Thanks a lot to editor for your suggestions and decision for our manuscript, which are all important in improving our manuscript. We have revised the manuscript accordingly and have responded to the reviewers' comments in line with your recommendations.

-About the comment: *All three reviewers recognize that the manuscript addresses an important problem and is supported by a valuable, high-frequency dataset documenting lacustrine groundwater discharge (LGD) and associated nitrogen and phosphorus fluxes in a closed lake. The overall study design and use of* ^{222}*Rn tracing are viewed as appropriate, and the work has potential relevance for understanding nutrient dynamics and lake management. However, the reviewers also identify several substantive issues that require attention. Among the main issues are the need to more clearly articulate the novelty of the study and the specific knowledge gap addressed by the high-frequency observations, which are presented as the main advance but not sufficiently contrasted with prior work. The manuscript is often descriptive, and stronger mechanistic interpretation is needed to explain observed linkages among meteorological forcing, hydraulic gradients, LGD, and nutrient dynamics. Reviewers also request clarification and justification of several methodological choices, including sampling frequency, variable sample sizes, well placement, tracer selection, and the use of steady-state assumptions in the ^222Rn mass balance under dynamic water-level conditions. In addition, several conclusions—particularly regarding the dominant role of LGD in the nutrient budget, the control of chlorophyll-a by TN/TP ratios, and the generalization of results to closed lakes more broadly—are viewed as too strong and in need of qualification. Finally, improvements are needed in organization, definitions (e.g., "closed lake"), figure clarity, discussion of limitations, and the articulation of broader implications, with Reviewer 3 emphasizing the need to better demonstrate what new insights are uniquely enabled by the high-frequency monitoring. The manuscript is based on a strong dataset and addresses a timely topic, but substantial revisions are required before it can be reconsidered. I encourage the authors to carefully and thoroughly address all reviewer comments, with particular emphasis on clarifying novelty, strengthening mechanistic interpretation, justifying key assumptions and methodological choices, and appropriately qualifying the conclusions and their broader applicability.*

-Response: Thank you for your careful evaluation of our manuscript and for the systematic summary of the reviewers' comments. We appreciate the positive assessments provided by the three reviewers regarding the importance of the scientific question addressed in this study and the value of the dataset. At the same time, we fully recognize the substantive issues raised by the editor and the reviewers, and we understand the importance of these comments for further improving the scientific rigor and clarity of the manuscript. In the revised version, we have responded to all comments point by point and have made corresponding revisions and additional clarifications where feasible.

First, in response to concerns regarding the clarity of the study's novelty and the articulation of knowledge gaps, we have reorganized and revised the Introduction and Discussion sections. We now more clearly clarify the information that high-frequency observations can provide in revealing LGD and nutrient dynamics, and we compare our results with previous studies based on low-frequency observations, in order to better situate this study within the existing body of knowledge.

Second, in response to comments that the manuscript was overly descriptive and lacked mechanistic interpretation, we have provided a more intuitive explanation of the relationships among meteorological forcing, hydraulic gradient variations, and LGD dynamics through schematic logical diagrams illustrating the relevant processes and mechanisms.

Third, with regard to methodological aspects, we have provided further clarification and discussion on the sampling frequency, differences in sample size among variables, and the applicability of the steady-state (or quasi-steady-state) assumption in the ^{222}Rn mass-balance model.

Fourth, in response to concerns that some conclusions were overly generalized, we have made corresponding adjustments to the Conclusions and Discussion sections. Specifically, we have moderated statements regarding the strength of LGD's role in nutrient budgets, the relationship between TN/TP ratios and chlorophyll-a regulation, and the broader applicability of our findings, and we have more clearly defined the conditions and study context under which these conclusions apply.

Finally, we have made corresponding improvements to the overall structure and presentation of the manuscript. These include unifying and clarifying key terminology (e.g., "closed lake"), improving the clarity and readability of figures, expanding the discussion of study limitations, and presenting the potential implications of our results in a more cautious manner.

We hope that these revisions adequately address the main concerns raised by the editor and the reviewers. We sincerely thank the editor and the reviewers for the time and effort devoted to the evaluation of our manuscript, and we look forward to the further consideration of the revised version.

Thanks a lot to Anonymous Referee #1 for your suggestions for our manuscript, which are all important in improving our manuscript. Below are our responses to the comments, and all changes are clearly marked in red in the version of "Revised manuscript with tracked changes".

-About the comment (1): *L. 45: The authors mention that "the understanding of monthly scale LGD modulation by meteorological forcing remains limited". Why does this gap matter for lake management or biogeochemical cycling?*

-Response: Thanks for your good suggestion. We consider that understanding the regulatory mechanisms of meteorological forcing on monthly-scale LGD is of great significance for lake management, particularly in terms of both water resources and water quality.

(1) From a water resources perspective, accurately characterizing the monthly variation of LGD can support the development of more targeted strategies for water allocation and protection. Under the current context of increasingly frequent and intense extreme weather events, fluctuations in precipitation–evaporation patterns significantly influence the timing of groundwater recharge, which in turn affects lake water level stability and the ability to meet ecological water demands. As a key flux linking terrestrial water cycles and lake water bodies, the monthly dynamics of LGD provide critical information for precise water resource management and for responding effectively to climate disturbances.

(2) From a water quality perspective, LGD represents a substantial yet often hidden pathway for nutrient inputs, including nitrogen and phosphorus. Its monthly variability can directly drive seasonal changes in lake nutrient loads. A thorough understanding of how LGD is regulated by meteorological factors not only helps identify periods of heightened eutrophication risk but also provides scientifically grounded time windows for implementing management interventions, thereby avoiding resource waste and substantially enhancing management efficiency and remediation effectiveness.

In the revised manuscript, we have added this content to the third paragraph of the Introduction, phrased as follows:

"Understanding the monthly-scale variations and their controlling mechanisms is essential not only for predicting responses to extreme hydrological events but also for identifying critical periods of nutrient input that drive eutrophication." **(Line 65-67)**

-About the comment (2): *Please clearly define the term "closed lake" early in the introduction to provide immediate conceptual clarity for readers.*

-Response: Thanks for your good suggestion. We acknowledge that a clear definition of closed lakes was not explicitly provided in the manuscript, and this was an oversight on our part. Here, we define closed lakes as lakes that lack perennial surface river inflows, or for which inflowing runoff has a negligible influence on hydrodynamic processes, lake water balance, and water residence time. For such lakes, the water balance is primarily regulated by precipitation, evaporation, and groundwater exchange, and, compared with open lakes, their hydrological cycle is more independent and exhibits a very low reliance on external surface-water inputs.

In the revised manuscript, we have added this definition at the second occurrence of the term "closed lakes" in the second sentence of the second paragraph of the Introduction.

Here is the revision for addressing this comment.

"...closed lake systems (lacking perennial surface river inflows or where inflowing runoff has minimal impact on hydrodynamics, water balance, or residence time)...." **(Line 40-41)**

-About the comment (3): *Provide a brief justification for the selection of ^{222}Rn as the primary tracer in this study to clarify its advantages over other potential tracers.*

-Response: Thanks for your good suggestion. In the Introduction, we added a paragraph specifically discussing the use of radon as a tracer for LGD, highlighting its advantages.

Here is the revision for addressing this comment.

"Environmental tracers are increasingly applied in studies of LGD. An ideal tracer typically exhibits significant concentration differences between lake water and groundwater (often spanning orders of magnitude) and stable chemical properties (Arnoux et al., 2017; Petermann et al., 2018). Commonly used tracers include ^{222}Rn, ^{226}Ra, stable hydrogen and oxygen isotopes (δ^2H, δ^{18}O), Cl$^-$, and electrical conductivity (Sun et al., 2021). Among these, ^{222}Rn and ^{226}Ra often show concentration differences of up to two-three orders of magnitude between the two water types, whereas differences in Cl$^-$ and electrical conductivity are generally smaller (sometimes only several times). Therefore, ^{222}Rn and ^{226}Ra are frequently the preferred tracers in LGD studies, with other indicators used as auxiliaries when conditions permit (Dimova & Burnett., 2011). The applicability of stable hydrogen and oxygen isotopes is strongly influenced by hydrological stability; in lakes with pronounced seasonal hydrological fluctuations, their quantitative accuracy may be significantly reduced (Sun et al., 2025a). Regarding radioactive tracers, ^{226}Ra primarily desorbs from particles into the water phase in brackish or saline environments (Webster et al., 1995; Gonneea et al., 2008), and its concentration is typically low in freshwater lakes. Consequently, in freshwater lake LGD studies, ^{222}Rn is more commonly used and effective due to its high solubility, large concentration gradient, and ease of detection..” **(Line 68-82)**

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Arnoux, M., Gibert-Brunet, E., Barbecot, F., Guillon, S., Gibson, J., and Noret, A.: Interactions between groundwater and seasonally ice-covered lakes: using water stable isotopes and radon-222 multilayer mass balance models, Hydrol. Process., 31, 2566–2581, 2017.

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Webster, I. T., Hancock, G. J., and Murray, A. S.: Modelling the effect of salinity on radium desorption from sediments, Geochim. Cosmochim. Acta, 59, 2469–2476, 1995.

Gonneea, M. E., Morris, P. J., Dulaiova, H., and Charette, M. A.: New perspectives on radium behavior within a subterranean estuary, Mar. Chem., 109, 250–267, 2008.

-About the comment (4): *The study states “bi-monthly, high-frequency monitoring”. Justify why this frequency was sufficient to capture seasonal dynamics.*

-Response: Thanks for your good question. Regarding why a bimonthly monitoring frequency is sufficient to capture the seasonal dynamics of lake–groundwater interactions, our considerations are mainly based on the following points:

(1) Seasonal variation characteristics: Hydrological processes in the study area are primarily

driven by seasonal climate factors (e.g., precipitation, temperature, and evaporation), which typically vary on a monthly rather than daily or weekly scale. Bimonthly monitoring provides six data points per year, adequately covering the four typical seasons (spring, summer, autumn, and winter) and capturing key evolutionary trends within each season.

(2) Response rate of hydrological processes: LGD and related water quality parameters exhibit lagged and cumulative responses to external conditions. A bimonthly interval effectively records these gradual changes without generating redundant high-frequency data, while still capturing important seasonal transition signals.

(3) Alignment with research objectives: The focus of this study is to reveal seasonal differences and their controlling mechanisms, rather than to characterize short-term events (e.g., storm runoff).

In summary, a bimonthly monitoring design allows systematic capture of seasonally based dynamics, aligns with the natural pace of hydrological processes, and thus adequately supports the effective identification and mechanistic analysis of seasonal variations in this study.

-About the comment (5): *The authors used ECMWF reanalysis datasets for meteorological data. Explain why this dataset was chosen over local station data.*

-Response: Thanks for your good question. The selection of meteorological data sources, which you highlighted, is indeed a key consideration in the design of this study. We chose reanalysis data from the ECMWF for the following reasons:

(1) Lack of long-term observational data: The study area and its surroundings lack long-term, continuous, and complete meteorological observations, particularly reliable direct measurements of evaporation. Reanalysis data provide spatiotemporally continuous and physically consistent meteorological fields, compensating for the spatial and temporal limitations of ground-based observations.

(2) Spatial uniformity and global consistency: ECMWF reanalysis data offer good spatial uniformity and global consistency, enabling objective and systematic meteorological inputs in regions with sparse station coverage. This is particularly important for analyzing catchment-scale hydrological processes and long-term trends.

(3) Validation and reliability: Reanalysis products such as ECMWF have been extensively validated in previous studies, showing good correlation with observations for variables such as

precipitation and air temperature. Although some local biases may exist, the temporal trends and seasonal signals are reliably represented.

(4) Suitability for study objectives: Our study focuses on revealing the seasonal dynamics and long-term associations of lake–groundwater interactions rather than simulating short-term extreme hydrological events. The climate characteristics and seasonal evolution provided by reanalysis data are sufficient to support trend analysis and causal inference at this scale.

We fully agree that, ideally, local observational data should be used for calibration and validation. In future work, if such data become available, we will carry out comparative analyses and revise results accordingly. Nevertheless, the current analyses based on reanalysis data robustly capture the main seasonal patterns of precipitation–evaporation processes in the region and their influence on LGD.

