Measuring Submarine Groundwater Seepage Using an Ultrasonic Flow Meter and the "Drum Method" – A Comparative Study

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Abstract

To accurately quantify groundwater seepage at the sediment water interface, the conventional "drum method" was compared with the recently developed ultrasonic flow meter. Data obtained using the ultrasonic seepage meter are determined to be quite reliable and accurate with measurements taken using the drum method. Data obtained using both methods show an inverse relationship with tidal stage. This relationship was expected and previously observed using the ultrasonic seepage meter; however, this has not been previously shown on Long Island using the drum method. The existence of this relationship as well as the good agreement between seepage data using both methods supports the accuracy of the time transient ultrasonic seepage meter. The ultrasonic seepage meter is therefore comparable with the drum method and is an efficient tool in quantifying groundwater flux at the sediment water interface. Flows measured at West Neck Bay using both devices ranged from 3.1×10^{-4} to 4.56×10^{-4} cm/s, corresponding to a strong seepage face of 99.85 to 146.4 ℓ/d.

Introduction

West Neck Bay has been subjected to blooms of *Aureococcus anophagefferens,* an algal species commonly referred to as Brown Tide. Recharge to the Bay is largely through groundwater seepage at the sediment - water interface and has been recently thought of as a controlling factor for the accumulation of Brown Tide attributing to high concentrations of nitrogen that the groundwater supplies to the Bay (LaRoche, 1997). As a first step to understanding the coupling of hydrogeologic and geochemical processes at West Neck Bay, it is necessary to develop a groundwater flow model that can provide a basis for the movement and quantity of groundwater into the bay.

A major parameter for the model is the groundwater flux at the sediment water interface. Traditionally, this flux has been quantified using a seepage device designed by Lee (1977), consisting of a portion of a 55 gallon drum and a plastic bag, a method both widely accepted and used extensively (Bokuniewicz and Zeitlin, 1980; Schneider, 1994; Shaw and Prepas, 1989). Recently, however, Paulsen et al (1997) introduced a time transient ultrasonic seepage meter to measure groundwater flux at the sediment - water interface. To assess the reliability and accuracy these two methods, a comparative study was conducted at West Neck Bay in Shelter Island, NY as well as in Riverhead, NY where Meetinghouse Creek meets Flanders Bay (Fig. 1).

