Submarine ground-water discharge and its role in coastal processes and ecosystems

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INTRODUCTION

Submarine ground-water discharge (SGD) has recently been recognized (Figure 1) as a phenomenon that can strongly influence coastal water and geochemical budgets and drive ecosystem change (D'Elia et al., 1981; Valiela et al., 1990; Burnett et al., 2003). For example, the discharge of nutrient-enriched ground water into coastal waters may contribute significantly to eutrophication (Bokuniewicz, 1980; Giblin and Gaines, 1990) and blooms of harmful algae (LaRoche et al., 1997). Similarly, the quantity of SGD can also directly affect the availability of fresh water to coastal communities, impact fragile coastal ecosystems such as estuaries and coral reefs (D'Elia et al., 1981), and influence geomorphology of shoreline features.

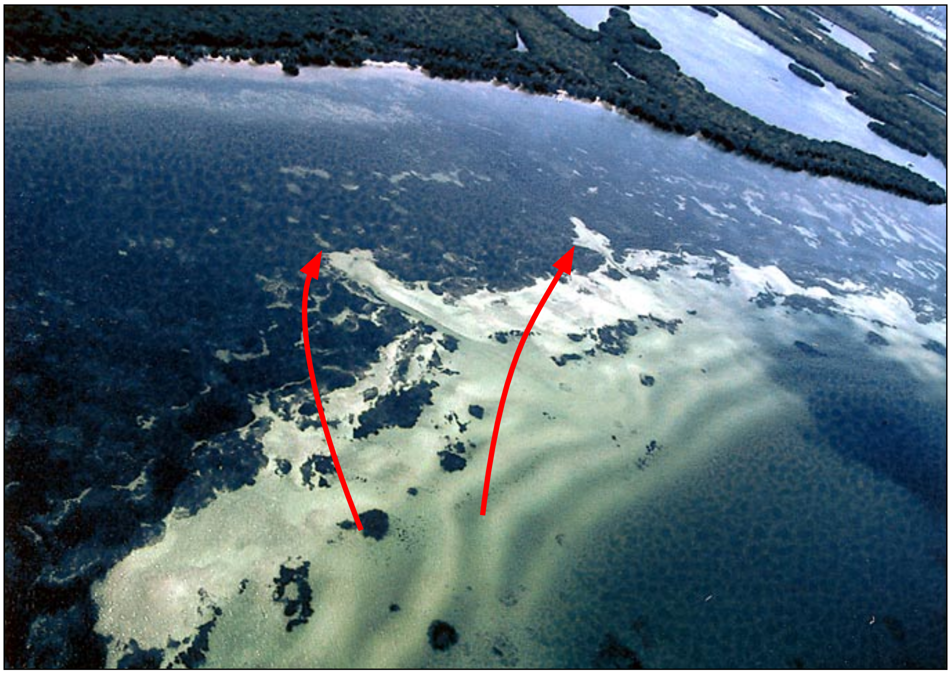

Figure 2: Aerial photo (courtesy of C. Kovach, FL DEP) of two coastal SGD sites (Tampa Bay, FL) directly affecting shoreline geomorphology.

Moore (1996) raised awareness of the global importance of SGD and much effort has been devoted to developing new tracer techniques and methods for the identification and quantification of SGD. Because the discharge of coastal ground water commonly occurs as diffuse seepage rather than focused discharge through identifiable springs (Swarzenski et al., 2001), assessing SGD has remained difficult for both oceanographers and hydrologists. Through national and international research programs, Burnett, Moore, Charette, and others have developed a rigorous, systematic approach for quantifying SGD using a wide assortment of tracers and methods (Burnett et al., 2003, Charette et al., 2001 and references therein). Intercalibration experiments, such as those conducted in coastal waters off Australia, Brazil, and Long Island, NY, demonstrate that careful measurements can accurately quantify SGD, confirm some of the driving mechanisms (e.g. climatic and tidal forcing), and constrain the spatial and temporal scales at which these mechanisms operate. Now that approaches for rigorously quantifying SGD are becoming better established, scientists can now begin to investigate the wide variety of coastal processes affected by SGD (e.g., Figure 2).

