An autonomous, electromagnetic seepage meter to study coastal groundwater/surface-water exchange

PW Swarzenski[1], M Charette[2] and C Langevin[3]
[1]USGS – St Petersburg, FL
[2] WHOI – Woods Hole, MA
[3]USGS – Miami, FL

INTRODUCTION

The bi-directional exchange of groundwater with coastal surface waters may influence not only coastal-water and geochemical budgets, but may also impact and direct coastal ecosystem change (D'Elia, et al., 1981; Valiela, et al., 1990; Burnett et al., 2003). For example, the widespread discharge of nutrient-enriched submarine groundwater into an estuary or lagoon may contribute directly to the onset and duration of eutrophication (Bokuniewicz, 1980; Giblin and Gaines, 1990), as well as the development of harmful algal/bacterial blooms (Laroche et al., 1997). Most often, this submarine groundwater discharge (SGD) (defined here as a composite of meteoric, connate and sea water) occurs as hard-to-constrain diffuse seepage (Figure 1), rather than as focused discharge either through vent or collapse features (Swarzenski et al., 2001). As a result, quantifying SGD rates has remained difficult for both oceanographers and hydrologists alike. This report describes an adaptation of an old tool, the Lee-type manual seepage meter (Lee, 1977), with a state-of-the-art electromagnetic flow meter that enables rapid, autonomous, bi-directional measurements of fluid exchange rates across the sediment/water interface (Rosenberry and Morin, 2004). When such measurements are coupled and inter-

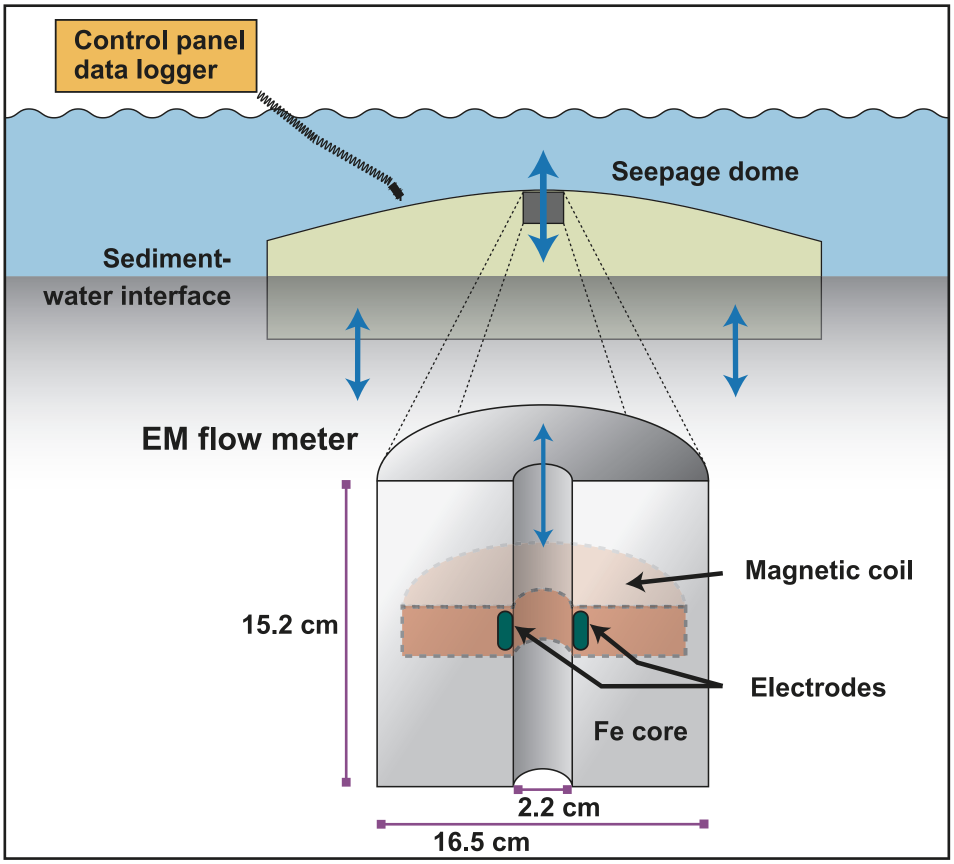

Figure 2: Illustration depicting the various components of an EM seepage meter.