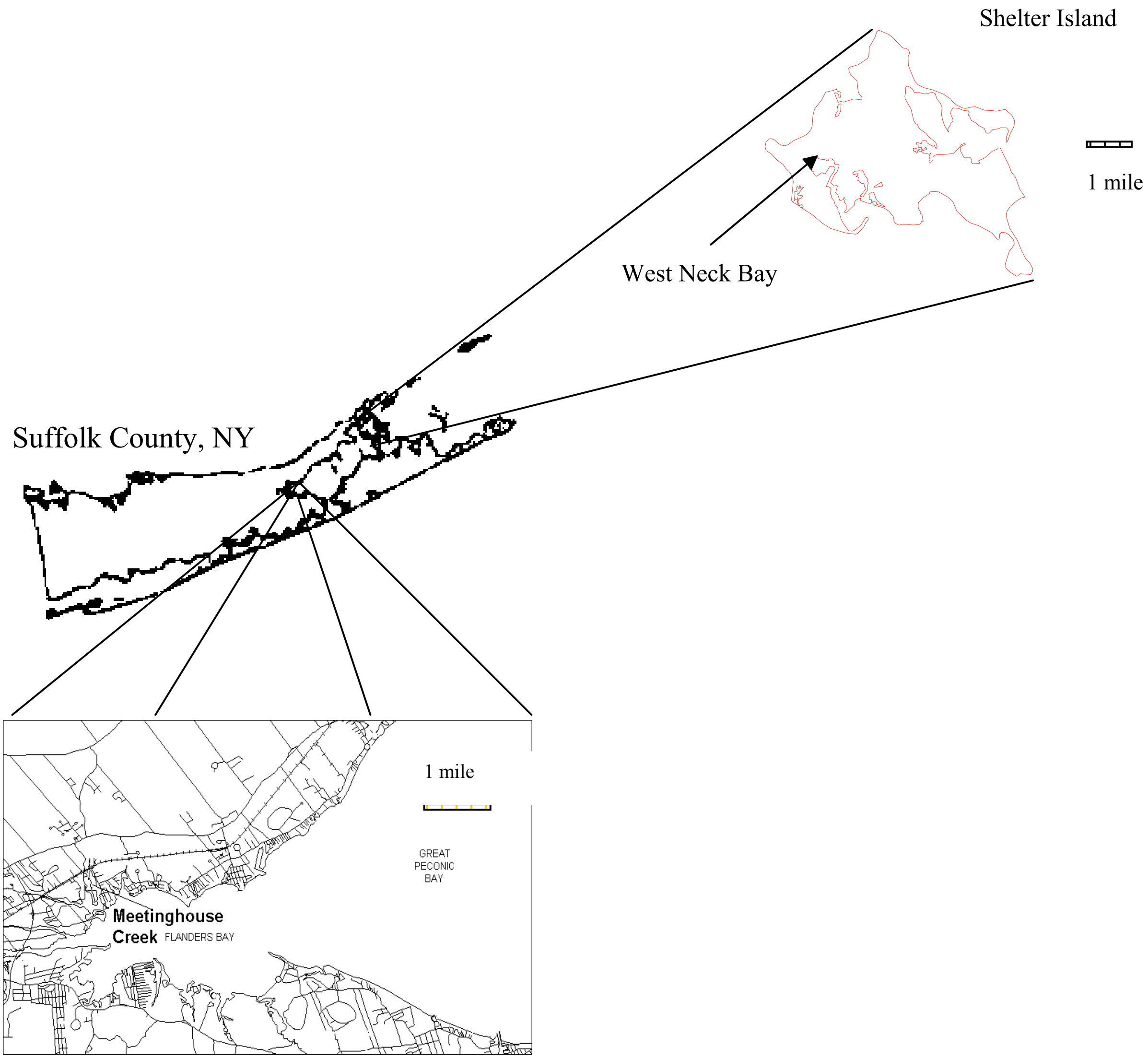


Figure 1 *Location maps.*

Measuring Groundwater Discharge at the Sediment – Water Interface

The Drum Method

To measure the groundwater flux across the sediment water interface, a measuring device developed by Lee (1977) has been widely accepted (Fig. 2). The device consists of a section of a 55 gallon drum with a single opening at the top to allow groundwater to escape. A plastic bag is attached to the opening to collect the flow as it leaves the drum. Also attached to the drum is a galvanized bucket that encloses the collection bag as a means of protection against wave action (Bokuniewicz and Zeitlin, 1980).

In this comparative study, a design modified by Bokuniewicz and Zeitlin (1980) was adopted. The top 17-cm section of a 55 gallon drum was used and welded to the drum was a nozzle that allowed water to escape and be collected by a 3.79ℓ plastic bag. The plastic bags were sealed on one end using a standard 1100W clothing iron. Approximately 12-cm of tygon tubing were prepared by tightly wrapping clear plastic wrap over one end, securing it with a rubber band. The tube was then filled with water (approximately 2.5-ml) to minimize the amount of air in the tube. The open end of the tube was then placed into the plastic bag via a 2.5-cm opening. The bag was rolled tightly in order to minimize the amount of air in the bag and a rubber band was wrapped tightly around the bag and onto the tube. Although crude, this technique proved to be quite effective in the field.

