www.publish.csiro.au/journals/env A. Paytan et al., *Environmental Chemistry* **2004**, *1*, 1–2. doi:10.1071/EN04002

Bacterial Contamination and Submarine Groundwater Discharge—A Possible Link

Adina Paytan,[A,C] *Alexandria B. Boehm*,[B] *and Gregory G. Shellenbarger*[B]

[A] Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305, USA.
[B] Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA.
[C] Corresponding author (e-mail: apaytan@pangea.stanford.edu).

Environmental Context. *Pathogenic bacteria and viruses are sometimes detected in coastal waters, high levels of which correlate with occurrence of acute gastrointestinal illness in recreational beach users. The source of the bacterial and viral contamination to the beach is not always easy to decipher, and therefore efforts to prevent these occurrences are limited by lack of full understanding of their cause.*

Abstract. Beach water contamination by pathogenic agents is monitored by Fecal Indicator Bacteria (FIB) levels. A source of these agents may be submarine groundwater discharge. At Huntington Beach, California high FIB levels in the surf zone are shown to be associated with high ^{224}Ra and ^{223}Ra activities, indicators of groundwater discharge.

Keywords. bacteria — groundwater — radium — sewage — water analysis

Manuscript received: 9 February 2004.
Final version: 5 April 2004.

Pathogenic bacteria and viruses are sometimes detected in coastal waters. Incidents of high levels of pathogenic bacteria have been correlated with occurrence of acute gastrointestinal illness in recreational beach users and result in beach closures that impact coastal communities.[1–4] Accordingly, public beaches with high visitor loads are routinely monitored for FIB levels, an indicator for pathogenic agents.[5] The source of the bacterial and viral contamination to the beach is not always easy to decipher and therefore efforts to prevent these occurrences are limited by lack of full understanding of their cause. One possible source of FIB pollution to the surf zone is submarine groundwater discharge from the coastal unconfined surface aquifer. Here we show that at Huntington Beach, CA, USA, high abundances of FIB are typically associated with high activity of short-lived radium isotopes. High radium activities in coastal waters are indicators for submarine groundwater discharge.[6–8]

Radium is a naturally occurring radioactive element that forms from uranium and thorium decay in soil, rocks, and sediments. When fresh water is in contact with the aquifer rock the radium remains adsorbed, however when these rocks are exposed to saline water with high ionic strength the radium desorbs from the rocks and is incorporated into the saline groundwater.[9,10] As a result saline groundwater is enriched in radium and high radium levels in coastal waters have been extensively used as indicators for saline groundwater discharge.[6–8] We have determined FIB levels, radium isotope activities, salinities, and dissolved nutrient (phosphate, nitrate, ammonia, and silica) concentrations in water samples obtained from the perched aquifer intersecting the beach, as well as samples within the surf zone (ankle and knee depth) and offshore at Huntington Beach. Samples were collected weekly in August 2003, during both low and high tides, around lifeguard stations 9 and 10, a 128-m stretch at Huntington Beach (see Experimental Methods).

The activities of the naturally occurring short-lived radium isotopes in seawater close to shore within the surf zone (average activities of 29.6 and 0.97 dpm per 100 L for ^{224}Ra and ^{223}Ra respectively) were consistently elevated compared to off shore samples (11.8 and 0.46 dpm per 100 L for ^{224}Ra and ^{223}Ra respectively). Radium activities in saline groundwater collected from holes dug in the sand a few meters inshore from the coastline and from wells installed 50-m inshore were at least 20 times higher than any seawater sample (average 472 and 20 dpm per 100 L of ^{224}Ra and ^{223}Ra respectively). Nutrient concentrations in the surf zone are significantly elevated (factor of two) when compared to offshore waters, and the perched aquifer water contained much higher nutrient concentrations than the seawater samples. This saline radium and nutrient-rich groundwater is in direct communication with the coastal water and presumably discharges directly at the beach line. It must be emphasized here that this discharge is not of fresh groundwater, but rather it consists of a mixture of tidally flushed seawater with a very small component of freshwater that is locally recharging.[11,12]

