Preface to the Book Series

An integrated view of *Physics of Lakes* requires expert knowledge in different specialities which are hardly found in single scientists. Even in a team the overall subject must be restricted; this has also been done here, as we only treat in this book series the *geophysical aspects of fluid dynamics*. Being applied to very complicated natural objects and phenomena, this science traditionally uses three main complementary approaches: *theoretical description*, *field observation* and (numerical, laboratory and other kinds of) *modelling*. The present work extensively uses all three approaches, this way providing to the reader an opportunity to build a coherent view of the entire subject at once—from the introduction of governing equations to various field phenomena, observed in real lakes. Several features, we believe, will make the series of especial interest for a wide range of students and scientists of geophysical interest as well as specialists in physical limnology. Before plunging into the main focus of lake physics we start with a detailed introduction of the main mathematical rules and the basic laws of classical physics; this makes further work with equations and their solutions much easier for readers without solid knowledge in the common trade of the background of mathematics and physics of continuous systems—biologists, chemists, ecologists. These sciences are today the most active branches in limnology and are utterly needed for the development of modern society; thus, an easily available physical background for them cannot be overestimated. A feature of this treatise is a consolidated view expressed in its three books of a wide panoramic overlook of various lake phenomena, inherent in physical oceanography and a fairly thorough theoretical treatment of fluid mechanics. This way, the reader will find here both the mathematical background and general physical laws and considerations of natural phenomena with their driving mechanisms (waves, turbulence, wind action, convection, etc.), and also a zoo of field examples from many lakes on our Globe. Special attention is devoted to the dynamic response of lakes on their free surface and in their interior, perhaps best coined as the climatology in response to external driving mechanisms—wind action and seasonal input of solar energy. These subjects reflect the many years of professional interests of the authors.

The content of the books and the manner of the presentation are, of course, significantly influenced by the composition of the authors' team. Being professionals of slightly different branches of the same science (limnology, fluid dynamics, and oceanography), we tried to present lake physics in the most coherent way, extracting important kernels from all the mentioned fields. The differences in opinions, what procedures might be the optimal approach in presenting a certain topic have occasionally been quite extensive, requiring compromises, but we believe that the interference, rather than simple sum, of our knowledge contributed to an enhancement of the present product than would have been reached otherwise. An additional joy for us is the national composition of our international team; translation of this Preface from the English into our native languages can be directly understood by more than 70 % of the Earth population.

The subjects of this treatise on *Physics of Lakes*, divided into three volumes, cover the following topics:

Volume 1: Physics of Lakes—Formulation of the Mathematical and Physical Background

It commences in the introduction with a general, word-only motivation by describing some striking phenomena, which characterize the motion of lake water on the surface, in the interior of lakes and then relate these motions to the density distribution. It lists a large number of lakes on Earth and describes their morphology and the causes of their response to the driving environment.

Because physics of lakes can not be described without the language used in mathematics and only limited college knowledge calculus and classical Newtonian physics is pre-assumed, these subjects are introduced first by using the most simple approach with utmost care, and continuing with increasing complexity and elegance. This process leads to the presentation of the fundamental equations of Lake Hydrodynamics in the form of 'primitive equations', to a detailed treatment of angular momentum and vorticity. A chapter on linear water waves then opens the forum to the dynamics in water bodies with free surface. Stratification is the cause of large internal motions; this is demonstrated in a chapter discussing the role of the distribution of mass in bounded water bodies. Stratification is chiefly governed by the seasonal variation of the solar irradiation and its transformation by turbulence. The latter and the circulation dynamics are built on input of wind shear at the surface. The early theory of circulation dynamics with and without the effect of the rotation of the Earth rounds-off this first book into the dynamics of lakes. A chapter on turbulence modelling and a further chapter collecting the phenomenological coefficients of water complete this book on the foundations of the mathematics and physics of lakes.

Volume 2: Physics of Lakes—Lakes as Oscillators

The overwhelming focus in this volume of the treatise is on linear waves in homogeneous and stratified lakes on the rotating Earth. It comprises 11 chapters, starting with rotating linear shallow-water waves and demonstrating their classification into gravity and ROSSBY waves for homogeneous and stratified water bodies. This leads naturally to the analysis of gravity waves in unbounded, semi-bounded and bounded domains of constant depth: KELVIN, inertial and POINCARÈ waves, reflection of such waves at the end of a gulf and their description in sealed basins as so-called 'inertial waves proper'. The particular application to gravity waves in circular and elliptical basins of constant depth then builds further confidence towards the treatment of barotropic and baroclinic basin wide wave dynamics affected by the rotation of the Earth. The classical analytical approach to the baroclinic motion in lakes is done using the two layer approximation. Recent observations have focused on higher order baroclinicity, a topic dealt with in two chapters. Whole lake responses are illustrated in barotropic and baroclinic wave analyses in Lake Onega[1] and Lake Lugano, respectively, with detailed comparisons of field data. The final three chapters are then devoted to a detailed presentation of topographic ROSSBY waves and the generalized CHRYSTAL equations and their identification by field observations.

Volume 3: Physics of Lakes—Methods of Understanding Lakes as Components of the Geophysical Environment

Red line of this volume is the presentation of different methods of investigation of processes taking place in real lakes.[2] Part I is devoted to numerical modeling approaches and techniques, applied to demonstrate the response of a lake to wind

[1] In today's Latin orthography from Russian, 'Onega' and 'Onego' are both in use. In this book we use 'Onega'.

