Lakes: a significant thermal energy source

Using heat from Lake Constance equivalent to the energy produced by one or two nuclear power plants would lead to a change in water temperature of less than 0.2°C, with no appreciable impacts on the ecosystem. This is one of the findings of a recent Eawag study which, for the first time, systematically simulated how lake stratification and water temperatures would be affected by substantial withdrawals of thermal energy in the winter or inputs of cooling water in the summer. *By Andri Bryner*

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Fig. 1: Thermal energy from Lake Constance could be used without producing adverse impacts on the ecosystem (pictured here: Lake Constance and Mount Säntis).

Given the goals of switching to more sustainable energy supplies and reducing CO_2 emissions, the use of lake water for heating and cooling is becoming increasingly attractive. In Switzerland, non renewable fossil fuels still supply around 65 per cent of the energy required for heating buildings. With urban centres located close to large lakes such as Constance, Zurich, Lucerne or Geneva, it would seem obvious to exploit the vast thermal potential of deep perialpine lakes. While a number of plants are already in operation – e.g. in Zurich, Lausanne and St Moritz – the amounts of thermal energy used to date have been modest. In addition, the efficiency of older heat pumps is often poor, with a low ratio of useful heat produced to drive energy (usually electricity, sometimes combustion engines for larger systems).

Little is known about thermal pollution

Apart from the question of the efficiency and cost-effectiveness of plants, there is also a need to protect lakes from so-called thermal pollution. This term refers to adverse impacts on water quality or biotic communities caused by inputs of warmed or cooled water (i.e. when lake water is used for cooling or heating, respectively). Here, very few scientific studies are available. One question which needs to be addressed, in particular, is the level of discharges of cooler water which could be problematic in a lake. In rivers, higher drifting rates of benthic macroinvertebrates have been observed in association with abrupt temperature decreases of more than 3°C. On the basis of older studies, it is assumed that, as a general rule, temperature changes of -0.5 to +0.5°C have no or only insignificant effects on ecology in rivers and lakes.

Somewhat more is known about the effects of artificially increased temperatures: in Lake Stechlin (Germany), temperature increases of 1°C due to discharges of (nutrient-rich) cooling water led to an increase in primary production, increased abundance of benthic macroinvertebrates and changes in community structures. In rivers, warmer temperatures are known to lead to a decrease in cold-water fish species – especially if water temperatures are already generally high. Different studies have suggested different thresholds for the occurrence of significant impacts on aquatic life, but it is widely agreed that adverse effects are to be expected with temperature alterations exceeding 4°C.

Modelling based on a realistic demand scenario

For their study, rather than assuming levels of heat use that could cause surface water temperatures to drop by several degrees, the Eawag scientists developed a realistic scenario based on demand of around 1 kilowatt per person living near Lake Constance. For a population of 1 million, the total demand is then 1 gigawatt or 2 watts per square metre of lake surface – roughly equivalent to the output of a nuclear power plant. Compared to the small number of existing heat pumps and cooling water outlets, this figure is fairly high (a 30-fold increase), but compa-

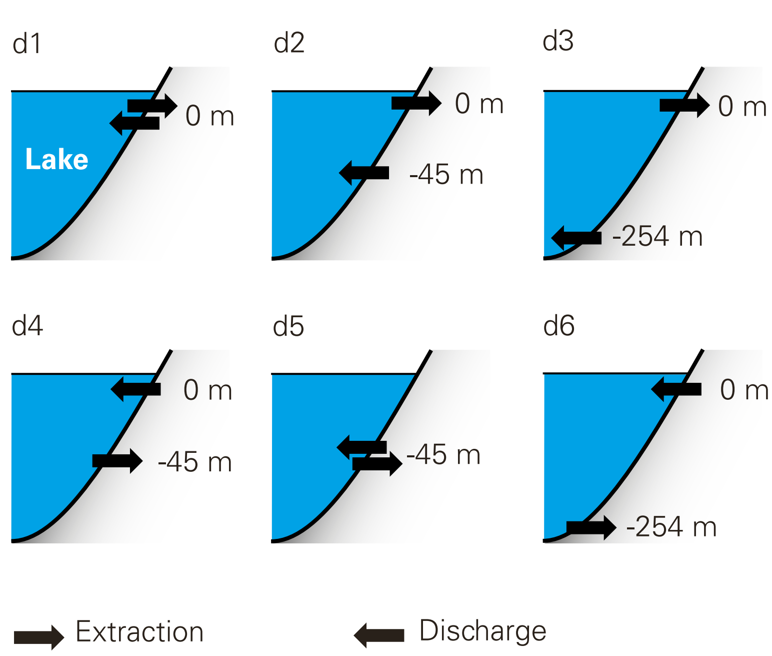

Fig. 2: The various water extraction and discharge designs (d1–d6) used in the study; in each case, the two flows balance out.