-About the comment (6): *The wells are described as being "0.5 to 2.5 km from the lakeshore," but the rationale for their spatial distribution is not explained. Specify the criteria for selecting monitoring well locations.*

-Response: Thanks for your good question. The spatial layout of monitoring wells is critically important, as it directly affects our ability to accurately collect samples that represent groundwater end members. In selecting well locations, we followed two main considerations:

First, based on prior knowledge of HWL Oxbow Lake, we recognized that groundwater primarily enters the lake through two pathways: (1) springs emerging along the lake shoreline, representing direct groundwater discharge to the littoral zone, and (2) confined aquifers that are directly connected to the deep-water areas of the lake. Accordingly, our sampling design targeted both end members: eight spring sites were sampled along the lake shore, and additional wells were selected to represent the confined groundwater.

In practice, however, the availability of suitable monitoring wells with evenly distributed locations was limited. The final selected wells were located 0.5-2.5 km from the lake shore, representing the closest accessible points whose water quality could reflect natural background conditions. Despite the spatial constraints, all wells were situated within the same hydrogeological unit, and their water chemistry matched the regional confined groundwater background.

Regarding whether these wells truly represent the groundwater entering the lake, we note that groundwater levels in the surrounding area are generally higher than the lake water level, ensuring that the overall flow direction is toward the lake. Within this relatively homogeneous aquifer, groundwater chemistry is typically stable over several kilometers, and ^{222}Rn concentrations are primarily controlled by aquifer lithology rather than flow distance. To further minimize the influence of single-point fluctuations, we collected samples simultaneously from all eight wells and used the mean ^{222}Rn value to represent this end-member. This multi-point averaging approach is commonly employed in groundwater studies to smooth local anomalies and enhance regional representativeness.

-About the comment (7): *In Section 3.3.1, LGD-TP loads are stated to be "mainly controlled by the concentration of TP in groundwater" rather than by LGD rate. Explain what might drive these TP-concentration variations.*

-Response: Thanks for your good suggestion. The TP load carried by LGD is typically calculated as the product of LGD rate and TP concentration in groundwater. In the current manuscript, this load is reported to be "primarily controlled by groundwater TP concentration" rather than LGD rate, mainly because the seasonal variability of TP concentration is generally larger than that of LGD rate. To investigate the mechanisms driving TP concentration dynamics, we further examined key hydrogeochemical parameters, including electrical conductivity (EC), dissolved oxygen (DO), and redox potential (Eh). Based on monitoring data from August 2022 to April 2023, the TP dynamics can be roughly divided into three stages:

(1) Aug–Dec 2022 (TP rise followed by decline): During this period, Eh increased markedly from −97.43 mV to −56.24 mV, and DO rose from 1.24 to 2.60 mg/L, indicating rapid aquifer oxidation. In the early oxidation phase (up to October), "oxidative dissolution" of phosphate-bearing minerals may have temporarily elevated TP to 2.00×10^{-2} mmol/L. Subsequently, strong oxidative conditions promoted the formation of iron and manganese oxides, which adsorbed phosphorus. Although EC increased from 823.83 to 942.61 μS/cm, suggesting an increase in competitive anions, adsorption dominated, and TP ultimately declined to the monitoring minimum of 6.46×10^{-3} mmol/L by December.

(2) Dec 2022–Feb 2023 (TP increase): Eh continued to rise substantially to −27.26 mV, and DO remained relatively high at 2.29 mg/L, indicating that the system had not returned to a reducing state. The TP peak (2.19×10^{-2} mmol/L) during this stage was therefore not due to reductive release. Instead, it was primarily driven by external phosphorus inputs associated with enhanced precipitation and agricultural activities. Meanwhile, EC reached the monitoring-period maximum of 973.69 μS/cm,

indicating the influx of high concentrations of dissolved salts. These competitive anions may have temporarily weakened sediment phosphorus retention, jointly contributing to the TP increase.

(3) Feb–Apr 2023 (TP decline): Oxidative conditions intensified further, with Eh and DO reaching the monitoring-period maximum values of −13.94 mV and 3.58 mg/L, respectively. Strong oxidative adsorption dominated once again, effectively removing most of the previously input phosphorus. Despite EC remaining high (961.83 μS/cm), TP concentration declined substantially to 8.24×10^{-3} mmol/L by April.

Overall, the fluctuations in TP concentration reflect the combined effects of internal adsorption and fixation, external input pulses, and geochemical competition (as indicated by EC changes) under a macro-scale context of aquifer oxidation driven by declining water levels (Eh and DO continuously increasing).

Table S3. EC, DO and Eh values in groundwater for each sampling period.

Date	Groundwater EC (μS/cm)	Groundwater DO (mg/L)	Groundwater Eh (mv)
08/2022	823.83	1.24	-97.43
10/2022	920.44	1.41	-81.26
12/2022	942.61	2.6	-56.24
02/2023	973.69	2.29	-27.26
04/2023	961.83	3.58	-13.94

To simplify the description and integrate it into the manuscript, we refined the statement as follows: "Based on Eh, DO, and EC results (Table S3), TP concentration fluctuations likely result from the combined effects of internal adsorption and fixation, external input pulses, and geochemical competition under the background of an oxidation-enhanced environment driven by declining water levels (Eh and DO continuously increasing). For a detailed analysis, see the SI." **(Line 418-422)**

-About the comment (8): *The CV is mentioned in the context of* ^{222}*Rn stability but is not defined. Add a short explanation or cite a standard reference for clarity.*

-Response: Thanks for your good suggestion. The coefficient of variation (CV) used in our study is a dimensionless statistic employed to measure the relative dispersion, or variability, of a dataset. It is defined as the ratio of the standard deviation (σ) to the arithmetic mean (μ) and is typically expressed as a percentage: $CV = (\sigma / \mu) \times 100\%$.

We have added this concept to the manuscript as follows: "CV, used to measure the relative dispersion of data, defined as the ratio of the standard deviation to the arithmetic mean". **(Line**

278-279)

-About the comment (9): *Given the strong control of precipitation-evaporation balance on LGD, briefly discuss how projected changes in regional climate (e.g., increased drought frequency, higher evaporation) might alter LGD patterns and, consequently, nutrient loading in closed lakes over decadal timescales.*

-Response: Thanks for your good suggestion and question. We discussed the potential future trends of LGD under the context of climate change and its implications for nutrient inputs. Previous studies indicate that in the East Asian monsoon region, future climate scenarios are likely to lead to more precipitation concentrated in summer, while non-summer periods (especially autumn and winter) will experience reduced rainfall and increased evaporation. Under such conditions, the net precipitation (precipitation minus evaporation) during the non-summer periods—when LGD predominantly occurs—may increase, potentially enhancing groundwater discharge to lakes. This would directly elevate the total TN and TP loads delivered by LGD, further highlighting the critical role of groundwater processes in regulating nutrient balances in closed lakes. Relevant discussion has been incorporated into the revised manuscript.

Here is the revision for addressing this comment.

"Moreover, climate change is expected to modulate these processes. In the East Asian monsoon region, future precipitation is projected to become more concentrated in summer, while non-summer periods, particularly autumn and winter, may experience reduced rainfall and increased evaporation. Because LGD predominantly occurs during non-summer periods, increased net precipitation (precipitation minus evaporation) could enhance groundwater discharge, directly elevating associated TN and TP fluxes. These considerations further underscore the critical role of groundwater in regulating nutrient balances in closed lakes and highlight the need for future nutrient management strategies to account for both LGD variability and climate-driven hydrological changes." **(Line 563-570)**

Furthermore, based on our long-term research and related insights, LGD trends can also be considered at the interannual scale. Our previous studies indicate that LGD rates during the dry season in HWL are jointly regulated by annual Yangtze River runoff and regional total annual precipitation: in years with higher runoff and precipitation, LGD rates are relatively higher, and vice versa (Sun et al., 2024). Therefore, under future scenarios of overall increased precipitation, LGD rates may show a gradual upward trend over decadal scales, accompanied by higher absolute TN and TP input loads.

However, our four consecutive years of observations revealed an important phenomenon: higher LGD and associated nutrient loads at the interannual scale do not necessarily lead to elevated TN and TP concentrations in lake water; they are often associated with lower concentrations. This is likely due to dilution and concentration effects driven by changes in lake water volume dominating the regulation of nutrient concentrations. Specifically: (1) in high-LGD years, greater precipitation and larger lake volume dilute the nutrients delivered by LGD, reducing their relative contribution to total lake TN and TP; (2) in low-LGD years, often associated with drought, lake volume is smaller, so even modest LGD nutrient inputs contribute relatively more, and evaporative concentration during dry years further amplifies LGD's impact on lake water chemistry.

These findings carry important management implications: under future scenarios of increased frequency and intensity of droughts, even if absolute LGD nutrient loads decline, their regulatory effect on lake water quality—particularly TN/TP concentrations—will become more sensitive, potentially increasing the risk of water quality deterioration in closed lakes. This mechanism underscores the need for nutrient management strategies that consider the interaction between LGD variability and lake water volume dynamics. Systematic studies on this topic are ongoing and will be further validated through long-term monitoring and multi-scale analyses.

References

Sun, X., Du, Y., Wu, J., Xu, J., Tian, H., Deng, Y., and Wang, Y.: Two-decadal variability of lacustrine groundwater discharge: coupled controls from weather and hydrologic changes, Water Resour. Res., 60, e2024WR037173, 2024.

Thanks a lot to Anonymous Referee #2 for your suggestions for our manuscript, which are all important in improving our manuscript. Below are our responses to the comments, and all changes are clearly marked in red in the version of "Revised manuscript with tracked changes".

#Major Comments

-About the comment (1): *Multiple field sampling campaigns were conducted, yet Table 1 shows that the number of samples varies among different periods. Please clarify the reasons for this variation. For example, was it caused by water level fluctuations that limited access to certain sites, or by logistical constraints such as equipment availability or adverse weather conditions? Differences in sample size may introduce uncertainty into statistical analyses and model results, and this issue should be explicitly discussed.*

-Response: Thanks for your good question. As you correctly pointed out, the number of samples indeed varies among different sampling campaigns. As shown in Table 1, the sample numbers in August and October 2022 and in February and April 2023 are identical, and the spatial locations of the sampling sites are largely consistent across these periods. In contrast, some differences in sample numbers are observed in the other months. These discrepancies mainly arise from practical limitations on sampling feasibility under different hydrological conditions.

Specifically, June 2022 corresponded to the high-water period, during which the lake water level increased substantially. In most areas, the lake water reached the shoreline embankment and was retained by the dike, making it impossible to use the push-point device to collect porewater samples within the embankment. As a result, only two porewater samples were obtained during this campaign. July 2023 was also a high-water period; however, the lake level at that time was lower than in June 2022, and several accessible sites remained along the shoreline, allowing more porewater samples to be collected.

In addition, the number of lake water samples in December 2022 increased to 35 because another study was conducted simultaneously during this period, which required as high a spatial sampling density as possible. The results of that study have already been published (Sun et al., 2025b). To ensure data consistency and comparability between the two studies, we fully adopted the sample number and corresponding data from that study for this period.

For LGD studies, the primary principle of sampling design is to achieve a spatially uniform distribution of sampling sites that can represent the overall characteristics of the lake, rather than relying solely on the absolute number of samples. Further analysis shows that even when only 16 samples located at positions consistent with those in other campaigns are selected from the 35 lake water samples collected in December 2022, the mean ^{222}Rn concentration is 235.59 Bq/m^3, which differs by only about 1.6% from the mean value calculated using all 35 samples (231.61 Bq/m^3). This difference is far smaller than the approximately 25% uncertainty adopted in the quantification of LGD rates.

Therefore, we consider that the variations in sample numbers among different periods are mainly attributable to objective sampling constraints and study design requirements, and they have a negligible impact on the subsequent statistical analyses and LGD estimations, without affecting the overall conclusions of this study.

References

Sun, X., Du, Y., Xu, J., Tian, H., Deng, Y., Gan, Y., and Wang, Y.: Control of groundwater–lake interaction zone structure on spatial variability of lacustrine groundwater discharge in oxbow lake, Water Resour. Res., 61, e2024WR039334, 2025b.

