Understanding Saline Water Dynamics in Coastal Aquifers Using Sand Tank Experiment and Numerical Modeling

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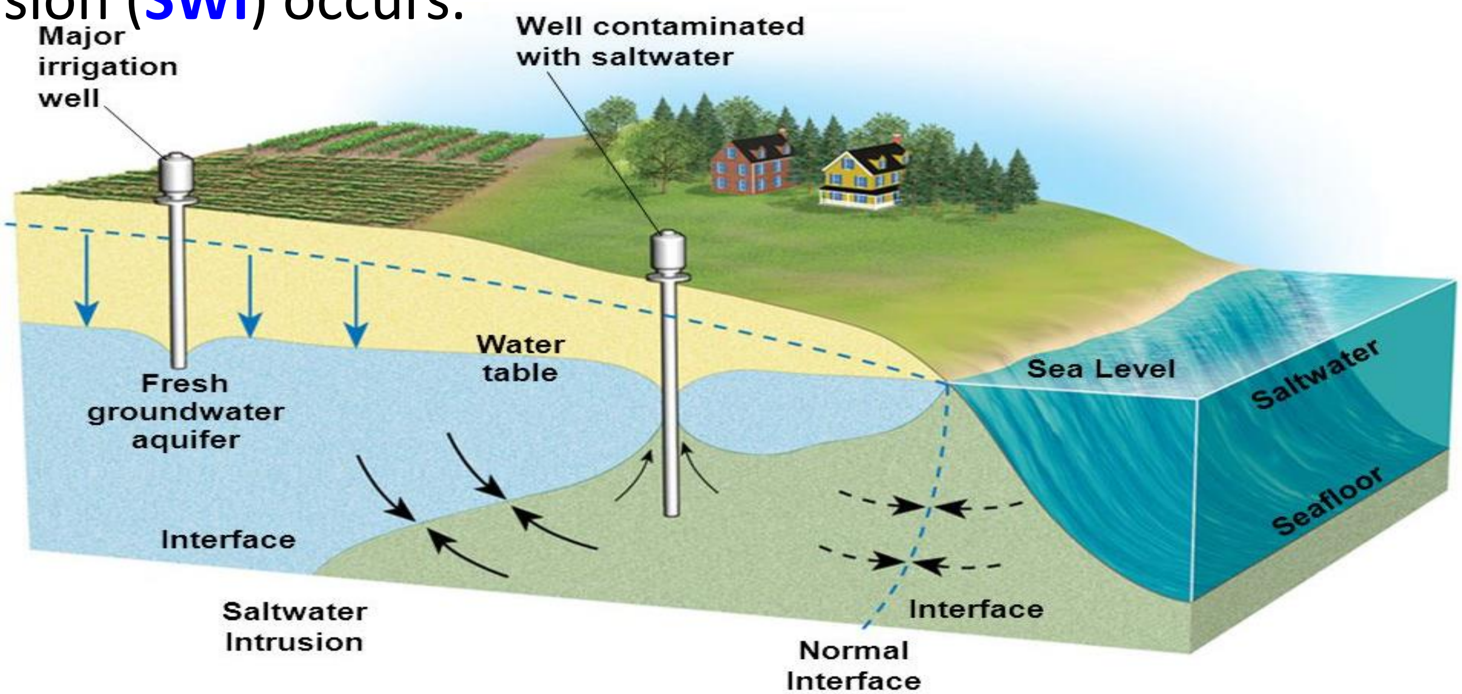
Overview

- Introduction
- Methodology
- Results
- Conclusion and Recommendations

Introduction

- Water resources in arid regions.
- Groundwater resources are heavily utilized, especially in densely populated and developed coastal areas (coastal aquifers).
- Coastal aquifers must be protected and managed properly. Wherever mismanaged, seawater intrusion (**SWI**) occurs.



Source: Figure 1 : seawater intrusion (natural process and pumping water). https://cheap library.com/book/20de2da16da65cbd79db561142b4fb05

- **SWI** is affected by various hydrogeological and hydrological parameters.
- In many coastal aquifers (especially, in arid regions), **SWI** is accelerated by over-abstraction of fresh groundwater and limited natural recharge.
- **SWI** can decelerate and control by using managed aquifer recharge (MAR).

- **The objective of this paper is twofold:**

1. Study the impact of different hydraulic gradients and MAR (by injection wells) on the dynamics of the saline water interface by using sand tank experiment.
2. Numerically (by using **SEAWAT** code) study the impact of saturated hydraulic conductivity (K_{sat}) on the efficiency of MAR in countering **SWI** problem.

