Responses to the comments on the manuscript “From salinity to nanoplastics: redefining safe yield in strip-island aquifers under emerging contaminant threats” by Zheng et al. submitted to *Hydrology and Earth System Sciences*

Dear Anonymous Referee #1,

We sincerely appreciate your thorough review, insightful comments, and constructive suggestions on our manuscript. Your professional evaluation has greatly helped us identify areas for improvement and significantly enhance the logic, clarity, and academic rigor of this work. We have carefully addressed every comment you raised, with detailed revisions and explanations provided below.

Comments:

This study addresses the issue that existing groundwater management frameworks are largely based on salinity intrusion and do not account for the distinct transport behavior of nanoplastics. A multi-physics numerical model was developed, incorporating variable-density groundwater flow, salt transport, and nanoplastic migration processes, to investigate the transport characteristics of nanoplastics in idealized strip-island aquifers under pumping conditions. The model was validated using laboratory experiments, and its scale effects were evaluated while sensitivity analyses were conducted. The application of this model provides a process-based scientific framework for adapting groundwater management strategies to emerging nanoplastic pollution in vulnerable island environments. Although this is a very comprehensive study, the following issues still need to be addressed:

Response:

Thank you for your positive feedback and constructive suggestions provided. We have addressed all points as detailed below:

Comment (1): *The nanoplastics is the primary keywords in the manuscript title, but the deep introduction of nanoplastics comes too late in the introduction section, so it is suggested to simplify or even rephrase the statements from the beginning to Line 79.*

Response:

Line 1-79:

Thank you for your constructive suggestion. We fully agree with your comment that the introduction of nanoplastics appears relatively late in the original Introduction section, which is not consistent with its status as the core keyword of the manuscript.

To address this issue, we have simplified and streamlined the sentences from the beginning up to Line 79, and rearranged the paragraph order by moving the original third paragraph (focused on nanoplastics) ahead of the original second paragraph. This adjustment ensures that nanoplastics are introduced much earlier and more prominently, highlighting the core research object at the start of the Introduction and improving the logical flow and readability of the manuscript.

The revised content is presented as follows: “

1.Introduction

Islands host nearly 10% of the global population and cover approximately 6.7% of the Earth’s terrestrial surface (Sayre et al., 2019). On many small islands, limited surface water availability makes groundwater a critical resource for local communities (Dose et al., 2014). Notably, numerous Pacific islands rely on shallow freshwater lenses — buoyant bodies of freshwater overlying saltwater in highly permeable aquifers — as their primary water supply (Sharan et al., 2021; White and Falkland, 2010). The formation, stability, and morphology of these lenses result from the interplay between density contrasts and multiple external factors, including climate, geological structures, and anthropogenic activities such as groundwater pumping and subsurface barrier installation (Alsumaiei and Bailey, 2018; Ketabchi et al., 2014; Tang et al., 2021, 2022; Yan et al., 2021; Yang et al., 2025; Gao et al., 2025; Zheng et al., 2025). Excessive pumping readily induces saline upconing, degrades water quality, and threatens long-term water security (Abdoulhalik and Ahmed, 2018; Dagan and Bear, 1968; Houben and Post, 2017; Werner et al., 2009).

Beyond salinity intrusion, nanoplastic contamination has emerged as an additional and largely unaddressed threat to island groundwater systems. Microplastics are pervasive environmental pollutants detected in marine environments, soils, and groundwater worldwide (Koelmans et al., 2022; Koutnik et al., 2021; Li et al., 2018; Ren et al., 2021; Thompson et al., 2024). Oceanic concentrations continue to rise due to plastic persistence and ongoing inputs (Isobe et al., 2019). The concentrations of nanoplastics—which are formed as a result of their breakdown—are even higher, with coastal waters often exhibiting higher levels than open-ocean regions (ten Hietbrink et al., 2025). Emerging evidence indicates that seawater intrusion facilitates the transport of microplastics into coastal aquifer systems (Chen et al., 2024). Because island aquifers are completely surrounded by seawater, freshwater lenses are particularly vulnerable to marine-sourced nanoplastic contamination (Fig. 1).

