Ecological Significance of Submarine Ground-Water Discharge to the Puget Sound Nearshore

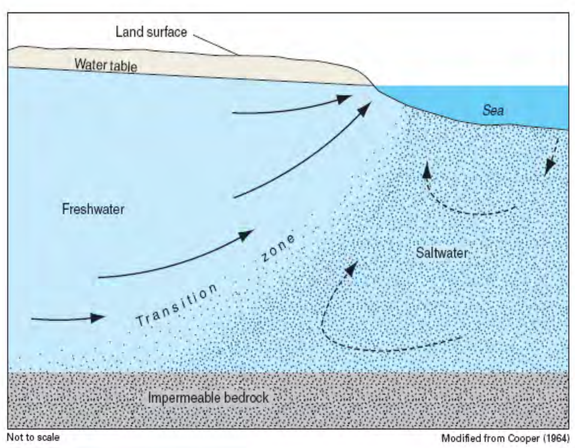
Background

Submarine groundwater discharge (SGD) to the nearshore in Puget Sound likely plays an ecologically significant role in processes such as:

- Transport and biogeochemical cycling of nutrients and dissolved substances (Johannes, 1980)
- Moderation of the microclimate of exposed intertidal habitats (Rice, 2006; Penttila, 2001)
- Sustenance of environmental (temperature and salinity) refugia in nearshore embayments (Nielsen and Lisle, 1994)

The significance of SGD to forage-fish spawning is of particular interest to the Urbanization Task of the USGS Coastal Habitats in Puget Sound (CHIPS) project. SGD in general (freshwater and saltwater) is potentially related to herring spawning through its influence on eelgrass health, and is potentially related to surf smelt and sand lance spawning through its influence on intertidal beach microclimates. Freshwater SGD in particular has been associated with dense herring spawning off the coast of Japan (Hoshikawa and others, 2004) and dense seagrass beds in the northeastern Gulf of Mexico (Rutkowski and others, 2005). Additionally, nitrate in freshwater SGD can be utilized by marine macrophytes such as eelgrass (Zostera marina L.) during summers in Puget Sound when surface water nitrate concentrations are low (Maier and Pregnall, 1990).

We have a mechanistic understanding of the possible impacts of urbanization on ground-water flow and chemistry in Puget Sound uplands, and we have predictive tools (numerical and stochastic models) to evaluate such impacts. We do not have a comparable understanding of shoreline development impacts on ground-water flow and chemistry in the nearshore environment. Thus, Puget Sound nearshore restoration activities generally do not consider SGD processes.



Ground-water flow patterns and the freshwater-saltwater transition zone in an idealized coastal aquifer. A circulation of saltwater from the sea to the transition zone and then back to the sea is induced by mixing of freshwater and saltwater in the transition zone. Submarine ground-water discharge includes both freshwater and saltwater discharge.

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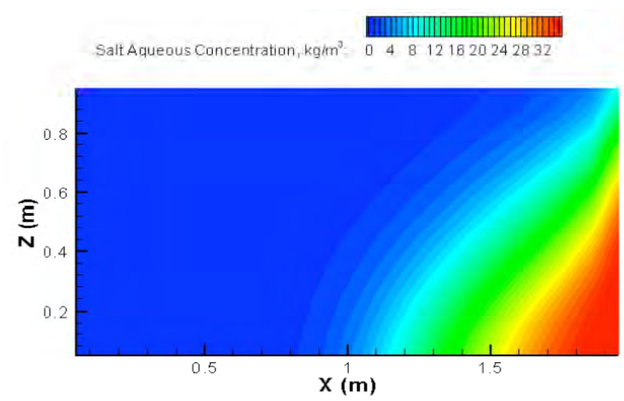
Objectives

Our goal is to develop predictive models of salinity, moisture, temperature, and chemistry for intertidal and subtidal beaches at scales that are relevant to nearshore biota. In addition, we are developing insight into how shoreline armoring, nearshore pumpage, and other urbanization activities impact SGD processes and associated beach habitats.