Laboratory Methods

- **Sand Tank Design and Set-up:**

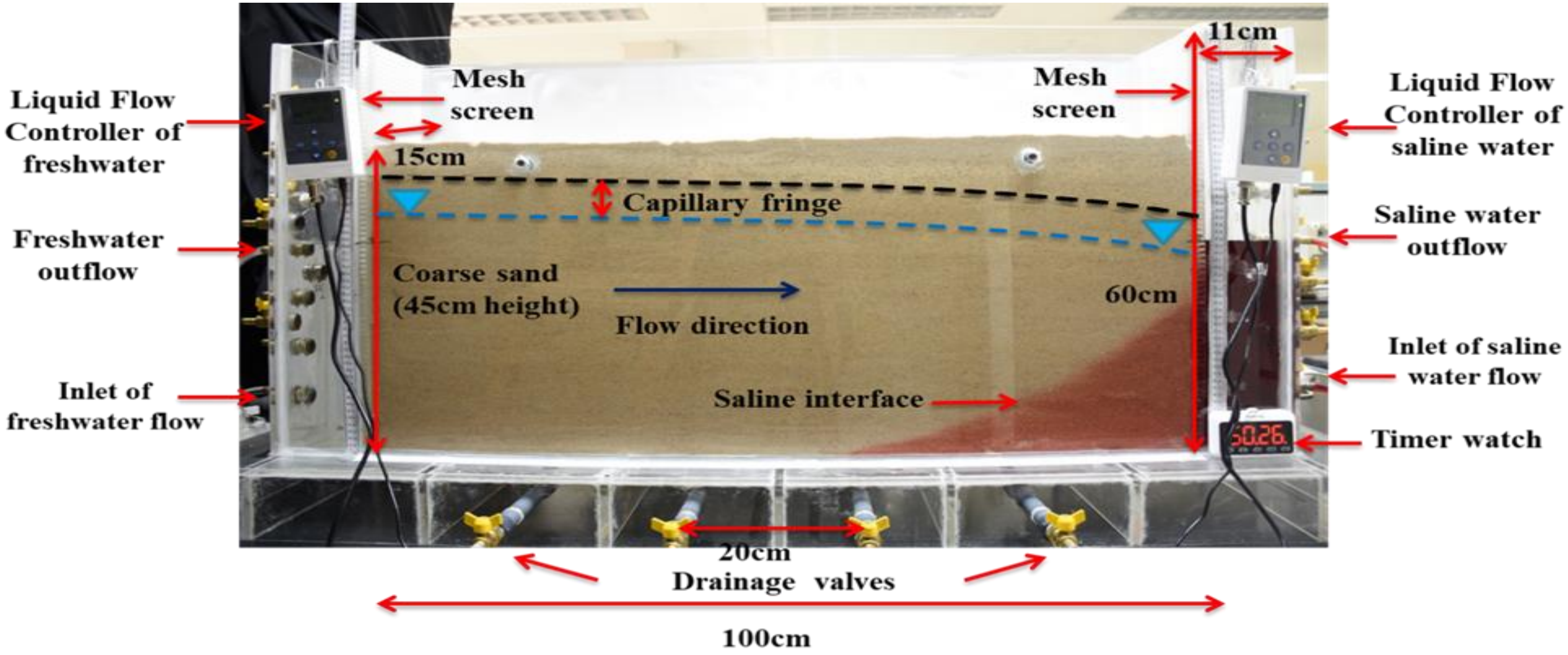


Figure 2: Design of the sand tank

- **Steps:**

1. Using homogenous layer of artificial white sand (0.4 – 0.8 mm).
2. Sand tank experiment runs (Experimenting the dynamics of saline water interface under different hydraulic gradient):
   - Different hydraulic gradients across the tank as shown in Table 1.

Table 1: Experimenting the dynamics of saline water interface under different hydraulic gradient

No. of runs	h_f (cm)	h_s (cm)	dh/dl	Concentration of inlet saline water (g/l)
1	23	22.6	0.004	50
2	23	20.6	0.024	50
3	30.5	29.7	0.008	50
4	30.5	27.5	0.03	50
5	30.4	27.8	0.026	50
6	34	27.8	0.062	50

- **Steps:**

2. Sand tank experiment runs (Experimenting the dynamics of saline water interface under different hydraulic gradient):

- The interface advances and retreats backwards to the right compartment was measured using rulers fixed along the bottom side of the tank and along the vertical seawater boundary.
- The saline water interface toe (X_{toe}) position, depth to the interface at x=0 (the coastline) (zw), the discharge zone (DZ), and the seepage face (SF) were recorded during all runs.
- The inflow rates of freshwater and saline water into the tank was measured (using a flow rate controller).
- The areas cleaned from the saline water for all laboratory sand-tank experiments were calculated using *Mathematica5* program.
- The results were compared when the system reaches steady-state.

- **Steps:**

3. Sand tank experiment runs (Experimenting the dynamics of saline water interface under the injection well):

- One injection well was fixed at the middle of the sand tank (50 cm from the saline water compartment) and at 42 cm depth from the top of the porous medium.
- The injected volume was 1.06 L (1060 cm^3).
- The level of the water table was monitored and measured using water level sensors.
- The water samples were collected from four drainage ports and three piezometers during all runs to observe the change on the salinity concentration of water.
- The discharge rate of water across the sand tank constant head boundaries was monitored by using flow meter and graduated cylinder.

