Plate 7.3 Temperature in Rivers and Lakes

Introduction

The expansion of the network of hydro-electric power stations has promoted the installation of limnigraphs and water-measuring stations. In the 1960's the future prospects concerning thermal power stations – mainly nuclear fuelled – encouraged the development of a temperature-measuring network in the rivers important to Switzerland. When the network of hydrometric stations was set up the emphasis was on the use of the water, whereas in the case of the temperature network the focus was on the protection of waters. The network made it possible to observe any systematic increases in temperature and to enable steps to be taken to avoid negative effects on the water system. The Swiss National Hydrological and Geological Survey (SNHGS) began setting up a national network of measuring stations in 1963.

It became more and more unlikely that new thermal power stations would be built because of growing opposition among the general public to the use of nuclear or fossil fuels to produce energy. The original reasons for setting up the network of temperature-measuring stations were thus no longer valid, which meant that the network had to be redesigned. Because of this particular development there is an ideal supply of comparable measurement series for the period 1978 to 1984 with respect to the number of stations. The evaluation of this data formed the basis for a report by the SNHGS [2]. This report shows that it is possible to observe river temperatures over a longer period with a less dense network of measuring stations and that interesting information can be obtained from occasional, more or less regular isolated measurements. Such samples are made, for example, in the routine examination of rivers and lakes by the cantonal water protection offices or university study groups. The map is thus based on a selection of stations which are part of different networks from which regular measurements for the period 1978 to 1984 are available. The sources of the data are given in table 1 and in the tables added to the map 7.1.

Temperature variations

The temperature in a river or a lake depends strongly on the air temperature and the solar radiation. Several overlapping patterns of variation can be observed:

(1) The diurnal variations during sunny weather have a marked, mostly sinusoidal, periodic pattern. The difference between day-time and night-time temperatures is often several degrees. The NADUF graphs (NADUF: National programme for long-term analytical studies of Swiss rivers) included in [7] illustrate such variations in larger rivers. Articles published on diurnal variations in smaller rivers are infrequent [4].

(2) The pattern of seasonal variation is clearly sinusoidal in shape, in the midlands of Switzerland even more so than in the Alps. This sinusoidal shape is not surprising if one considers that this seasonal variation is dependent on the solar radiation due to the course of astronomical events. This effect is so dominant that in practically all studies, when models of seasonal variation are drawn, the values observed are illustrated by a sine curve fitted using the least squares method. The parameters obtained using this method, which is described in more detail below, also comprise the principal contents of the present map. The diagrams incorporated into the map show these variations in rivers at a number of selected stations. The purpose of selection was to emphasise the difference between alpine and lowland waters as well as the effect of lakes on the temperature compared at inflow and outflow stations. Of the years included here, the first two have average water temperatures and the last (1983) has above average water temperatures.

(3) Occasional irregular fluctuations occur as a result of meteorological changes such as cold or warm fronts, northerly or southerly air-flow. They appear as clear deviations from the sinusoidal seasonal pattern. If the latter is substracted a «de-seasoned» temperature pattern occurs and the unpredictable, irregular influences of the weather are quite apparent. Comparison with these de-seasoned time-series [2] shows that the patterns are synchronous across large areas.

(4) The long-term variations are due to climatic changes. These are changes evident in the de-seasoned series over a longer period of time, analogous to the occasional fluctuations. One is often tempted these days to conclude from the data a general warming of rivers and lakes due to human influence. Depending on the period of observation, clear and unexplainable increases in temperature have been observed in larger rivers [5]. However, the climate on our planet has always been subject to certain variations, be it since we first started keeping records or over geological times [6]. Some examples of longer time-series are given in figures 1 and 3. In rivers the influence of the lakes in particular is evident, especially in the increase in the annual mean daily minimum temperature (fig. 1). The data concerning lakes includes time-series of samples taken at depths of 5 m and 100 m (fig. 3). In contrast to rivers, lake temperatures vary greatly with depth.

Temperature stratification in lakes

In addition to the representation on the map of seasonal fluctuations in rivers, figure 2 shows data for the same period (1981 to 1983) for selected lakes. The three-dimensional graphs show clear differences in the seasonal temperature pattern at different depths. In every lake a distinct system of layers develops in summer through physical causes (temperature-dependent density of the water); this is called summer stagnation. At the surface is the epilimnion, the layer of warmed water. The transition layer, the metalimnion, is beneath and includes a significant temperature gradient. The deep water, which remains at more or less the same low temperature throughout the year, is called the hypolimnion. In autumn and winter winds help to mix the cooling upper layers of water deeper into the lower layers so that the water usually circulates in such a way that the temperature becomes equal in the whole lake. During winter, depending on the weather, the depth of the water and the geographical location, a system of layers can develop once more, formed this time by surface water below 4 °C, covered with ice in parts (winter stagnation). In spring a phase of overturn normally occurs before the temperature of the surface water rises again. Depending on depth and aspect of the lake, the usual overturn between autumn and spring may not develop every year.

