Investigating Contaminant Inputs via Submarine Groundwater Discharge to Coastal Waters Using Radium Isotopes

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Grant Number: N00014-99-1-0038
http://cafethorium.whoi.edu

LONG-TERM GOALS

Our long-term goal is to determine if submarine groundwater discharge (SGWD) is an important mechanism for delivering contaminants (i.e. heavy metals, organics) to harbors. We plan to accomplish this goal using a suite of naturally-occurring radium isotopes as tracers of SGWD and the dispersion of contaminants from the embayment (Buesseler/WHOI). In addition, we plan to develop a comprehensive hydrological model (Harvey/MIT) to determine the importance of SGWD in the transport of pollutants to coastal harbors.

OBJECTIVES

We will apply recently developed analytical techniques for measuring radium (^{223}Ra, ^{224}Ra delayed coincidence counting; ^{226}Ra, ^{228}Ra low-background gamma counting) in the study of contaminant fluxes via SGWD. Recent studies suggest that groundwater may be important in the mass balance of many elements in nearshore environments and cannot be ignored in the accurate prediction of the fate of contaminants originating in marine sediments and pore waters. Even if SGWD flows are modest, pollutant concentrations in groundwater may be sufficiently high for SGWD to have an important impact on the source and fate of pollutants in coastal harbors and estuaries.

APPROACH

Our scientific approach involves the use of radium isotopes and hydrodynamic models to study the contaminant flux via SGWD in coastal harbors. The short-lived radium isotopes are then used to predict contaminant residence times within the harbors. We spent much of the past year revisiting field sites occupied during Year 1 of the proposal. Specifically, we performed additional seepage meter deployments in our local study estuary (Waquoit Bay, MA) which has been well studied and is known to contain zones of high SGWD. Also, two additional week-long surveys of our main study area Boston Harbor were completed to assess general circulation patterns in the harbor as well as the baseline

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**

4. TITLE AND SUBTITLE **Investigating Contaminant Inputs via Submarine Groundwater Discharge to Coastal Waters Using Radium Isotopes**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Marine Chemistry and Geochemistry,,Woods Hole Oceanographic Institution,,Woods Hole,,MA,02543**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

distribution of radium isotopes. We performed a week-long study of Norfolk Harbor, VA using a sampling approach similar to our Boston Harbor study site.

WORK COMPLETED

During May 2000, we conducted an intensive week-long sampling effort in Norfolk Harbor (Elizabeth River Estuary), VA. We collected samples for water column radium isotopes, salinity/temperature, nutrients, trace metals, and trace organics. The same parameters were also measured in shallow groundwaters located along the land-water interface of the estuary. We coordinated sampling efforts with other ONR-Harbor Processes PIs (J. Donat, B. Sunda, A.Gordon).

This past summer (June and September), we surveyed water column radium activities in Boston Harbor during two week-long cruises. The data is currently being processed and will be combined with data obtained during a cruise in Year 1 of the proposal. We performed measurements of four radium isotopes and salinity/temperature profiles at over 50 stations including two transects extending over 15 km from shore. New to this year's Boston Harbor program was the collection of trace metal and trace organic samples to be analyzed during the Fall/Winter 2000.

We also constructed 40 seepage meters to capture SGWD, and deployed these meters in Waquoit Bay. The meters provide direct measurement of the groundwater flux, as well as water samples that are analyzed for radium concentrations and salinity. These measurements were taken from a 67 x 150m grid of 40 seepage meters at 2-hour intervals over a tidal cycle.

For the long-lived radium isotopes (^{226}Ra, ^{228}Ra), we acquired a Canberra Industries pure-germanium well-type gamma spectrophotometer. This detector, which arrived at WHOI during the Spring 2000, will be modified to include an active cosmic shield thus reducing background count rates and enhancing the signal to nose ratio. The cosmic shield is in the final stage of modification and will bring unique counting capabilities to ocean sciences.

