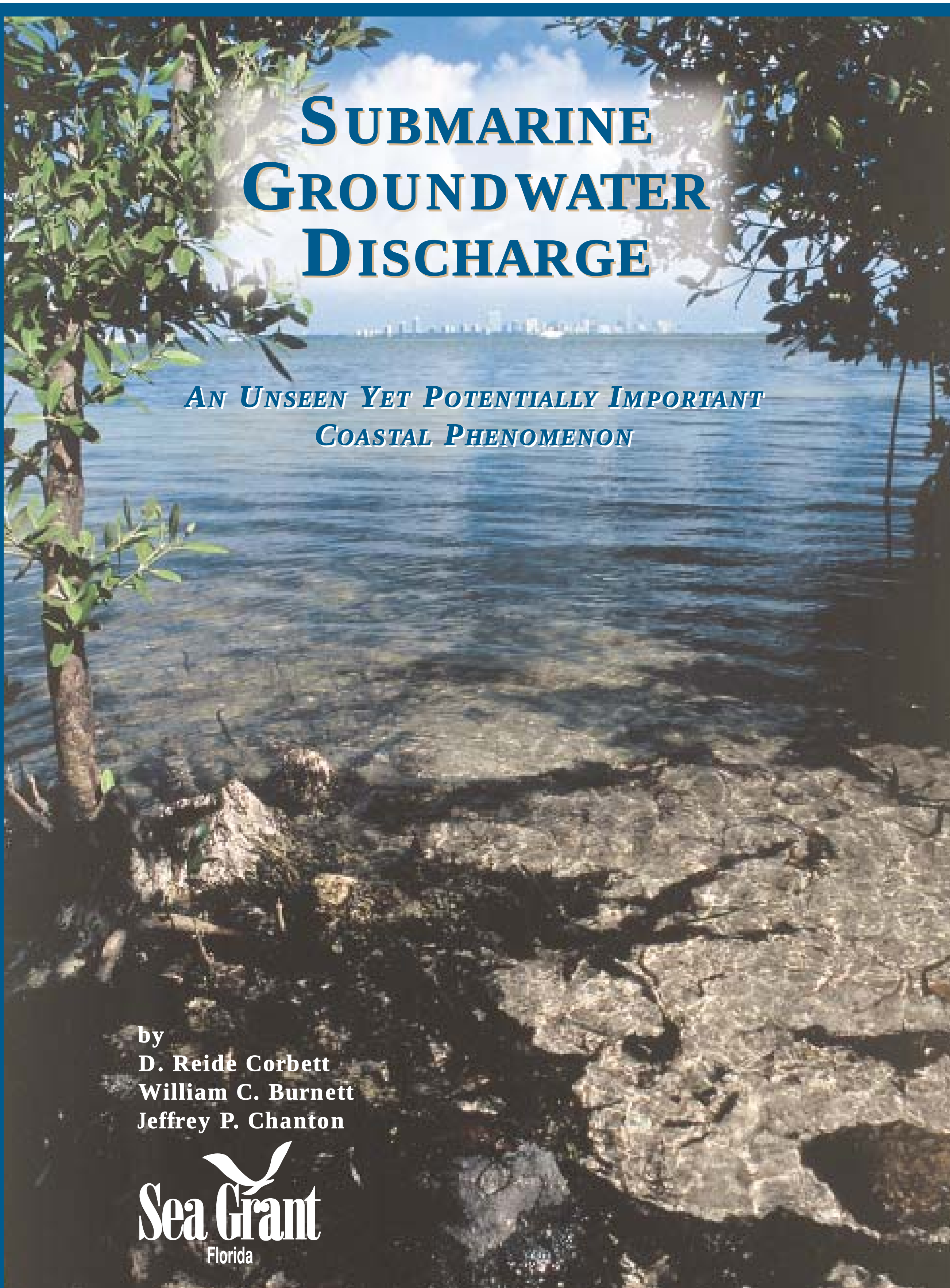

SUBMARINE GROUNDWATER DISCHARGE

AN UNSEEN YET POTENTIALLY IMPORTANT COASTAL PHENOMENON

by
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Sea Grant
Florida

SGEB-54

Submarine groundwater discharge: an unseen yet potentially important coastal phenomenon

All of us benefit from healthy coastal ecosystems. If we want related recreational, commercial and other social benefits to continue, we have a responsibility to protect the health of these systems. Balancing protection and use of coastal systems creates some difficult decisions.

