EAWAG NEWS

Federal Institute for Water Resources and Water Pollution Control

Swiss Federal Institutes of Technology

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NEWS About EAWAG Collaborators

The Government of the Federal Republic of Germany announced the appointment of *Prof. R. Braun* to the *Advisory Council for Environmental Protection.* Dr. Braun, the first foreigner to be selected, is Professor of Solid Waste Managment at the ETHZ and Head of the Division of Solid Wastes Research at the EAWAG. This choice is not only an acknowledgment of Prof. Braun's outstanding qualifications, but also an honor for the EAWAG and ETHZ.

At the Fifth World Ozone Conference (Berlin, 1981), *J. Stähelin* and *Dr. J. Hoigné* were awarded the prize for best presentation and best paper for their contribution on "Ozone Effects on Organic Substances Contained in Water". Their seminar concerned the "Chemical Kinetics of Ozone Decomposition".

This was a repeat performance because *Dr. Hoigné* (together with *H. Bader*) received the same recognition at the *Fourth World Ozone Congress* (Houston, Texas, 1979) for their paper entitled "Oxidation-Competition Values for Different Types of Water Used in Switzerland".

Markus A. Boller has been awarded the Swiss Federal Institute of Technology's (ETHZ) Kern Medal for his outstanding doctoral dissertation entitled "Flocculation-Filtration for the Treatment of Wastewater – Optimization for the Elimination of Phosphorus and Suspended Solids".

Erich A. Staub has been awarded ETHZ's Silver Medal by the Faculty of Natural Sciences for his outstanding Doctoral dissertation entitled "Diagenesis in Recent Sediments of Lake Lucerne and their Alteration by Eutrophication; Depth Profiles of Biological-Chemical Parameters in Sediments and Pore Waters" (in German).

The 1981 Otto Jaag Price for Water Pollution Control was awarded to *Dr. Hansjörg Fricker* for his excellent Doctoral Thesis "Critical Evaluation of the Application of Stastical Phosphorus Loading Models to Alpine Lakes". Dr. Fricker's work concerned the effects of phosphorus fertilization on lake eutrophication.

Course on Pollution and Quality Control of Ground Water

An international workshop entitled "Pollution and Quality Control of Ground Water" was held at the Swiss Federal Institute of Technology's Institute for Hydromechanics and Water Engineering during March 8–12, 1982. The course was directed towards civil engineers, hydrologists, geologists, environmental engineers, and regional planners who are engaged in the development, management, and protection of ground water systems. Prof. Jacob Bear from the Technion, Haifa, Israel, and Prof. Werner Stumm and Dr. René Schwarzenbach, both from EAWAG, served as lecturers. Fourty participants from various countries attended during five days of seminars on the mathematical description of transport phenomena and on the chemical and biological processes occuring in ground water systems.

A similar course may be planned for next year.

The Contributing Authors

As reported before, Prof. Geoffrey Hamer succeeded Prof. Karl Wuhrmann, as head of EAWAG's Department of Technical Biology. In this EAWAG News Prof. Hamer outlines some major research areas in his department.

The other article is by Dr. Dieter Imboden, a physicist and lecturer at ETH, who is one of the heads of EAWAG's Lake Research Laboratory in Kastanienbaum. Dr. Imboden has submitted a habilitation thesis to the Faculty of Natural Sciences of ETH to become a Privatdozent. In this article here he presents results on his research on lake mixing processes and approaches on lake restoration.

New Programmes in Aerobic Microbiology

Geoffrey Hamer

Introduction

The three principal research areas in the Technical Biology Department are:

i Aerobic Microbiology;
ii Anaerobic Microbiology;
iii Model Flowing Water Systems.

Work in the first two areas is presently undertaken at Dübendorf, whilst the programmes comprising the third area are carried out at Tüffenwies. Some of the research activities in all three areas are oriented towards the effects of wastewater discharges on natural, receiving waters and some parts of both the aerobic and the anaerobic microbiology programmes are oriented towards wastewater treatment technology. The programmes concerned with anaerobic microbiology and with model flowing water systems are logical developments from the vigorous programmes that were established in the Technical Biology Department during the past decade, but a major part of the aerobic microbiology programmes are new, because of the relatively lower degree of emphasis that was placed on aerobic microbiological research in the Technical Biology Department after 1972.

In Switzerland, most secondary wastewater treatment systems are aerobic biological systems and aerobic processes are, of course, of considerable significance in both rivers and in lakes. Therefore, it is justified that a greater expenditure of experimental effort should be directed towards important aerobic microbiological problems occuring in both treatment systems and in the natural environment. Such a revision of emphasis in the programmes of the Technical Biology Department is being achieved by some staff redeployment and recruitment and by the accomodation of increased numbers of both doctoral students and post-doctoral fellows. As a matter of policy, viable levels of experimental effort will be maintained in the programmes concerning both anaerobic microbiology and model flowing water systems.

The basis for selection of new research projects that has been used is:

i That projects must have a potential impact on and application to real problems concerning either waste water treatment technology or environmental protection in Switzerland;
ii That project objectives should be either medium or long term so that sufficient time will exist to allow the results to be incorporated in development work and, subsequently, in practice;
iii That the research capability either exists or could be developed to adequately handle the proposed project;
iv That projects should incorporate recent new advances in scientific knowledge and/or new scientific hypotheses;
v That projects should seek to further exploit earlier aerobic microbiological research work undertaken in the Technical Biology Department in order to provide some degree of continuity.

New Projects oriented towards Wastewater Treatment Technology

Of the five new research projects that have been established, the primary orientation of three is towards potential improvements in the design, operation and performance of aerobic microbiological wastewater treatment processes.

The first of theses projects is concerned with the fate of biodegradable fine particulate matter in activated sludge processes. Analyses of domestic sewage suggest, that after primary clarification, up to 75 per cent of the biodegradable organic matter present is in suspension rather than in the dissolved state. This fine particulate matter includes fats, proteinaceous matter, cellulose, hemi-cellulose and lignin. In activated sludge processes, some of the fine particulate matter will be oxidized, some will probably only be partially oxidized and some may become part of the inactive fraction of the suspended solids in the reactor. Any one of these fates will affect overall process operation and performance. It is intended, in the light of the various hypotheses concerning the microbial utilization of solid substrates that have been developed, particularly in the fluid energy fermentations sphere, to examine the utilization, by defined mixed microbial cultures, of mixtures of model soluble and model insoluble organic substrates under conditions where the microbial population is present both as flocs and as discretely dispersed cells. In addition to making possible contributions to both the better design and the better operation of activated sludge treatment systems by incorporating advances in our understanding of mixed culture microbiology and of microbial attack on solid substrates, it can be anticipated that some of the findings will also have application in our understanding of the oxidation of biodegradable particulate matter in natural water bodies.

