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REMOTE SEMI-CONTINUOUS FLOW RATE LOGGING SEEPAGE METER

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ABSTRACT

The movement of groundwater and its associated solutes from upland regions has been implicated in the degradation of receiving surface water bodies. Current efforts to directly measure this influx of water incorporate manually operated seepage meters which are hindered by severe limitations. A prototype seepage meter has been developed by NASA Langley Research Center and Virginia Polytechnic Institute and State University that will allow for the semi-continuous collection and data logging of seepage flux across the sediment-water interface. The meter is designed to operate at depths to 40 meters, and alleviate or minimize all disadvantages associated with traditional methods while remaining cost effective. The unit was designed to operate independently for time periods on the order of weeks with adjustable sample sequences depending upon hydrologic conditions. When used in conjunction with commercially available pressure transducers, this seepage meter allows for correlations to be made between groundwater discharge and tidal/sea state conditions in coastal areas. Field data from the Chesapeake Bay and Florida Bay systems are presented.

INTRODUCTION

Considerable research has been devoted to defining material input into inland and coastal waters. Advective transport of water and associated solutes across the sediment-water interface has been shown to be of significant importance in lacustrine, estuarine and marine environments [1,2,3,4,5]. Mechanisms responsible for advective transport of solutes within nearshore sediments include: 1) elevated upland hydraulic head (i.e., groundwater discharge) [5], 2) convective flows caused by thermal and salinity density differences [6,7,8], 3) sedimentation [9], 4) spatial variations in sea state (i.e., subtidal pumping) [10], 5) benthic boundary currents [11] and 6) bioadvection. In addition to influencing water quality management efforts, such transport mechanisms are of biological and geological importance.

Macroscopic seepage rates of water across the sediment-water interface typically range from 0.0 to 5.0 $Lm^{-2}hr^{-1}$. Hydraulic head differences between overlying surface waters and interstitial water is on the order of millimeters or centimeters for most nearshore environments [12]. Given such low and varied flow rates and hydraulic head differences, current flow meter technology is inadequate and the measurement of such phenomena remains a technical problem.

Conventional methods to directly measure water exchange across the sediment-water interface are limited to manually operated seepage meters [3]. In its simplest form, seepage meters consist of a cylinder covered by a vented lid that allows a water collection bladder to be attached. In principle, seepage meters are placed into the sediment and water entering the meter displaces water into the collection bladder. Discharge is determined by the volume of water displaced per cross sectional area of seepage meter per unit time. Discharge rates are corrected for anomalous short-term influx of water to the collection bladders [13]. Primary disadvantages of current meters include: 1) limited time series data, 2) extensive work effort required, 3) limited to safe diving depths, and 4) anomalous short-term water influx to collection bladders. The remotely operated seepage meter presented here, Sea Seep I, was designed to alleviate or minimize all disadvantages associated with traditional methods while remaining cost effective.

DESIGN AND CONSTRUCTION

The prototype seepage meter is a remotely operating self contained system consisting of seven major components, these are: 1) a magnetically controlled proximity switch, 2) motor driven system operating valve, 3) seepage collection bladder, 4) discharge adjustable metering pump, 5) data logger, 5) rechargeable battery powered electrical system, and 7) dual chamber seepage meter housing (Figures 1 and 2). Total weight of the seepage meter and components is approximately 50 kilograms.

System Operation

The main body of the prototype seepage meter is a cylinder made of 16 gauge stainless steel with dual compartments having a cross sectional area of 0.25 m^2. Batteries, system operating electrical circuit, data logger, metering pump, motorized valve and vented bladder isolation chamber are housed in the water proof upper compartment of the meter base. Compartment reenforcement allows the device to be used at depths to 40 meters. A ceramic magnet attached to the collection bladder decreases in proximity to the reed switch as the bladder fills with displaced water from the main body. When the reed switch is closed by the magnet, an electrical circuit initiates to sequentially rotate the 3-way valve from the sampling position to the input of the metering pump. The pump discharges water from the collection bladder until the proximity of the magnet increases and opens the reed switch. Subsequently, the pump is deactivated, data is logged, the motor resets the valve to the sampling position, and the system shuts down to conserve electrical power. The valve operation, pump out and data logging cycle interrupts sampling for only 15 seconds. Depending upon hydrologic conditions and data requirements, pump out volumes can be modified over a wide range by varying bladder size, proximity switch adjustment and pump cycle timer. The seepage meter is initiated and deactivated by an external magnet and internal magnetic switch.