Approximately 3/4 of the drum was pushed into the sediment. Much of the underlying bay water was displaced or vented through the nozzle of the drum upon insertion, but the drum stood between 30 minutes to several days before measurements

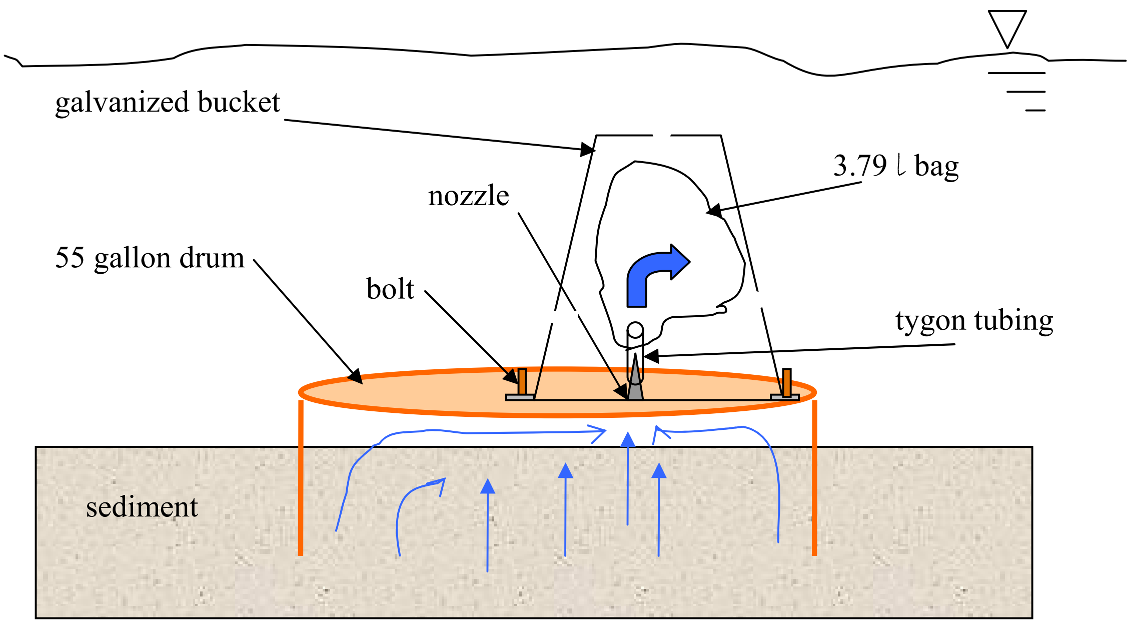


Figure 2 *Illustration of the "drum method" developed by Lee (1977).*

began, minimizing the amount of bay water between the sediment and the drum. The prepared plastic bags were then inserted onto the drum such that the nozzle of the drum pierced the clear plastic wrap around the tygon tubing. A galvanized bucket was then placed over the bag and attached to the drum (Fig. 2). The galvanized bucket had four small (approximately 0.8 cm in diameter) holes drilled into it in order to equalize pressure inside and out of the pail (Bokuniewicz and Zeitlin, 1980). Seepage collected in the plastic bag was measured using a 1000-ml volumetric flask.

Ultrasonic Groundwater Seepage Meter

To continuously measure submarine groundwater seepage, a transient time seepage meter was developed that uses ultrasonic signals and two piezoelectric transducers to determine flow rate (Paulsen et al, 1997; Fig. 3). As water enters the flow tube, it passes through the ultrasonic beam path. The direction and velocity in which the flow is moving is directly proportional to the difference in travel times of the ultrasonic signals. As shown in Figure 3, the ultrasonic signal that travels with flow will arrive sooner than the signal travelling against flow.

To collect groundwater seepage at the sediment water interface, a funnel with a square cross section of 0.372 m^2 was inserted into the sediment (Paulsen et al, 1997). As with the drum method, the funnel is equipped with a nozzle that allows water to escape. Attached to the nozzle of the funnel was 44-cm of tygon tubing (1.8 cm I.D.) which lead to the flow tube. The flow tube is connected to a data logger that records both incremental and cumulative discharge simultaneously (Fig. 4). The data logger is also able to detect reversals of flow such as a negative groundwater flux across an interface. In the field, the data logger and a back-up battery are often housed in a buoy that is anchored to shore so that long - term, continuous measurements are made with minimal risk of damage to the equipment. The battery life of the logger itself is approximately 12 hrs. while the back-up battery has a life span of approximately 48hrs.

