EGU25-2056, updated on 17 May 2025
https://doi.org/10.5194/egusphere-egu25-2056
EGU General Assembly 2025

From satellite to well: integrated techniques for understanding groundwater flow in a Cretaceous volcanic aquifer of South America

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This research presents an integration of techniques such as remote sensing, field geology, geophysical profiling, hydrodynamic monitoring, and chemical analysis of groundwater, to develop the conceptual hydrogeological model of a volcanic fractured aquifer. The research area has 8000 km^2, is located in South America, specifically in the southern region of Brazil, the state of Paraná, and is called Paraná 3 Hydrographic Basin (BP3). In this hydrographic basin, 83% of the public supply is by the groundwater of the Serra Geral Aquifer System. The water balance was estimated by remote sensing. The average monthly recharge between 2001 and 2022 was estimated at 61 mm/month. October (105.3 mm), February (75.8 mm), and September (75.4 mm) are the months with the highest recharge while June (16.4 mm), April (40.1 mm), and July (40.2 mm) have the lowest potential. Recharge was also observed from a network of 36 monitoring wells. There is a delay between precipitation and the arrival of this volume in the aquifer, which varies between 30 and 120 days. The results obtained with the monitoring network were compared to the results of the GRACE satellite and showed excellent correlation. During the hydrodynamic monitoring period, the reflection of an intense drought in the groundwater storage was observed. This demonstrates the influence of regional-scale climate events (for example, El Niño and La Niña) on the aquifer recharge process. Two main types of Cretaceous volcanic rocks outcrop in BP3: basalts and volcanoclastics. These rocks present discontinuities whose origin is related to the brittle tectonics, and discontinuities whose origin is associated with the cooling of the rock. In the tectonic discontinuities, a transtensive system stands out, with an E-W direction, favorable to the circulation and storage of groundwater. This same direction is observed in acoustic and heat flow metter profiles, suggesting that the E-W planes are hydraulically active. The E-W direction also proved favorable for groundwater prospecting when analyzing the relationship between the direction of structural lineaments (from digital elevation models) and the production of tubular wells. The presence of volcanic breccias, associated with the proximity of contact zones between flows, is the most important geological (non-tectonic) proxy. The horizontality of these contacts allowed us to observe interferences between wells more than 200 meters apart. Groundwater flows up to 59 meters deep present waters with calcium bicarbonate type, with higher concentrations of nitrate and other micropollutants, when compared to flows that occur between 119 and 200 meters deep, whose chemical signature is sodium bicarbonate, in which sulfate,

carbonate, and TDS increase with increasing flow depth. These deeper waters reach up to 17.000 years old in C14 ages. The integration of techniques allowed the aquifer characterization and development of the aquifer hydrogeological model. This activities can be repeated in other fractured aquifers to understand the hydrogeological characteristics of the geological formations. This knowledge will reduce exploratory risk and contribute to the sustainable management of groundwater in the BP3 region.