-About the comment (2): *A steady-state assumption was applied when constructing the ^{222}Rn mass balance model for each sampling period. However, the monitoring data indicate notable water level fluctuations, including periods when lake levels exceeded groundwater levels. Under such dynamic hydrological conditions, the applicability of a steady-state assumption warrants further justification.*

-Response: Thanks for your good question. Although pronounced water-level variations do occur in the study area, such changes predominantly operate on relatively long time scales (i.e., monthly to seasonal), rather than on the short time scales relevant to the ^{222}Rn mass balance calculations. As noted in the manuscript, the lake water level changed by approximately 10 m over a 10-month period, with nearly 8 m of this decline occurring between June and August 2022, mainly driven by the rapid recession of the Yangtze River, which induced lake outflow and a corresponding drop in water level.

During the period used for LGD quantification (August 2022 to April 2023), however, the water-level change between consecutive sampling campaigns (approximately every two months) averaged only 0.73 m, corresponding to a mean daily change of about 1.2 cm. At the daily time scale adopted in the ^{222}Rn mass balance model, such water-level variations are negligible and are unlikely to significantly affect the model results.

If a non-steady-state formulation were to be applied, it would require explicit consideration of the temporal change in lake-water ^{222}Rn inventory. Using December 2022, when lake-water ^{222}Rn concentration was highest (mean value of 231.61 Bq/m^3), the resulting daily change term in the ^{222}Rn inventory is estimated to be approximately 2.82 Bq/m^{2}d. This value is orders of magnitude smaller than the groundwater-derived ^{222}Rn input (162.31 Bq/m^{2}d), indicating that inclusion of the non-steady-state term would have a negligible influence on the calculated LGD rates. Consequently, the results obtained from non-steady-state and steady-state models would be nearly identical.

In addition, during the study period we routinely collected repeated lake water samples at the same sites within different time. The observed variability in lake-water ^{222}Rn concentrations remained within 15%, which is smaller than the 25% uncertainty assigned to lake-water ^{222}Rn concentrations in the subsequent uncertainty analysis. This further supports the appropriateness of the steady-state assumption.

In practice, non-steady-state ^{222}Rn mass balance models are most applicable to systems characterized by pronounced short-term water-level fluctuations and require continuous or high-frequency ^{222}Rn monitoring, such as large lakes, estuaries, coastal oceans, or lakes strongly influenced by rapid inflow and outflow. The studied HWL does not exhibit such hydrological behavior. Therefore, given the hydrological characteristics of the study area and the time scales involved, the steady-state assumption adopted in this study is reasonable and unlikely to introduce significant bias into the LGD estimates.

-About the comment (3): *During June 2022 and July 2023, groundwater levels were lower than lake levels, suggesting potential leakage of lake water into the aquifer. Could the authors clarify the ^{222}Rn concentrations in the lake during these periods? Were these concentrations noticeably lower than those observed during other sampling campaigns?*

-Response: Thanks for your good question. As shown in Figure. 2, during the two periods when the groundwater level was lower than the lake water level (June 2022 and July 2023), lake-water ^{222}Rn concentrations were 87.50 and 95.59 Bq/m^3, respectively, which are significantly lower than those observed during the other periods. Nevertheless, measurable ^{222}Rn was still detected in the lake water, indicating that sources other than groundwater discharge may have contributed to the observed ^{222}Rn.

During these two periods, the rise in lake water level was mainly driven by inflow from the Yangtze River. The ^{222}Rn concentrations in the Yangtze River water measured concurrently were 90.50 Bq/m^3 in June 2022 and 50.47 Bq/m^3 in July 2023. In June 2022, the ^{222}Rn concentration in HWL was very similar to that in the Yangtze River, suggesting that lake-water ^{222}Rn was primarily controlled by Yangtze River inputs during this period.

In contrast, in July 2023 the lake-water ^{222}Rn concentration was slightly higher than that of the Yangtze River, implying that, in addition to river-water input, a small amount of groundwater discharge may still have occurred. As shown in Fig. 2a, not all groundwater levels around the lake were lower than the lake water level during this period; water levels in two monitoring wells were slightly higher than the lake level, indicating the possible presence of weak, localized groundwater discharge into the lake. Consequently, the lake-water ^{222}Rn signature during this period likely reflects the combined effects of minor groundwater discharge and substantial Yangtze River input.

Moreover, enhanced summer precipitation resulted in increased catchment runoff entering the lake. Measurements of ^{222}Rn concentrations in the inflow channels show generally high values (>500 Bq/m^3), with some samples exceeding 1000 Bq/m^3. However, we suggest that these elevated ^{222}Rn concentrations do not originate from aquifer groundwater but are mainly associated with interactions between rainfall and surface-soil minerals during runoff generation, which promote the release of ^{222}Rn from near-surface soils into the lake. The surface soils in the study area are dominated by clay and silt, and previous investigations have shown that porewater in such lithologies commonly exhibits ^{222}Rn concentrations exceeding 10,000 Bq/m^3, which are much higher than those typically observed in aquifer groundwater. Therefore, the higher lake-water ^{222}Rn concentration in July 2023 compared to June 2022 can be attributed to the combined influences of Yangtze River input, localized weak groundwater discharge, and summer precipitation-driven runoff.

Given that this study focuses on groundwater discharge under relatively closed-lake conditions, periods characterized by strong surface-water hydraulic connectivity between the lake and external water bodies are not considered key intervals for LGD quantification.

The related discussion have added to the section describing the characteristics of lake-water ^{222}Rn concentrations.

“Notably, as shown in Figure. 2a and c, during the two periods when the groundwater level was lower than the lake water level (June 2022 and July 2023), lake-water ^{222}Rn concentrations were 87.50 and 95.59 Bq m^{-3}, respectively, which are lower than those in the other periods, indicating that groundwater discharge was generally limited. Nevertheless, measurable ^{222}Rn was still detected in the lake water, suggesting additional inputs from other water sources. Concurrently, ^{222}Rn concentrations in the Yangtze River were 90.50 and 50.47 Bq m^{-3}, respectively. In June 2022, the lake-water ^{222}Rn concentration was very similar to that of the Yangtze River, indicating that the lake was mainly controlled by Yangtze River inputs during this period. In contrast, in July 2023 the lake-water ^{222}Rn concentration was slightly higher than that of the Yangtze River; together with the observation that groundwater levels in some monitoring wells were still slightly higher than the lake level, this suggests the presence of weak, localized groundwater discharge during this period. In addition, intense summer precipitation led to increased catchment runoff into the lake, which generally exhibited high ^{222}Rn concentrations, primarily derived from ^{222}Rn released through interactions between rainfall and surface soils rather than from aquifer groundwater. Overall, the higher lake-water ^{222}Rn concentration in July 2023 compared with June 2022 reflects the combined effects of Yangtze River input, localized weak groundwater discharge, and precipitation-driven runoff.” **(Line 287-302)**

-About the comment (4): *The monitoring results suggest temporal changes in the hydraulic relationship between groundwater and lake water at different locations. It would be helpful to know whether spatial variability in these exchange patterns was also observed. For instance, do nearshore areas behave differently from deeper parts of the lake?*

-Response: Thanks for your good question. During the different sampling campaigns, variations in lake-water ^{222}Rn concentrations indicate that the relative magnitude and spatial ranking of ^{222}Rn among sampling sites are not consistent across all periods, but instead change over time. This observation suggests that the spatial variability of LGD exhibits clear temporal dynamics. Groundwater-level records from monitoring wells likewise show that the magnitude of water-level decline differs among regions, further supporting this interpretation. Such differences are likely related to variations in land-use type and anthropogenic groundwater abstraction. For example, in areas where the surface is occupied by fish ponds, downward seepage from pond water may partially recharge groundwater, resulting in smaller declines in groundwater levels, whereas areas with intensive groundwater extraction tend to exhibit much larger groundwater-level drawdowns.

Although the spatial distribution of LGD may vary to some extent at local scales over time, its overall spatial pattern remains relatively stable at the whole-lake scale. Our previous studies have demonstrated that the spatial pattern of LGD in HWL is primarily controlled by the lake–aquifer interaction structure, with LGD rates in the deep central lake area consistently exceeding those in the shallow nearshore zones (Sun et al., 2025b). This fundamental spatial characteristic remains robust across different observation periods.

References

Sun, X., Du, Y., Xu, J., Tian, H., Deng, Y., Gan, Y., & Wang, Y. (2025). Control of groundwater-lake interaction zone structure on spatial variability of lacustrine groundwater discharge in oxbow lake. Water Resources Research, 61(1), e2024WR039334.

-About the comment (5): *Lines 359–365 attribute variations in chlorophyll-a primarily to changes in the N/P ratio of nutrients supplied by lacustrine groundwater discharge. While this explanation is reasonable, phytoplankton dynamics are typically controlled by multiple interacting factors, including water temperature, light availability, community succession, and suspended solids. I recommend moderating the language in this section by presenting groundwater-derived nutrients as one important driver rather than the sole controlling factor, and by acknowledging the potential influence of other environmental variables.*

-Response: Thanks for your good suggestion. We agree with your point that light availability and water temperature also influence Chl *a* growth. In general, during this study, summer and autumn are characterized by higher air temperatures and favorable light conditions, which are theoretically conducive to phytoplankton growth. However, as shown in Fig. 5f of the manuscript, Chl a concentrations continuously decreased from August 2022 to February 2023, whereas they increased rapidly and reached a peak in April 2023. The pronounced increase during this period may, to some extent, be attributed to improved light and temperature conditions. Nevertheless, it should be noted that during the summer wet season—when temperature and light conditions are most favorable and LGD does not occur—the mean Chl a concentration was only about 60 μg/L, which is substantially lower than the 98.69 μg/L observed in April 2023. This comparison indicates that, although light and temperature exert a positive influence on Chl *a* growth, they are not the dominant controlling factors; instead, lake water nitrogen and phosphorus concentrations and their molar ratio (TN/TP) play the key role in regulating Chl *a* dynamics.

We have added the following text to the revised manuscript.

"In addition, light availability and water temperature can also affect Chl *a* growth. Although higher temperatures and favorable light conditions in summer and autumn are theoretically conducive to phytoplankton proliferation, Figure. 6f shows that Chl *a* concentrations decreased continuously from August 2022 to February 2023, but increased rapidly and reached a peak in April 2023. This increase may be partly related to improvements in light and temperature conditions. However, during the summer wet season, when temperature and light are most favorable and LGD is absent, the mean Chl *a* concentration was only ~60 μg/L, which is much lower than the 98.69 μg/L observed in April 2023. These results suggest that light and temperature are not the dominant drivers of Chl *a* variability; instead, nitrogen and phosphorus concentrations and their TN/TP are the key controlling factors." **(Line 463-471)**

-About the comment (6): *Section 3.4 concludes that nitrogen and phosphorus inputs via lacustrine groundwater discharge dominate the nutrient budget of this closed lake. Although this conclusion is plausible, it requires careful qualification. During periods of weak groundwater discharge, or in other closed lakes with limited groundwater inputs, internal nutrient loading from sediments may play a dominant role. To provide a more balanced perspective, the authors are encouraged to consider sediment nutrient release processes in the nutrient budget discussion. In addition, the manuscript would benefit from more explicit and actionable management implications, such as how regulating groundwater-driven nutrient inputs could help mitigate eutrophication.*

-Response: Thanks for your good suggestion. Yes, we fully agree with and appreciate your comment and suggestion. In lakes or during periods when LGD is relatively weak, the contribution of LGD-borne nutrients to the overall lake nutrient budget may indeed be minor. This aligns with the conventional understanding that internal nitrogen and phosphorus release from bottom sediments can represent the dominant nutrient source for lakes under such conditions. Accordingly, we have revised this section to reflect this perspective.

We have added the following text to the revised manuscript.