Numerical modeling

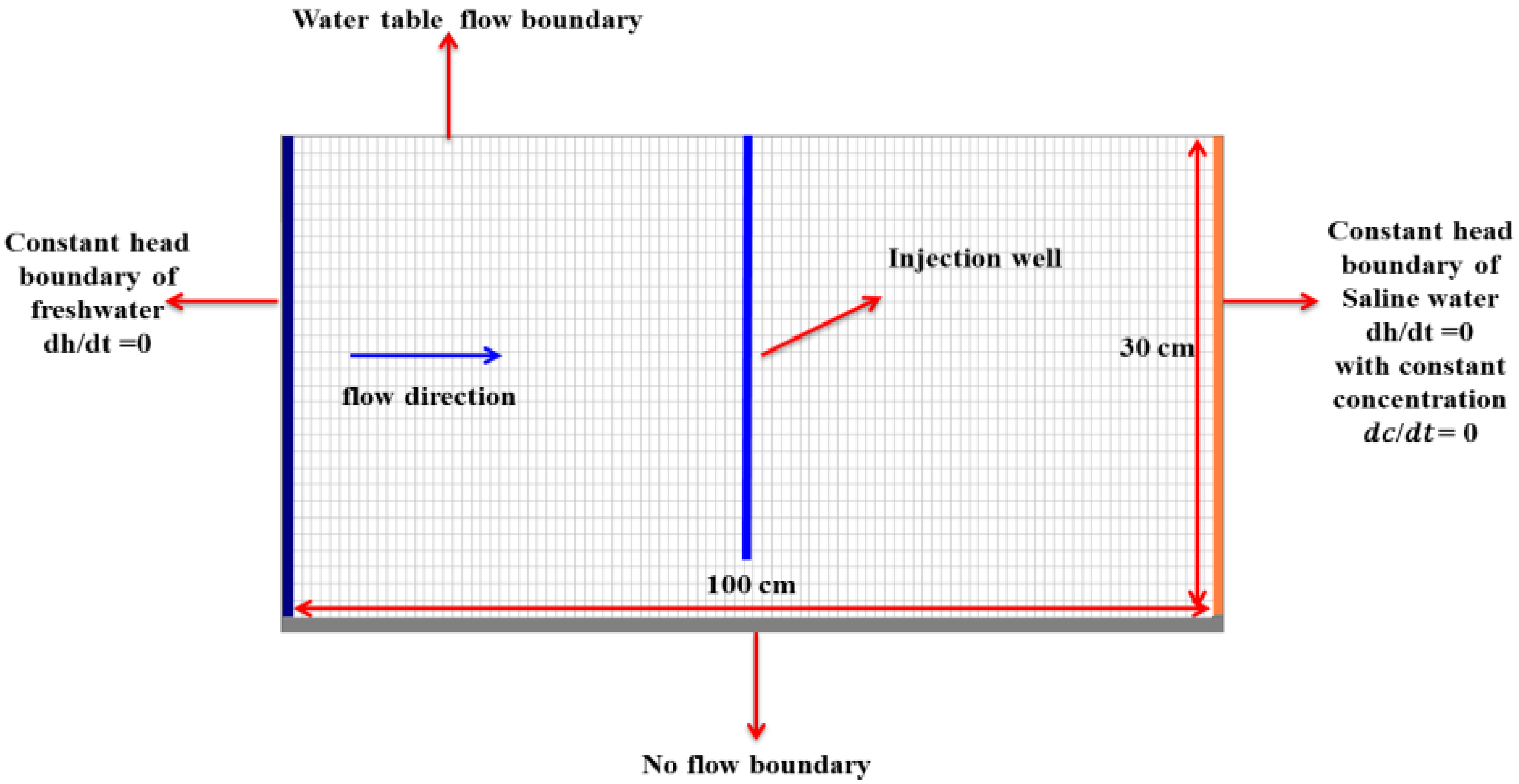
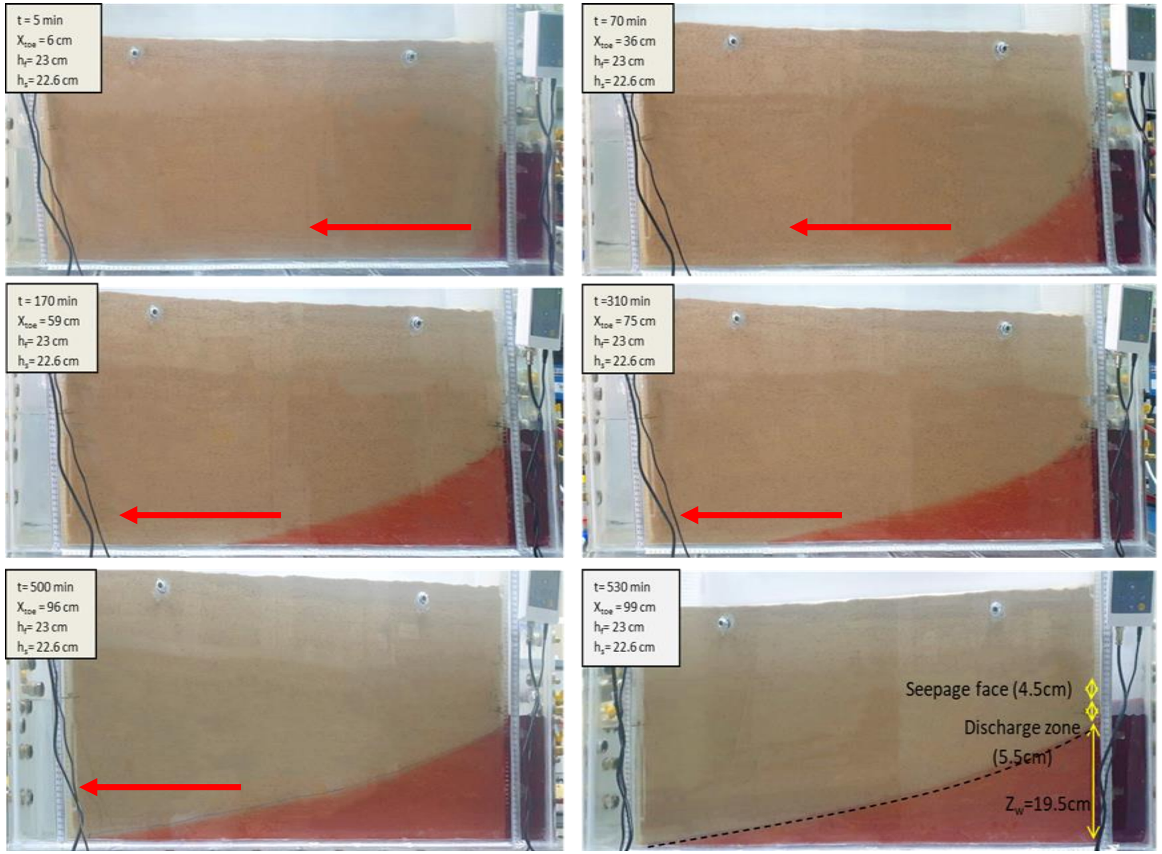


