Use of thermal energy from lakes and rivers

Thermal use of surface waters (heat extraction for heating and disposal for cooling purposes) is becoming increasingly important – not least as part of Switzerland's new federal energy strategy. But what are the ecological impacts of the use of thermal energy from lakes and rivers? To help address this question, Eawag has carried out an applied research project.

This factsheet is addressed to planners and operators of thermal use installations, engineering consultants, federal and cantonal agencies, and the relevant authorities. Further information can be found on the project website: https://thermdis.eawag.ch/en

Long-term strategy: catchment-scale heat management and aquatic ecosystem monitoring

In rivers, the seasonal temperature regime varies according to the discharge regime. In addition, the influence of extensive thermal use of rivers may be evident a long way downstream. In large rivers, measurable effects on temperature can be observed over hundreds of kilometres (Fig. 1). In such cases, there is a need for thermal uses to be coordinated within the catchment so as to (i) ensure equal treatment of the various users, (ii) limit the physical and environmental impacts, and (iii) preserve the ecological and socioeconomic functions of the river. This calls for planning at the supraregional level. Control measures (typically restrictions imposed on thermal uses) should be applicable for all users of the waters concerned.

Procedures (e.g. authorisation practice, requirements, etc.) should also be harmonised in the case of lakes bordered by different cantons (and/or countries). A standard procedure can be developed and supported by a commission responsible for the protection of surface waters (e.g. CIPEL for Lake Geneva, AKV for Lake Lucerne, IGKB for Lake Constance).

As well as taking (legal) protection requirements into account, the physical and environmental impacts of thermal uses should be assessed. Monitoring carried out in collaboration with the authorities can help operators to gain a better understanding of thermal pollution and to optimise installations. For example, the following questions should be considered for each season:

- What are the local maximum temperature changes?
- To what extent does thermal pollution extend downstream or spread within a lake?

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- How do sensitive species react in the areas subject to thermal pollution?

Exchanges of heat between different waterbodies should also be taken into account in planning and impact assessment (e.g. inputs of heat to a lake from a thermally polluted river).

Recommendations

Characteristics of lakes and rivers relevant for thermal use

- Because of their low water temperatures, mountain rivers may be well suited for cooling applications during the summer. In the winter, however, these temperatures often fall below 3°C, and discharge is low. Such rivers are therefore not suitable for heat extraction during the winter.

- Lowland rivers are particularly suitable for heat extraction since, in the winter, discharge remains adequate and water temperatures scarcely drop below 4°C. High water temperatures, however, make these rivers less suitable for heat disposal in the summer. Especially downstream of low-lying lakes or in slow-flowing rivers, the summer temperatures increasingly often exceed the legal limit of 25°C specified for thermal use. This leads to restrictions and reduced efficiency with regard to cooling applications.

- The operation of installations can be adversely affected by biofouling (e.g. algae bacteria, or mussels) and incrustations. This needs to be taken into account at the design stage. Biofouling is promoted by warm, nutrient-rich water, which generally precludes withdrawals at the surface of lakes. Filters are usually required to control biofouling and thus reduce operating costs.

