Assessment of groundwater resources resilience to future climate change impacts using a high-resolution aquifer model: the case of Emilia-Romagna region in Italy

Ilaria Delfini*[1], Andrea Chahoud[2], Daniel Zamrsky[3], Alberto Montanari[1]
[1]Department of Civil, Chemical, Environmental and Materials Engineering (DICAM), Alma Mater Studiorum – University of Bologna, Italy (*ilaria.delfini2@unibo.it)
[2]ARPAE Emilia-Romagna, Bologna, Italy
[3]Utrecht University, The Netherlands

1. INTRODUCTION

- **Aquifer depletion** and **over-exploitation** of groundwater through increased **pumping** are well known global challenges.
- The **impacts** of groundwater withdrawal on aquifer **storage** and groundwater **recharge** need to be carefully studied to assess its effect on groundwater conditions in regions where **extensive groundwater withdrawals** occur
- The **Emilia-Romagna region (Italy)** is a highly monitored aquifer system playing an essential role for **water supply** for civil, agricultural, and industrial use.

OBJECTIVES:

- To estimate the **effects** of possible **precipitation reduction** on the **groundwater head** distribution over the study area.
- To get an insight of the **combined effects** of changes in **natural and artificial stresses** on aquifers.
- To identify guidelines for **sustainable aquifer management** under **different climatic conditions**.

2. METHODOLOGY

- **MODFLOW 6** numerical groundwater flow model based on a previous application of MODFLOW to the whole Emilia-Romagna region by the Regional Agency for Environmental Protection (**ARPAE**).
- After the **calibration** of the model (**2002-2018**), three **scenarios** (**2019-2030**) were outlined:

Reference Scenario (R): time dependent input parameters (boundary head, river stage, distributed recharge, groundwater withdrawals) are considered as constant at the seasonal scale, and estimated as their average over the last years of the simulation period (2014-2018).

Scenario A: 2019-2030 monthly average precipitation reduced by a fixed percentage for each month with respect to Scenario R .

Scenario B: 2019-2030 extraction rates increased by 20% with respect to Scenario R. Precipitation as in Scenario A.

Precipitation reduction:

- From **statistical analysis of meteorological droughts** in Emilia-Romagna over the last two centuries.

MONTH	PRECIPITATION RATE REDUCTION (%)
January	16.3
February	12.4
March	17.1
April	20.5
May	11.8
June	11.4
July	12.8
August	23.5
September	15.1
October	12.7
November	14.0
December	21.0

3. STUDY AREA

- Portion of Emilia-Romagna region (Italy). **7000 km²** east of the river Secchia.
- Cells are **1000x1000 m²**. The system is subdivided into **35 layers** of variable thickness.
- Large **agricultural plain**. The subsurface consists of **multiple aquifers** in fluvial sediment deposits underlaid by marine sediment.
- **Simulation period**: from 2002 to 2018.

Figure 3.1. Emilia-Romagna Region, Italy.

