Chapter 11

The Residence Time of the Water in Lake MAGGIORE:
Through a Eulerian–Lagrangian Approach

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ABSTRACT

This chapter describes a study designed to evaluate the spectrum of the residence time of the water at different depths of a deep lake, and to examine the mechanisms governing the seasonal cycle of thermal stratification and destratification, with the ultimate aim of assessing the actual exchange time of the lake water. The study was performed on Lake Maggiore (depth 370m) using a multidimensional mathematical model and computer codes for the heat and mass transfer in very large natural water bodies. A 3D Eulerian time-dependent CFD (Computational Fluid Dynamics) code was applied under real conditions, taking into account the effects of the monthly mean values of the mass flow rates and temperatures of all the tributaries, mass flow rate of the Ticino effluent and meteorological, hydrological, and limnological parameters available from the rich data-base of the CNR-ISE (Pallanza). The velocity distributions from these simulations were used to compute the paths of a large number of massless markers with different initial positions and evaluate their residence times in the lake.

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INTRODUCTION

The findings presented here are the result of a two-year simulation and may be briefly summarized as follows: a) much of the water arriving in the lake from tributaries and/or from depths from 0.0 to around 50-70 m below the free surface has probable residence time values between 250 days and 2 years or more; b) the water flowing below 150-180 m shows some movement but is very unlikely to rise vertically; c) we can make no general hypothesis as to the fate of the water flowing in the intermediate zone. The fate of the intermediate water mass is linked to the fact that this water undergoes the year-to-year impact of the vertical winter mixing, and its renewal time depends on the extent to which it is involved in the circulatory system.

One of the major problems in theoretical and applied limnology is to establish the mean actual residence time of the water in a complex lake such as Lake Maggiore (Ambrosetti et al. 2003). Taking account also of the ongoing climate changes, it is only by determining this mechanism in real terms that that the velocity of the processes of concentration, dilution and permanence of substances in the lake can be assessed, with the resulting implications for water quality and the planning of effective policies to protect the environmental resources of the whole territory. The actual water exchange time can only be determined through an evaluation of the hydrodynamics of the lake. This means creating a numerical-mathematical model which can come as close as possible to making an exact evaluation of the residence time of the water in Lake Maggiore and which takes account primarily of its internal circulation, as well as the hydrology of its drainage basin. By "internal circulation" we mean the quantitative assessment of the longitudinal, transverse and vertical movements of the lake water at the various bathymetric depths in relation to its thermal structure and the meteorological and hydrological parameters responsible for the process.

The creation and study of a multidimensional mathematical model and calculation codes for the transfer of heat and mass in very large natural free surface water bodies has been one of the most pioneering applications of applied research and advanced engineering in the field of fluid dynamic methods. The problem was treated some decades ago by Orlob (1967), Cheng and Tung (1970), Dailey and Harleman (1972), Castellano and Dinelli (1975), while recent researchers have included Rueda and Schladow (2005), Yue et al. (2004), Leon *et al.* (2005), Pham Thi et al. (2005), Wang et a*l.* (2005), Castellano et al. (2008). Advances made so far are mainly due to the huge increase in computer calculating power, allowing researchers to use several hundred million calculation cells. With the quantity of input available, this has enabled us to develop a useful model for limnological studies, making it possible to work on the whole volume of a lake by dividing it into thousands of cells, and within time intervals ranging from a few months to years – an impossible enterprise in the past. Each of the simulations presented here, performed by applying our model, has required the use of extremely powerful processors and elaboration times which may go on for several days without interruption.

We should stress that the research performed so far represents a preliminary, if essential, study, aimed at fine-tuning and using the guidelines of a campaign of numerical simulations developed to study the time scales of the hydrodynamics and transport phenomena in Lake Maggiore. This work, continuing previous research, documents the capacities of the computer code used and shows evaluations of major importance regarding the fate of massless Lagrangian markers inserted at different locations in the lake at zero time of a biennial simulation. This process is a necessary preliminary to understanding the overall hydrodynamics of Lake Maggiore, an essential premise for the assessment of the actual exchange time of its water, which was our aim.