Groundwater modeling based on scarce data: the case of Patiño Aquifer in Paraguay

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INTRODUCTION

The Patiño aquifer is currently providing drinking water to 74% of the nearly 3 million inhabitants of Asunción and nearby cities. The aquifer area is 1,173 km^2 (Monte Domecq & Báez, 2007) and it is considered unconfined. The aquifer has a triangular shape and it is limited at the northwest and west by the Paraguay river; the estimated depth for the aquifer formation is around 300 m (Labaky, 2007). The main land uses in this area are urbanized regions (around 30 to 50% of the area) (IC-HQA, 2017) and agriculture. Figure 1 displays the localization and the districts of the study area.

Groundwater extraction has been increasing since 1980 (Jerozolimski & Gaal, 2007), due to better access to well drilling technology and low coverage of drinking water provision by the state´s agency. Previous water budget and modeling studies indicated that the availability of water should already be limited nowadays (Labaky, 2007; Monte Domecq & Báez, 2007); however, recent field data indicate that this has not occurred (PMSAS & SEAM, 2016; IC-HQA, 2017). These results may be related to lack of hydraulic head data (just one data set of 41 observation wells for 2007), in conjunction with scarce information about extraction rates and recharge, which limit the accuracy of the water balance.

This study aims to contribute to the understanding of the groundwater flow dynamics and to obtain a robust base line for further transient state simulations, studying different conditions in terms of aquifer boundaries, and taking into consideration the trend of very low variability observed for water levels between 2007 and 2015 (IC-HQA, 2017).

