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Groundwater–surface water interactions in a freshwater lagoon vulnerable to anthropogenic pressures (Pateira de Fermentelos, Portugal)

Clara Sena [a,*], M. Teresa Condesso de Melo [b]

[a] CESAM – Centre for Environmental and Marine Studies, Geosciences Department, University of Aveiro, 3810-193 Aveiro, Portugal
[b] CVRM – Geosystems Centre, Instituto Superior Técnico, Avenida Rovisco Pais, 1049-001 Lisbon, Portugal

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SUMMARY

Groundwater–surface water interactions are investigated in the Pateira de Fermentelos lagoon, a shallow freshwater body with important aquatic and terrestrial ecosystems. The monthly monitoring of water levels proves that the lagoon drains phreatic aquifers which in turn contribute to recharge the underlying semi-confined aquifers. Besides rainwater, four types of natural waters contribute for the water balance and water quality in the lagoon: (1) the Cértima River with a Ca–HCO_3 water type and circum neutral pH; (2) the Cretaceous aquifers with a Na–Cl–HCO_3 water type and acidic pH; (3) the Triassic aquifers with a mixed water type, and slightly alkaline pH; and, (4) under certain conditions, the Águeda River with a diluted Na–Cl water type. Calculation of the water budget of the lagoon was developed with a lumped parameter model earlier proposed. The results of the lumped parameter model show that subsurface lateral flow is an important contributor to surface water bodies when compared to aquifer discharge. Albeit the lagoon drains impacted aquifers with high nitrate content, surface water bodies revealed low nitrate content throughout most of the 1-year monitoring period. The low nitrate content in the lagoon reflects a natural attenuation capacity that ranges between 8% and 13% which is mainly attributed to biogeochemical processes occurring in the hyporheic and riparian zones associated to the lagoon.

1. Introduction

Surface water bodies and surrounding wetlands are integral parts of groundwater flow systems. The interactions of streams, lakes and wetlands with groundwater are mainly governed by the positions of the surface water bodies with respect to groundwater flow systems, geological properties and their climatic settings (Winter, 1999). Shallow aquifers with overlying wetlands or rivers are areas of marked fluxes of water, nutrients, and biological material which sustain important ecosystems (Hancock et al., 2005). Furthermore, these ecosystems often provide the appropriate conditions for agriculture and human development. Hunt et al. (2006) emphasize the importance of quantitative hydrology for the management of wetland-stream ecosystems.

When assessing groundwater–surface water interactions two important interface zones must be considered (Fig. 1):

1. The hyporheic zone, composed by the water-saturated sediments lying beneath the surface water bodies. In the hyporheic zone biogeochemical processes exert a great control on the partitioning of matter (nutrients, metals, trace elements and organic matter) between the solid matrix and porewater (Gandy et al., 2007; Hancock et al., 2005; Sophocleous, 2002).
2. The riparian zone, composed by unsaturated sub-aerial sediments deposited along the margins of surface water bodies. In the riparian zone exuberant vegetation may develop, and nutrients are transferred between water, the solid matrix, biomass and the atmosphere (Hoffmann et al., 2006; Rivett et al., 2008). Depending on its hydrologic regime and plant cover, the riparian zone can act as a hydraulic barrier limiting direct flow of nutrient-rich groundwater to a surface water body (Cirmo and McDonnell, 1997; Banaszuk et al., 2005; Hill et al., 2000; Hefting et al., 2006; Hoffmann et al., 2006; Jacks and Norrström, 2004; Pfeiffer et al., 2006; Rivett et al., 2008). In addition, metals from contaminated surface runoff and subsurface flow can be retained via bioaccumulation in riparian plant tissues before reaching surface water bodies (Ali et al., 2004; Bargato et al., 2005; Madejón et al., 2004; Ye et al., 2003).

Groundwater–surface water interactions have been studied worldwide in different hydrogeological settings, and focusing on distinct aspects of the hydrological continuum. Devito et al. (1996) studied groundwater–surface water interactions in two conifer swamps of the southern Canadian Shield from June 1990 to August 1992. This study was based on the regular measurement

* Corresponding author. Tel.: +351 234 370 357.
E-mail address: csena@ua.pt (C. Sena).

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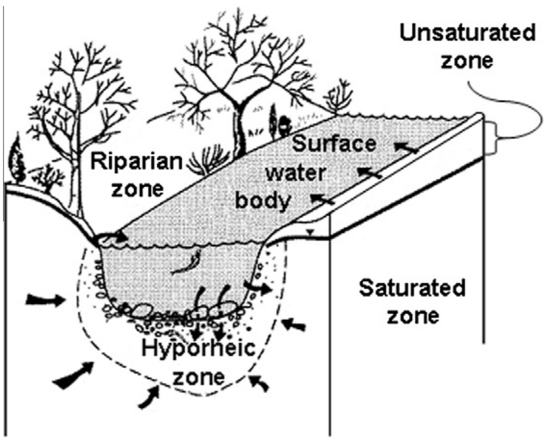

Fig. 1. Sketch of the hyporheic and riparian zones delineating a surface water body. Arrows indicate water flow directions (modified from Sophocleous, 2002).

