Journal of Hydrology 540 (2016) 457–468

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Flood frequency matters: Why climate change degrades deep-water quality of peri-alpine lakes

Gabriel Fink [a,*], Martin Wessels [b], Alfred Wüest [a,c]

[a] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Surface Waters – Research and Management, Seestrasse 79, CH-6047 Kastanienbaum, Switzerland
[b] Institute for Lake Research – State Institute for Environment, Measurements, and Nature Conservation, Baden-Württemberg LUBW, Argenweg 50/1, DE-88085 Langenargen, Germany
[c] École Polytechnique Fédérale de Lausanne, Physics of Aquatic Systems Laboratory – Margaretha Kamprad Chair, EPFL-ENAC-IIE-APHYS, CH-1015 Lausanne, Switzerland

ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form 30 May 2016
Accepted 10 June 2016
Available online 16 June 2016
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Alon Rimmer, Associate Editor

Keywords:
River underflow
Flood frequency
Lake Constance
Water renewal
Water quality

SUMMARY

Sediment-laden riverine floods transport large quantities of dissolved oxygen into the receiving deep layers of lakes. Hence, the water quality of deep lakes is strongly influenced by the frequency of riverine floods. Although flood frequency reflects climate conditions, the effects of climate variability on the water quality of deep lakes is largely unknown. We quantified the effects of climate variability on the potential shifts in the flood regime of the Alpine Rhine, the main catchment of Lake Constance, and determined the intrusion depths of riverine density-driven underflows and the subsequent effects on water exchange rates in the lake. A simplified hydrodynamic underflow model was developed and validated with observed river inflow and underflow events. The model was implemented to estimate underflow statistics for different river inflow scenarios. Using this approach, we integrated present and possible future flood frequencies to underflow occurrences and intrusion depths in Lake Constance. The results indicate that more floods will increase the number of underflows and the intensity of deep-water renewal – and consequently will cause higher deep-water dissolved oxygen concentrations. Vice versa, fewer floods weaken deep-water renewal and lead to lower deep-water dissolved oxygen concentrations. Meanwhile, a change from glacial nival regime (present) to a nival pluvial regime (future) is expected to decrease deep-water renewal. While flood frequencies are not expected to change noticeably for the next decades, it is most likely that increased winter discharge and decreased summer discharge will reduce the number of deep density-driven underflows by 10% and favour shallower riverine interflows in the upper hypolimnion. The renewal in the deepest layers is expected to be reduced by nearly 27%. This study underlines potential consequences of climate change on the occurrence of deep river underflows and water residence times in deep lakes.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Oxygen-rich rivers plunge into lakes most noticeably during floods (Lenzi and Marchi, 2000). After plunging, these dense, sediment-laden discharges flow along the lakebed as density-driven underflows (Alavian et al., 1992; Sturm and Matter, 1978). Over a century ago, Forel (1885) discovered that these flood-induced density currents created subaquatic canyons in Lake Geneva (Corella et al., 2014).

On the way to the deepest location in a lake, entraining water and settling particles continuously decrease the density of the underflows or so-called density currents. Once equal density with the ambient lake water is reached (maximal intrusion depth), the underflows detach from the lakebed, cease to follow the bottom topography and intrude into the ambient water column. Sometimes parts of it split at density steps (Cortés et al., 2015). The underflows spread into lake water of equal density (Marti et al., 2011) and may slightly rise due to continuing sedimentation and subsequent decrease in density of the sediment-containing water. The constituents of turbidity currents, such as dissolved and particulate substances, become part of the lake water body and sediments (Pennington, 1979; Yang et al., 2002).

The density-driven underflows are very important for lake water quality. They can transport large amounts of heat and lake ambient surface water into the hypolimnion (Wüest et al., 1988) and thereby alter the physical, chemical, and biological environment of the deep-water (Vincent et al., 1991; Schindler, 2009).

* Corresponding author at: University of Kassel, Center for Environmental Systems Research (CESR), Wilhelmshöher Allee 47, DE-34109 Kassel, Germany.

E-mail addresses: gabriel.fink@uni-kassel.usf.de (G. Fink), martin.wessels@lubw.bwl.de (M. Wessels), alfred.wueest@eawag.ch (A. Wüest).

http://dx.doi.org/10.1016/j.jhydrol.2016.06.023
0022-1694/© 2016 Elsevier B.V. All rights reserved.

The deep-water warming supports deeper convective mixing during the subsequent winter, which is the major process for dissolved oxygen enrichment in lakes (Schwefel et al., submitted for publication).

Underflows are also important for deep-water renewal (Lambert et al., 1984) and, consequently for the dissolved oxygen levels and water quality in the deeper layers of lakes. It is reported that dissolved oxygen injection into the meta- and hypolimnion by underflows could dampen the effects of eutrophication (Vincent et al., 1991). Moreover, the oxygen dissolved in the intruding river water could substantially alter the hypolimnetic oxygen concentration (Marcé et al., 2008).

Climate governs all these processes as it defines the frequency of floods and subsequent underflows. Thus, climate change will affect the underflow frequency and, subsequently, also deep dissolved oxygen delivery. This hypothesis is based on the fact that (i) the intrusion depth as well as the frequency of such underflows (and consequently deep oxygen entrainment), strongly depend on the intensity, duration, and frequency of floods, and (ii) that hydrologic regimes will change with future climate (Hartmann et al., 2013; Fink et al., 2014; Birsan et al., 2005; Bernhard et al., 2011). Particularly in the European Alps, substantial seasonal discharge shifts are expected for the upcoming decades, as shown by Middelkoop et al. (2001) for the Rhine Basin.

