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Ra and Rn isotopes as natural tracers of submarine groundwater discharge in Tampa Bay, Florida

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Abstract

A suite of naturally occurring radionuclides in the U/Th decay series (^{222}Rn, ^{223,224,226,228}Ra) were studied during wet and dry conditions in Tampa Bay, Florida, to evaluate their utility as groundwater discharge tracers, both within the bay proper and within the Alafia River/estuary — a prominent free-flowing river that empties into the bay. In Tampa Bay, almost 30% of the combined riverine inputs still remain ungauged. Consequently, groundwater/surface water (hyporheic) exchange in the discharging coastal rivers, as well as submarine groundwater discharge (SGD) within the bay, are still unresolved components of this system's water and material budgets.

Based on known inputs and sinks, there exists an excess of ^{226}Ra in the water column of Tampa Bay, which can be evaluated in terms of a submarine groundwater contribution to the bay proper. Submarine groundwater discharge rates calculated using a mass balance of excess ^{226}Ra ranged from 2.2 to 14.5 L m^{-2} day^{-1}, depending on whether the estuarine residence time was calculated using ^{224}Ra/xs^{228}Ra isotope ratios, or whether a long term, averaged model-derived estuarine residence time was used. When extrapolated to the total shoreline length of the bay, such SGD rates ranged from 1.6 to 10.3 m^3 m^{-1} day^{-1}. Activities of ^{222}Rn were also elevated in surface water and shallow groundwater of the bay, as well as in the Alafia River estuary, where upstream activities as high as 250 dpm L^{-1} indicate enhanced groundwater/surface water exchange, facilitated by an active spring vent. From average nutrient concentrations of 39 shallow, brackish, groundwater samples, rates of nutrient loading into Tampa Bay by SGD rates were estimated, and these ranged from 0.2 to 1.4×10^5 mol day^{-1} (PO_4^{3-}), 0.9–6.2×10^5 mol day^{-1} (SiO_4^-), 0.7–5.0×10^5 mol day^{-1} (dissolved organic nitrogen, DON), and 0.2–1.4×10^6 mol day^{-1} (total dissolved nitrogen, TDN). Such nutrient loading estimates, when compared to average river discharge estimates (e.g., TDN $= 6.9 \times 10^5$ mol day^{-1}), suggest that SGD-derived nutrient fluxes to Tampa Bay are indeed important components to the overall nutrient economy of these coastal waters.

Keywords: Tampa Bay; Submarine groundwater discharge; Radium; Radon; Nutrient loading estimates; Estuary; Coastal waters

1. Introduction

Submarine groundwater discharge (SGD) into coastal waters historically has been overlooked in the development of nearshore material and water budgets. This omission stems in part from the inherent complexities in identifying and quantifying such SGD rates, which most often are diffuse. Recent studies, however, highlight the importance of SGD as an important potential vector for nutrient and trace element transport to coastal waters (Bokuniewicz, 1980; Johannes, 1980; Harvey and Odum, 1990; Oberdorfer et al., 1990; Valiela et al.,

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1990; Moore, 1996, 1997, 1999; Corbett et al., 1999; Li et al., 1999; Charette et al., 2001; Swarzenski et al., 2001, 2004a; Burnett et al., 1990, 2001, 2002, 2003; Slomp and van Cappellen, 2004). The relative impact of SGD to a particular coastal water body has a clear geologic control that is defined by the underlying strata, as a complex matrix for material transport, as well as a source for SGD-derived constituents and tracers. Karstic terrain and paleo-river channels are just two examples where SGD rates are likely enhanced (Swarzenski and Kindinger, 2003). SGD is also controlled by local and climatic hydrologic constraints. For example, the hydraulic gradient or aquifer pressure may influence the transport and mixing of coastal groundwater into seawater. The complex relations between climate cycles and off-continent material flux, including SGD, remain mostly unknown. Due to their implicit riverine contribution of both water and terrigenous material, estuaries may not be the most ideal receiving environments in which to evaluate the role of SGD. Instead, coastal bays and waters without direct influence from rivers may carry a more distinct SGD signature. Being able to adequately characterize the nature of the underlying sediments or bedrock, both as a continuous source for U/Th series SGD tracers, as well as to define particular hydraulic conductivities or transmissivities in a coastal environment, are essential to comprehensively evaluate the role of SGD in coastal systems.