The second treatment technology oriented project is an extension of earlier work undertaken in the Technical Biology Department and involves studies of the influence of specific compounds on biodegradation processes. The objectives of this project are to develop a better fundamental understanding of variability in biotreater performance when specific trace materials are either present in or absent from the wastewater undergoing treatment and also to develop improved, increasingly realistic, biodegradation test methods. The scientific basis for this project stems from earlier observations in the Technical Biology Department and, in addition to the primary objectives of the programme, the data collected should also contribute to our fundamental understanding of some effects of discharges of treated wastewater in the natural aquatic environment.

The third treatment technology oriented project concerns the bio-oxidation characteristics of defined mixtures of soluble, potentially inhibitory, industrial chemicals by stable mixed cultures of bacteria. In general, wastewaters of either industrial origin or municipal origin with a significant industrial fraction are the most difficult to treat effectively in established processes. Industrial wastewater resulting from chemicals manufacture is frequently unbalanced from the physiological viewpoint, but usually such wastewaters contain a relatively restricted range of organic pollutants, which given appropriate conditions, can be effectively treated in biological processes. Where wastewater treatment facilities are industry owned, processes of the "high rate" type are generally favoured, and the initial, orientation of this project is towards such treatment systems. Activated sludge wastewater treatment processes are by far the largest and most extensively used continuous flow microbiological processes, but, in general, cannot be adequately described by the general equations that have been developed to describe microbial growth and oxidation processes in continuous flow reactors. In fact, many persons in the wastewater treatment industry believe that activated sludge processes are so unique as to require their own set of basic principles and concepts, and the view that general microbiological growth and substrate oxidation equations can describe the operation of the aeration tank in activated sludge processes is frequently met with scepticism. Many problems arise from the widespread use of "lumped parameters" for the description of wastewaters and the applicability of such "lumped parameters" for incorporation in microbiological equations, but even more important, is the selection of the microbiological equations that describe the microbiological and biochemical processes that actually occur in interacting, multi-substrate, multi-microbial, flocculated systems. Initial work in this project is directed towards simple multi-substrate / multi-microbe systems where interactions can be predicted and where both the mixed substrates and mixed microbial populations can be defined. The first model substrate mixture undergoing investigation is one comprizing methanol, phenol, acetone and isopropanol as key components, but it is intended that the work will be extended to other substrate mixtures of greater direct industrial significance and possibly to simulated leachates from waste dumping sites for chemicals and oil contaminated wastes. It is hoped that ultimately this project will contribute to improvements in both design and the operation of biotreatment plants handling either wastewaters from the chemicals manufacturing industry or wastewaters containing significant concentrations of simple organic chemicals.

New projects oriented towards the effects of discharges on and cycles in natural water bodies

Two of the new aerobic microbiological projects that are proposed are primarily oriented towards bacteriological problems in natural water bodies, one concerning the cycling of nutrients in lake systems and the other concerning one possible fate of biocidal compounds, particularly herbicides and fungicides.

The primary objective of the first of these programmes is to evaluate the rôle of methane-oxidizing bacteria and associated methanol-oxidizing bacteria in the aquatic nitrogen cycle. Because of the activities of anaerobic methane-producing bacteria, methane is an ubiquitous carbon energy substrate in the natural environment. Various estimates of the quantity of methane escaping to the atmosphere have been made, but this probably represents only a small fraction of the total production, the remainder being utilized by methane-oxidizing bacteria present in both the soil and surface water bodies. In aquatic environments, obligate methane-oxidizing bacteria are invariably found growing in association with facultative methanol-oxidizing bacteria, particularly *Hyphomicrobium* spp., that can utilize any over production of methanol resulting from methane oxidation under sub-optimal conditions, and with various heterotrophic bacteria which have the ability to utilize bacterial lysis products, that might inhibit the growth of methane-utilizing bacteria. Such methane-oxidizing bacterial associations exhibit diverse properties with respect to their nitrogen metabolism. Some obligate methane-oxidizing bacteria are able to fix dinitrogen and there is some evidence that they are also able to nitrify ammonia and ammonium compounds. In addition, *Hyphomicrobium* spp. are well known for their ability to denitrify and there are possibilities that the denitrification process might occur in micro-aerophilic environments.

In the past, the rôle of methane-oxidizing bacteria and of mixed culture associations in which such bacteria are dominant, has probably been totally underestimated, largely because of the difficulties of isolating and culturing such bacteria using conventional laboratory techniques and, of course, the deeply engrained microbiological philosophy that requires micro-organisms to be studied only in pure culture in the laboratory. In addition to contributing to our necessary understanding of a most important cycle in the natural environment, some scientific spin-off from this project can be expected in the area of wastewater treatment processes. Some years ago, methane was suggested as a carbon energy substrate for denitrification in treatment processes, but the technique did not gain acceptance because of a failure to understand the necessary process conditions which would allow methanotrophic/methylotrophic associations to function in a denitrifying mode. The use of methane as the carbon energy substrate for wastewater denitrification would be one step towards the integration of unit operations in wastewater treatment systems.

The second project oriented toward processes occuring in the natural environment is concerned with the co-oxidation (or cometabolism) of biocidal molecules by methane-oxidizing bacteria and naturally occuring mixed culture associations of such bacteria. Largely because of the non-specificity of their methane mono-oxygenase, methane-oxidizing bacteria have been found to oxidize, but not grow on, an increasingly wide range of complex organic molecules. The objective of this project is to determine the potential effectiveness of methane-oxidizing bacteria, present in natural aquatic environments, in either degrading or partially degrading both terrestrial and aquatic herbicides and fungicides that enter natural water bodies due to agriculture and other activities. As with the previous environmentally oriented project, potential spin-off with respect to watewater treatment processes exists. If methane-oxidizing bacteria are found to co-oxidize, at significant rates, a range of biocidal molecules, they could offer real potential for the treatment of wastewaters resulting from the manufacturing processes for such products.

