Authors' Responses to Comments from Reviewer #2:

General Comments

This manuscript investigates the mechanisms of soil water movement and groundwater recharge in the North China Plain, a region facing significant water scarcity issues. The authors employ numerical simulations combined with multiple regression analysis to quantify the influence of vadose zone thickness, soil texture (clay and sand fractions), and lithology on percolation velocities and recharge rates. The study compares different infiltration modes (such as precipitation vs. managed aquifer recharge/riverbed infiltration) and aims to provide theoretical support for sustainable groundwater extraction and crop production. The topic is highly relevant to regional water resources management and addresses a pressing global concern regarding aquifer depletion. But there are significant methodological concerns that must be addressed to ensure the validity of the results.

Response: We sincerely thank the reviewer for the comprehensive summary and for recognizing the high relevance of our study to regional water resources management in the North China Plain and the global concern of aquifer depletion. We greatly appreciate your positive evaluation of our research topic and objectives.

In the revised manuscript, we will address these issues to ensure the validity and robustness of our results. Specifically, we will strengthen the justification for our model parameterization and improved the statistical rigor of our regression analysis.

1. Since measured initial soil water content was unavailable, the reliability of the simulation results depends heavily on the sufficiency of the spin-up period. It is unclear from the current text whether the spin-up period has made the initial state reached a dynamic equilibrium state, especially for deep soil layers. The authors should provide justification or graphical evidence (e.g., time series of soil water content or pressure head deeper than a certain depth at the profile) to demonstrate that the model achieved a robust equilibrium prior to the main simulation period.

Response 1: We thank the reviewer for this critical comment regarding the initial conditions and the model spin-up. We fully agree that in the absence of measured initial

profiles for such deep vadose zones, ensuring a sufficient spin-up period is essential to eliminate the influence of the arbitrary initial setup (uniform pressure head of -50 cm). In the revised manuscript, we will provide additional graphical evidence to justify the sufficiency of the 6-year spin-up period (July 2016 - July 2022). Specifically:

1) We will add a new figure (Figure B1 in the Appendix B.) that displays the temporal evolution of soil water content at deep layers (at intervals of 10 m from 20 m to 80m) for all boreholes during the spin-up phase.
2) We will update Section 2.3.5 (Model spin-up) to include this analysis, clarifying that the system had achieved a robust equilibrium prior to the main simulation period starting in August 2022.

2.The multiple regression models employ clay, sand fractions, and depth as independent predictors. Since soil textural components are compositional data (summing to 100% with silt, clay and sand), there is an inherent negative correlation between these variables. To ensure the robustness of the regression coefficients presented in Tables A.1 and A.2, please check the independence of the input variables or calculate the Variance Inflation Factors for the predictors. If high multicollinearity is detected, the authors should discuss how this affects the physical interpretation of the coefficients.

Response 2: We thank the reviewer for raising this important statistical point. To verify the independence of the selected predictors (vadose zone thickness**,** clay fraction, and sand fraction), we will perform a multicollinearity test using the Variance Inflation Factor (VIF). In our preliminary analysis, the VIF values for all three predictors have been calculated to be well below the critical threshold of 5 (1.018 for Depth, 1.208 for Clay, and 1.225 for Sand), indicating that there is no significant multicollinearity among the predictors in our dataset. We will add these VIF values to Section 2.5 Multiple regression analysis to confirm the independence of the input variables.

3. The Conclusions suggest the construction of recharge basins; however, the implications for groundwater management could be further strengthened. Given the

limited land resources in the North China Plain, does this recommendation adequately consider land-use constraints?

Response 3: We appreciate the reviewer's valuable perspective on land-use constraints. We are fully aware that the North China Plain is a densely populated region and a critical agricultural base where land resources are extremely limited. We will refine our recommendations in the Discussion and Conclusion sections to explicitly address land scarcity. Instead of proposing the conversion of arable land into large-scale artificial basins, we advocate for a strategy that optimizes Managed Aquifer Recharge (MAR) by leveraging existing geomorphological features.

We will clarify that recharge basins should be prioritized along existing seasonal dry riverbeds or river edges. As noted in our study area description, the main river covers only 0.35% of the area, and many channels are seasonally dry. Utilizing these channels minimizes land acquisition costs and avoids conflict with agricultural land use.

