How might groundwater flow systems be modified by climate change?

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Background and objectives

This study aimed to evaluate the influence of climate change-impacted recharge on groundwater levels and on inter-connected groundwater flow patterns, with special emphasis on how flow system fragmentation and hierarchy may change in the future. Possible consequences of these modifications on groundwater-related shallow surface water bodies and on interaction between groundwater and surface water are also examined.

Study site and predicted climate change

Being a natural conservation area, the Tihany Peninsula in Hungary was an ideal test site for examining the impact of climate change on groundwater levels and groundwater flow systems.

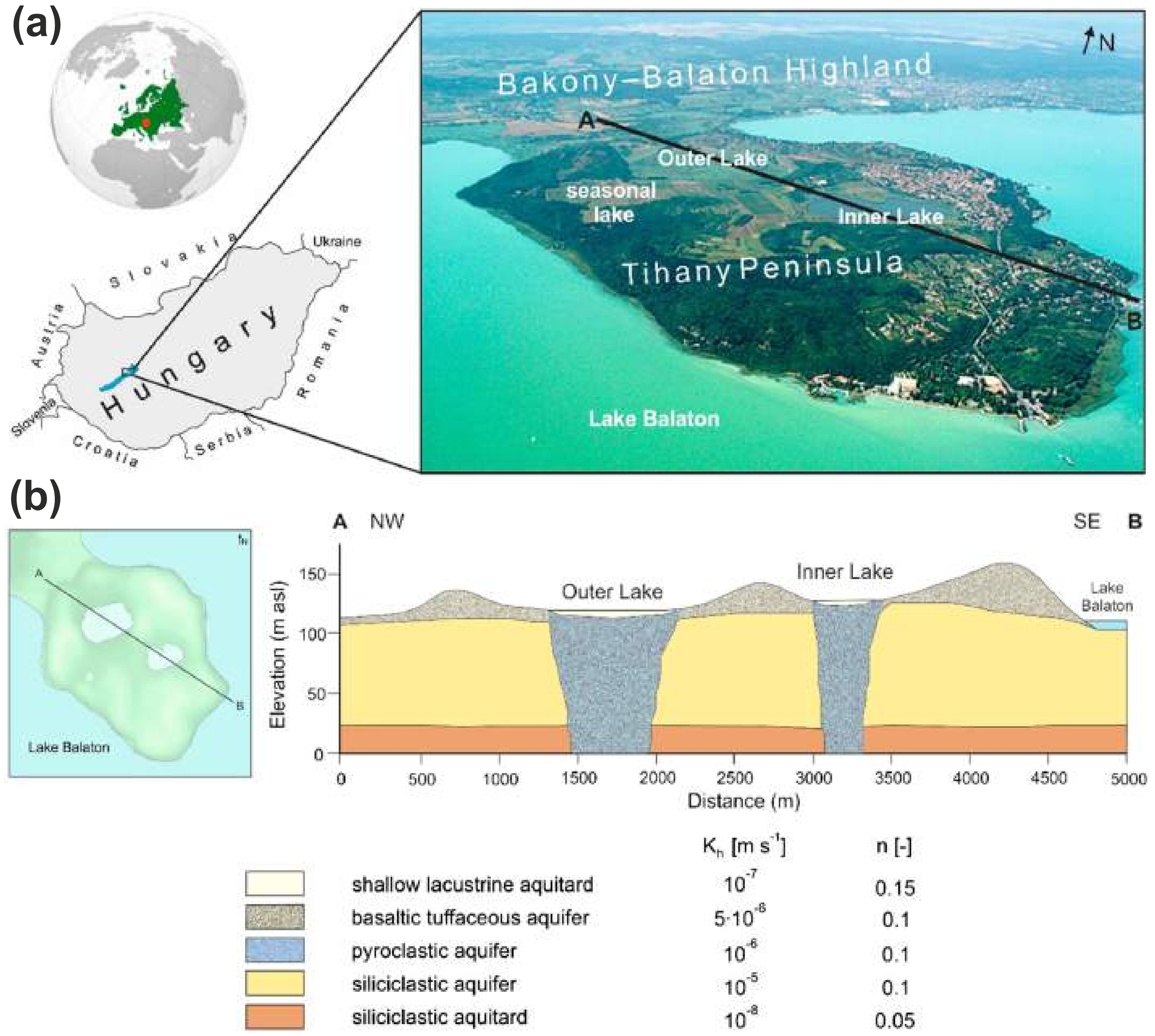

Figure 1: Characteristics of the Tihany study area, Hungary, Europe, showing: (a) Location of the wetlands on the Tihany Peninsula, (b) location of the cross-section AB and hydrostratigraphic units along the cross-section with horizontal hydraulic conductivity and porosity values.

Based on regional climate change modelling predictions for Hungary, a 20% decrease in precipitation and a 4 °C increase in temperature is predicted by the end of the century (Pieczka et al., 2011, Bartholy et al., 2014), which can cause a significant 67% decrease in recharge for the groundwater system of the Peninsula.

Methodology

Future changes in groundwater levels and flow system characteristics due to climate change were simulated using the transient numerical flow module within the Heatflow-Smoker code (Molson and Frind, 2015) along a 2D vertical plane, focuses on the processes acting in the upper approx. 100 m, where the most significant changes in the flow field are expected.

Results and conclusions

Effects of shorter-scale climatic variability

Results of the simulations suggest that short-term hydrological extreme conditions (e.g. extreme wet or dry periods) can cause dynamic evolution and dissipation of transient groundwater flow systems, and the characteristic flow system hierarchy can change from nested flow systems to a set of single flow cells, which also modifies the groundwater – surface water interaction (Fig. 2).