The projects that have been described in this short article, have been selected to re-establish a significant aerobic microbiological effort in the Technical Biology Department. All are of relevance of wastewater treatment and/or natural surface water quality.

Mixing Processes in Lake Baldegg

Dieter Imboden

A fish swimming the 4 km from one end of Lake Baldegg to the other would hardly notice any changes in his physical or chemical surroundings. However, if he somehow came upon the ridiculous idea of diving just 10 meters deeper, then in the summer he would find himself gasping for air. Instead of oxygen, there would be methane (and somewhat deeper, even foulsmelling hydrogen sulfide) flowing through his gills. The fish would quickly cut short his excursion into the third dimension and let himself be satisfied with a horizontal (two-dimensional) world.

A medium in which certain characteristic properties vary differently in one direction (e.g. horizontal) than in another (e.g. vertical) is called "anisotropic". The anisotropy of a lake (or in the language of the limnologist its "stratification") is so ingrained in the world of the limnologist that he often begins to ignore its causes and consequences. However, in order to discuss "Mixing Processes", we will need to go into a brief explanation of the stratification phenomenon.

Due mostly to gravity, the physical, biological and chemical parameters of even the largest Swiss lakes vary almost purely in vertical, but not horizontal direction. The so-called "horizontal density currents" created by gravity prevent water masses of different density from existing within the same depth for very long. A similar phenomenon occurs in the atmosphere, where high and low pressure areas cause horizontal currents (wind), except that the earth's rotation hinders the currents from compensating directly between the high and low pressure zones. Such effects of the earth's rotation are likewise evident in the current patterns of large lakes and in the ocean.

Simply stated, the anisotropy of a chemical water constituent (e.g. oxygen) follows the anisotropy of the current, which in turn follows the anisotropy of the density (i.e. the temperature). Currents and unordered water movements (turbulence) normally occur along lines of similar density. Due to varying densities in the vertical direction, vertical movement of a water parcel generates a repelling force which tends to drive the parcel back to its original depth. In water bodies the size of the larger Swiss lakes, this effect results in a complete horizontal mixing within a few days, whereas exchange times in the vertical direction are on the order of months, or even years, in the event of a permanent stratification.

However, the biblical word that "the first will be the last" holds true here also. Just *because* of their slowness, vertical mixing processes are the most important in considering the influence of currents on the condition of a lake. For example, they are responsible for the transport of oxygen into the deeper layers and for the recirculation of planktonic nutrients into the photosynthetically active upper layer.

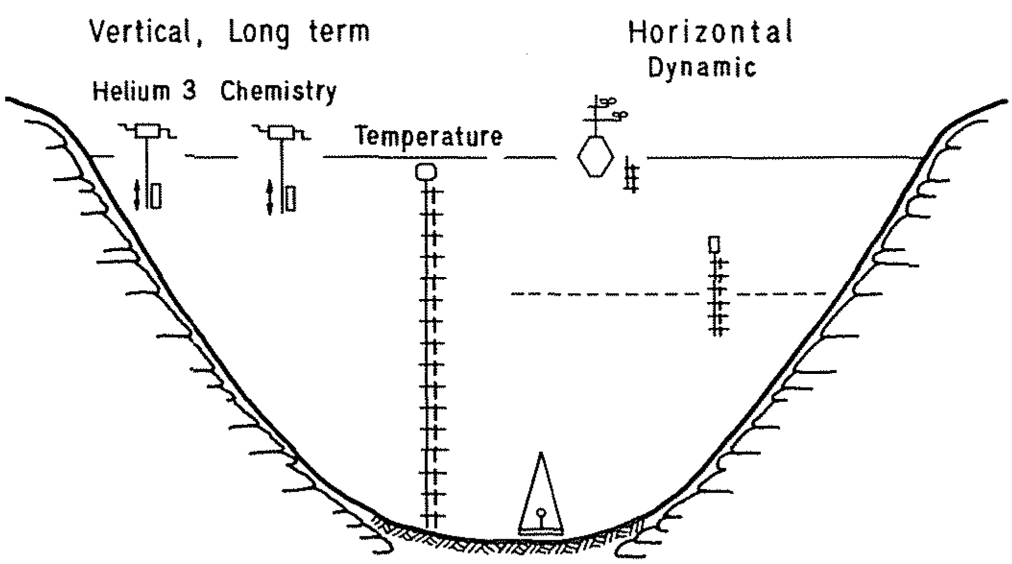


Fig. 1:
Measurements in Baldegg Lake for the study of mixing processes at the three interfaces: lake surface, thermocline, and lake bed. The long-term effects of vertical mixing are followed by natural chemical tracers (helium-3, chemical parameters such as phosphate or methane) and by temperature measurements along the whole lake depth.

Right: A meteorological buoy, combined with a short measuring chain for recording air and water temperatures near the surface, aids in studying the effect of wind on the lake. A temperature sensitive chain in the thermocline measures the internal waves, and an underwater camera records the currents at the deepest point in the lake.