RESULTS

The large-scale input of radium isotopes along the boundaries of a harbor is akin to a purposeful tracer release, with the short-lived radium isotopes providing the rate of dispersion based on their decay as they mix away from the source. To calculate residence times, we chose an approach based on the ratio of ^{223}Ra/^{228}Ra in the endmember groundwaters relative to that found in the estuary. This method is based on the decay rate of ^{223}Ra relative to ^{228}Ra, which corrects for mixing effects, and upon the assumption that the initial ^{223}Ra/ex^{228}Ra ratio is constant. The short half-life of our ^{223}Ra tracer ($t_{1/2}$ =11.4 d) makes it ideal for estimating water residence times in coastal harbors.

Using a physical-mixing model for Boston Harbor, Signell and Butman (1992) estimated a flushing time of 10 days with an upper limit of 17 days. From our August 1999 Boston Harbor data, the radium approach was in reasonable agreement yielding an average water residence time of 8.5 days. Application of the radium approach to Norfolk Harbor suggests that it was less efficiently flushed with a mean water residence time of 15 days. Upon completion of the contaminant analyses, these values will be integral to the mass-balance calculations for contaminant fluxes from the urban harbors.

In Waquoit Bay, a distinct spatial seepage pattern was observed indicating that most of the groundwater discharge occurs in a narrow band, which is between 25 and 45 meters from the shoreline (Fig. 1).

Tests using seepage meter clusters indicate significant variability in discharge at the meter scale. However, statistical analysis indicates that 20 seepage meters or more are sufficient to obtain a reliable estimate of both the amount of seepage and the spatial discharge pattern at the 50 meter scale. The temporal change, however, was not as significant; the groundwater flux varied less than a factor of two over the tidal cycle.