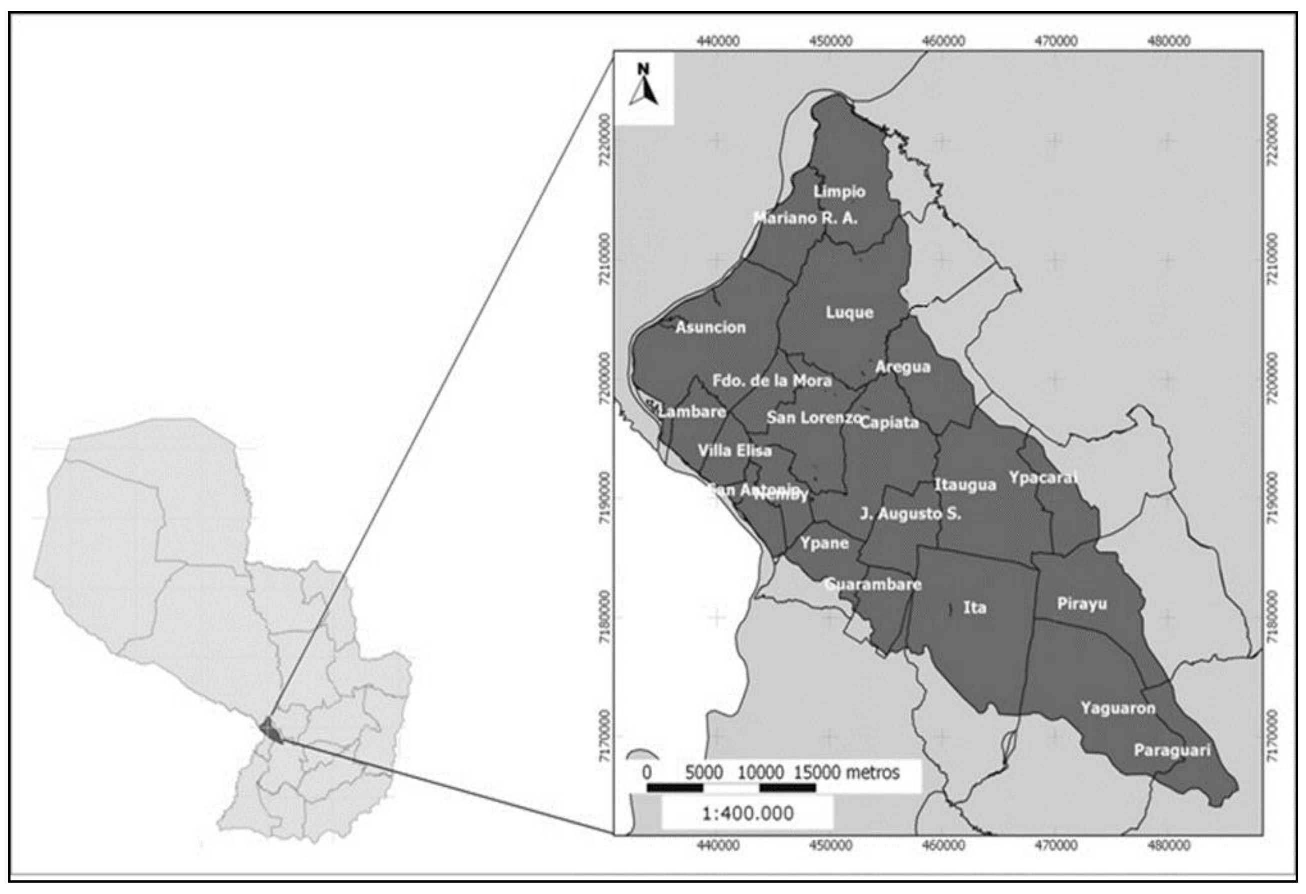

Figure 1. Location of the study area in Paraguay, and districts overlying the Patiño aquifer.

METHODS

The model domain considered is 54,054 by 60,001 meters, using square cells with 175 meters side. The aquifer is defined as unconfined and is represented by a one-layer model (Jerozolimski & Gaal, 2007; IC-HQA, 2017). PMWIN was used as graphic interface for MODFLOW simulations.

The Paraguay river (north of the aquifer) is assigned as a constant head boundary in all simulations. The internal streams are represented through the RIVER package from MODFLOW. The different models presented vary in boundary conditions for the east and south-west limits, which are assigned as no flow (model SS1), constant head (model SS2), general head boundary (model SS3) and a combination of no flow and constant head (model SS4).

Pre-calibration conditions

Extraction. The steady state situation modelled included 513 extraction wells, considered to represent the situation of the aquifer in 1985.

Calculated recharge. Natural recharge by precipitation is taken as 9% of the precipitation mean value (1,400 mm/year); an artificial recharge based on land use and distribution system loses is also included (Báez, Villalba, & Nogués, 2014).