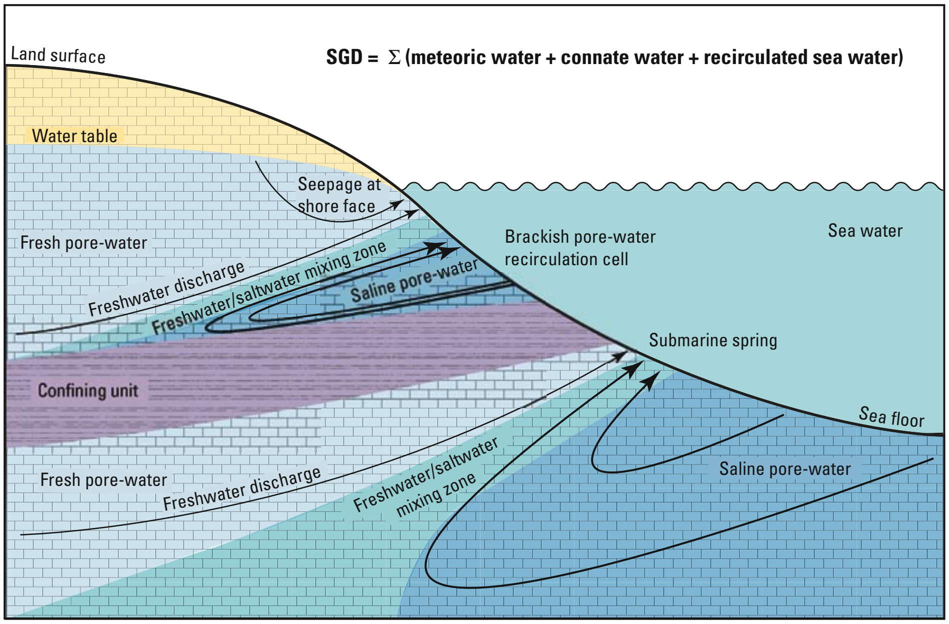

Figure 1: Idealized SGD-influenced freshwater/saltwater interface. Note that SGD may define a composite water mass that includes recirculated sea water, as well as meteoric and connate groundwater.

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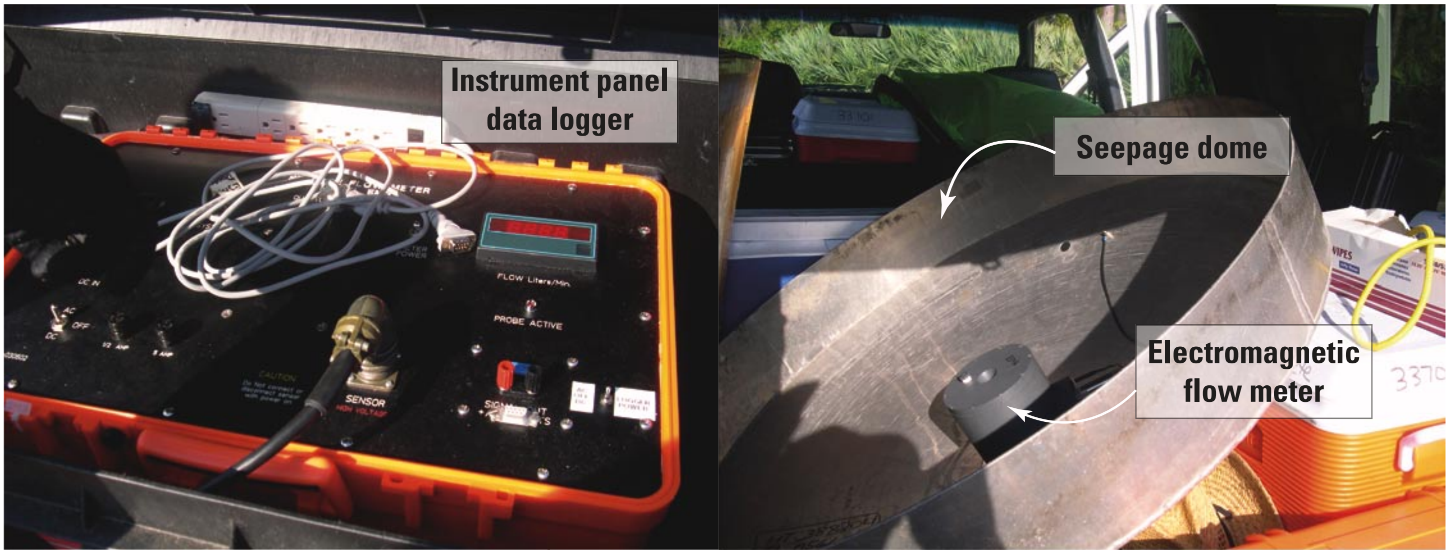

