*Supplementary Information*

## Contents



## Instrument calibration

The accuracy of the FLEXIM F7407 ultrasonic flow sensor (FLEXIM Corp., Edgewood, NY, USA) was tested against gravimetrically measured flow rates in the laboratory. The transducers were mounted to the exterior of a 36 cm long, 9.5 mm ID, 1.75 mm wall thickness titanium flow tube following manufacturer specifications and secured to the lab bench in a horizontal orientation. The configuration used in the lab test is the same as that used in the field (Fig. S1). Flow of water from a constant-head tank through the tube was manually controlled with a 3 mm ID ball valve across a range of -10 to +14 L $h^{-1}$ for ~10-20 min at each flow rate. Flows were measured gravimetrically on a digital scale to a precision of 0.01 g and converted to volumetric units. Ultrasonic data recorded at 1 s frequency was averaged across each measurement period, plotted against volumetric flow, and fitted with a linear model (Fig. S2). Accuracy and precision of ultrasonic flow measurements under zero-flow conditions were measured by closing the valve and calculating the average and standard deviation across a 20 min period (dashed black line in Fig. S3). Standard deviation in $q$ under zero-flow conditions across the 20 min interval was 0.07 cm $d^{-1}$ ($n$ = 1,200).

Precision of ultrasonic groundwater seepage measurements under zero-flow conditions in the field, representing inherent instrument noise plus in situ variability due to influence of variable conditions, such as temperature, was also measured. The regulated seepage meter with ultrasonic sensor were deployed into the sediment in the nearshore subtidal zone as described in the main text. Zero-flow conditions were achieved with a fully closed valve on the end of the flow tube as described above for the laboratory test. Data are shown in Fig. S3 as the solid red line. Standard deviation in $q$ across a 20 min interval was 0.14 cm $d^{-1}$ ($n$ = 1,200).

Variability in ultrasonically measured groundwater discharge ($q$) was analyzed against laboratory and field measurements of precision. A 20 min span of data collected during the overnight high tide in June (t ≈13 h, main text Fig. 2a) was selected on the basis that the variability during this time period represented a minimum baseline variability in positive discharge at the interface present during calm nighttime conditions at high tide. First a linear model was fitted to the data, and slope- and intercept-adjusted data were calculated as:

$$q_{adj} = q_{raw} - (mt + b) \tag{S1}$$

where $q_{raw}$ is the raw field data; $m$ and $b$ are the slope and y-intercept of the regression line; $t$ is the sample interval duration, and $q_{adj}$ is the adjusted field data, which represents variability in the rate of (+) discharge at the interface. Data are shown in Fig. S3 as the solid blue line. Standard deviation in $q_{adj}$ across the 20 min interval was 0.40 cm $d^{-1}$ ($n$ = 1,200).

A tracer injection test was conducted in the field to determine the time required for the 10 L $min^{-1}$ capacity pump to mix the water contained in the headspace and recirculating flow system of the regulated seepage meter (Fig. S4). The seepage meter was deployed into the sediment in the nearshore subtidal zone as described in the main text, and zero-flow conditions were achieved with a fully closed valve on the end of the flow tube as described above for the laboratory bench test. The YSI 600XLM sonde was set to log field parameters, including pH, at one second frequency. Once a stable pH reading was achieved, 20% (w/w) hydrochloric acid solution was injected through the port on the lid of the seepage meter (Fig. S1). The time required for the water to be 95% equilibrated was measured as the difference in time from when the tracer was injected to when the pH reached 95% of its new stable value. (≈1.3 min, Fig. S4). A separate test was done for the SSM, but the result was inconclusive, possibly due to a compromised pH probe. However, the theoretical turnover time of water within the SSM and circulation loop based on total volume and pump rate is 21 L/ 4 L $min^{-1}$ ≈ 5.3 min, less than that of the RSM (≈ 7.8 min). Therefore, we anticipate the actual mix time of the SSM to be comparable, or perhaps slightly faster than the RSM.