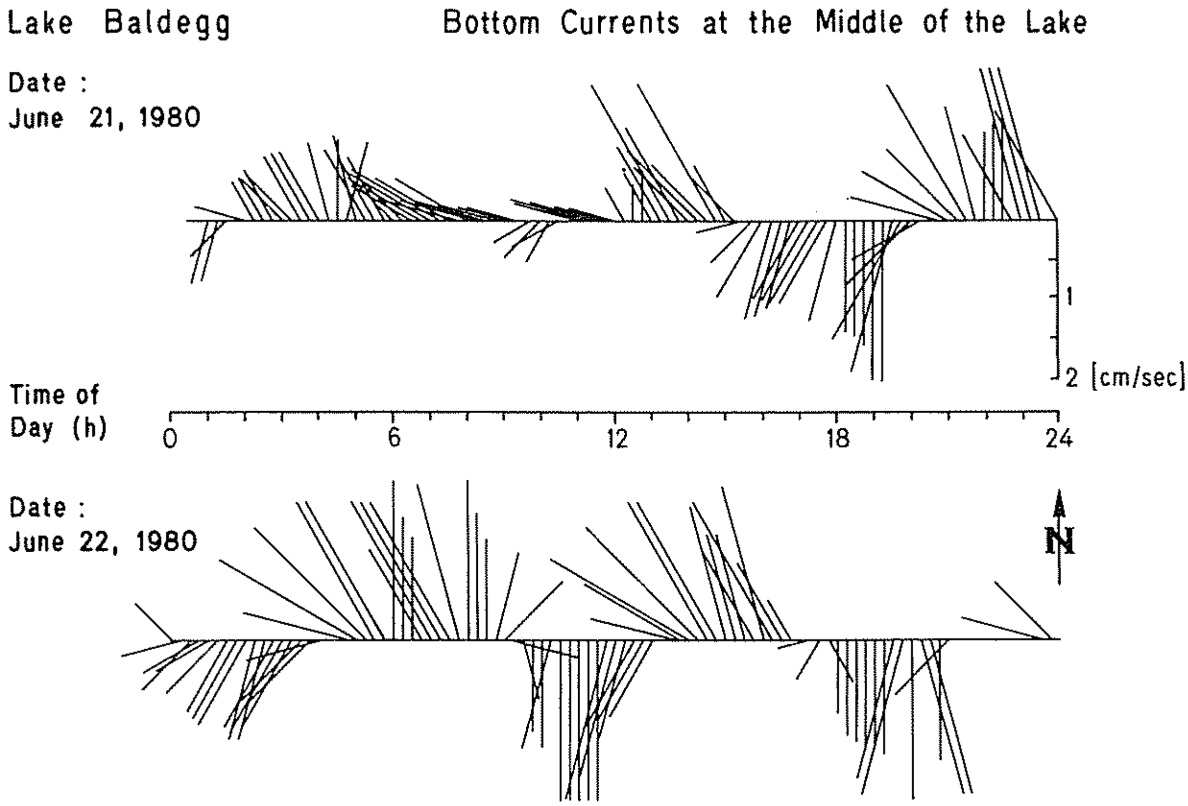


Fig. 2:
Spectral analysis of the temperature oscillations in Lake Baldegg. The basic oscillation has a period of about 10 hours. The spectrum also shows at least the first three harmonics.

A group of EAWAG scientists in the Multidisciplinary Limnological and Earth Sciences Research Group (D. Imboden, U. Lemmin, T. Joller and M. Schurter) has now been studying vertical mixing processes in lakes for 4 years, as part of a research program funded by the Swiss National Science Foundation and entitled «Lake Currents». Lake Baldegg has served as the main object of study. Physics tells us that the energy transfer required to generate motion always manifests itself at boundary surfaces. There are three such interfaces which are important in a stratified lake: The lake surface (boundary between atmosphere and hydrosphere), the so-called "thermocline" (boundary between the warm, upper layer and the cold, deeper waters), and the lake bottom (boundary between the water and sediment). Several different approaches were taken in our research program to study these three interfaces (Fig. 1). Although not all the data have been evaluated, we have come to recognize several important phenomena which will be described here.
The first phenomenon concerns the thermocline. A wind blowing over the lake surface not only causes surface waves, but also induces horizontal currents which drive the thermocline to greater depth at the downwind end of the lake and to smaller depth at the upwind end. Should the wind stop, the thermocline would try to level itself out again, which leads to a pattern of standing internal waves (internal "seiches"). These waves are slower than surface seiches but have greater amplitude. A thermistor (temperature sensor) fixed at an appropriate depth registers the internal seiches as periodic temperature oscillations (see EAWAG Annual Report 1979, p. 54). The basic oscillation has a node in the middle of the lake and a wavelength approximately equal to the length of the lake basin. The first harmonic has a wavelength half as large.
Naturally, limnologists have known about internal waves for a long time. The surprising feature of those found in Lake Baldegg is their exceptionally small damping. Internal waves are observed at nearly full strength even after ten or more days without a meteorological perturbation. Even the harmonic oscillations, which are in theory more strongly damped, have an unexpectedly long lifetime. Of course, in order to make them visible beside the dominating pattern of basic oscillations it becomes necessary to employ a mathematical trick called spectral (or frequency) analysis. In this method, a complex spectral pattern is separated into its component pure sinusoidal waves (see Fig. 2).
The small damping suggests a specially small energy loss due to turbulence. Although the water layers near the thermocline are continually bobbing up and down, they hardly lose their identity; there is at most a small net vertical transport of water and its dissolved substances. Indeed, this conclusion is verified in studies using natural chemical tracers to observe directly the transport of water solutes (see Fig. 1).
Although the thermocline very strongly hinders the transport of matter and thermal energy, it is thoroughly transparent to the flow of kinetic energy into the hypolimnion (deeper, colder water layer). This energy manifests itself as turbulence in the hypolimnion. For example, compounds which are released from the sediment, such as phosphates, methane and hydrogen sulfide, are dispersed towards the surface more rapidly (although still very slowly) than can be accounted for by molecular diffusion. Until now, it could only be

speculated that the energy transfer responsible for mixing is associated with internal waves and that the mixing occurs predominantly along the lake bottom (lowest boundary surface). To test this hypothesis, we constructed an apparatus for measuring very low currents. (The conventional rotor devices are poorly suited for currents below 2 to 3 cm/sec.) The principle of the method is very simple (see EAWAG Annual Report 1979, p. 53): A small ball with a density slightly less than that of water is attached to the end of a thread and its displacement from rest position is observed as a measure of the direction and speed of the current (inverted pendulum). A camera takes a sequence of pictures of the ball's position, from which the horizontal hypolimnic current patterns can be evaluated.

Figure 3 is a representation of a small segment of such a series of measurements. The alteration of the current direction has the same periods as the basic oscillation of the internal waves supporting the hypothesis that hypolimnic currents are associated with internal seiches. Beside the pattern of the bottom currents, we were also astounded at their speed. Typical average values were 1 cm/sec in summer and 2 cm/sec in winter, which is greater than could be expected from the classical theory of internal waves. Therefore, we are presently proposing that hypolimnic currents develope predominantly along the lake bottom and that they are ultimately responsible for the vertical exchanges observed in the long term measurements.