The maximum safe extraction rate for freshwater lenses is typically estimated using analytical solutions that assume a sharp interface between freshwater and seawater (Muskat, 1937). Such approaches are widely used in two-dimensional strip-island models to determine the pumping threshold at which the saline interface reaches the well screen (Tang et al., 2020, 2021, 2024). While computationally efficient, these models neglect hydrodynamic dispersion and the development of a brackish transition zone, which can be extensive in highly permeable island aquifers (Coulon et al., 2022; Babu et al., 2020). Consequently, current safe-yield assessments often overlook realistic mixing processes and contaminant transport within the transition zone, potentially underestimating water-quality risks."

Comment (2): *Lines 86-90: Some relevant citations are encouraged to be added here.*

Response:

Line 86-90:

Thank you for your valuable suggestion. We have supplemented the relevant citations at Lines 86–90 to strengthen the academic support and logical rigor of this section.

Specifically, we have added the studies of Wang and Sedighi (2023), Alkindi et al. (2011), and Lee et al. (2017) to elaborate the fundamental differences between nanoplastic transport and dissolved solute transport:

- Wang and Sedighi (2023) confirmed that nanoplastics exhibit higher effective dispersivity than common dissolved solutes.
- Alkindi et al. (2011) pointed out that, as particulate phases, nanoplastics migration is accompanied by interface disturbance, velocity contrast, and pressure gradient fluctuations in porous media.
- Lee et al. (2017) indicated that nanoplastics behave as a discrete phase with much stronger equivalent drag effects than dissolved solutes.

Together, these studies clearly demonstrate that, especially at pumping wells where pressure changes sharply, nanoplastics with higher dispersivity present distinctly different transport behaviors from solutes, which can lead to unexpected groundwater contamination risks during extraction.

Reference

Alkindi, A., Al-Wahaibi, Y., Bijeljic, B. and Muggeridge, A. (2011), Investigation of longitudinal and transverse dispersion in stable displacements with a high viscosity and density contrast between the fluids. Journal of Contaminant Hydrology, 120-121, 170-183. https://doi.org/10.1016/j.jconhyd.2010.06.006.

Lee, J., Rolle, M. and Kitanidis, P. (2017), Longitudinal dispersion coefficients for numerical modeling of groundwater solute transport in heterogeneous formations. Journal of Contaminant Hydrology, 212, 41-54. https://doi.org/10.1016/j.jconhyd.2017.09.004.

Wang, Z., & Sedighi, M. (2023), Dispersion properties of nanoplastic spheres in granular media at low Reynolds numbers, Journal of Contaminant Hydrology, 259, 104244. https://doi.org/10.1016/j.jconhyd.2023.104244.

Comment (3): *Lines 91-94: It is recommended to add one or two sentences to highlight the correlation between these two gaps, so that readers can understand the systematic nature of this study.*

Response:

Line 91-94:

We appreciate this insightful comment. To better emphasize the systematic logic of the research gaps and their internal connections, we have revised Lines 91–94 by adding explanatory sentences that link the two key gaps together.

This revision makes it clearer that the shortcomings of traditional safe-yield models and the lack of nanoplastic transport knowledge are interrelated rather than independent, which strengthens the overall motivation and coherence of the study. Specifically, neglecting the transition zone (Gap 1) creates an oversimplified flow and mixing field, which in turn invalidates the direct application of solute-based models to predict nanoplastic transport (Gap 2).

The modified content is shown below:

Taken together, there are two critical gaps that are interdependent and collectively undermine reliable groundwater management. First, existing safe-yield models oversimplify the freshwater-seawater transition zone by neglecting dispersion-driven mixing. This oversimplification is further exacerbated when combined with the poorly characterized transport of nanoplastics, which exhibit unique migration dynamics that cannot be captured by traditional solute models. Second, the distinct migration behavior of nanoplastics under pumping-induced coning remains poorly understood. Current modeling frameworks, largely derived from solute transport theory, do not adequately capture transient nanoplastic breakthrough or particle-specific transport dynamics.

