XXVI Simpósio Brasileiro de Recursos Hídricos
23 a 28 de novembro de 2025 - Vitória - ES

ABRHidro
Associação Brasileira de Recursos Hídricos

XXVI SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS

SYSTEM DYNAMICS MODELING OF A COMPLEX WATER SYSTEM IN BARRETOS, SÃO PAULO

Carolina Stager Quaggio [1] ; Didier Gastmans [2] & Jan Boll [3]

Abstract: Interactions among components of the hydrologic cycle determine the intensity, pathways, and exchanges of water between atmospheric, surface, and subsurface reservoirs. Together, these components constitute a Complex Water System (CWS), where the interconnection between reservoirs promotes constant adaptation. A System Dynamic (SD) model a CWS in the municipality of Barretos was developed to simulate groundwater storage and evaluate potential hydrogeological context-related scenarios. Barretos is one of the largest cities in the northeastern region of the State of São Paulo State. SD is a modeling methodology that focuses on system behavior by conceptualizing and explaining the causality between multidisciplinary components through stocks and flows. The Barretos System Dynamic (BSD) model aimed to simulate the storage of the three main groundwater sources, namely the sandy and unconfined Bauru Aquifer (BAS), the fractured and semi-confined Serra Geral Aquifer (SGAS), and the sandy and confined Guarani Aquifer (GAS). The hydrogeological processes represented in the model are river-aquifer interaction, unconfined and semi-confined aquifer interaction, groundwater pumping, recharge, land use, and water pricing. Despite numerical differences between the actual well elevations used in validation and the modeled water available in the aquifers' stocks, the model simulates the observed behavior of groundwater depletion in the aquifers. From a water management perspective, the results demonstrate the need for more reliable monitoring data and an urgent need to reduce and optimize water demand.
Key-World: system dynamics, complex water systems, groundwater simulation.

INTRODUCTION

System Dynamics (SD) is a modeling methodology that focuses on system behavior by conceptualizing and explaining the causality between multidisciplinary components through stocks and flows (Beall *et al*., 2011). The water cycle represents a Complex Water System (CWS) that can be modified by the connections between the reservoirs, in which the functions and services provided by each component are assumed to be of greater value than the component itself (Huggins *et al.*, 2023). This study presents SD modeling for the municipality of Barretos.

The Barretos System Dynamic (BSD) model aims to simulate the storage of the three main groundwater sources, considering river-aquifer interaction, interaction between the unconfined and semi-confined aquifers, groundwater pumping, recharge, land use and land cover and attempt to water pricing. The purpose of this model is not to predict discrete values. The goal is to represent the endogenous dynamic system that influences groundwater storage behavior and simulates how it behaves under different hydrogeological conditions.

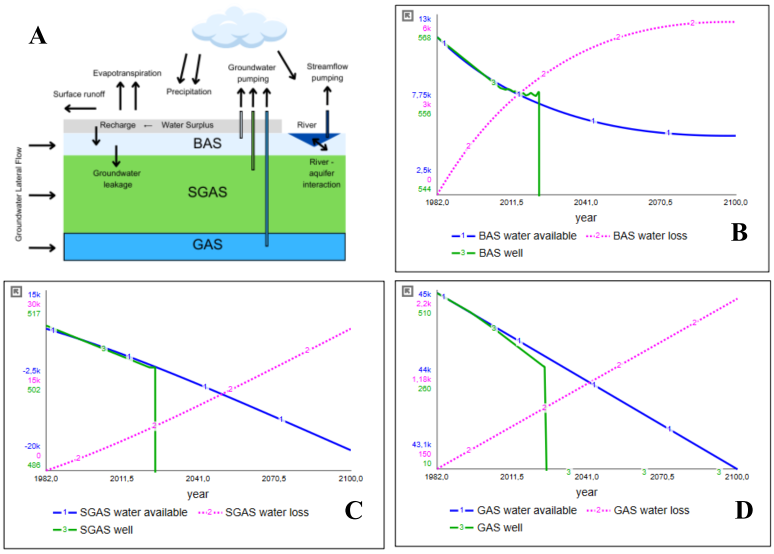
MATERIALS AND METHODS

The data were sourced from government open-access databases and included information on population, water demand, groundwater and surface water monitoring, hydroclimatic remote sensing data, hydrogeological data, sanitation indices, and pricing. The data input covers the period from 1982 to 2024 and simulates up to 2100. It is worth noting that the groundwater level data was used only

1) Environmental Studies Center, São Paulo State University (CEA/UNESP), Av. 24 A n° 1515 Rio Claro (SP), stager.quaggio@unesp.br
2) Environmental Studies Center, São Paulo State University (CEA/UNESP), Av. 24 A n° 1515 Rio Claro (SP), didier.gastmans@unesp.br
3) Civil and Environmental Engineering, Washington State University (WSU), 001 E Grimes Way, Pullman (WA), j.boll@wsu.edu

for validation. Definition of the stocks and flows was based on the water balance equation and the aquifers hydrogeological definitions (Figure 1A), translated into the Stella Architecture interface.

Figure 1 – Conceptual model (A), and relationship between the actual well elevation (green line), the modeled water available (blue line) and water loss (pink dashed line) of the BAS (B), SGAS (C), and GAS (D).



RESULTS AND DISCUSSIONS

Despite the numerical differences between well elevations and available aquifer stock, model outputs can illustrate groundwater behavior. All aquifers show a decrease in available water associated with an increase in water loss and an increase in pumping rate (Figure 1B, C, D). By the end of the simulation in 2100, the BAS water volume decreased by about 50%, the SGAS water volume decreased by more than 300%, becoming negative by 2040, and the GAS water volume decreased by less than 5%. Conversely, the available SGAS water remains positive when receiving the GAS contribution at a rate of 0.004. In the current simulation, total water loss increases over time due to consumption from surface water and aquifers, leading to a decrease in saved water. As the total water loss subject to wastewater treatment increases, the total cost of the water system is expected to rise.

CONCLUSIONS

The data-driven approach directs the model to behave in a way that describes the conceptual hydrogeological Paraná Basin, mimicking the CWS. The data available for the municipality of Barretos was sufficient to feed the SD model and simulate groundwater stock behavior. The model shows that the fractured and semiconfined SGAS water stock depends on the other aquifers. In terms of modeling, stocks cannot be negative. The only scenario in which this rule is met is when both the BAS and the GAS contribute to the SGAS stock. This is conceptually in agreement with previous studies regarding groundwater mixing processes in the Paraná sedimentary basin.

ACKOWLEDGMENTS

To the Coordination of Superior Level Staff Improvement (CAPES), for the grant under the process 88887.637660/21, and the São Paulo Research Foundation (FAPESP) for the grants under the processes 2022/14.849-7 and 2023/13.079-6. The opinions, hypotheses and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of FAPESP.

REFERENCES

BEALL, A.; FIEDLER, F.; BOLL, J.; COSENS, B. (2011). "*Sustainable Water Resource Management and Participatory System Dynamics. Case Study: Developing the Palouse Basin Participatory Model*". Sustainability, 3(5), Artigo 5. https://doi.org/10.3390/su3050720

HUGGINS, X.; GLEESON, T.; CASTILLA-RHO, J.; HOLLEY, C., RE, V.; FAMIGLIETTI, J. S. (2023). "*Groundwater Connections and Sustainability in Social-Ecological Systems*". Groundwater, 61(4), pp. 463–478. https://doi.org/10.1111/gwat.13305