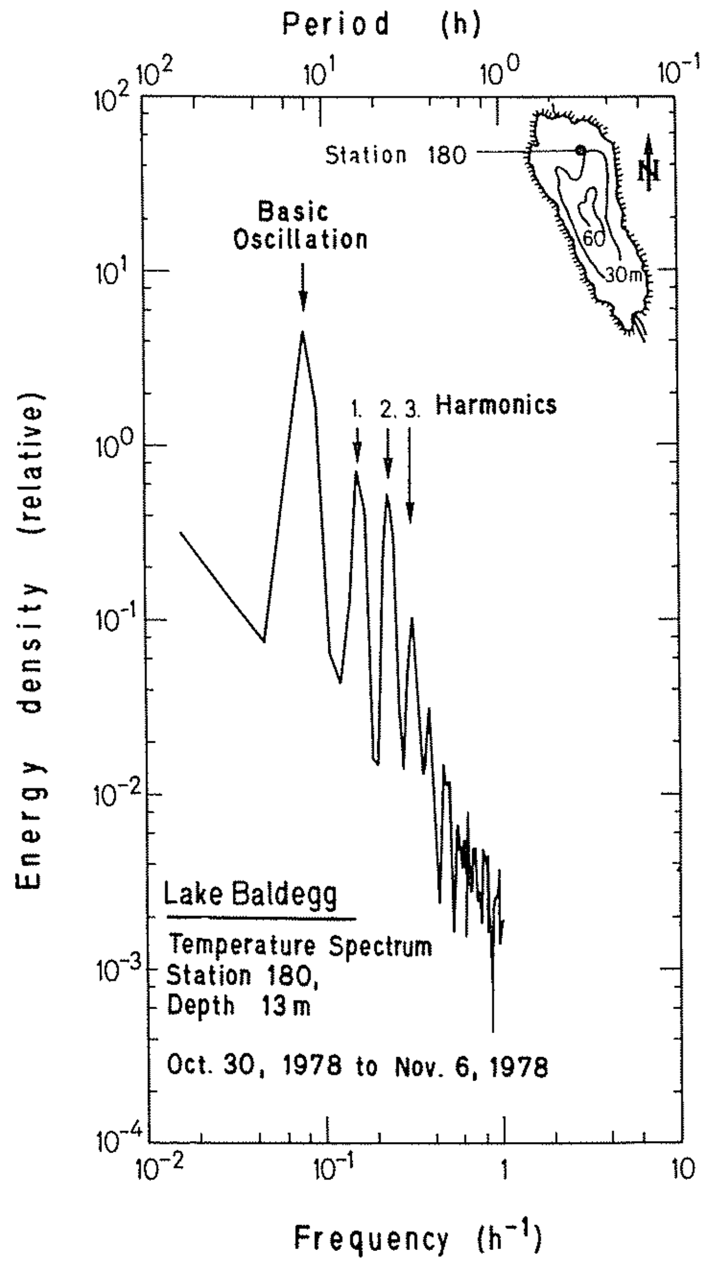


Fig. 3:
Bottom currents in Lake Baldegg represented by a line diagram. The length and direction of the lines reflect the speed and direction of the current. Each line represents the average of 5 values measured 3 minutes apart. The major axis of the lake runs SSE to NNW. The irregularly rotating current exhibits a period close to that of the internal seiches (ca. 10 hours).

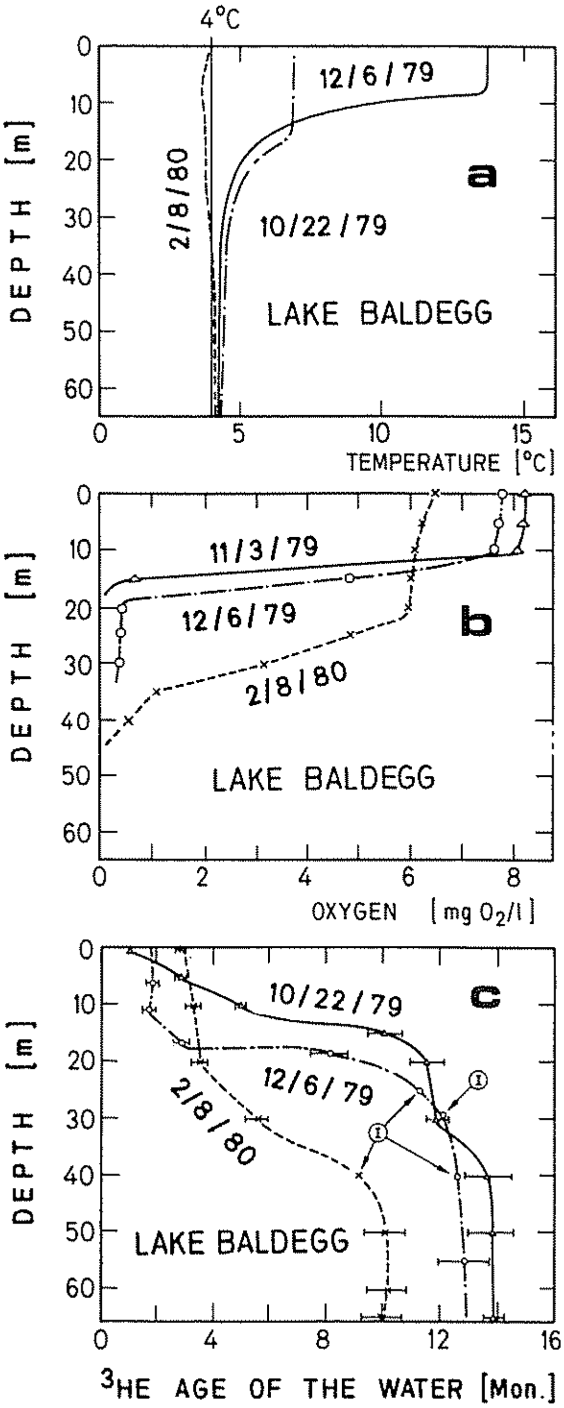


Fig. 4:
Vertical profiles for the period October 1979 to February 1980 in Lake Baldegg for
a) temperature,
b) oxygen,
c) helium-3.
If the hypolimnion were completely isolated from the other layers in the lake, then the helium-age of the deep waters would have risen from 14 months in October 1979 to 15.5 months in December and to 17.5 months in February 80. Actually measured values indicate a deep water renewal rate of 10 to 20% per month. However, this transport is not rapid enough to cause an enrichment of oxygen in the deeper layers; oxidation processes use up the oxygen faster than it is being supplied.