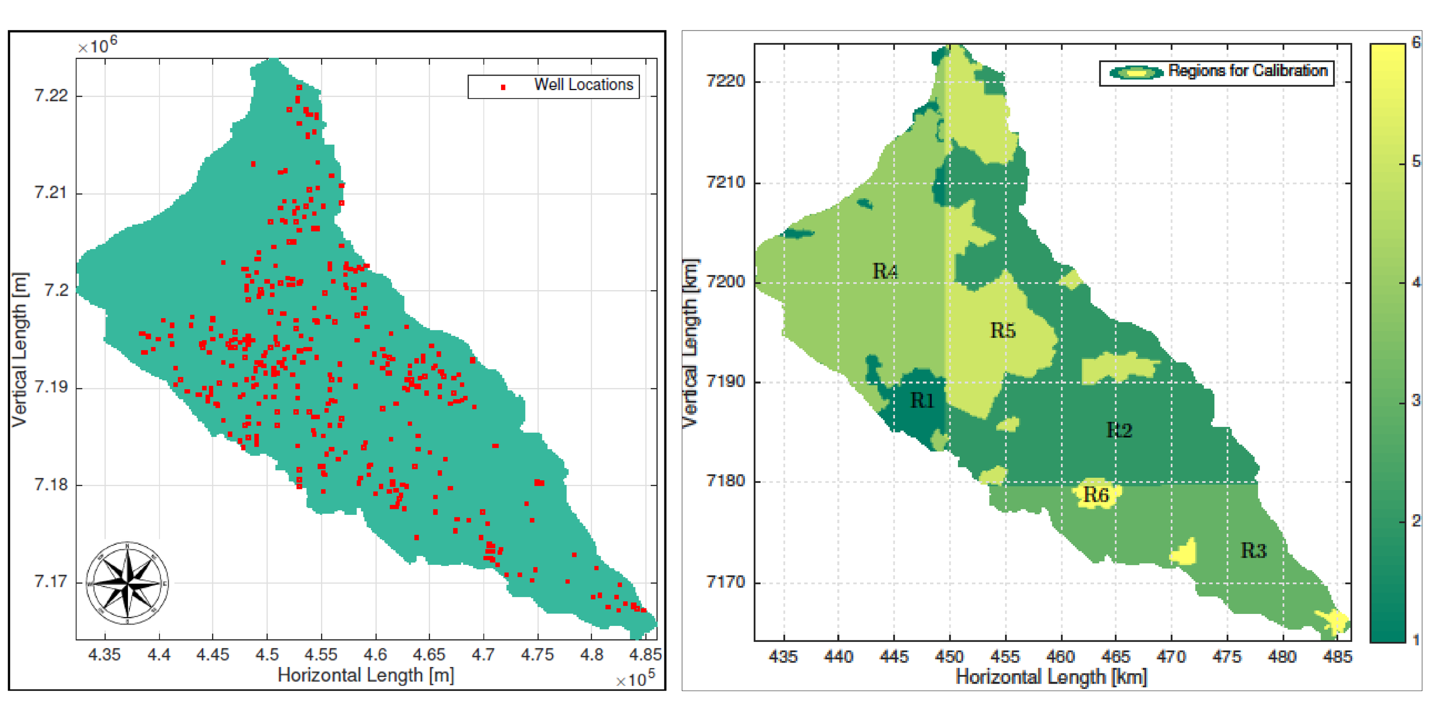

Figure 2. Left: extraction wells considered active in 1985. Right: recharge zones considered for calibration.

RESULTS AND DISCUSSION

Calibration

The recharge was calibrated using the draw down values in 41 observation wells, measured in 2007, as calibration target (assuming that water level for 2007 doesn´t change much from 1985). PMWIN allows to select head values or draw down values in the observation wells as calibration target. Since the 300 m width considered for the aquifer representation is based on the maximum depth reached in field tests from previous studies, the draw down values are assigned as calibration target. The observed draw down values used as calibration target are assigned a weight of 1 if the variation of the water levels presented correlation with precipitations between 2007 and 2015, and a weight of 0.5 if this correlation was low; this correlation was analysed in previous studies (IC-HQA, 2017).

Table 1. Calibration results for different boundary conditions and internal streams representation.

	Model SS1	Model SS2	Model SS3	Model SS4
Boundary conditions (E/ SW)	No flow	Constant head	General head	No Flow/ Constant head
Internal streams	RIVER	RIVER	RIVER	RIVER
Correlation coefficient	0.83	0.82	0.83	084
Water budget discrepancy (%)	0.03	-0.02	0.01	0.00
Static level error (% active cells)	16.9%	11.8%	16.9%	15.0%

The correlation coefficients obtained through automatic calibration with the Parameter Estimator (PEST) package from PMWIN, indicate a good agreement between observed and simulated draw down values, and the discrepancy percentages for the water budget in the four models presented here are considered consistent.

Water budget

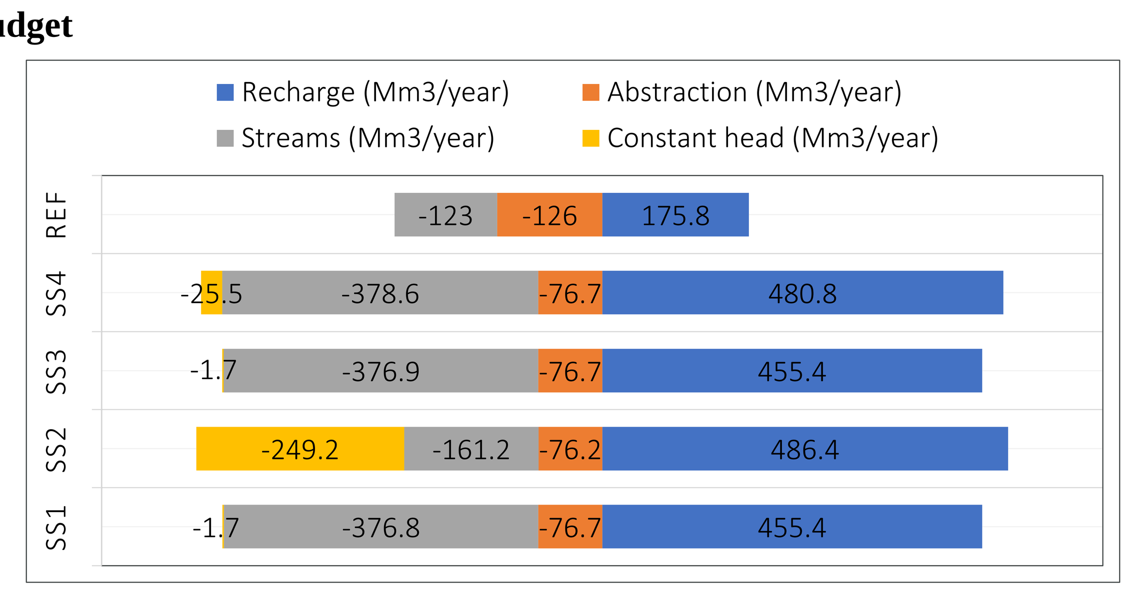

Figure 3. Water budget in Millions of cubic meters per year for four different models and reference values from previous studies. REF values correspond to Monte Domeq and Báez (2007).