Figure 3: Photographs of the EM seepage meter and the instrument control panel.

preted with surface and groundwater pressure, salinity and temperature data, as well as other complementary measurements such as excess water-column ^{222}Rn activities, then realistic groundwater/surface-water exchange rates can be obtained in dynamic coastal environments (Swarzenski et al., 2004).

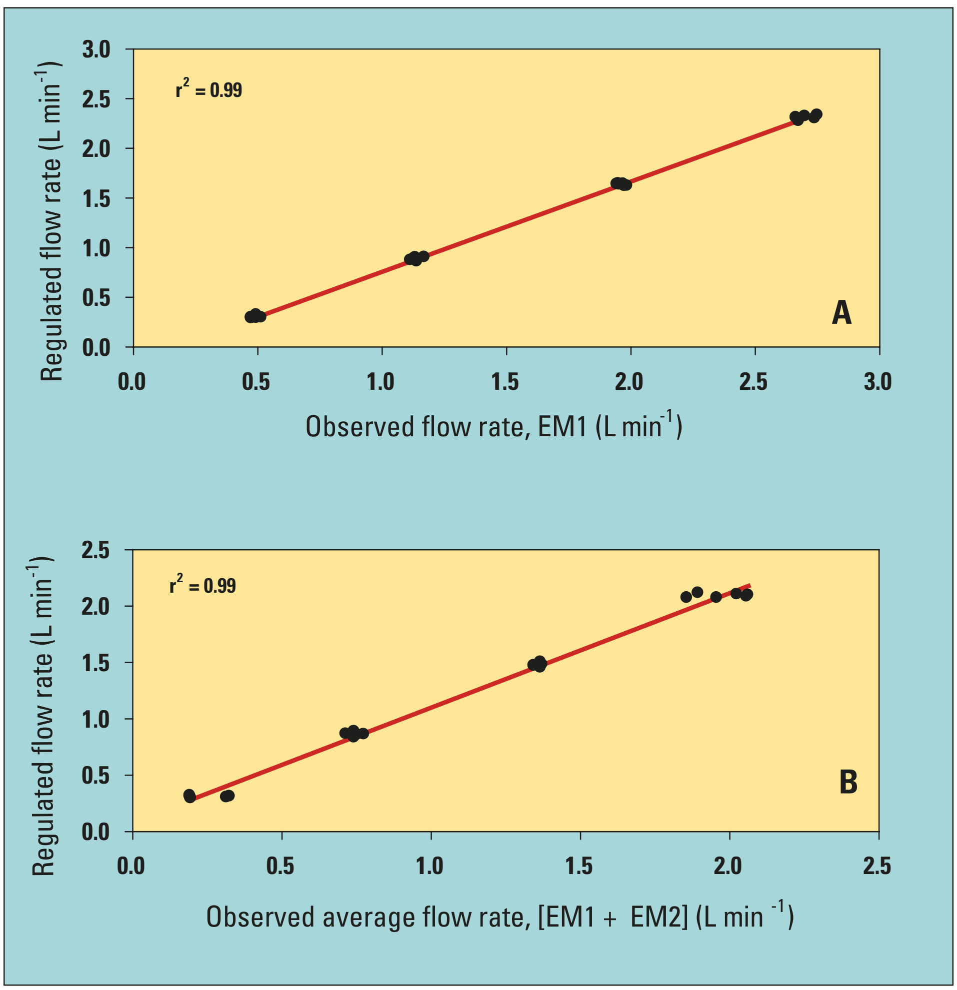

Figure 4: Results from two laboratory calibration tests, where flow rates are controlled using a high-volume peristaltic pump; A) seawater and meter EM1, B) fresh water and two EM meters, plumbed in series.

PRINCIPLES OF AN EM SEEPAGE METER

As illustrated in Figures 2 and 3, there are three principle components that describe our electromagnetic (EM) seepage meter: 1) the seepage dome, 2) the EM flow meter, and 3) the control panel. The aluminum seepage dome consists of a 100-cm x 20-cm dome, welded to a 25-cm cylinder. Attached to the inside center of the dome is the Quantum Engineering Corp. (Lourden Tennessee) EM flow meter that measures 16.5 x 15.2 cm and contains a 2.2-cm-diameter cylinder. This electromagnetic flow meter, which consists of a PVC cylinder surrounded by electromagnets and electrodes, measures the velocity of any fluid (fresh or salt water) as it moves through an electromagnetic field. According to Faraday's Law, a fluid that moves through this electromagnetic field will induce a voltage that is directly proportional to its velocity. The induced voltage is then measured by the adjacent electrodes. The control panel is connected to the EM flow meter with a 50-m cable and consists of a DC-AC power inverter, an LCD screen to display flow rates (L min^{-1}), and a programmable data logger that can be accessed with a computer. The EM seepage meter

