# Saltwater Intrusion in Coastal Aquifers

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## Groundwater Pollution

1. Environmental: type of pollution is due to the characteristics of the environment through which the flow of groundwater takes place. For example, flow through carbonate rock, seawater intrusion and invasion by brackish water from adjacent aquifer.
2. Domestic: domestic pollution may be caused by accidental breaking of sewers, percolation from septic tanks, rain infiltrating through sanitary landfills, acid rains, artificial recharge using sewage water after being treated to different levels and biological contaminants (e.g., bacteria and viruses).

3. **Industrial:** industrial pollution may come from sewage disposal, which contains heavy metals, non-deteriorating compounds and radioactive materials.

4. **Agriculture:** this is due to irrigation water and rain water dissolving and carrying fertilizers, salts, herbicides, pesticides, etc., as they infiltrate through the ground surface and replenish the aquifer.

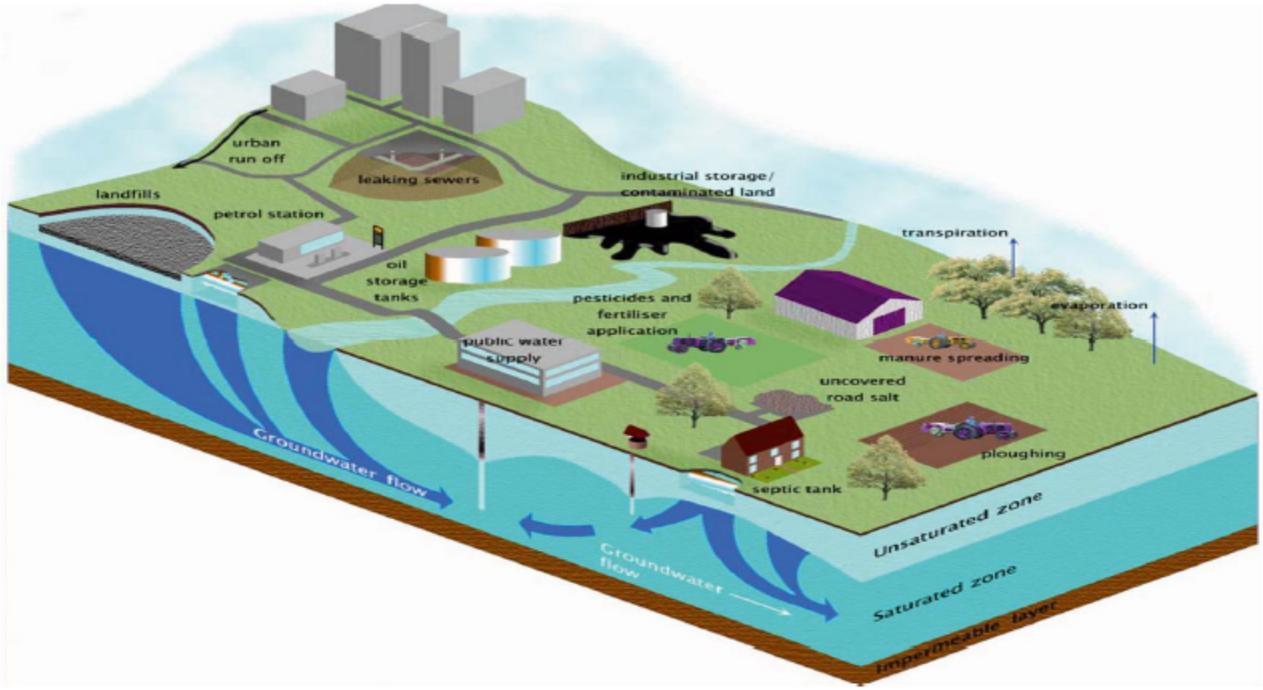



**Figure 1: Main groundwater contaminant pathways and sources**

- http://www.euwfd.com/html/groundwater.html

## Saltwater Intrusion

**Saltwater intrusion** is the movement of **saline** water into freshwater aquifers, which can lead to contamination of drinking water sources and other consequences.

