Novel geophysical and geochemical techniques used to study submarine groundwater discharge in Biscayne Bay, Florida

INTRODUCTION

Submarine groundwater discharge (SGD) is a problem of major proportions on a world-wide scale. The ubiquitous nature of SGD along varied coastlines and its importance to coastal water and geochemical budgets have recently been thrust into the global spotlight [(Moore, 1996, and colleagues (cf. Burnett et al., 2003, and references therein)]. For example, the discharge of nutrient-enriched groundwater into coastal waters may cause nutrient imbalances that can lead to eutrophication (Bokuniewicz, 1980; Giblin and Gaines, 1990) or near-shore micro-organism blooms (Valiela and D'Elia, 1990; Laroche et al., 1997). Similarly, SGD can also directly affect threatened coastal freshwater resources and impact fragile coastal ecosystems, such as coral reefs.

Recently, much effort has been devoted to developing and adapting new tracer techniques and methods for the identification and quantification of SGD. As the discharge of coastal groundwater most often occurs as diffuse seepage rather than through a single vent feature (Swarzenski et al., 2001), assessing SGD has remained difficult for both oceanographers and hydrologists alike. Burnett and colleagues have developed a systematic approach to investigate SGD by using a combination of both physical seepage measurements and a suite of naturally occurring isotopic tracers in the U/Th decay chain – ^{222}Rn and ^{223,224,226,228}Ra. Manheim et al. (2002) further extended SGD investigations by adapting geophysical resistivity techniques to examine fine-scale change in conductivity fields within coastal sediments. Such streaming resistivity profiling has been successfully applied to identify sites of SGD (Belaval et al., 2003), as well as the dynamic position of the fresh water/saltwater interface.

