# The Influence of Soil and Vegetation on Hydrological Modeling in a Sub-Basin of the Araguaia River in the Brazilian Cerrado

## A influência do solo e da vegetação na modelação hidrológica de uma sub-bacia do Rio Araguaia no Cerrado Brasileiro

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**A B S T R A C T**

This study analysis the impact of soil hydraulic parameters and canopy storage on hydrological modeling in a sub-basin of Araguaia River, Brazilian Cerrado, using the MOHID Land model. Parameters analyzed included vertical saturated hydraulic conductivity (Ks), saturated water content (Θs), residual water content (Θr), and canopy storage were analyzed for their effects on river discharge. The sensitivity analysis showed that changes in Θs had a greater impact on reducing discharge than Θr, although both parameters had limited effects. Higher Ks values effectively lowered discharge peaks by enhancing soil infiltration but showed variability over time. Canopy storage was the most significant parameter, with higher values reducing peak discharge rates by intercepting and evaporating rainfall, minimizing surface runoff, achieving the best model performance. In summary, a detailed parametrization of these parameters is crucial for improving the accuracy of hydrological models.

**Keywords:** soil hydraulic parameters, canopy water storage, MOHID Land, watershed

**R E S U M O**

Este estudo analisa o impacto dos parâmetros hidráulicos do solo e da interceção da precipitação pela vegetação na modelação hidrológica numa sub-bacia do Rio Araguaia, no Cerrado brasileiro, utilizando o modelo MOHID-Land. Foram analisados a condutividade hidráulica saturada vertical (Ks), o teor de água de saturação do solo (Θs), o teor de água residual do solo (Θr) e a interceção foliar, e seus efeitos no caudal do rio. A análise de sensibilidade mostrou que as variações de Θs tiveram maior impacto na diminuição do caudal em comparação com as de Θr. Ks reduziu picos de caudal ao melhorar a infiltração do solo. A interceção foliar mostrou-se a mais significativa, diminuindo picos de caudal ao intercetar e evaporar a água da chuva, reduzindo o escoamento. A parametrização detalhada desses parâmetros é crucial para melhorar a precisão dos modelos hidrológicos.

**Palavras-chave:** parâmetros hidráulicos do solo, interceção foliar, MOHID Land, bacia hidrográfica

## INTRODUCTION

Soil stores water through groundwater, sustaining some rivers during dry periods (Miguez-Macho & Fan, 2012), while vegetation contributes through root water uptake, rainfall interception, and evapotranspiration (Gaberščik & Murlis, 2011). The representation of these processes is essential in hydrological models (Worqlul *et al*., 2018; Van Tol *et al*., 2020) to accurately simulate river discharge.

MOHID-Land is a physically based model, that employs the soil hydraulic parameters using the van Genuchten–Mualem functional relationships (Mualem, 1976; van Genuchten, 1980) and simulates the porous media water movement considering the Richards equation. MOHID-Land also models vegetation growth and estimates evapotranspiration, responsible for the water loss from the system, using the Feddes *et al*. (1978) macroscopic approach. Previous research used several parameters to evaluate the sensitivity of MOHID-Land (Oliveira *et al*., 2020). This research comes as a complement by focusing on specific parameters of the soil and the vegetation.

Therefore, this study aims to evaluate the influence of soil hydraulic parameters and the rainfall canopy interception in an Araguaia river sub-basin, in Brazilian Cerrado. The parameters modified include vertical saturated hydraulic conductivity (Ks), saturated water content (Θs), residual water content (Θr), and canopy storage. Ks was chosen for its impact on soil infiltration. Θs and Θr were included because they represent the soil's water-holding capacity. Canopy storage was selected for its role in intercepting rainfall, influencing evaporation and reducing surface runoff.