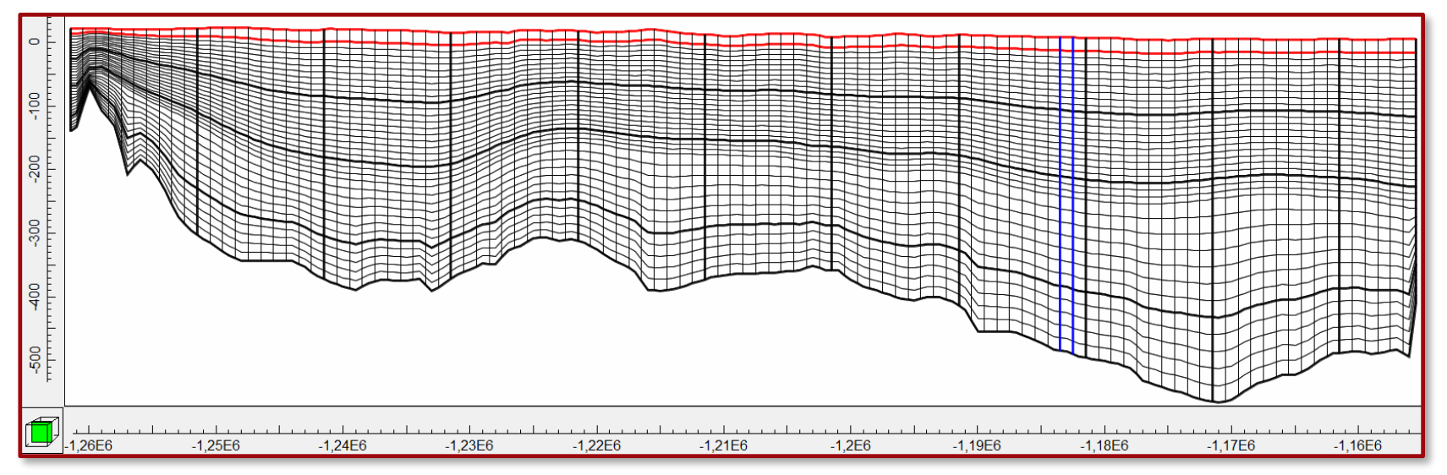

Figure 3.2. Subdivision into layers; vertical representation of the green section in *Figure 3.3*.

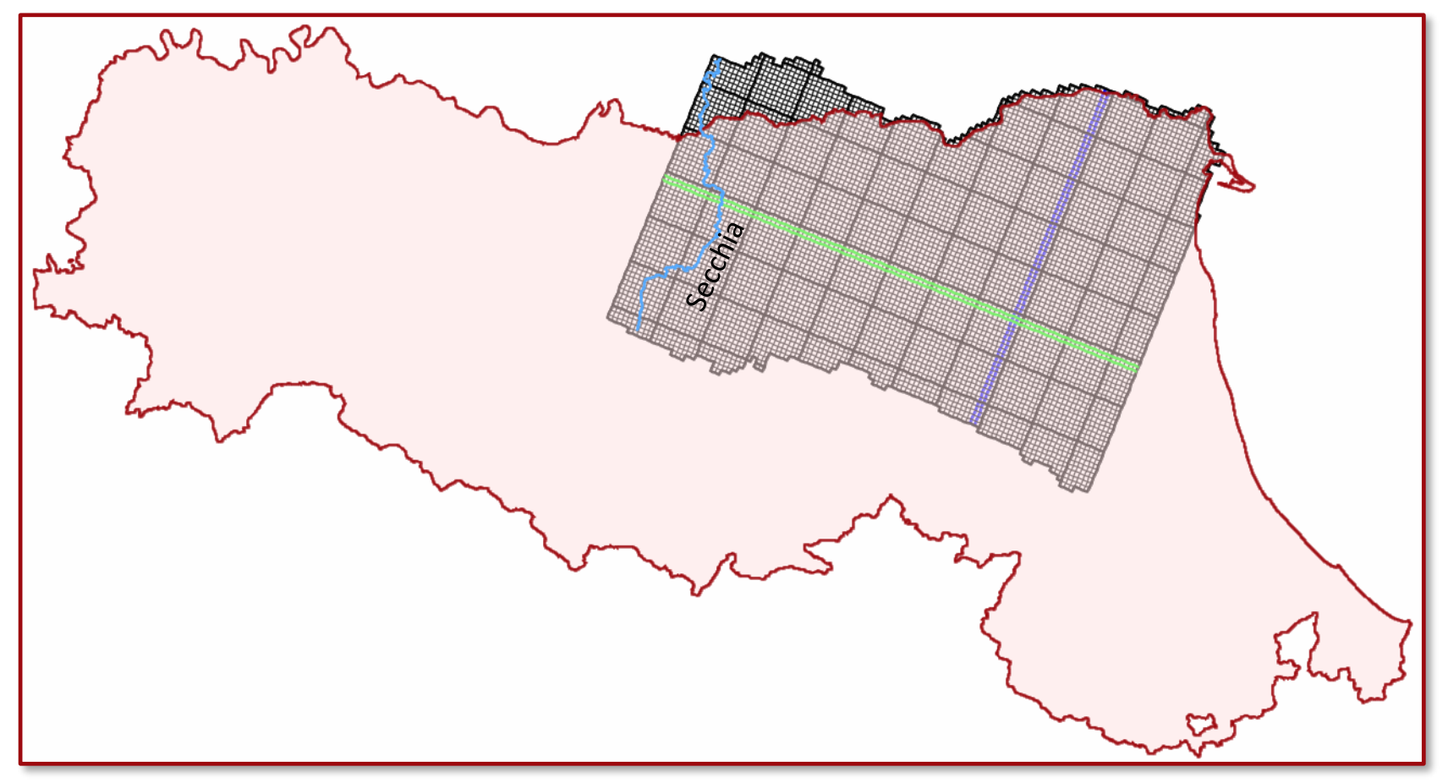

Figure 3.3. Simulated area compared to the whole territory of the Emilia-Romagna Region.

