FRESHWATER OBSERVATION SYSTEMS, NETWORKS, AND EXISTING DATABASES

Martinenghi L.
Studio d'ingegneria Martinenghi SA, Cureglia, Switzerland

Zamboni F.
University of Applied Sciences of Southern Switzerland, Canobbio, Switzerland

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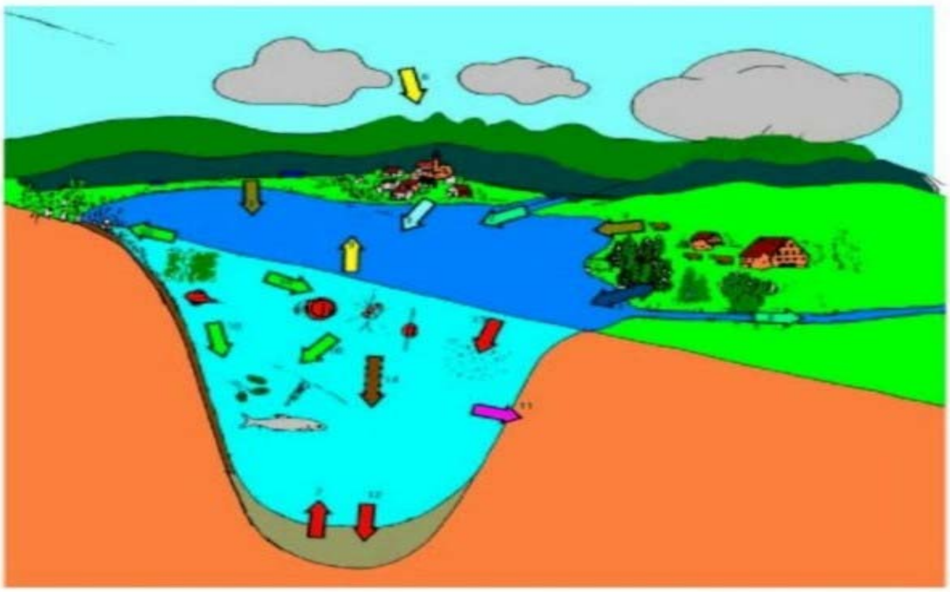
Often a glance is sufficient to judge the general state of a body of water. From riverbanks or lakeshores, simple observations permit a first evaluation of water quality. Even though visual observation is an important first step, scientific studies are necessary to determine if the water quality corresponds to legal requirements for certain uses. Ever since scientists have started to study freshwater bodies (rivers, streams, and lakes), chemists and biologists have endeavored to describe them using clearly defined variables. Monitoring of rivers and streams implies, first of all, the regular measurement, continuously if possible, of flow (i.e., the volume of water transported). The ecological monitoring of a river should include physical-chemical measurements as well as biological ones. In order to study the development of living organisms in rivers,

it is necessary to plan scientific observations at several points along the river, from the source to the outlet. In industrialized countries, monitoring of water quality is carried out on a regular basis by governmental agencies in accordance with a pre-prescribed program with a minimum of data measurements. The treatment of fresh water data is carried out by the organizations responsible for the monitoring programs. The development of computerized systems over the last several decades has brought about a more rational approach to data management and enables the data to be consulted more easily; however, one unique, universal form does not yet exist for the databases.

1. Introduction

Often a glance is sufficient to judge the general state of a body of water. From riverbanks or lakeshores, simple observations permit a first evaluation of water quality: stones that shine in clear water; green, brown, or gray deposits that cover the bottom; luxuriant aquatic plants and algae that block a clear view of the lake floor; the presence of waste; the presence or absence of certain fish. Even though visual observation is an important first step, scientific studies are necessary to determine if the water quality corresponds to legal requirements for certain uses. Ever since scientists have started to study freshwater bodies (rivers, streams, and lakes), chemists and biologists have endeavored to describe them using clearly defined variables.



