

Aquifer Barreiras: Evaluation of ground water reserves in northern Espírito Santo, southeastern Brazil

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Abstract— The aquifer Barreiras is porous, free and semi-confined, with high porosity and permeability. It is composed of alluvial and fluvial sediments of the Barreiras Formation, in a complex association of permeable/impermeable strata. The mean hydrodynamic parameters of the 107 registered and evaluated tubular wells are a depth of 100.81 m, static level of 14.18 m, dynamic level of 51.48 m, drawdown of 37.30 m, a flow rate of 43.52 m, specific flow of 2,3681 m and transmissivity of 175.54 m²/day. The natural outflow of Barreiras Aquifer is 296.10⁶ m³/year, the Infiltration Rate is 0.82%, the Regulatory Reserve or Recharge Volume 321.10⁶ m³ and the Permanent Reserve volume 1,27.10¹⁰ m³. The hydrodynamic characteristics of the Aquifer Barreiras indicate a promising underground source and high heterogeneity throughout the formation.

Keywords— Aquifer Barreiras; Groundwater; Rio Doce Basin.

I. INTRODUCTION

Surface water and groundwater must be considered as the same natural resource, inseparable and in continuous interaction between surface flows and the aquifer, forming the composition of a hydrological cycle. Groundwater plays an important and unique role in the public water supply and agricultural irrigation in northern Espírito Santo. The catchment area of the Rio Doce, with a length of 853 km, covers 82,000 km², 14% of which lie in the state of Espírito Santo. The regional climate is classified as tropical hot humid, with annual averages of 1,200 mm rainfall and evaporation from 70 mm in June to 110 mm in January. The study area of 3,568.4 km² is founded on the sedimentary basin of Espírito Santo, in the lower course of Rio Doce drainage system, in the region of the river mouth to the sea, between the cities of Linhares, São Mateus, Jaguaré and Nova Venécia. For this study, 107 tubular wells were registered across the region, resulting in a rather high density of 33.4 wells per km² (Gonçalves et al. 2005), representing the entire studied terrain (Figure 1), which together exploit relevant

flow rates of the ground water. The great productivity of this aquifer has attracted a large number of public and private users. The main objective of this study was to characterize and evaluate the natural physical conditions as well as the hydrodynamic parameters of the Aquifer Barreiras in northern Espírito Santo, with a view to implementing a sustainable exploitation of the groundwater flow.