Florida Sea Grant recognizes the importance and complexity of such decisions. As part of its efforts to enhance the practical use and conservation of coastal and marine resources, it contributes to informed debate by producing and distributing objective, valuable, and understandable information. In order to produce such information, Florida Sea Grant works with scientists from many collaborating organizations.

This brochure represents one of Florida Sea Grant's efforts to generate understanding and debate. In collaboration with researchers from Florida State University, we introduce an important but poorly known topic: submarine groundwater discharge. Although nearly invisible, submarine groundwater discharge is an influence on coastal systems that we can no longer ignore. This brochure helps us understand and be in a better position to manage this important phenomenon.

Florida Sea Grant recognizes that issues related to use and protection of Florida's coast extend well beyond those of submarine groundwater discharge. For that reason, it is producing other documents to accompany this one. For example, a brochure on nutrients in coastal systems and a citizen's guide to Florida's estuaries are in preparation.

We ask that you read this material and pursue some of the links provided to discover additional information. We also ask that you contact us with questions or comments. Florida Sea Grant's ability to achieve its objectives and our collective ability to ensure sustainable use of coastal systems depends, in large part, on your involvement and input.

Thank you for your time and interest.

Charles Jacoby
Extension Specialist, Estuarine Ecology
Leader, Florida Sea Grant Coastal Environmental and
Water Quality Design Team

Acknowledgments

This publication is a culmination of several years of research and education in and around coastal ecosystems. We would like to thank all the students and staff involved with us in this endeavor. We would also like to thank the federal agencies that have provided research funds to Florida State University in support of coastal groundwater studies: Florida Sea Grant; U.S. Environmental Protection Agency; Office of Naval Research (ONR); and the National Oceanic and Atmospheric Administration (NOAA) through its South Florida Restoration Prediction and Modeling Program, National Undersea Research Center, and National Estuarine Research Reserve Program. In addition, the State of Florida has provided funding from the Florida Department of Environmental Protection and Florida Department of Health.

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This publication was supported by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA Grant NO 76 RG-0120 and by the UF/IFAS Center for Natural Resources. The views expressed are those of the authors and do not necessarily reflect the views of these organizations.

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Cover photo: City of Miami across Biscayne Bay. Photo courtesy of NOAA.

We live on a planet covered nearly 70 percent by water. However, most all of the Earth's water is in the ocean; less than 5 percent is fresh. Of all the fresh water, just over 30 percent is groundwater. In the United States, groundwater supplies 50 percent of the people with drinking water.

Pulled by gravity, groundwater seeps from the surface slowly downward through aquifers in the earth's subsurface and eventually discharges into lakes, rivers, and the coastal ocean. The discharge of groundwater directly into marine waters is called submarine groundwater discharge (SGD). While it is an unseen phenomenon, the influence of submarine groundwater discharge on the ecology of coastal systems may be more important than once thought, due to the potential impacts resulting from contaminants carried in groundwater. This phenomenon is being studied by scientists to better understand the interaction of groundwater and surface waters along coastlines.

Groundwater Basics

Groundwater is one part of a continuous water cycle between land, ocean, and atmosphere called the Hydrologic Cycle (Figure 1). Surface water, from bodies of water such as oceans and lakes, evaporates from the Earth's surface by energy from the sun. Water vapor forms clouds and eventually returns to the Earth's surface in the form of rain, snow, or other precipitation. This water re-enters surface waters either directly or through surface runoff.

The remainder seeps underground and flows slowly through geologic formations called aquifers. An aquifer is an underground formation of loose soil and permeable rock that is capable of storing useful quantities of water. Aquifers also transmit water. The rate at which the groundwater travels depends on the pressure from the up-gradient direction, the size of the spaces in the soil or rock and how well the spaces are connected, or simply the extent of permeability. There are two primary types of aquifers: (1) confined; and (2) unconfined or water table (Figure 2).