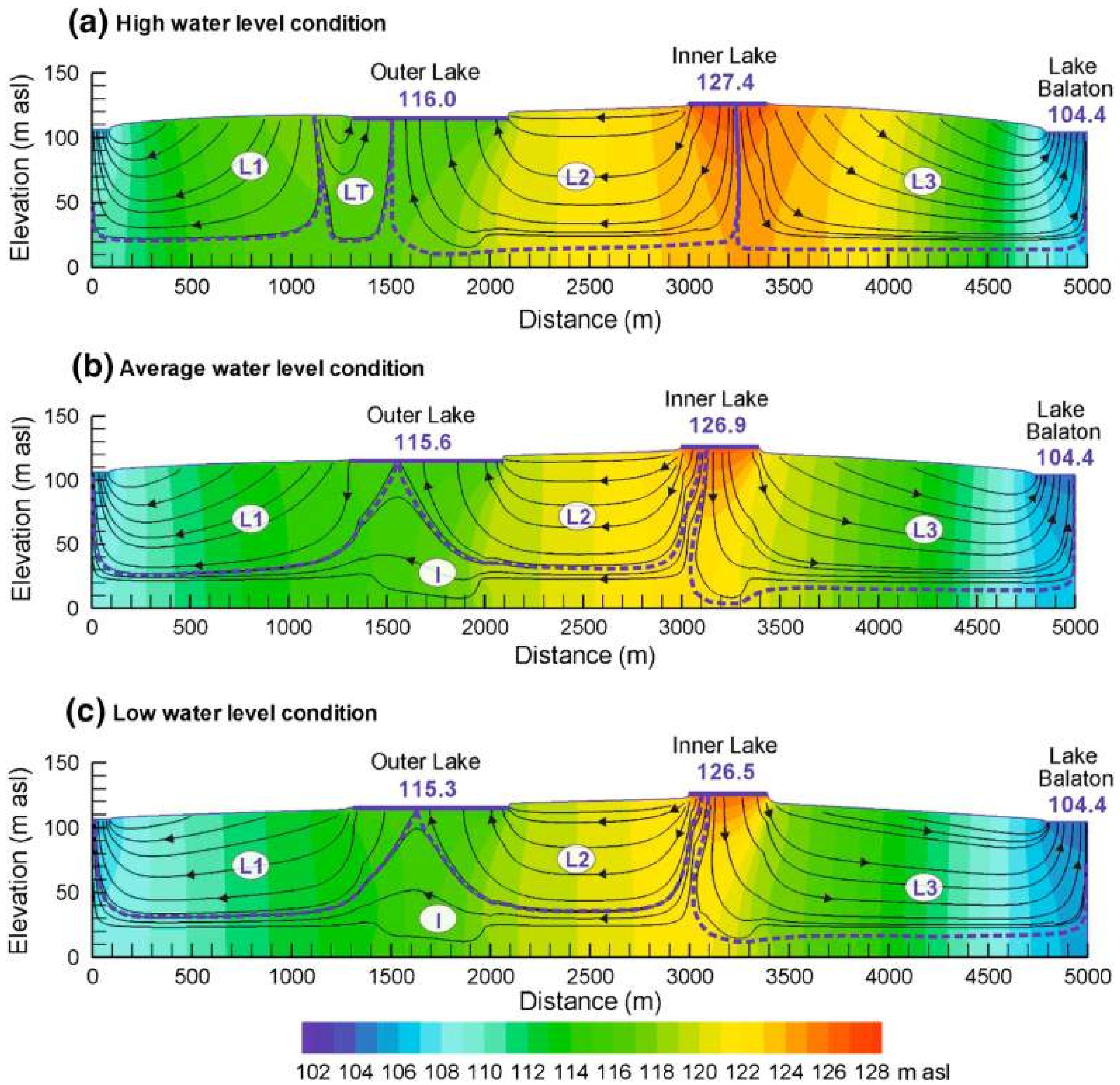

Figure 2: Results of the steady-state groundwater flow simulation for a) high water level conditions, b) average current water level conditions, and c) low water level conditions. Hydraulic head values are colour-shaded; dark blue lines and numbers represent the lake water levels (m asl); groundwater flow directions are indicated by black arrows. Dashed lines show the boundary of different flow systems. L1, L2, L3 are local, I is intermediate flow system. Distances between streamlines are not proportional to water flux. Cross-section has 7× vertical exaggeration.

Long-term changes and its consequences

The most important effect of long-term recharge reduction related to modification of the flow system hierarchy along the studied section, in which the current local flow system between the lakes gradually degrades over time, rendering the groundwater flow field less fragmented and more uniform. As groundwater levels decrease, horizontal flow becomes dominant, and the character of the groundwater – surface water interaction is modified. The groundwater level is predicted to decrease below the bottom of Inner Lake in approx. 30–35 years, by which time the lakebed is assumed to become dry, and the lake will disappear (Fig. 3).

A reduction in groundwater levels under climate-driven recharge change could strongly affect ecologically-significant flow regimes by the modification of its penetration depth (Fig. 3). Since water and nutrient budgets of groundwater-related surface waters are strongly influenced by groundwater, wetland water quality could also change in the future. Preservation of associated groundwater-dependent ecosystems would be challenging under these conditions since long-term climate change could potentially have serious consequences, including wetland disappearance.

