Managed Aquifer Recharge as an Adaptation Strategy to Climatic and Hydrological Extremes

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1 Introduction

According to the DWD (2019), Brandenburg's mean annual temperature has experienced a rapid rise in recent decades, and under RCP 8.5 it's projected to climb 0.7–2.3 °C by 2050 and 2.7–5.2 °C by 2100. However, annual precipitation shows no clear trend. Higher temperatures boost evapotranspiration, reducing groundwater recharge and driving long-term water-level declines—underscoring the need for sustainable groundwater management strategies.

This study explores managed aquifer recharge (MAR) as a management strategy to address these challenges.

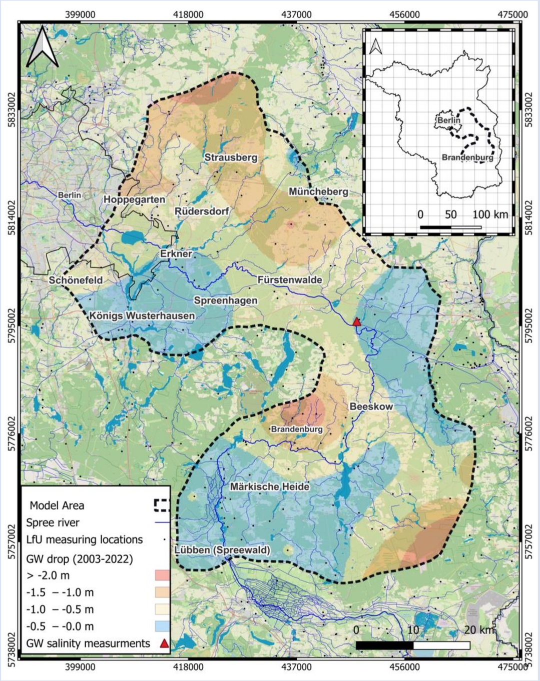


Fig. 1: Groundwater Level Declines in the Lower Spree (Brandenburg, Germany), 2003-2022

The objective of this research is to identify sites suitable for Aquifer Storage Transfer and Recovery (ASR/ASTR), quantify water available for aquifer recharge, and develop a numerical model that will be used as a decision support tool to evaluate ASR/ASTR.

2 Methods

A high-resolution groundwater flow model using MODFLOW was developed that serves as a decision support tool to assess the feasibility of ASTR as an adaptation strategy to changing water supplies. ASTR is the process by which groundwater storage is replenished, in this case via injection, during times of surplus, and later extracted. ASR/ASTR can be used to supplement water supplies during times when surface water supplies are limited.