"Previous studies have long approached the issue of internal nutrient loading in lakes primarily from the perspective of nitrogen and phosphorus release from bottom sediments, emphasizing the role of sediment-derived nutrients in shaping lake trophic status (Donohue and Garcia Molinos, 2009). For lakes where LGD-derived nutrient loads are relatively small during specific seasons, sedimentary nutrient release can indeed constitute a major source to the overlying water column, consistent with traditional understanding (Xu et al., 2017). However, in systems where LGD inputs are substantial, focusing solely on sedimentary release may not fully capture the true structure of lake nutrient sources. Although systematic studies that simultaneously assess both sediment nutrient release and LGD-derived inputs remain limited, existing evidence indicates that LGD is likely a key mechanism sustaining nutrient cycling and ecological succession in closed-basin lakes, highlighting the need for more comprehensive and quantitative investigations." **(Line 536-546)**

-About the comment (7): *Does the close lake imply the absence of surface outflow, reliance on precipitation and groundwater recharge, or a long water residence time? Providing a clear definition would improve the transferability of the results to other lake systems.*

-Response: Thanks for your good suggestion. We acknowledge that a clear definition of closed lakes was not explicitly provided in the manuscript, and this was an oversight on our part. Here, we define closed lakes as lakes that lack perennial surface river inflows, or for which inflowing runoff has a negligible influence on hydrodynamic processes, lake water balance, and water residence time. For such lakes, the water balance is primarily regulated by precipitation, evaporation, and groundwater exchange, and, compared with open lakes, their hydrological cycle is more independent and exhibits a very low reliance on external surface-water inputs.

In the revised manuscript, we have added this definition at the second occurrence of the term "closed lakes" in the second sentence of the second paragraph of the Introduction.

Here is the revision for addressing this comment.

"... closed lake systems (lacking perennial surface river inflows or where inflowing runoff has minimal impact on hydrodynamics, water balance, or residence time)...." **(Line 40-41)**

-About the comment (8): *The conclusion section mainly summarizes the key findings. Its impact would be enhanced by adding a brief discussion of the study's limitations, such as the monitoring duration, spatial resolution, or model simplifications, as well as outlining directions for future research, including long-term observations, coupled surface-subsurface modeling, or the inclusion of biogeochemical transformation processes.*

-Response: Thanks for your good suggestion. Identifying research limitations and outlining future perspectives are critically important. Based on the findings and insights of this study, we have added a dedicated section in the manuscript to discuss the study limitations and to call for future research.

Here is the revision for addressing this comment.

"Previous studies have long approached the issue of internal nutrient loading in lakes primarily from the perspective of nitrogen and phosphorus release from bottom sediments, emphasizing the role of sediment-derived nutrients in shaping lake trophic status (Donohue and Garcia Molinos, 2009). For lakes where LGD-derived nutrient loads are relatively small during specific seasons, sedimentary nutrient release can indeed constitute a major source to the overlying water column, consistent with traditional understanding (Xu et al., 2017). However, in systems where LGD inputs are substantial, focusing solely on sedimentary release may not fully capture the true structure of lake nutrient sources. Although systematic studies that simultaneously assess both sediment nutrient release and LGD-derived inputs remain limited, existing evidence indicates that LGD is likely a key mechanism sustaining nutrient cycling and ecological succession in closed-basin lakes, highlighting the need for more comprehensive and quantitative investigations." **(Line 536-546)**

"Based on the above understanding, future research should adopt a systems-based perspective, focusing on comparative analyses of LGD inputs versus internal sediment release and quantitatively identifying their relative importance across different lake types and temporal scales to clarify the primary nutrient sources. This approach can provide a scientific basis for designing targeted nitrogen and phosphorus reduction strategies, as well as effective lake management and ecological restoration measures, thereby improving water quality and ecological function in closed lakes." **(Line557-562)**

#Minor Comments

-About the comment (9): *The background shading in panels (c), (d), and (e) of Figure 2 differs from that used in other figures. Please remove the background color to ensure visual consistency throughout the manuscript.*

-Response: Thanks for your good suggestion. We have removed the background shading in Figure 2(c), (d), and (e). The revised figure is shown below:

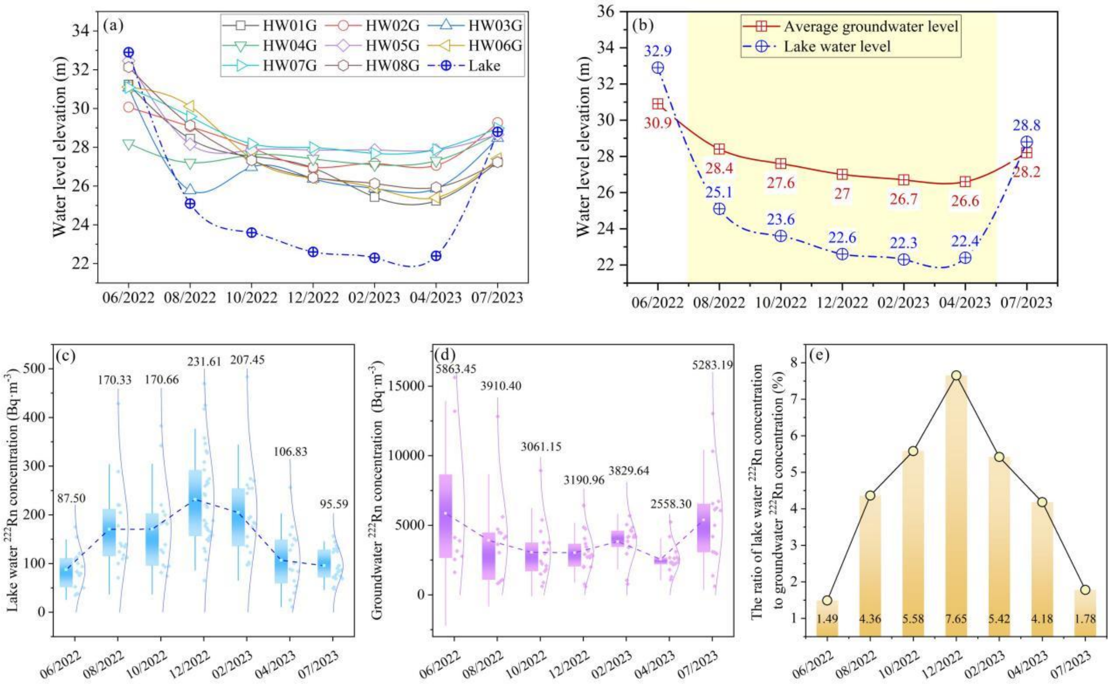

Figure 2. (a) Variations in lake water level and groundwater levels across all groundwater monitoring points. (b) Variations in lake water levels compared with the average groundwater level, the yellow area indicates the period of LGD. (c) Variations in the lake water concentrations of ^{222}Rn. (d) Variations in the groundwater concentrations of ^{222}Rn. (e) Variations in the ratio of ^{222}Rn concentrations in lake water to groundwater.

-About the comment (10): *Figure 3b contains a large amount of information. The components related to correlation analysis could be separated and presented as an individual figure in the supplementary material to improve clarity.*

-Response: Thanks for your good suggestion. We have prepared these correlation plots and included them in the Supporting Information as Figure S1. "During the groundwater discharge period, the changes in precipitation and evaporation were inversely related to the changes in LGD, demonstrating a clear negative correlation with LGD rates, with correlation coefficients of $R^2=0.61$, $P < 0.01$ and $R^2=0.67$, $P < 0.01$, respectively (Figure 3b, Figure S3 a and b)." **(Line 356-357)**

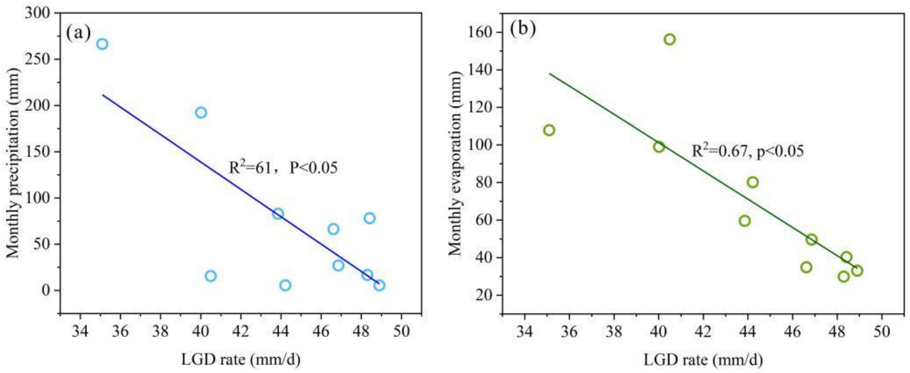

Figure S3. The correlation between the simulated LGD rate and monthly precipitation and monthly evaporation volume.

-About the comment (11): *Adding a schematic or conceptual figure in Section 3.2 to illustrate the sequence from meteorological drivers to water level differences, hydraulic gradients, and lacustrine groundwater discharge would greatly improve readability and strengthen the mechanistic framework.*

-Response: Thanks for your good suggestion. We have developed a conceptual model illustrating the mechanisms by which precipitation and evaporation influence LGD rates.

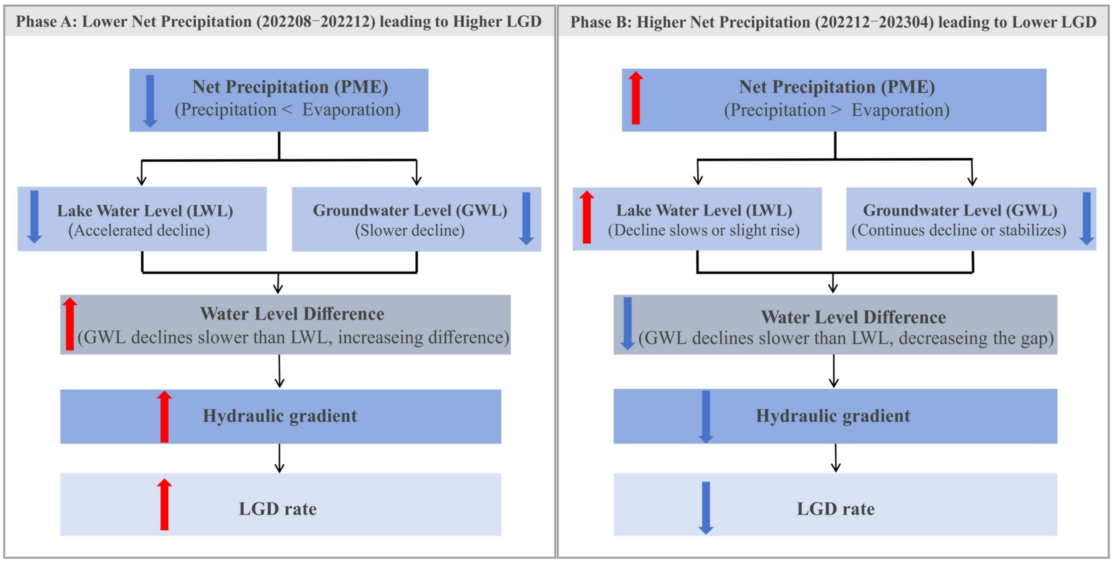

Figure 5. Conceptual model illustrating the mechanisms by which precipitation and evaporation influence LGD rates. Red upward arrows and blue downward arrows indicate increasing and decreasing trends of the corresponding parameters, respectively.

(Line 405-408)

-About the comment (12): *Line 282 refers to Section "3.3.2," which appears to be a typographical error. It likely should read "3.2.2." Please check and correct the section numbering throughout the manuscript.*

-Response: Thanks for your good suggestion. We have revised Section 3.3.2 to Section 3.2.2 and have carefully checked and verified the numbering of all section headings throughout the manuscript. **(Line 371)**

Thanks a lot to Anonymous Referee #3 for your suggestions for our manuscript, which are all important in improving our manuscript. Below are our responses to the comments, and all changes are clearly marked in red in the version of "Revised manuscript with tracked changes".

#Major comments

-About the comment (1): *Clarification of knowledge gap and novelty. The introduction would benefit from a clearer articulation of the specific knowledge gap addressed by this study. High-frequency observations appear to be the primary advance, yet prior observational frequencies and their limitations are not explicitly discussed. Clearly contrasting the temporal resolution of previous studies with the present work would help establish novelty.*

-Response: Thanks for your good suggestion. Yes, high-frequency observations are indeed a key feature and innovation of this study, and we sincerely appreciate the reviewer for highlighting this point, which was not sufficiently emphasized in our original manuscript. By employing high-frequency continuous monitoring, this study systematically identifies the monthly variability of LGD and its associated nitrogen and phosphorus input fluxes in a closed lake, as well as the underlying controlling mechanisms. In response to this comment, we have revised the Introduction to explicitly highlight the importance and novelty of high-frequency observations in resolving LGD dynamics.