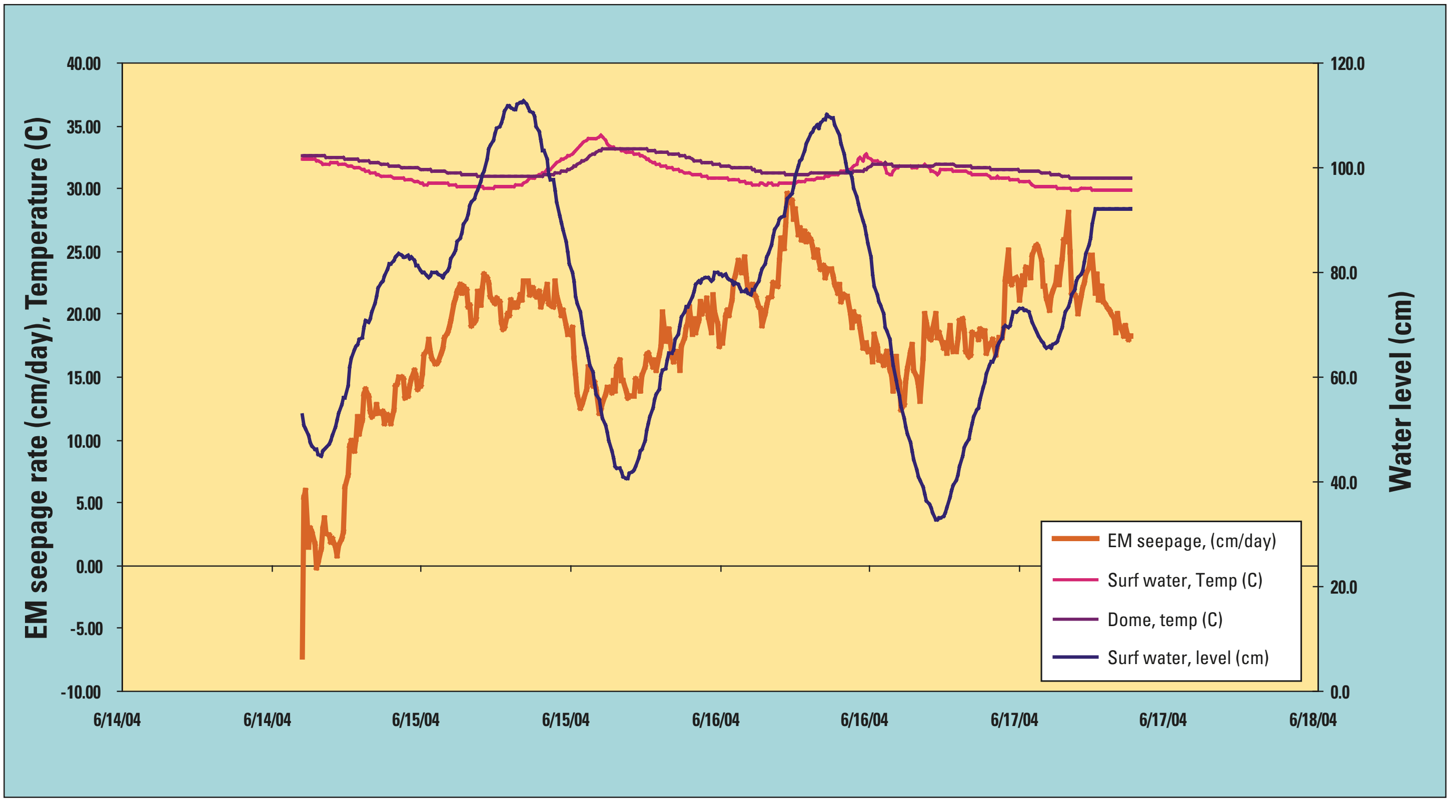

Figure 5: EM seepage meter results from a deployment in Sarasota Bay, Florida; June, 2004. Note that surface-water levels (cm) and temperature (°C) as well as dome water-column temperature are also shown. Seepage data (cm day^{-1}) represent a 10-min. averaged composite.

and data logger can be powered either with 12-v DC or 110-v AC. Typically, in 12-v DC mode, several large-capacity batteries connected in parallel to a 60- x 122-cm solar panel provide sufficient power for at least ~48 hours of continuous operation. Using AC, power is provided either by a small generator or, if possible, shore power. Under either power configuration, it is possible to collect continuous groundwater/surface-water exchange data over many days. To calculate a site-specific seepage rate, the electromagnetic flow rate is then simply multiplied by the area of the dome and displayed in cm day^{-1} or L m^{-2} day^{-1}.