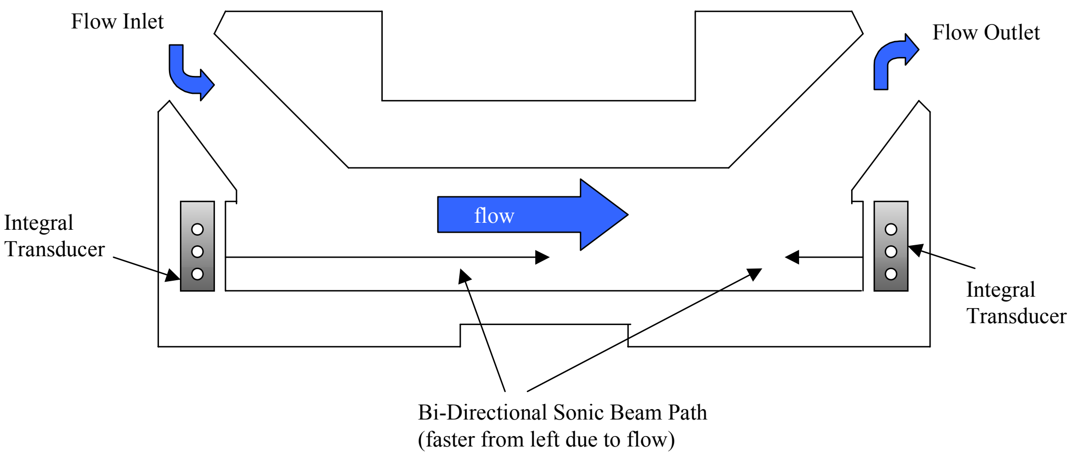


Figure 3 *Cross section of the ultrasonic seepage meter flow tube showing the difference in signal arrival times with flow* (from Paulsen et al, 1997).