Samples from the surf zone with high radium activities (^{224}Ra exceeding 30 dpm per 100 L), indicating a significant contribution of water from the perched coastal saline

1448-2517/04/010001

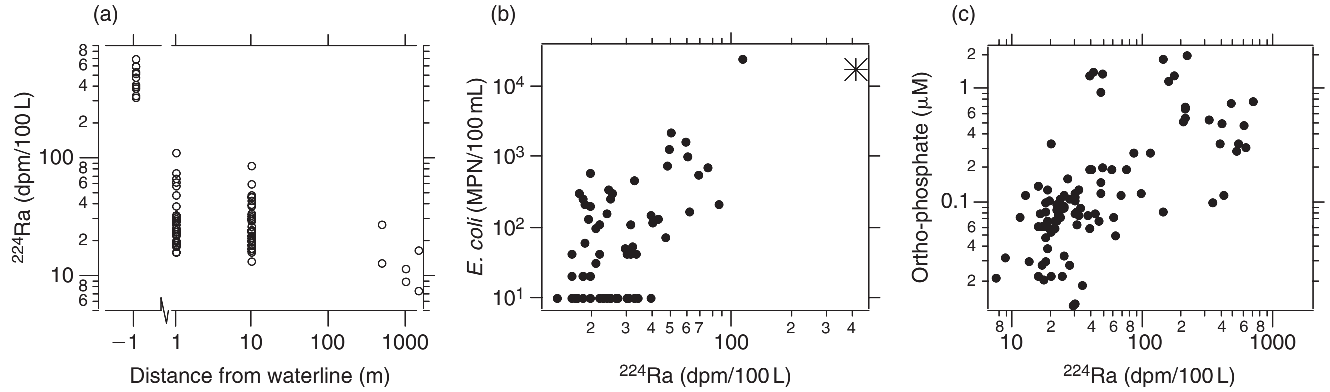

Fig. 1. (a) Distribution of ^{224}Ra activity at Huntington Beach in water collected between lifeguard stations 9 and 10. Distance is in meters from the waterline at the time of sampling. Negative distance indicates samples taken from holes in the sand inshore from the water line at the time of sampling. Note the log scale of both axes. Only ^{224}Ra are shown because ^{223}Ra and ^{224}Ra activities for all samples collected were highly correlated. (b) Correspondence between ^{224}Ra activity and FIB levels in surf zone water samples. Note the positive correlation at Ra activities higher than 30 dpm per 100 L. The asterisk represents the FIB levels in one saline groundwater sample from the surficial unconfined aquifer. Variance analysis (*Matlab*, Mathworks, Natick, MA) indicated that ^{224}Ra accounts for ~33% of variance in log FIB ($P < 0.05$). (c) ^{224}Ra versus dissolved phosphate concentration in all water samples (surf zone, offshore, and surficial aquifer). Positive, significant correlation exists for FIB and phosphate accounting for 12–20% of the variability in log FIB ($P < 0.05$).

aquifer, were associated with elevated levels of FIB (Fig. 1). Based on our radium data it is evident that the flux of saline groundwater discharge to the surf zone is tidally influenced with greater quantities present during spring tides and low tide, suggesting that tidal pumping drives water exchange. The spring–neap variation in groundwater discharge is consistent with the spring–neap pattern observed in FIB levels[13] and nutrients in the surf zone. The spatial–temporal consistency between FIB and radium and nutrients (Fig. 1) points to a possible connection between groundwater and microbial pollution at Huntington Beach. These results suggest that there might be a link between groundwater discharge and FIB levels in the surf zone. Our data support the hypotheses that either nutrients or other constituents such as dissolved organic matter from submarine groundwater influence the persistence/growth of FIB in the surf zone, or that the surficial perched aquifer groundwater itself is a source of FIB. Indeed, all of the saline groundwater samples we collected had elevated nutrient concentration and one saline groundwater sample collected at station 9 from a shallow hole dug in the intertidal zone (Fig. 1b) contained FIB in excess of the single-sample standard for all FIB used for beach monitoring. The exact mechanism by which groundwater discharge and FIB levels are related should be further investigated.

