LIMNOLOGY OF RIVERS AND LAKES

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Contents

Summary

Limnology deal with the study of fresh waters contained within continental boundaries. Limnology evolved into a distinct science only in the 20th century, integrating physical, chemical and biological disciplines to enable us to describe and manage freshwaters ecosystems. Although inland water bodies are well below the oceans size, they are complex systems and they can't be fully understood if studied without taking into account the complex interrelations between physical, chemical and biological aspects. This chapter offers an overview of the basic principles of limnology. Particular attention has been devoted to the integration of physical, chemical and biological information, highlighting how abiotic and biotic compartments deeply interact to determine lakes' and rivers' evolution. Thus this chapter is aimed at improving the mutual understanding between the different disciplines dealing with the specific compartments of freshwater ecosystems.

1. Introduction

The science studying the water bodies located on the surface of the continents is called limnology (from the Greek λίμνη (*limne*) = lake and λόγος (*logos)* = study. It is considered as a part of ecology. It covers the biological, chemical, physical, geological, and other attributes of all inland waters, both running as in rivers (lotic ecosystems) and standing as in lakes (lentic ecosystems). The study of rivers, springs, streams and wetlands, lakes and ponds, both fresh and saline, natural or man-made is included in limnology. The term limnology was firstly proposed by François-Alphonse Forel (1841–1912) when publishing his researches on Lake Geneva. Because of its practical value, the interest in the discipline rapidly expanded, and in 1922 August Thienemann (a German zoologist) and Einar Naumann (a Swedish botanist) co-founded the International Society of Limnology (SIL, *Societas Internationalis Limnologiae*).

2. Inland Waters and the Water Cycle

Most of inland water bodies are freshwater and they account only for a small fraction (~0.02%) of the whole hydrosphere. Some more freshwater (~1%) is groundwater and the ~2% of the hydrosphere is confined as ice in polar caps and in glaciers. Most of the water on Earth (~97%) is made up by seawater (Shiklomanov, 1999). In spite of the uncertainty of these estimates, without doubt the usable freshwater allowing for the existence of life on the continents is a very small fraction of the hydrosphere. The mechanism supplying new freshwater to continents as the water flows away from them is the water cycle (Figure 1). The sun provides the energy that keeps the water cycle moving through the evaporation of oceanic and inland surface waters and the evapotranspiration of terrestrial vegetables. Water vapor then progressively condenses in the atmosphere, eventually returning to the ground as rain or snow. The oceans lose for evaporation more water than they get back through precipitations and the opposite occurs in the continents. Thus the water flow through the continents is maintained. The residence times of water in the compartments of the cycle are very different. A certain mass of water can stay about ten days in the atmosphere, it will remains few weeks in the rivers and reside years or centuries in lakes and several centuries in groundwater (Trenberth et al. 2007).

In spite freshwater covers a small fraction of the Earth's surface, they are important quantitative components of the carbon cycle at either global or regional scales. Lakes, rivers, and reservoirs trap roughly half of carbon entering inland aquatic systems from land. A small fraction of such carbon is buried in aquatic sediments, a larger part is returned to the atmosphere as gas exchange while the remaining is delivered to oceans (Cole et al. 2007).