1) GROUNDWATER MODEL DEVELOPMENT → 2) WATER AVAILABILITY ASSESSMENT → 3) SITE SELECTION AND OPTIMIZATION

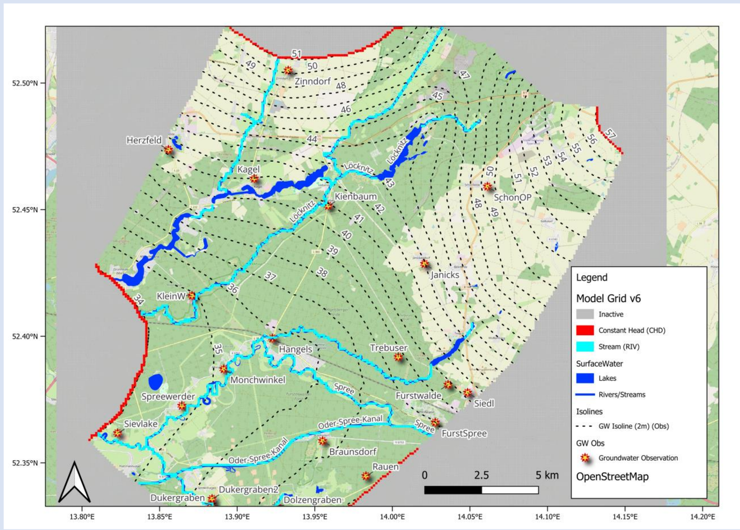


Fig. 2: Trebuser-Graben Pilot Area Model Domain

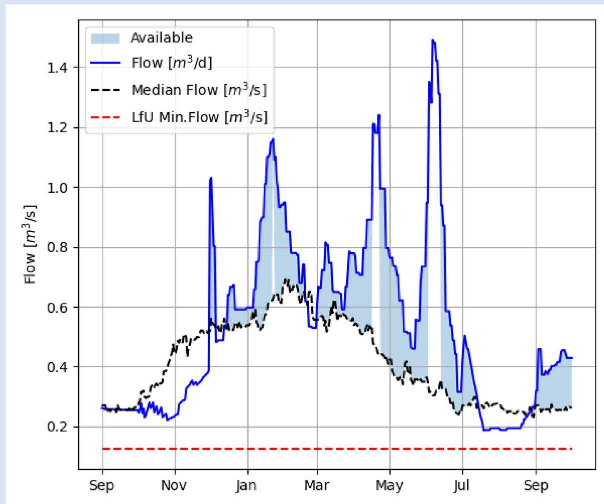


Fig. 3: Hydrograph separation method to determine the volume and frequency of water available to recharge

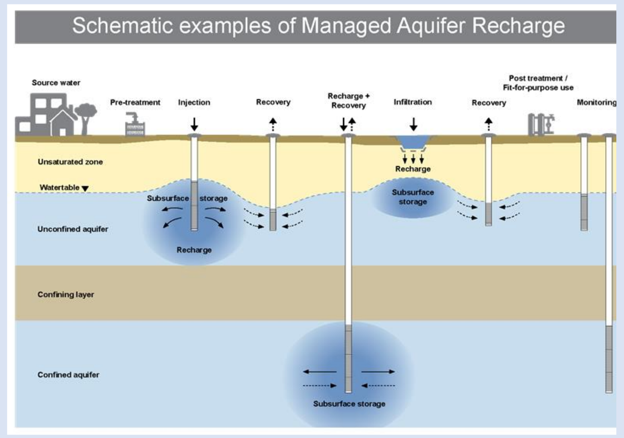


Fig 4: A multi-criteria assessment of site suitability and multi-objective optimization simulations to determine optimal locations for ASR/ASTR

3 Groundwater Model Development

A numerical groundwater flow model of the study area was developed using MODFLOW-NWT. The study area consists of highly heterogenous multi-layered aquifer (Fig. 5), including areas with significant vertical gradients. The model uses a 100-m horizontal and 5-m vertical discretization and simulates stresses using monthly stress periods (1979-2019).