To ensure consistency with the original Introduction, this content has been incorporated into its second paragraph.

"Although previous studies have made progress, understanding of LGD dynamics at the monthly scale remains limited due to insufficient observational frequency. Most existing studies focus on extreme hydrological periods (wet and dry seasons) or adopt seasonal observations, thus lacking monitoring at higher temporal resolution. However, the responses of lake and groundwater levels to precipitation and evaporation typically occur on monthly timescales, making it difficult for low-frequency or seasonal observations to adequately capture the processes by which water-level variations regulate LGD." **(Line 46-52)**

-About the comment (2): *Interpretation and mechanistic understanding. Many sections in the Results and Discussion read as descriptive summaries of observations rather than analyses of underlying* *mechanisms. Stronger interpretation is needed to explain why observed patterns occur, rather than simply documenting that they occur. This is particularly important for linking meteorological forcing, hydraulic gradients, LGD rates, and nutrient dynamics.*

-Response: Thanks for your good suggestion. We understand the concern that some parts of the Results and Discussion place greater emphasis on descriptive summaries of observed phenomena, while the underlying controlling mechanisms may require further clarification.

In this manuscript, the Results and Discussion are not strictly separated, which reflects the data-driven nature of this study based primarily on high-frequency field observations. Because the main conclusions rely heavily on first-hand observational data, directly presenting and comparing the observations provides intuitive and robust evidence to support our interpretations and facilitates understanding of the underlying mechanisms. Within this framework, the Results and Discussion are organized using a progressive structure that moves from phenomenon identification to mechanistic interpretation, rather than serving as purely descriptive reporting.

Specifically, the logical structure of each subsection is as follows. In Section 3.1, we first identify and verify the monthly variability of LGD, representing a qualitative identification stage. Section 3.2 then provides quantitative estimates of LGD rates during different periods, constituting a quantitative characterization stage. In Section 3.3, we focus on the mechanisms by which the precipitation–evaporation balance regulates lake and groundwater levels, alters hydraulic gradients, and ultimately controls LGD rates, representing an in-depth analysis of the key driving processes. Section 3.4 further examines the relationships between LGD-derived nitrogen and phosphorus input fluxes and corresponding changes in lake-water nutrient concentrations, and reveals the response of Chl *a* to nutrient inputs, reflecting the ecological response of lake trophic status to LGD-driven nutrient loading. Finally, in Section 3.5, we synthesize our findings in the context of previous studies and provide several broader implications.

Therefore, overall, although the Results and Discussion are presented in a combined section, the structure remains clear: Sections 3.1 and 3.2 primarily present the results; while data are shown, they are not merely listed, and we also discuss the causes of observed variations. Sections 3.3 and 3.4 focus on analyzing the underlying controlling mechanisms, and Section 3.5 summarizes the broader implications of the study. Thus, the Results and Discussion do not simply record observational patterns, but systematically reveal a complete chain of processes: meteorological factors drive changes in precipitation and evaporation, which regulate lake and groundwater levels, alter lake–groundwater hydraulic gradients, influence LGD intensity and its associated nitrogen and phosphorus fluxes, and ultimately modify lake nutrient concentrations and affect Chl *a* levels.

We also acknowledge that the mechanistic explanation in Section 3.3—specifically regarding how precipitation and evaporation affect lake–groundwater levels, hydraulic gradients, and subsequently LGD rates—may not be sufficiently intuitive due to necessary condensation of the text. In response to this issue, and following the suggestion of Reviewer 2, we have added a conceptual diagram to facilitate clearer understanding of the mechanisms by which meteorological factors control LGD variability.

We have developed a conceptual model illustrating the mechanisms by which precipitation and evaporation influence LGD rates.

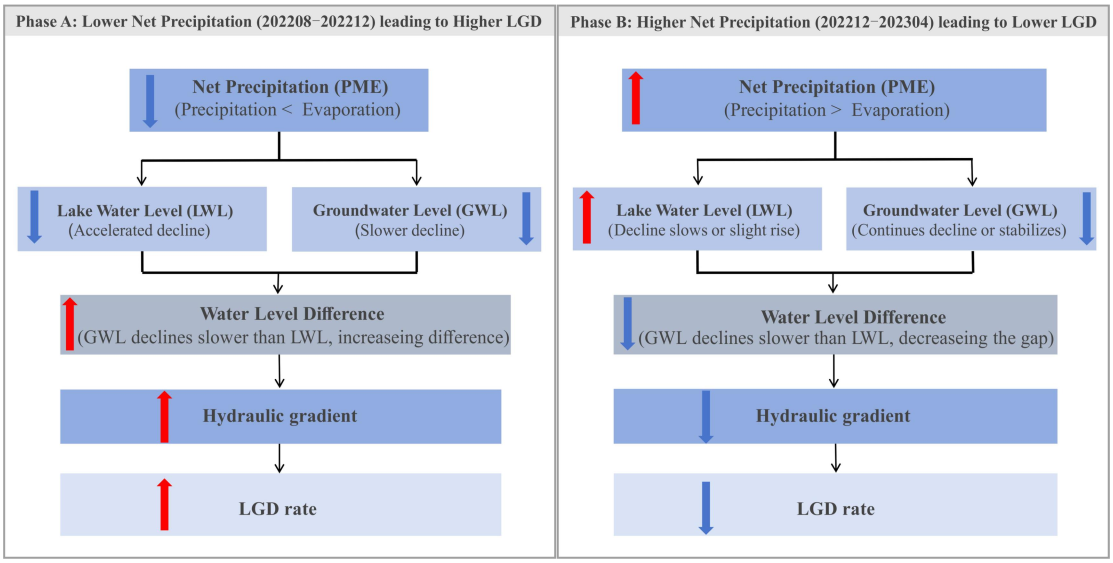

Figure 5. Conceptual model illustrating the mechanisms by which precipitation and evaporation influence LGD rates. Red upward arrows and blue downward arrows indicate increasing and decreasing trends of the corresponding parameters, respectively.

(Line 405-408)

-About the comment (3): *Generalization of findings. Several statements extend the conclusions to a global context of closed lakes. Given the strong dependence of LGD on local hydrogeology, climate, and landscape setting, the manuscript should more carefully justify the scope of generalization or clearly acknowledge its limitations.*

-Response: Thanks for your good suggestion. We fully agree with the your comment that LGD processes are highly dependent on local hydrogeological conditions, climatic context, and landscape patterns. This point is also strongly supported by our experience: variations in climate type, topography, hydrogeological conditions, human activity patterns and intensity, as well as surface hydrological characteristics, all influence the seasonal dynamics of LGD. Under the combined effects of these factors, the peak LGD rate may occur in any season. Systematically summarizing these patterns is of significant scientific value, which is why we are currently conducting a related study; however, such work requires additional multi-seasonal, quantitative LGD observations.

At the same time, we consider that, regardless of how LGD varies across seasons, the nitrogen and phosphorus inputs it carries remain important drivers of lake nutrient status, affecting lake nitrogen and phosphorus concentrations and N/P ratios to varying degrees in the corresponding seasons. This influence may be more pronounced in closed lakes where external nutrient inputs are limited. Therefore, even if the seasonal pattern of LGD differs from that observed in our study, LGD can still deliver nitrogen and phosphorus to lakes, thereby exerting an effect on lake nutrient status.

We acknowledge that the points raised in the "Implications" section of the manuscript require a more appropriate presentation. In the revised manuscript, we have provided a new and improved discussion.

"HW lake and other study cases are all typical closed shallow lakes, with limited exchange between the lake water and surface inflows, making LGD the primary hydrological input. A large number of similar lakes exist worldwide (e.g., closed lakes in the North American Great Plains, inland lakes in Africa and Central Asia), which may also be significantly influenced by LGD. Moreover, the regulatory effect of LGD on the spatial distribution of nitrogen, phosphorus, Chl *a*, and algal growth is amplified in lakes with long water residence times and stable sediment–water exchange. Therefore, this mechanism can be extended to other closed shallow lakes, particularly those with pronounced seasonal climates and a high proportion of shallow areas." **(Line 547-554)**

-About the comment (4): *Discussion of implications. The implications section should be strengthened by explicitly connecting the high-frequency observations to new conceptual or management insights. Emphasis should be placed on what is newly learned about closed-lake systems that could not be resolved with lower-frequency sampling.*

-Response: Thanks for your good suggestion. Yes, we fully agree with this comment.We have revised Section 3.4 to emphasize the role of high-frequency observations as an important approach for quantifying LGD.

“**3.4.1 Advantages of high-frequency observations in LGD research**

Traditional low-frequency sampling (e.g., single or quarterly measurements) has difficulty capturing short-term variations in LGD and its coupling with short-term meteorological conditions and water-level fluctuations. High-frequency observations can capture LGD responses to environmental factors such as meteorology and water temperature over relatively short timescales, and provide higher-resolution hydrological time series, thereby supplying reliable data for accurate estimation of LGD rates. In addition, high-frequency observations can record the short-term contributions of LGD to lake N and P inputs, enabling more precise flux assessments, avoiding biases associated with low-frequency sampling, and revealing the response relationships between LGD and Chl *a* concentrations or algal bloom events. Based on high-frequency data, LGD predictive models that account for the coupling of meteorological and hydrological factors can also be developed. Therefore, in LGD research, high-frequency observations are of significant value for accurately quantifying the impacts of groundwater on lake aquatic ecosystems and should be given priority.” **(Line 487-499)**

#Specific comments

-About the comment (5): *Line 17: Please clarify between which seasons the reported increase and subsequent decline in LGD were observed.*

-Response: Thanks for your good suggestion. We have revised this sentence to emphasize the seasons during which LGD rates increase and decrease.

“Water level data and ^{222}Rn tracing revealed a seasonal LGD pattern characterized by an increase from summer to winter, followed by a decline from winter to spring, with LGD rates ranging from 35.36 to 51.71 $\mathrm{mm \cdot d^{-1}}$.” **(Line 17)**

-About the comment (6): *Lines 22 and 40: The manuscript generalizes findings to a global perspective. Please clarify how such generalization is justified given variability in climate, hydrogeology, and lake morphology among closed lakes.*

-Response: Thanks for your good suggestion. As you pointed out, it is essential to summarize this study together with a few other relevant cases and discuss its rationale for global applicability.

During the preparation of the original manuscript, we may have overlooked a key factor—shallow lakes. The referenced studies all focus on shallow lakes, where the nitrogen and phosphorus carried by groundwater contribute relatively more to the lake's nutrient pool or are less diluted by lake water, making the role of groundwater more pronounced. Based on this, we have explicitly specified in the manuscript title and text that the lakes considered are "closed shallow lakes."

Regarding the rationale for extending this study to a global context, we provide the following explanations:

(1) Representativeness of physical and hydrological conditions

HW Lake and other reviewed cases are typical closed shallow lakes, with limited or negligible exchange with surface water, making LGD the main source of hydrological input. Globally, many closed or semi-closed lakes (e.g., closed lakes on the North American Great Plains, inland lakes in Africa and Central Asia) share similar characteristics and may also be strongly influenced by LGD. Therefore, the LGD monitoring methods and water quality analysis framework established in this study are highly applicable to lake systems with similar physical and hydrological conditions.

(2) Universality of ecological and nutrient cycling mechanisms

Our study on HW Lake reveals that LGD regulates the spatial distribution of nitrogen, phosphorus, chlorophyll a, and algal growth. Closed lakes generally have long water residence times and relatively stable exchange between sediments and overlying water, which amplifies the role of groundwater in nutrient cycling and ecological succession. Accordingly, the mechanisms by which LGD influences nutrient structure and ecological status can be extended to other similar closed lakes, particularly those with pronounced seasonal climate variability and a high proportion of shallow areas.

We have integrated the above discussion into the "Implications" section of Section 3.4 and to condense it in the abstract, as you suggested.