4. DATA

Data are mainly available from:

A. MODFLOW **application** to the whole groundwater flow system of **Emilia-Romagna** by **ARPAE**:
  - **geometry** and **hydrogeologic properties** of the aquifers (vertical and horizontal hydraulic conductivity, specific storage, specific yield);
  - **extraction rates** of the wells present in the study area;

B. freely accessible datasets on the **Emilia-Romagna Region** and **ARPAE websites**:
  - rainfall at several raingauges
  - **water stage** in the main rivers.

Areal recharge estimation:

- **Areal recharge** contribution is mainly due to **rainfall** and **infiltration**.
- Estimated as the **difference** between **precipitation** (P) and **actual evapotranspiration** (ETa).
- P and ETa are available at dailly time scale, so they are averaged at the **three-monthly time scale** required by the simulation.

$$ET_a = \frac{P}{\left[\alpha + \left(\frac{P}{ET_p}\right)^{\beta}\right]^{1/\beta}}$$

R_A: mean extra-terrestrial radiation (function of latitude)
δ_T: difference between maximum and minimum temperature
T: mean air temperature

5. CALIBRATION

- Comparison of **simulated** and **observed groundwater head values** at the same time and location (2010-2018).
- **130 observation wells** from the regional monitoring network (ARPAE), each providing **2 measures per year**.
- Variation of the ***Conductance*** term in both the **rivers** and the **boundary** cells.
- **R² = 0.89**
- The points with the largest difference between observed and simulated values refer to 9 observation wells close to the **southern boundary** of the study area.