Comment (4): *1 and 2: There is no information about nanoplastics in this figurem.*

Response:

Fig. 1 and 2:

We greatly appreciate your careful check on the figures. We have noticed the lack of nanoplastic - related labels in Fig. 1 and 2, and have added clear nanoplastic identifiers and annotations to both figures accordingly.

These revisions make the core research object more visible in the conceptual model diagrams, improving the clarity and completeness of the figure presentation.

The updated figures are shown below and included in the revised manuscript.

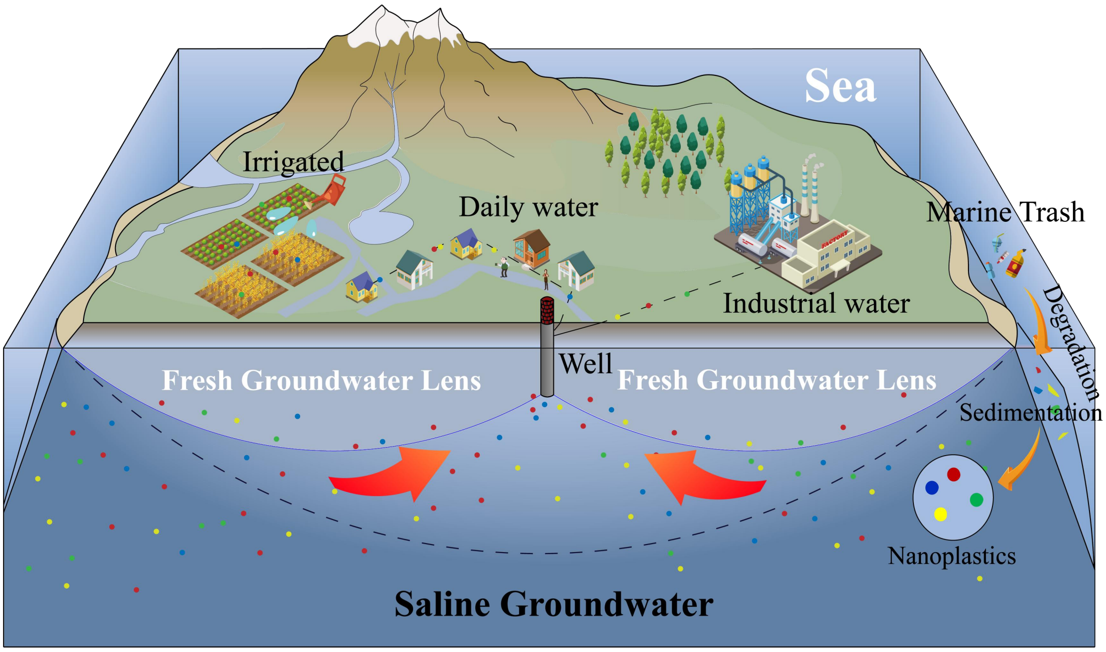

Fig. 1. Schematic diagram of freshwater lenses and nanoplastic contaminant distribution in an idealized strip-island aquifer under groundwater extraction.