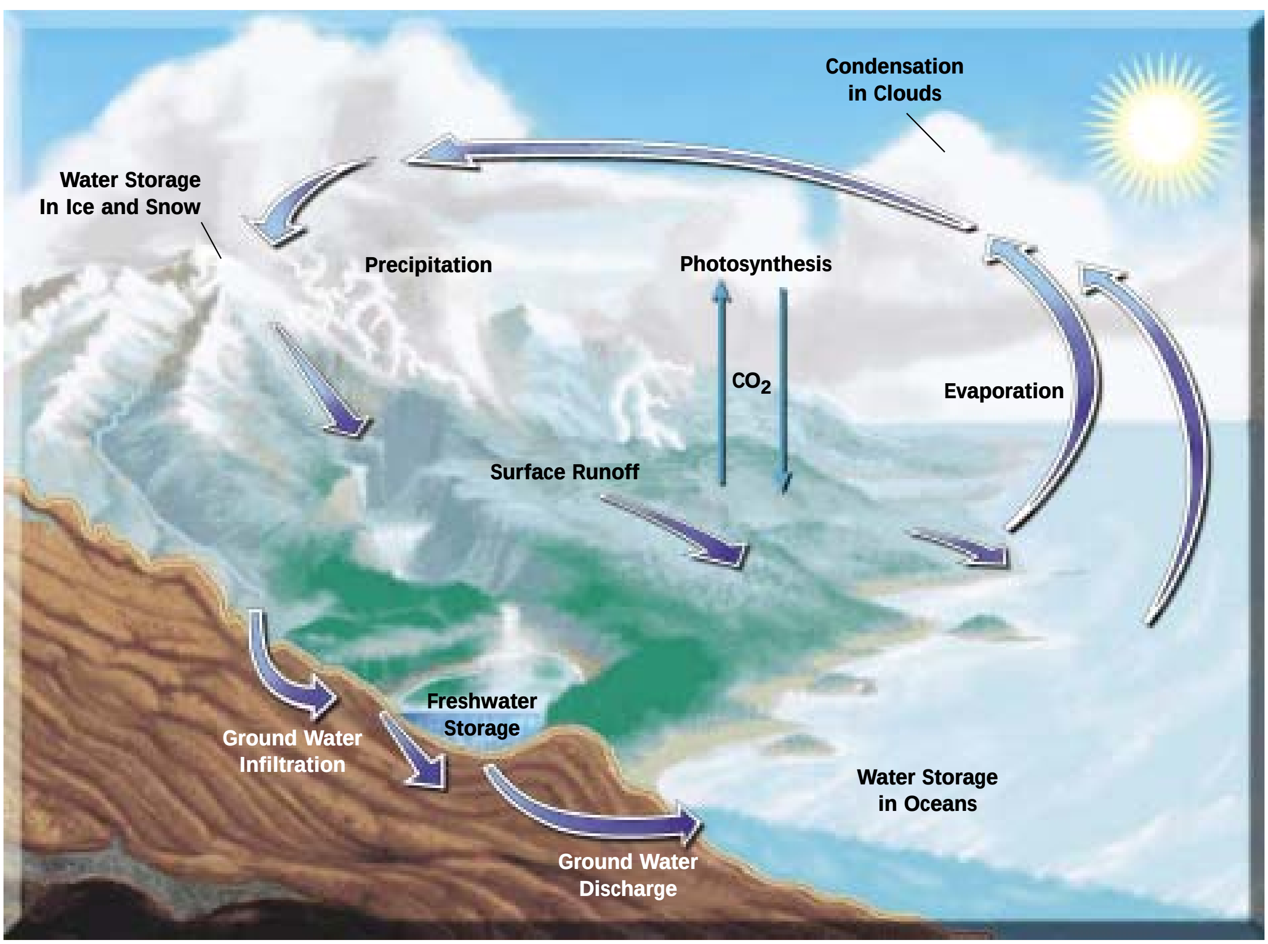

Figure 1: A schematic representation of the cycles through which water moves between the earth and the atmosphere. (Source: United States Geological Survey)