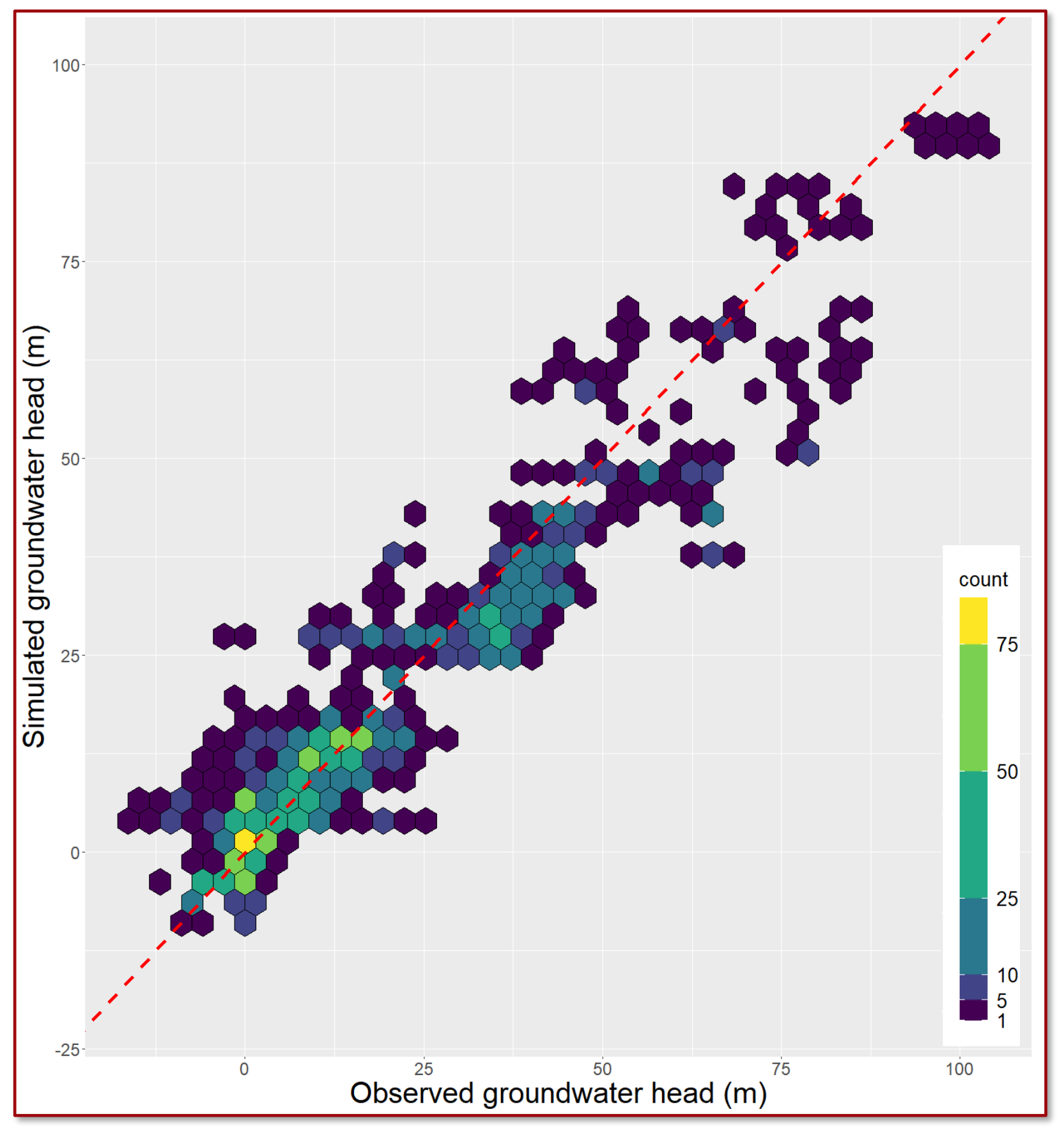

Figure 5.1. Calibration plot.

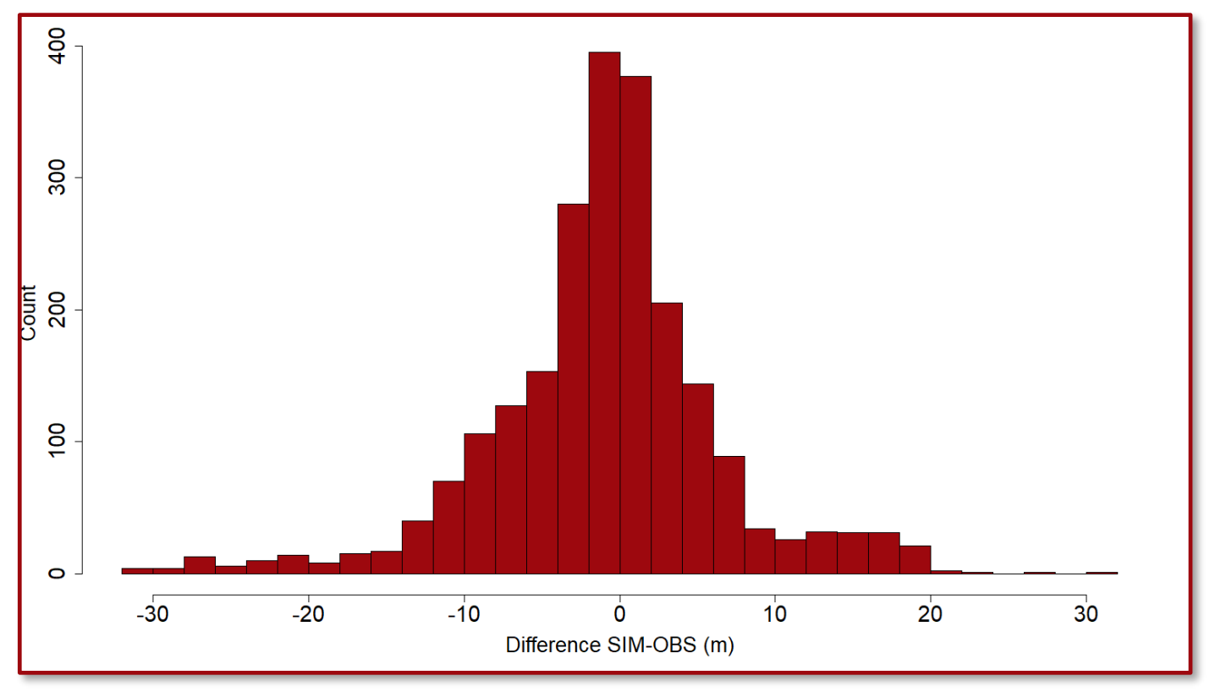

Figure 5.2. Differences between observed and simulated head values.