## METHODOLOGY

### *Study area*

The study area is in central Brazil, focusing on the Araguaia-Caiapó-Claro sub-basin of the Araguaia River, covering approximately 18,000 km² (Figure 1). The region experiences a dry season from May to September and a rainy season from October to April (Ministério do Meio Ambiente, 2006). The Cerrado biome dominates the basin, growing

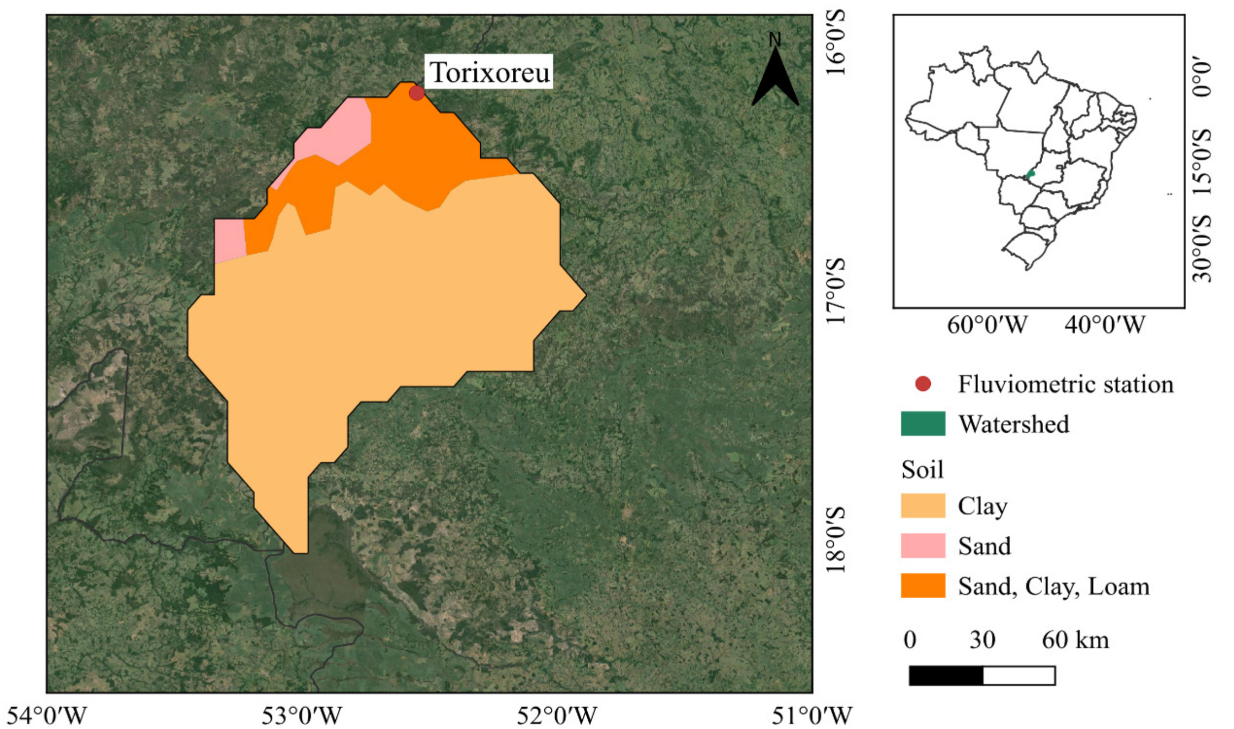


**Figure 1 -** Location of the watershed in central Brazil. The map highlights soil types: light orange indicates clay soils, light pink represents sandy soils, and dark orange denotes sand-clay-loam soils.

in the rainy season, with greater photosynthetic activity and biomass accumulation (Becerra *et al*., 2009; Trentin *et al*., 2021), while in the dry season, biomass production is smaller. The main soil type is clay, with smaller areas of sand and sand-clay-loam in the northern part, based on United States Department of Agriculture (USDA) textures.

### Model implementation

The model was implemented using a uniform-spaced grid with a resolution of 1 km. Topography data were sourced from United States Geological Survey raster images (USGS, 2022). The Manning coefficient for roughness was derived from Copernicus Land Cover maps (Copernicus, 2024). The river network is a 1D domain defined from the digital terrain model (DTM). The National Water Agency of Brazil (ANA) provided the drained area and cross-section geometry information from two fluviometric stations (Table 1), as well as observed flow values, for Torixoréu station (ID 24200000).