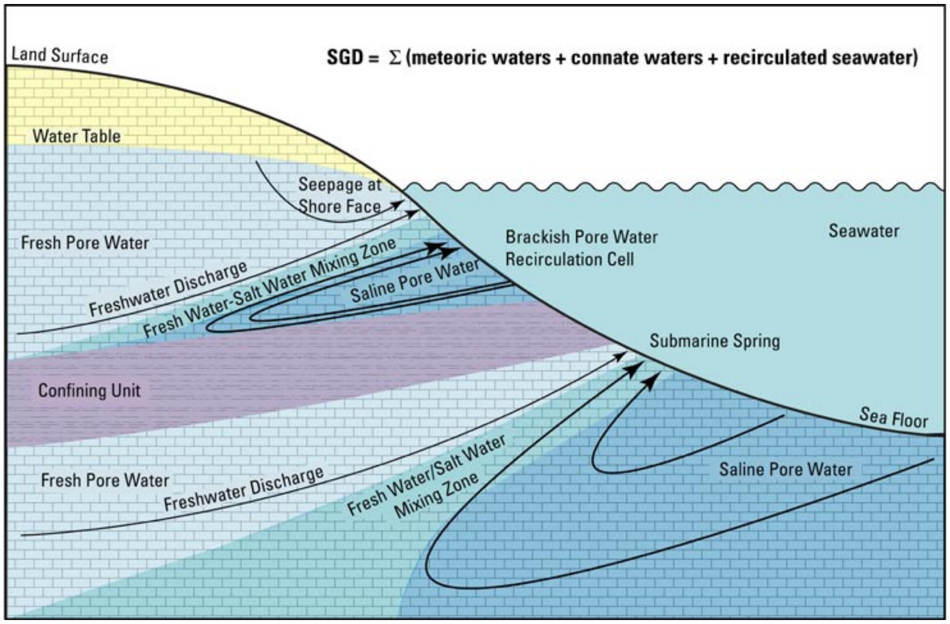

Figure 1: Cartoon depicting an idealized SGD-influenced hydrogeologic cross-section.

OBJECTIVES AND APPROACH

Figure 4: Drilling rig at Delmarva used for porewater sampling.

The USGS is uniquely poised to delineate SGD influence on coastal processes and ecosystems because the USGS has unparalleled collective expertise in the full set of tools that can be used to study SGD. USGS scientists representing the Water Resources Discipline (WRD) have well-established expertise in ground-water sampling and modeling techniques, including development and use of variable-density flow models such as SEAWAT, but their data for constraining models usually ends at the coastline. Scientists funded by the USGS Coastal and Marine Geology Program (CMGP) have been helping to develop and utilize a host of complementary new geophysical and geochemical tools and specialized instrumentation. Such techniques will comprehensively extend SGD work to the coastal ocean. Locations of ground-water discharge can be inferred using streaming resistivity instrumentation (Figure 3), which rapidly detects fresh and saline water below the sediment-water interface based on variations in the electrical resistance (inverse of conductivity) of the water. This technique complements approaches (sidescan, multibeam, subbottom acoustics) for mapping the surficial and subsurface geology, and inferring its influence on ground-water discharge locations and styles of discharge. New instruments capable of rapid, sensitive determination of radon activities can also pinpoint locations of ground-water discharge due to the frequent observation of greatly elevated radon (3.8-day half-life) activities in ground water, compared to typical surface-water activities. This technique can also be used to infer regionally averaged discharge rates by contrasting the ground-water and surface-water activities. A complementary tool is the autonomous seepage meter, which allows identifying localized rates of discharge over areas of <1 m^2. Multi-port piezometers and related equipment, including floating drilling platforms (Figure 4), allow samples of submarine ground water to be collected at different depths prior to discharge. These samples can then be analyzed for salinity, human-derived dissolved gases for age dating (CFCs, SF_6, and ^3H), and other constituents, especially nutrients like nitrate and ammonium. Residence times of waters can be estimated by measuring the four natural isotopes of radium, due to their range of half-lives from 3.8 days to 1600 years. These measurements can be made using a combination of new scintillation techniques and well-established gamma spectroscopy approaches. The USGS Science Centers in St. Petersburg and Woods Hole have recently acquired many of these instruments. Additional instruments and analyses are available through collaborations with other USGS scientists and researchers at academic institutions.