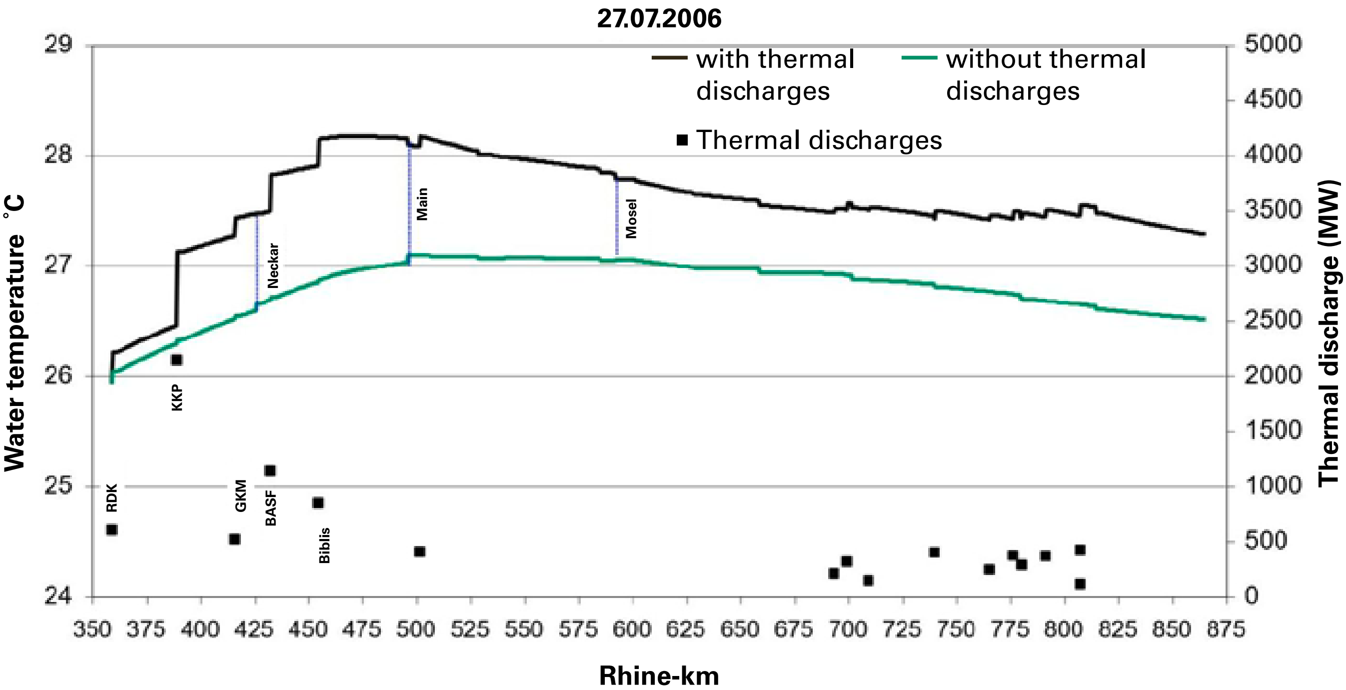
- The surface layer of lakes serves a variety of functions. This layer exhibits higher biological activity and highly variable temperatures. Accordingly, lake water should not generally be withdrawn above a depth of 15 m. For cooling applications, it is advisable for withdrawals to be made below a depth of 30 m. For installations requiring a constant low and stable temperature, depths of 50–70 m may be ideal. In large lakes, however, higher temperatures may arise even at such depths as a result of autumn storms; this should be taken into account when the installations are planned.

- When sites are selected, consideration must be given to existing water withdrawals and discharges, as well as other uses (e.g. protected areas). Operations may be disrupted by nearby thermal discharges or wastewater disposals.