Hydraulic heads

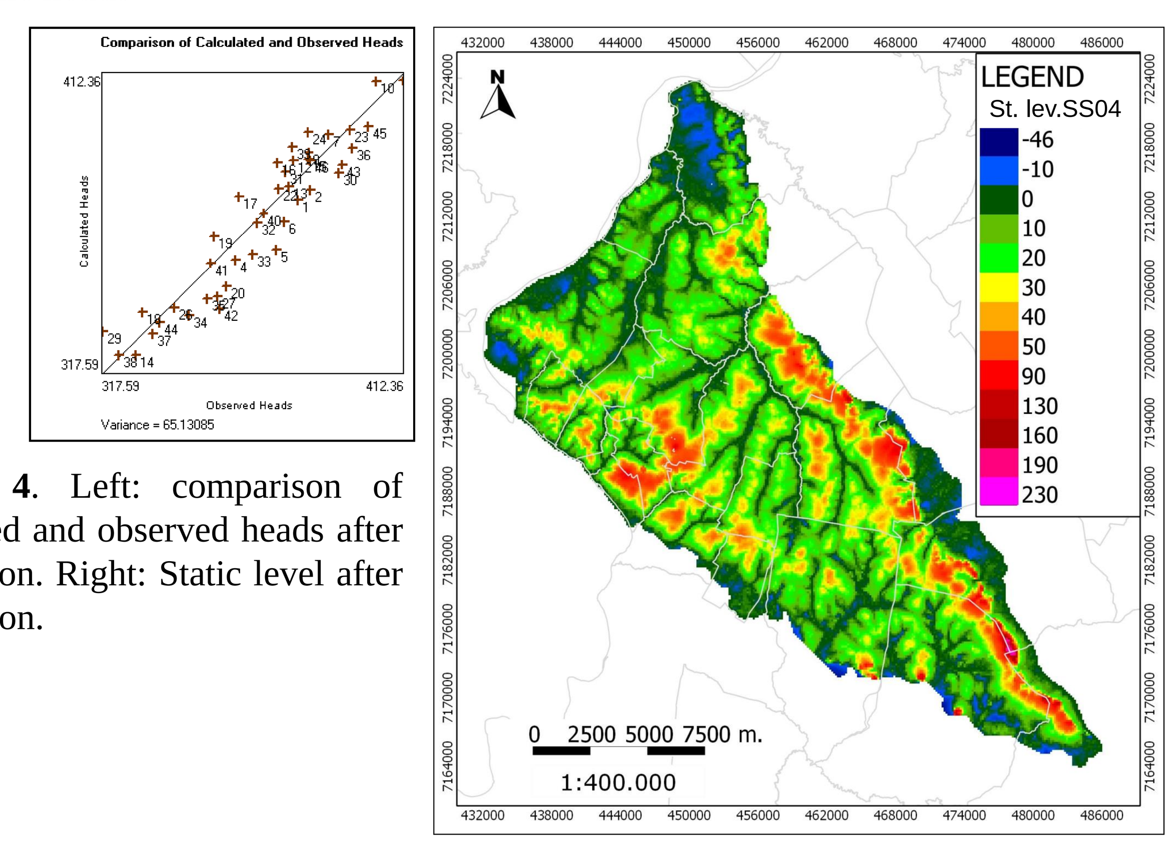

Figure 4. Left: comparison of simulated and observed heads after calibration. Right: Static level after calibration.

CONCLUSIONS AND FUTURE WORK

The calibrated recharge and further water budget results are compared to previous studies, suggesting that recharge for this aquifer has been underestimated, leading to a misinterpretation of groundwater availability. The recharge calibration results suggest that the main problem facing the aquifer management in the future will not be water availability, but rather groundwater pollution related to the current land uses and lack of contamination monitoring and control.

The hydraulic heads obtained from these steady state simulations are considered as a satisfactory base line for performing further transient simulations, which aim to provide an insight into the future behaviour of the aquifer under different conditions. An interesting approach to study the recharge variability to be considered for the transient simulations is the development of recharge scenarios under climate change conditions through the SWAT software package.

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