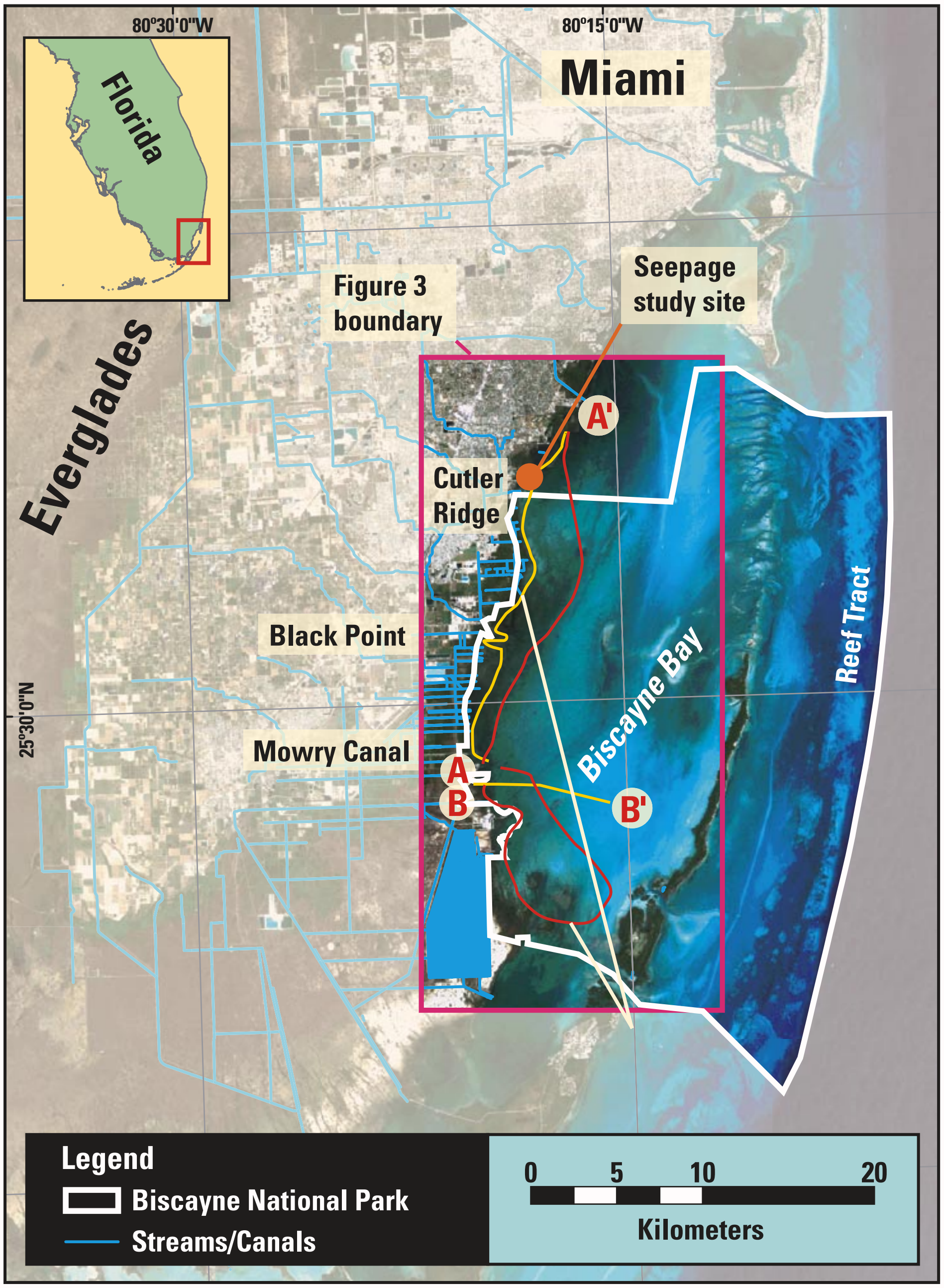

Figure 1. Landsat TM image of south Florida showing Biscayne Bay and Miami. Water-column ^{222}Rn and streaming resistivity survey track lines (A-A' and B-B') as well as the electromagnetic seepage meter site (●) at Cutler Ridge are identified.

In this paper, we report on the use of streaming resistivity profiling, continuous water-column ^{222}Rn mapping, and the deployment of electromagnetic seepage meters to identify and quantify submarine groundwater dis-

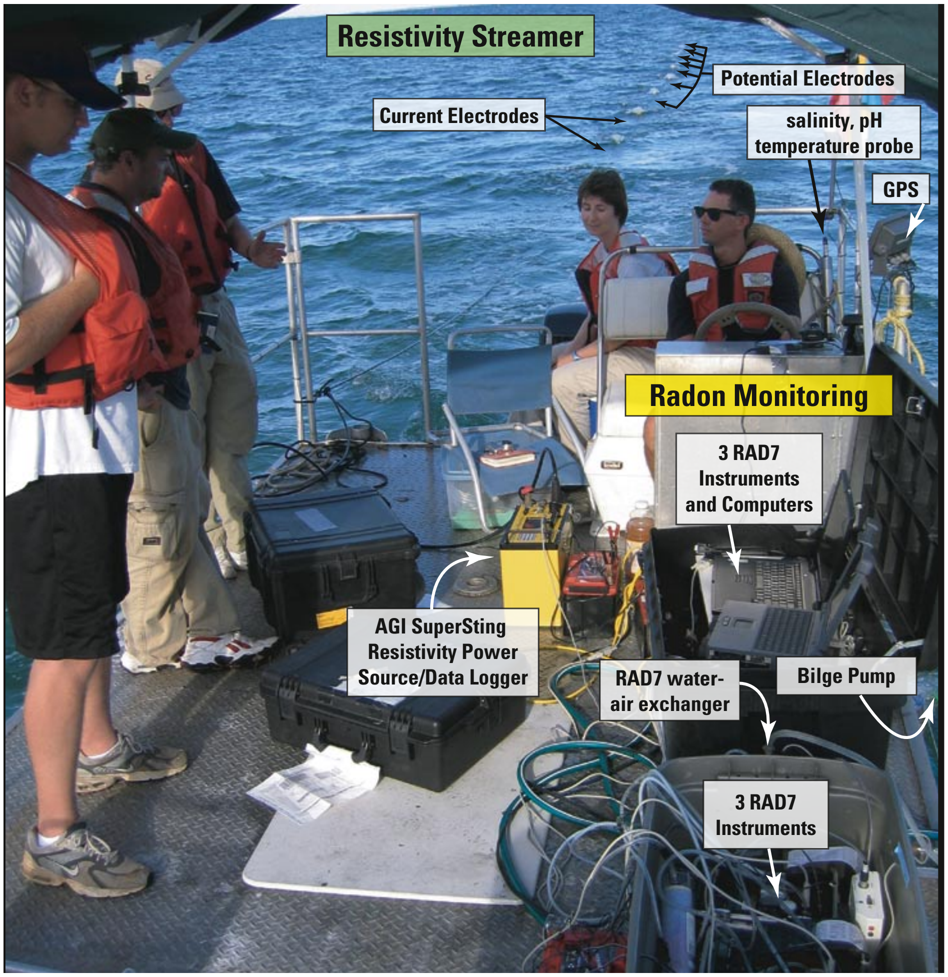

Figure 2. Operational configuration of the continuous ^{222}Rn and streaming resistivity equipment deployed on a 25-ft-long pontoon boat.

charge at select sites in Biscayne Bay, FL. Such data support and validate variable-density modeling results, and provide insight into the mechanisms and scales of SGD in Biscayne Bay.