As mentioned above, the study of SGD is immensely valuable for understanding the availability of water for both humans and coastal ecosystems. In addition, the study of SGD is of value because of SGD's influence on many coastal processes that span the disciplines of geology, geomorphology, geochemistry, biology, hydrology, and ecology. Specific examples of research areas where USGS SGD studies can help to solve interdisciplinary problems include:

i) assessment of the redox- and microbially-controlled delivery of SGD-borne nutrients and trace elements *(linking the fields of geochemistry and coastal hydrogeology)*

ii) evaluation of coastal ecosystem change in response to variable SGD *(linking the fields of biology, ecology, and biogeochemistry to coastal hydrogeology and meteorology)*

iii) examination of SGD-breached shorefaces and the influence of SGD associated with paleo-channels on erosional hotspots *(linking the fields of coastal geology and geomorphology to coastal hydrology),*

iv) developing the capability to predict/forecast SGD-associated processes and events *(e.g., can we predict lag times between initiation of wastewater*

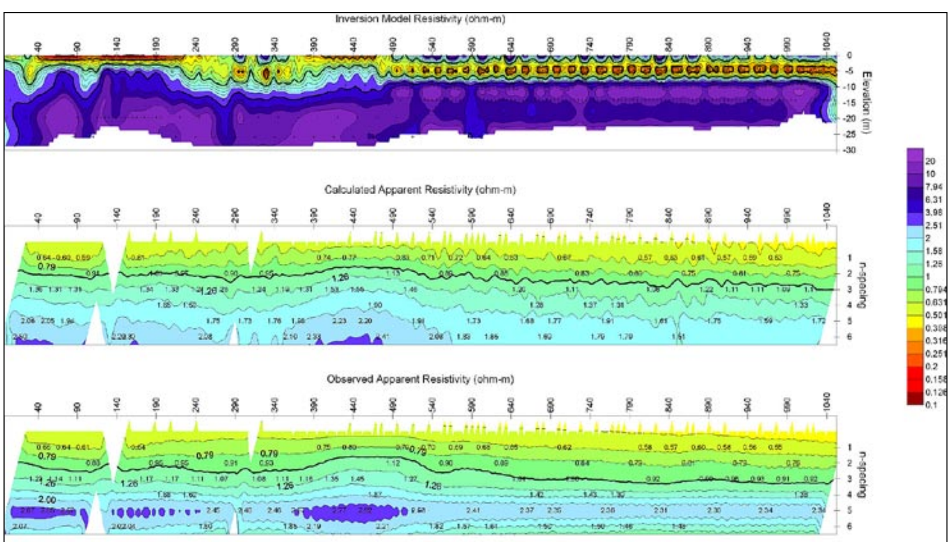

Figure 3: Modeled (top graph) resisitivty contours reveal freshened (indicated in blue/purple) ground-water masses at depths > 10m in Tampa Bay.