Study Approach

We are using numerical models of nearshore beach hydrology in combination with state-of-the-science and traditional field data collection to improve our understanding of SGD. The modeling and field efforts are advancing in parallel, with results from one effort intended to enhance the other. For example, the model-simulated moisture content and porewater salinities of beach sediments throughout a tidal cycle will improve our processing of the surface geophysical resistivity data, while the measured temperature and salinity of saturated beach sediments will constrain our model simulations.

Numerical modeling



Steady-state STOMP solution of Henry's problem, which addresses the a diffused salt-water wedge within a confined aquifer balanced against a flowing fresh-water field. Freshwater enters the confined aquifer at a constant rate from a hypothetical inland boundary and discharges into a hypothetical coastal boundary. Salt water from the coastal boundary advances and mixes with the discharging fresh water.

In concert with W.M. Herkelrath of the USGS National Research Program, we are using the variably-saturated density dependent STOMP (Subsurface Transport over Multiple Phases) numerical code. This model is well suited for this investigation because it:

- allows the user to choose the solved governing equations (water mass, salt mass, and thermal energy for our application),
- recognizes a number of boundary conditions and allows their specification internally and externally to the model domain,
- can directly solve solute transport, radioactive decay (radon/radium isotopes), and first-order chemical reactions (denitrification),
- simulates both water temperature and solute concentration (salinity), both of which can be measured in the field for model verification

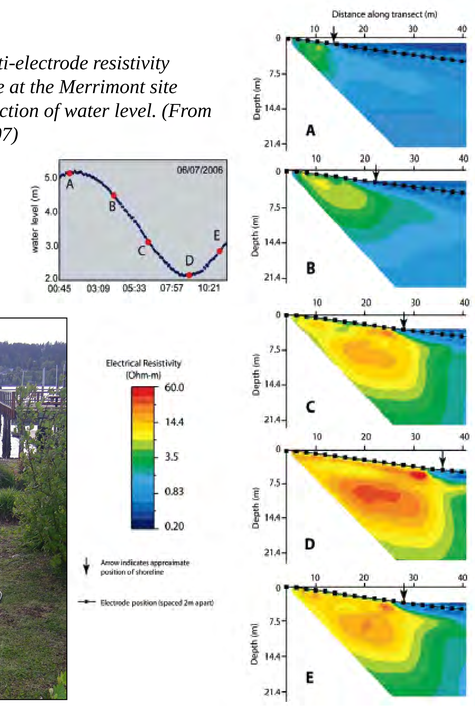
Our initial modeling is being constrained by stationary resistivity profile data data collected by Swarzenski, Reich, Simonds, Dinicola, and others in Hood Canal and Liberty Bay. Those and other geochemical data were collected primarily to quantify nutrient loads in SGD to marine waters, but they will be equally useful for guiding and constraining our numerical modeling.

Geophysical and Hydrological Data Collection

Our field investigation of SGD at the Possession Point/Brown's Bay interdisciplinary study site will employ state-of-the-science technologies to quantify hydrologic and geochemical processes. Data collection techniques will include stationary and streaming resistivity profiling, fiber-optic based distributed temperature sensing systems, and more traditional seepage meters and piezometers. With support from the WRD Office of Ground Water Geophysical group we are building the local expertise to better measure and quantify SGD processes at the relatively small scales that appear to be particularly significant for nearshore biota.

Fixed Resistivity Profiling

Stationary time-series, multi-electrode resistivity profiles across a beach face at the Merrimont site (Hood Canal, WA) as a function of water level. (From Swarzenski and others, 2007)



Fiber-Optics Distributed Temperature Sensor

Charles Harvey (MIT) and Fred Day-Lewis (USGS) prepare fiber-optic distributed temperature system for deployment at Waquoit Bay National Estuarine Research Reserve, Massachusetts.