**Table 1 -** Characteristics of stations used for cross-section definitions

| Station name | Width (m) | Depth (m) | Drainage area (km²) |
|---|---|---|---|
| Montante do Ribeirão Babilônia | 38 | 1 | 1760 |
| Torixoreu | 109 | 3 | 18400 |

Meteorological data were obtained from the ERA-5-Reanalysis dataset (Hersbach *et al*., 2018) for the variables wind velocity; dewpoint temperature; air temperature; surface solar radiation; and surface pressure. Precipitation data was obtained from ANA's rainfall stations following Pereira *et al*. (2024) methodology.

Soil data were obtained using SOTER-based estimates (SOTWIS), covering five horizons from 0 to 1 m at 0.2 m intervals (Batjes, 2005). To manage the dataset, a simplified classification based on USDA textures was created, identifying 11 soil types for five horizons. Soil hydraulic parameters were calculated using the Rosetta model available online (HB60, 2024). Vegetation data was obtained from the Land-Cover maps developed by the Annual Mapping Project of Land Use and Coverage in Brazil (MapBiomas, 2024), for the year 2010.

### Calibration Parameters

Simulations covered the period from 2008 to 2014, with 2008-2009 as warm-up period. Five scenarios were considered: the Reference scenario and four additional scenarios, each modifying one parameter. The parameters adjusted included an increase in vertical saturated hydraulic conductivity (Ks), higher saturated water content (Θs), lower residual water content (Θr), and higher canopy storage (mm), according to the ranges presented in

**Table 2 -** Parameters modified during the calibration of the watershed model

| Parameter | Unit | Reference value range | Final value |
|---|---|---|---|
| Ks | $m\ s^{-1}$ | $7.99\times10^{-7}$- $6.53\times10^{-5}$ | $1.28\times10^{-5}$ - $1.04\times10^{-3}$ |
| Θr | $m^3\ m^{-3}$ | 0.05 - 0.15 | 0.04 - 0.12 |
| Θs | $m^3\ m^{-3}$ | 0.37 - 0.54 | 0.45 - 0.65 |
| Canopy storage | mm | 0 | 4 |

Model evaluation metrics included Coefficient of Determination ($R^2$), Nash-Sutcliffe efficiency (NSE), Root Mean Square Error (RMSE), and Percentage Bias (PBIAS). The ideal target values for these criteria are described in Table 3.

**Table 3 -** Metrics performance values based on Cardoso de Salis *et al*. (2019) and Moriasi *et al*. (2007)

| Metrics | Very good | Satisfactory |
|---|---|---|
| **NSE** | 0.7 | 0.5 |
| **R²** | - | 0.6 |
| **PBIAS** | ±10% | ≤ ±15% |

## RESULTS AND DISCUSSION

Overall, the simulations demonstrated some sensitivity to the tested parameters (Figure 2). The Θr and Θs simulations showed a slight reduction in discharge during rainy season peaks. Comparing the goodness of fit, the Reference and Θr scenarios had minor differences, with RMSE values of 410 $m^3.s^{-1}$ and 403 $m^3.s^{-1}$, respectively. Similar trends were observed for other goodness of fit metrics, as detailed in Table 4. Increasing Θs values had a more significant impact than lowering Θr values, leading to significant reduction in discharge peaks, and a slight increase in baseflow from April to August. The RMSE decreased to 380 $m^3.s^{-1}$, but, overall, the metrics did not show substantial improvement.

The lowest sensitivity was found for Θr, followed by Θs, Ks, and the most significant parameter being canopy storage. These findings align with previous research reported by Rezaei *et al*. (2016), and Mertens *et al.* (2006), who also noted low sensitivity for Θr, and Stahn *et al*. (2017), who identified sensitivities to Θs and Ks. The Ks parameter effectively reduced discharge during the rainy season by enhancing soil infiltration and reducing surface runoff. This improvement was notable in 2010 and early 2011, but in the following years, the Ks simulation resembled the Reference scenario. Additionally, Ks slightly reduced baseflow during the dry season.