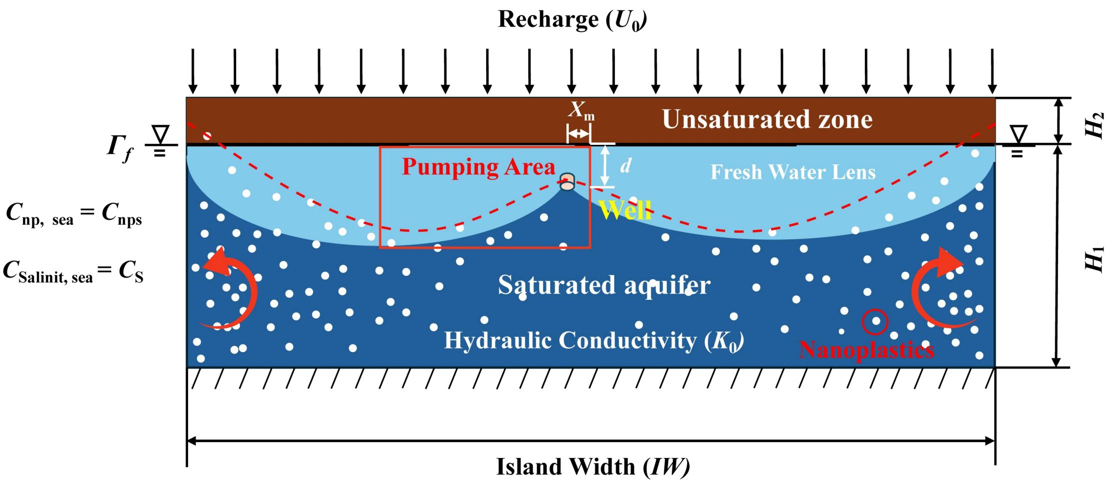

Fig. 2. Conceptual model of nanoplastic pollution in an idealized strip-island aquifer with central pumping. The model depicts an unsaturated zone (height H_2) over a saturated zone (height H_1). Freshwater lenses are shown in light blue and saline groundwater in dark blue. Key parameters include island width (IW), continuous precipitation (U_0), seawater salinity (C_s), and seawater nanoplastic concentration (C_{nps}).

Comment (5): *Lines 142-143: More specifically, it should be called bulk density.*

Response:

Lines 142-143:

Thank you for this precise correction. We have revised the relevant term to bulk density at Lines 142–143 to ensure accuracy and standardization in the description of aquifer medium properties.

Comment (6): *The title of chapter 2.2 is suggested to be revised into numerical soluton, since “numerical simulation” includes the establishment of mathematical model in chapter 2.1.*

Response:

Section 2.2:

Thank you for your professional suggestion on optimizing the section structure. We have revised the title of Section 2.2 from “Numerical Simulation” to “Numerical Solution” in accordance with your comment.

This adjustment better distinguishes the mathematical model establishment (Section 2.1) from the subsequent numerical solving process, making the logical hierarchy of the methodology clearer and more rigorous.

Comment (7): *Line251: double "represents".*

Response:

Line251:

Thank you for catching this typographical error. We have removed the redundant represents at Line 251 to ensure grammatical accuracy and fluency of the manuscript.

Comment (8): *About the evaluation indicators: It is recommended to present the functions or roles of these indicators mentioned here in a concise list format at the end of the section, which can help readers easily understand what they are used to indicate.*

Response:

Line251:

We appreciate this valuable suggestion for improving readability. To help readers quickly grasp the purpose and implications of the evaluation indicators, we have added a concise table at the end of the evaluation indicators section.

This table clearly summarizes the application role of each indicator, making the framework more intuitive and systematic.

The revised section with the new table is shown below and provided in the revised manuscript:

Table 2 provides a systematic description of the representative roles of the three evaluation metrics used in this paper:

Table 2. Summary of Evaluation Indicators and Their Functions

Symbol	Full name	Description
VR	Volume reduction rate of freshwater lenses	Quantifies the shrinkage degree of usable freshwater lens volume under pumping

		and nanoplastic contamination.
ASYR	Ratio of the actual maximum safe extraction capacity to the theoretical maximum safe extraction capacity	Evaluates the reduction degree of practical safe extraction capacity relative to the theoretical threshold.
RRSY	Ratio of the maximum safe extraction capacity reduction caused by nanoplastic retention to the maximum safe extraction capacity	Assesses the additional loss of safe extraction capacity specifically caused by nanoplastic retention and contamination.