**Saltwater intrusion** occurs naturally to some extent in most coastal aquifers, owing to the hydraulic connection between groundwater and **seawater**.

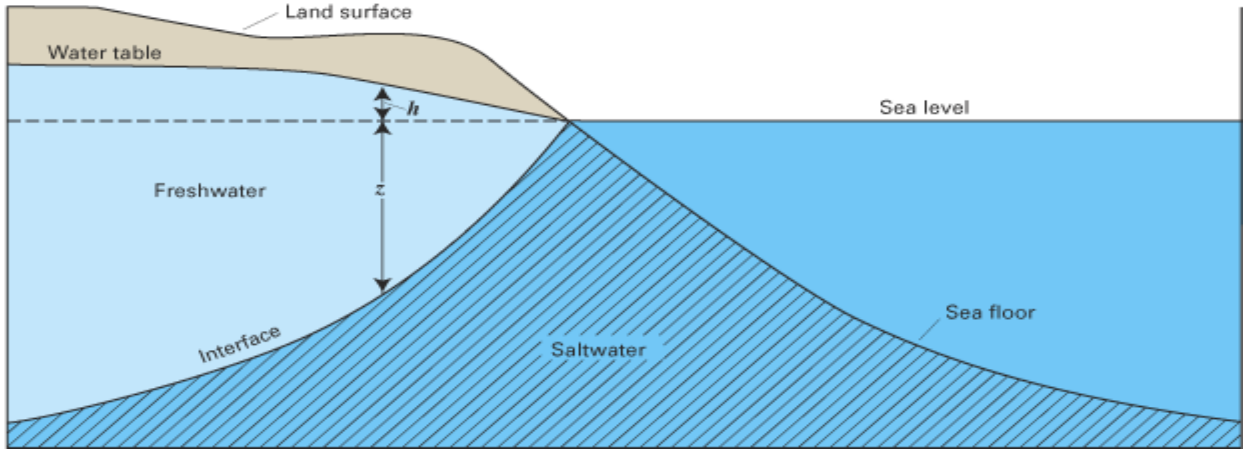



Figure 2: Ghyben–Herzberg relation

For every foot of fresh water in an aquifer above sea level, there will be forty feet of fresh water in the aquifer below sea level