of hydrometeorological parameters throughout the studied period, continuous monitoring of stream stage at the catchment outflow and at the outflow and inflow of each conifer swamp. Instantaneous stream discharge was also measured on an event basis. In addition, groundwater wells and piezometers were installed along longitudinal and transverse transects in the swamps in order to monitor water table elevation at least once a month. Water table elevation was also measured continuously at selected sites. Devito et al. (1996) concluded that morphology and shallow subsurface geology exert a great control on the hydrology of valley bottom swamps influenced by local aquifers. Hunt et al. (2006) developed measurements of groundwater–surface water exchange in three wetland stream sites which were related to patterns of benthic productivity. At each site, hydrologic instrumentation collected stream stage and temperature, water table elevation in the streambank, groundwater elevation from below the streambed, shallow groundwater temperature below the streambed, and groundwater specific conductance from a monitoring well below the streambed. Biological sampling of macroinvertebrate and periphyton was performed on the streambed. The results attained by Hunt et al. (2006) suggest that groundwater–surface water interactions can strongly influence benthic productivity. Langhoff et al. (2006) studied groundwater seepage to an alluvial stream and two tributary streams at nine field sites using hydrological, geophysical, and geomorphological observations. These authors concluded that in 40% of the studied sites more than 50% of groundwater seepage to the stream occurs through the streambed, while the remaining seepage occurs as a nearly superficial flow from diffuse discharge areas or as a combination of both processes. Turner and Townley (2006) assessed groundwater flow-through regimes of wetlands from numerical analysis of stable isotope and chloride tracer distribution patterns. Field data from the case studies plotted on appropriately configured transition diagrams demonstrated the overall validity of the modelling approach. These authors concluded that isotopic and hydrogeochemical data are invaluable in interpreting the interaction between lakes and wetlands with regional aquifers.

Studies focusing on groundwater–surface water interactions reflect the need for an effective integrated management of water resources based on a comprehensive understanding of the interactions between groundwater and surface water bodies and their implications for the sustainability of wetlands. The study developed by Devito et al. (1996) proves that a detailed hydrometeorological monitoring and the construction of selected transects of the studied systems throughout two hydrological years provide a solid basis for assessing hydrodynamic groundwater–surface water interactions. On the other hand, the study developed by Hunt et al. (2006) presents the additional data related to the biological sampling of the streambed. By developing this methodology, Hunt et al. (2006) were able to evaluate the influence of groundwater–surface water interactions on benthic productivity. By using hydrological, geophysical, and geomorphological observations, Langhoff et al. (2006) were able to assess the detailed processes of water transfer from groundwater bodies to alluvial streams. By developing numerical models of flow regimes near shallow lakes and wetlands that account for the mass balance of water, solute and stable isotope, Turner and Townley (2006) were able to assess the interaction between lakes or wetlands and regional aquifers in terms of information value versus the cost of its acquisition.

In the present work, the hydrodynamic and biogeochemical interactions between Pateira de Fermentelos lagoon, its affluent streams and surrounding aquifers are identified and described for the first time. The methodology followed in this study is based on the monthly monitoring of water levels and hydrogeochemical data in Pateira de Fermentelos region. Water budget of the lagoon and its main affluent, the Cértima River, was carried out by developing a lumped parameter model with the code Visual Balan v.2.0 (Samper et al., 2005). Based on the outputs of the lumped parameter model and on the results of the hydrochemical monitoring of water bodies, mass balance calculations were performed to identify the main mass sources and sinks.

The present study was developed with limited resources, mainly based on the monitoring of pre-existing points during one hydrological year. A scientific computer programme (Visual Balan v.2.0) was used to calculate the daily water budget of the main stream that feeds the Pateira de Fermentelos lagoon. Finally, and taking into account the major anthropogenic pressures that are nowadays stressing this region, namely cattle raising, agriculture and electroplating industry, the natural attenuation capacity of the lagoon and related wetlands was quantitatively assessed.

Pateira de Fermentelos is a shallow freshwater lagoon which hosts important aquatic and terrestrial ecosystems and has well developed riparian and hyporheic zones. It is the largest natural freshwater lagoon of the Iberian Peninsula. Due to the seasonal occupation by several migrating wild birds, Pateira de Fermentelos is included in a Special Protection Area (SPA) under the European Union Directive on the Conservation of Wild Birds (Law-Decree 140/1999). On the other hand, the intense agricultural activity, inefficient urban and cattle wastewater treatment are leading to the eutrophication of the lagoon, and therefore, threatening the sustainability of the dependent ecosystems (Teles et al., 2007). For this reason and taking into account the implementation of the Directive 91/271/CEE (European Commission, 1991), the Pateira de Fermentelos lagoon and corresponding catchment are included in the list of the Portuguese Sensitive Areas with respect to nutrient loads.

2. Hydrogeological setting and soil occupancy

Pateira de Fermentelos is a natural shallow lagoon (with an average depth between 0.8 and 2 m), located in the NE of Portugal (40°29′N, 8°36′W), at a distance of 20 km from the Atlantic coast (Fig. 2). The lagoon is the downstream part of the Cértima River and is located immediately upstream the confluence between the Cértima River and the Águeda River. In terms of regional hydrology, the study area is located in the lower Vouga basin (Fig. 2).

The Pateira de Fermentelos lagoon lies on a topographically lowland area of the Cértima River catchment. However, in terms of regional hydrogeology, the area surrounding the Pateira de Fermentelos lagoon is part of the recharge area of the Aveiro Cretaceous Groundwater Body (ACGWB). On the west bank of the