Methods that have proven useful in the identification of SGD sites and subsequent quantification have developed along four, often coincident, themes: (i) geochemical tracers, (ii) geophysical techniques, (iii) numerical modeling, and (iv) actual physical measurements of fluid exchange across the sediment/water interface. The suite of geochemical tracers that are employed to identify and quantify SGD include: Cl^- (Martin et al., 2004), temperature (Taniguchi, 2000; Taniguchi et al., 2003), four naturally occurring Ra isotopes (Moore et al., 2002; Crotwell and Moore, 2003; Charette et al., 2001; Swarzenski et al., 2001), ^{222}Rn (Cable et al., 1996, 1997, 2004; Hussain et al., 1999; Burnett and Dulaiova, 2003; Lambert and Burnett, 2003), and CH_4 (Corbett et al., 1999, 2000). Recent developments in the acquisition of continuous or time-series resistivity data (Manheim et al., 2004; Swarzenski et al., 2004a) in coastal sediments can yield powerful information on the dynamic position and movement of the fresh water/saltwater interface down to depths in excess of 10's m. Such data can provide large scale information to complement the more traditional geochemical approaches that tend to examine, for example, the pore water or sediment geochemistry to depths <100 cm. Conventional seepage meters (Lee, 1977) have historically provided actual physical measurements of fluid exchange across the sediment/water interface, but some reports have recently challenged the validity or consistency in such data (Taniguchi and Fukuo, 1993; Cable et al., 1997). Regardless, second-generation seepage meters that rely either on electromagnetic, heat-flow, or ultrasound principles to acquire high-resolution, autonomous, bi-directional seepage rates may provide useful SGD information (Taniguchi and Fukuo, 1993; Lambert and Burnett, 2003; Sholkovitz et al., 2003; Rosenberry and Morin, 2004; Swarzenski et al., 2004b, 2006).

In this study, we investigate the distribution of a suite of naturally occurring U/Th-series isotopes (^{222}Rn, ^{223,224,228,226}Ra) collected in the water column and shallow groundwater of Tampa Bay, Florida, as proxies of submarine groundwater discharge, as well as hyporheic exchange within one prominent tributary. By developing a Ra mass balance, a bay-wide estimate of submarine groundwater discharge is used to calculate SGD-derived nutrient fluxes into the bay. Such SGD-derived nutrient flux estimates are then compared to local riverine nutrient loading estimates.

2. Physiographic setting

The climate of west-central Florida is subtropical humid, and characterized by long, hot, and relatively wet summers. A long-term (1948–2005) annual precipitation rate measured at St. Petersburg is 1332 mm (http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?fl7886) and is distributed unevenly throughout the year; roughly 60% falls during June–September. Annual evapotranspiration rates in west-central Florida ranged from about 970–1060 mm, depending on the composition of the native vegetation (Bidlake et al., 1995), and are expected to be lower over urban areas and the bay.

There are four major geologic sequences that define the local hydrogeology: (i) surficial sand deposits, (ii) highly heterogeneous carbonate and clastic sections of interbedded limestone, dolomite, sand, clay, and marl, (iii) a carbonate section of limestone and dolomite, and (iv) carbonate rocks consisting of intergranular gypsum and anhydrite (Hutchinson, 1983). The sediments of Tampa Bay were first studied systematically by Goodell and Gorsline (1961), who concluded that the bay sediments consist mostly of eroded quartz sands from Pleistocene-aged deposits and shell fragment-derived carbonates. Interspersed in this matrix are clays and silts eroded from the U-rich Miocene phosphatic deposits