1 - Urban waste
2 - Tributary river (inlet)
3 - Runoff
4 - Agricultural percolation
5 - Exchange with ground water
6 - Atmospheric precipitation
7 - Redissolution of sediment
8 - Emitting river (outlet)
9 - Evaporation
10 – Assimilation of algae and microorganisms (plankton)
11 - Infiltration
12 – Reactions with the sediment
13 – Adsorption of particulate matter
14 - Sedimentation

Figure 1. Exchange of substances in a lake

Chemists analyze substances which are dissolved in the water, even if only in weak concentrations. Some of these substances are vital for plants and animals, while others may be harmful or toxic. Biologists see freshwater bodies as richly populated ecosystems, where living organisms must continually adapt to survive and develop. These organisms serve as indicators of the state of the water, especially in the case of pollution due to waste water. Experience has shown that the composition of these populations reflect water quality. The number of individuals increase with the intensity of the pollution (organic pollution is food for many species), while the number of certain, more delicate, species decreases.

Limnology is the science of the study of lakes. This discipline may be termed as the “oceanography of small bodies of water." Compared to oceans and seas, lakes have specific properties which are not always possible to study using mathematical or numerical models. For example, an ocean is so vast that it may be considered “infinite” in a model, while the dimensions and floor shape of a lake often determine its behavior. This is why limnology should not be considered inferior to oceanography.

The principal problem of limnology in recent years has been the study of lake water degradation due to increases in population and industrial activities. Limnological research aims at providing indications as to how lakes may be restored. Figure 1 shows a schematic presentation of substance exchanges in a lake.

Rivers and streams are other freshwater bodies which may also be monitored. Regular monitoring of such bodies of water is less common than that of lakes.

2. Methods for Monitoring of Rivers and Streams

2.1. Hydraulic Measurements

Monitoring of rivers and streams implies, first of all, the regular measurement, continuously if possible, of flow (i.e., the volume of water transported). This information may be determined from the measurement of water levels and from available information concerning the section of the river or stream. If the river is extremely long, flow measurements are carried out in various points along the river. For large rivers, measuring stations are generally placed at all of the principal tributaries in order to obtain, if possible in real time, an overview of the hydraulic situation of the entire watershed.

2.2. Physical-Chemical Measurements

The ecological monitoring of a river should include physical-chemical measurements as well as biological ones. Temperature, conductivity, and the salinity index of the water are easily measured using an electronic probe installed in the permanent measuring stations. For smaller rivers, these measurements are usually carried out by hand from time to time. Temperature may also be measured using simple, battery-powered, portable instruments in conjunction with data loggers to record the measurements. The concentration of transported sediments is extremely important for river management and is measured through periodic sampling. This is usually done automatically in fairly large measuring stations. Optical probes that measure water turbidity are also now available that yield continuous information concerning sediment concentration.

The true chemical loads of a river are measured through periodic sampling followed by laboratory analyses. If information is available concerning the substances which are discharged into the river, specific analyses to target these substances may be carried out. The standard parameters which are habitually measured are total phosphorus, total nitrogen, dissolved oxygen, and pH. For rivers whose water will be used for drinking purposes, these measurements, in addition to biological measurements, must be carried out systematically and continuously in the sampling stations. If particular chemical loads are present in the river, special measurements of these substances should be carried out. Examples of such substances are herbicides, pesticides, hydrocarbons, and other pollutants.

2.3. Biological Measurements

In order to study the development of living organisms in rivers, it is necessary to plan scientific observations at several points along the river, from the source to the outlet. In fact, along the same river, the environmental conditions, and therefore the development of the species present, can be highly variable. Since environmental conditions vary most rapidly near the source, and not where the river flow conditions are more regular, the observation points should be closer to the source and not located downstream. When planning a study program, the first thing to be considered is whether the observations are to be limited to qualitative aspects, or if quantitative measurements are to be carried out. The quantitative method gives rise to many problems and is often unsatisfactory. Direct observations *in situ* are difficult to carry out quantitatively and, therefore, laboratory models are often used. Such models channel river water in an effort to reproduce environmental conditions identical to those *in situ*.

