1. Introduction

High rates of exchange between seawater and fresh groundwater in beach subsurface drive significant chemical reactions, but the groundwater flow that controls this is poorly understood. Current conceptual models for groundwater flow in beaches highlight an upper saline plume, which is separated from the traditional freshwater-saltwater interface by a zone of brackish to saltwater interface in beaches with slopes varying from 0.1 to 0.01. We also varied hydraulic conductivity, dispersivity, tidal amplification, and concentration gradient between the center of the upper saline plume and the freshwater-saltwater interface in beaches with slopes varying from 0.1 to 0.01. We also varied hydraulic conductivity, dispersivity, tidal amplification, and concentration gradient between the center of the upper saline plume and the freshwater-saltwater interface in beaches with slopes varying from 0.1 to 0.01.

2. Conceptual Model

![Image]

Figure 2a. The freshwater-saltwater interface in a beach. (After Cooper, 1999).

![Image]

Figure 2b. The upper saline plume and measured flow path. (After Bascom et al., 2006).

3. Purpose

The lack of an upper saline plume at our study site led us to ask whether the plume exists in all beaches and what hydrogeological controls its formation. We tested the role that an upper saline plume is in presence in coastal beach aquifers. Major hydrogeological properties such as hydraulic gradient, beach slope, permeability, dispersivity, and fresh groundwater flow control whether or not a beach can sustain an upper saline plume.

4. Methods

Simulations of three-dimensional tidal fluctuations in five beach domains were conducted using SUTRA (Voss and Provost, 2002). We used variable-density, unconfined, unsteepened groundwater models to investigate the geometry of the freshwater-saltwater interface in beaches with slopes ranging from 0.01 to 0.01. We also used hydrodynamic conductivity, dispersivity, tidal amplitude, and fresh groundwater flow and precipitation. In these simulations, we used a reduced version of the Richards equation that handles changes in everything from soil to tidal loading (Wilson and Gabites, 1986).

5. Sensitivity Analysis

![Image]

Figure 3. The example of our model domain and boundary conditions for the flood simulation. The surface boundary condition assigns total flow through specifying a porosity at a point based on the height of the volume of seawater that passes. The model scenario is extended from the surface boundary into a defined zone. Concentration distributions were established when the water table intersects land surface, infiltration from the surface of the domain is exposed, and pressure is specified at a point based on the height of the surface of the domain.

Table 8. Parameters varied in the sensitivity analysis. A total of 100 separate simulations were performed for each model with different parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability (m/s)</td>
<td>10⁻¹³, 10⁻¹², 10⁻¹¹</td>
</tr>
<tr>
<td>Longitudinal dispersivity (m)</td>
<td>0.1, 0.2, 0.3</td>
</tr>
<tr>
<td>Concentration gradient (C/H₁₀⁻²)</td>
<td>0.05, 0.15, 0.25</td>
</tr>
<tr>
<td>Slope of the intertidal zone</td>
<td>0.05, 0.075, 0.1</td>
</tr>
</tbody>
</table>

6. Model Results

![Image]

Figure 4. Simulations results for a beach with tidal amplitude of 0.05 meters (a) High tide, (b) Ebb tide, (c) Low tide and (d) Flood tide. Variations indicate sensitivity as evaluated by the model distribution. The top and bottom panels show the concentration gradient and the vertical exaggeration are 2:1 and 4:1 for models (a) and (b) respectively.

7. Synthetic

![Image]

Figure 5. The synthetic simulation results for a beach with tidal amplitude of 0.05 meters (a) High tide, (b) Ebb tide, (c) Low tide and (d) Flood tide. Variations indicate sensitivity as evaluated by the model distribution. The top and bottom panels show the concentration gradient and the vertical exaggeration are 2:1 and 4:1 for models (a) and (b) respectively.

8. Discussion

The two most important hydrogeological controls on the development of an upper saline plume in a beach are the permeability and the slope of the intertidal zone. The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

9. Conclusions

In the models using a permeability of 10⁻¹³ m/s, no upper saline plumes formed in beaches with a slope less than 0.01. The salinity of brackish groundwater that discharges upstream of the upper saline plume became less saline with higher fresh groundwater flux into the model.

In the models using a permeability of 10⁻¹¹ m/s, no upper saline plumes formed in beaches with a slope less than 0.01. The salinity of brackish groundwater that discharges upstream of the upper saline plume became less saline with higher fresh groundwater flux into the model.

Prior studies of groundwater flow and salinity in beaches have used small dispersivities. This study, which systematically varied tidal amplitude, dispersivity, freshwater and saltwater interface in beaches with slopes varying from 0.1 to 0.01, also tested the hypothesis that a concentration gradient greater than 0.05 m/s is required to sustain an upper saline plume. The concentration gradient for the beach with a slope of 0.01 is 0.11 m/s, and the concentration gradient for the beach with a slope of 0.05 is 0.13 m/s.

In the models using a permeability of 10⁻¹³ m/s, no upper saline plumes formed in beaches with a slope less than 0.01. The salinity of brackish groundwater that discharges upstream of the upper saline plume became less saline with higher fresh groundwater flux into the model.

Prior studies of groundwater flow and salinity in beaches have used small dispersivities. This study, which systematically varied tidal amplitude, dispersivity, freshwater and saltwater interface in beaches with slopes varying from 0.1 to 0.01, also tested the hypothesis that a concentration gradient greater than 0.05 m/s is required to sustain an upper saline plume.

References


10. Synthesis

The two most important hydrogeological controls on the development of an upper saline plume are the permeability and the slope of the intertidal zone. The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

11. Synthesis

The two most important hydrogeological controls on the development of an upper saline plume are the permeability and the slope of the intertidal zone. The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).

The slope of the intertidal zone was an important control on the development of an upper saline plume (Fig. 5).