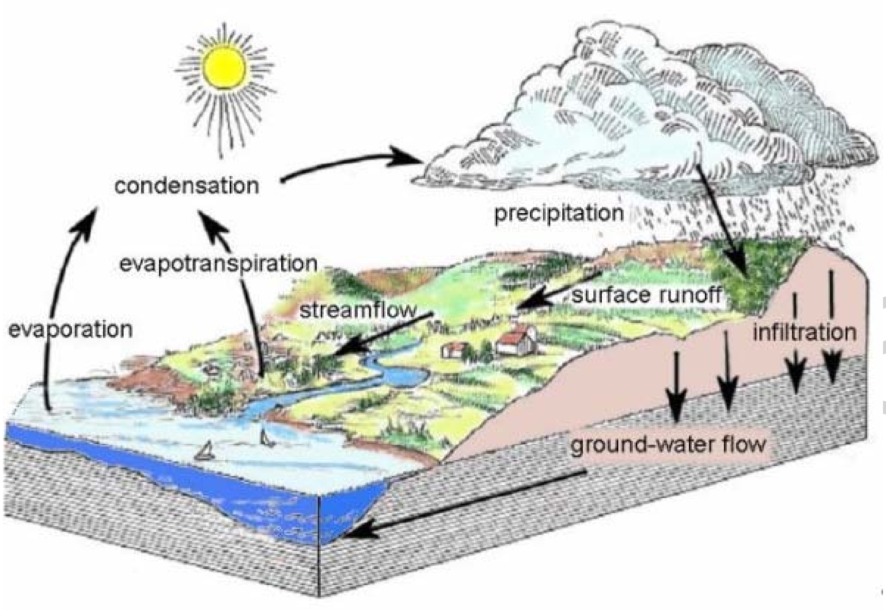

Figure 1. The water cycle

2.1. Physical Properties of Water

The water molecule is formed when two atoms of hydrogen establish a covalent bond with one atom of oxygen (Figure 2). In the covalent bond electrons are shared between atoms. In the water molecule the sharing does not have equal strength: the oxygen atom attracts electrons more strongly than the hydrogen atoms. As a consequence, in the water molecule the charges are asymmetrically distributed. The molecules that have partially negative or positive edges are called bipolar. This property makes water a good solvent for many substances. The positive region of a water molecule attracts the negative of another molecule, creating a hydrogen bond (dashed in Figure 2). In this bond the hydrogen atom is shared by two oxygen atoms: the donor atom is that to which hydrogen is more closely tied and the acceptor (that with partial negative charge) is the one attracting the shared hydrogen atom. The hydrogen bond is significantly weaker than the covalent bond but when many hydrogen bonds are acting together they constitute the strong cohesive force that gives water a high surface tension.

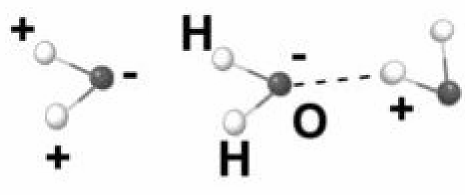

Figure 2. Structure of water molecule.

When the temperature falls and ice forms, the movements of the molecules are greatly reduced, and they bind together forming a rigid crystalline structure, allowing for large intermolecular voids (Figure 3). Because of this, a defined volume can accommodate less iced water molecules than liquid water molecules.

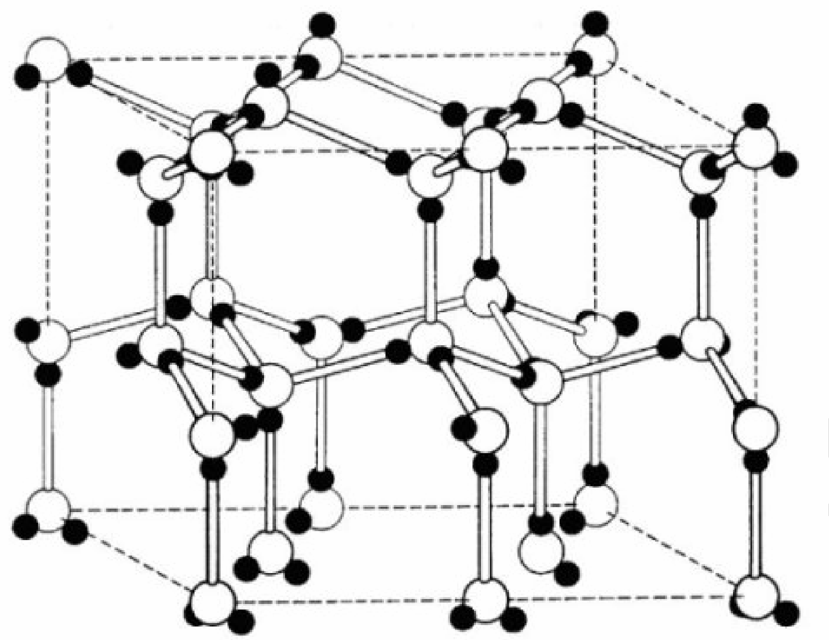

Figure 3. Crystalline structure of water molecules in ice.