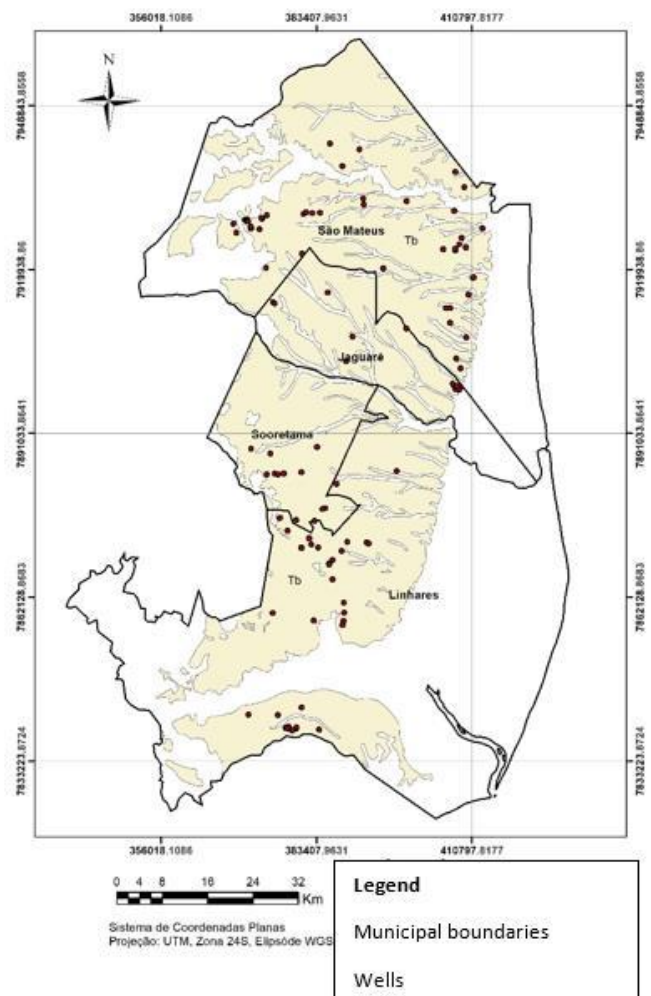


Fig.1: Well location map

II. GEOLOGY

The Barreiras formation (Vieira & Menezes, 2015) is composed of unconsolidated tertiary detrital sediments of continental origin, covering a narrow strip along the coast, extending from the state of Rio de Janeiro up to Pará. In Espírito Santo, this formation is found everywhere in the East and Northeast, with a strip width of approximately 30 km (Costa, 1980) and thickness decreasing westwards. The relief of the Barreiras formation consists of sedimentary layers with typical topographic features of tablelands, with wide shallow valleys, flat surfaces and slopes of 1.2 km/m facing the sea, due to the inclination of the staggered structures along the coast (Nunes et al. 2011). The particle size of the sedimentary composition of the Barreiras formation is regionally extremely heterogeneous, with faciological variations, containing sandstones of medium, fine or coarse particle size, and siltstones and argillites (Martin et al. 1997). The sediments are immature, coarse,

poorly classified, with clay lenses and fine quartz sand, from pinkish to red, purplish, yellowish or whitish, and cross-stratified (Costa, 1980). Their composition is regionally varied, but the predominant mineral is quartz, followed by weathering clay minerals and feldspar. The accessory minerals are magnetite, limonite, zirconium, barite, micas, fluorite and tourmaline (Leal, 2007).

III. HIDROGEOLOGY

The aquifer Barreiras is porous, free and sometimes semi-confined, with enormous spatial distribution and generally high porosity and permeability. It is composed of alluvial and fluvial sediments in a complex association of permeable/impermeable strata. The great heterogeneity is the result of the discontinuity of the aquifers (lenticular geometry), associated with permeability barriers caused by more clayey sedimentary facies. This lithological association affects the permo-porous characteristics of the layers.

Table.1: Hydraulic characteristics and statistics based on 107 registered wells of the aquifer Barreiras.

AQUIFER BARRERAS	MEDIA	MEDIANA	MAXIMUM	MINIMUM	No. of wells
Depth – D - (m)	100.81	105	190.00	15.00	107
Static Water Level- SWL - (m)	14.18	10.25	80.00	0.00	
Pumping water level- PDL - (m)	51.48	49.77	139.00	5.50	
Drawdown – S - (m)	37.30	32.00	115.2	1.70	
Yield – Q - (m ³ /h)	43.52	27.46	216.00	0.21	
Specific Capacity - Q/S (m ³ /h.m)	2.3681	1.0067	21.1752	0.0066	
Saturated thickness (m)	85.86	85.00	179.70	13.00	46
Transmissivity – T - (m ² /day)	175.54	167.67	302.23	110.00	

The values listed in Table 1 and analyses of the hydraulic characteristics of the Aquifer Barreiras indicate great heterogeneity of this underground source throughout its wide area of occurrence. The alimentation of the aquifer Barreiras is mainly based on rainfall on its outcrop area. During the flood periods, there is also fluvial contribution.

The thickness of the formation is very variable, since the bed rock outcrops at some points, emerging from a few to 150 m high in the coastal region (Mourão, 2002), with on average 60 m, estimated from construction reports of tubular wells. The sediments of the Barreiras formation constitute a major aquifer that transmits water to the common outflows: the sea, rivers, sources and diffuse resurgence zones, as well as vertical infiltrations into the Rio Doce Formation and crystalline bedrock,

aside from evapotranspiration, which is an important outflow.

The transmissivity (T) values were calculated by the high flow rate pumping test, and the recovery values interpreted by the method of Cooper and Jacob (1946) for 46 tubular wells, included in the list of 107 wells evaluated statistically (Table 1). Although this method was created to evaluate confined aquifers, it was used here to estimate transmissivity in from free to confined aquifers (Domenico & Schwartz, 1990), where aquifer tests were not available. The lack of transmissivity data for the wells required the determination of the relationship between these and the specific flow rate capacity (Q/s), showing a clear relationship between these parameters. The T evaluation did not include the necessary corrections for partial penetration of the wells

in the aquifer, since there were not enough data of the total aquifer depth (Hirata, 2012).

