C. R. Geoscience 344 (2012) 25–32

Contents lists available at SciVerse ScienceDirect

Comptes Rendus Geoscience

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Hydrology, environment

Use of major and selected trace elements to describe mixing processes in a water reservoir

Utilisation des éléments majeurs et traces pour décrire les mélanges d'eaux au sein d'un lac de barrage

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ARTICLE INFO

Article history:
Received 24 June 2011
Accepted after revision 21 November 2011
Available online 3 February 2012

Presented by Ghislain de Marsily

Keywords:
Reservoir
Major and trace elements
Stratification
Layers

Mots clés :
Lac de barrage
Constituants majeurs et traces
Stratification
Couches d'eau

ABSTRACT

Data on temperature, major constituents and some trace elements, measured in the dissolved and particulate phases, were used to identify the hydrodynamics of a reservoir (the Bicaz reservoir, Romania). Results revealed that the reservoir experiences two thermal stratifications per year (summer and winter). However, the summer stratification is delayed by the high river inflow of June–July. Two layers were identified, a surface and a deep layer, whose location and impact vary with time. The surface layer originates from the river inflow (intrusion layer) and the deep current is produced by the outflow (velocity current). According to season, the river inflow either supplies the deep current or remains recordable up to the dam. Consequently, the structure of the water column, and thus the biogeochemical processes within it, are governed both by thermal stratification and by these layers.

RÉSUMÉ

La température, les teneurs en constituants majeurs et quelques traces, en phases dissoute et particulaires, ont été utilisées pour déterminer la circulation des eaux d'un lac de barrage (le lac de Bicaz, Roumanie). Le lac est soumis à deux stratifications par an (en été et en hiver), bien que la stratification estivale soit retardée par les importants apports des rivières en juin–juillet. Une couche de surface et une profonde, dont la position et l'importance varient au cours du temps, ont été identifiées. La couche de surface est générée par les apports de rivières (couche d'intrusion) et la couche profonde est due au soutirage de la vanne (courant de vitesse). Selon les saisons, les eaux de rivières alimentent la couche profonde ou sont identifiables jusqu'au barrage. La structure de la colonne d'eau et donc les processus biogéochimiques sont contrôlés à la fois par la stratification thermique et par ces couches d'eau.

1. Introduction

In natural lakes, thermal stratification of the water column leads to the formation of water layers (Wetzel, 1983) allowing stable chemical conditions to develop. In reservoirs, thermal and chemical stratification of the water

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1631-0713/$ – see front matter
doi:10.1016/j.crte.2011.11.001

column is influenced by river inflows (Han et al., 2000) and outflows (Casamitjana et al., 2003; Fontane et al., 1981). Reservoirs are generally built in areas where river inflow is sufficiently high that they can be filled rapidly. The impact of the river inflow depends on its volume and on its penetration depth. This depth is controlled by density differences between the river and the reservoir waters, including differences in temperature and in dissolved and particulate load, as well as by the geometry of the banks and of the reservoir slope at the inflow location. As a river enters a reservoir, it pushes ambient water ahead of itself until buoyancy forces arrest the flow. If the incoming water mixes thoroughly with the upper layer or its density is less than that of the ambient, then the intrusion layer flows across the surface of the reservoir. Atmospheric conditions (temperature, wind, rain) may control the longitudinal dispersion and mixing of this layer with the reservoir water. If the inflow mixed water is denser than the reservoir surface, it will plunge under the surface and create a density current. If the density current is created, it will entrain water from the passing depths of the reservoir water until finding a level of neutral buoyancy to form an underflow in that layer depth, or will continue to the reservoir bottom down the reservoir slope. Mixing of reservoir waters with the inflow occurs in the region of the plunge (initial mixing) and after the flow has formed an intrusion layer. At the end of the reservoir basin, the outflow creates a current at the depth of the sluice, varying according to hydroelectric demand. There are thus two potential layers, one entering upstream at the top of the reservoir and one at the bottom of the water column, at the level of the sluice, with some thickness, sometimes not negligible if compared to the height of the water column. These layers, combined with, and involved in, the thermal and chemical stratification, control the ecological and geochemical behaviour of the reservoir (Bonnet and Poulin, 2002, 2004; Hamilton and Schladow, 1997; Lopes et al., 2010; Rueda et al., 2007; Søballe and Kimmel, 1987).