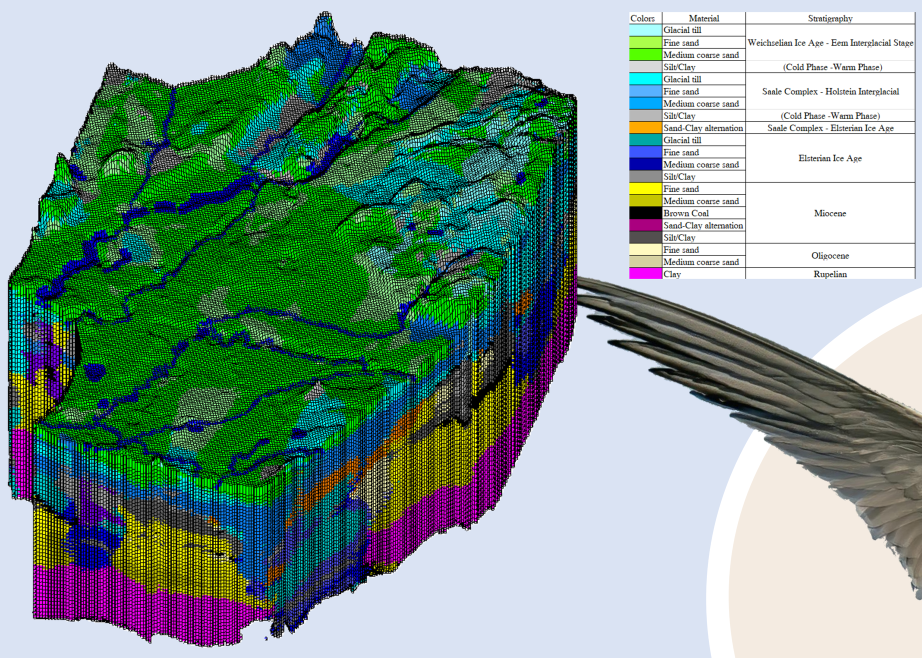


Fig. 5. Pilot Study Area 3-D Geological Model

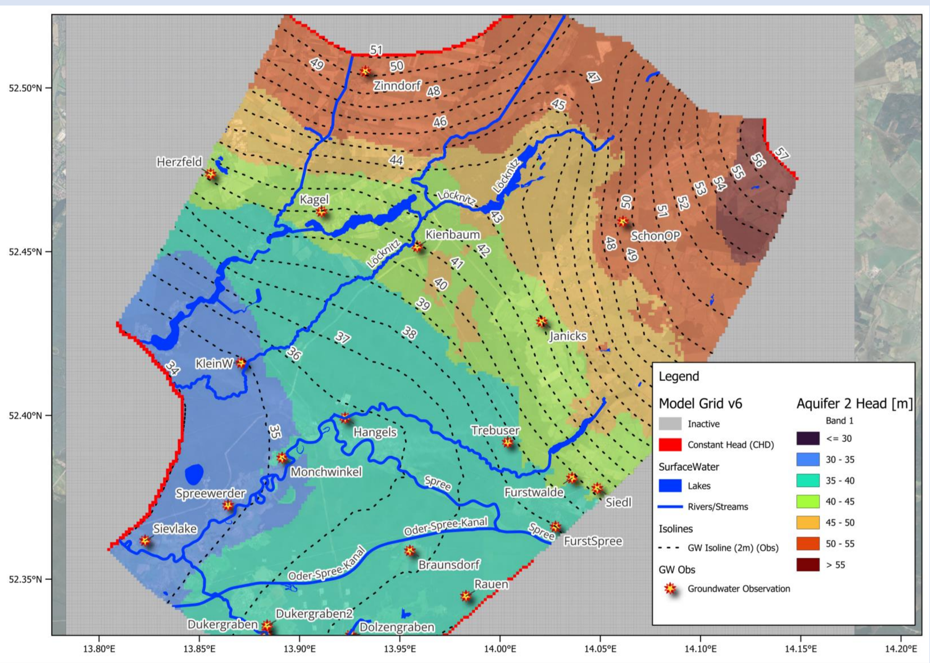


Fig. 6: Simulated vs. Observed Water Level Contour Map

The model was calibrated using PEST++ (Fig. 6). The model serves as decision support tool to simulate and assess the feasibility of managed aquifer recharge.

4 Water Availability and Site Selection

Water Availability: Two approaches to assess water availability were reviewed based on a hydrograph analysis method (Yarnell, 2015/2020 & Stein, 2021).

Approach 1: Hydroecological limit + 20% rule when flows exceed the LfU hydroecological limit, up to 20% of the flow can be diverted (Fig 7a).

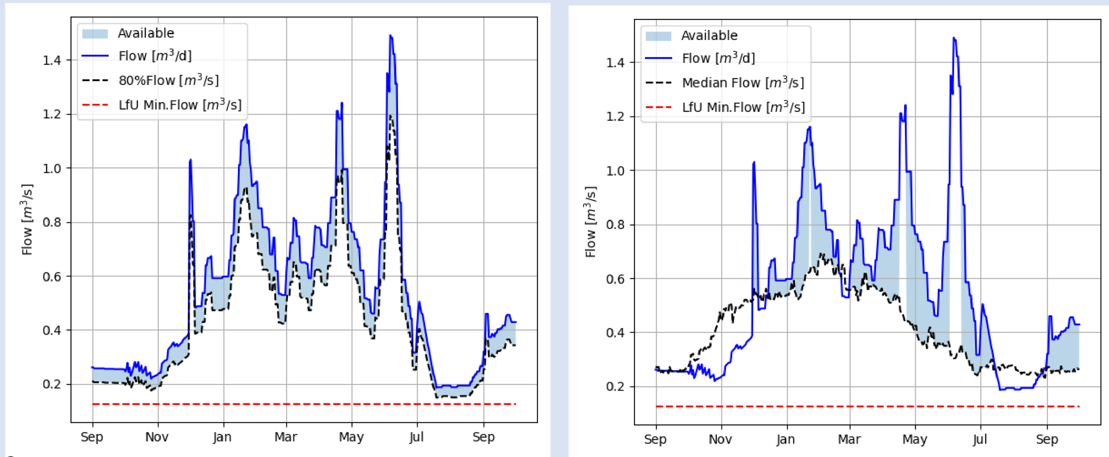


Fig. 7a/b: Hydrograph Separation Approach 1 and 2

Approach 2: Combination of thresholds: when flows exceed the median daily flow, excluding flow between The 2- & 5-year flood level (Fig 7b).