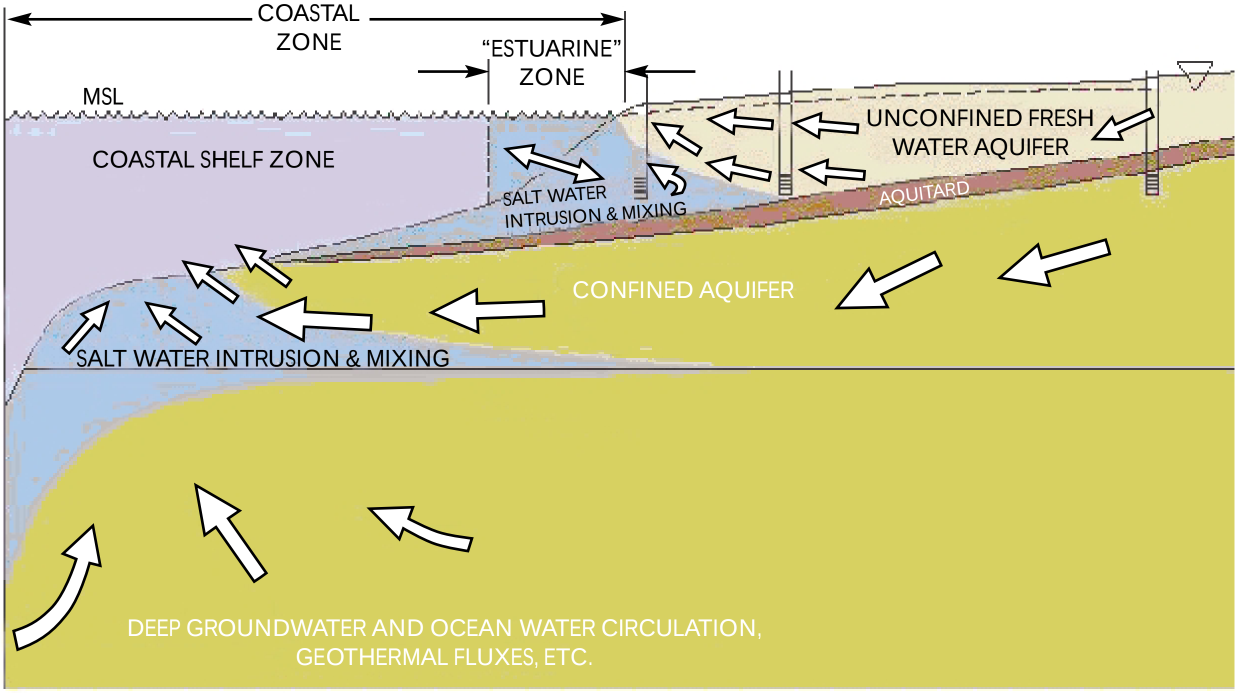

Figure 2: A hydrogeologic cross-section of the interaction between coastal groundwater aquifers and surface waters. (Source: Florida Sea Grant)

A relatively impermeable layer, a confining unit or aquitard, overlies a confined aquifer. Usually, the groundwater found in these confined aquifers is under extreme pressure. If a well penetrates the aquifer, the water will rise above the top of the aquifer, referred to as the piezometric surface. Water that flows freely from a well drilled into a confined aquifer is called an artesian well. The water moves upward due to pressure within the aquifer.

An unconfined aquifer, or water table aquifer, has no confining layer between the top of its saturated zone and the earth's surface. The water level, or water table, in this aquifer rises and falls in response to infiltration of rainfall, evapotranspiration, pumpage, and discharge to surface waters. Water table aquifers are typically the uppermost aquifers and are more susceptible to contamination resulting from surface intrusions such as wastewater systems, chemical spills, and fertilizers.