The results of the model calculations shown in the map and in table 2 include data solely from the upper part of the epilimnion, viz. mean values of the temperatures between the surface and a depth of 10 m.

The sine curve model

The seasonal pattern of temperatures in rivers and in the upper layers of water in lakes shows a clear sinusoidal shape. The next step is to determine the parameters for the sine function which is closest to the measurement values, using the least squares method. In this case one cannot talk directly of a harmonic analysis or a Fourier transformation, since only the parameters of a single sine curve are to be calculated. The divergent method of calculation used here has been described in only a few studies so far [1,2,3]. It is based on obtaining a linear sine function using a trigonometric process. The parameters are then determined using multiple regression analysis. The parameters of the sine curve are the mean value, the half-amplitude and the angle of the phase. In our case the latter is defined as the day in the year on which the sine curve passes through the minimum. In order to determine the parameters from the measurement data a computer programme which is available from the SNHGS was used on a personal computer.

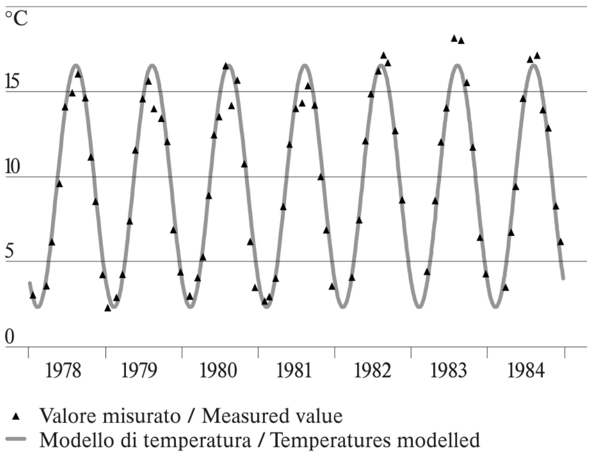
Figure 4 shows a sine curve calculated using data from the lake Pfäffikon measured over the years 1978 to 1984. The sine curve alludes to the fact that minimum temperatures were possibly not measured in winter in 1982, 1983 and 1984.

Using the sine curve model it is possible to calculate the mean temperature to be expected on any one day of the year. The formula used for this is:

$$T_{(j)} = A \cdot \sin[(J - J_m) \cdot 360°/365.242 - 90°] + M$$

where $T_{(j)}$ is the expected temperature (°C) on day j, A the half-amplitude, J the number of the day j within the calendar year, J_m the day on which the minimum temperature is recorded and M the mean annual temperature. The information necessary for this calculation is to be found in the map and table 2. In order to estimate the temperatures in a river between two stations the parameters can be interpolated as an approximation. For rivers without measurement stations it is usually not feasible to interpolate or extrapolate since other factors, such as the altitude of the catchment or the distance from the source, must be taken into consideration.

Fig. 4
Temperature misurate nel lago di Pfäffikon e relativo modello delle temperature
Temperatures measured and modelled in the lake Pfäffikon



References

[1] **Ball, J. A. (1978):** Algorithms for RPN calculators. New York.

[2] **de Montmollin, F., Parodi, A. (1990):** Température des cours d'eau suisses. Communication du Service hydrologique et géologique national No 12, Berne.

[3] **Güttinger, H. (1980):** Die Anwendung einer Fourier-Transformation zum Ausgleich von Saisonschwankungen bei der physikalisch-chemischen Charakterisierung von Fliessgewässern In: Schweizerische Zeitschrift für Hydrologie 42/2:309–321, Basel.

[4] **Jakob, A., Tschumi, P.A. (1988):** Tagesschwankungen chemischer und physikalischer Faktoren in einem Fliessgewässer (Schüss, Berner Jura). In: Archiv für Hydrobiologie 113:607–620, Stuttgart.

[5] **Jakob, A. et al. (1995):** NADUF – Observation à long terme de l'état physico-chimique des eaux. In: Gaz-Eaux-Eaux usées 5/95:378–393, Zurich. Deutsche Fassung in: Gas–Wasser–Abwasser 3/94:171–186, Zürich.

[6] **Le Roy Ladurie, E. (1967):** Histoire du climat depuis l'an mil. Paris.

[7] **Service hydrologique et géologique national (dès 1972):** Annuaire hydrologique de la Suisse. Berne.