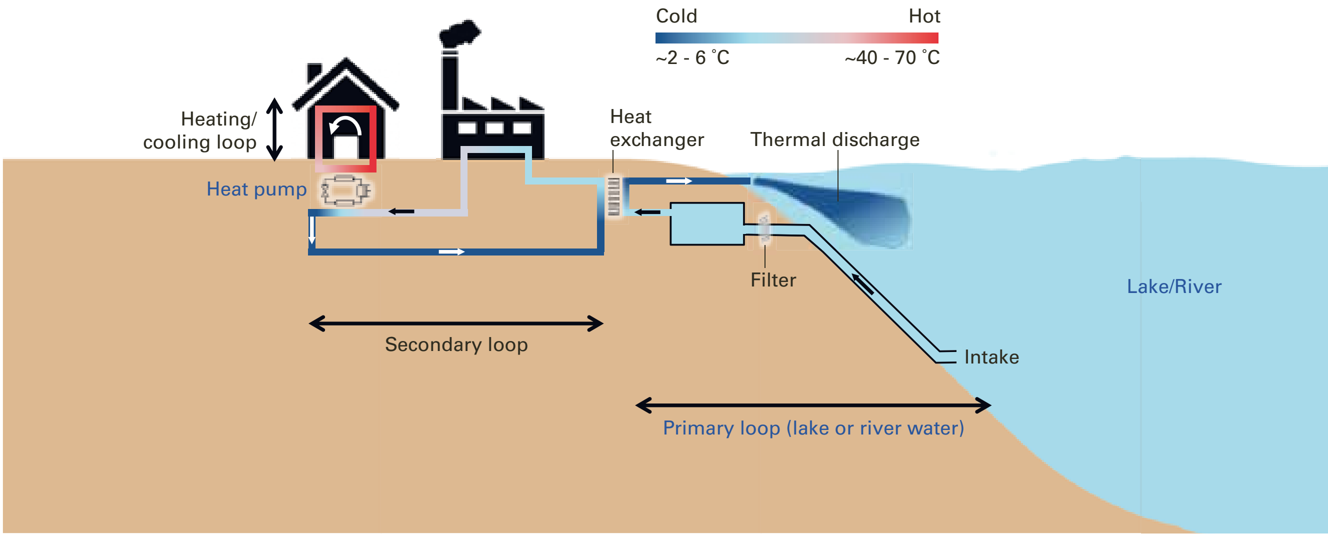
Withdrawal and discharge structures

- The construction of a water withdrawal or discharge structure always involves some perturbation for the waterbody concerned. Potential impacts on protected areas or aquatic organisms must be carefully assessed in advance, including the question of whether the site is of particular importance for certain species (e.g. during the spawning season).

- In waterbodies, the number of installations such as water withdrawal and discharge structures should be kept to a minimum. For a given amount of energy, a small number of relatively large installations is to be preferred to numerous small installations. When new installations are planned, existing or possible future uses in the local area should therefore be taken into account.



Example of summer water temperatures along the Rhine from Karlsruhe to the Dutch-German border with and without the influence of thermal discharges from the cooling of power plants. Periods of very high temperatures, posing problems for certain aquatic organisms, will be further intensified by climate change. (Source: ICPR)



Thermal use of a lake/river: in this example, an industrial plant is cooled and a residential building is heated. As heating predominates, the water discharged is colder than the water withdrawn. (Graphic: Adrien Gaudard, Eawag)

- Water intakes in lakes and rivers should be designed so as to prevent large or small fish from being drawn in. To this end, screens or similar protective structures should be installed, and the intake velocity should not exceed 10 cm/second. To ensure that fish-screen contacts are kept as short as possible, the angle between the screen and the direction of flow should be reduced as far as possible.

- In the case of combined heating and cooling systems ("anergy grids"), part of the heat can be reused directly within the thermal network, without entering the waterbody. Such combined uses are advantageous from a water protection perspective.

- In lakes, shoreline stability must be taken into account. Sites with an unstable subsurface and areas prone to subaquatic landslides should be avoided.

Water withdrawals and thermal discharges

- The flow rate and the temperature difference (ΔT) determine the amount of heat withdrawn from or discharged into a waterbody. From the viewpoint of operational efficiency, a higher ΔT and lower flow rate are desirable. A higher ΔT is, however, generally associated with more pronounced local ecosystem impacts. But a higher flow rate can also have adverse impacts, e.g. when water is transferred between different layers of a lake.

- Returning lake water to a lake outflow may possibly help to reduce the impacts, and this should be taken into consideration when an installation is being planned.

- Knowledge of seasonal cycles in aquatic ecosystems makes it possible to reduce the impacts, e.g. via improved timing and optimal siting of thermal discharge systems.

- Submerged heat exchangers may represent an alternative to water withdrawals, provided that the local current is adequate to ensure efficient heat exchange. They offer the advantage of not causing any water transport within the waterbody; they may, however, require more significant structural interventions.

Thermal use of rivers

- The creation of residual flow stretches should be avoided. In cases of extensive use (withdrawal of a considerable proportion of the natural flow), water should be returned immediately after withdrawal.