The molecular structure of water gives it unique physical characteristics affecting the movements of water masses in lakes. Water maximum density is at 3.98° C: the water at lower temperature is less dense, i.e. lighter, so that a cube of ice (0°C) of 1 dm side weighs 85 grams less than a cube of water of same size at 3.98° C. Above this value, water becomes less dense (lighter) with increasing temperature (Table 1).

Temperature (°C)	**Density** (g dm^{-3})
0 (solid)	915.0
3.98	1000
20	998.2
40	992.2
60	983.2
80	971.8
100 (gas)	0.6

Table 1. Change of water density as a function of temperature.

Also the specific heat, i.e. the amount of heat (in calories) necessary to raise by 1°C the temperature of 1g of water is a physical characteristic unique to water. It is = 1, the highest among all solids and liquids, with the exception of liquid ammonia. For this reason water is an accumulator of heat, ensuring that the aquatic environment is thermally more stable than the ground. The thermal fluctuations in lakes are, therefore, gradual with changing seasons. Also the interval between the extreme daily values is much more reduced in water than in air, thus making the underwater climate thermally rather uniform. Exhaustive information on the structure and properties of water can be found in Eisenberg & Kauzmann (2005).

2.2. Inland Waters Dynamics

Waters moves into the cavities of the Earth's crust transporting solutes and suspended matter from and to neighboring ecosystems, exchanging heat and gases with the atmosphere. By gravity the water flows in rivers along the lines of maximum slope with a current speed that tends to decrease from the mountains to foothills, although deviations from this rule are possible due to variation of other parameters also influencing the current velocity (e.g., flow increase for a tributary input). The current velocity of a mountain stream is around 3 ms^{-1} (about 10 km h^{-1}), that of a river in the plain is less than 1 ms^{-1} and in a lake the flow velocity decreases to values close to 1 cm s^{-1}. In rivers the kinetic energy of moving water is the main force fostering the exchanges with the neighboring environment and determining the life conditions in the ecosystem.

Reaching the lake, the river bed widens considerably and the current velocity decreases rapidly. So the water movement in lakes is no longer promoted by gravity but depends on other energy sources: the heat supplied by solar radiation and the mechanical energy supplied by wind. These determine the movement of water masses and, therefore, the exchanges between them and the atmosphere. Because these sources of energy suffer obvious seasonal variations and are influenced by the regional climate, the lake waters chemistry (particularly the oxygen availability) and the activity of organisms living in the lake is highly dependent on seasonal thermal events of the lake itself.

Rivers and lakes, according to the different water flow velocity are called, respectively, lotic ecosystems (running water) and lentic ecosystems (still water).

Lakes need a river or at least an underwater spring to exist. This obvious succession prompts to deal with rivers first, but most of the concepts related to water physics and chemistry and aquatic food webs will be illustrated in details in the sections dealing with lakes (Section 4 on).

3. Running Waters: The Rivers

3.1. River Morphology

Meteoric water flowing down slopes ends up merging to form small streams which then channel into a river. Because of the kinetic energy of the moving water, the river develops various landforms through channel processes. It is outside the aim of this chapter to discuss in detail the river landforming activity, already illustrated in Matsuda (2004).

For the purpose of this chapter it is enough to recall some basic terminology constituting the necessary context for river ecology illustration.

As shown in Figure 4, the area supplying water into a river is the drainage basin (db). The boundary between drainage basins is a water divide (wd). A river system is composed of the main stream (ms) and many tributaries (t). However, in many cases several tributaries have similar length and flow, and it is difficult to find the main stream. The main fluvial processes are erosion, transportation and sedimentation. In the upper area of a drainage basin, where current velocity is higher, erosion predominates and valleys composed of channels and slopes are formed. The materials swept downstream are the sediment load, produced mainly by weathering of the rocks composing slopes. Sediment load is deposited to form an alluvial plain. The channel patterns forming in alluvial plains can be braided, meandering or straight. The channel patterns and forms bring about the river morphology, decided by many inter-related factors such as discharge, water velocity, slope, depth and width of the channel, and riverbed geology.

