

# UC San Diego

## Research Final Reports

### Title

Understanding submarine groundwater discharge and its influence on coastal water quality along the California Coast

### Permalink

<https://escholarship.org/uc/item/94q158zd>

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### Publication Date

2010-01-26

### Supplemental Material

<https://escholarship.org/uc/item/94q158zd#supplemental>

**California Sea Grant Sea Grant  
Final Project Progress Report**

01/26/2010

R/CZ-197

07/01/2006-01/30/2010

Understanding submarine groundwater discharge and its influence on coastal water quality along the California Coast

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**Project Hypotheses**

We proposed directed field and modeling research to address the following hypotheses:

(H1) Submarine groundwater discharge (SGD), its quality, and the percentage that is fresh versus saline, is modulated by season, tides, and wave conditions,  
(H2) the chemical (nutrient, carbon, trace metal) and biological (human health indicators) composition of SGD is affected by land use and geology,  
(H3) human health indicators and nutrients can be freely transported through the beach aquifer and are not removed via interactions with the sediments, and  
(H4) SGD impacts the water quality of the nearshore environment at a level comparable to surficial runoff.

**Project Goals and Objectives**

Over the last two decades, researchers have come to recognize that submarine groundwater discharge (SGD) can be a significant contributor of nutrients and freshwater to the coastal environment. SGD is also recognized as a potentially important pathway for non-point pollution migration to the nearshore, particularly where agricultural or urban activities have impacted the groundwater. In order to fully understand pollutant transport in coastal and estuarine waters of California, and develop sound management practices and policies for protecting coastal ecosystem and human health (Sea Grant priorities), it is necessary to quantify this hydrological link between the land and sea and its effects on coastal water quality in California. Our project goals included the quantification of SGD and associated chemical and microbiological fluxes across multiple timescales at a single California beach with varied land use. The research was conducted at Stinson Beach, California, a coastal community that uses on-site wastewater treatment (septic systems) for wastewater disposal. The research included fieldwork, laboratory experiments, and computer modeling.

### **Briefly describe project methodology**

Submarine groundwater discharge was calculated across multiple timescales and wave conditions using radium and salinity as tracers. Results were compared with estimates produced by analytical models and Darcy calculations. Chemical fluxes of dissolved inorganic nitrogen and phosphate associated with SGD were calculated by multiplying appropriate groundwater end member concentrations by their respective calculated discharge rates. These same fluxes were compared with measured fluxes of nutrients and bacteria from local surficial sources including Bolinas Lagoon and local perennial streams. A single leach field at the coastal margin was instrumented to investigate field-scale spatial variability and transport characteristics of human health indicators and nutrients in groundwater at the land/sea interface. Transport properties of human health indicators and nutrients in porous media from the site were measured directly via bench-top column experiments in the laboratory. A groundwater model incorporating field measurements of groundwater head, hydraulic conductivity, aquifer recharge characteristics, and measured contaminant attenuation rates was then created to explore annual cycles of SGD and associated contaminant fluxes.

### **Describe progress and accomplishments toward meeting goals and objectives**

In July 2006, field research was conducted to estimate fresh and saline SGD and associated nutrient and microbiological fluxes from the Calles district of Stinson Beach, a residential area with a high density of septic leach fields within approximately 300 m of the ocean. From this work, one paper was written and published which documented fortnightly neap-spring variability in fresh and saline SGD (de Sieyes, N. R., K. M. Yamahara, B. Layton, and A. B. Boehm. 2008. Fresh submarine groundwater discharge at Stinson Beach, California, is enhanced during neap tides. *Journal of Limnology and Oceanography*. 53(4): 1434-1445; H1 & H2). This paper documented a strong fortnightly component linked to neap-spring tides, and a short phytoplankton bloom following a pulse of nutrient-enriched SGD observed at neap tide. Fieldwork was conducted again at the Calles field site in March 2007, and a second paper was written comparing SGD based on natural radium tracers across multiple timescales and wave conditions experienced during the two experiments (de Sieyes, N. R., K. M. Yamahara, A. Paytan and A. B. Boehm. Submarine groundwater discharge to a high-energy surf zone at Stinson Beach, California, estimated using radium isotopes. Submitted.). In this paper, we found that semidiurnal and neap-spring tides, swell height, and season each significantly impacted radium tracer activities in the surf zone, illustrating the importance of multiple factors influencing the timing and magnitude of SGD (H1). In this paper, nutrient fluxes associated with SGD were found to be greater than or equal to that of local surface water inputs (H4). Our monitoring at Stinson Beach Park has documented the high degree of variability in coastal groundwater quality over small geographic distances due to anthropogenic impacts – in this case, septic systems – indicating the importance of land use on the quality of SGD with respect to certain anthropogenic contaminants (H2). Detailed monitoring of a single septic system at Stinson beach Park has also shown that the fate of groundwater contaminants is highly seasonal in nature, and significantly greater concentrations of both dissolved inorganic nitrogen species as well as fecal indicator bacteria (FIB) were observed in the beach aquifer in summer following periods of high septic system usage and fast groundwater flow. Though evidence of annual cycles in FIB transport was documented, throughout our experiments we found little evidence that SGD-associated fecal indicator bacteria is impacting surf zone water quality at Stinson Beach, and bench-top column experiments conducted in the laboratory showed moderate to fast attenuation of human health indicators in beach aquifer material collected from the site (H3). Collectively, the measured attenuation rates for both FIB and nutrients have been incorporated into a groundwater model along with other hydrogeologic data from the site in order to