## Figures and Tables

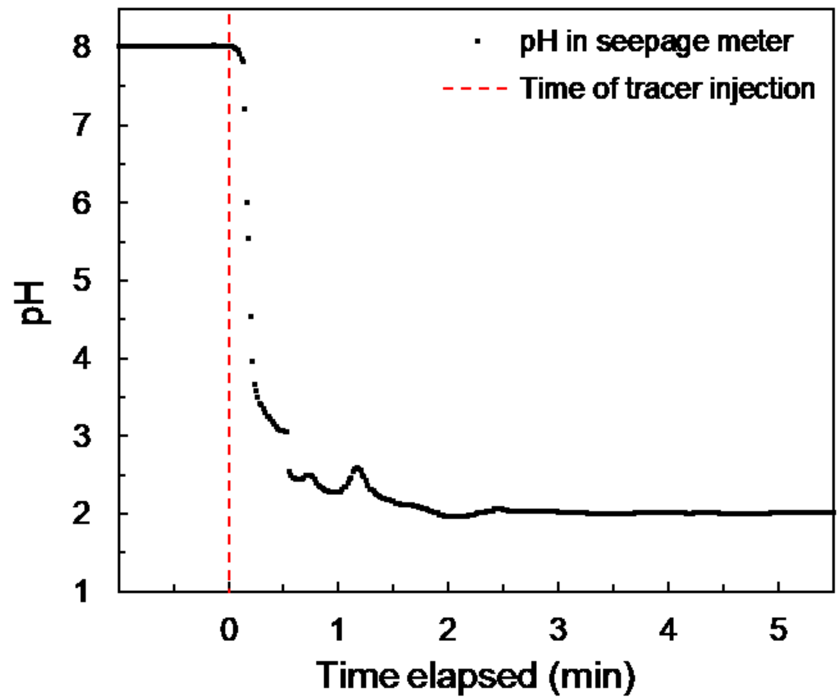


**Fig. S1.** Results of mixing test of the regulated seepage meter (RSM). pH recorded at 1 s frequency, and time of injection of a 20% (w/w) hydrochloric acid solution are shown with black markers and red dashed line, respectively. Results indicate the water contained within the seepage meter headspace and circulation system is 95% mixed in ~1.3 min.

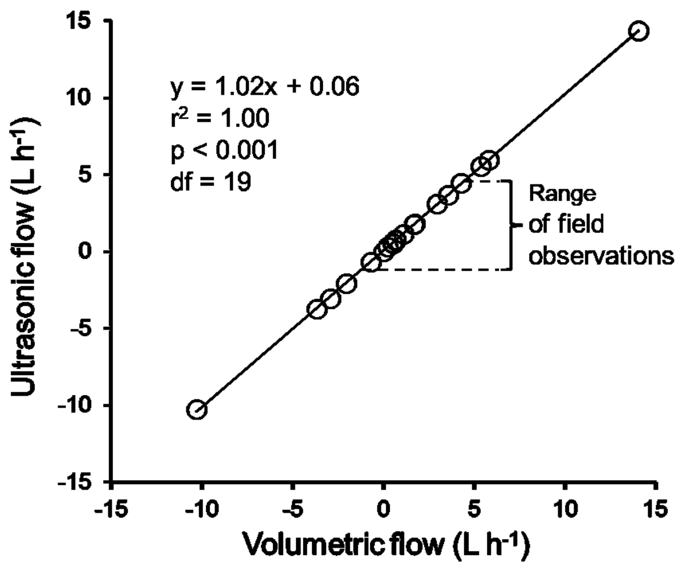


**Fig. S2.** Comparison of ultrasonically measured flow (y-axis) and gravimetrically measured flow reported in volumetric units (x-axis) from laboratory bench test. The range of measured groundwater discharge and recharge rates in Guinea Creek are also shown. Data are provided in Supplemental Table S1.