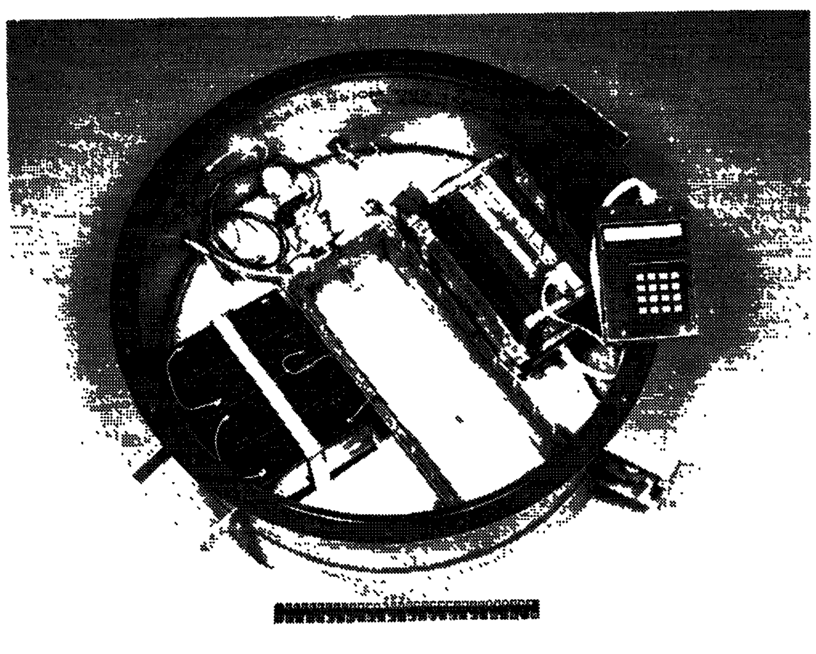

Figure 1. Photograph of remote semi-continuous flow rate logging seepage meter.

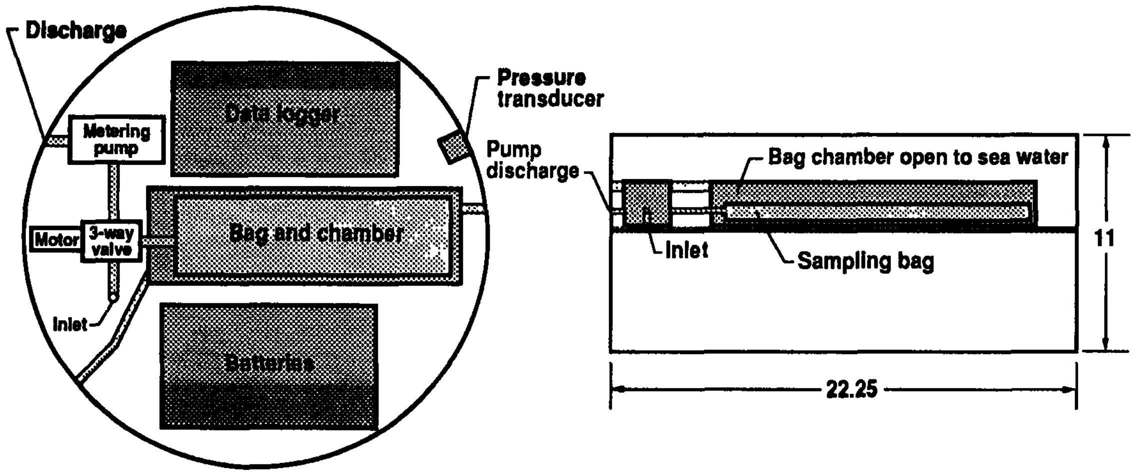

Figure 2. Schematic drawing and major components and overall dimensions of remote semi-continuous flow rate logging seepage meter.