- Water should always be returned to the same waterbody. Otherwise, there is a risk of spreading diseases (proliferative kidney disease in fish, crayfish plague in crustaceans) or invasive alien species, if the water is diverted into previously unaffected reaches.

- Under the Waters Protection Ordinance, the discharge structure must be designed so as to ensure rapid mixing across the river channel, in order to avoid marked local temperature differences. However, exceptions may be appropriate if it is demonstrated that slower mixing would be beneficial for the ecosystem (e.g. more rapid heat loss to the atmosphere, preservation of a largely unaffected migration corridor for fish or a cold-water refugium associated with groundwater upwelling or cool tributaries).

- Cooling applications should not lead to an increase in summer temperature extremes. These can be critical for the survival of aquatic organisms and will further increase as a result of climate change, even without additional thermal uses.

- In assessing the impacts of thermal discharges, consideration should be given not only to the legally prescribed guide values, but also to the seasonal requirements of species occurring in a river (e.g. temperature preferences for fish migration or spawning, which may be subject to local variation).

- Heat released into a river will generally persist over long distances. In the assessment of possible impacts, other upstream and downstream sources of thermal pollution must therefore also be taken into account.

Thermal use of lakes

- Warming of the surface layer should be avoided. Also to be avoided, in particular, are marked delays in seasonal mixing or marked reductions in the intensity thereof.

- In lower layers of lakes, discharged heat can accumulate over an extended period until the next winter mixing. The maximum temperature change resulting from thermal use is therefore attained shortly before each complete mixing. To assess this temperature change, one needs to take into account not only the amount of heat withdrawn/discharged but also its vertical distribution due to the spread of the thermal plume (= wastewater, from a legal perspective), as well as natural mixing processes. The depth zone where most of the heat accumulates seasonally is known as the receiving water volume.

- As a result of the combination of all thermal uses of a lake, the temperature in the receiving water volume should not be increased by more than 0.5°C or reduced by more than 1°C. In general, no adverse impacts are to be expected with cooling of a few tenths of a degree. In cases where cooling exceeds 0.5°C and in general whenever heat is discharged, detailed assessments of the impacts are recommended.

- Isolated lake basins (limited water exchange with the rest the lake) should be considered separately.

- Depending on the discharge depth, two cases are to be distinguished:

  a) The water returned to the lake ends up in the same depth zone as is used for water withdrawal. It must be avoided that the discharge influences withdrawal (short circuit).

  b) The water returned to the lake ends up in a different depth zone from that used for water withdrawal. As well as heat transport, this also leads to water transport between these two depth zones. This water transport should not give rise to any substantial nutrient flows or any marked changes in stratification. Reducing the flow rate (typically by increasing the ΔT) makes it possible to reduce the amounts of water transported. Such a design is desirable if the expected impacts of water transport are greater than those of local temperature changes in the discharge area.

- Discharge should be designed in such a way that the resultant currents do not disrupt natural processes (e.g. ice cover, sedimentation, growth of riparian vegetation).

Information on related topics (external sources)

- General: Overview of reports from the "Thermal Networks" programme (available in French / German / Italian; Swiss Energy, SFOE 2021)
- Pipe systems: Use of surface waters for thermal networks (available in French / German ; SwissEnergy, SFOE 2017)
- Heat exchanger contamination in wastewater heat recovery: Wärmerückgewinnung aus Abwasser; (Schriftenreihe der Eawag, Nr. 19; Eawag 2009)
- Heat pumps: Handbook on heat pump planning, optimisation, operation and maintenance (available in French / German / Italian ; SFOE, 2008, revised edition 2018)
- District heating: White Paper on district heating in Switzerland – VFS/ASCAD strategy: Long-term outlook for renewable, energy-efficient local and district heating in Switzerland (available in French/German; eicher+pauli, 2014) and F1 District Heating Guidelines (available in French/German; SVGW/SSIGE, 2017 edition)
- Cooling applications: Heating and cooling with wastewater: Guidance for developers, local authorities and operators (available in French/German/Italian; SwissEnergy, SFOE 2016)