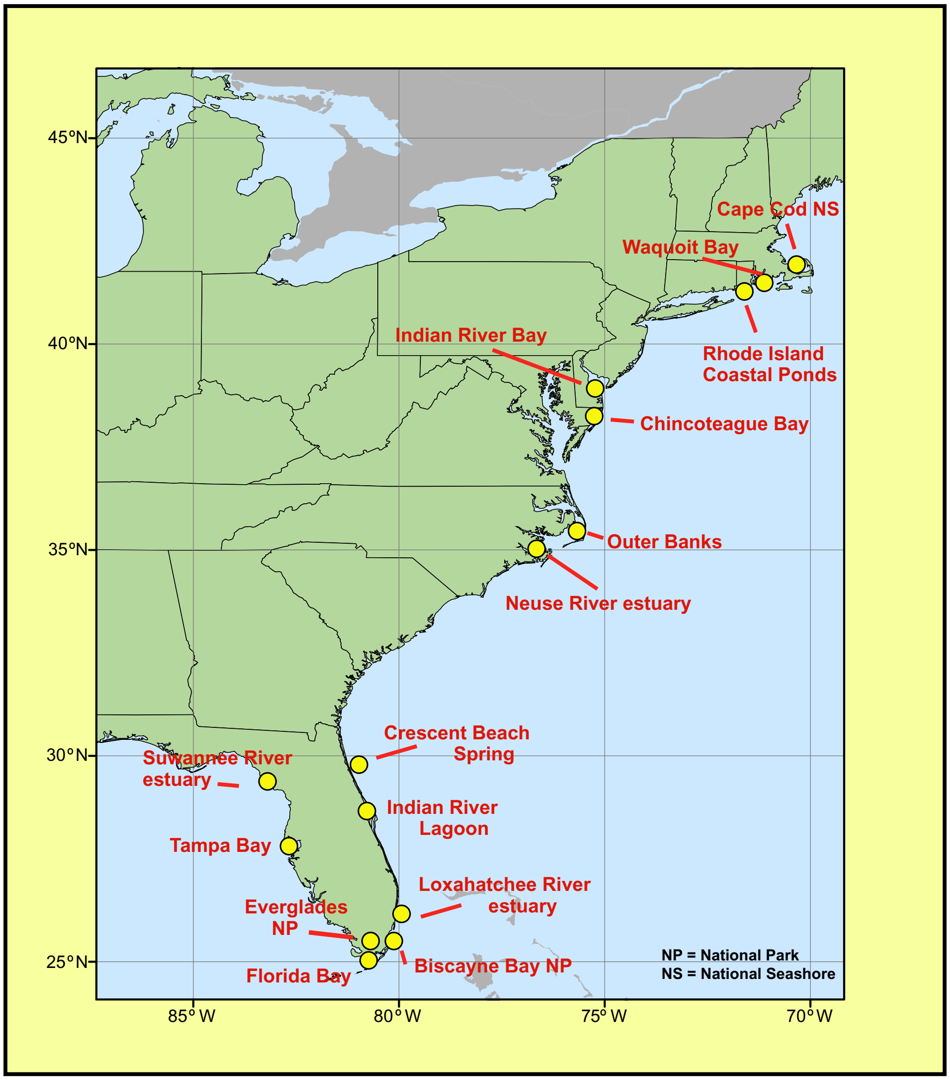

Figure 5: US east coast map depicting selected USGS SGD project sites.

discharge into coastal aquifers and appearance of impacts of SGD-derived nutrients on coastal ecosystems?)

As this list suggests, studies of SGD can play integral roles in a host of interdisciplinary research projects in the coastal zone.