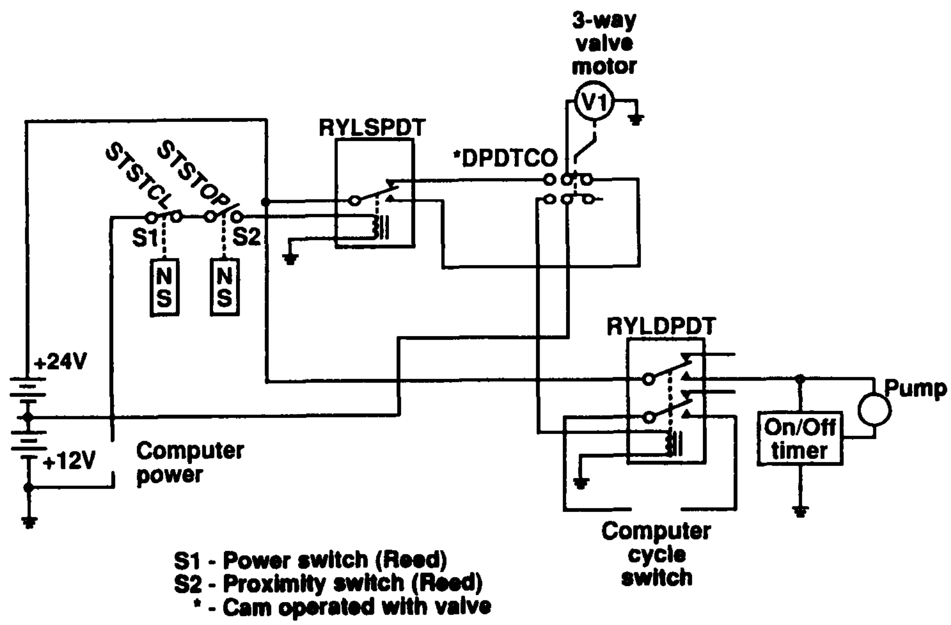

Figure 3. Electrical schematic of major circuits of remote semi-continuous flow rate logging seepage meter.

RESULTS

Calibration Tests

Due to the flow resistance caused by the components inherent to seepage meter designs and alteration of water flow paths induced by meter placement, experiments were conducted to compare actual versus measured discharge rates. Efficiency experiments were conducted in a constant head flow tank (1.0 m^2 cross sectional area) filled with a well-sorted fine sand. The constant head flow tank was allowed to equilibrate to a specific discharge for 1 hour and calibration experiments were conducted for a 2 hour period. The seepage meter was reinstalled for each individual test. Measured discharges (Q') were determined by equation (1):

$$Q' = (C_c * V)/(A * T) \qquad (1)$$

Where:

Q' = Measured discharge ($ML^{-2}T^{-1}$)
C_c = Cumulative counts
V = Pump out sequence volume (L^3)
A = Area enclosed by seepage meter (L^2)
T = Time period (T)

The ratio of Q':Q , where Q is the actual discharge rate, was compared to determine seepage meter efficiency and accuracy [14]. Experimental results comparing seepage meter efficiency under varying discharge rates are given in Table 1. Mean efficiency of standard manual meter design has been shown to be approximately 60 percent [14]. Following initial installation, a specific time period is required to equilibrate hydraulic pressures between ambient surface water and water enclosed within the meter system, however this is generally on the order of minutes.

Table 1. Seepage meter efficiency under varying discharge rates.

Actual Discharge Rate ($Lm^{-2}hr^{-1}$)	Measured Discharge Rate ($Lm^{-2}hr^{-1}$)	Percent Mean Efficiency
6.00	1.26	21
10.32	2.52	26

Even though the seepage meter displays a slight negative buoyancy, settling of the meter into the sediment may occur resulting in an increase of pressure inside the meter and displacement of water into the collection bladder (i.e., 1 mm of settling would result in a 250 ml displacement of water). The effect of settling was determined by installing the meter into the sediment under no-flow conditions. Results for the well sorted sand indicated no significant settling effect. However, caution should be exercised in high porosity, low dry bulk density unconsolidated sediments (i.e, silt-clay mixes).