Experimental Methods

The study took place in Huntington State Beach, Orange County, California (33°38′ N, 117°59′ W). This coastline, and in particular the beach stretch between lifeguard stations 9 and 10, has been plagued by elevated levels of FIB since the summer of 1999. Four sampling excursions were conducted during August 2003 to include two neap tides and two spring tides. Surface seawater was collected at ankle and waist depth in the surf zone at low and high tide and outside the surf zone, 1500 m offshore. In addition, groundwater samples from the surficial unconfined aquifer were obtained from (a) shallow holes (<1 m deep) dug in the intertidal zone away from the swash area and (b) wells installed 50 m from mean low water at 3 m depth using screened polyvinylchloride well points. All samples were analyzed for ^{223}Ra and ^{224}Ra activities, FIB, salinity, temperature, and nutrient concentrations.

Water for Ra analyses (between 30 and 100 L) was passed over manganese impregnated acrylic fibers in the field and fibers were analyzed within at most 3 days for short-lived Ra isotope activities using a scintillation cell interfaced to a photomultiplier and delay coincidence counter. The analytical error associated with this measurement is ~10%. ^{228}Th-supported ^{224}Ra activity was $2.8 \pm 1.2\%$, with no difference between groundwater and surf zone samples, and thus insignificant in our samples, consistent with observations of Rama et al.[14] A 50-mL aliquot of each sample was used for determination of FIB, including total coliform, fecal coliform, and *Enterococcus* using Colilert-18 and Enterolert (IDEXX, Westbrook, ME) tests.

Acknowledgements

Funding was provided by a UPS Urbanization Research Fund to A.P.; A.B. was funded by the Clare Boothe Luce Professorship.

References

[1] D. Turbow, N. Osgood, S. C. Jiang, *Environ. Health Perspect.* **2003**, *111*, 598. doi:10.1289/ehp.5563
[2] E. K. Lipp, S. A. Farrah, J. B. Rose, *Mar. Pollut. Bull.* **2001**, *42*, 286. doi:10.1016/S0025-326X(00)00152-1
[3] S. R. L. Rabinovic, et al., *Environ. Sci. Technol.* **2004**, in press.
[4] V. J. Cabelli, A. P. Dufour, L. J. McCabe, M. A. Levin, *Am. J. Epidemiol.* **1982**, *115*, 606.
[5] R. J. Haile, et al., *Epidemiology* **1999**, *10*, 355.
[6] W. S. Moore, *Nature* **1996**, *380*, 612. doi:10.1038/380612A0
[7] J. M. Krest, J. W. Harvey, *Limnol. Oceanogr.* **2003**, *48*, 290.
[8] W. S. Moore, *Biogeochemistry* **2004**, in press.
[9] I. T. Webster, G. J. Hancock, A. S. Murray, *Limnol. Oceanogr.* **1994**, *39*, 1917.
[10] H. S. Yang, D. W. Hwang, G. B. Kim, *Mar. Chem.* **2002**, *78*, 1. doi:10.1016/S0304-4203(02)00004-X
[11] W. S. Moore, *Mar. Chem.* **1999**, *65*, 111. doi:10.1016/S0304-4203(99)00014-6
[12] G. B. Kim, D. W. Hwang, *Geophys. Res. Lett.* **2002**, *29*, 14. doi:10.1029/2002GL015093
[13] A. B. Boehm, et al., *Environ. Sci. Technol.* **2002**, *36*, 3885. doi:10.1021/ES020524U
[14] Rama, J. F. Todd, J. L. Butts, W. S. Moore, *Mar. Chem.* **1997**, *22*, 43. doi:10.1016/0304-4203(87)90047-8