Groundwater in any aquifer typically flows from areas of high hydraulic head – defined as the elevation to which water rises in a well – to areas of low hydraulic head under the force of gravity. More simply, groundwater flows downhill. Yet it must follow a tortuous path through small pores in the aquifer material, typically slowing its flow to a crawl. Unlike surface waters that move at noticeably rapid rates, groundwater may only move a few inches in a day. Ultimately, it flows into the coastal ocean through seeps and springs, thus closing the continuous water cycle between land, ocean, and atmosphere.

There has been relatively little scientific study of the magnitude and effects of submarine groundwater discharge, although its importance has been recognized for some time. People have observed springs and seeps of fresh water in the marine environment over the centuries. In fact, there are Roman reports of submarine springs in the Black Sea from the 1st century. More recently, stories have been told of ships filling their ballast tanks from submerged freshwater springs in Biscayne Bay.

Measuring Submarine Groundwater Discharge

Although springs and seeps funnel large amounts of fresh water and dissolved constituents into a small area, the slow, more diffusive seepage of groundwater that flows out along most shorelines of the world may be volumetrically more important. How much water and dissolved constituents (nutrients, carbon, contaminants) this dispersed source of groundwater delivers to the coastal ocean is unknown because of the difficulty involved in trying to measure it. Three different methods of measurement are typically used to study SGD:

$$Q = KiA$$

- The French engineer, Henry Darcy, first described the movement of water through the ground analytically in 1856. His mathematical expression has been widely used in hydrological studies ever since.

He observed that at steady-state, the volumetric flow rate of water (Q) is directly proportional to the local hydraulic gradient, or the change in hydraulic head over some distance (i), the aquifer hydraulic conductivity (K), a measure of the ease that water will pass through an aquifer, and the cross sectional area (A) of the aquifer. This is one of the simplest equations used to describe groundwater flow and acts as the foundation for more complex systems.

- Direct measurements of SGD – A seepage meter provides a simple, inexpensive method to measure the discharge of groundwater into surface waters. The basic seepage meter may consist of the top or bottom section of a standard 55-gallon drum with an open port placed near the rim to attach a plastic water collection bag. The volume of water that enters the bag over a known time and area is a direct measure of the seepage rate (Figure 3). More recently, scientists have begun to automate seepage meters by use of thermal and ultrasonic technologies for measuring flow rates.
- Tracer studies – A tracer is a natural or artificial substance dissolved in the fluid so that it can be followed in space and time, providing information on the patterns of events. When using a tracer to study SGD, the tracer would typically occur at high concentrations in the groundwater relative to surface waters. By measuring the groundwater and surface water concentrations and accounting for all other sources and sinks of the tracer in the system, the magnitude of groundwater flux can be estimated.

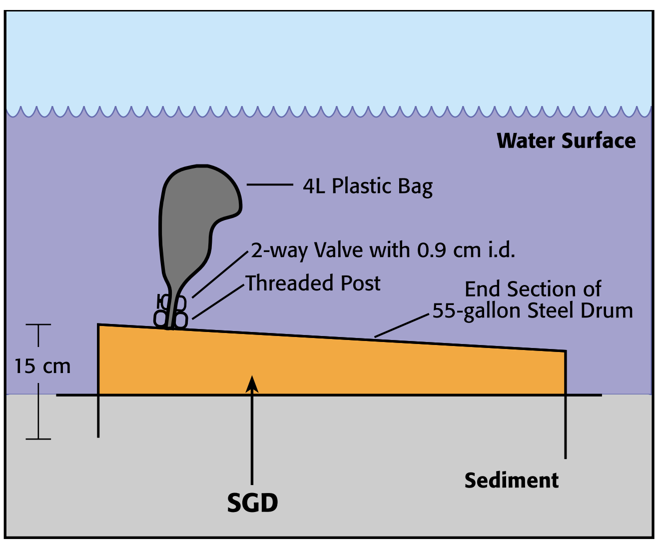

Figure 3: The seepage meter offers a simple, inexpensive method for measuring groundwater discharge into surface waters. This diagram shows the seepage meter placement in the sediments and its collection bag attachment. (Source: Florida Sea Grant)

For example, Rn-222, a naturally-occurring radioactive gas, has been used to estimate the groundwater fluxes to the coastal zone in several locations around Florida. An important advantage of tracers is that they provide an integrated estimate of SGD over a large area, rather the very local coverage that seepage meters provide.