We will emphasize our finding that riverbed percolation velocities (109.1 cm d^{-1}) are approximately 4 times higher than precipitation-fed infiltration (26.4 cm d^{-1}). This high efficiency implies that a smaller surface area can achieve significant recharge volumes, reducing the need for extensive land occupation.

We specifically recommended targeting the foothill alluvial fan areas (e.g., near the Long 12 and Bai 1), where coarse-grained lithology combined with riverbed infiltration yields the shorter lag times.

Specific comments:

1.Line 18 "...sustainable groundwater extraction and crop-production," "Crop production" is typically not hyphenated unless used as a compound modifier before a noun.

Response 1: We appreciate these suggestions. Clarifications will be made on Page 1, in the Abstract of the revised manuscript.

2. Line 19, The word "however" is redundant following "few studies".

Response 2: We appreciate these suggestions. Clarifications will be made on Page 1, in the Abstract of the revised manuscript.

3.Line 23 "…compared between these two infiltrations," the word "infiltrations" is a non-standard pluralization in this context. Please revise "compared between these two infiltrations" to "compared between these two infiltration modes".

Response 3: We appreciate these suggestions. Clarifications will be made on Page 1, in the Abstract of the revised manuscript.

4. Line 33, there is a subject-verb agreement error. "…the depletion of aquifers have become…" should be corrected, as the subject "depletion" is singular.

Response 4: We appreciate these suggestions. Clarifications will be made on Page 2, in the Introduction of the revised manuscript.

5. Line 33, in the same sentence, "pressing global concerns" should be changed to "a pressing global concern" to match the singular subject.

Response 5: We appreciate these suggestions. Clarifications will be made on Page 2, in the Introduction of the revised manuscript.

6. Line 43, In soil science, the standard term is "matric potential." Please change "matrix potential gradient" to "matric potential gradients".

Response 6: We appreciate these suggestions. Clarifications will be made on Page 2, in the Introduction of the revised manuscript.

7. Line 118, A preposition is missing in the phrase "holistic understanding soil water movement." Please change it to "holistic understanding of soil water movement".

Response 7: We appreciate these suggestions. Clarifications will be made on Page 4, in the Introduction of the revised manuscript.

8. Line 198, it should be corrected to "and t represents time".

Response 8: We appreciate these suggestions. Clarifications will be made on Page 9, Section 2.3 of the revised manuscript.

9. Line 202, "set up" should be written as two words when used as a verb.

Response 9: We appreciate these suggestions. Clarifications will be made on Page 9, Section 2.3 of the revised manuscript.

10. Line 244, in the sentence "…and then apply the same average water level data…" the verb "apply" should be in the past tense to match the preceding "were obtained".

Response 10: We appreciate these suggestions. Clarifications will be made on Page 11, Section 2.3.3 of the revised manuscript.

11. Line 328, for more formal academic tone, please change "interplay between these factors in controlling water movement" to "interaction between these factors in governing water movement."

Response 11: We appreciate these suggestions. Clarifications will be made on Page 16, Section 3.2.1 of the revised manuscript.

12. Line 335, to ensure grammatical parallelism with "thickness," please change the adjective "lithological" to the noun "lithology".

Response 12: We appreciate these suggestions. Clarifications will be made on Page 17, Section 3.2.1 of the revised manuscript.

13. The fonts in Figures 5 and 8 are inconsistent with those in the manuscript. If there is no special meaning, it is recommended to make them consistent with the fonts of the other figures.

Response 13: We appreciate these suggestions. Clarifications will be made in Figures 5 and 8 of the revised manuscript.

14. In the titles of Figures 5 and 8, the unit of "Groundwater recharge time" should be marked as (d).

Response 14: We appreciate these suggestions. Clarifications will be made in the titles of Figures 5 and 8 of the revised manuscript.

"Figure 5: Groundwater infiltration time (d) and average percolation velocity (cm d^{-1}) for locations under precipitation infiltration recharge scenarios."

“Figure 8: Groundwater infiltration time (d) and average percolation velocity (cm d^{-1}) for locations under riverbed infiltration recharge scenarios.”