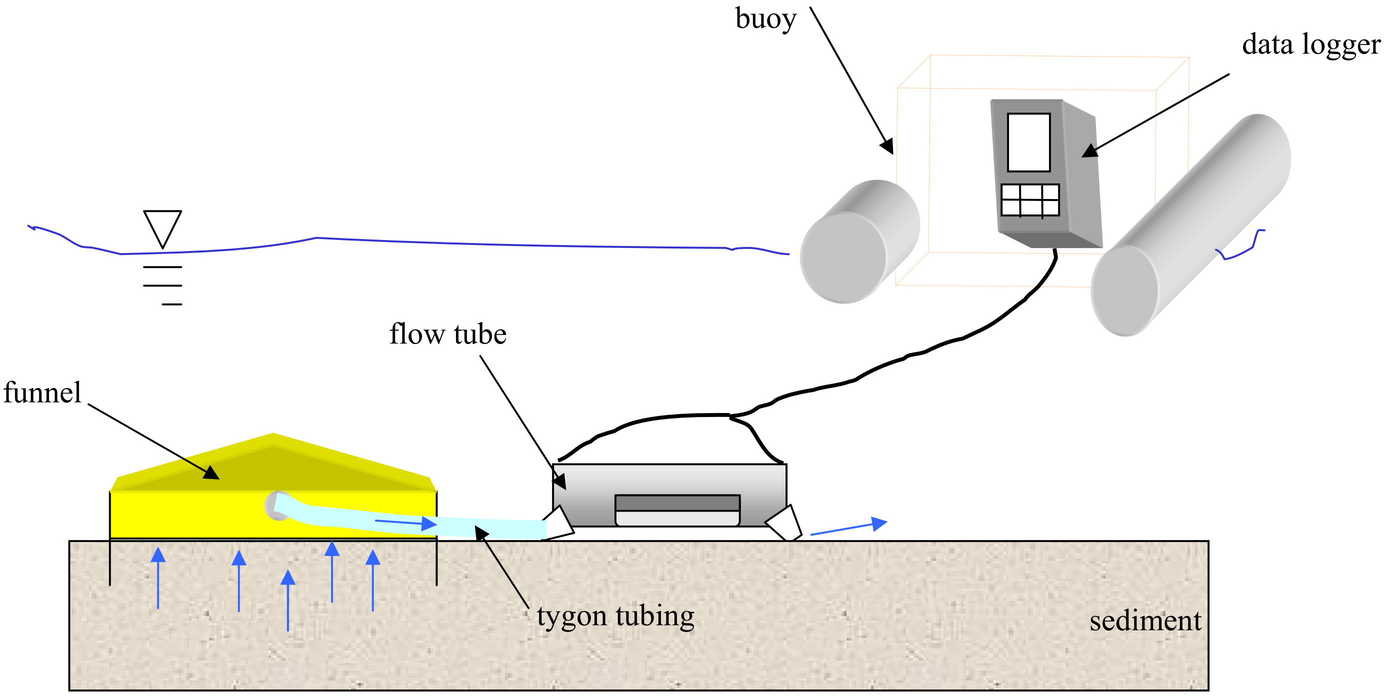


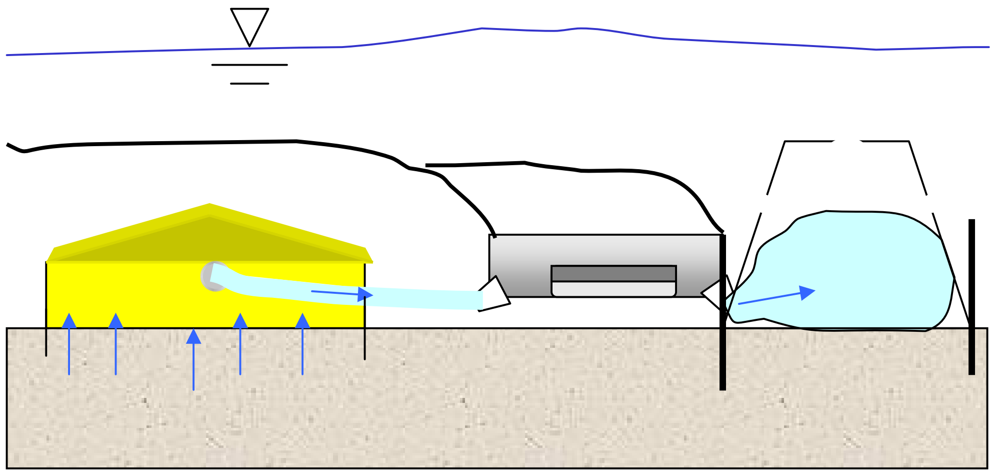
Figure 4 *Diagram showing field deployment of the ultrasonic seepage meter (not to scale).*

Methods

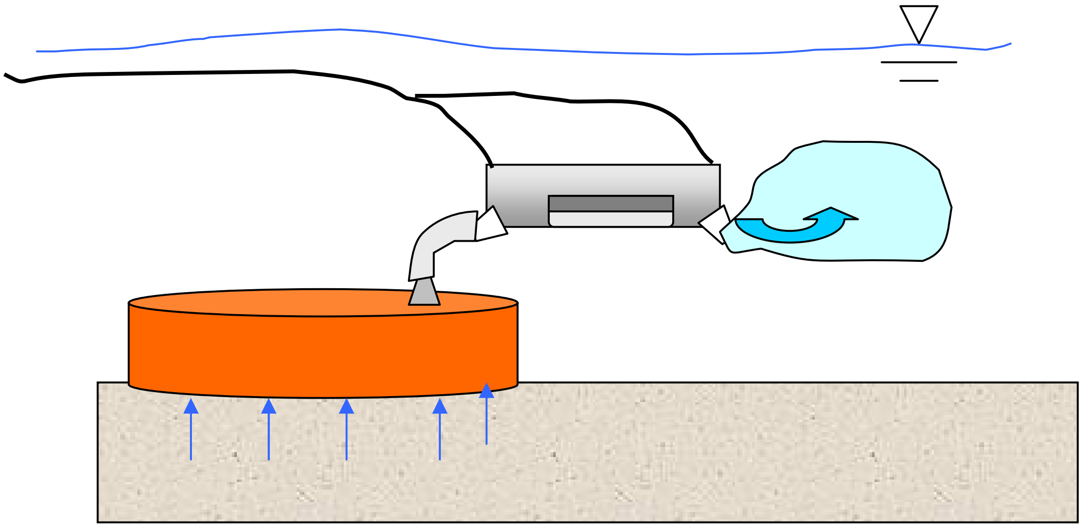
The methods utilized for the comparative study are shown in Figure 5. Using both the drum method and the ultrasonic seepage meter individually was another option, but was only used in preliminary measurements. It has been suggested that bay sediments may show a high variation in permeability, therefore varying seepage rates could exist for adjacent areas (Bokuniewicz and Zeitlin, 1980). Variability of bottom sediments was also reported as a major factor in seepage variability in meters that were separated by only 1-m (Shaw and Prepas, 1990). It was decided that in order to achieve the highest accuracy in comparing the two methods, measurements needed to be taken at the same location in the bay. Only one of the two collection devices was used (either the drum or the funnel) at a particular location to displace as little stratigraphy as possible.