Figure 3: Sketch of conceptual model for SEAWAT simulations

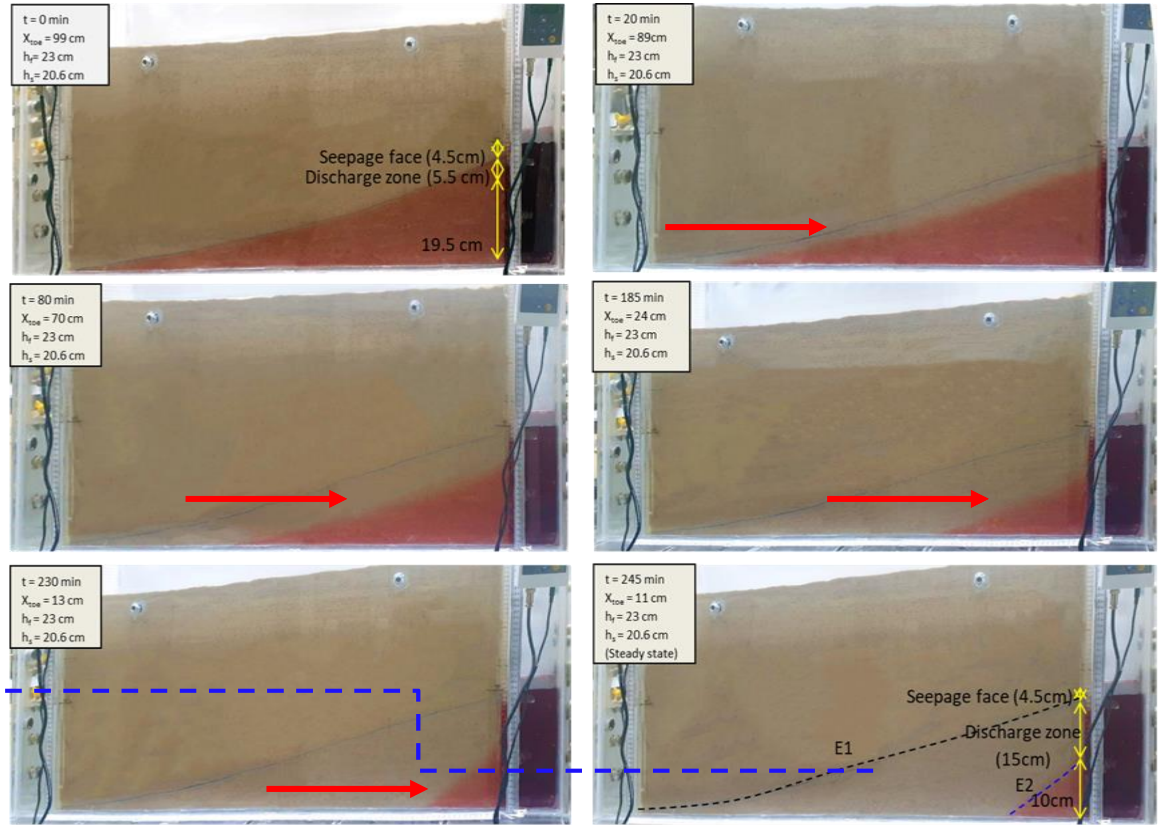
Results

- Sand tank experiments (Experimenting the dynamics of saline water interface under different hydraulic gradient):



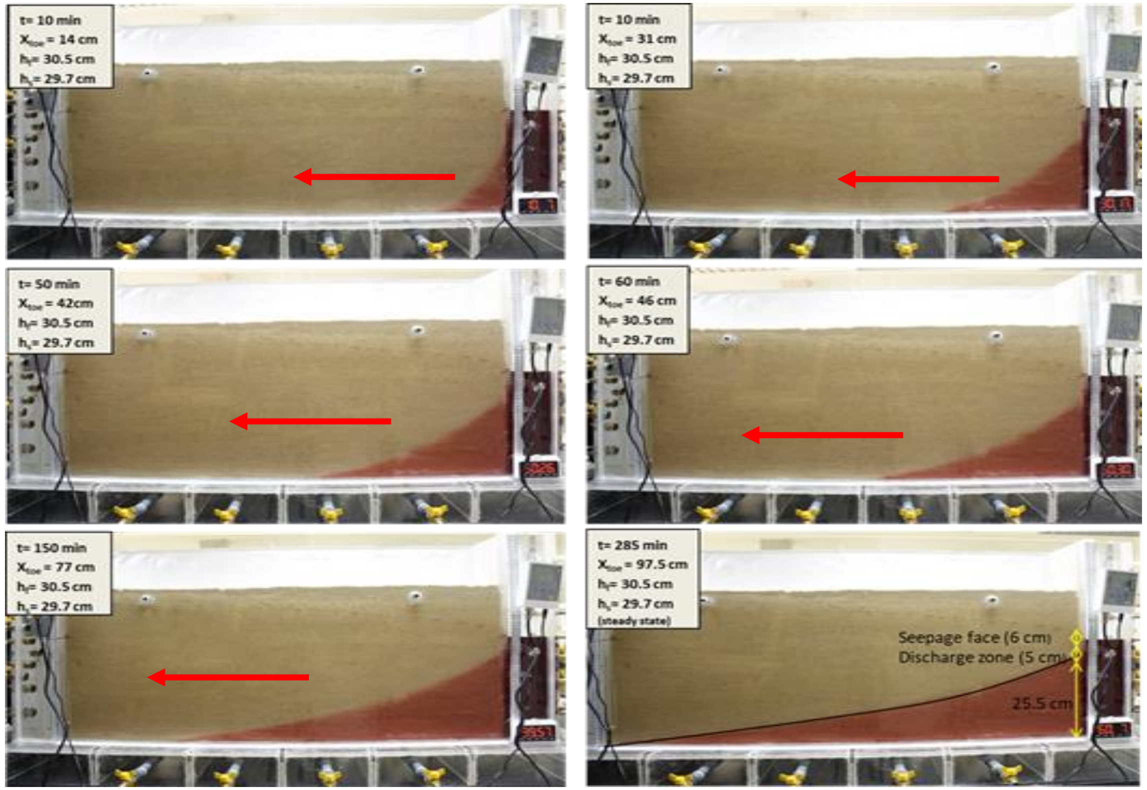
Run 1: Photos for the SWI at selected times for i of 0.004