forecast the timing and magnitude of septic effluent-contaminated SGD, the subject of a third publication which is presently in preparation.

### **Project modifications**

Originally, we had proposed to conduct seasonal monitoring experiments at two California beaches with varying land use to examine the importance of that factor. After two initial field experiments were completed at the Calles residential area of Stinson Beach site, our careful consideration of potential second field sites led us to conclude that it would be very interesting and informative to continue our research at Stinson Beach, a community that uses exclusively on-site wastewater treatment, or septic systems. This change was made after discussions with Sea Grant, and was in keeping with original advice provided by reviewers during the initial grant proposal review process. This decision followed partially from our new understanding that (1) land use over short spatial scales affects groundwater quality and thus submarine groundwater discharge quality, and that (2) transformation processes in the subsurface likely play a large role in modulating input of pollutants from the land to the sea via submarine groundwater discharge.

An ancillary research topic investigated during our study in the Calles residential area of Stinson Beach was the topic of mercury discharging to the coastal ocean with submarine groundwater. Working with researchers from the University of California, Santa Cruz, fluxes of total mercury (HgT) and monomethyl mercury (MMHg) associated with SGD at Stinson Beach were estimated by combining measurements of HgT and MMHg in groundwater and surface water with estimates of SGD based on short-lived naturally occurring radium isotope tracers. This work demonstrated that SGD is an important source of both HgT and MMHg to coastal waters along the central California coast. The results of this work were published in a paper (Black, F., Paytan, A., Knee, K., de Sieyes, N., Ganguli, P., Gray, E., and Flegal, R. 2009. Submarine groundwater discharge of total mercury and monomethyl mercury to central California coastal waters. *Environmental Science and Technology*. 43(15): 5652-5659).

Beginning January 2008, we shifted our attention and resources to a new part of Stinson Beach approximately 1.5 km south of the Calles field site, within the boundaries of Stinson Beach Park, Golden Gate National Recreation Area (GGNRA). Water level measurements collected in an existing monitoring well network in this area confirm the existence of a steep seaward hydraulic gradient. Here, three large leach fields service upwards of 100,000 park visitors per month. Working with GGNRA and the National Park Service, we permitted the installation of a large, dense array of monitoring wells in the area up- and down-gradient from a single leach field in order to observe the transport and transformation of contaminants from the leach field to the coastal ocean. Using our dense monitoring network, we have been able to estimate the contributions of nutrient-, fecal-, and other anthropogenic pollution to groundwater and the coastal ocean from a single leach field. The information from this second field site, in combination from the data from our first field site, provides in-depth information about how septic systems along the coast impact coastal water quality – information that is desperately needed by policy makers.

### **Project outcomes**

Data collected during experiments has been shared primarily through peer-reviewed publications, conference proceedings, and presentations for local stakeholders and agencies. In July 2006, field research was conducted to estimate fresh and saline SGD and associated nutrient fluxes, and from this work a first paper was published in the *Limnology and Oceanography* (de Sieyes et al., 2008). A second publication comparing the July 2006 results to those from a second study in March 2007 is in the final stages of submission, and will compare seasonal and tidal variability in SGD and associated fluxes at the Calles field site based on natural radium isotopic tracers. A third publication in preparation uses the data from the dense monitoring well array at the Stinson Beach Park site with the results of the numerical groundwater model to elucidate the temporal and spatial variability in concentration and flux of a plume of septic effluent-impacted groundwater as it flows through the beach and discharges to the sea. An ancillary paper we coauthored estimated flux of total- and methylated mercury associated with SGD. In addition to these peer-reviewed publications, we have presented our research to the broader scientific community at conferences and directly to the public and local stakeholders including the National Park Service and the Stinson Beach County Water District. Details regarding the time and place of each presentation are below.