To accurately compare the results of both methods, the flow tube of the ultrasonic seepage meter was attached to the seepage collection device (either the drum or the funnel) via tygon tubing. Attached to the outlet of the flow tube was a 3.79 ℓ plastic bag that collected the discharge from the flow tube. Since the flow tube does not impede flow into the plastic bag, the drum method was essentially being utilized. However, since flow was travelling through the flow tube of the ultrasonic seepage meter en route to the plastic bag, both methods were being utilized simultaneously.

The method using the funnel as a seepage collection device (Fig. 5a) as opposed to the drum was preferred and used throughout the majority of this study. Using this method, the plastic bag could be protected against wave action by staking a galvanized



a)



b)

Figure 5 *a) Preferred method of comparison using the funnel and the galvanized bucket; b) Method of comparison using the drum and leaving the bag open to wave action (not to scale).*

bucket into the sediment. Although wave action was minimal in both localities, this was an added precaution. The method shown in Figure 5a was also more stable than the method shown in Figure 5b. The method shown in Figure 5b was therefore used infrequently, only during times of almost zero wave activity.

Measurements were replicated at various time intervals. At each interval, the volume of seepage collected in the bag was measured using a 1000-ml volumetric flask and then compared with the read out on the data logger at that particular time. The duration of the measurements on any particular day were limited by high tide, which created difficulties regarding proper installation of the bag since the tide would raise as much as 2.5-3.0 ft. in a matter of hours.

Results

West Neck Bay

Results from West Neck Bay are shown in Figure 6. High seepage rates (1.27×10^{-3} cm/s) have been previously measured at the northeast section of the bay and was therefore chosen as a site for the comparative study (Paulsen, 1997). Four drum measurements were taken at 10-minute intervals and one measurement was taken at a 15-minute interval. As shown on Figure 6, there is a slightly higher value of seepage using the drum/bag method than the ultrasonic seepage meter. This variation is most likely attributed to initial surges of water entering the bag upon insertion to the meter. Shaw and Prepas (1989) also reported initial surges as a cause for seepage variability. Also noteworthy is the short time span for which the data were collected. This was due to several factors including tide stage, boating activity in the bay, and the need to transfer the seepage meter to the Riverhead site. Nevertheless, there exists a good relationship between seepage measured using the drum and bag method and data recorded using the ultrasonic seepage meter.