The observation of populations of vegetation concern algae, cyanobacteria, bacteria, fungi, moss, and other macrophytic plants. The qualitative sampling of macrophytes is very simple; samples are taken directly at the bottom in shallow water or using a drag net in deeper water. The sampling of phytoplankton is carried out by filtering the water directly through a flexible filter or by samples taken in bottles. It is more difficult to sample algae that grow on rocks. This needs to be removed using a spatula or knife. Samples of microscopic bacteria and fungi that populate organically polluted water are taken by washing the rocks on which they are deposited.

The quantitative observation of the populations of vegetation in a river is very difficult. The measurement of macrophytes is limited to the indication of density per unit of bottom surface. The quantity of fungi and bacteria per unit area is used to describe those that cover rocks. The measurement of microphytic plants (epiliptic algae) is carried out by removing samples from rocks with a nylon knife and placing them directly in a flask. Phytoplankton may be measured in water samples by filtering and weighing the dried algae with respect to the water volume of the sample. Small animal organisms which populate a river generally live in areas which are protected from currents, near the bottom or in sediments. To observe and classify them, it is necessary to sample the sediment with nets in the areas where they usually live. The quantitative measurement of their population density is difficult and imprecise due to the large amount of variability from place to place. Shellfish and fish populations that live in a river are measured through periodic capture with nets and traps and are then counted directly. All of the observations relative to the populations of vegetation and animals in a river should be compared with previous measurements in order to observe variations in their number as a function of water quality and the loads of transported substances.

3. Methods for Monitoring of Lakes

3.1. Hydraulic Measurements

The monitoring of lakes enables, above all, the control of the hydrology of the system. Water level is measured in permanent stations using limnographs, which graphically record variations in level as a function of time and, generally, send these data in an electronic form via modem to the control center. As the water surface of a lake is an equipotential, one single limnograph station is sufficient for each lake.

In order to obtain a complete hydrological budget of the lake basin, it is necessary to measure all water inputs and outputs. Generally, permanent measuring stations that measure water flow continuously are installed in major tributaries. For minor tributaries, estimations are usually made on the basis of existing average flow data. The contribution due to rainfall directly on the lake surface or runoff from the shores is estimated using measured precipitation data from the local pluviometric network and then applying interpolations for the area in question.

The water output of a lake is obtained by measuring the flow of the outlet. There is usually only one outlet for each lake. The contribution due to evaporation of the water surface may be evaluated based on data obtained from meteorological stations located on the shore of the lake.

In the temperate zones of Earth, the contribution due to evaporation of the water body is small with respect to the outlet output and is of the same order of magnitude as the contribution due to rainfall that falls directly on the lake. Therefore, the error due to the indirect calculation of its value is not important in the hydrological budget. In the warmer zones of Earth, this situation is exactly the opposite. In such zones, evaporation of the water body may represent the majority of the output.

On the basis of input, output, and lake level data, it is possible to calculate the hydrological budget and to compare its annual trend with that of the previous year. In this way, the evolution as a function of time may be observed and any changes or anomalies may be noted.

In lakes that contain dams, weirs, or structures that regulate flow regimen, data gathered for the hydrological budget is fundamental for the planning of correction interventions of the lake level. For large and complex lakes, elaborate intervention programs based on models that permit the prediction of the evolution of the lake level as a function of water supply trends have been developed.

3.2. Physical Measurements

The measurement of physical characteristics that concern lake water must be carried out at least four times annually, in all four seasons, in order to study trends over time. In lakes where water quality has undergone large variations due to rapid urbanization over the last few decades, such measurements should be carried out monthly.

The measurements are made using an equipped boat, which, in large lakes, carries out a series of measurements at various, predetermined points.