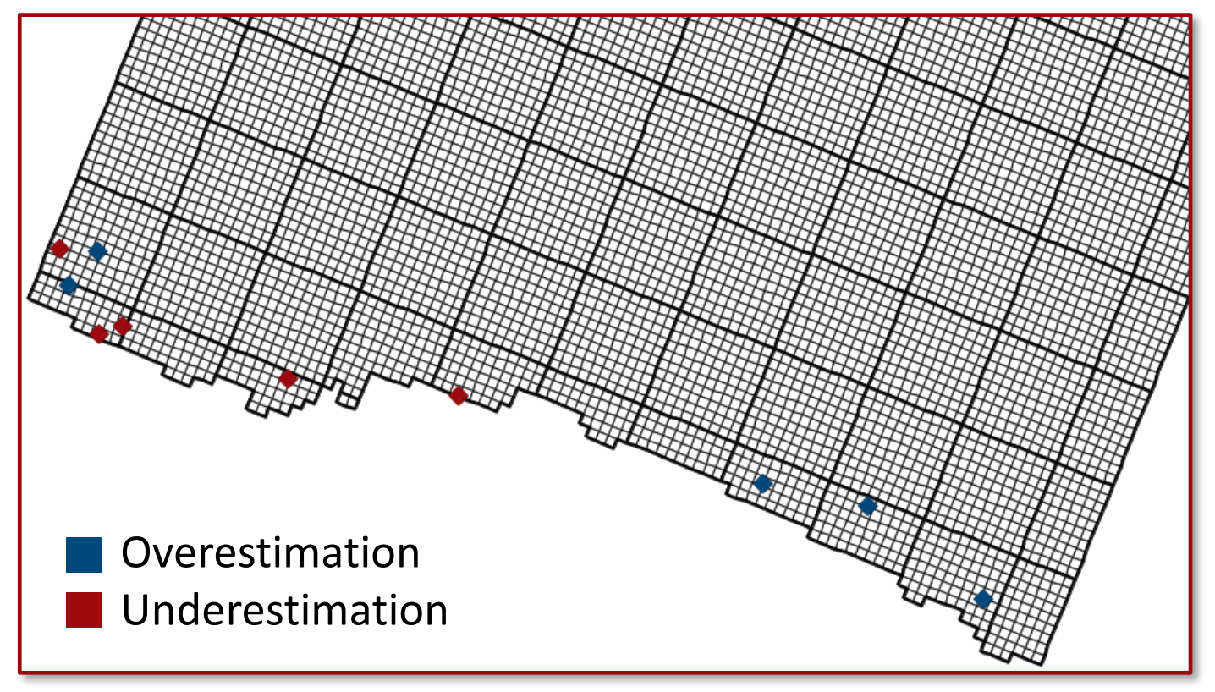

Figure 5.3. Points providing the largest differences between observed and simulated head values.