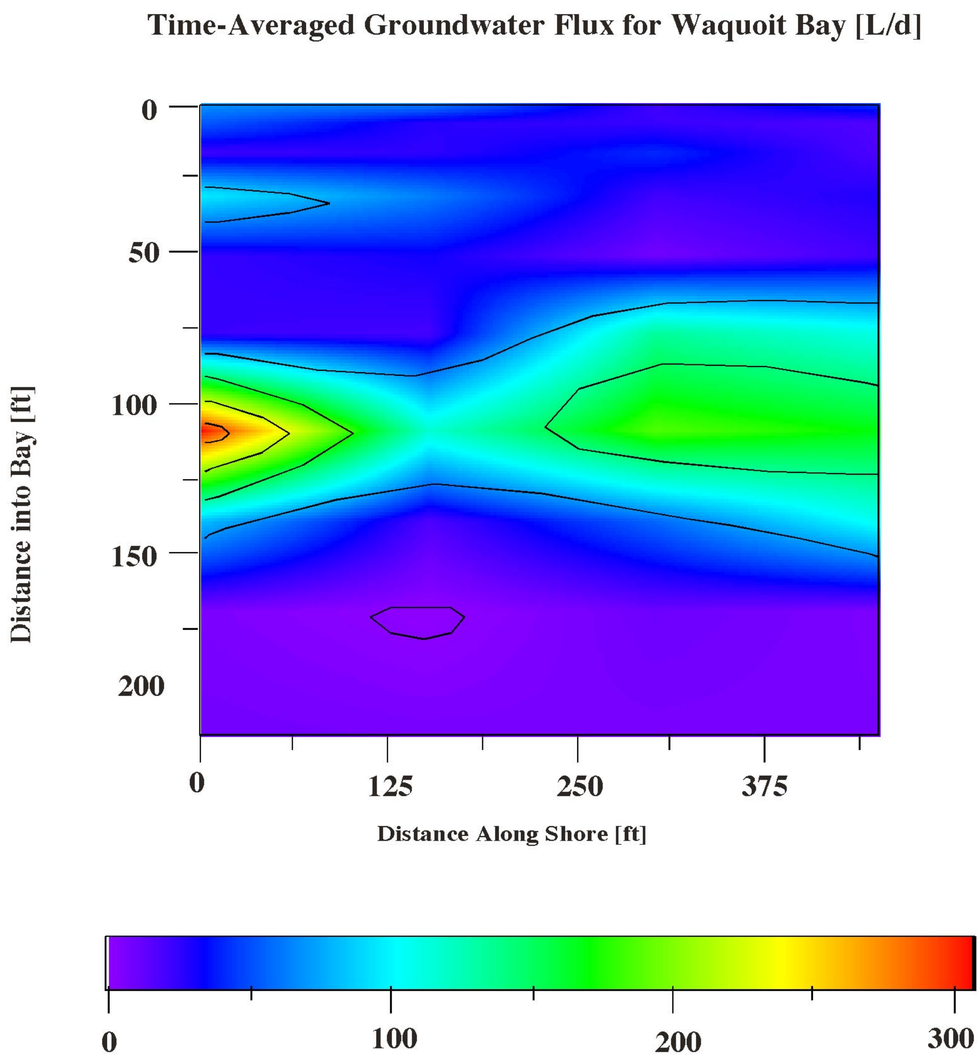

Figure 1. Interpolated spatial representation of groundwater seepage rate into Waquoit Ba.y Data was obtained by sampling a grid of 40 seepage meters 6 times over a tidal cycle and averaging in time.

Salinity analysis of the seepage meter samples indicates that most of the discharge is between 0 and 5 percent freshwater, with the exception of fresher discharge very near the shoreline. The behavior of the saltwater-freshwater interface during a tidal cycle, as well as radium concentrations near the interface, were characterized with samples drawn from a transect of piezometers perpendicular to the shoreline, driven to depths of up to 5 m.

Finally, a temperature probe was designed and constructed to measure vertical temperature gradients continuously over long periods of time. Because the thermal conductivity and capacity of submarine sediments are well known, this probe has the potential to provide an accurate measurement of localized groundwater flux.

IMPACT/APPLICATIONS

The residence time of water in an estuary is a complex function of topography, tidal range, and external inputs. In harbors with slow flushing rates, contaminants are retained and can lead to adverse biological effects. In contrast, a well-flushed embayment will likely be a source of contaminants to offshore waters. The short-lived radium isotopes (^{223}Ra-$t_{1/2}$ =11.4 d; ^{224}Ra-$t_{1/2}$ =3.6 d) have proven to be powerful *in situ* tracers of mixing rates and water residence times in coastal waters. Such information can be applied to modeling the dispersion of contaminants from coastal harbors. Also, because the calculated residence times are integrated over the half-lives of these short-lived tracers, estimates can be generated on a weekly to monthly time scales and used to estimate seasonal to interannual variability water residence times. The Waquoit Bay seepage meter data, combined with information from radium measurements, will aid in the future development of both a conceptual and numerical model of submarine groundwater flow patterns and discharge into nearshore marine environments.

TRANSITIONS

The nuclear detection equipment (well-type gamma detector and delayed coincidence counters) partially funded by ONR have received much use in studies other than this project. These include sedimentation studies in Lake Sisskiwit, MI and Santa Barbara Basin, CA, estimates of cross-shelf exchange in the Mid-Atlantic Bight, and nutrient and SGWD studies in West Falmouth Harbor, MA and Great Sippiwisset Marsh, MA.

RELATED PROJECTS

1 — Our radium data is being used to estimate water residence times and nutrient fluxes via SGWD in Waquoit Bay, Great Sippiwisset Marsh, and West Falmouth Harbor, MA (Rick Crawford, WHOI visiting scientist; Richard Splivalo, WHOI Summer Student Fellow).

2 — Instrumentation acquired and developed during this project has been used for preliminary measurements of cross-shelf exchange in the Mid-Atlantic Bight (Linda Rasmussen, WHOI/MIT Joint Program Student).

PUBLICATIONS

Andrews, J.A., M.A. Charette, R. Crawford, R. Splivalo, and K.O. Buesseler (2000). Utility of radium isotopes for evaluating the input and transport of groundwater-derived nitrogen in a Cape Cod estuary, EOS, 80 (49), OS15.

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