The transparency of the surface water is measured in a simple manner using the Secchi disk, which permits the visual evaluation of light adsorption as a function of water depth. Transparency is a function of seasonal biological activity of the lake and is of primary importance for the photosynthesis of phytoplankton.

The transparency of the deep water, properly termed turbidity or transmittance, is measured using an optical probe that is let down from a boat. Turbidity measurements permit the observation of the movement of small sediment particles brought into the lake from the tributaries or rising from the lake floor.

Water temperature is a fundamental parameter in physical limnology. It is important to measure surface temperature as a function of time, but also its evolution with depth. The most modern temperature measuring method is that using a multiparametric probe (CDT Probe), which also measures other physical and chemical parameters simultaneously.

The probe is attached to the boat with a winch and it measures temperature at predetermined depths with a precision of ~0.01 °C.

The electrical conductivity of the water depends on the ionic concentration and, therefore, on the salinity of the water. If the principal ionic species present in the lake are known, conductivity measurements, together with temperature measurements, permit the calculation of the water density.

The multiparametric probe enables the measurement of conductivity profiles, along with temperature measurements, permitting the construction of vertical density profiles.

3.3. Thermal Budget

Figure 2 presents an overview of the dynamics of a lake.

In most cases, lakes have several tributaries and one outlet. Their dimensions and water supply determine the residence time of the water in the lake. This may vary from several months for small lakes to several years in large lakes. Rapid renewal with fresh water, low in nutritive substances, is favorable. On the surface, the water is permanently agitated by wind and waves. These movements also occur at depth.

