

**RC1:** '[Comment on egusphere-2026-3787](#)', Anonymous Referee #1, 24 Aug 2026

The manuscript is an excellent contribution to GMD as it highlights a new module for the popular GLM-AED model that provides scientists and managers with the option to simulate heat extraction from lakes and reservoirs, which, potentially, can be a low emission heating method. I very much enjoyed reading the draft and only offer a couple of minor comments to an overall well-described study.

1. L33: The link between the sentences seems off. First, you describe how the method is environmentally friendly but is nonetheless a manipulation of the lake regime, with all the associated potential ecological consequences. Then you derive a challenge, which is mostly technical. Wouldn't the challenge be to derive quantifications on how heat extraction would affect the thermal regime, and for this you are developing these tools and processing workflows?

Thank you for your valuable comments. We have rewritten the sentence to reflect that the challenge lies in deriving quantifications on how heat extraction would affect the thermal regime. We also split the paragraph to better organize the section.

(L. 42) *"The challenge, therefore, is to quantify how heat extraction affects the thermal regime of lakes. For this reason, we are developing a simulation tool that is able to (i) quantify the thermal potential of a given lake over the full season, (ii) assess the changes in thermal dynamics arising from the thermal extraction and different regimes for injection of the cooler backflows, (iii) define a temperature threshold that minimizes potential environmental risks; and (iv) define the optimized depth for injection/extraction."*

2. L52: "model here presented was verified against first principles"

We adopted the suggested wording and the sentence was changed to (L. 59):  
*"model here presented was verified against first principles"*.

3. L66-70: These advantages seem very general and fit also well to Simstrat. Maybe you can first describe that GLM is popular (wide spread use) with active development and then that it offers (1) open-source and modularized source code, which is easier to change, plus (2) coupling to AED, and (maybe) (3) its historical research focus on reservoir dynamics, which would be an ideal application for heat extraction?

We accepted the suggestion. The comparison with Simstrat was removed and the paragraph now opens with GLM's wide use, mentioning the open-source code and the reservoir management features (L. 74):

*“We chose the GLM framework to develop this tool because it is widely applied in the limnological community and remains under active development. Its modularized source code is open and users can edit it to add features or refine existing ones (Weber et al., 2017). It is possible to couple to the Aquatic Ecodynamics (AED) library, and it includes selective withdrawal routines developed for reservoir operation (Hipsey et al., 2019). The thermal heat extraction relies on two operations, water extracted at one depth and reinjected at another. The module developed here is built on those routines.”*

4. Figure 1 and lines 80-88: I suggest to rename “open and closed-loop system” to something more akin to extraction and injection in the text? Also I suggest to add additional information to the figure caption.

We agree on both points. We have replaced the open and closed-loop wording both in the text and in Figure 1 so it is more coherent for the reader. The first label in Figure 1 now reads *"extraction and injection depths set independently"*. In making that change we realized that label 3, which read *"depth flexible"*, was easy to confuse with the new wording. It now reads *"static or dynamic depths"*. The first label refers to the two elevations being chosen independently of each other, the third to each of them being constant or varying through the run. We have also edited the abstract accordingly.

We have expanded the caption of Figure 1 to explain each label (L. 93):

*“Main features of the heat exchange module implemented in GLM. Water is extracted from the lake at a user-defined depth, its temperature is altered, and the water parcel is returned at the same or a different depth. (1) The extraction and injection depths are set independently at the same or different elevations. (2) The user prescribes the flow rate together with either the temperature spread  $\Delta T$  (Mode 1) or the heat transfer rate  $P$  (Mode 2). (3) Both elevations may be held constant or varied throughout the simulation. (4) When GLM is coupled to the Aquatic Ecodynamics (AED) library, water quality variables are carried with the extracted water and injected with it.”*

5. L116 and below: please standardize the amount of digits, sometimes it's default: 2 deg C, sometimes default: 2.0 deg C; same in Table 1

The number of digits has now been standardized throughout the main text (including Table 1 and 2) and also in the supplementary information.