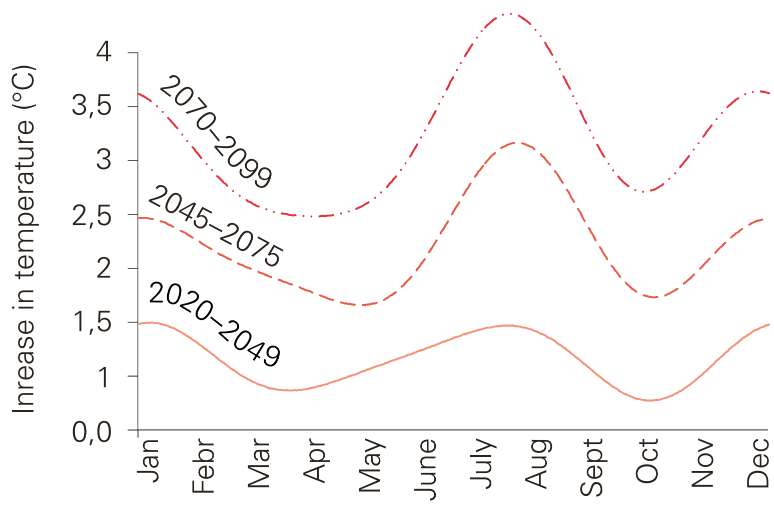

Fig. 3: Mean increase in daily air temperature on Lake Constance relative to the period 1980–2009 under the IPCC climate change scenario A1B.

red to the natural heat fluxes in Lake Constance it is minimal: for example, heat loss due to long-wave radiation emission alone is around 170 gigawatts, and heat loss by evaporation is 20 gigawatts.

To estimate the spatial and temporal distribution of temperatures in the lake, the researchers used a mathematical turbulence model. As well as various discharge rates and temperature differences, they considered a variety of water extraction and discharge designs (Fig. 2). For comparison, they also modelled the effects of heat input under climate change scenarios (Fig. 3).

Minimal effects on temperature

Under the realistic demand scenario, modelling indicates only minor effects on water temperature: with 1 gigawatt of heat use, the surface temperature would decrease by no more than 0.2°C. The range of change would be even smaller (0.1°C) if heat extraction in the winter was offset by heat input (discharge of used cooling water) in the summer.

The modelling showed that, depending on the extraction and discharge design, temperature changes in the lake can also be influenced – or minimized – by the rate of water discharge and the difference between extracted and discharged water temperature. With the exception of discharges of (warmed) surface water into the deepest layer (design d3, right-hand panel of Fig. 4), the various extraction/discharge designs have a minimal influence on changes in temperature.

The summer stagnation period may be slightly extended as a result of significant withdrawals of cooling water and discharges of warmed water; on average, this period will begin one day earlier for each gigawatt of heat discharged to the lake. As most scenarios assume additional heat extraction in the winter, the (desired) mixing of the lake in the autumn and spring will tend to be promoted. According to lead author Gabriel Fink, "Smart design of a large-scale combined

