Technical Notes and Comments


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Introduction

Seepage meters were initially introduced as a viable field measurement tool for estimating fluid discharge from canal sediments by Israelson and Reeve (1944). Lee (1977) improved this device and demonstrated its utility in lakes and coastal marine systems. Since 1977, seepage meters have been used in marshes, lagoons, bays, rivers, and lakes with varying degrees of success (e.g., Shaw and Prepas 1989; Belanger and Walker 1990; Shaw and Prepas 1990; Belanger and Montgomery 1992; Reay et al. 1992; Simmons 1992; Lébel and MacIntyre 1994; Cable et al. 1996, 1997a,b; Gallagher et al. 1996; Corbett et al. 1999; Martin et al. 2000; Chanton et al. 2003). Since Lee’s design—e.g., top or bottom section of a 55-gal drum with an open port placed near the rim to attach a plastic collection bag—researchers have sought to improve approaches for direct measurements of seepage discharge from sediments. Shaw and Prepas (1989) and Cable et al. (1997a) demonstrated the importance of pre-filling collection bags to prevent an anomalous influx of water associated with the mechanical properties of an empty bag attached to the meter. Automated meters have been designed that use heat-pulse (Taniguchi and Fuku 1993; Krupa et al. 1998) and acoustic Doppler technologies (Paulsen et al. 2001) to improve measurement accuracy, increase sampling frequency, and reduce labor. A large portion of this research and development has been conducted in “areas exposed to currents, waves, and ocean swells” and should, according to Shinn et al. (2002, p. 131), be “viewed with caution.” We will argue below that the conclusions of the authors are premature and that it is too early to dismiss 20 yr worth of ground water discharge research employing seepage meters.

We certainly agree seepage meters can be problematic. Most field measurement devices have limitations and precautions should always be considered when implementing a field program that includes seepage meters. If steps are taken to minimize error and control experiments are used, seepage meters make a very cost-effective technique for evaluating advective discharge from sediments. Shinn et al.’s (2002) study had methodology problems, such as not prefilling collections bags, inconsistent bag sizes, measurement frequency too low for the environment, and questions being asked, among others to be discussed, that may have misled the authors to find fault with the meters. We suggest in this comment that perhaps some moderation is in order for the conclusions drawn by Shinn et al. (2002).

Accuracy of Measurements

Shinn et al. (2002) apparently first developed concern over the seepage meter technique when their initial measured rates (1–60 L m−2 d−1) showed substantial local variations, “high rates of flux,” and did not indicate reverse flow into the underlying rock. Numerous researchers have pointed out that seepage meters provide only local estimates of flux due to substrate heterogeneity in lakebeds and coastal environments (e.g., Lewis 1987; Cherkauer and Nader 1989; Guyonnet 1991). Shaw and Prepas (1990) found that the most sensitive parameter affecting the accurate interpretation of seepage patterns is the spatial distribution, which is attributed to sediment physical properties rather than the seepage meter device. Substantial local variations in seepage rates are not simply due to a measurement error. In our opin-
The finding of consistent patterns of variability in flow indicates that the meters are responding to more than simply Bernoulli’s principle. Seepage rate variations should be expected considering the area where their meters were deployed (Table 1 and Fig. 3 in Shinn et al. 2002). The same spatial variation is present when the meters were measured more than once (Fig. 3 in Shinn et al. 2002), i.e., areas with relatively higher seepage are higher throughout the study suggesting a spatial pattern. Seepage rates also measured over consecutive days at the same location have approximately the same magnitude of seepage. Their results support both spatial and temporal variations in flux which are unlikely to be driven systematically by Bernoulli’s principle alone.

The authors refer to their data as “high rates of flux” on p. 127, but other seepage measurements made throughout the area are of the same magnitude as those presented by Shinn et al. (2002). Corbett et al. (1999) presented early results of seepage measurements made throughout Florida Bay. Seepage rates measured along the Keys bay side (defined as measurements made within 3 km of Keys coast) averaged $30.5 \pm 7.5 \text{ L m}^{-2} \text{ d}^{-1}$ (Corbett et al. 1999). Corbett et al. (2000) used two natural tracers, $^{222}\text{Rn}$ and $\text{CH}_4$, as an independent method for evaluating seepage flux in tandem with direct seepage measurements and found similar rates of discharge to both Corbett et al. (1999) and Shinn et al. (2002). They concluded that the best estimate of ground water discharge to Florida Bay was approximately $17 \text{ L m}^{-2} \text{ d}^{-1}$, almost identical to the average ($15.1 \text{ L m}^{-2} \text{ d}^{-1}$) presented by Shinn et al. (2002). So although the values obtained from the seepage meters appear to be high rates of flux, independent measurements corroborate the results of Shinn et al. (2002). Collectively, the seepage meter and tracer data paint a picture of enhanced exchange at the sediment-water interface consistent with a process like ground water seepage.