The cleaned pore volume was 7210.2 cm^3



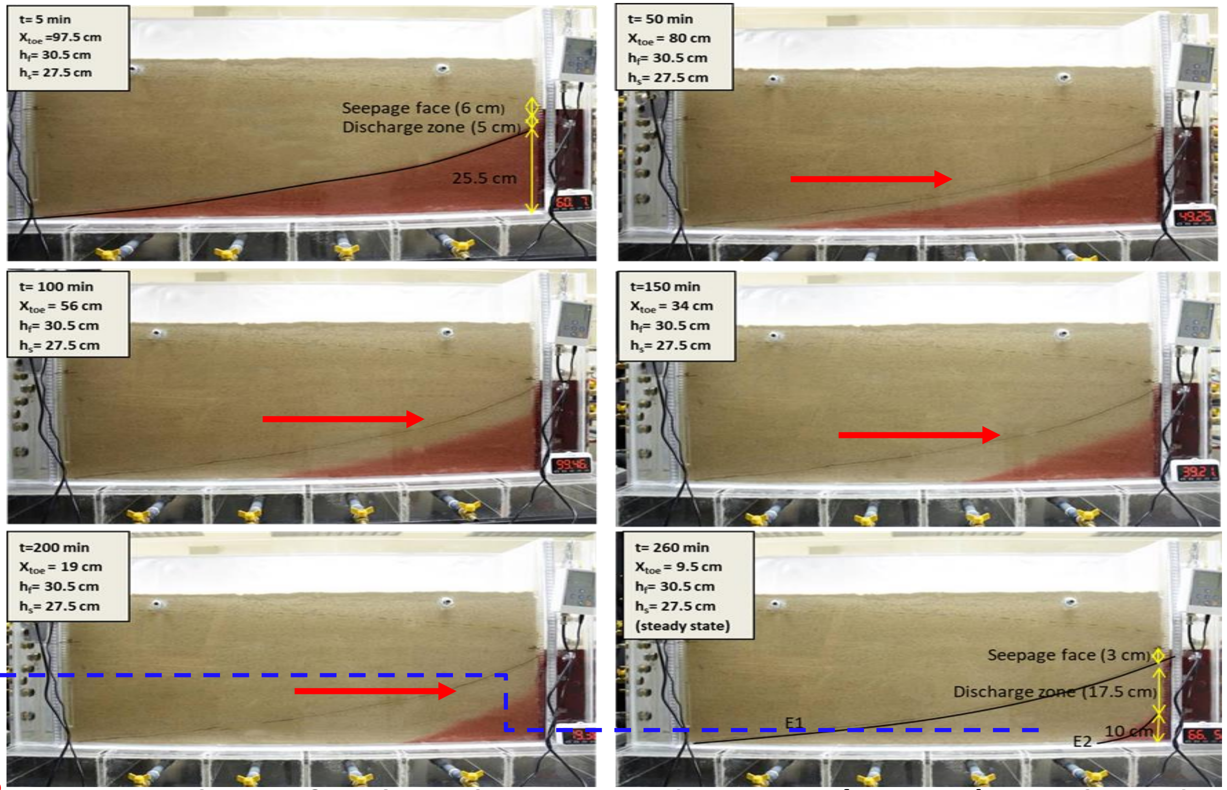
Run 2: Photos for the seawater retreat at selected times for i of 0.024 when the i reset to 0.024 instead of 0.004. Note that, the initial condition is the steady state condition of i=0.004

- Sand tank experiments (Experimenting the dynamics of saline water interface under different hydraulic gradient):



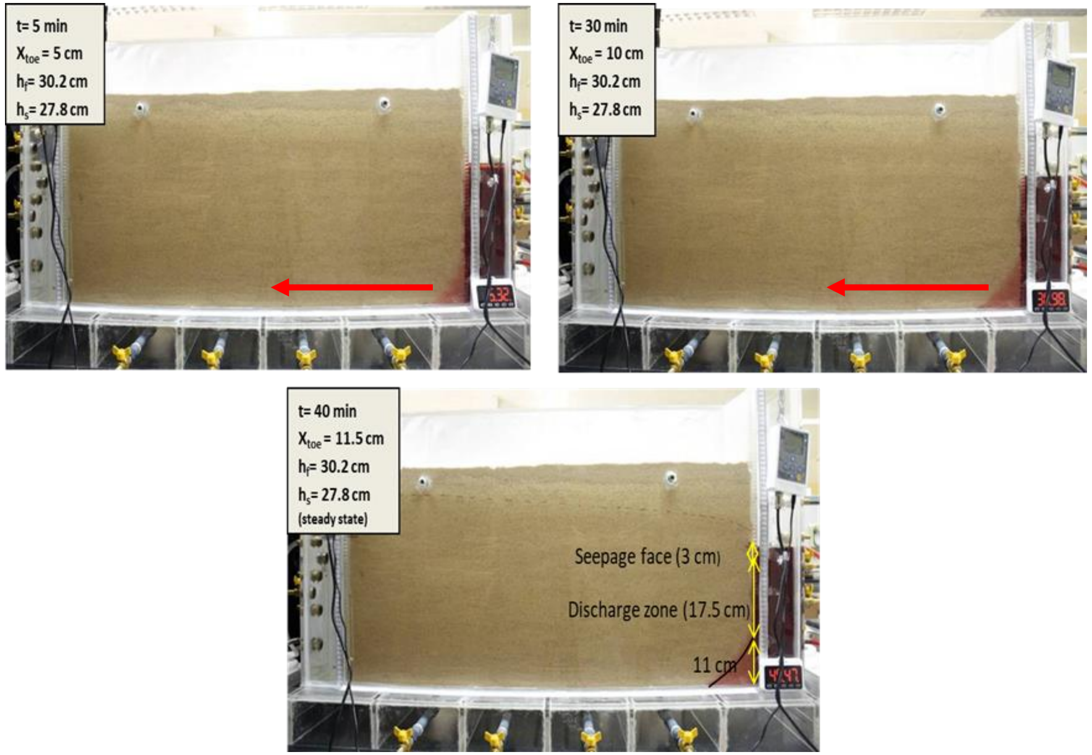
Run 3: Photos for the SWI at selected times under i of 0.008

