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". The text highlighted in blue in the response file indicates the content that will be added or revised in the amended manuscript.

-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 plan to add this content at the second paragraph of the Introduction, phrased as:

"Understanding these 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."

-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 plan to add this definition at the second occurrence of the term "closed lakes" in the second sentence of the second paragraph of the Introduction.

The revised wording will be as follows:

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

-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, briefly highlighting its advantages.

"Environmental tracers are increasingly applied in studies of lake–groundwater interactions. An ideal tracer typically exhibits significant concentration differences between lake water and groundwater (often spanning orders of magnitude) and stable chemical properties. Commonly used tracers include ^{222}Rn, ^{226}Ra, stable hydrogen and oxygen isotopes (δ^2H, $\delta^{18}O$), Cl^-, and electrical conductivity. Among these, ^{222}Rn and ^{226}Ra often show concentration differences of up to two 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. 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. 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."

References

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Gonneea, M. E., Morris, P. J., Dulaiova, H., & Charette, M. A. (2008). New perspectives on radium behavior within a subterranean estuary. Marine Chemistry, 109(3–4), 250–267.

-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)."

-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: "coefficient of variation (CV, used to measure the relative dispersion of data, defined as the ratio of the standard deviation to the arithmetic mean)".

-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.

We will add the following text to the revised manuscript::

"Furthermore, climate change is expected to modulate these processes. In the East Asian monsoon region, future scenarios predict more precipitation concentrated in summer, while non-summer periods—especially autumn and winter—may experience reduced rainfall and increased evaporation. Because LGD predominantly occurs during these non-summer periods, increased net precipitation (precipitation minus evaporation) could enhance groundwater discharge to lakes, directly elevating TN and TP loads delivered by LGD. This underscores the critical role of groundwater processes in regulating nutrient balances in closed lakes and suggests that future nutrient management strategies should consider both LGD variability and climate-driven hydrological changes."

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., ... & Wang, Y. (2024). Two-decadal variability of lacustrine groundwater discharge: Coupled controls from weather and hydrologic changes. Water Resources Research, 60(10), e2024WR037173.