As noted by Shinn et al. (2002) and others (Halley et al. 1994; Corbett et al. 1999; Dillon et al. 2000), ground water flow in the Florida Keys is dependent on the Atlantic tide (semi-diurnal) and the seepage flux should reverse directions accordingly. One of the concerns the authors had is that they did not observe reverse flow in their seepage measurements or in an independent experiment utilizing Rhodamine dye. Their description of the seepage measurements is somewhat unclear, but it appears the authors may have chosen to test for net flow at the end of a complete tidal cycle, i.e., the collection bags were deployed for approximately 24-hr intervals. Reverse flow cannot be evaluated when seepage rates are measured over such a long period. In order to evaluate changes in seepage flow due to tides, measurements would have to be performed throughout the tidal cycle with bags changed approximately every hour to evaluate both the effects of high and low tides. In addition, the Rhodamine dye experiment, although interesting and innovative, may not have been sensitive enough to observe reverse flow. Dye tracers usually require large dilutions of the concentrated solution before a color change can be observed. With the low volumes associated with the small diameter plastic tubing, it is plausible that underwater visual observation, such as the one used by Shinn et al. (2002), would likely have minimal precision in estimating the degree of dye movement and dilution. Without more quantitative information using dye concentrations, it is difficult to accept the notion that the seepage meter design is the flaw.

Tidal experiments have been conducted in the Florida Keys using Lee-type seepage meters, hourly measurements, and prefilled 4-L collection bags with successful observation of reverse flow (Fig. 1; Chanton et al. 2003). Measurements made at Hammer Point, Key Largo, in February and March 1995 show a strong relationship to tidal stage in the Atlantic Ocean. When Atlantic tides were low, negative seepage rates in Florida Bay were observed and when Atlantic tides were high, positive seepage rates were observed. Measurements conducted later that year showed similar results, with decreasing seepage rates observed during the falling Atlantic tide (Chanton et al. 2003). Time-series seepage measurements were also made at the Bayside Well Cluster (BSWC) location described by Shinn et al. (2002). These measurements responded to the Atlantic head pressure in a direct fashion. Although
negative rates were not observed, an obvious relationship exists between the Atlantic tidal height and Florida Bay measured seepage rates (Fig. 2; Chanton et al. 2003).

**Artificial Pumping (or Bernoulli’s Revenge)**

Drawing on recent work related to effects of bottom topography on advective flow of pore solutions (e.g., Huettel and Gust 1992; Huettel et al. 1996), Shinn et al. (2002) refer to the pressure gradients currents may induce on a seabed chamber as Bernoulli’s Revenge. While such artifacts may exist, we question whether the magnitude of this effect is sufficient to dominate the results provided by seepage meters. Shum (1992, 1993) demonstrated that water movement over a seabed can provide penetration of water into sediments if microtopography, such as ripples, are present. Other variables that influence circulation of water into sediments include sediment permeability, ripple length and amplitude, and the wavelength, height and period of water waves. No measurements exist of ripple heights in Florida Bay. Perhaps the seepage meter does act as a macrotopographical seabed feature as proposed by the authors, but it seems unlikely that enhanced flow as a result of water wave penetration to sediments is the only control on seepage meter measurements. It also seems unlikely that the consistent spatial pattern observed in their data would be as evident if the advective flux was simply dependent on wave set-up. If Bernoulli’s principle was acting to enhance flow in seepage meters, then this technique seems unlikely to be so well correlated to independent advection estimates (Corbett et al. 1999, 2000). Many investigators report achieving high quality and internally consistent results with seepage flux chambers (e.g., Bokuniewicz 1980; Whiting and Childers 1989; Reay et al. 1992; Cable et al. 1997a,b; Burnett et al. 2002). We suggest some of Shinn et al.’s (2002) misgivings are associated with their experimental design.

**Methodological Approach**

Most of the research cited above was conducted using a similar seepage device to the one described by Lee (1977), e.g., top or bottom section of a standard 55-gal drum, 4-l plastic bags, etc. The previous research cited by Shinn et al. (2002), (e.g., Shaw and Prepas 1989, 1990; Cable et al. 1997a,b; Corbett et al. 1999) used this experimental setup. Although one of Shinn et al. (2002) seepage meter designs (the other two meters differed considerably) was identical to these earlier studies, the size of the bags they used in most of their experiments was approximately twice the size of previous work (~7 l). In measurements made at the deep fore-reef, Shinn et al. (2002, p. 131) used even larger plastic bags (565 l; 30 cm radius, 2 m length) on their modified seepage meters and acknowledged that “bag design may have influenced the results of our study.” The question the authors did not address is whether these variations in seepage meter design or bag size could account for the results presented. Little or no work has been done on the field evaluation of the meters or variation in bag sizes designed and used by Shinn et al. (2002). Without first making direct comparisons between the earlier instrumentation and those manipulated by Shinn et al. (2002), it is difficult to draw any clear conclusions on the relevance of these data to previous work involving seepage meters.