This project produced significant amounts of raw physical, chemical and microbiological data. For example, physical data includes piezometric head measurements and surveyed beach topography. Chemical and microbiological data includes radium activity, salinity, and concentrations of dissolved oxygen, nitrogen, and carbon species as well as fecal indicator bacteria concentrations in both surface waters and groundwaters at the site. Following publication, this data will be made available upon request. Data requests can be made to Professor Alexandria Boehm via California Sea Grant.

### **Impacts of project**

This project has contributed to the understanding of land/sea interactions by providing important estimates of groundwater discharge and associated chemical and microbiological fluxes to the sea. These fluxes are comparable with those associated with surficial runoff and highlight the importance of protecting shallow groundwater quality along the California coastline, particularly with respect to the use of septic systems in coastal communities. Specifically, our 2008 publication in *Limnology and Oceanography* was the first study in California to show definitively that septic tanks can affect coastal water quality through submarine groundwater discharge. This was a timely result given recent controversy surrounding California Assembly Bill 885, which proposes new regulations for onsite wastewater treatment systems (septic systems). This result was also highlighted in a Sea Grant press release that was picked up by numerous newspapers across California (<http://www-csgc.ucsd.edu/NEWSROOM/NEWSRELEASES/2009/CoastalWaterQuality.html>). Given the recent interest in this topic, we expect that our two upcoming publications will have similarly high impact.

### **Benefits, commercialization and application of project results**

Our results were incorporated into the Bolinas Lagoon Ecosystem Restoration Project (<http://farallones.noaa.gov/ecosystemprotection/bolinas.html>), which cited our results in stressing the importance of monitoring and protecting groundwater resources from septic system pollution for the restoration of Bolinas Lagoon. Contact: Gulf of the Farallones National Marine Sanctuary, 991 Marine Drive, The Presidio, San Francisco, CA 94129, 415-561-6622. Results were also included as evidence in the Marin County Local Coastal Plan update as evidence for negative impacts on groundwater quality from septic systems in Marin County. Contact: Kristin Drum, Marin County Planning Commission, 3501

Civic Center Dr., San Rafael, CA 94903, MarinLCP@co.marin.ca.us, (415) 499-6290. Boehm also was consulted by the state water board to assist in preparing the report that was used to uphold the ruling that septic tanks would no longer be allowed in Malibu Beach.

**Economic benefits generated by discovery**

n/a

**Issue-based forecast capabilities**

Our work has improved the general ability of managers to forecast the nature of potential SGD-associated coastal pollution due to septic systems at Stinson Beach.

Tools, technologies and information services developed

n/a

**Publications**

**Conference papers, proceedings, symposia**

Title: An interdisciplinary study of submarine groundwater discharge from a coastal aquifer receiving leachate from septic tanks

Authors: de Sieyes, N. R. and A. B. Boehm.

Date: February 23, 2010

Conference Title: 2010 Ocean Sciences Meeting

Location: Portland, Oregon

Title: Submarine groundwater discharge at an open ocean marine beach in California.

Authors: de Sieyes, N. R. and A. B. Boehm.

Date: June 25 2008

Conference Title: 20th Salt Water Intrusion Meeting

Location: Naples, Florida

Title: Fresh submarine groundwater discharge from a contaminated beach aquifer is enhanced during neap tide.

Authors: de Sieyes, N. R., K. M. Yamahara, and A. B. Boehm

Date: May 23, 2007

Conference Title: Joint Assembly of the American Geophysical Union

Location: Acapulco, Mexico

Title: Submarine groundwater discharge of total mercury and monomethyl mercury to central California coastal waters.

Authors: Black, F., Paytan, A., Knee, K., de Sieyes, N., Ganguli, P., Gray, E., and Flegal, R.

