



Hydrogeology of the Azores volcanic archipelago (Portugal)

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The archipelago of the Azores is made of nine islands of volcanic origin located in the North Atlantic Ocean, with an area of 2333 km² and approximately 237500 inhabitants, which are 98% dependant from groundwater sources for their water consumption. Therefore, groundwater is a resource that plays a vital role as drinking water source and as ecosystem support matrix. Nevertheless, besides the environmental, social and economical value of groundwater, this resource is subject to an increase pressure and in several islands water quality deterioration is shown by monitoring data. This pressure is also shown by the 42.7% increase expected for domestic use until the year 2020 at the Azores, with higher groundwater abstraction.

The Azores climate can be considered as marine temperate, which is reflected by the low thermal amplitude and high precipitation. A well-established difference between a dry season and a colder and wet season occurs, as from October to March about 75% of the annual precipitation is registered. The average annual precipitation at the Azores is 1930 mm, exceeding by far the average annual actual evapotranspiration, which is 581 mm. Recharge rates range from 8.5% to 62.1%, and the highest values are observed at Pico, Terceira, Faial, São Miguel and Graciosa islands, especially in areas where the terrain is covered by recent basaltic lava flows and the soil cover is sparse. Groundwater resources estimates point to a total volume of about 1600x10⁶ m³/yr. Values above the recharge median, equal to 101.3x10⁶ m³/yr. were estimated for the São Miguel, São Jorge, Terceira and Flores islands.

Despite differences in the islands growth, as a result of successive volcanic eruptions of various types, groundwater occurrence can be described in function of two main aquifers systems: (1) the basal aquifer system, which corresponds to fresh-water lenses floating on underlying salt water, and (2) perched-water bodies, which are usually drained by springs spread in the volcanic edifices slopes. The basal aquifer system is in the coastal area, presenting generally a very low hydraulic gradient.

Hydrogeological surveys that have been made in the Azores archipelago points out to more than 1000 springs and wells spread all over the archipelago (950 springs and 83 drilled wells). Spring distribution is heterogeneous, with densities varying between 0.01 springs/km² at Pico island and 0.72 springs/km² estimated at Santa Maria.

Specific capacity ranges from 1.4x10⁻² to 266.7 L/sm, with a median value of 32.3 L/sm. Transmissivity also present a large range, with values ranging between 1.65x10⁻⁵ and 4.03x10⁻¹ m²/s, and a median of 3.66x10⁻² m²/s. The heterogeneous distribution shown by these values expresses the influence of the hydrogeological characteristics of volcanic terrain, resulting from syngenetic characteristics and secondary processes, like weathering. The highest values are observed in wells drilled in recent basaltic lava flows, which generally are thin and fractured, with frequent clincker levels interbedded, and the lowest data was estimated in the older volcanic formations of Santa Maria island.

Groundwater on perched-water bodies, excluding the numerous mineral waters that are spread in several islands of the archipelago, present usually a low mineralization, shown by the electrical conductivity values (36-725 μS/cm; median=158.0 μS/cm). The average temperature is equal to 15°C. Waters have an average temperature of 15°C and are mainly slightly acid to slightly alkaline, with a pH range from 4.7 to 8.6, but showing a median value of 7.2. The main water types are Na-Cl to Na-HCO₃ waters, with numerous samples lying in the intermediate compositional fields that characterize Na-Cl-HCO₃ and Na-HCO₃-Cl waters.

The groundwater composition in the basal aquifer system is usually from the Na-Cl type and presents a higher

mineralization, resulting in a median value for electrical conductivity equal to 1044 $\mu\text{S}/\text{cm}$, expressing the influence of sea salts mixture.