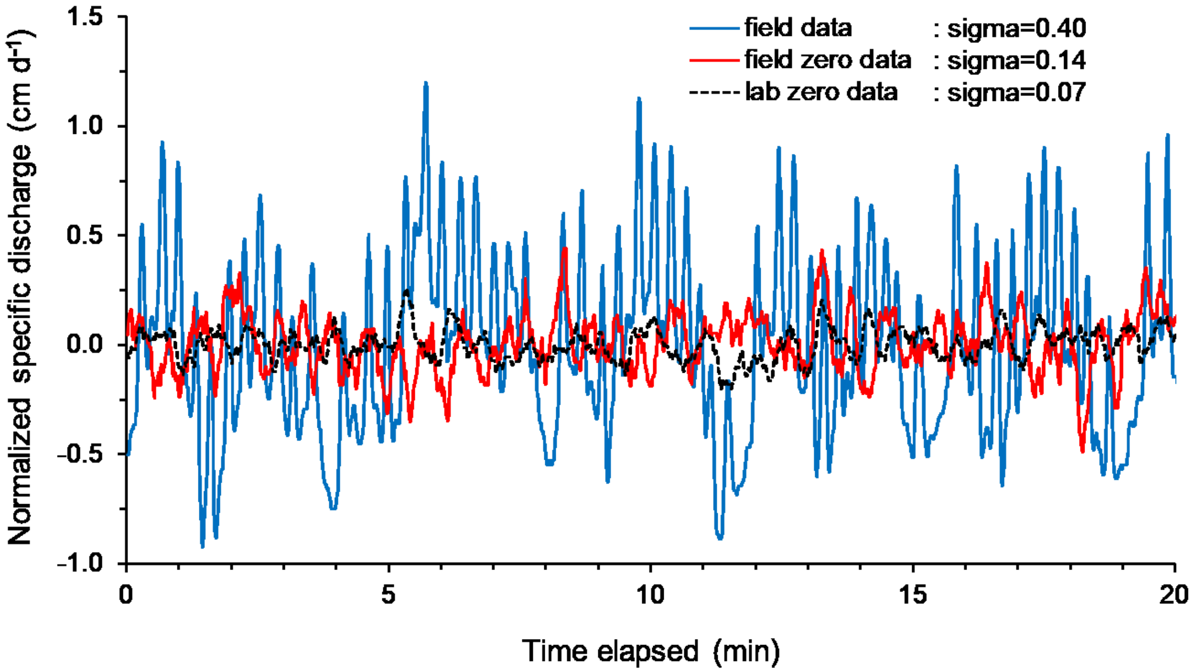


**Fig. S3.** Comparison of precision in ultrasonic measurements in three scenarios: slope- and intercept-adjusted ultrasonic groundwater discharge (Eq. S1, blue line), and ultrasonic data measured under zero-flow conditions in the field (solid red line) and laboratory (dashed black line). Data are shown relative to the same timescale for comparison in variability across a 20 min period, however data are not concurrent. Standard deviations are also shown for each measurement approach (*n* = 1,200).

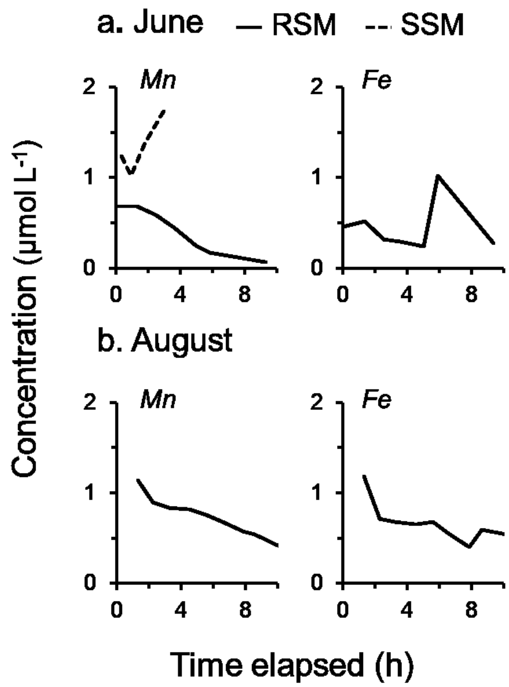


**Fig. S4.** Total dissolved manganese (Mn) and iron (Fe) in the regulated seepage meter (RSM, solid black line) and standard seepage meter (SSM, dashed black line) during June (top row), and August (bottom row) daytime paired deployments. Elapsed time is shown on the x-axes. Start times (t=0) were 9:44 AM and 8:37 AM local time for June and August, respectively.