An international working group composed of hydrologists and oceanographers has been established with sponsorship from the Scientific Committee on Oceanic Research (SCOR) and the Land-Ocean Interactions in the Coastal Zone (LOICZ) Project to help develop innovative measurement techniques.

Groundwater as a Pathway to the Coastal Ocean

Since groundwater ultimately discharges into the coastal ocean, any groundwater that is contaminated through industrial or agricultural discharge or sewage treatment may eventually become a marine contamination problem. This in turn may lead to poor water quality, algal blooms, or shellfish and fishery closings. To better protect the coastal ocean, it is important to better understand how groundwater and surface water interact.

SGD as a nutrient transport

Many researchers have demonstrated the influence of SGD in the transport of nutrients to coastal systems, especially in areas with a high density of on-site disposal and treatment systems. While nutrient elements such as nitrogen and phosphorus act as fertilizers when introduced into nutrient-poor surface water, an excess may degrade surface water quality by stimulating significant primary production of microscopic plants and animals, and potentially a harmful algal bloom. Increased nutrient concentrations is a pervasive man-made alteration throughout the world, and can lead to a significant decrease in the number of plant and animal species in the water. We need to understand nutrient delivery to coastal waters and the potential harm that may occur through its introduction, whether it is by surface water or groundwater.

On-site disposal and treatment systems

In areas with a shallow freshwater system, where on-site sewage treatment and disposal systems are typically installed less than 1 meter above the water table, leaching