The Bicaz reservoir (Izvorul Muntelui-Bicaz, here called Bicaz), located in a mountainous area in the East Carpathians, Romania (Fig. 1), was built to supply hydroelectric power. The watershed of the Bistriţa River, its main tributary, comprises numerous manganese and polymetallic sulfide ore deposits. A geochemical study of the Bistriţa River (water and sediments) and the Bicaz reservoir has been undertaken to assess the behaviour of trace elements originating from the weathering of ore deposits.

The water quality of reservoirs is controlled by the origin and quality of the entering waters (tributaries of the reservoir) and advection, convection and dispersion processes occurring in the water column. In the case of the Bicaz reservoir, the mean annual discharge is greater than the volume of the reservoir (Apetroaei, 2003). This implies that the renewal time of water is less than one year and that water-sediment interaction within the reservoir is low. It also implies that influent waters will create a strong current. There are considerable seasonal variations in discharge, both in volume and in the accompanying dissolved and suspended load. In this mountainous area, there is low discharge in winter (snow precipitation) and high discharge in early spring (snow melt and spring precipitation). During spring, river waters also carry large loads of particulate matter originating from soil erosion. At the mouth of the river, the inflowing waters may produce an intrusion layer in the reservoir, while the outflow generates a current of water whose velocity depends on the rate of withdrawal. Simulation of reservoir hydrodynamics is based on a large data set of meteorological inflow and withdrawal data and requires complex mathematical models (Boegman et al., 2001; Cole and Buchak, 1995; Herczeg and Imboden, 1988; Imberger and Patterson, 1981; Samolyubov et al., 2000). To simulate stratification and transport, these models are usually coupled to temperature (e.g. Bonnet et al., 2000; Rueda et al., 2006), isotopic composition (e.g. Bergonzini et al., 2001; Brigault et al., 1998) or to tracer numerical simulation (Hocking and Patterson, 1994; Rueda et al., 2006). In the water column, the distribution of an element depends on its origin and then on mixing of waters. Furthermore, according to element characteristics, its speciation depends on chemical conditions prevailing in the water. By studying temperature, major element and selected trace element concentrations, the aim of this paper was to assess location and extent of layers, and the thermal stratification characteristics.

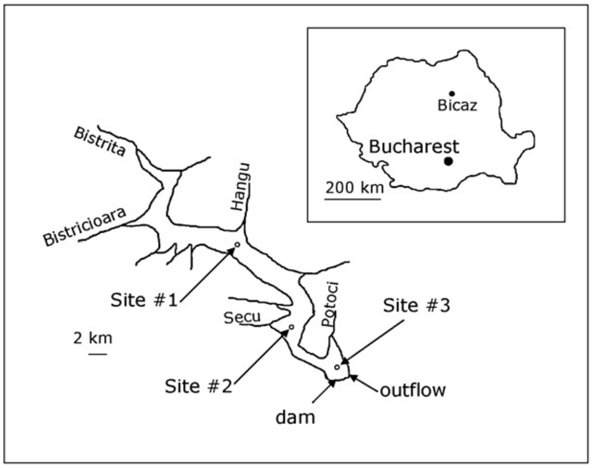

Fig. 1. Location of the Bicaz reservoir and the data collection sites.

Fig. 1. Localisation du lac de barrage de Bicaz et des points de prélèvement.

2. Geological and hydrological characteristics of the reservoir

The geology of the drainage basin of the Bicaz reservoir is complex. The Bistriţa River crosses three major geological units: a crystalline zone (schists, micaschists, gneisses, amphibolites), a flysch zone (conglomerates, sandstones, clays, marls, limestones), and a magmatic rock zone (pyroclastites, dacites, andesites, microgabbros, diorites, microdiorites). The reservoir basin itself lies within the flysch zone.

The Bicaz reservoir is long (31.1 km) and narrow (2 km) (Fig. 1). Its main tributaries are the Bistriţa (catchment area 2985 km^2) and the Bistricioara (770 km^2). Other influents can be ignored. The outflow is located about 45 m below the maximum water level of the reservoir, between the