"HW lake and other study cases are all typical closed shallow lakes, with limited exchange between the lake water and surface inflows, making LGD the primary hydrological input. A large number of similar lakes exist worldwide (e.g., closed lakes in the North American Great Plains, inland lakes in Africa and Central Asia), which may also be significantly influenced by LGD. Moreover, the regulatory effect of LGD on the spatial distribution of nitrogen, phosphorus, Chl a, and algal growth is amplified in lakes with long water residence times and stable sediment－water exchange. Therefore, this mechanism can be extended to other closed shallow lakes, particularly those with pronounced seasonal climates and a high proportion of shallow areas." **(Line 547-554)**

"A large number of typical closed shallow lakes similar to the studied cases exist worldwide, and therefore, the regulatory role of LGD on lake nutrient status revealed in this study can be reasonably extended to other closed shallow lake systems" **(Line 22-25)**

-About the comment (7): *Line 41: Since observational frequency is a key advance, please explicitly state the sampling frequencies used in prior studies and how they limit interpretation.*

-Response: Thanks for your good suggestion. Here, we examine the sampling frequencies used in previous studies and how they constrain the interpretation of the findings. We have inserted it at the corresponding location in the main text.

"Although previous studies have made progress, understanding of LGD dynamics at the monthly scale remains limited due to insufficient observational frequency. Most existing studies focus on extreme hydrological periods (wet and dry seasons) or adopt seasonal observations, thus lacking monitoring at higher temporal resolution. However, the responses of lake and groundwater levels to precipitation and evaporation typically occur on monthly timescales, making it difficult for low-frequency or seasonal observations to adequately capture the processes by which water-level variations regulate LGD." **(Line 46-52)**

-About the comment (8): *Lines 48–55: The transition from water balance to nutrient transport would be improved by first emphasizing the importance of LGD as a nutrient pathway, then introducing prior nutrient-flux studies and their temporal limitations.*

-Response: Thanks for your good suggestion. We have revised this paragraph by adding a transitional sentence at the beginning:

"In existing studies, groundwater is regarded not only as an important source of lake water recharge, but also as a major contributor of nitrogen and phosphorus inputs to lakes." **(Line 55-56)**

-About the comment (9): *Lines 58–61: The relevance of these statements is unclear. Please clarify how they motivate the present study.*

-Response: Thanks for your good suggestion. We combined previous research findings with the local research context to introduce the representativeness and importance of the study area in a more direct and concise manner. Accordingly, the introductory statement was revised to: "The middle Yangtze

River plain is characterized by a high density of lakes, and previous studies have shown that lakes of different types commonly exhibit groundwater discharge of varying intensities, along with associated nitrogen and phosphorus input fluxes." **(Line83-85)**

-About the comment (10): *Line 63: The abbreviation "HWL" is not intuitive. Consider using "HW Lake" or spelling out the full name more frequently.*

-Response: Thanks for your good suggestion. We agree with your comment, and we have revised the manuscript throughout by replacing "HWL" with "HW lake."

-About the comment (11): *Line 86: Please clarify the hydrological or geomorphological implication of a slope less than 0.0001.*

-Response: Thanks for your good suggestion. A terrain slope lower than 0.0001 generally indicates an extremely flat plain with very limited surface runoff formation. In the absence of artificial channel connectivity, gravity-driven surface runoff is almost negligible, and precipitation primarily infiltrates or remains stagnant rather than forming effective directed flow. Under such ultra-flat conditions, the water level gradient, rather than terrain slope, becomes the key factor controlling groundwater-lake water exchange. We have condensed this sentence and incorporated it into the revised manuscript text.

Here is the revision for addressing this comment.

"This indicates that, except for runoff through artificial channels, surface runoff generated by other precipitation is almost negligible, and the water level gradient, rather than the terrain slope, becomes the key factor controlling groundwater-lake water exchange." **(Line124-127)**

-About the comment (12): *Line 91: Consider explicitly stating that the water-level fluctuation is large, with the 8 m variation provided as quantitative evidence.*

-Response: Thanks for your good suggestion. We have revised this description as follows: "In a typical hydrological year, HW lake experiences substantial water level fluctuations between the wet and dry seasons, with a magnitude of up to 8 m" **(Line113-114)**

-About the comment (13): *Line 95: If the 50–80 m aquifer thickness is not shown in Figure 1, please* *clarify this in the figure or its caption.*

-Response: Thanks for your suggestion. We have included the following note in Figure 1: "...(c) hydrogeological cross-section along profile A-A' (profile location indicated by line A-A' in b). The cross-section shows only the upper part of the confined aquifer that interacts with the lake, and does not display the full thickness of the aquifer." **(Line137-138)**

-About the comment (14): *Line 100: Since "Yangtze River (YR)" is used relatively infrequently, consider using the full name throughout for clarity.*

-Response: Thanks for your suggestion. We have revised the manuscript throughout to use the full name, "Yangtze River."

-About the comment (15): *Figure 1: Figures should be self-contained. Please define HWL and LGD in the caption and clarify whether the lake is always connected to the river via groundwater or whether surface-water exchange occurs seasonally.*

-Response: Thanks for your suggestion. We labeled HW Lake in the figure and explained in the caption its connectivity with the Yangtze River and with groundwater. In June 2022 and July 2023, HW Lake was connected to the Yangtze River through a channel, receiving inflow from the river, which led to higher water levels and an expanded inundated area. In the other months, HWL was isolated from the Yangtze River, representing the period when LGD occurred.

Here is the revision for addressing this comment.

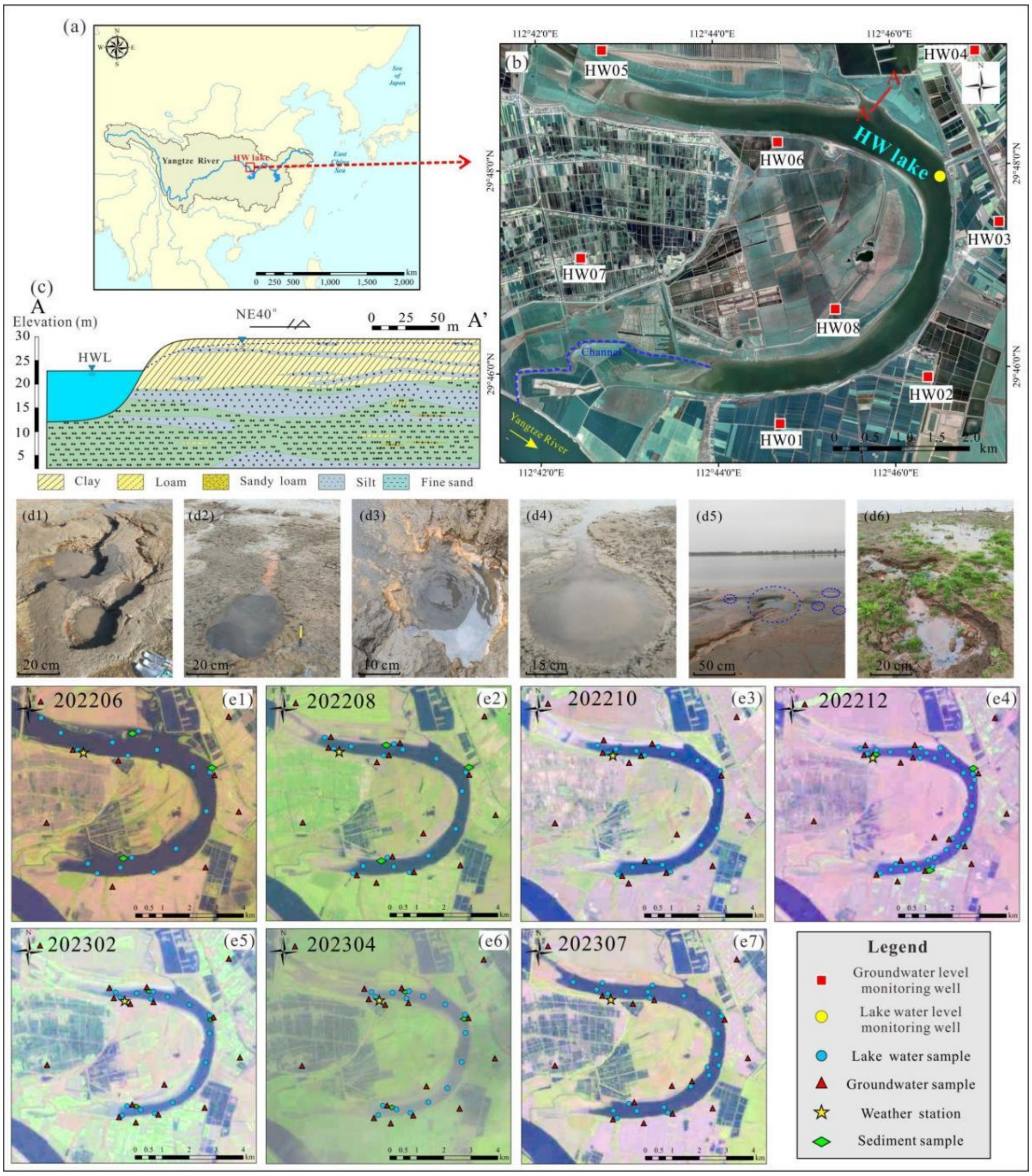

Figure 1. Overview of the study area. (a) Geographical location of the HW lake (study area marked by a red box, from Esri). (b) satellite image of HW lake (from Google Maps). (c) Hydrogeological cross-section along profile A–A' (profile location indicated by line A–A' in b). The cross-section shows only the upper part of the confined aquifer that interacts with the lake, and does not display the full thickness of the aquifer. (d1–d6) Zones of concentrated LGD phenomena in HW lake, primarily manifested as spring outlets. (e1–e7) Spatial distribution of field sampling sites collected between June and July 2022 (from Landsat 8). The numbers in the figure indicate the sampling periods. For example, 202208 represents August 2022. In June 2022 and July 2023, HW Lake was connected to the Yangtze River through a channel, receiving inflow from the river, which led to higher water levels and an expanded inundated area. In the other months, HWL was isolated from the Yangtze River, representing the period when LGD occurred.

(Line134-144)

-About the comment (16): *Line 119: Please clarify whether "spring water" and "pore water" refer to the same samples. If so, use consistent terminology throughout.*

-Response: Thanks for your suggestion. In fact, all of these samples were collected from pores within the lake shoreline zone. The pore water samples were extracted using a push-point sampler, whereas the spring water samples represent groundwater that emerges through preferential flow paths in the terrestrial pores of the lake shore under relatively large hydraulic gradients. Fundamentally, these spring waters also originate from the aquifer or the lake shore pore space and therefore can be regarded as pore water. Accordingly, we classified all of these samples collectively as pore water.

-About the comment (17): *Table 1: Please clarify the meaning of "pore/spring water" in the caption. Additionally, indicate whether replicate samples were collected and discuss potential uncertainties if only single samples were obtained.*

-Response: Thanks for your questions. In response to the previous comment, we collectively refer to these samples as pore water. During each field campaign, a single sample was collected, whereas in the bimonthly monitoring program, pore water samples were collected in each monitoring period. For uncertainty assessment at individual time points, we adopted the instrumental measurement uncertainty of approximately 25%, as determined from tests of well water and pore water using a RAD7 equipped with the H_2O accessory. When quantifying LGD using the ^{222}Rn mass balance model, this 25% uncertainty associated with the groundwater end member was incorporated into the calculations. The resulting LGD uncertainties are reported as the values following the "±" symbol for each corresponding estimate.

-About the comment (18): *Line 139: Consider reordering this section to first describe ^{222}Rn measurements, followed by TN, TP, and chlorophyll-a, with other physicochemical parameters presented as supporting data.*

-Response: Thanks for your suggestion. We have revised the order of presentation of these contents according to your suggestion.

"For ^{222}Rn analysis, the water samples were collected in 250 mL or 2.5 L glass bottles using an overflow method to eliminate residual air. ^{222}Rn concentrations were quantified using a RAD7 system (Durridge Company, Inc.) equipped with RAD7-H_2O and RAD7 Big Bottle accessories. To reduce the measurement uncertainty in the lake water samples, the counting time was extended to 60 min per sample. All ^{222}Rn analyses were completed within 24 h of sampling, using the RAD7 aqueous system.

$$A_0 = A \times e^{\lambda t} \quad (1)$$

where A_0 represents the ^{222}Rn concentration (Bq·m^{-3}) at the sampling time; A represents the ^{222}Rn concentration (Bq·m^{-3}) at the measurement time; λ represents the decay coefficient of ^{222}Rn, 0.181 d^{-1}; and t represents the time interval (d) between sampling and measurement. The uncertainty in ^{222}Rn testing for lake water was approximately 35%, and the uncertainty in ^{222}Rn testing for groundwater is approximately 25%.