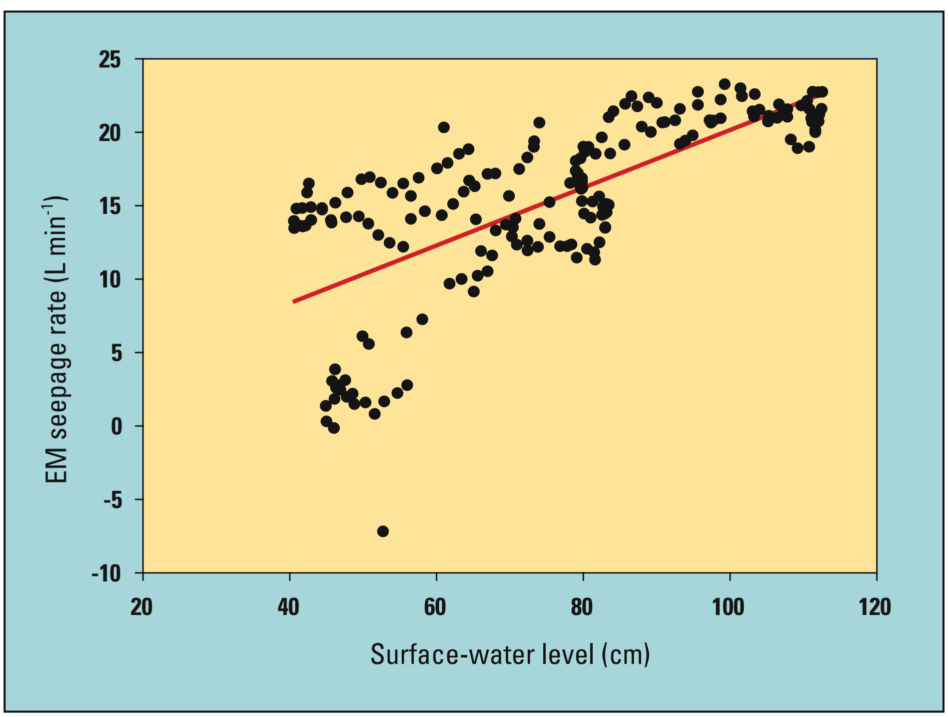

Figure 6: EM seepage rate as a function of surface water levels at one site in Sarasota Bay.

Distinct advantages of the EM seepage meter as a tool to study submarine groundwater discharge include *i)* lack of moving parts and thus less down time, *ii)* AC or DC power options, *iii)* ease of calibration prior to operation, *iv)* very rapid measurement of a wide range of groundwater/surface-water exchange rates that can span at least three orders of magnitude, and *v)* rapid sampling rate (typically one measurement per minute), well suited for dynamic coastal environments where tidal forcing, wind, and currents can complicate groundwater/surface-water exchange.

FIELD TESTING THE EM SEEPAGE METERS

Bench calibration studies

A series of calibration experiments was performed on the two EM flow meters (EM1, EM2) at the USGS-St. Petersburg office. A regulated and quantified flow rate (0 - 3 L min^{-1}) of both sea water and fresh water was recirculated through the EM1 and EM2 meters using a large-volume peristaltic pump, first individually and then plumbed serially. Figure 4 illustrates results from two of these experiments, using first (A) sea water and meter EM1, and then (B) fresh water and average flow rates obtained from both the EM1 + EM2 meters.

A USGS-WHOI intercalibration experiment in Everglades National Park, FL

To assess the utility of the EM seepage meters in environments with very low groundwater/surface-water exchange rates, we installed our EM seepage meters in highly organic bottom sediments of Bottle Creek, a distal reach of the Shark River Slough, Everglades National Park, Florida, in August and October, 2003. Directly adjacent to our EM seepage meter sites, we also installed a dye-dilution type seepage meter (Sholkovitz et al., 2003) that can autonomously record bi-directional rates of groundwater/surface-water exchange. During a 5-day intercalibration