The cleaned pore volume was 7183 cm^3

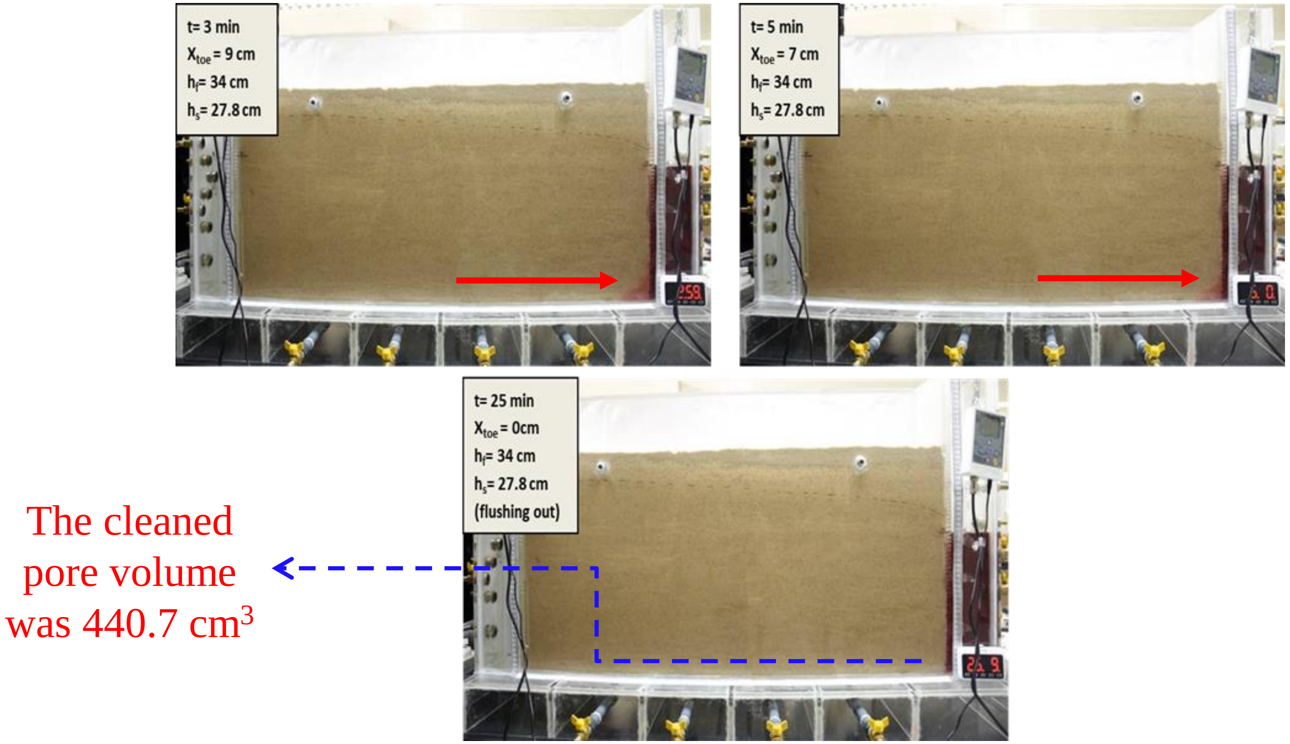


Run 4: Photos for the saline water dynamics (retreat) at selected times under i of 0.03 when the i reset to 0.03 instead of 0.008. Note that, the initial condition is the steady state condition of i=0.008

- Sand tank experiments (Experimenting the dynamics of saline water interface under different hydraulic gradient):