The model was most sensitive to canopy storage, reducing RMSE by about 200 $m^3.s^{-1}$ compared to the Reference scenario, and achieved positive and satisfactory NSE values, unlike other scenarios. During peak discharge periods, canopy storage decreases discharge by over 2000 $m^3.s^{-1}$. Canopy storage helps reduce surface runoff by storing and

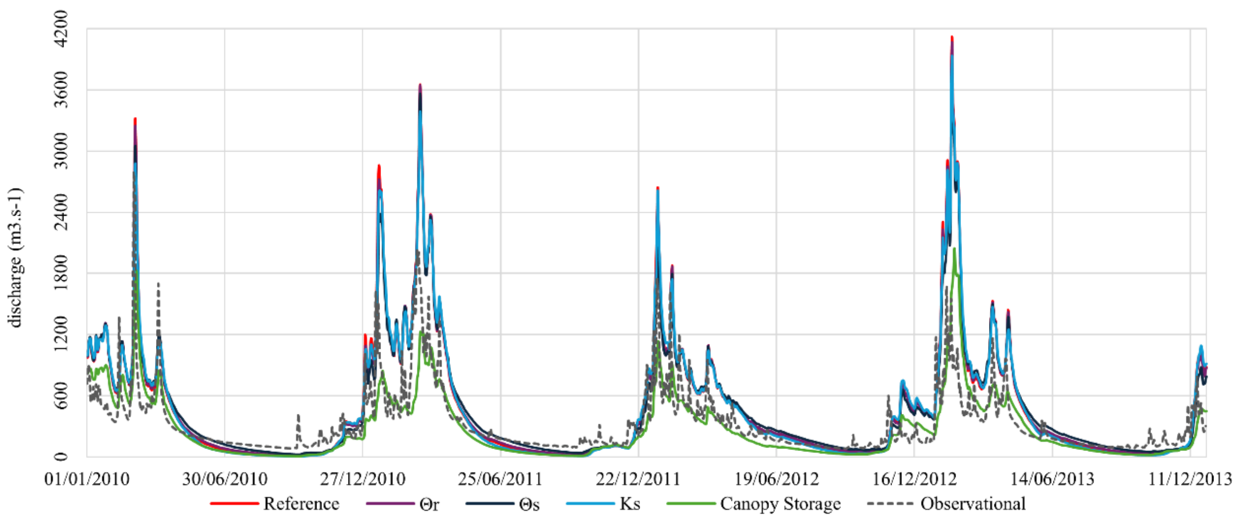


**Figure 2 -** Discharge results from different simulation scenarios. The red line represents the Reference simulation, the purple line indicates the simulation with saturated water content (Θs), the dark blue line corresponds to the residual water content (Θr) simulation, the light blue line shows the vertical saturated hydraulic conductivity (Ks) simulation, and the green line depicts the canopy storage simulation. The grey line represents the observed discharge for comparison.

**Table 4 -** Goodness-of-fit metrics for different simulation scenarios

| Simulations | RMSE ($m^3.s^{-1}$) | RRMSE (%) | NSE | $R^2$ | PBIAS (%) |
|---|---|---|---|---|---|
| **Reference** | 410 | 125 | -0.65 | 0.74 | -48 |
| **Ks** | 406 | 123 | -0.62 | 0.72 | -46 |
| **Canopy storage** | 214 | 65 | 0.55 | 0.62 | 17 |
| Θr | 403 | 122 | -0.59 | 0.74 | -49 |
| Θs | 380 | 116 | -0.42 | 0.73 | -50 |

evaporating rainfall intercepted by vegetation (Véliz-Chávez *et al*., 2014). This process is considered a loss from the system (Kozak *et al*., 2007), as it reduces the volume of water reaching the ground and lowers peak discharge rates during rainfall events.

## CONCLUSION

The study emphasizes the significance of soil hydraulic parameters and canopy storage in hydrological models, focusing on the Araguaia River sub-basin in the Brazilian Cerrado. Sensitivity analysis showed that Θs had a more notable effect on discharge than Θr, although both had a small impact. Higher Ks values effectively reduced discharge during the rainy season by enhancing soil infiltration, though its impact varied over time. Canopy storage had the greatest impact, lowering peak discharge rates by intercepting and evaporating precipitation, preventing it from contributing to surface runoff. It also achieved the best performance. In summary, detailed parameterization of soil hydraulic properties and canopy storage is crucial for improving the predictive accuracy of hydrological models.

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