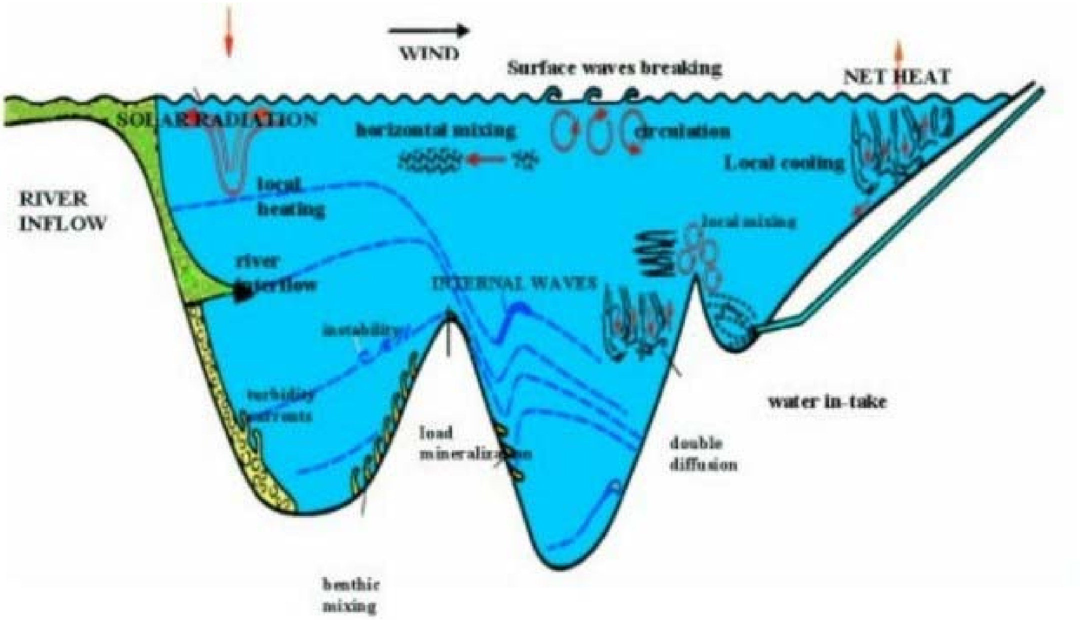


Figure 2. Dynamics of a lake

The fact that water density has a maximum value at 4 °C dictates the thermal behavior of the lake and influences the biological phenomena there. In the spring, the surface waters gradually warm up. Since their winter temperature was less than 4 °C, they become heavier as they warm and begin to sink. When the density reaches the maximum, and is therefore equal to that of deeper layers, the entire lake has a uniform temperature. The wind produces currents that may be felt down to the lake bottom. This is termed "spring mixing." This mixing is of primary importance for water quality. As summer arrives, the surface waters heat up and become lighter, floating on the deeper water that is colder and denser. This stratification reigns until the end of the summer. The vertical profile shows this "summer stagnation," characterized by warm (15 °C) surface water that cools slowly with depth. This layer is termed the “epilimnic layer." The lower, cooler (10 °C) layers are termed the "metalimnic zone." Below this zone, the hypolimnic layer is found. This water remains very cold (4–6 °C) from year to year.

At the end of summer, the surface water slowly cools down, becomes heavier, and sinks to the bottom. The winds provoke an "autumnal mixing," similar to that which takes place in the spring. The “winter stagnation” follows, in which very cold water (less than 4 °C) floats on the deeper, heavier layers. Thus, theoretically, twice a year the lake water is mixed down to its bottom. This brings about a regeneration of the deepest water layers.

The natural temperature variations that may be observed in lake water may be considered as oscillations with respect to a stationary thermal state (i.e., invariable as a function of time). Thus, on the average, the thermal inputs must be equal to the thermal losses of the system. If this is not the case, we speak of a nonstationary thermal state and the lake will slowly heat up or cool down. The amount of heat exchanged from the lake is the sum of various components: global shortwave solar radiation, reflected shortwave solar radiation, longwave radiation, thermal exchange due to conduction, thermal exchange due to evaporation, thermal exchange due to advection (tributaries and outlets), the contribution due to snowfall and the geothermal contribution at the floor.

These various components are calculated based on water temperature measurements and meteorological data: solar radiation, atmospheric pressure, relative humidity, air temperature, average cloud altitude, cloud cover, and wind regimen. The annual thermal budget calculation of a lake, with the contribution of the monthly measured temperature profiles, permits the observation of heat fluxes between the atmosphere and the lake and between lake layers at different depths. In this way, the thermal dynamics of the body of water may be followed during the seasonal cycle. The vertical water circulation is of primary importance, as this determines the oxygenation of the deeper layers. The global circulation, with oxygen transport down to the lake floor and temperature homogenization over the entire lake, is characteristic in many lakes, termed holomictic. In temperate zones, this occurs at the end of autumn or at the beginning of winter, corresponding to very low air temperatures and the action of strong winds which brings about the mixing. Other lakes, termed meromictic, maintain their thermal stratification over the entire year, with a consequent oxygen lack in the deep water layers. In meromictic lakes, annual circulation concerns only the upper water layer.

The thermal budget calculation of a lake, compared to that of previous years, permits the observation of the thermal evolution of the lake, which is a fundamental component of the quality of its water.

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Biographical Sketches

Dr. Lisa Martinenghi is currently a lecturer at the University of Applied Sciences of Southern Switzerland in Lugano as well as a private consultant in geotechnical engineering. She received her doctoral degree from the Swiss Federal Institute of Technology in Lausanne in 1992, after which she lectured at the Swiss Federal Institute of Technology in Zurich in Environmental Geotechnics. Current research interests include soft soil behaviour, especially that of silty soils.

Dr. Febo Zamboni received his Ph.D. in Physics at the University of Milan in 1961, after which he worked almost 10 years at the Physics Institute at the University of Zurich. From 1977 until retirement in 2001, he worked at the laboratory for terrestrial physics at the now University of Applied Sciences of Southern Switzerland in Lugano in applied research in the field of physical limnology with special accent on the recovery of Alpine lakes. He is the author of more than 20 publications in international scientific reviews.