The samples for total nitrogen (TN) and total phosphorus (TP) analysis were field-filtered using a 0.45 μm membrane filter and then stored in 30 mL polyethylene bottles and 20 mL brown screw-cap glass bottles, respectively. The TP samples were acidified with concentrated HNO_3 to a pH below 2, sealed, and subsequently analyzed using an inductively coupled plasma optical emission spectrometer (ICP-OES, iCAP 6000 series, Thermo Fisher Scientific, USA) at the School of Environmental Studies, China University of Geosciences (Wuhan), with a detection limit of 0.001 mg·L^{-1}. TN samples were analyzed using a total organic carbon/nitrogen analyzer at the Wuhan Botanical Garden, Chinese Academy of Sciences, with a detection limit of 0.01 mg·L^{-1}. Chl a concentrations were determined immediately after sampling using an AquaFluor fluorometer, with a detection limit of 0.5 μg·L^{-1}. Water quality parameters, including pH, temperature, DO, ORP, and EC, were measured in situ using a HACH-HQ40D multi-parameter probe.” **(Line171-192)**

-About the comment (19): *Line 148: Please consider adding a supplementary figure showing temporal changes in ^{222}Rn and the fitting of Equation (1), along with an explanation of how uncertainty was quantified.*

-Response: Thanks for your suggestion. We understand your concern. However, under the framework and experimental conditions of this study, the suggested approach is difficult to implement in practice. The radioactive decay relationship described in Equation (1) was proposed by Ernest Rutherford and Frederick Soddy in 1902 and represents a fundamental law in classical nuclear physics. This equation is applicable under the following assumptions: (a) a single radionuclide; (b) a decay process that is independent of environmental conditions; (c) no external input or chemical production; and (d) a closed system. In this study, ^{222}Rn was sampled using sealed glass bottles and analyzed within 24 h, with only time-based decay correction applied, fully satisfying these conditions.

The measurement procedure is as follows. The sampling time was recorded during sample collection, and the measurement time was recorded during analysis. Based on the time interval between sampling and measurement, Equation (1) was used to correct the measured ^{222}Rn concentration for radioactive decay. During field campaigns, samples were typically collected during the daytime and analyzed indoors in the evening; the time interval between these two steps corresponds to the actual radioactive decay period of the samples. In principle, in situ measurement of radon concentrations would be ideal; however, due to limitations related to field conditions, equipment, and logistics, in situ measurements were not feasible in LGD study. Except for investigations targeting local (point-scale) LGD, all studies using radon as a tracer are unable to measure radon concentrations in situ and therefore correct the measured ^{222}Rn concentrations using decay equations.

Regarding your suggestion to fit Equation (1), this is also difficult to achieve in practice. On the one hand, Equation (1) is a fundamental law of classical nuclear physics rather than an empirical fitting relationship. On the other hand, a large number of samples were collected during each sampling campaign. If a total duration of 24 h were considered, with measurements conducted every 4 h to obtain seven time points for fitting Equation (1), each individual sample would need to be measured seven times. Given that each measurement requires approximately 1–1.5 h, at least 7 h would be needed to obtain a complete dataset for a single sample. As each lake-wide campaign involved 32 samples, this approach would require approximately 224 h per campaign, which is operationally impractical.

With respect to uncertainty, it primarily originates from instrumental measurement errors associated with the RAD7 radon detector. The RAD7 measurement protocol involves 4–9 repeated measurements of the same sample, with the final concentration reported as the average of these measurements and the associated uncertainty determined from the standard deviation of the repeated results. For groundwater samples, which typically exhibit relatively high radon concentrations, four measurements of a 250 mL sample using the RAD7-H_2O system are sufficient to reduce the uncertainty to within approximately 25%. In contrast, for lake water samples with lower radon concentrations, larger sample volumes and a greater number of repeated measurements are required to further reduce uncertainty. Accordingly, this study employed the RAD7 system combined with the Big Bottle accessory, conducting nine repeated measurements for lake water samples, thereby reducing the uncertainty to approximately 35%.

It should be noted that the magnitude of this uncertainty depends on the background radon levels of the local water bodies as well as the selected instrument operating modes. In the quantification of LGD, we incorporated ^{222}Rn measurement uncertainties of approximately 35% for lake water and 25% for groundwater, together with uncertainties from other relevant parameters, through uncertainty propagation analysis. The resulting uncertainties are reported as the values following the "±" symbol for each LGD rate estimate.

-About the comment (20): *Line 162: A simplified conceptual diagram illustrating water and isotope fluxes among the lake, groundwater, sediments, and atmosphere would greatly aid reader understanding.*

-Response: Thanks for your suggestion. We have added a conceptual model figure to help readers better understand the treatment of the lake as a radon box and to clearly illustrate the relationships among its source and sink terms. This figure has been included in the Supporting Information and labeled as Figure S1.

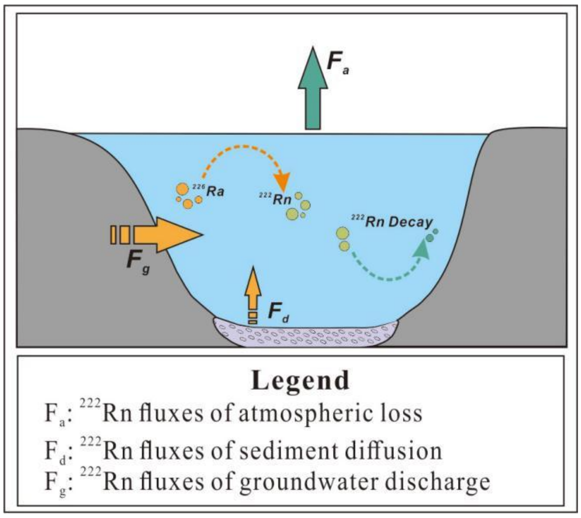

Figure S1. Conceptual diagram of source and sink terms in the lake ^{222}Rn mass balance model.

-About the comment (21): *Line 168: Briefly summarize how ^{222}Rn data were used to estimate Fg, Fd, and Fa in the main text before referring readers to the Supplement.*

-Response: Thanks for your good suggestion. We have added an overview of these calculation procedures to the main text.

"The measurement times before and after sampling were the first day and the last day of the sampling period, respectively. Since there is almost no difference in the lake water level and ^{222}Rn concentration at the same location before and after sampling, the change in the ^{222}Rn in lake water on the left side of the equation can be approximated as 0 (Kluge et al., 2007).

The ^{222}Rn flux diffused from the sediment to the lake is one source of the ^{222}Rn mass balance model, and it is calculated by the following formula:

$$F_d = \sqrt{\left(\lambda^{222}Rn \times nD_m\right)}\left(C_p - C_w\right) \tag{3}$$

where C_p ($Bq \cdot m^{-3}$) and C_w ($Bq \cdot m^{-3}$) are ^{222}Rn concentrations of pore water in sediments and overlying lake water, respectively; D_m ($cm^2 \cdot s^{-1}$) is the ^{222}Rn molecular diffusion coefficient in wet bulk sediment; n is the porosity of the sediment.

To determine the ^{222}Rn concentrations in sediment pore water, a sediment equilibrium incubation experiment was carried out following the procedure proposed by Corbett et al. (1998). The D_m is expressed as:

$$-\log D_m = \left(\frac{980}{T_w + 273}\right) + 1.59 \tag{4}$$

where T_w is water temperature (°C). An equilibrium incubation experiment with lakebed sediments was carried out to obtain the ^{222}Rn concentration in sediment pore water (Corbett et al., 1998).

The atmospheric loss of ^{222}Rn is estimated based on the following empirical equation, which is related to temperature and wind speed (MacIntyre et al., 1995):

$$F_a = K\left(C_w - \alpha C_a\right) \tag{5}$$

where K values are in cm h^{-1} but have been scaled to $m \cdot d^{-1}$ for input into Eq. (5); C_w is the concentration of lake water ^{222}Rn ($Bq \cdot m^{-3}$); C_a is the concentration of ^{222}Rn in the air ($Bq \cdot m^{-3}$); α is the gas distribution coefficient (dimensionless) and is a temperature dependent function; ^{222}Rn from the decay of dissolved ^{226}Ra can be generally omitted for ^{222}Rn mass balance model.” **(Line205-227)**

-About the comment (22): *Lines 181–230: Many results sections would benefit from beginning with a brief statement of the key observation or takeaway before presenting detailed data.*

-Response: Thanks for your good suggestion. we have added a brief summarizing sentence at the beginning of the relevant paragraph.

Here is the revision for addressing this comment.

"The fluctuations in lake water levels and groundwater levels reflect a pronounced interaction between groundwater and the lake. During the field monitoring period, both exhibited significant changes in water level." **(Line240-242)**

"As a limited tracer for LGD, the concentration of ^{222}Rn can indicate changes in LGD. During the field monitoring period, both lake water and groundwater concentrations underwent some variations, with differing magnitudes." **(Line266-268)**

-About the comment (23): *Figure 2: Please clarify what the symbols, lines, and bars represent in panels (c) and (d), as these plots are difficult to interpret.*

-Response: Thanks for your good suggestion. In (c) and (d), the top and bottom of each box represent the 75th and 25th percentiles of the data, respectively; the ends of the whiskers indicate the maximum and minimum values within 1.5 times the interquartile range; the small white square inside the box denotes the mean; the side curves illustrate the data's dispersion and distribution pattern; the dark blue dashed line connects the mean values across different periods. We have added the following content to the caption of Figure 2.

Here is the revision for addressing this comment.

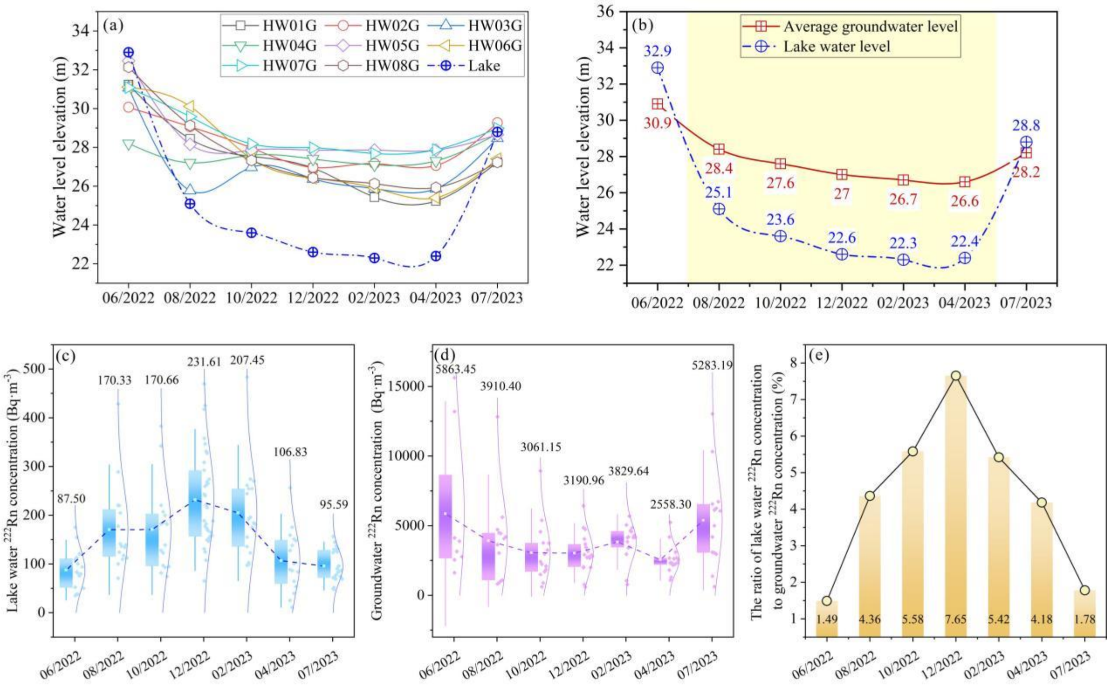

Figure 2. (a) Variations in lake water level and groundwater levels across all groundwater monitoring points. (b) Variations in lake water levels compared with the average groundwater level, the yellow area indicates the period of LGD. (c) Variations in the lake water concentrations of ^{222}Rn. (d) Variations in the groundwater concentrations of ^{222}Rn. In (c) and (d), the top and bottom of each box represent the 75th and 25th percentiles of the data,

respectively; the ends of the whiskers indicate the maximum and minimum values within 1.5 times the interquartile range; the small white square inside the box denotes the mean; the side curves illustrate the data's dispersion and distribution pattern; the dark blue dashed line connects the mean values across different periods. (e) Variations in the ratio of ^{222}Rn concentrations in lake water to groundwater.