Date: 2009

Journal Name: Environmental Science and Technology

Issue/Page Numbers: 43(15): 5652-5659

Title: Fresh submarine groundwater discharge at Stinson Beach, California, is enhanced during neap tides.  
Authors: de Sieyes, N. R., K. M. Yamahara, B. Layton, and A. B. Boehm.  
Date: 2008  
Journal Name: Limnology and Oceanography  
Issue/Page Numbers: 53(4): 1434-1445

Title: Submarine groundwater discharge to a high-energy surf zone at Stinson Beach, California, estimated using radium isotopes.  
Authors: de Sieyes, N. R., K. M. Yamahara, A. Paytan, and A. B. Boehm.  
Date: submitted

**Theses, dissertations**

Title: Onsite Wastewater Treatment Systems and Submarine Groundwater Discharge at Stinson Beach, California.  
Authors: de Sieyes, N. R.  
School: Stanford University  
Date: 09/2010 (expected)

**Media coverage**

Name of publication/radio station, etc: *Malibu Surfside News*  
City: Malibu  
State: CA  
Date of publication/broadcast: 03/18/2009,  
Headline or topic: Study Provides Ammo for Malibu Septic Critics; Stanford Research Project Says Leakage Pollutes Ocean

Name of publication/radio station, etc: *Humboldt Beacon*  
City: Fortuna  
State: CA  
Date of publication/broadcast: 03/18/2009  
Headline or topic: Septic tanks affect coastal water quality say Sea Grant researchers

**Please list any workshops/presentations given**

08/18/2007, 07/19/2008, and 01/16/2010: oral presentations made to Stinson Beach County Water District (SBCWD), audience of approximately 10 members of the public and board of directors, held at SBCWD headquarters in Stinson Beach, CA; content presented in each case was an update of data collected and conclusions made from research to date.

02/23/2010: poster presentation made to scientific audience of conference attendees at the Ocean Sciences Conference, Portland, Oregon; content presented was the compilation of results from the project, including estimates of submarine groundwater discharge and associated chemical fluxes across multiple timescales, importance of driving forces including tides, waves, and annual evapotranspiration cycles, fate and transport of nutrients and human health indicators in the beach aquifer, and the comparison of SGD-associated nutrient fluxes with those of local surface inputs.

11/10/2009: oral presentations made to National Park Service staff, held at Golden Gate National Recreation Area (GGNRA) headquarters at Stinson Beach, CA; content presented was an update of data collected and conclusions made from research to date.

06/25/2008: poster presentation made to scientific audience of 150 conference attendees at 20th Salt Water Intrusion Meeting in Naples, Florida; content

presented in each case was an update of data collected and conclusions made from research to date.

05/24/2007: oral presentation made to scientific audience of 20 conference attendees at the Joint Assembly of the American Geophysical Union, Acapulco, Mexico; content presented was the results of the July 2006 study at Stinson Beach comparing fresh and saline groundwater discharge and associated chemical fluxes across a neap-spring tidal cycle.

#### **Students**

Nicholas R. de Sieyes  
Stanford University  
Department of Civil & Environmental Engineering  
Degree program enrolled in: Ph.D.  
Theses/dissertation title: Onsite Wastewater Treatment Systems and Submarine Groundwater Discharge at Stinson Beach, California  
Supported by Sea Grant funds?  yes  no  
Start date: 09/01/2005  
End : 09/01/2010

Lillian Lam  
Swarthmore College  
Department of Biology  
Degree program enrolled in: B.S.  
Theses/dissertation title: n/a  
Supported by Sea Grant funds?  yes  no  
Start date: 05/01/2008  
End date: 07/31/2008

Elizabeth Joyce  
Stanford University  
Department of Civil and Environmental Engineering  
Degree program enrolled in: CEE  
Theses/dissertation title: n/a  
Supported by Sea Grant funds?  yes  no  
Start date 05/01/2007  
End date 7/31/2007

**How many students/volunteers were involved in the project? 6**

#### **Cooperating organizations**

##### **Federal**

Daphne Hatch, Golden Gate National Recreation Area, National Park Service (NPS); Assisted with permitting of project.

Kristen Ward, Gulf of the Farallones National Marine Reserve, National Oceanic and Atmospheric Administration (NOAA); Assisted with permitting of project.

##### **Local and state**

Toby Bisson, Manager, Stinson Beach County Water District; allowed for use of district monitoring wells, provided local knowledge of hydrogeology, climate, and development, and assisted with general project details

##### **Academic Institutions**

Adina Paytan, Institute of Marine Sciences, University of California -- Santa Cruz; provided access to radium analytical equipment.

##### **Awards**



Adina Paytan, Mildred Mathias Award as the outstanding proposal in the natural sciences – University of California, 2008  
Adina Paytan, Distinguished Lecture Award – Consortium for Ocean Leadership, 2008

**Keywords**

submarine, groundwater, discharge, radium, fecal indicator bacteria, nitrogen, phosphate