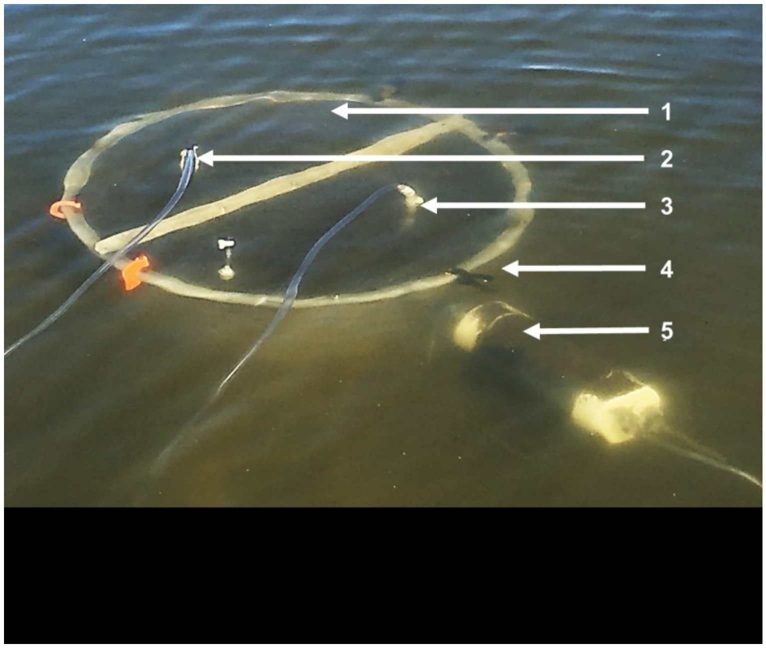


**Fig. S5.** Photograph of the oxygen- and light-regulated ultrasonic seepage meter (RSM) deployed in the shallow subtidal zone. Components shown are: 1. transparent removable lid, 2-3. inflow and outflow tubes for the recirculating flow system, 4. stainless steel base, 5. ultrasonic flow transducers mounted on a titanium flow tube encased in watertight plastic enclosure. Not shown are the gas permeable tubing, and the above-water sampling platform which contains: a syringe port for collection of dissolved constituents, YSI water quality sonde, ultrasonic flow sensor/ data logger, and 2 12-volt, 80-amp hour batteries powering electronic components. Photo credit: T.W. Brooks.

**Table S1.** Mean ultrasonically measured flow, and gravimetrically measured flow reported in volumetric units from laboratory bench test. Linear regression is shown in Fig. S2.

| Ultrasonic $Q$ (L h$^{-1}$) | Manual $Q$ (L h$^{-1}$) |
|---|---|
| -10.26 | -10.30 |
| -3.69 | -3.66 |
| -3.06 | -2.94 |
| -2.07 | -2.03 |
| -0.66 | -0.68 |
| 0.00 | 0.00 |
| 0.33 | 0.24 |
| 0.52 | 0.52 |
| 0.59 | 0.49 |
| 0.74 | 0.68 |
| 0.78 | 0.68 |
| 1.14 | 1.10 |
| 1.77 | 1.67 |
| 1.85 | 1.71 |
| 3.14 | 2.97 |
| 3.69 | 3.57 |
| 4.47 | 4.27 |
| 5.54 | 5.35 |
| 5.98 | 5.81 |
| 14.36 | 14.06 |

**Acknowledgements**

This work was supported by an award from Delaware Sea Grant (award No. NA100AR4170084 to J.K.Y and K.D.K.), and by the USGS Coastal and Marine Hazards and Resources Program. We thank Dan Torre, Beata Szymczycha, Stephanie DeVries, and Meagan Eagle for field and/ or analytical support. Chris Russoniello and Carlos Duque provided valuable comments on the preparation of this manuscript. We thank Don Rosenberry (USGS) and two anonymous reviewers for their constructive and valuable comments. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.