(Line303-311)

-About the comment (24): *Table 2: Consider presenting key results graphically (e.g., bar plots) in the main text or Supplement to improve readability.*

-Response: Thanks for your good suggestion. We converted the ^{222}Rn source and sink fluxes from Table 2 into a figure to better compare the different periods. This figure has been included in the SI and is labeled as Figure S2.

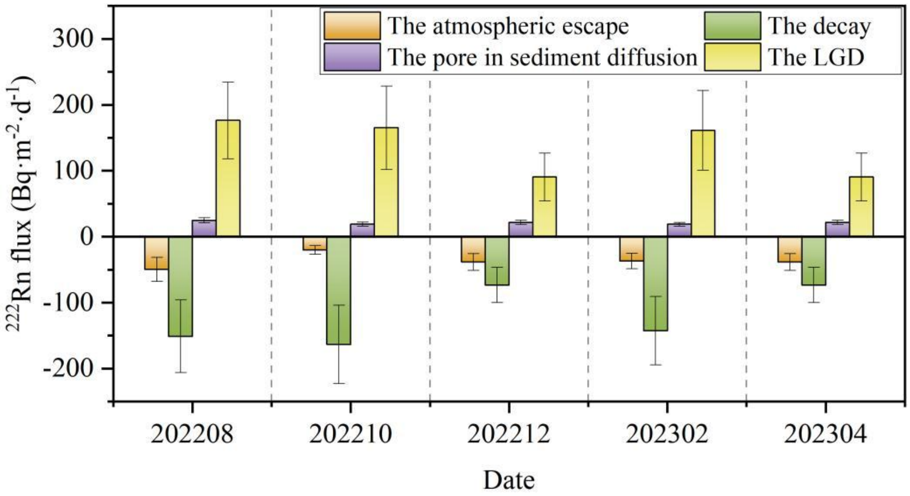

Figure S2. The ^{222}Rn source and sink fluxes in different periods.

-About the comment (25): *Lines 254 and 273: The quadratic fitting is based on only five data points and may be statistically fragile unless supported by a physical justification. Please clarify the rationale or temper the interpretation.*

-Response: Thanks for your good question. Indeed, we only have five data points, so the robustness may be limited, and we will provide a specific note on this point. Given the small sample size, the statistical robustness of this fit is limited; therefore, the results are primarily intended to provide a reference for the trend of LGD rates within the hydrological year rather than precise predictions. In fact, in the field observations, because the monthly fluctuations of lake and groundwater levels were relatively small, the monthly variation of LGD exhibited a predictable "increase followed by decrease" pattern. The fitted curve was used only to interpolate LGD rates for months without measurements, and its predicted values fell between the two measured values, which we consider suitable as a reference for the overall trend.

Here is the revision for addressing this comment.

"Due to the small sample size, the robustness of the model's fit may be limited. Nonetheless, under the field observed conditions, the monthly fluctuations of lake and groundwater levels were relatively small and exhibited regular patterns, so the actual monthly variation of LGD showed a predictable "increase followed by decrease" pattern. Therefore, the predictions of this model are considered reliable." **(Line 342-346)**

-About the comment (26): *Line 335: The contrasting behavior of TN and TP warrants mechanistic discussion (e.g., redox sensitivity, sorption, or biogeochemical controls), rather than only reporting observed differences.*

-Response: Thanks for your good suggestion. The TP load carried by LGD is typically calculated as the product of LGD rate and TP concentration in groundwater. In the current manuscript, this load is reported to be "primarily controlled by groundwater TP concentration" rather than LGD rate, mainly because the seasonal variability of TP concentration is generally larger than that of LGD rate. To investigate the mechanisms driving TP concentration dynamics, we further examined key hydrogeochemical parameters, including electrical conductivity (EC), dissolved oxygen (DO), and redox potential (Eh) (Table S3). Based on monitoring data from August 2022 to April 2023, the TP dynamics can be roughly divided into three stages:

(1) Aug–Dec 2022 (TP rise followed by decline): During this period, Eh increased markedly from −97.43 mV to −56.24 mV, and DO rose from 1.24 to 2.60 mg·L^{-1}, indicating rapid aquifer oxidation. In the early oxidation phase (up to October), "oxidative dissolution" of phosphate-bearing minerals may have temporarily elevated TP to 2.00×10^{-2} mmol·L^{-1}. Subsequently, strong oxidative conditions promoted the formation of iron and manganese oxides, which adsorbed phosphorus. Although EC increased from 823.83 to 942.61 μS·cm^{-1}, suggesting an increase in competitive anions, adsorption dominated, and TP ultimately declined to the monitoring minimum of 6.46×10^{-3} mmol·L^{-1} by December.

(2) Dec 2022–Feb 2023 (TP increase): Eh continued to rise substantially to −27.26 mV, and DO remained relatively high at 2.29 mg·L^{-1}, indicating that the system had not returned to a reducing state. The TP peak (2.19×10^{-2} mmol·L^{-1}) during this stage was therefore not due to reductive release. Instead,

it was primarily driven by external phosphorus inputs associated with enhanced precipitation and agricultural activities. Meanwhile, EC reached the monitoring-period maximum of 973.69 μS·cm^{-1}, indicating the influx of high concentrations of dissolved salts. These competitive anions may have temporarily weakened sediment phosphorus retention, jointly contributing to the TP increase.

(3) Feb–Apr 2023 (TP decline): Oxidative conditions intensified further, with Eh and DO reaching the monitoring-period maximum values of −13.94 mV and 3.58 mg·L^{-1}, respectively. Strong oxidative adsorption dominated once again, effectively removing most of the previously input phosphorus. Despite EC remaining high (961.83 μS·cm^{-1}), TP concentration declined substantially to 8.24×10^{-3} mmol·L^{-1} by April.

Overall, the fluctuations in TP concentration reflect the combined effects of internal adsorption and fixation, external input pulses, and geochemical competition (as indicated by EC changes) under a macro-scale context of aquifer oxidation driven by declining water levels (Eh and DO continuously increasing).

Table S3. EC, DO and Eh values in groundwater for each sampling period.

Date	Groundwater EC (μS·cm^{-1})	Groundwater DO (mg·L^{-1})	Groundwater Eh (mv)
08/2022	823.83	1.24	-97.43
10/2022	920.44	1.41	-81.26
12/2022	942.61	2.6	-56.24
02/2023	973.69	2.29	-27.26
04/2023	961.83	3.58	-13.94

To avoid making this section overly long in the main text, we have simplified and integrated it into the manuscript, with detailed information provided in the Supporting Information (SI).

“Based on Eh, DO, and EC results (Table S3), TP concentration fluctuations likely result from the combined effects of internal adsorption and fixation, external input pulses, and geochemical competition under the background of an oxidation-enhanced environment driven by declining water levels (Eh and DO continuously increasing). For a detailed analysis, see the SI.” **(Line 418-422)**

-About the comment (27): *Line 363: Since the role of TN/TP ratios in controlling chlorophyll-a is well established, please clarify whether this represents a new finding or how the present results extend prior knowledge.*

-Response: Thanks for your good suggestion. The control of chlorophyll-a by the TN/TP ratio is not a new finding; however, the regulation of lake TN/TP ratios by groundwater represents a novel discovery.

Previous studies on lake TN/TP ratios have rarely considered the influence of groundwater. Even in studies that did include groundwater, they only noted differences in N:P ratios between groundwater and lake water and regarded groundwater as a potential factor affecting lake TN/TP, without providing direct evidence that groundwater N:P ratios indeed influence lake TN/TP. More importantly, studies systematically investigating how groundwater N:P ratios affect lake TN/TP and, in turn, control chlorophyll-a in lake water are extremely scarce. Therefore, this study presents clear novelty and represents a new discovery.

-About the comment (28): *Line 378: Given that high-frequency sampling is the main advance, the discussion should focus more on what new insights this temporal resolution provides relative to prior sparse observations in closed lakes.*

-Response: Thanks for your good suggestion. We greatly appreciate your suggestion. In the "Implications" section of the manuscript, we have added a discussion regarding high-frequency sampling.

"**3.4.1 Advantages of high-frequency observations in LGD research**

Traditional low-frequency sampling (e.g., single or quarterly measurements) has difficulty capturing short-term variations in LGD and its coupling with short-term meteorological conditions and water-level fluctuations. High-frequency observations can capture LGD responses to environmental factors such as meteorology and water temperature over relatively short timescales, and provide higher-resolution hydrological time series, thereby supplying reliable data for accurate estimation of LGD rates. In addition, high-frequency observations can record the short-term contributions of LGD to lake N and P inputs, enabling more precise flux assessments, avoiding biases associated with low-frequency sampling, and revealing the response relationships between LGD and Chl *a* concentrations or algal bloom events. Based on high-frequency data, LGD predictive models that account for the coupling of meteorological and hydrological factors can also be developed. Therefore, in LGD research, high-frequency observations are of significant value for accurately quantifying the impacts of groundwater on lake aquatic ecosystems and should be given priority." **(Line 487-499)**

-About the comment (29): *Line 399: The manuscript suggests TN/TP ratio is more influential than absolute concentrations. Please discuss the implications of this finding.*

-Response: Thanks for your good suggestion. In lake eutrophication management, while controlling the absolute concentrations of nitrogen and phosphorus is important, the N:P ratio (TN/TP) also plays a critical role. When the TN/TP ratio is low (relatively low nitrogen and high phosphorus), the water body is nitrogen-limited (N-limitation), and the growth of phytoplankton is constrained by nitrogen availability, even if phosphorus is abundant. Conversely, when the TN/TP ratio is high (relatively high nitrogen and low phosphorus), the water body is phosphorus-limited (P-limitation), and phytoplankton growth is constrained by phosphorus availability, even if nitrogen is sufficient. Therefore, the accumulation of chlorophyll a depends not only on the absolute concentrations of nitrogen or phosphorus but also on the N:P ratio and its influence on the type of nutrient limitation. In lake management and protection, it is essential first to identify the nutrient limitation type of the lake to implement targeted nitrogen and phosphorus reduction strategies.

Here is the revision for addressing this comment.

"In lake eutrophication management, Chl *a* accumulation is governed not only by the absolute concentrations of nitrogen and phosphorus but also by the TN/TP, which determines the dominant type of nutrient limitation. Low TN/TP indicate nitrogen limitation, whereas high TN/TP indicate phosphorus limitation. Given that present study has shown that groundwater can significantly alter lake TN/TP, its influence should be explicitly considered when identifying nutrient limitation mechanisms and developing targeted nitrogen and phosphorus reduction strategies." **(Line 472-477)**

-About the comment (30): *Line 399 and elsewhere: Please use consistent terminology for "chlorophyll-a" or "Chl a" throughout.*

-Response: Thanks for your good suggestion. In the revised manuscript, we have standardized the terminology as "Chl *a*".

-About the comment (31): *Line 414: The conclusions should be revised to more clearly highlight new insights enabled by high-frequency observations and their implications for understanding and managing closed-lake systems.*

-Response: Thanks for your good suggestion. We have revised the conclusion section to highlight the role and implications of high-frequency monitoring.

“These findings offer new insights into eutrophication control in closed, shallow lakes, and suggest that the advantages of high-frequency LGD observations should be incorporated into lake management frameworks, along with the development of targeted control strategies during critical periods of groundwater–lake interactions.” **(Line589-592)**