BISCAYNE BAY

Biscayne Bay is an estuarine lagoon that is ~ 61 km long and 18 km wide, located just south of the Miami-Dade County metropolitan area (Figure 1). Several rivers and canals on the western shore discharge surface water into the bay. On the seaward side of Biscayne Bay, coral reef structures make up the northern extent of the Florida reef tract. Most regions of the bay have been variably impacted by agricultural, municipal, and industrial activities. For almost 100 years, the natural hydrogeologic regime adjacent to the bay has been altered through an extensive network of dredged waterways and drainage canals (Parker, 1955). Numerous retention ponds and lakes store water and modulate surface runoff. Infiltration of organic and inorganic pollutants into the groundwater from such storage sites is likely enhanced by the highly porous and transmissive Biscayne Aquifer limestone. Submarine groundwater discharge into the bay has been prominently observed (Kohout, 1960) and more recently modeled (Langevin, 2001, 2003). Noted declines in adjacent offshore coral reef health and overall ecological stress may be linked to alterations to the groundwater and surface water flow paths, groundwater and surface water pollution, or other large-scale factors such as sea-level fluctuations.

A ~75 km survey of Biscayne Bay (Figure 2) for surface water ^{222}Rn activities and streaming resistivity profiling was conducted during June 7-9, 2004. Simultaneous GPS positions, depth soundings, salinity, and temperature were obtained using a Lowrance echo sounder and an In Situ profiler, respectively.

RADON-222

Radon-222, an inert gas produced by the decay of ^{226}Ra in sediments, is typically present in groundwater at much greater activities than in surface waters. Its short half-life of 3.8

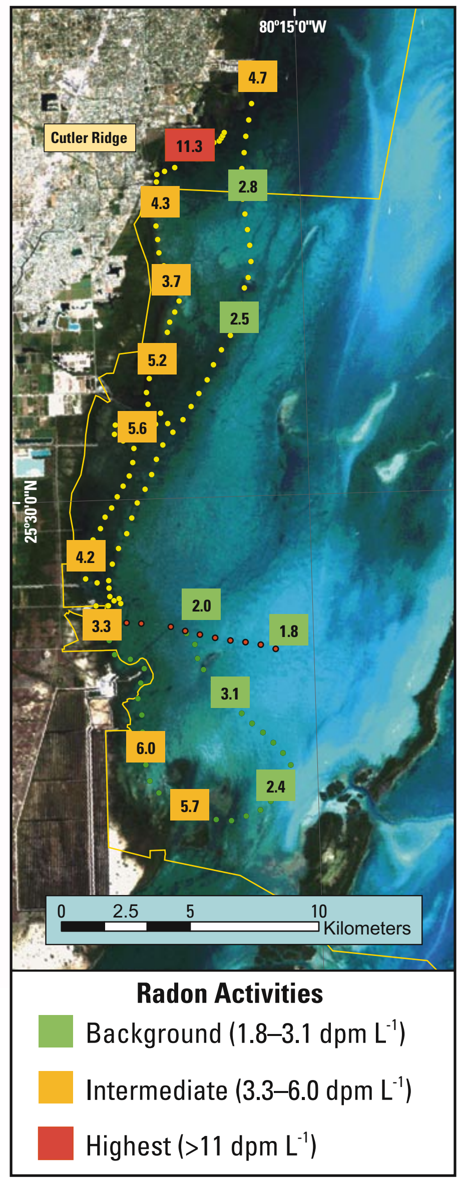

Figure 3. Continuous water-column ^{222}Rn ($t_{1/2}$ = 3.8 d) activities as a tracer for identifying sites of enhanced submarine groundwater discharge. Note elevated activities (~ 11 dpm L^{-1}) at Cutler Ridge relative to mid-bay background activities (~ 2-3 dpm L^{-1}).

