# THE SEASONAL QUANTIFICATION OF GROUNDWATER FLUX INTO THE VENICE LAGOON, ITALY: MASS BALANCE OF RADIUM ISOTOPES AND HYDRODYNAMIC MODEL

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## Abstract

An integrated approach, combining the directly measured individual radium contributions and hydrodynamic model results, allowed for the calculation of the mass balance of naturally occurring short-lived Ra isotopes ($^{223,224}$Ra) in the Venice Lagoon. Hydrodynamic data allows for the calculation of the Ra mass balance in sub-areas of the Venice Lagoon, which are characterized by physically homogeneous properties, instead of the entire lagoon. Both the seasonal and spatial variability of the submarine groundwater discharge (SGD) in the Venice Lagoon were investigated. SGD estimates were correlated with the residence time calculation to better understand spatial and seasonal variation.

*Keywords: Circulation Models, Hydrology, Lagoons, Water Transport*

**Introduction - Methods**

Submarine groundwater discharge (SGD) has gained increasing attention, both from the scientific community and coastal resource managers over the last decade [1]. Previous investigations showed that SGD plays an important role in the physical and biological properties of the Venice Lagoon ecosystem [2, 3]. In this study we extended the investigation of SGD to the whole lagoon, through the use of Ra measurements and hydrodynamic modelling. The mass balance for Ra can be expressed by the equation:

$$L_{out} + L_{decay} = L_{in} + L_{river} + L_{diff} + L_{marsh} + L_{desorp} + L_{SGD} \quad (1)$$

which considers the different Ra sources and sinks from the lagoon: water exchanges at the inlets ($L_{in}$, $L_{out}$), river discharge ($L_{river}$), desorption from sediments ($L_{desorp}$), diffusion from sediments ($L_{diff}$), percolation of porewater from marshes ($L_{marsh}$), and SGD ($L_{SGD}$). Each of these contributions were calculated by using the experimental data obtained from an extensive field and lab campaign (APAT research project "Afflusso di Acque Sotterranee in Laguna di Venezia", 2005-2008) and the application of a hydrodynamical model (SHYFEM), as described by Ferrarin et al. [4]. The lagoon was divided into 4 sub-basins with similar physical characteristics to better characterize SGD using the $^{223,224}$Ra mass balance and to allow a more precise estimate of the fluxes from the different sub-basins and through the inlets which connect the lagoon to the Adriatic Sea. Integrating the results of the hydrodynamic model and the point measurements of Ra enabled the calculation of the different sources of Ra for each sub-basin in every season and the volume of the flux associated with SGD. The Ra mass balance calculation utilizes the hydrodynamic information and was effective for both $^{223}$Ra and $^{224}$Ra. In addition, the application of the hydrodynamic model and a transport model allowed for the calculation of the residence time in each sub-basin per season.

**Results**

Surface distribution of $^{223,224}$Ra showed significant seasonal variation during the six surveys, however, in general, the spatial pattern of distribution within the lagoon was similar with higher activities in the northern and southern sub-basins. In all seasons activities were elevated in the lagoon as compared to river and open Adriatic Sea waters. $^{224}$Ra activities were much lower, throughout the lagoon, during the winters of 2007 and 2008 (avg. 43±21 and 55±27 dpm 100 $L^{-1}$ respectively) than during the falls of 2006 and 2007 (avg. 75±52 and 90±33 dpm 100 $L^{-1}$ respectively), the spring of 2007 (avg. 108±41 dpm 100 $L^{-1}$), and the summer of 2007 (avg.108±65 dpm 100 $L^{-1}$). $^{223}$Ra activities were lower in the winters of 2007 and 2008 (avg. 2.8±1.4 and 3.2±1.6 dpm 100 $L^{-1}$ respectively) than in the falls of 2006 and 2007 (avg. 4.9±2.8 and 6.4±3.1 dpm 100 $L^{-1}$ respectively), the spring of 2007 (avg. 6.3±3.3 dpm 100 $L^{-1}$) and the summer of 2007 (avg. 5.4±3.6 dpm 100 $L^{-1}$). The activities of $^{223}$Ra in lagoon waters show a similar pattern. Average $^{233,224}$Ra activities for the whole lagoon in all seasons are 4.8±3.5 and 79.1±43.6 dpm 100 $L^{-1}$. The results of the hydrodynamic model show that the residence time of the lagoon has an average value of 7.7±4.6 days and has a marked seasonal variation. The average and standard deviation of the water residence times in the four sub-basins are 8.8±3.6 and 4.9±2.8 days for the two northern sub-basins, 8.3±4.8 and 5.9±3.1 for the central sub-basin and southern sub-basin. More than half of the total Ra entering the lagoon cannot be accounted for by the inputs detailed above and the significant excess of short-lived Ra observed in the Venice Lagoon can, reasonably, be attributed to submarine groundwater discharge. The calculated total input of groundwater into the Venice Lagoon is 43±25 and 40±17×109 L $d^{-1}$ using the $^{223}$Ra and $^{224}$Ra mass balance respectively. Remarkably, both $^{223}$Ra and $^{224}$Ra suggest that SGD accounts for 6% by volume of all water flux into the lagoon. Fig. 1 shows the pattern of clear seasonality in the Venice Lagoon. The discharge calculated by both short-lived isotopes is lowest in winter, and higher in spring, summer, and fall. Some divergence occurs between the isotopes in the spring and summer of 2007 which is likely a function of residence time. It is possible that the same forces that determine residence time also drive a re-circulation of seawater through the sediment as there is a strong inverse correlation between residence time calculated using a hydrodynamic model and SGD as calculated by the Ra mass balance method (R2 values are 0.85 and 0.66 for $^{223,224}$Ra respectively.

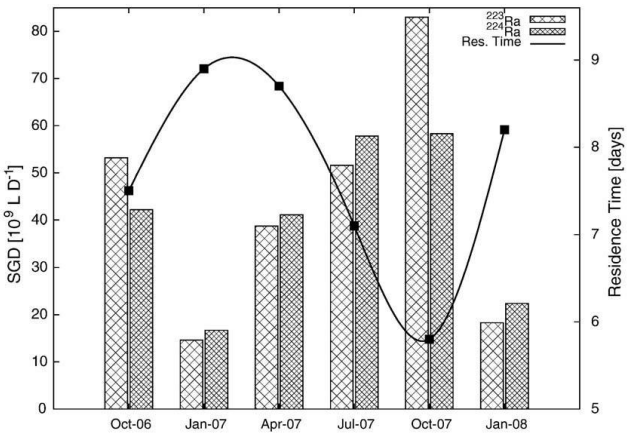


Fig. 1. Seasonal SGD (223Ra and 224Ra) and residence time (dashed line) variation in the Venice Lagoon

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