Field Application

Sea Seep I was field tested at two locations varying in sediment type and seepage discharge. The first site was located in a tidal creek on Virginia's Eastern Shore and characterized by a tidal range of approximately 1.0 meter. Nearshore surficial (upper 20 cm) quartz sandy sediments were conducive for water transport, exhibiting a mean porosity and vertical hydraulic conductivity of 0.45 and $10^{-2.4}$ $cmsec^{-1}$, respectively. The second site was located in the nearshore zone of Florida Bay which exhibits a tidal range on the order of 0.10 meters. Vertical hydraulic conductivity and porosity of surficial carbonate sediments were on the order of $10^{-2.0}$ $cmsec^{-1}$ and 0.40 respectively. Field test results for the Virginia Eastern Shore and Florida Bay sites are presented in Figures 4 and 5, respectively.

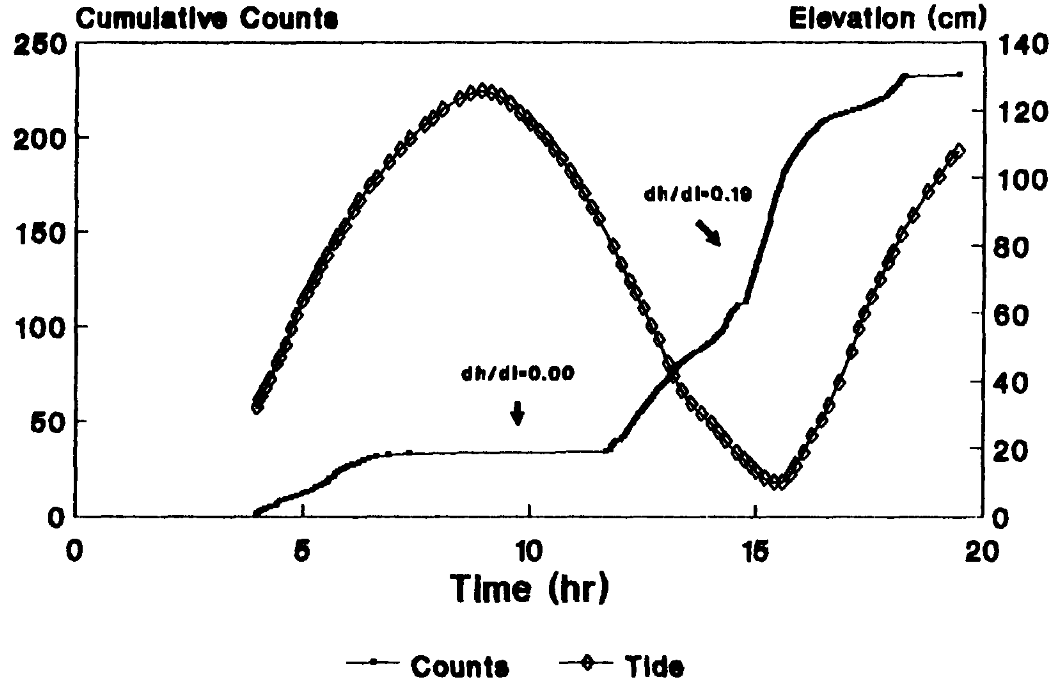

Figure 4. Graphic representation of Sea Seep I field test of tidal creek site in Chesapeake Bay.