6. RESULTS

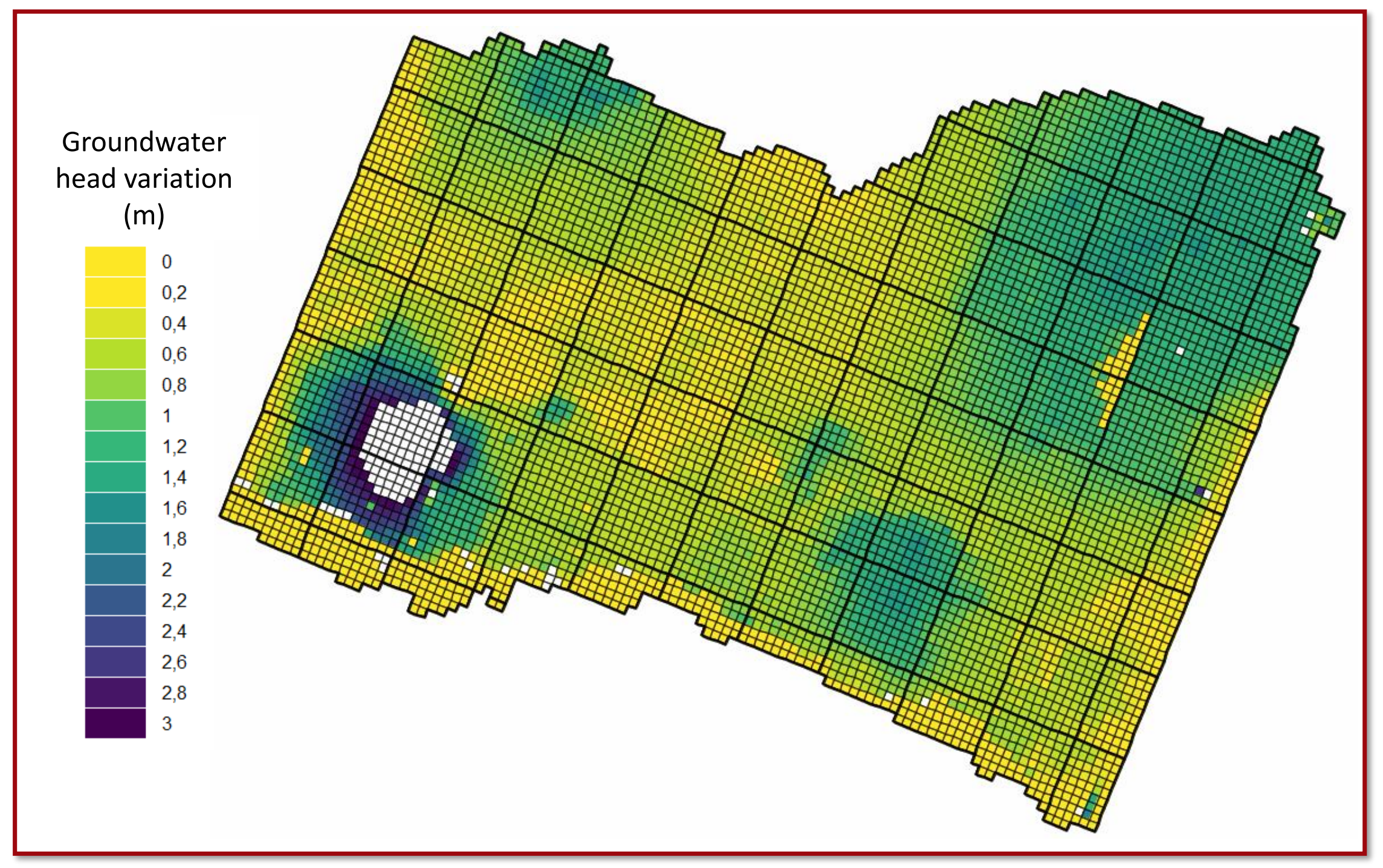

Figure 6.1. Groundwater head variations between scenario R and scenario A at the end of the simulation period (31st December 2030). Layer 6. White cells represent groundwater head differences > 3 or < 0 m.

Scenario A

- If a **precipitation reduction** is applied, a general **groundwater head reduction** is simulated. Reductions mainly range from few centimeters to a couple of meters.
- Groundwater head reduction mostly affects **north-east** and **south-west** parts of the study area.
- On average, **inflows** to the aquifer system due to distributed recharge **decrease** by 93.3 Mm³/year.
- In the groundwater budget, this variation (-93.3 Mm³/year) is balanced by:
  - **Groundwater storage reduction** (-79.3 Mm³/year – 85% of the total amount)
  - **Variation of inflows and outflows** to the system (-9.5 Mm³/year – 10% of the total amount).