$$z = \frac{\rho_f}{\rho_s - \rho_f} h$$

$$z = 40\, h$$

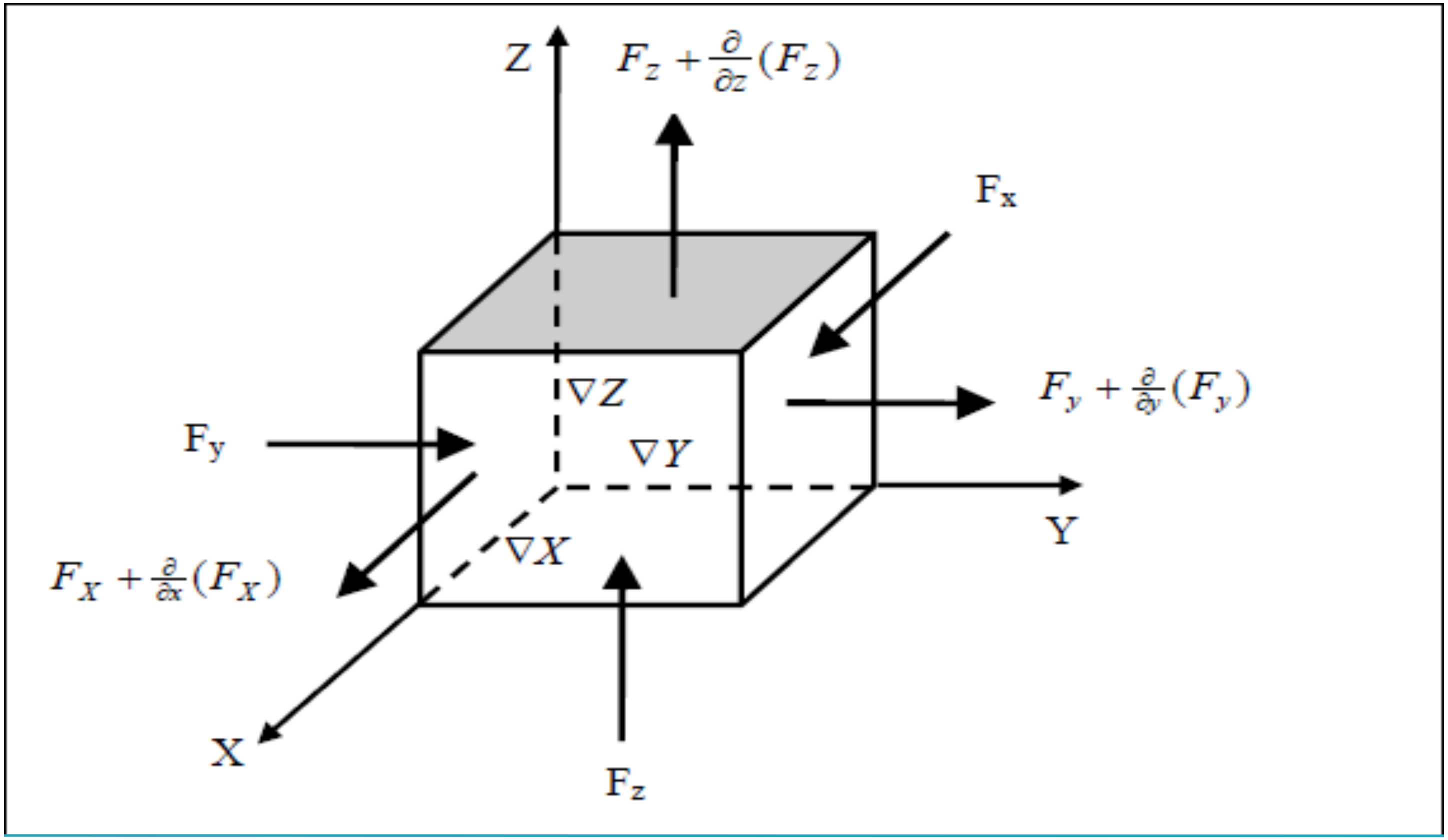



Figure 3: A unit volume of salt

$Solute\ inflow\ net\ rate$

$$= F_x - \left[F_x + \frac{\partial}{\partial x}(F_x)\right] + F_y - \left[F_y + \frac{\partial}{\partial y}(F_y)\right] + F_z - \left[F_z + \frac{\partial}{\partial z}(F_z)\right]$$

$$= -\frac{\partial}{\partial x}(F_x) - \frac{\partial}{\partial y}\left(F_y\right) - \frac{\partial}{\partial z}(F_z)$$

$$F_x = -D_m \frac{\partial c}{\partial x}$$

Diffusion

$$F_x = v_x c$$

Advection

$$F_x = -D_{wx} \frac{\partial}{\partial x}(\theta_w c) - D_{wy} \frac{\partial}{\partial y}(\theta_w c)$$

Dispersion

- Net Rate of Solute Inflow will be………

$$
\begin{aligned}
&Net\ rate\ of\ solute\ Inflow \\
&\quad = \frac{\partial}{\partial x}\left[D_{xx}\frac{\partial}{\partial x}(\theta c) + D_{xy}\frac{\partial}{\partial x}(\theta c)\right] \\
&\quad + \frac{\partial}{\partial y}\left[D_{yx}\frac{\partial}{\partial x}(\theta c) + D_{yy}\frac{\partial}{\partial y}(\theta c)\right] \\
&\quad - \left[\frac{\partial}{\partial x}(vc) + \frac{\partial}{\partial y}(vc)\right]
\end{aligned}
$$