6. L143: Can this cause numerical instabilities under extreme injection scenarios, e.g., because the model fails to create enough layers for mixing afterwards? Is that possible?

What could cause numerical instabilities is either the layer pool running out due to extreme injections or extractions or an inversion that is not resolved. An extreme extraction cannot empty a layer, since GLM caps how much is taken from one layer in a single step. An extreme injection could leave denser water above lighter water, and `check_layer_stability()` merges the affected layers until the column is sorted. The sentence the reviewer refers to (previous L. 143) lacked the routine that solves density instability `check_layer_stability()`. Section 2.4 now names it (L. 167).

We did a test to check how the model performed driving a submerged inflow at the injection elevation at 100 and 1000 times the operational flow, with the layer settings used in the paper, all one-year runs completed, the layer count peaked at 122 of the 500 available, and the thickest layer stayed at the configured maximum throughout. For the scenario HP-ON reported in the paper, over the 19-year run the layer count stayed between 41 and 87, against the configured maximum of 500, while HP-OFF, without the heat pump, reached 98.

The heat exchange module also carries its own constraint system, which the user can configure (Table 1). It bounds the flow rate, the temperature spread, the injection temperature and the withdrawal temperature. When a limit is exceeded, the value is clamped to that limit and the number of affected time steps is reported to the user in the terminal.

7. L155: Maybe revise to “Assuming that residence time is negligible, the model does not account for any biogeochemical transformations between intake and backflow.” The suggestion was incorporated in the text. Now it reads (L. 182):  
*“Assuming that residence time is negligible, the model does not account for any biogeochemical transformations between extraction and injection.”*
8. L186: Unclear to me where point (1) controlled verification is? Aren’t all points related to this one?

We agree, item (1) did not belong to that list. The list now has four items and each one names the section it refers to. The controlled set-up is explained in the paragraph that follows (L. 211):

*“The evaluation of the thermal exchange module follows this approach: (1) mass and energy conservation checks; (2) assessment of simulated thermal dynamics; (3) physical constraint system behavior; and (4) computational efficiency.”*

9. L189: The scenarios are later defined sometimes as HP-OFF instead of HP off. Also, HP-on should also be explicitly defined somewhere

We have incorporated the suggestion and now only the hyphen version (HP-ON and HP-OFF) is used, including the table headers and the figure captions. We have also defined HP-ON and HP-OFF where they first appear (L. 217):

*“We ran two simulations of Große Dhünn. In HP-ON the heat pump is active, with the configuration given in Table 2. In HP-OFF the heat pump module is turned off and the model runs as standard GLM simulation.”*

10. L290: Would it be possible to also discuss the energy benefits of heat extraction from lakes? Is this economically feasible? Can your model results quantify this in back-of-the-envelope calculation?

We have added two paragraphs to the end of Section 4 (L. 360):

*“The removed heat can counteract the warming that lakes are currently experiencing, and Fink et al. (2014) suggested that thermal use could compensate climate-induced warming. The present simulations quantify this for one reservoir and show that it is strongly graded with depth: the mean cooling is 0.06 K at the surface, 0.38 K for the whole lake by volume, and 1.48 K at the extraction elevation. The buffering is therefore concentrated in the hypolimnion and is small at the surface, where most assessments of lake warming are focused.”*

Regarding the economic feasibility we cited a paper we wrote with colleagues from the Fraunhofer Institute ISE (Oberfeier et al., submitted) so a reader who wants a deeper look into the economic analysis is directed to it (L. 363).

Regarding the back-of-the-envelope calculation we have added a short paragraph:

(L. 365) *“In the simulated scenario (HP-ON), the heat pump removes  $4.96 \times 10^{15} \text{ J}$  over the 19 years, corresponding to a mean heat transfer rate of 8.3 MW, or 73 GWh per year.”*