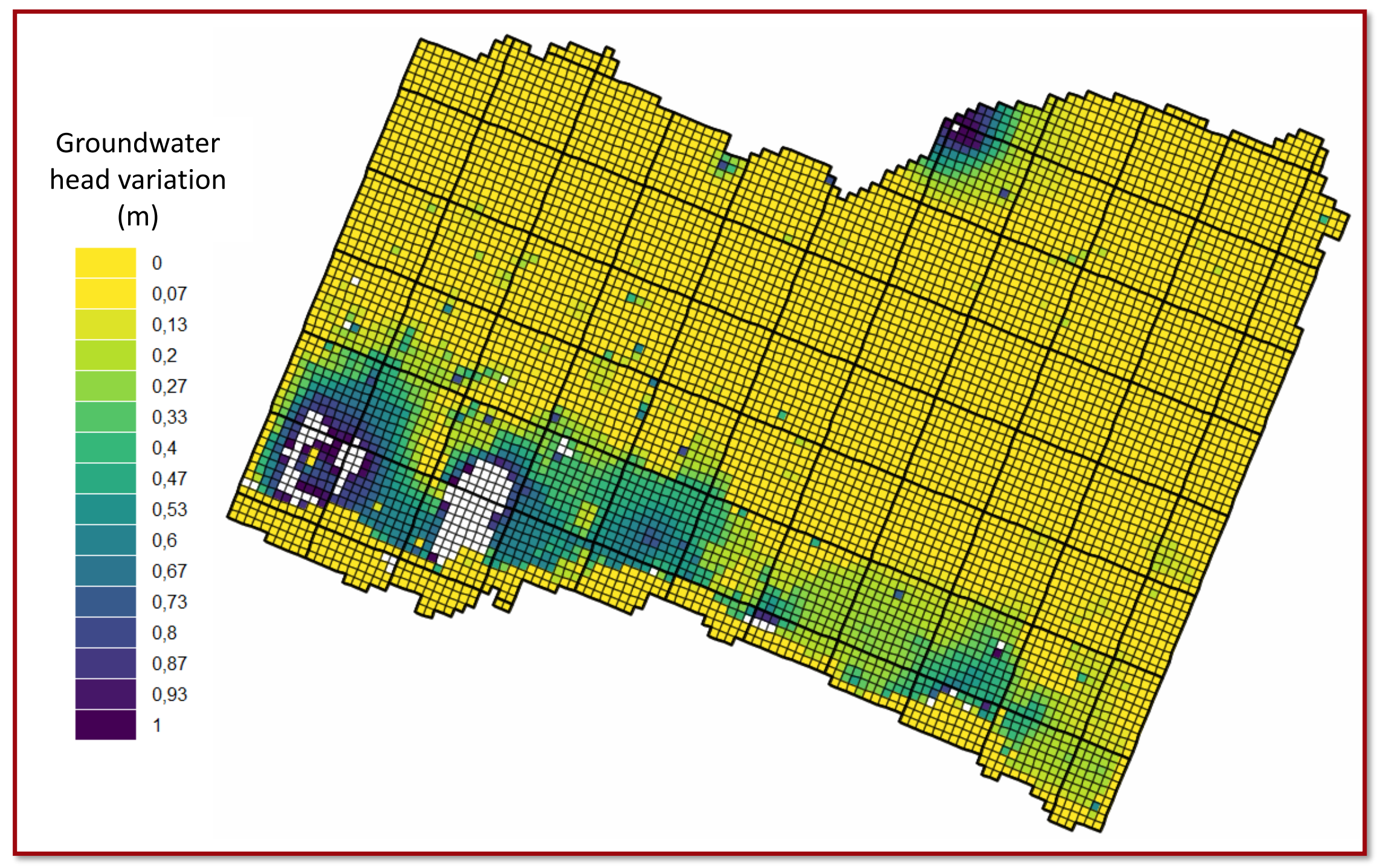

Figure 6.2. Groundwater head variations in scenario B with respect to scenario A at the end of the simulation period (31st December 2030). Layer 6. White cells represent groundwater head differences > 1 or < 0 m.

Scenario B

- When the **pumping rate increment** is added, **groundwater head** further **decreases**. With respect to scenario A, the largest part of reduction is within 10 cm.
- Groundwater head reduction mostly affects **southern** part of the study area.
- On average, extracted groundwater volumes increase by 33.6 Mm³/year.
- In the groundwater budget, this variation (-93.3 and -33.6 Mm³/year) is balanced by:
  - **Groundwater storage reduction** (-108.9 Mm³/year – 86% of the total amount)
  - **Variation of inflows and outflows** to the system (-16.6 Mm³/year – 13% of the total amount).

Considering the volumes, the recharge reduction has a greater effect than the groundwater extraction increment.

References

Pistocchi, A., **Bouraoui**, F., & **Bittelli**, M. (2008). *A simplified parameterization of the monthly topsoil water budget*. Water Resources Research, 44(12).

Guo, R., & **Montanari**, A. (2023). *Historical rainfall data in northern Italy predict larger meteorological drought hazard than climate projections*. Hydrology and Earth System Sciences, 27(15).

Chahoud, A., **Patrizi**, G., **Zaccanti**, G., & **Gelati**, L. *Il modello di flusso delle acque sotterranee della Regione Emilia-Romagna*. In Farina, M., Marcaccio, M., Zavatti, A. (2014). *Esperienze e prospettive nel monitoraggio delle acque sotterranee. Il contributo dell'Emilia-Romagna*. Pitagora Editrice, Bologna.

Future work

- Better assess the **local effects** of **water pumping** in the study region.
- Consider the **effects** of the variation of **rivers parameters** on the groundwater balance.
- **Compare** the numerical model performance to a **random forest model**, both in simulating hystorical observations and in predicting future values.