The objective of this study is to quantify the effects of climate change on the frequencies, intrusion depths, and intrusion exchange volumes of density-driven underflows in deep lakes. The paper aims to explicate the importance of effects caused by altered discharge characteristics such as flood frequency and seasonality. In a broader sense, it is of paramount interest to understand how lake water quality and its sensitivity to hydrological changes are related to climate change in the catchment. To answer these questions, we investigated the connection between changing hydrologic regimes in the lake catchment (discharge statistics) and the statistics of the underflow-induced deep-water renewal for Lake Constance. We consider this lake as a large representative system for the peri-alpine environments of Central Europe. This paper presents results of forcing a simple hydrodynamic underflow model with different inflow scenarios for potential climate-induced hydrologic changes and provides an analysis of the statistics. In particular, the paper discusses how the frequency distribution of the underflow events in deep lakes is affected by climate/hydrological changes.

2. Study site

2.1. Lake Constance

Lake Constance is situated on the northern Plateau of the European Alps (Fig. 1) at 47°3′N and 9°2′E. It is the source of drinking water for more than 4 million people and serves as well for

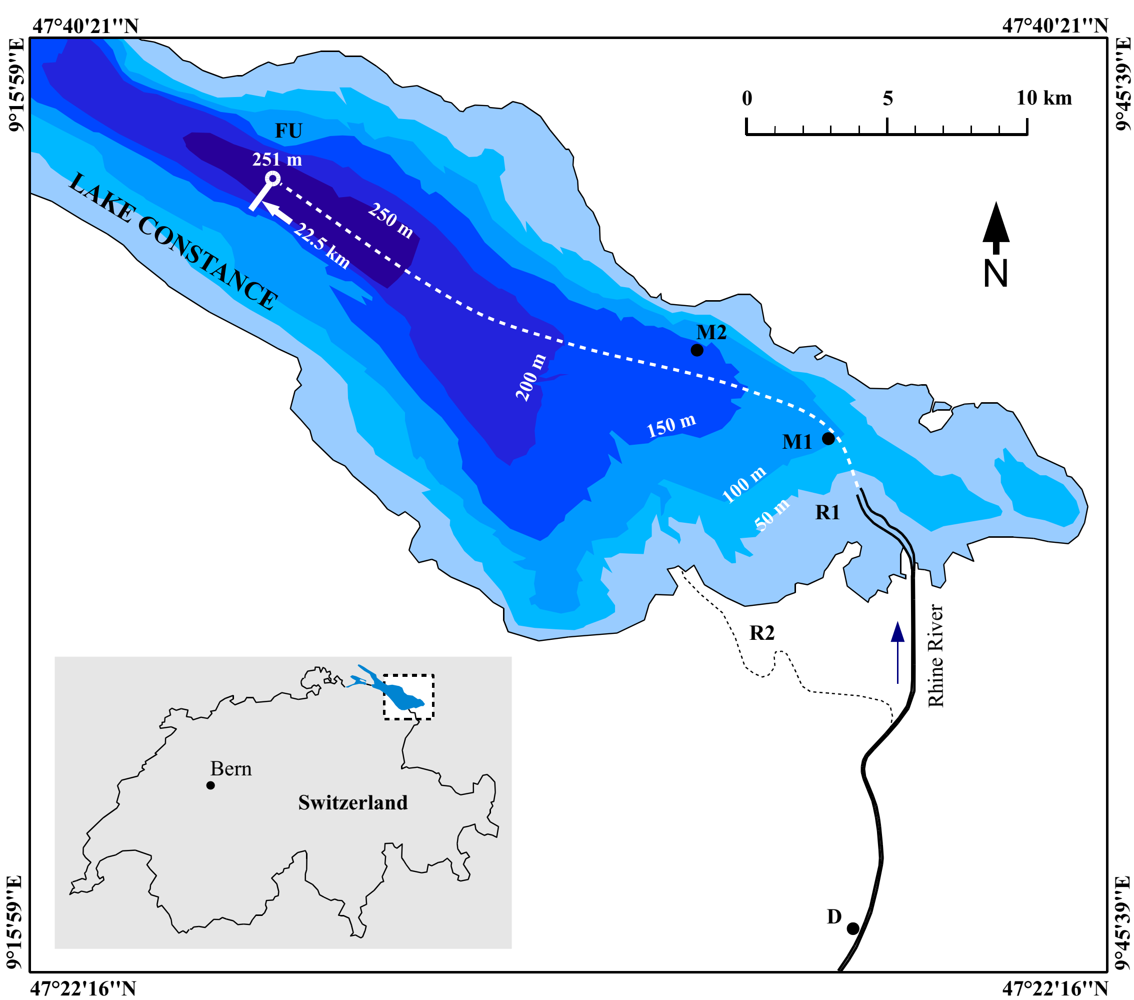

Fig. 1. Map of the eastern part of Lake Constance. The white dashed line is the route of a River Rhine underflow starting at the mouth (R1) along the lake bottom to the deepest point in 251 m depth (FU). M1 and M2 are two moorings for underflow detection, ~5 km apart. D indicates the upstream gauging station Diepoldsau. At the end of the 19th century, the river mouth was shifted from R2 to R1.

Download English Version:

https://daneshyari.com/en/article/6409547

Download Persian Version:

https://daneshyari.com/article/6409547

Daneshyari.com