CURRENT AND FUTURE PROJECTS

Current SGD projects at USGS are primarily focused on the first-order questions of the locations and rates of discharge, as well as studies of nutrient delivery from SGD (Figure 5). These include:

Delmarva Peninsula

- Characterization of submarine extensions of surficial aquifers in Delaware and Maryland beneath coastal bays, especially Indian River Bay and Chincoteague Bay, including determination of the contribution of SGD to eutrophication (2000-present)

Florida

- *Indian River Lagoon:* estimating the contribution of SGD to the lagoon using radium isotope measurements (1999-2001).
- *Biscayne Bay:* Characterization of SGD rates and hydrogeologic control thereof (1998-present)
- *Crescent Beach Spring:* geological and geochemical characterization of a large submarine spring located approximately 4 km from shore (1998-2000)
- *Tampa Bay:* determination of the quantity and quality of freshened ground water discharging to the bay and its possible impacts on seagrass health (2001-present)
- *Loxahatchee River Estuary:* Determining the contribution of SGD to the estuary as part of the South Florida Water Management District's Everglades restoration (2003-2005)

North Carolina

- *Outer Banks:* characterization of the thickness of fresh-water lenses beneath the barrier islands, and the salinity of deep ground water flowing beneath adjacent Albemarle Sound and Pamlico Sound (2001-2004)
- *Neuse River Estuary:* study of the geologic controls on the rates and locations of SGD, drawing upon other investigations, especially at Marine Corps Air Station Cherry Point (2003-2005)

Massachusetts

- *Waquoit Bay National Estuarine Research Reserve:* testing of new instruments to detect SGD, including a boat-based radon mapping system, in an area used as a natural laboratory for previous SGD studies by other investigators (2004-present)
- *Cape Cod National Seashore:* characterization of the role of SGD in eutrophication of the Nauset Marsh and Pleasant Bay systems, with special attention to impacts on seagrasses (2004-present). Water and nutrient fluxes and denitrification rates are all being assessed.

Mediterranean Sea

- *Israel:* use of various tools to develop an estimate of total SGD along the entire Mediterranean coast of Israel, along with academic collaborators (2004-present)

Possible future research areas and topics:

- *Alaska:* investigation of SGD in regions with intense seasonality, active glaciation, permafrost; study of the role of SGD in water and nutrient delivery (nitrate and iron) to the N. Pacific Ocean.
- *Hawaii:* assessment of SGD to fringe coral reef ecosystems, and study of the style of discharge from fractured rock aquifers and lava tubes
- *Yucatán Peninsula:* determination of interconnections between ocean waters and the cenote ring associated with the Chicxulub impact crater; the area has been chosen as a prime candidate for a coordinated study of chemical fluxes in

COLLABORATORS AND RELATED PROGRAMS

Table 1: Selected USGS and academic collaborators:

Institution	Collaborator
USGS-WRD	Böhlke, Masterson, Colman, Langevin
USGS-BRD	Neckles, Kopp, Smith
National Park Service	Portnoy
Woods Hole Oceanographic Inst.	Charette
Marine Biological Laboratory	Giblin
U. Rhode Island	Moran
U. Toledo	Krantz
East Carolina U.	Corbett
Florida State U.	Burnett
U. South Carolina	Moore
U. of Florida	Martin
Louisiana State U.	Cable

Table 2: Links to other programs/projects

Organization	Contact/program	Focus
NSF	GEOTRACES	Distribution of trace elements and isotopes in the ocean
	MARGINS	Understand processes that control evolution of continental margins
	CoOP	Coastal ocean processes
	LTERs	Plum Island Santa Barbara Coastal Georgia Coastal Ecosystems Florida Coastal Everglades
NPS	Cape Cod National Seashore Assateague Island Bicayne Bay Everglades	
NOAA	National Estuarine Research Reserves National Estuarine Eutrophication Assessment	
EPA	National Estuary Program Coastal Intensive Site Network National Coastal Condition Report EMAP	
Army Corps of Engineers	Duck, NC	List/McNinch erosion hotspot study
Water Management Districts	South Florida Dare County, NC	Loxahatchee River, Tampa Bay and Outer Banks water supply (desalinization plant issues); habitat restoration (Everglades)

the GEOTRACES program (see below and *http://www.ldeo.columbia.edu/res/pi/geotraces/index.html*) and was recently featured in a National Geographic article (*http://magma.nationalgeographic.com/ngm/0310/feature4/)*

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