ASTR Simulations:

- The model is used to optimize ASTR operational parameters, well spacing, rates, and assess storage feasibility (Fig 9a/b).

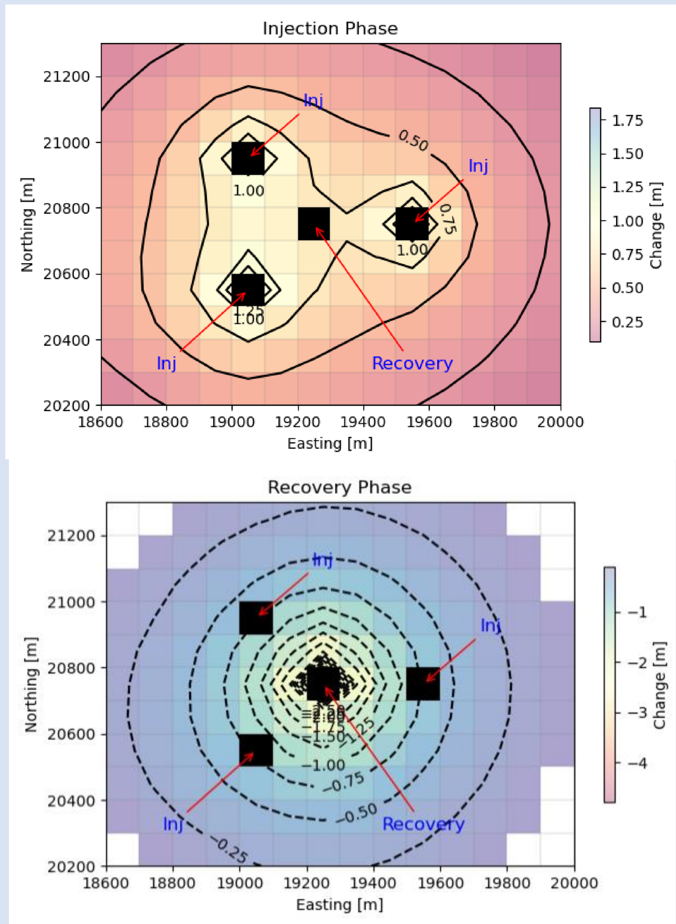


Fig. 9 a/b: Example of Simulated Injection/Recovery

Site Selection:
Sites ranked based on: Aquifer properties (transmissivity, thickness), confining conditions, distance to/from source water, and land use (Fig 8).