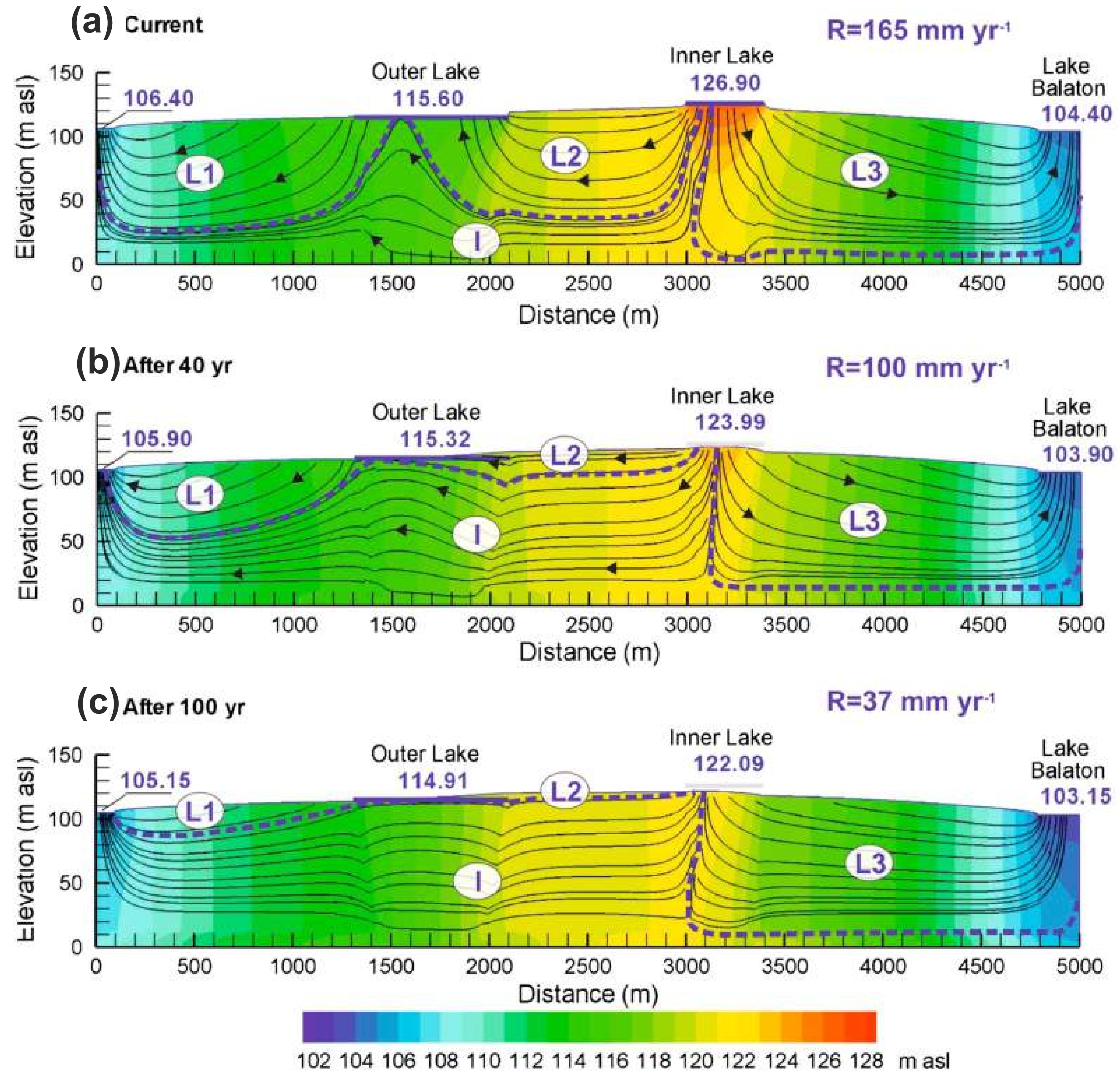

Figure 3: Snapshots of the transient flow simulation. a) Current situation, b) after 40 years, c) after 100 years. Hydraulic head values are colour-shaded; groundwater flow directions are indicated by black arrows; dashed lines show the boundaries of different flow systems. L1, L2, L3 are local, I is intermediate flow system. Dark blue lines and numbers represent the lake water levels (m asl) which are characteristic of each simulation time. Grey lines represent areas where the hydraulic head is beneath the lakebed elevation, i.e. when the lakebed is assumed to be dry. "R" represents actual recharge at the corresponding time. Distances between streamlines are not proportional to water flux. Cross-section has 7× vertical exaggeration.

Acknowledgements

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