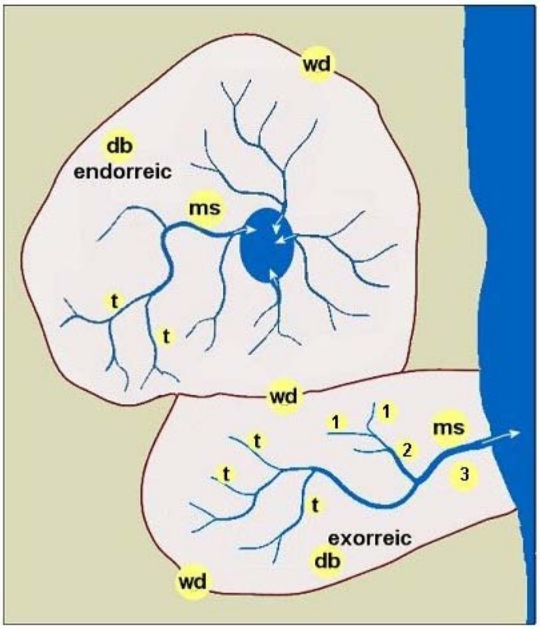

Figure 4. The hydrographic net: drainage basin (db), water divide (wd), main stream (ms), tributaries (t); first (1) second (2) and third (3) order stream.

A list of the main (length over 650 km) rivers of Europe is available at the website: http://en.wikipedia.org/wiki/List_of_rivers_of_Europe

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Biographical Sketch

Roberto Bertoni is Senior Scientist at CNR-ISE (National Research Council - Institute for the Study of Ecosystems) Verbania Pallanza, formerly “Istituto Italiano di Idrobologia”.

He obtained the Degree in Biological Sciences at the University of Milan in 1971. Its field of interest is Aquatic Microbial Ecology and, in particular, the spatial-temporal trend of particulate and dissolved organic matter and of microbial assemblages. His activity is also addressed towards the development of innovative tools to solve specific sampling problems (two patents) and to the application of image analysis techniques to quantify the microorganisms. The ultimate objective of his research is the study of the role of autotrophic and heterotrophic microorganisms in modifying the flow of energy and of organic matter in lakes. His research is developed through numerous international contacts which enabled him to study pristine environments (North Patagonian Andean lakes). He was responsible for the EU project MICOR, for the evaluation of UVB radiation effects on microbial communities. He collaborated in research activities in extreme environments in the Program EV-K2 and in the EU project MOLAR. He participated in the EU EMERGE project and collaborated in the EU project Euro-limpacs. He is currently involved in life plus project EnvEurope. He is engaged in student training and is support teacher in the PhD cycles of the University of Parma, where he was external Professor of Limnology (2004-2005).

He has produced and is maintaining the website of ISE (www.ise.cnr.it) and of its Department of Verbania, formerly Italian Institute of Hydrobiology (www.iii.to.cnr.it). He is editor of the online version of the Journal of Limnology (www.jlimnol.it). Since 1990 he has been a member of the Scientific Council of the Italian Institute of Hydrobiology until 2002, when the Institute has joined the ISE. Since then he has been responsible for the Department of Ecology of Inland Waters until its termination in June 2005. Since 1997 he is coordinator of the research on the limnological evolution of Lake Maggiore, promoted by the International Commission for the Protection of Italian-Swiss waters (CIPAIS), and editor of the annual scientific reports. From 2002 to 2008 he was Assistant Editor of the Journal of Environmental Engineering & Science of Research Board of Canada.

He is member of the Council Board of the Italian Society of Ecology (SitE) since 2008, and of the Italian Association of Limnology and Oceanography (AIOL) since 2009. Since 2000 he is the webmaster of AIOL website (www.aiol.info). He is national coordinator of the International Society of Limnology (SIL) (www.silitaly.it). He is involved in the Italian network for the Long Term Ecological Research (LTER) since its beginning as Member of Coordination Committee. He is also coordinator of the Southern Alps Lakes LTER site (www.ise.cnr.it/lter/) and webmaster of the website of the LTER Network Italy (www.lteritalia.it). He is author of over 140 scientific publications.