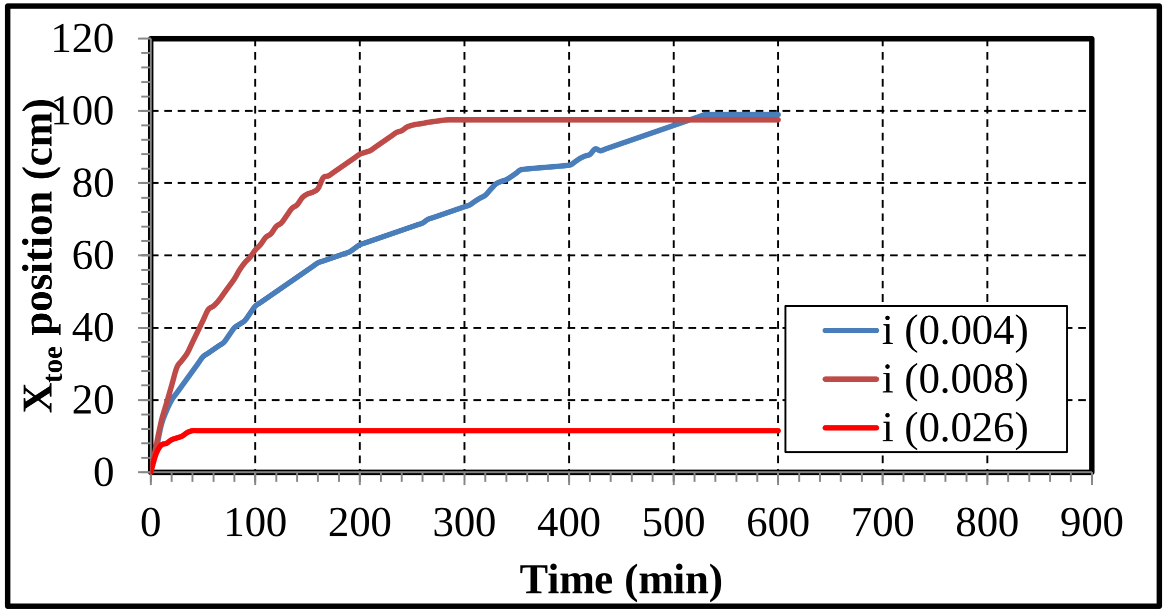


Run 5: Photos for the SWI at selected times under i of 0.026

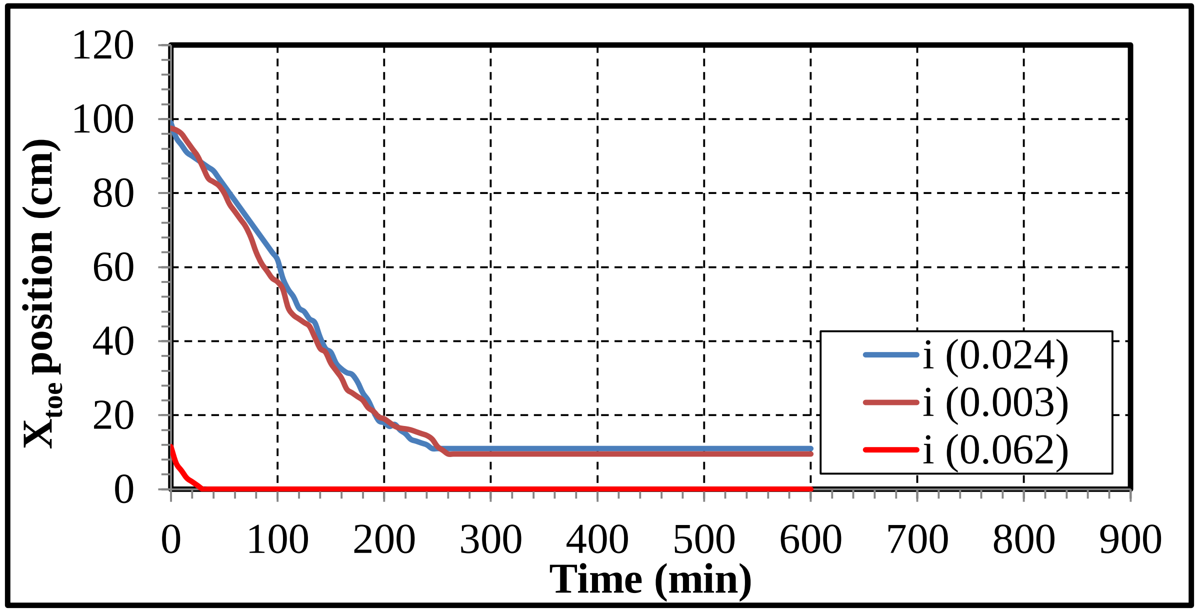


Run 6: Photos for the seawater retreat at selected times under i of 0.062 when the i reset to 0.062 instead of 0.026. Note that, the initial condition is the steady state condition of i=0.026

- Sand tank experiments (Experimenting the dynamics of saline water interface under different hydraulic gradient):



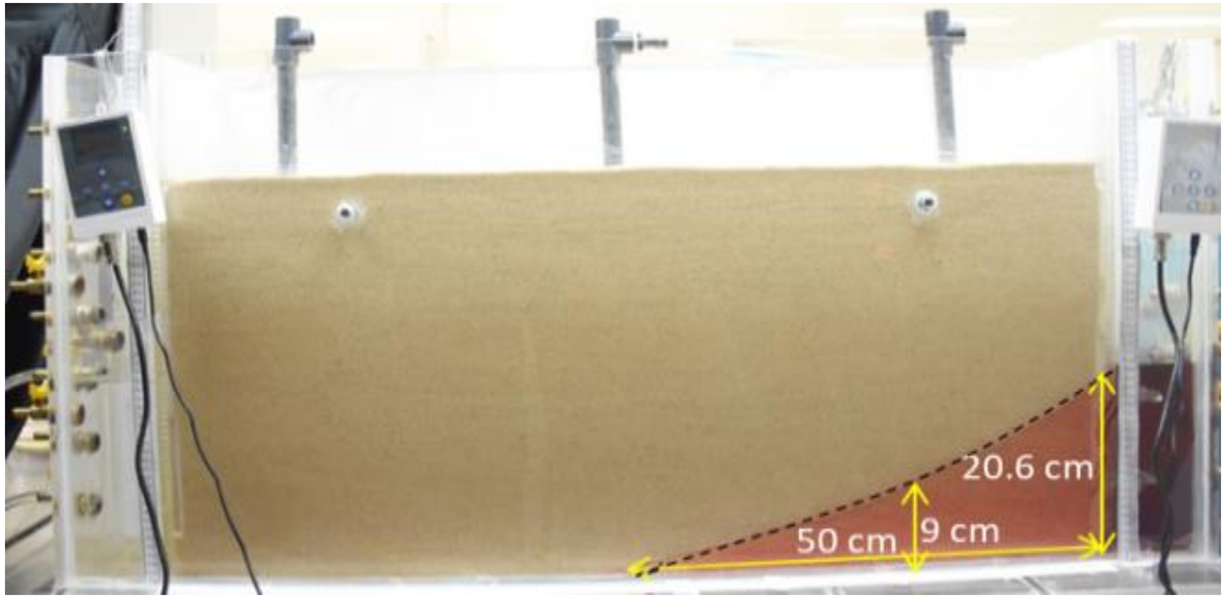
(a)



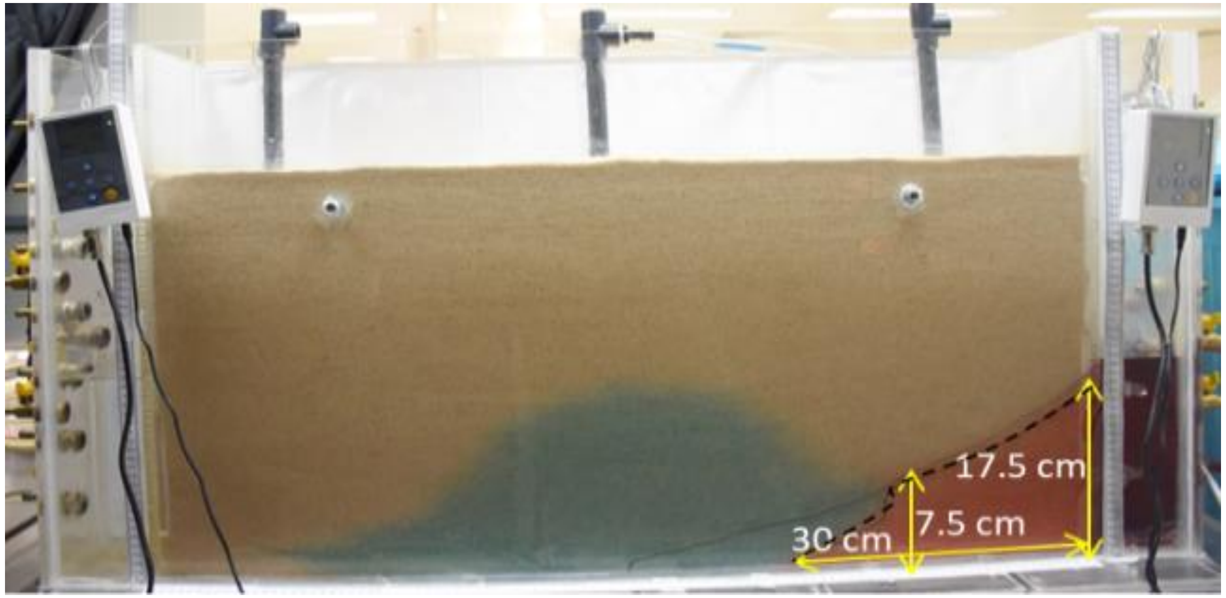
(b)

