Numerical simulations of oil contaminant transport in sandy coastal aquifers

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Motivation

- With the increasing developments of tourist and industrial estates in coastal area, different sources of contaminants can be discharged into the sea.

- Marine pollution: Oil spills happen when people make mistakes or are careless and cause an oil tanker to leak oil into the ocean.
彭薩科拉海灘 (Pensacola)
Objectives

- when a petroleum spill reaches the beaches, there may be deeper penetration in the soil, which depends on sand grain size, so causing serious damages to the ecosystem.

(1) how much and how deep oil is transported into the beaches.

(2) Whether oil polluted groundwater or not.

(3) Other factor of influence oil transportation : tidal, wave, beach slope, pumping well, recharge water …
Methodology - HYDROGEOCHEM-2D

- A coupled model of fluid flow, thermal transport, and HYDROGEOCHEMical transport through saturated-unsaturated media.

- Deal with equilibrium and kinetic reaction in terms of reaction networks.

- Incorporate the effect of precipitation/dissolution on the change of pore size, hydraulic conductivity, and diffusion/dispersion.
Flow Equations

\[
\frac{\rho}{\rho_0} F \frac{\partial h}{\partial t} = \nabla \cdot \left[ K \left( \nabla h + \frac{\rho}{\rho_0} \nabla z \right) \right] + \frac{\rho^*}{\rho_0} q
\]

\[
F = \alpha' \frac{\theta}{n_e} + \beta' \theta + n_e \frac{dS}{dh}
\]

\[
K = \frac{\rho g}{\mu} k_s = \left( \frac{\rho}{\rho_0} \right) \rho_0 g k_s k_r
\]

\[
k_s \text{ is saturated permeability tensor} \left[ \frac{L^2}{T} \right]
\]

\[
k_r \text{ is relative permeability or relative hydraulic conductivity}
\]

\[
F \text{ is storage coefficient} \left[ \frac{1}{L} \right]
\]

\[
\theta \text{ is effective moisture content}
\]

\[
\alpha' \text{ is the modified compressibility of the soil matrix} \left[ \frac{1}{L} \right]
\]

\[
\beta' \text{ is modified compressibility of the liquid} \left[ \frac{1}{L} \right]
\]

\[
\rho \text{ is fluid density with dissolved chemical concentrations} \left[ \frac{M}{L^3} \right]
\]

\[
\rho_0 \text{ reference fluid density at zero chemical concentration} \left[ \frac{M}{L^3} \right]
\]

\[
\rho^* \text{ is the density of the injected fluid} \left[ \frac{M}{L^3} \right]
\]

\[
q \text{ is the source/sink} \left[ \frac{1}{T} \right]
\]

\[
S \text{ is degree of effective saturation of water} \left[ \frac{L^2}{L^3} \right]
\]

\[
\frac{dS}{dh} \text{ is saturated permeability tensor}
\]
Reactive Chemical Transport Equations

\[ \frac{\partial \theta C_i}{\partial t} + \nabla \cdot (\theta C_i V_f) + \nabla \cdot J_j = \theta r_j + M_i \]

\[ \frac{\partial \theta C_i}{\partial t} \] The rate of mass accumulation

\[ \nabla \cdot (\theta C_i V_f) \] The net rate of mass flux due to advection

\[ \nabla \cdot J_j \] The net mass flux due to dispersion and diffusion,

\[ J_j = -\theta D \cdot \nabla C_i = -[a_T |V| \delta + (a_L - a_T)VV / |V| + a_m \theta \tau \delta] \]

\[ \theta r_j \] The source/sink term corresponding to artificial injection and/or withdrawal

\[ M_i \] The rate of mass production and reduction due to chemical reactions and radioactive decay
Test example

\[ K = 15 \text{ m/day} \quad \text{porosity of the aquifer} = 0.35 \]

Pressure head = 85m

Variable boundary condition

Pressure head = 84m

100 m

400 m

Impermeable bottom
Pressure head = 85m

No rainfall

Pressure head = 84m

1.0 mole/liter (C₆H₆)

Beach slope = 0.2, 0.3

Impermeable bottom

400 m

100 m
Beach slope = 0.2

Beach slope = 0.3
Beach slope = 0.2

Beach slope = 0.3
Beach slope = 0.2

Beach slope = 0.3
Recharge

I = 0.01 m/day

Pressure head = 85 m

Pressure head = 84 m

Beach slope = 0.2

Impermeable bottom

400 m

1.0 mole/liter (C₆H₆)
Total head

No rainfall

I = 0.01 m/day
No rainfall

I = 0.01 m/day
Pumping well

Pressure head = 85 m

Beach slope = 0.2

No rainfall

1.0 mole/liter (C₆H₆)

Impermeable bottom

100 m

400 m

Pressure head = 84 m

-20 m²/day (抽水)
Total head

no pumping well

pumping well
27day

no pumping well

pumping well
no pumping well

pumping well
Future work

No surface oil related to the Deepwater Horizon spill has been observed since Aug. 3.
Thanks for your attention