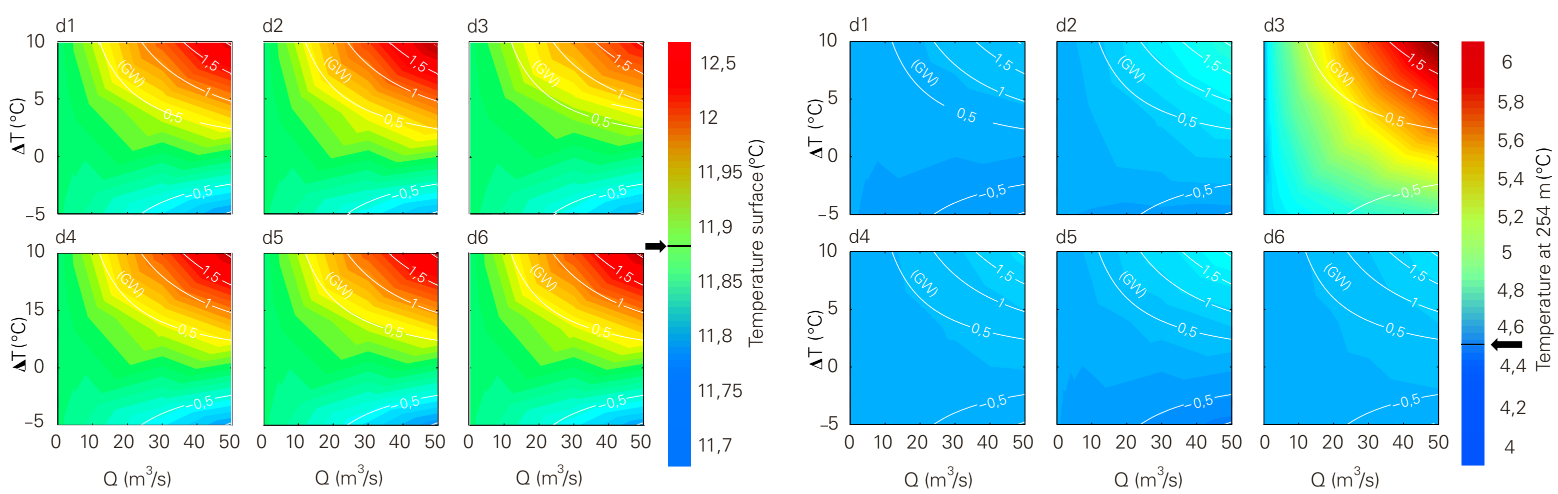

Fig. 4: Mean water temperature at the lake surface (left) and at a depth of 254 metres (right) for the heat extraction and discharge designs d1–d6, with various rates of water discharge (Q = 0 to 50 m³/s) and differences between discharged and extracted water temperature (ΔT = -5°C to +10°C). The white lines indicate the related thermal power in gigawatts (-1 to +2 GW). The black arrow on the coloured temperature scales (right) indicates the current average temperature of the surface or bottom water. With the exception of discharges of warmed water into the deepest layer (d3, right-hand panel), the various extraction/discharge designs have only a minimal influence on water temperature.

plant can help to ensure that the two effects – additional cooling in the winter and additional warming in the summer – offset each other, at least partly."

Even if heat discharge is (realistically) doubled to 2 gigawatts, the impact is clearly eclipsed by climate-induced effects. By the end of the 21st century, the warming predicted by the IPCC would be equivalent to heat discharge of around 40 gigawatts (85 watts per square metre). Conversely, the effects of climate change could be mitigated or even offset by greater heat extraction: to compensate for the warming projected to occur by 2049, around 14 gigawatts of heat would need to be extracted.

Caution required with smaller lakes

The aim of the study – supported by the Interreg IV programme – was to explore the potential and limits of heat use from Lake Constance. Project manager Alfred Wüest believes that the results are also applicable to other large, deep lakes; caution is, however, required in the case of small, shallow lakes. In addition, any adverse impacts at the local level would need to be closely monitored. But Wüest concludes: "Under the conditions we specified ourselves in the study – that temperature changes at the surface should not exceed 0.2 degrees – the effects on lake mixing in the winter and stagnation in the summer are negligible." The effects on the ecosystem, he adds, are expected to be minimal, especially given the benefits arising from a reduction in fossil fuel consumption. Wüest hopes that some of the major thermal use projects currently under development can be realized – e.g. the projects on Lake Geneva for heating/cooling of the EPFL and Lausanne University, and of the UN complex («Genève-Lac-Nations» project). For Lakes Constance, Geneva, Neuchâtel, Lucerne and Thun combined, he has already roughly estimated the thermal potential that could be exploited if temperature changes of no more than 1°C up to a depth of 100 metres were accepted. The result? A total of 60 gigawatts.

Riparian states permit thermal use of water from Lake Constance

Since 1987, the use of water from Lake Constance for heating or cooling has been strictly limited. The restrictions have now been eased in new guidelines issued by the International Commission for the Protection of Lake Constance (IGKB) in May 2014. Thermal use of lake water is to be permitted insofar as it does not adversely affect the condition of the lake or its biotic communities. According to the revised version of Chapter 5, priority should continue to be given to ecosystem protection and drinking water abstraction. For example, water extracted from the lake must not be chemically modified. Withdrawals are only permitted up to a depth of 40 metres, and the discharge depth is to be selected so that the water is stratified at depths between 20 and 40 metres. The discharge temperature must not exceed 20°C. Outside a small mixing zone, the change in temperature must not exceed 1°C. Finally, the IGKB notes that, in order to limit the number of interventions affecting the lake and shore, larger-scale facilities should be preferred: plants with an output of less than 200 kilowatts are to be avoided.

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