Summary of the effect of i in saline water intrusion over time considering X_{toe}: a) saline water intrusion, b) saline water retreat

- Sand tank experiments (Experimenting the dynamics of saline water interface under the injection well):



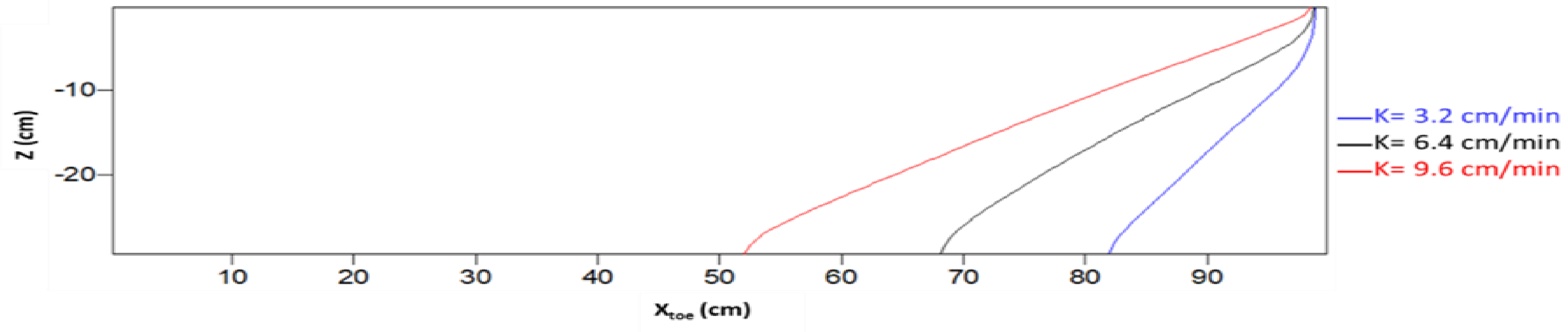
(a)



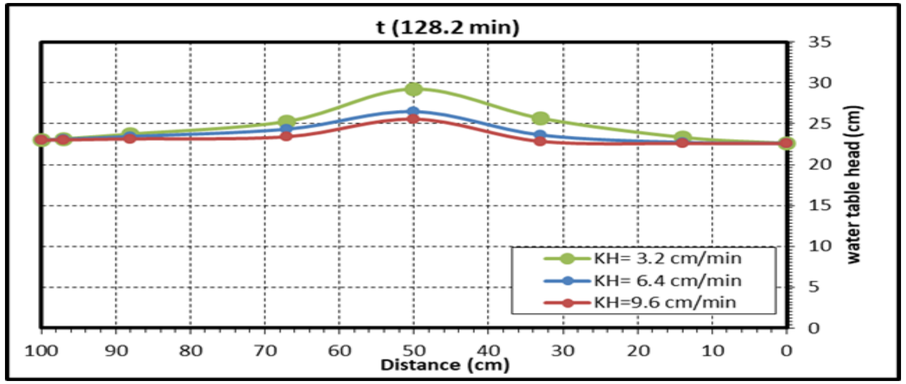
(b)

Saline water interface: a) before injection, and b) during injection (after 15 min since commencement of injection)

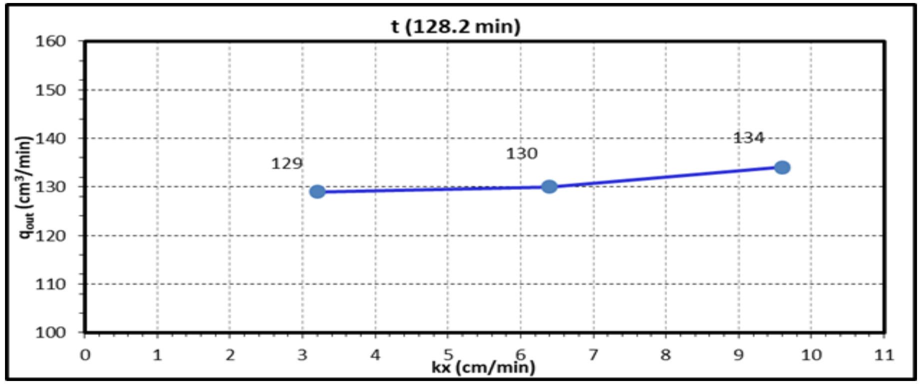
- Numerical modeling: (Numerical simulations)
    - The effect of hydraulic conductivity (K)



(a)



(b)



(c)

a) The interface lines of the 70% isochlor for different values of K , b) water table height for different K values, and c) simulated q_{out} volume for the simulations of different K value

Conclusion and Recommendations

- The rate of interface retreatment was found faster than the rate of its advancement.
- The sand tank experiment illustrates the importance of the hydraulic gradient in controlling **SWI**.
- SEAWAT simulations manifested that low aquifer's hydraulic conductivity increases the effectiveness of MAR in controlling **SWI**.
- In very permeable aquifers, the height of the developed water table mound is relatively small that limits induced piezometric heads needed for a seaward push of the saline water interface.
- Sand tank experiments and numerical modeling should be extended to consider **heterogeneous aquifers and other hydrological drivers, like the abstraction rate of groundwater, and parameters of tidal fluctuations at the sea boundary.**

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Thank you

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