The cycle from horizontal boundaries and currents to vertical mass transport would thus be essentially complete, had not a new problem cropped up during the interpretation of the tracer measurements. In the classical theory of turbulent diffusion, it is assumed that dissolved substances and thermal energy (temperature) are affected by a large number of tiny eddies, resulting in a net transport from a layer of high concentration to one of low concentration. For example, the eddy diffusion coefficient, which characterizes the exchange, can be calculated from the temporal variation of the temperature in a lake (Fig. 4a). It should be the same for all tracers.

Working in cooperation with the Institute for Environmental Physics at the University of Heidelberg, we have employed a new method for limnological studies, namely the measurement of helium-3. This rare isotope of helium is present in air in only trace quantities. In water it is produced by the radioactive decay of tritium, the heavy isotope of hydrogen which has become nearly omnipresent since the advent of nuclear weapons testing. Helium-3 tends to accumulate in water parcels which are isolated from the atmosphere. This allows one to determine the age of a water mass within a lake and (by comparing several profiles) to calculate the vertical exchange rate (Fig. 4c). Two surprising results: First, there is a significant renewal of the deeper waters even during periods in which the temperature indicates a persistent stratification (October to December, 1979). Secondly, the exchange rate calculated from the helium-3 measurements is 5 to 8 times larger than that calculated from the temperature data. This discrepancy can only be explained by the caveat that the classical view of turbulent mixing is not always valid. Alternative mechanisms would again point into the direction of boundary surface mixing.

Finally, I would briefly like to mention a phenomenon which is of greater import to the Lake Baldegg recovery program presently being discussed. As can be seen from the temperature profile measured in February of 1980 (Fig. 4a), the lake should have undergone a complete circulation sometime between December and February. On the other hand, the helium-3 data indicate that the deep waters of February 1980 were still 10 months old, and oxygen could be found no deeper than 40 meters. Today we know that a chemically caused density jump occurs at a depth of 30 to 40 meters, which hampers adequate renewal of the deeper waters. This stratification could be a result of the high productivity of the lake and the associated enrichment of matter in the hypolimnion. It prevents adequate aeration of the deeper waters in winter and thereby promotes the undesired recirculation of phosphate from the sediment to the water.

The Canton of Lucerne proposes to tackle this vicious circle of lake eutrophication by employing artificial mixing and aeration of the hypolimnion. Physical-limnological research is thus of direct importance for an integral understanding of the ecology of a lake; it is a useful tool for the planning of strategies for the restoration of our lakes.

Use of heat Pumps on Surface Waters

Dieter Imboden

The search for alternative energy sources has brought a nearly forgotten (due to the availability of cheap oil) invention back into the limelight. The so-called heat pump operates on the same principle as a refrigerator (Fig. 5). A heat pump takes heat from the surroundings and "pumps" it into a medium of higher temperature, such as would be useful for home heating. A constant and high temperature in the heat source increases the efficiency of a heat pump. For this reason, and due to its high heat capacity, water is especially suited as a surrounding medium for heat pumps. Most of earlier systems in Switzerland use groundwater as a heat source, but due to possible adverse effects on water quality, the use of surface waters (lakes, rivers) has become more advantageous especially for large installations.
In considering this possible new use for lakes and rivers, the Swiss Federal Commission on Waste Heat has contacted the EAWAG to study the effects of heat removal from surface waters. The study was completed in the spring of 1981 and has been released as Publication No. 19 of the Federal Energy Commission (distribution: EDMZ, 3000 Bern). The article was authored by H. Güttinger with help from co-workers in the Divisions of Fisheries and Informatics. Two students (C. Riedi and M. Zoller) in the Department of Electrical Engineering of the ETHZ completed term projects on the heat capacity of flowing waters. D. Imboden served as project director.
The goal of the study was to estimate the total heat producing capacity of Swiss surface waters based on the maximum cooling allowable by ecological criteria. Such information is useful to cantonal agencies in setting limits for heat removal from specific water bodies. Since most of the large water bodies border on several cantons, this information will also play an important role in intercantonal heat use planning.
Determination of the ecological tolerance limits for cooling was outside the scope of this project. If one ignores the compensating atmospheric heat exchange resulting from lowered water temperatures, the total cooling capacity of rivers is dependent only on the water flux. For the four major rivers flowing out of Switzerland, this amounts to 370 PJ (PJ = 10^{15} joule), i.e. about 85% of the Swiss energy demand for heating (1979: 430 PJ). A good quarter of this amount is already supplied by waste heat from the large nuclear power plants, which would decrease the effect of the heat pump on net cooling below the natural temperature level. The remaining municipal heat input via wastewater is negligible compared to the waste heat from power plants and thus has little