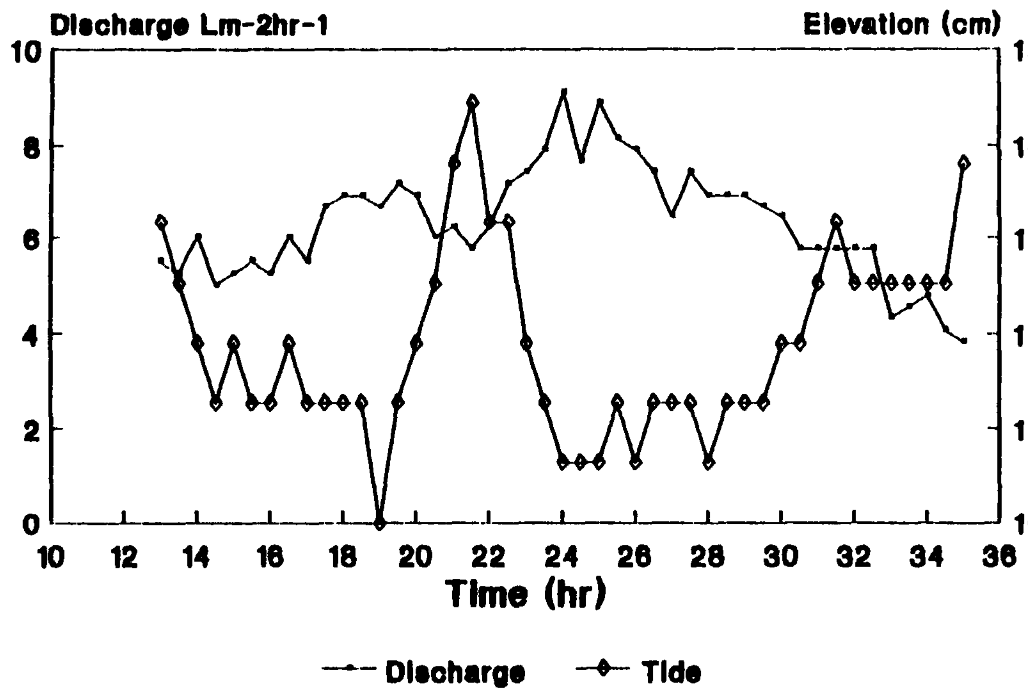

Figure 5. Graphic representation of Sea Seep I field test of nearshore site in Florida Bay.

Discharge (i.e., counts) rates show an inverse relation to tidal elevation at the Chesapeake Bay site. During high tides, water levels within the tidal creek caused hydraulic gradients between a point 0.7 meters below the sediment-water interface and surface waters to approach and equal 0.00, thereby effectively shutting down submarine groundwater discharge. Hydraulic gradient (dh/dl) is the change in hydraulic head per unit distance (l), where hydraulic head (h) describes the total energy in a moving mass of water at a particular point. Conversely, as the tide recedes, vertical hydraulic gradients (up to 0.19 at ebb tide) and discharge rates increase in concert. The remotely controlled seepage meter allowed for the collection of 246 discharge data points as compared to the 4-10 time integrated data points that would have normally been collected using manual methods. As with the Chesapeake Bay site, the Florida Bay study site displayed a strong correlation with tidal stage (Fig. 5). It should be noted that the data set for Florida Bay was summarized and consists of 1166 data points collected over a 22 hour time period.

SUMMARY AND DISCUSSION

The reported remotely operated semi-continuous flow rate data logging seepage meter was developed to, 1) operate over extended periods of time without the need for recurrent monitoring, 2) measure relatively low flow rates over short periods of time, 3) log flow rate data in addition to tidal and sea conditions, and 4) to remain cost effective. To accomplish this, the design employed a modification of the collapsible bag method used in manual seepage meters and commercially available components such as rechargeable batteries, electrical valves and pumping systems, scientific data loggers, and pressure transducers.

Development of this prototype remote seepage meter was driven by an environmental concern for inland and coastal water bodies. The data presented for the Chesapeake Bay and Florida Bay region exemplifies the geographic universality and potential importance of the phenomena, submarine groundwater discharge. Time series data allows for comparison with hydrologic conditions such as tidal influence on discharge rates.

Current uses for this instrument are generally limited to research activities and water quality management applications. This basic concept in flow meter technology does provide an alternative to applications that address extremely low flow rates in conjunction with low pressures. When used in conjunction with proper hardware material, potential industrial uses of this flow meter concept may include flow rate measurements of caustic and corrosive fluids. A second remote seepage meter has been designed with modifications that increase meter efficiency and sensitivity, and allow for deeper water deployment.

We are proceeding to protect this technology with a patent.

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