Rate of Solute produced within will be ….

$$\frac{\partial}{\partial x}(\theta c)_{sorption} = -\rho_b k_d \frac{\partial C}{\partial t}$$

$$\frac{\partial}{\partial x}(\theta c)_{decay} = -\lambda(\theta c + \rho_b k_d c)$$

$$Net\ rate\ of\ solute\ production\ within = -\rho_b k_d \frac{\partial c}{\partial t} - \lambda(\theta c + \rho_b k_d c)$$

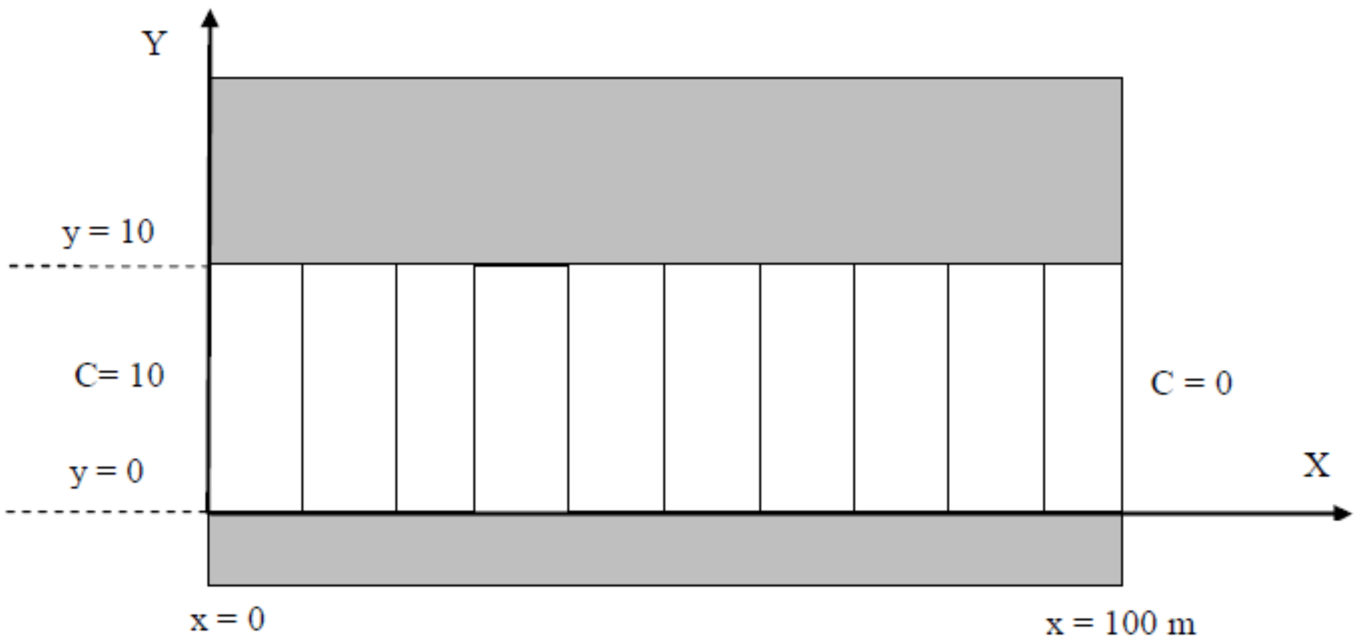
Adding gives…

- *Total c present*

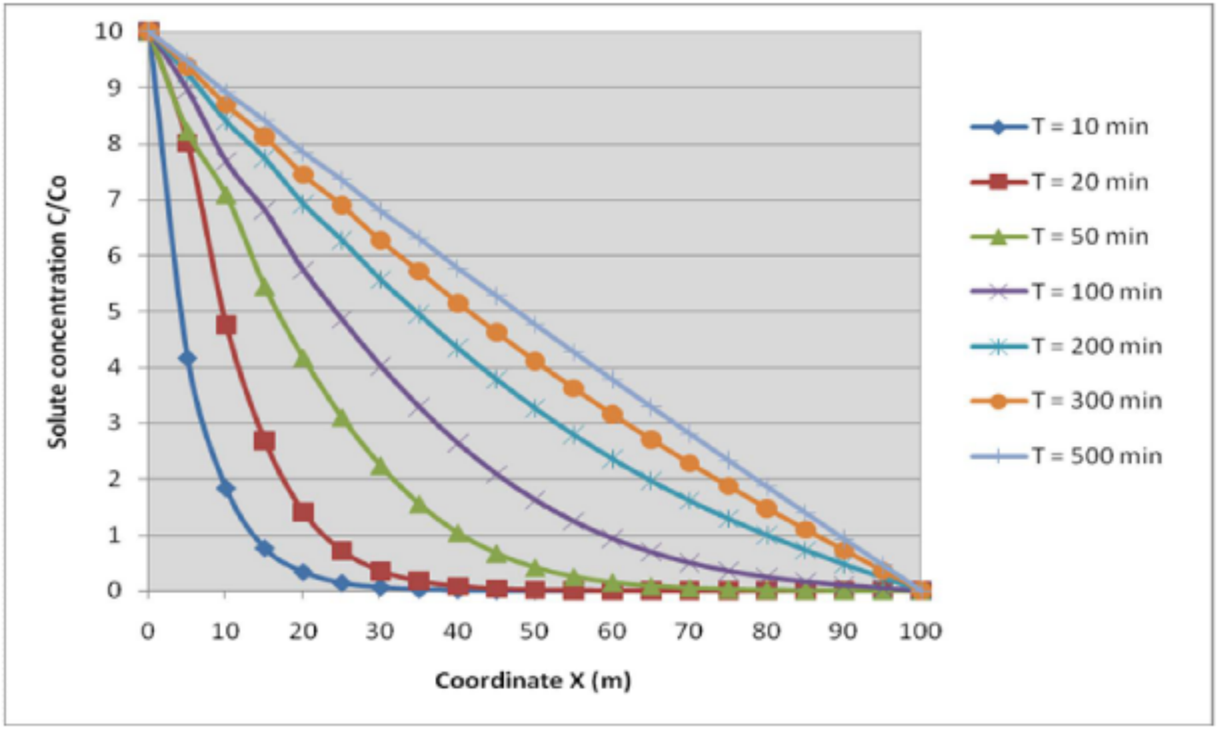
$$\frac{\partial}{\partial t}(\theta c) = \frac{\partial}{\partial x}\left[D_{xx}\frac{\partial}{\partial x}(\theta c) + D_{xy}\frac{\partial}{\partial x}(\theta c)\right] + \frac{\partial}{\partial y}\left[D_{yx}\frac{\partial}{\partial x}(\theta c) + D_{yy}\frac{\partial}{\partial y}(\theta c)\right] - \left[\frac{\partial}{\partial x}(vc) + \frac{\partial}{\partial y}(vc)\right] - \rho_b k_d \frac{\partial c}{\partial t} - \lambda(\theta c + \rho_b k_d c)$$

- Simplified

$$\frac{\partial}{\partial t}(\theta_w c_w) + \frac{\partial}{\partial t}(\rho_b k_d c) + \nabla(vc) - \nabla(\theta D \nabla c) + \lambda(\theta c + \rho_b k_d c) = 0$$




Abd-Elhamid (2010)



Solute concentration C/Co
Coordinate X (m)
T = 10 min
T = 20 min
T = 50 min
T = 100 min
T = 200 min
T = 300 min
T = 500 min

# THANK YOU