[2] This description of the contents of Volume 3 differs from the version stated in Volumes 1 and 2, which were written in June 2010. Since then, chapters on morphological dynamics of lakes have been added and topics on nonlinear internal oscillations, wave transformation, and meromixis have been published in a separate book [1]; also, investigations of convective exchange flows in basins with sloping bottom have been published [2]. Содержание Тома 3 несколько отличается от версии, представленной в Томах1 и 2, опубликованных в июне 2010. С одной стороны, нами были добавлены главы о морфологической динамике озёр, с другой - часть материалов уже увидела свет в новых отдельных книгах: о нелинейных внутренних волнах, их трансформации и перемешивании в глубинных слоях (Hutter, K. (Ed.): *Nonlinear internal waves in lakes*. Springer Verlag, Berlin, etc., 2012) и об исследованиях обменных течений конвективной природы над подводными склонами (Чубаренко И.П.: *Горизонтальная конвекция над подводными склонами*. Калининград, Тэрра Балтика. 256 стр. 2010).
(in Russian).

forcing. It commences with the presentation of the barotropic and baroclinic current and temperature distributions due to different wind scenarios applied to Lake Zurich. This shows that depth integrated models predict an adequate current distribution only for extremely restricted situations. Moreover, multi-layered simulation models require careful selection of the distribution of layer depths and layer number as well as horizontal and vertical turbulent diffusivities to reach trustworthy stable results for current and temperature distributions. This experience makes a thorough application of numerical implementation of the governing equations compulsory. Numerical methods for convectively-dominated problems are compared. Moreover, different numerical treatments of advection terms and subgrid turbulence parameterization are studied, which indicate that shock capturing and total variation diminishing procedures are required, if metalimnion dynamics is to be realistically reproduced, including possible meromixis processes.

Traditional field measurement tools and methods of observation as well as laboratory experimental procedures are laid down in Part II. It includes the presentation of principles of operation of commonly used current, temperature, conductivity, pressure, and other sensors and devices applied in the field, as well as the discussion of advantages and limitations of common measuring methods like long-lasting registration using stationary or drifting buoys, sounding and profiling from the boat, sampling, etc. This part aims to help the reader to develop a clear understanding of *what* and *how* things are measured in lakes, to draw attention to questions of data accuracy, quality, reliability, to emphasize that field experiments should be carefully designed in accord with the researchers' ideas—i.e., to introduce to the science of field experimentation. The third chapter of this part introduces the ideas of dimensional analysis and similarity solutions, later applied to transport of sediment, which is suspended in the turbulent water and/or moves as detritus[3] at the lake bottom.

Part III is devoted to the dynamics of lakes as particle laden fluids and the transport of the bottom sediments leading to morphodynamic changes of the bathymetry in estuarine and possibly whole lake regions. The sediment may be eroded from the ground and become suspended; or suspended non-buoyant particles may be deposited at the ground. The mixture type equations in the lake domain are akin to those also describing the transport of species and nutrients in the lake water. The equations of motion describing the sediment and water transport on the curved basal bed are formulated relative to time-dependent curvilinear coordinates. Erosion and deposition of solid particles will contribute to morphological changes of the bathymetry, especially in estuaries close to river mouths. A simple one-dimensional theory explains the formation of hypo- and

[3] The term 'detritus' used in this book is to mean solid material—gravel—transported at the basal surface of a river or lake/ocean. This is the terminology used in geology and hydraulic engineering.

hyper-pycnal deltas, very well supported by laboratory experiments. The three-dimensional general formulation is new and open for validation and verification.

Combined presentation of numerical, field, and laboratory approaches builds a general view of present-day methods of physical investigations in limnology.

Final Remarks

There is one change in the structure of Volume 3 as compared to Volumes 1 and 2, namely in Volume 3 each chapter has its own list of symbols. This was so made because some libraries now allow downloading of book chapters. Providing lists of symbols makes such documents more useful than otherwise.

With this third volume, this treatise on *Physics of Lakes* is declared to be abandoned by us. However, the subject as such cannot be viewed as closed. There are a wealth of topics that have not been treated at all or remain in an unfinished state. Mention was already made of *Non-linear internal waves in lakes* [1], of which their transformation or destruction through baroclinic instabilities with the metalimnion is responsible for the meromixis, i.e., strong mingling of phosphate, nitrate, oxygen, etc., from the epilimnion to the hypolimnion waters. Untouched has also been any serious attempt of a description of bio-chemical interactions with the physical processes. Quantification of the seasonal variation of the thermocline depends primarily on the interplay between the solar irradiation and the penetration of the turbulence into the water body. The attenuation of the coefficients of extinction of irradiation is coupled with the concentrations of the species (algies, nutrients etc.) through their bio-chemical reactions. An account on this in the German language is *Ein-dimensionales hydrodynamisches Modell in der Limnophysik. Turbulenz-Meromixis-Sauerstoff* [3]. These and a wealth of other topics could fill further volumes and will hopefully appear in the literature by experts of the younger generation.

Zürich, Switzerland, December 2012 — Kolumban Hutter
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