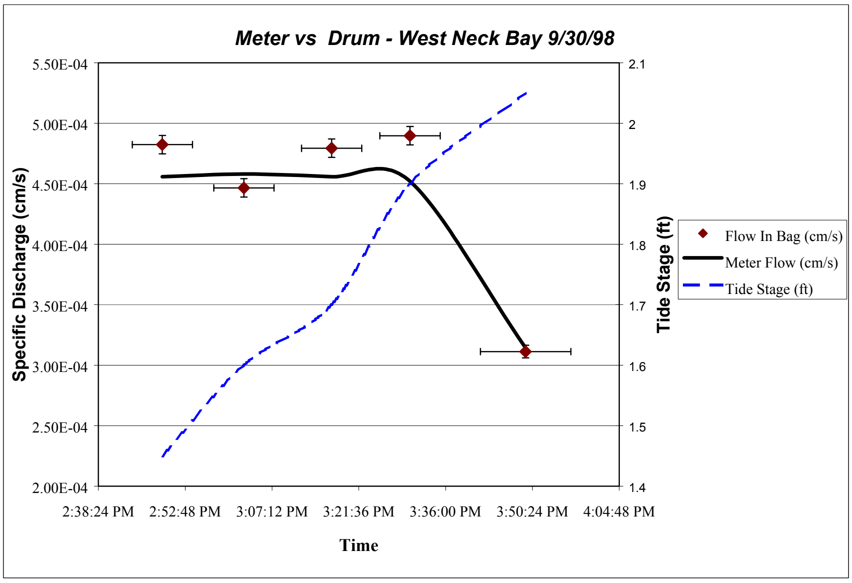


Figure 6 *Results of the comparative study between the ultrasonic seepage meter and the drum and bag method in West Neck Bay.*

Riverhead

The comparative study between the drum method and the ultrasonic seepage meter was transferred to a Riverhead site where Meetinghouse Creek meets Flanders Bay (Fig. 1). Results are shown in Figure 7.

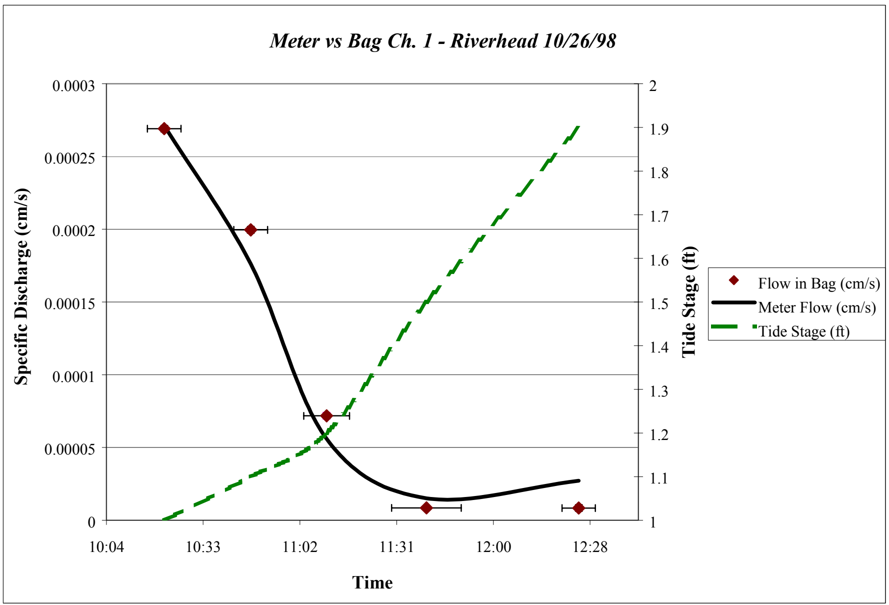


Figure 7 *Results of the comparative study in Riverhead, NY.*

Measurements were taken at 10, 15, and 20-minute increments. As in West Neck Bay, there is an initial surge resulting from the insertion of the bag on the flow tube, but the variability is not as great. Although the seepage face was not as strong as it was in West Neck Bay, the results obtained at the Riverhead site show strong evidence that the ultrasonic seepage meter, when compared to the conventional drum method, gives comparable results.

Discussion

Seepage measured at both sites using the ultrasonic seepage meter and the drum method are in good agreement. Perhaps the most supportive evidence for the data shown in Figures 6 and 7 is the relationship to tidal stage. Groundwater seepage is suppressed during high tide and tends to increase during times of low tide. Data collected show this relationship. The relationship between seepage velocity and tidal stage is stronger at the Riverhead site, most likely attributing to its weaker seepage face (Figs. 6 & 7).