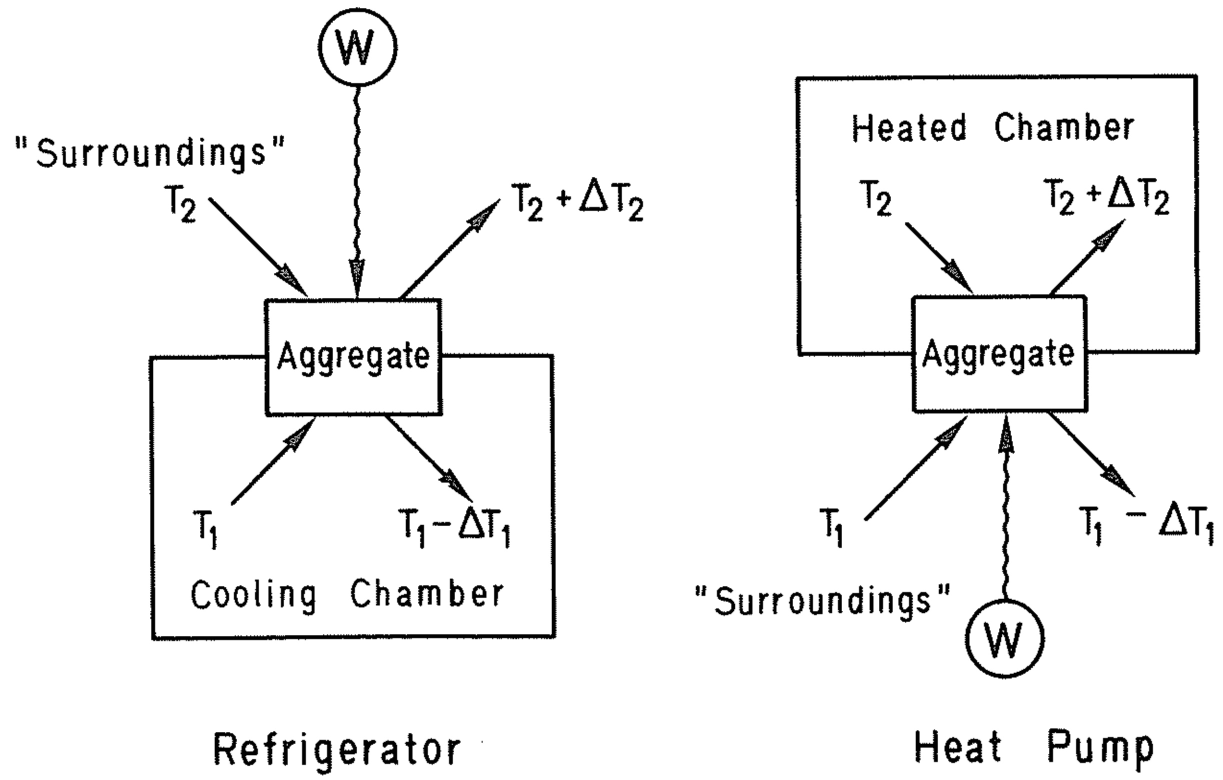
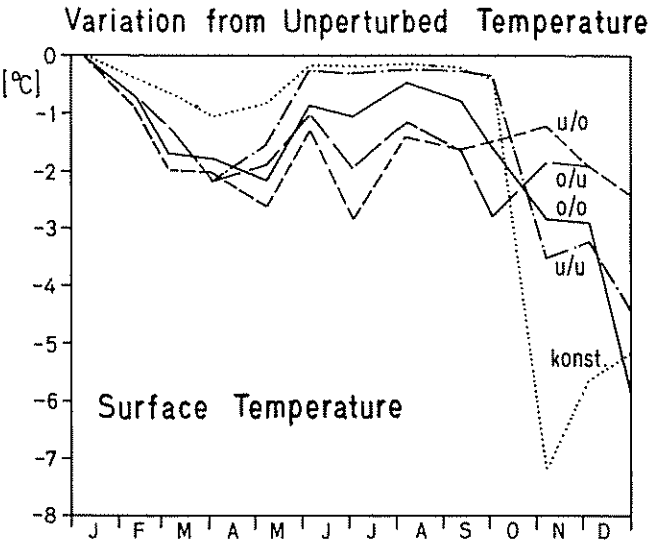
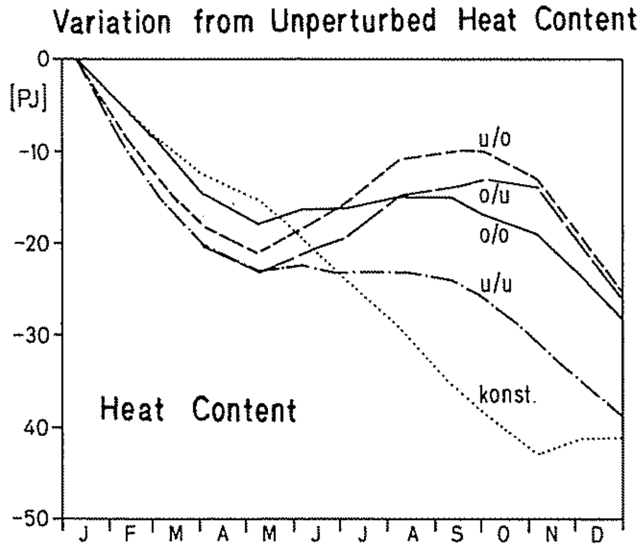


Fig. 5:
A heat pump works on the same basis as a refrigerator, except that the role of the "surroundings" and "internal system" are interchanged. The aggregate raises thermal energy from temperature T_1 to T_2, during which mechanical (or high-grade thermal) energy W is converted to heat, causing an additional increase of ΔT_2. The ratio between the total surrounding heat energy and the added energy (W) is the efficiency number of the heat pump. The Second Law of Thermodynamics (enthropy) sets an upper limit to the efficiency number. Typical values lie between 2 and 3.





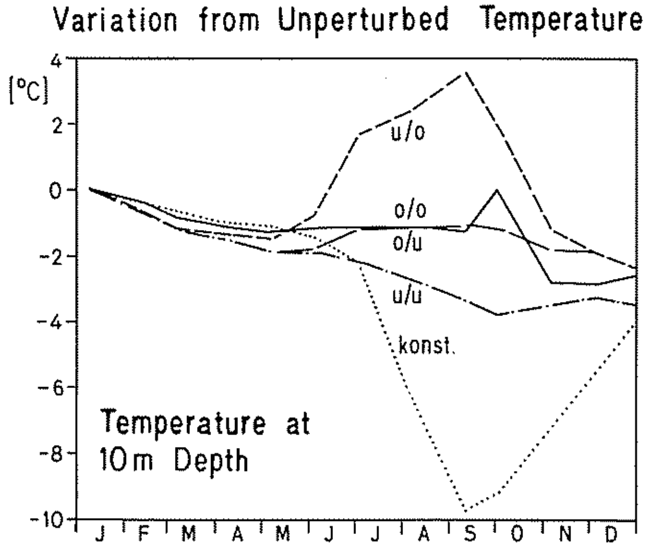


Fig. 6:
The influence of the depth of heat withdrawal and return by a heat pump on surface temperature, temperature at 10 m depth, and heat content of Lake Zurich. In order to make the effects more obvious, a large withdrawal rate (30 W/m²) was used in the calculations, even though this is well above the tolerance limit. The temporal variation of the withdrawal was taken proportional to the heating demands.

