an already drawn-up programme to install from the very beginning a hydrogeological observation and control system. This programme will complement the surface water gauging system which is already designed and planned for operation in the near future. The systematic follow-up will establish the exploitation rates and validate the applicability of the hypothesis and the concepts introduced in the present paper.

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