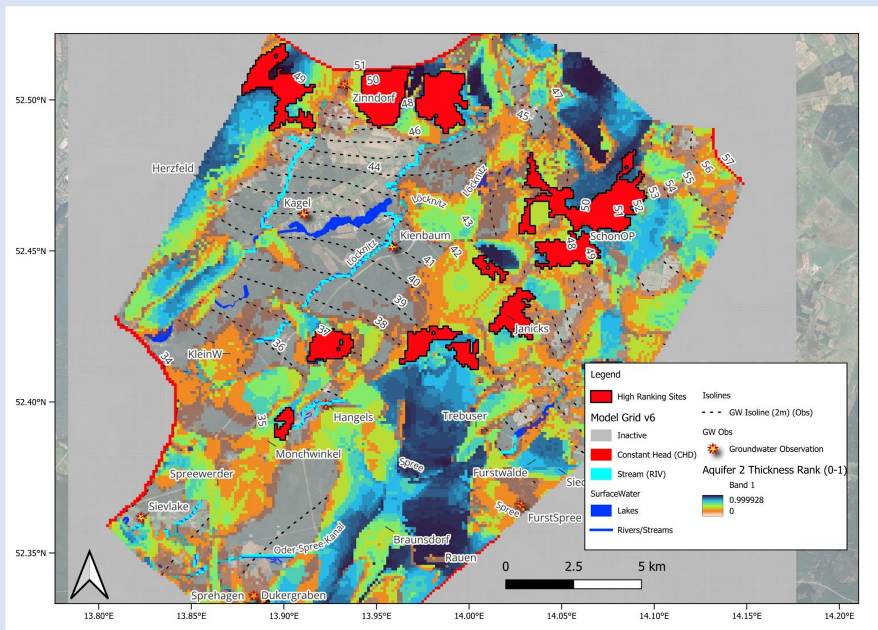
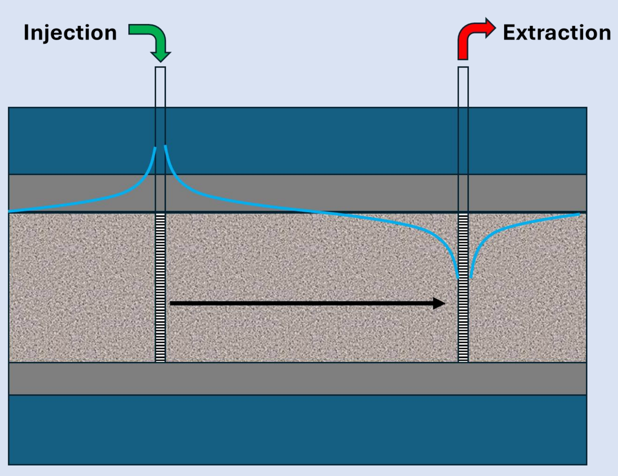


Fig. 8: Sites Suitable for ASTR

5 Discussion

This work establishes and builds on existing research to identify and assess the suitability of ASR/ASTR as an adaptation strategy in a complex geological setting. In this study we present a workflow to estimate the potential volume of water available for MAR, a method to identify and rank suitable sites, and the construction of a numerical groundwater model that can be used as a decision support tool.



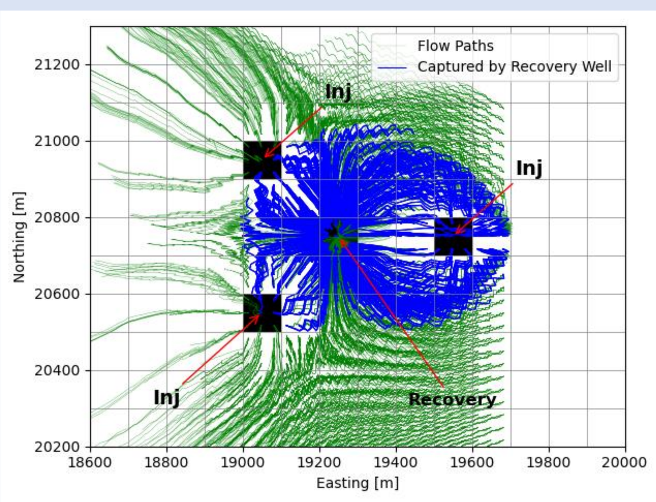


Fig. 10: MODPATH Particle Tracking Example to Illustrate Recovery Efficiency

NEXT STEPS

Suitable sites will be further evaluated and potential ASR/ASTR operational parameters will be determined for each site using a multi-objective optimization (PEST++MOU). This next step will help to further evaluate the feasibility of ASR/ASTR as an integrated water resources management strategy.

Modelling results will be incorporated into an online decision support tool that will allow decision markers to explore and evaluate scenarios under varying future climate projections.

LIMITATIONS

Incorporation of a high-resolution geological model results in long model run times making optimization difficult. Site specific field testing (aquifer pumping tests, etc.) is needed to verify modelling. Water quality and the legal framework to divert water for MAR need to be considered.

6 Conclusion

- ➢ A high-resolution MODFLOW model was developed and calibrated for a Pilot Study Area in the Lower Spree catchment near Berlin, Germany.
- ➢ Multiple methods were assessed to estimate the potential water available for MAR.
- ➢ A multi-criteria assessment of site suitability suitable for MAR was developed and applied.
- ➢ This study highlights the use of groundwater model to assist in the site selection and evaluation/optimization of ASTR as a strategy to store water during times of surplus for later use during times of shortage. The methods outlined in this study may serve as a decision support tool to enable decision makers to assess ASTR as a management practice.

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Project Partners

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