As shown in Figure 6, specific discharge measured at the sediment - water interface at West Neck Bay was up to 4.55 x 10^{-4} cm/s, while reaching a maximum value of 2.69 x 10^{-4} cm/s at the Riverhead site (Fig. 7). Therefore, seepage variability during the specified time interval will not vary as much at West Neck Bay attributing to a stronger flux of groundwater crossing the interface. Specific discharge at West Neck Bay decreases approximately 0.53% (2.42 x 10^{-6} cm/s) per minute corresponding with a 0.01

ft/min increase in tidal stage. Specific discharge at the Riverhead site, however, decreases 1.29% (3.47x 10^{-6} cm/s) per minute corresponding to an increase in tidal stage of 0.09 ft/min.

The results of this study are important regarding future application of the ultrasonic seepage meter. Essentially, this study can be viewed as a field calibration for the meter to a conventional method that has been accepted and used by several authors. Results show a good relationship between the two devices and therefore support the accuracy and validity of using the ultrasonic seepage meter for field measurements of groundwater seepage along the sediment - water interface.

Other Comparative Characteristics

As mentioned above, this study has shown that discharge measured using the ultrasonic seepage meter and the conventional drum method is in good agreement. Other qualitative characteristics, however, should be compared as well. These characteristics include: ease of field use, time, and quantity of data. The ultrasonic seepage meter has the advantage in all three of these categories.

As mentioned above, the ultrasonic seepage meter records real time measurements and can record these measurements over an extended period of time. The meter can be left unattended for up to three days. As mentioned previously, measurements are recorded both incrementally (seconds) as well as cumulatively (hours/days). The only maintenance required is to recharge the back up battery and check the flow tube and tygon tubing for blockages such as small crustaceans (snails, etc). The drum method, however, requires constant monitoring and measurements must be taken manually. The rate at which measurements are taken also depends on the strength of the seepage face. If a strong seepage face exists, measurements can be taken in several minute increments. However, if a weak face is present, measurements may be on the order of hours. This becomes quite time consuming as well as labor intensive. Another problem using the drum method is high tide, which increases the difficulty of bag removal and installation. Although, if implemented carefully, tidal effects can be measured using the drum method.

The data logger of the ultrasonic seepage meter is also able to take continuous measurements of two channels simultaneously. One can therefore measure seepage rates of two locations, with distance limited to the length of the cables to the flow tubes. In order to obtain seepage rates for more than one location using the drum method, other devices are needed and subsequently other workers to achieve the same accuracy as the ultrasonic seepage meter. Data are also easily accessible from the data logger of the ultrasonic seepage meter for spreadsheet analysis.

The cost of the two units differs substantially. The drum seepage device is quite cost effective. The equipment can be purchased for under $30, while the ultrasonic seepage meter can cost upwards of $1500. Cost is the one major disadvantage of the ultrasonic seepage meter. However, the meters are quite durable and if properly taken care of can last for an indefinite period of time.

Research is currently being conducted for additional applications of the ultrasonic seepage meter. These additional features include continuous measurements of pH, salinity, and temperature to occur simultaneously with seepage measurements. Applicability to other environments (rivers, ponds, etc.) is also being researched. These, when completed, pose additional advantages the ultrasonic seepage meter has over the drum method. Therefore, due to the factors discussed above, the ultrasonic seepage meter is preferred.

Conclusion & Future Work

Submarine seepage rates measured with the transient time ultrasonic seepage meter are in good agreement with those taken at the same location using the drum method. Both devices are inversely related to tidal stage, a condition previously documented using the ultrasonic seepage meter but not previously observed on Long Island with the drum method. Since both methods show this relationship, it can be concluded that the ultrasonic seepage meter, when compared to the drum method, proves to be a very efficient and effective tool in quantifying submarine groundwater seepage.

Seepage rates can be measured effectively, but the control of the seepage rates needs to be determined at West Neck Bay. This will be further understood with the completion of a finite difference groundwater model. Tidal stage has been shown to have an inverse relationship with seepage, so the relationship between seepage and salt water intrusion also needs to be addressed. Coupling of hydrogeology and geochemistry through the finite difference groundwater model will relate seepage rates with the occurrence of *Aureococcus anophagefferens* in West Neck Bay as well as the potential for salt water intrusion.

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