Second rebuttal to Report #2

My suggestions for revision remain similar to the first review.

We thank the reviewer for making the time to have another look at our manuscript and have highlighted where we have made changes according to their most recent feedback.

To me the knowledge gap that this paper is addressing is still not that clear

In the previous round of revisions we edited two sections in the introduction to clarify that SHOWER is intended as a rainfall-runoff model for managed groundwater-rich areas. We have now revisited these paragraphs to emphasize the novelty of this objective. We highlight how current modelling focuses either on simulating surface water in natural conditions (L44-45), including surface water abstractions (L46-47) or including managed reservoirs (L46-47), but does not do these things simultaneously. In the revised manuscript, we now highlight several key aspects of SHOWER which make it unique. Firstly, we emphasize that the combination of representing both surface water and groundwater abstractions in a model is rare. Unlike pre-existing modelling frameworks, we do not assume that groundwater is uninfluenced by abstractions, and as a result we avoid large errors in managed groundwater-rich areas (L48-53). We also note that SHOWER allows for dynamic abstractions or (drought) management interventions (L58-60) which none of the currently available models do.

In the last paragraph of the introduction, we now emphasize the novel aspects of our modelling framework whilst highlighting its simplicity. We also mention how we evaluate the model and make it clear that we have applied the model to three real case-studies, examining its performance on both simulated river flows and groundwater levels.

L82-99: The objective of this study is to present and evaluate a Socio-Hydrological Water Resource (SHOWER) model that is designed as a simple rainfall-runoff model aiming to represent managed groundwater-rich regions. SHOWER builds on the lumped socio-hydrological model introduced in Wendt et al. (2021) and can simulate groundwater levels, baseflow and reservoir levels for different hydrogeological conditions under different drought management strategies coordinating both reservoir and groundwater abstractions. In Wendt et al. (2021), the model was applied to three idealised hydrogeological settings to investigate the impact of different drought management strategies on hydrological droughts. Findings demonstrated that hydrological droughts characteristics can be significantly altered by management, particularly when applying integrated management strategies, which suggested a more efficient way of using water stores to alleviate shortages. In this paper, we present this novel combined rainfall-runoff model in three settings to evaluate its potential to apply drought management strategies in managed groundwater-rich catchments. We first carry out a Global Sensitivity Analysis of SHOWER as a form of 'response-based' (or 'data-free') model evaluation, which demonstrates the consistency of the model behaviour with our understanding of both key surface and groundwater processes (i.e. our perceptual model). Additionally, we examine the leverage of SHOWER, i.e. the model's ability to discriminate between parameter uncertainty and different drought management strategies (Wagener et al.,2022). This leverage is expressed as a measure of sensitivity in model outputs to the management strategies under normal and drought conditions. Second, we calibrate the model for three heavily managed catchments in England using open-source datasets and evaluate the model's ability to reproduce historical river flows and relative groundwater levels in those catchments using the three different groundwater modules ('data-based' evaluation).

and the overall manuscript is presenting a model evaluation, but doesn't provide a clear answer to what theoretical or practical advancement this brings for drought management in real catchments.

The first part of the results (section 3.1) presented in the revised manuscript highlight the theoretical advancement of modelling drought management strategies during flow recessions and low groundwater storage (L272-280 and Figure 4). In the revised manuscript, we dedicated more text to linking how and what kind of drought management scenarios result in a change in drought characteristics (L304-319).

To our knowledge, this theoretical advancement should be considered novel, since drought management strategies have not been modelled and evaluated for both surface water and groundwater storage before. We have revised the section 4.2 in the Discussion (L415-432 see below) to indicate how the theoretical individual drought management strategies relate to real-world examples and stress that more site-specific modelling is required to evaluate the suite of drought management strategies applied in water resource management regions in the UK. This information is not available at national scale and vary widely in drought reports of water companies across England (Wendt, et al. 2021).

For example, the conjunctive use scenario results in shorter drought events in the karstic and porous modules, but with a range of drought intensities. Given that conjunctive use might be applied in different manners across these hydrogeological systems, more site-specific details are needed to evaluate how this translates in practise.

L415-432: Our results show that integrated drought management scenarios have the most leverage on the SHOWER model outputs, and particularly the conjunctive use scenario. Discharge and groundwater results are significantly altered by management scenarios, particularly during drought periods. The impact of modelling a particular management scenario dominates discharge and groundwater level simulations, as this impact exceeds model parameter uncertainty. Even though these are theoretical drought management simulations, results indicate a substantial influence regardless of the parameters used within the national range. In practise, there will be a combination of drought management strategies applied in a catchment at the same time and drought strategies will be adapted to reflect specific operations. For example, we applied a theoretical application of conjunctive use in which water use is fully integrated and non-restrictive. This approach is in line with large conjunctive use schemes where a range of water sources is used and the increased flexibility within a water distribution system increase drought resilience (Shepley et al., 2009; Scanlon et al., 2016; Seo et al., 2018). The modelled surface water imports represent the common cross-company water transfers that are an additional tool to overcome (short-term) water shortages. These are commonly used when approaching low reservoir storage (Wendt et al., 2021) but likely used prior to reaching the 25th threshold as water is frequently transferred between regions to increase resilience high water demand or droughts (Dobson et al., 2020). These local and regional water transfers can also be used to maintain ecological minimum flows (Environment Agency, 2019). How a combination of these modelled measures translate to better protection of ecosystems can be complex to observe on the ground. It will also require more site-specific modelling efforts, particularly investigating the water quantity aspect of water resources management interventions, as maintaining specific surface or groundwater levels via conjunctive or augmentation schemes does not directly guarantee a 'good' ecological status (Jakeman et al., 2016; Murgatroyd et al., 2022).

Given this theoretical advancement, our recommendations for practical drought management focus on the identified shorter droughts using integrated measures (L433-436) and substantial impact of demand measures in fast-responding (shallow) groundwater systems compared to slow, high storage groundwater systems (L436-438). Considering that a multitude of drought measures are in place with a range of site-specific modifications, we recommend further site-specific research using SHOWER to investigate specific advancement in practical drought management. In this work, we aimed to develop and evaluate a suitable modelling tool that enables groundwater managers to do so.

The manuscript provides a thorough sensitivity analysis of the model, but an application, demonstrating how it can be used or a comparison with other models, demonstrating the improvement, or something else that shows how this model is filling a knowledge gap is missing and after reading the manuscript I am still left wondering what the contribution to the existing literature is.

In the Discussion (section 4.1) we compare SHOWER to other models, indicating how surface water simulations are improved from negative KGE to positive KGE values for *some models (G2G model: L387-388). For other models, the differences were smaller in terms of KGE and similar to SHOWER (L388-393). In the previous version of the manuscript, the difference in KGE was written out based on feedback from the review. We can reverse this to improve clarity of the manuscript given this new feedback in Report #2.*

Even though the performance metrices have a similar value, there are significant advantages to specifically accounting for surface water and groundwater abstractions and reservoir management in SHOWER. This introduces the opportunity for scenario testing and further advancement of drought management, as well as ensuring that the model is right for the right reasons. This advancement is not possible without explicitly accounting for management influences as impact on flows due to management is indirectly included in other model parameters (L393-395).

I do believe that the manuscript can provide a valuable contribution and should be considered for publication after revisions, but I feel that more substantial revisions are needed than the revisions that have been done so far.

We hope that the listed revisions are sufficient in clarifying the objective and contribution of the paper to the existing literature. If other, more substantial changes are requested, we would need more specific input as these would fall outside of the 'minor revision' iteration.