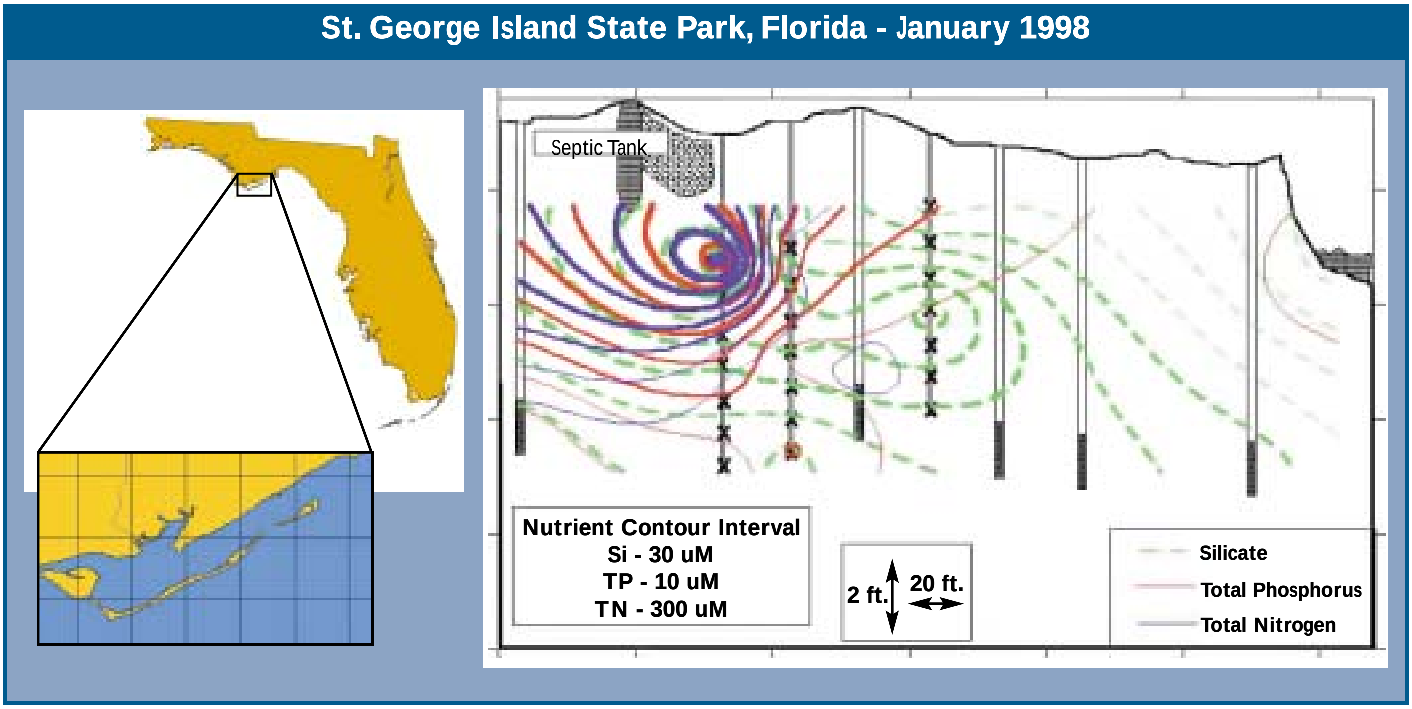

Figure 4: Cross-sectional view of the water table aquifer on St. George Island, Florida. Contours of silicate (green), total phosphorus (red), and total nitrogen (blue) concentrations indicate the movement of wastewater from an onsite treatment and disposal system (OSTDS) toward surface waters (Apalachicola Bay). Although there are current restrictions for the setback distance of OSTDS, natural groundwater movement may transport excess nutrients and other contaminants to surface waters. (Source: Florida Sea Grant)

nutrient elements and bacteria may easily contaminate groundwater. These contaminants travel through the aquifer and can pollute groundwater down gradient, which may become a marine contamination problem when the groundwater makes its way back to the surface through the coastal zone. While local regulations may vary in Florida, new construction requires the installation of systems intended to protect groundwater from sewage contamination. Unfortunately, antiquated systems still exist statewide.

Examples from Florida

Researchers at Florida State University have been studying submarine groundwater discharge in Florida's coastal environments for almost a decade. Recent studies have concentrated on the influence of wastewater discharge on groundwater quality and the potential transport toward ecologically-sensitive surface waters. Studies have been conducted in the Florida Keys and on St. George Island, a barrier island located along Florida's Panhandle.

St. George Island, (Figure 4), like many barrier islands, forms the outer perimeter of an estuary (Apalachicola Bay) and is critical to the bay's productivity because its orientation determines salinity distribution as well as other water quality features of the bay. The estuary is also an economic resource in north Florida, providing more than 90 percent of Florida's oyster landings and the third highest catch of shrimp in the state. Increased development and resulting population density on St. George Island has raised concerns of potential changes in local water quality and impacts on the oyster industry. Tracers were used there to provide estimates of groundwater and nutrient discharges to the bay from the island's surficial aquifer. In addition, studies were conducted on different types of septic treatment systems and the distance that an on-site treatment and disposal systems should be set back from surface waters. Results indicated that the most efficient on-site disposal system would be an aerobic system that was raised approximately 1 meter above the natural land elevation and set back from surface waters 50-75 meters.

The Florida Keys, unlike St. George Island, are built on very porous carbonate rock. The groundwater on these small islands is driven by the change in the Atlantic tide relative to Florida Bay (Figure 5). Because wastewater is injected underground, there is potential for a pathway of sewage-derived nutrients to the coastal environment via SGD. Tracer studies have verified that this is the case. Research is currently being completed to determine the potential for removal of nutrients before the ultimate discharge into surface waters. The nutrients injected into the subsurface may be removed from the groundwater by bacteria or by chemical absorption onto the carbonate matrix. This research shows the importance in understanding subsurface wastewater injections to better understand the potential of contaminants in groundwater systems.

Complexity of Water Management

Managing our surface waters and groundwater is complicated. In order to do so effectively, we must consider many issues, including water quality, freshwater supply, flood protection and floodplain management, and natural systems management. Managing our water resources involves the challenge of balancing varying water uses and demands with availability. Conflicting priorities often must be addressed to ensure that there are sufficient water supplies for human needs while maintaining water quality and viable, functioning natural systems. In Florida, this job is the legislated responsibility of the five water management districts that encompass all of Florida. These are: Northwest Florida, Suwannee River, St. Johns River, Southwest Florida, and South Florida Water Management districts.