Legal foundations

The general temperature-related requirements specified in the Waters Protection Ordinance (WPO) are applicable for all uses of thermal energy from lakes or rivers:

- WPO, Annex 1 No 1 para. [3]
  The water quality shall be such that:
  a. the temperature conditions are near-natural.
- WPO, Annex 2 No 12 para. [3]
  The hydrodynamics, morphology and temperature conditions of the waterbody must not be altered by water withdrawals, water discharges or engineering measures in such a way that its self-purification capacity is reduced or the water quality is no longer adequate to sustain typical biotic communities.

For watercourses, maximum temperature changes are defined relative to a condition which is as near-natural as possible. This means that existing temperature changes must be taken into account when a new system is planned. In addition, temperature changes are only permissible insofar as the above-mentioned general requirements are still met:

- WPO, Annex 2 No 12 para. [4]
  The introduction or withdrawal of heat must not alter the temperature in a watercourse by more than 3°C above or below the temperature associated with a condition which is as near-natural as possible, or, in trout water reaches, by more than 1.5°C, with the water temperature not exceeding 25°C. These requirements apply after thorough mixing.

For lakes, the WPO does not include any quantitative limits concerning maximum permissible temperature changes, but only qualitative guidelines:

- WPO, Annex 2, No 13 para. [3]
  For lakes, in addition, the following applies:
  a. a. the regulation of lake waters, water discharges and withdrawals, and the use of water for cooling or heat extraction must not adversely affect the natural temperature regime or the distribution of nutrients in the waterbody, or conditions for the life and reproduction of organisms, particularly in the riparian zone.

Requirements for direct (once-through) cooling systems:

- WPO, Annex 3.3 No 21 para. [1]
  Plants with direct cooling systems must be designed and operated according to the state of the art, so that heat generation is minimised and waste heat is recovered as far as possible.
- WPO, Annex 3.3 No 21 para.[4]
  In addition, for discharges into watercourses and dammed river sec tions, the following applies:
  a. The temperature of the cooling water must not exceed 30°C. By way of derogation, the authority may authorise a maximum temperature of 33°C if the temperature of the source waterbody exceeds 20°C.
  b. The increase in the temperature of the waterbody compared to a condition which is as near natural as possible must not exceed 3°C, or 1.5°C in trout water reaches, with the water temperature not exceeding 25°C. If the water temperature exceeds 25°C, the authority may grant exemptions in cases where the increase in the water temperature does not exceed 0.01°C per discharge or the discharge comes from an existing nuclear power plant.
  c. The discharge structure must ensure rapid mixing.
  d. The rate of warming in the waterbody must be limited so that there are no detrimental effects on communities of plants, animals or microorganisms.
- WPO, Annex 3.3 No 21 para. [5]
  For discharges into lakes, in addition to the requirements specified in paragraphs 1–3, the discharge conditions – in particular, the temperature of the cooling water and the depth and type of discharge – must be determined on a case-by-case basis according to the local situation.

Further information: Project website (available in English, French and German): https://thermdis.eawag.ch/en. Relevant characteristics of major Swiss lakes and rivers (usual temperatures, low water discharges, etc.); seasonal potential for thermal use; existing installations; thermal discharge model; the heat potentials of the larger Swiss lakes and rivers can be accessed at map.geo.admin.ch, map: Potential heat use of water bodies.

Contact: Martin Schmid, Surface Waters Research & Management, +41 58 765 2193, martin.schmid@eawag.ch

Factsheet contributors: Adrien Gaudard (†), Martin Schmid, Alfred Wüest, Surface Waters Research & Management; Andri Bryner, Peter Penicka, Communications; English translation: Jeff Acheson, Bottmingen

Address: Eawag, Überlandstrasse 133, CH-8600 Dübendorf, Switzerland, +41 58 765 5511, info@eawag.ch, eawag.ch

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