	Depth (m)	
	withdrawal	discharge
o/o	1	1
o/u	1	20
u/u	15	20
u/o	15	1
Konst.	15	20

effect on the capacity to be cooled. The annual cycle patterns of water flow (i.e., heat availability) and heating needs behave inversely, which limits the theoretical heat removal potential. Regarding geographic distribution of the heat supply: it is suggested that only that amount of heat be removed per river length and width (i.e. per surface area) which corresponds to a calculated temperature drop of 3 °C. Atmospheric compensation would tend to balance out the heat loss. This capacity amounts to ca. 50 W/m² in winter and more during the other seasons.
The removal of heat from flowing waters results in lower minimum winter temperatures, an expansion of the colder period, and more rapid temperature changes in the spring and fall. If the suggested limits are observed, the ecological consequences should be minimal and, at worst, observable only after long periods of time.
For lakes, it is suggested that at no point and at no time the heat removal should be allowed to result in a temperature change of more than 1 °C. The stricter limit result from the fact that one needs to consider not only the direct temperature change, but also its possible indirect effects on mixing processes. As with river waters, the motive behind these restrictive temperature limits is to minimize any noticeable effects on the subtile, hard-to-quantitate ecological equilibrium.

The calculation of temperature changes as a result of heat removal from a lake is very complex. Relatively simple models predict a heat removal capacity of between ca. 1 W/m² (shallow lakes) and 8 W/m² (deep lakes) for the major Swiss lakes. The application of a detailed one-dimensional temperature model to three characteristic lake types (Lake Zurich, Lake Greifen and Lake Constance) verifies that these values will indeed guarantee conformity to the suggested 1 °C limit. Also, the temporal distribution of the removal is unimportant, so the heat can be withdrawn according to the demand. The effects of heat withdrawal from lakes include a lowering of the surface temperature, a decrease in depth of the well-mixed surface layer, and an increase in circulation time. These effects can be minimized by removing the source water from and returning the cooled water to the hypolimnion, i.e. below the thermocline (Fig. 6). Ecological effects would run in the direction of lower algal production and increased oxygen transport into the deeper layers, although these would hardly be noticeable due to the strict regulatory limit.
The potential of Swiss lakes and rivers as a heat source is enormous (Fig. 7): They could supply the total demand for heating in all of Switzerland even in the coldest months. Beside possible local capacity limitations, the question of temperature decline is a minor consideration compared to other possible limitations such as technical, aesthetic, local-ecological (destruction of natural shorelines during construction), and energy political (competitive energy source factors).

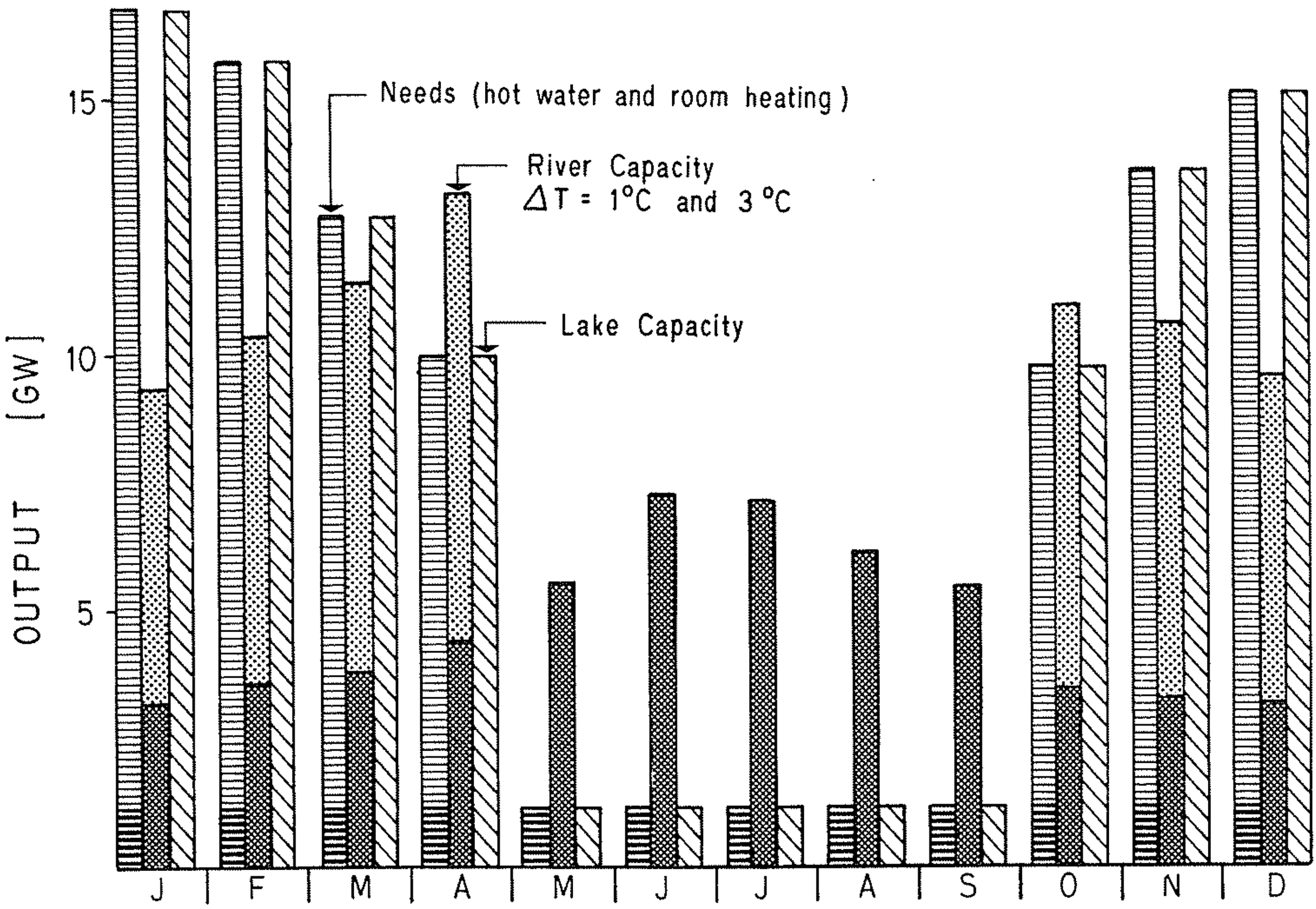


Fig. 7:
Heating needs in Switzerland and average heat withdrawal potential of surface waters during the course of a year (only the Swiss portion of the surface area was considered for waters which cross national borders). Heating needs = needs for ambient thermal energy only, i.e. 60% of the total need. The indicated lake capacities assume a heat withdrawal proportional to the demand. GW = 10^9 W.

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