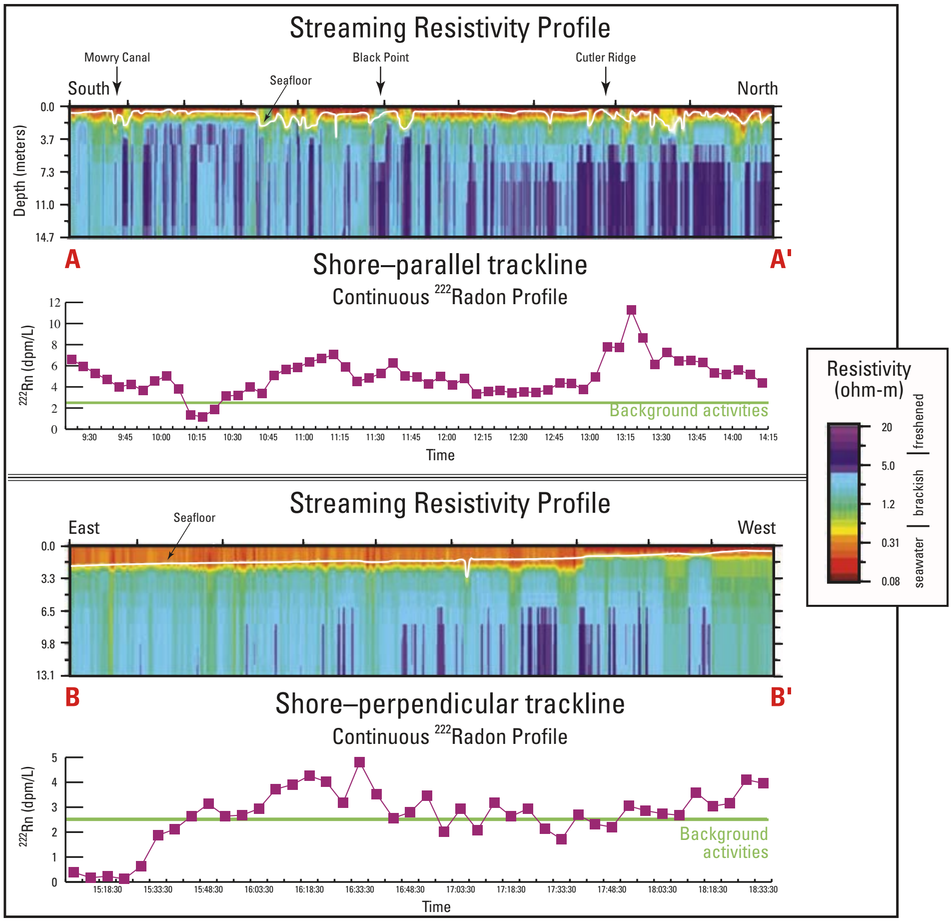

Figure 4. A comparison of two modeled streaming resistivity profiles (top) and simultaneous water-column ^{222}Rn activities from transects A – A′ and B – B′ (see Figure 1) in Biscayne Bay. Darker hues in the streaming resistivity interpretation correspond to freshened subsurface water masses (i.e., at Cutler Ridge).

days and its conservative geochemical nature make this isotope ideal to study exchange processes across the sediment/water interface over daily to weekly timescales. Burnett et al. (2001) modified a commercially available continuous radon-in-air monitoring system to accurately measure excess ^{222}Rn activities in coastal surface waters. To obtain near-continuous (~5 min. data updates) water-column ^{222}Rn activities in Biscayne Bay, we utilized six RAD7 (Durridge, Co., Inc.) systems fed simultaneously from one air-water exchanger, where the ^{222}Rn present in water is allowed to equilibrate with the Rn in air. By applying a temperature and solubility coefficient correction, one can calculate the activity of ^{222}Rn in water, as the Rn in air will equilibrate with the seawater flowing through the exchanger.

Results from the near-continuous ^{222}Rn survey (Figure 3) show greatest activities (> 11 dpm L^{-1}) at Cutler Ridge, a site where F. Kohout worked on freshwater/saltwater dynamics (Kohout, 1960). Such elevated ^{222}Rn activities can easily be discerned from background Biscayne Bay surface-water Rn activities (~2-3 dpm L^{-1}).

STREAMING RESISTIVITY PROFILING

A SuperSting Marine Logging System (AGI, Inc.,) was used for the streaming resistivity profiling measurements in Biscayne Bay. This system consists of a 50-m cable and an eight-channel resistivity receiver. The streaming resistivity cable contains two current electrodes and nine potential electrodes, and is towed across the water's surface at a speed of ~3 knots. Operating in continuous mode, the receiver injects current in the first two electrodes and then measures eight voltage potentials in the trailing electrode pairs. Streaming resistivity data were collected once every ~3 sec. Post-processing of the resistivity data involves several inverse modeling iterations.