Comment (9): Fig. 3: *It is necessary to clarify whether the results presented in Figure 3 and the accompanying explanations are obtained from numerical simulations or laboratory experiments. Other similar figures should also be handled following this suggestion.*

Response:

Thank you for this important comment on improving clarity. We have carefully checked Figure 3 and all other relevant figures in the manuscript. We have added clear annotations in the text to explicitly state whether each result is from numerical simulations or laboratory experiments, ensuring full transparency and consistency throughout the text.

These revisions make the data source of each figure unambiguous and greatly enhance the readability and reliability of the results:“

The relationship between well salinity and the extraction volume ratio (actual to theoretical) in numerical simulations is illustrated in Fig. 3. Results confirm that the presence of the unsaturated and transition zones reduces the extraction capacity to 50%−60% of the theoretical maximum (Q_{Tmax}).”

Comment (10): *8: It is recommended that the figure caption not be directly named “combined effects”; instead, it should directly describe the indicators presented in the figure.*

Response:

Thank you for your constructive suggestion to improve the accuracy and informativeness of figure captions. We have revised the caption of Figure 8 by replacing the general phrase “combined effects” with a direct, detailed description of the indicators and variables shown in the figure.

This revision makes the figure caption more specific, standardized, and consistent with academic publishing norms, allowing readers to immediately understand the content of the figure.

The revised figure caption is as follows:“

Variations with pumping depth (d) and horizontal distance from island center (x_m) in the idealized strip-island aquifer in (a) theoretical maximum safe extraction capacity (Q_{Tmax}), (b) actual maximum safe extraction capacity (Q_{Amax}), (c) freshwater lens volume reduction rate (VR), and (d) ratio of maximum safe extraction capacity reduction caused by nanoplastic retention (RRSY).”

Comment (11): *Conclusions1 to 3 do not seem to specify the environmental context in which this finding was made. Therefore, I am curious whether this conclusion applies universally to any scenario, or only in the context of pumping in coastal zones?*

Response:

We appreciate this critical and constructive comment. To enhance the precision and applicability of our conclusions, we have added clear contextual qualifiers to Conclusions 1–3, explicitly stating that these findings are derived under the scenario of groundwater pumping in coastal strip-island aquifers.

This revision clarifies the specific environmental setting of the study and avoids overgeneralization, making the conclusions more rigorous and scientifically sound.

The revised conclusions are presented as follows: “

(1) Nanoplastic transport differs fundamentally from dissolved salt transport within the freshwater lenses of idealized strip-island aquifers during groundwater pumping. In contrast to dissolved salts, whose behavior is mainly regulated by advection and dispersion, nanoplastics are further affected by particle-specific processes, such as adsorption-desorption, clogging, and filtration. The higher effective dispersivity leads to earlier breakthrough at extraction wells and the development of broader contaminant transition zones compared to salinity alone under pumping-induced upconing conditions in coastal island aquifers.

(2) Transport behavior exhibits strong scale dependence in strip-island freshwater lens systems under pumping stress. Laboratory-scale simulations showed rapid contamination and prominent "upper cone" formation within minutes, whereas site-scale simulations demonstrated attenuated upward coning and much longer stabilization times on the order of years. This contrast highlights the importance of multi-scale modeling when extrapolating experimental results to real-world island aquifers subject to freshwater extraction and seawater intrusion.

(3) Dispersivity is the dominant control on nanoplastic risk for pumping wells tapping freshwater lenses in strip-island coastal aquifers. Among the evaluated parameters, nanoplastic dispersivity exerts the strongest influence on contaminant accumulation in extraction wells, with hydraulic conductivity and recharge rates playing secondary but important roles. When nanoplastic dispersivity exceeds approximately 17 times that of dissolved solutes, the contaminant plume can fully envelop the well screen, reducing the maximum safe extraction rate by 37-50% compared to salinity-based thresholds under island pumping scenarios.”