In the context of submarine groundwater discharge, it is important to recognize that alterations in the groundwater system further inland than the coastline will ultimately impact the amount and quality of the water being discharged into coastal waters. While it may be difficult to set management guidelines, our coastal waters have a direct connection with inland aquifers and should therefore be considered as an integral part in any management plan. Current studies of coastal hydrology by researchers at Sea Grant universities and elsewhere are helping land managers and planners protect these areas for future generations.

It is important that we, as individuals, take an active role in protecting our limited surface and groundwater resources as well. By reducing the amount of fertilizer applied to lawns, responsibly disposing of our petroleum and hazardous waste materials, reducing the amount of water used at home and the office, and other common sense actions, we can help in protecting the water that we depend on in our daily lives.

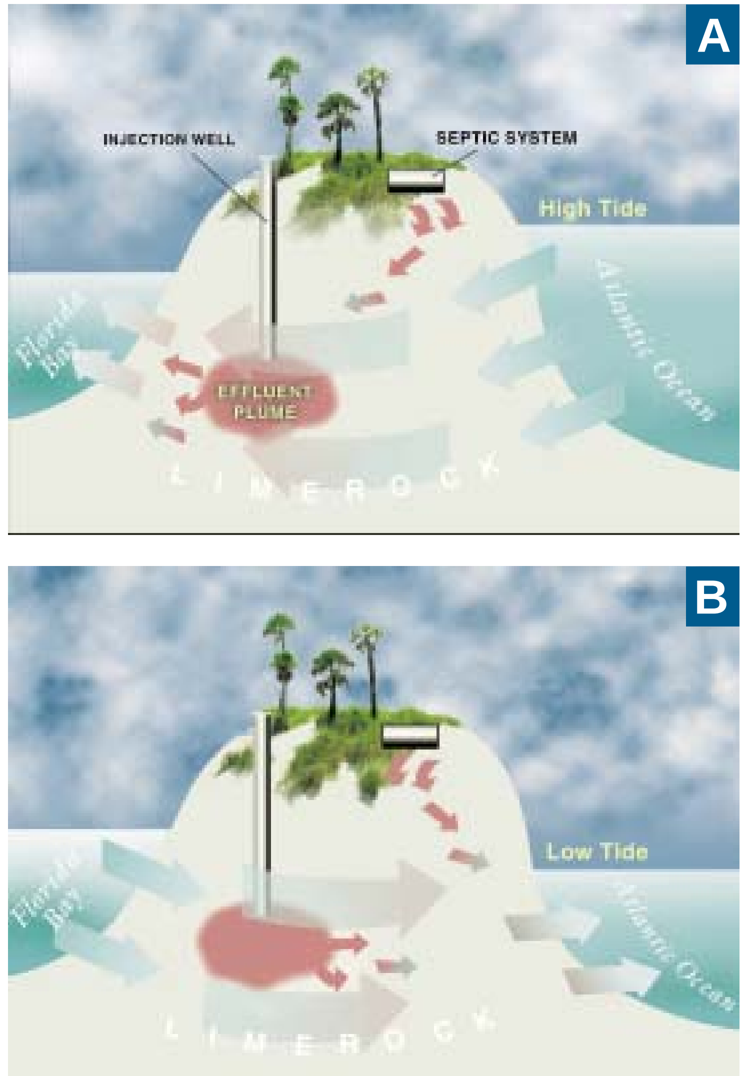

Figure 5: Groundwater movement in the Florida Keys is quite different than most coastal systems. Groundwater and surface waters continuously interact due to the porous nature of the water table aquifer. When tides are high in the Atlantic (A), Atlantic surface water is pushed into the subsurface and groundwater flows toward Florida Bay. When tides are low (B), groundwater flows toward the ocean. This continual sloshing of groundwater controls the overall path of injected wastewater and septic effluent in the subsurface, thus increasing the possibility of surface water contamination. (Source: Robert Celander, FSU Research in Review, 1999).

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