experiment, the EM and dilution seepage meters produced average exchange rates very close to one another, 2.3 cm day^{-1} and 2.4 cm day^{-1}, respectively. These encouraging results exemplify the potential of the EM seepage meter, even in challenging environments. Results from an instrumented shallow well proximal to our seepage meter site as well as from the dilution seepage meter suggest a gradual hydraulic response to our well/meter installation. In low-permeability sediments such as the peat deposits of Bottle Creek, one can expect that the lengthy equilibration time due to meter installation will compromise initial EM readings. In higher-permeability sediments, this initial equilibration time may be much lower, ~ 30 min. (Rosenberry and Morin, 2003).

Sarasota Bay, FL

To contrast the Bottle Creek site, we also deployed our EM seepage meter at one site in Sarasota Bay, Florida (June, 2004), where groundwater/surface-water exchange rates are expected to be much enhanced by physical and hydrogeologic characteristics unique to these coastal waters. At this site, during the seepage meter deployment, water levels fluctuated by about 80 cm (Figure 5) and correlated reasonably well ($R^2 = 0.49$; Figure 6) with 10-min. complied groundwater/surface-water exchange rates (average = 15.2 cm day^{-1}). A strong correlation between submarine groundwater discharge rates and surface-water levels implies that groundwater/surface-water exchange is controlled more by tidally and density-driven sea water recirculation, rather than by groundwater discharge. Our results thus suggest that submarine groundwater discharge at this site in Sarasota Bay is influenced by both physical and hydrogeological forces.

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For more information, please contact:

Peter Swarzenski
600 4th Street South
St. Petersburg, FL 33701
phone: 727-803-8747 x3072
fax: 727-803-2030
pswarzen@usgs.gov