IV. RESULTS

The potentiometric maps showed that the underground flow at the highest points has gradients of the order of 3%, and in the alluvial plain domain the gradients vary from 0.1% to 0.06%. There is a domain of gradients of the order of 0.25%. Based on the potentiometric curves, with data of the dry period, the discharge of the natural underground flow was estimated, so that the calculation of the natural flow of "Q" generated in the aquifer Barreiras domain by the representative formula of Darcy's law,:

$Q = TIL$ (1) where: Q = natural flow rate ($m^3/year$)

T = coefficient of transmissibility (m^2/s) - 175.54 m^2/day (means of 46 wells)

I = hydraulic gradient of the piezometric surface - $2.5 \cdot 10^{-3}$ or 0.25%

L = width of the flow front (m) - 185 km or $185 \cdot 10^3$ m (width of the flow front);

Thus:

$Q = 296 \cdot 10^6 m^3/year$, i.e., 26.7 mm in terms of water level.

Usually, this volume Q can be considered the exploitable reserve of an aquifer.

The flow rate of the underground flow was evaluated for the conditions of an exploited aquifer. Consequently, to compute the total annual flow amount, the annual exploitation by registered wells must be added. In this case however, the available data were insufficient for calculation.

For the calculation of the Infiltration Rate, we used the expression:

$IR = Q/VPA$ (2), where IR = infiltration rate (%)

Q - aquifer outflow volume - $296 \cdot 10^6 m^3/year$

V - annual rainfall volume - $3.6 \cdot 10^9 m^3/year$

Infiltration Rate - $IR = 296 \cdot 10^6 / 3.6 \cdot 10^9 \cdot 10^2 = 0.82\%$

For the calculation of the Regulatory Reserves, two methods were used:

1st - calculation based on the annually infiltrated water volume - $AIV = A \cdot \text{ANNUAL PPT} \cdot IR$ (3)

AIV = Annual infiltration volume

A - area in $m^2 = 3568 \cdot 10^6 m^2$

Annual RF - annual rainfall - 1100 mm

IR - Infiltration rate - 0.82%

$AIV = 321 \cdot 10^6 m^3/year$ (This volume represents the water resources available for exploitation each year).

2nd - Calculation of the Regulatory Reserve or Recharge Volume (RRV)

Let $RRV = A \times \Delta h \times \mu$ (4)

Where: RRV = Regulatory Reserve Volume

A - area in $m^2 = 3568.4 km^2$

Δh - mean annual variation in potentiometric height - 1.80 m

μ - effective porosity - 5%

$RRV = 321 \cdot 10^6 m^3$

The same result was obtained by both methods.

Considering the free aquifer Barreiras, the permanent reserve represents the cumulative water volume in the rock interstices as a function of the effective porosity, where:

$PRV = A \cdot h \cdot \mu$ (5) where: PRV = Permanent Reserve Volume

A = study area - $3568.4 km^2$

h = mean saturated thickness - mean static level = 71.68 m

μ = effective porosity - 5%

$PRV = 1.27 \cdot 10^{10} m^3$

The potential of an aquifer represents the water volume that can be used annually for a given number of years using a portion of the permanent reserve volume.

Potential - $PO = (PRV \times 0.002) + RRV$ (6)

Where: PRV - permanent reserve volume - $1.27 \cdot 10^{10} m^3$

RRV - regulatory reserve volume - $321 \cdot 10^6 m^3/year$

Maximum percentage of depletion of the permanent reserve in one year ("safe yield") - 0.002.

$PO = 346 \cdot 10^6 m^3/year$

V. CONCLUSIONS

1-The hydrodynamic characteristics of the Aquifer Barreiras indicate a promising underground source.

2-The transmissivity (T) values indicate the heterogeneity of the aquifers.

3-A well depth of up to 150 m is recommended, below the first 70 m of the surface layers.

4 - All users (public water supply, agriculture/irrigation and industry) who depend on groundwater should periodically evaluate the drawdown of the water level and flows explored.

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