In addition, continuous surface salinity, pH, temperature, and depth soundings were recorded to support post-processing of the resistivity data. Interpretations of the streaming resistivity data confirm enhanced freshened subsurface water masses at sites of increased ^{222}Rn activities (Figure 4).

ELECTROMAGNETIC SEEPAGE METER DEPLOYMENTS

The USGS has been developing and utilizing electromagnetic (EM) seepage meters to study groundwater/surface exchange (Rosenberry and Morin, 2004) and submarine groundwater discharge into coastal waters (Swarzenski et al., 2004). Such EM seepage meters were deployed at a site by Cutler Ridge in Biscayne Bay during March 2004. Electromagnetic seepage-rate data collected at this site show distinct and continuous discharge of groundwater. The rate of exchange across the sediment/water interface ranged from 10 to 50 cm day^{-1}, with an average of 23.2 cm day^{-1} (Figure 5). It appears that tidal forcing at least partially controls the pattern of submarine groundwater discharge. These data were collected during the south Florida dry season and therefore such seepage rates would most likely increase during periods of higher rainfall (July-November). The average seepage rate (23.2 cm day^{-1}) observed in this study corresponds very closely to modeled fluxes of groundwater into the bay (Langevin, 2001, 2003).

SUMMARY

Near-continuous excess ^{222}Rn measurements in the surface waters of Biscayne Bay show some striking anomalies that suggest enhanced submarine groundwater discharge

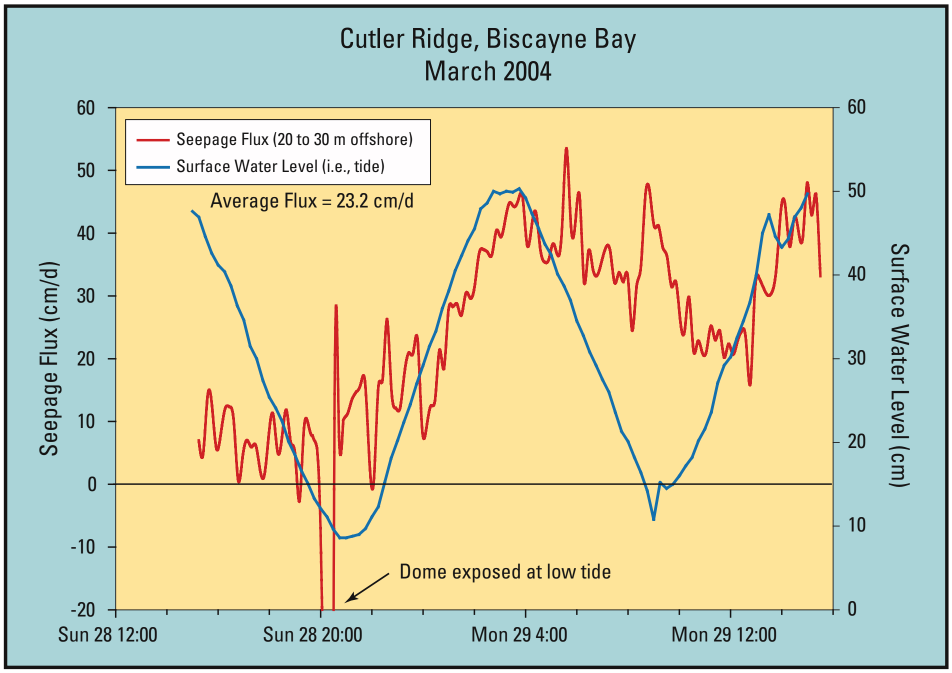

Figure 5. Ten-minute time-averaged electromagnetic (EM) seepage-meter results from Cutler Ridge site (see Figure 1). The EM seepage meter was likely exposed to air during a low-tide event at ~8:00 pm.

at discrete sites within the bay. Interestingly, at Cutler Ridge – the well-known site of Kohout's work on freshwater/saltwater dynamics – water-column ^{222}Rn activities are highest and indicate the most active submarine groundwater discharge. This is also supported by the streaming resistivity profiling data, which indicate greater freshened water masses in this region. Such data confirm the utility of these two techniques in identifying sites of SGD and provide direct evidence in support of ongoing modeling efforts on freshwater/saltwater interface processes in Biscayne Bay. The electromagnetic seepage-meter data provide the first continuous record of exchange rates across the sediment/water interface at Cutler Ridge and similarly support recent modeling predictions.

The use of trade, firm and brand names is for identification purposes only and does not constitute endorsement by the U.S. Government.

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