Several studies have demonstrated the importance of pre-filling the seepage collection bags. Shaw and Prepas (1989) first documented an anomalous influx of water into the collection bag and attributed it to a hydraulic gradient created by mechanical properties of the bags. They noted that this anomalous, short-term influx, which yielded high, inconsistent discharge measurements, could be eliminated by prefilling the bags with 1,000 mL of water. Cable et al. (1997a) used a similar version of the Lee-type seepage meter and 4-l plastic bags in a coastal setting and concluded that the most dependable measurements of ground water seepage were attained with 1,000-mL pre-filled collection bags, and the meters are not necessarily sensitive enough to measure rates below about 71 m$^{-2}$ d$^{-1}$. As previously mentioned, Shinn et al. (2002) chose not to pre-fill the collections bags, thus accepting this potential anomalous input during their field evaluations. In Shinn et al.’s (2002) control experiment design (using 74 plastic collection
bags), it is unknown what fraction of the seepage rate measurements is true seepage and what fraction is associated with the mechanical properties of the collection bags first identified by Shaw and Prepas (1989). Interpretation of their control experiment data is difficult based on their design. One hypothesis that springs to mind here regards the relationship between the anomalous short-term influx noted by Shaw and Prepas (1989) and the volume of seepage bags. Could the ratio between the volume of the bag and the volume of the seepage meter influence the magnitude of the anomalous short-term influx? Does a large bag to seepage meter ratio increase the hydraulic gradient in empty bags and artificially magnify the seepage flux beyond even previous measurements? Or, does increasing the bag size decrease the short-term influx error?

Several control experiments similar to those presented by Shinn et al. (2002) have been conducted in coastal environments. Cable et al. (1997b) had an almost identical experimental setup (Lee-type seepage meters, 41 plastic bags, 1.5 m diameter plastic swimming pool) in the coastal waters of the northeastern Gulf of Mexico. Temporal and spatial variability and forces driving this flux. While their argument that Bernoulli’s Principle affects seepage in this environment is not completely convincing, we agree that it may still be a contributing factor to some fraction of flow measurements. It is apparent (Fig. 1; Cable et al. 1997a; Chanton et al. 2003) that these devices respond to forces beyond the venturi effect. More quantitative work needs to be performed to assess this possible effect, as well as work to investigate its temporal and spatial variability and forces driving this flux. The measurements made by seepage meters, if made carefully and with some control experiments applied, are not artifacts. These measurements likely represent multiple water sources, such as infiltrating seawater and meteoric ground water fluxes. Mechanisms that drive pore water fluxes across the sediment-water interface may include wave-pumping (Bernoulli’s principle applied), but experiments to test this mechanism and other possible driving forces need to be performed. Shinn et al. (2002) have given us all something to think about, but we suggest that some moderation of their conclusions is needed. We eagerly anticipate and actively work to elucidate the sources of water measured in coastal benthic advective studies.

Summary

Shinn et al. (2002) seem convinced that seepage meters are not a practical instrument to use in coastal environments for questions related to advection across the sediment-water interface. While their premise is certainly worth considering since so many scientific studies are tackling the issue of ground water discharge in recent decades, we disagree that they have sufficient evidence to support their conclusions. Their field experiments produced more technical questions for us about experimental design than answered questions concerning the magnitude of seepage rates in Florida Bay. The practicality of seepage meters as a measurement tool for ground water discharge is a persistent question. Seepage meters are easy to make and easy to use. Their simplicity alone worries some scientists. In many studies where multiple techniques have been applied or where control experiments have been performed in conjunction with field measurements, seepage meters provide consistent reliable results. We suggest some other questions to ask. What is the effect of altering the collection bag to seepage meter volume ratio on the anomalous short-term influx? Does that volume ratio control the magnitude of the hydraulic gradient between the bag and the seepage meter? How significant is the short-term influx when a 7-L collection bag is placed in strong currents? How might this short-term influx be alleviated under different circumstances? How would the seepage results appear if tidal experiments were not performed as a net tidal effect, but instead evaluated seepage measurements on shorter time scales, such as less than a tidal cycle?

The conclusions drawn by Shinn et al. (2002) are generalizations that are not very well supported by their experimental design or by their results. While their argument that Bernoulli’s Principle affects seepage in this environment is not completely convincing, we agree that it may still be a contributing factor to some fraction of flow measurements. It is apparent (Fig. 1; Cable et al. 1997a; Chanton et al. 2003) that these devices respond to forces beyond the venturi effect. More quantitative work needs to be performed to assess this possible effect, as well as work to investigate its temporal and spatial variability and forces driving this flux. The measurements made by seepage meters, if made carefully and with some control experiments applied, are not artifacts. These measurements likely represent multiple water sources, such as infiltrating seawater and meteoric ground water fluxes. Mechanisms that drive pore water fluxes across the sediment-water interface may include wave-pumping (Bernoulli’s principle applied), but experiments to test this mechanism and other possible driving forces need to be performed. Shinn et al. (2002) have given us all something to think about, but we suggest that some moderation of their conclusions is needed. We eagerly anticipate and actively work to elucidate the sources of water measured in coastal benthic advective studies.

Literature Cited


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