Project: “Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation” Interreg CBC Italy-Croatia 2014.-2020.

Priority Axis: Safety and resilience

Specific objective: Improve the climate change monitoring and planning of adaptation measures tackling specific effects, in the cooperation area

(D_3.4.2) Report on the groundwater and transport flow model application to the flume experiment in Croatian lab

Work Package 3: Studying

Activity 4: Numerical modelling

Partner in charge: PP4 (UNIST-FGAG)

Partners involved: PP4 (UNIST-FGAG), PP5 (CROATIAN WATERS), PP6 (DUNEA)

Final version

Public report

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Contents

Laboratory experiment

Laboratory experiment was obtained in three phases.

Figure 1 to Figure 3 present phase 1, Figure 4 to Figure 6 present phase 2 and Figure 7 to Figure 9 present phase 3.

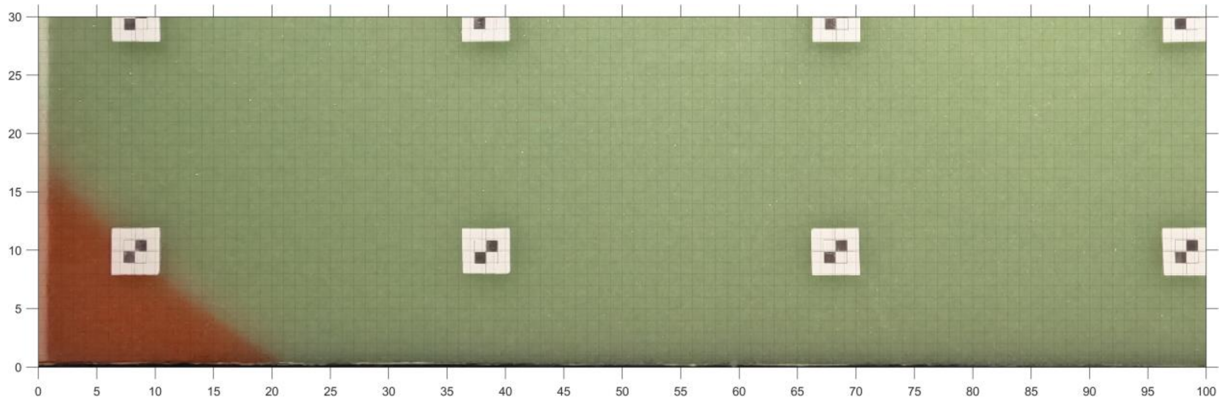

Figure 1 Laboratory experiment results in phase 1 after 10 min

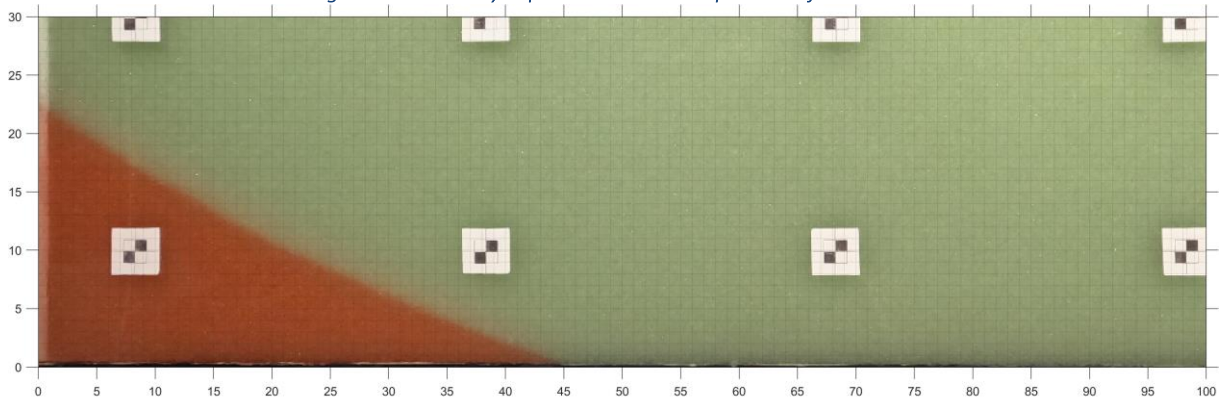

Figure 2 Laboratory experiment results in phase 1 after 100 min

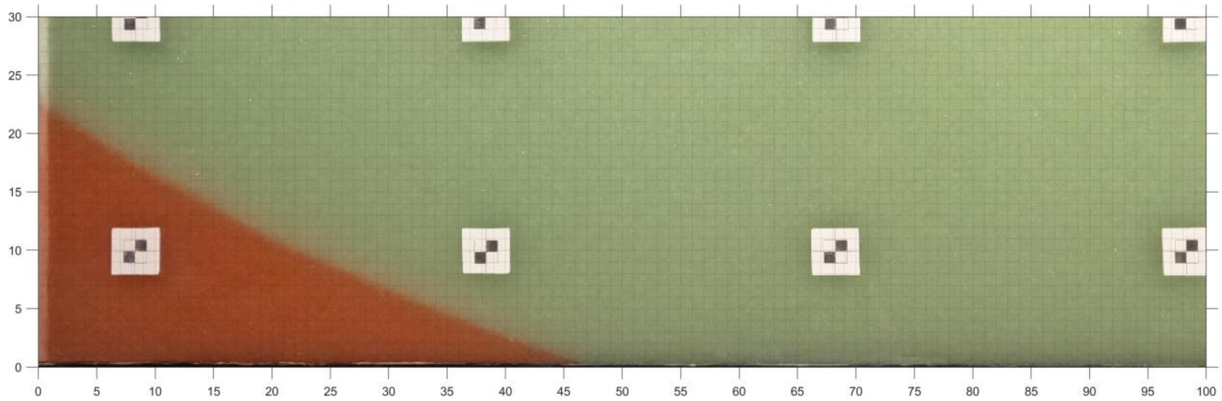

Figure 3 Laboratory experiment results in phase 1 after 190 min

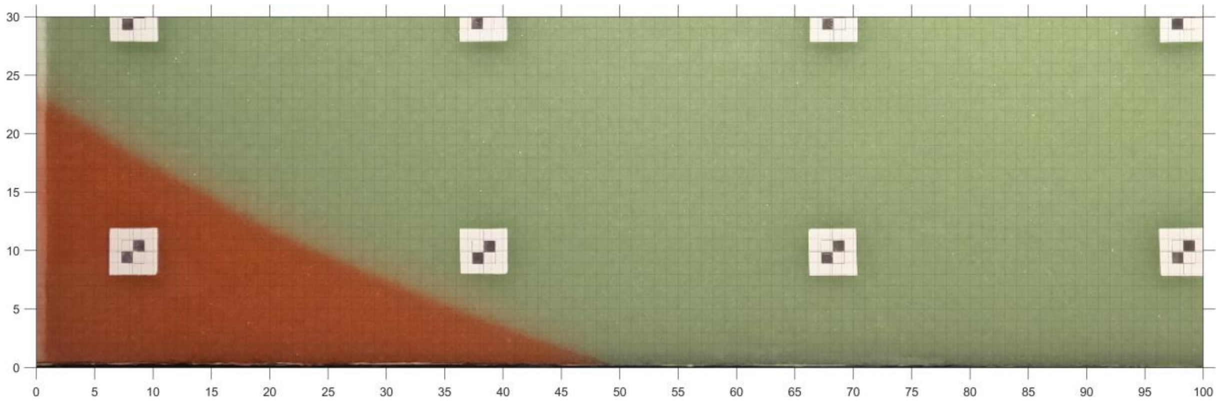

Figure 4 Laboratory experiment results in phase 2 after 10 min

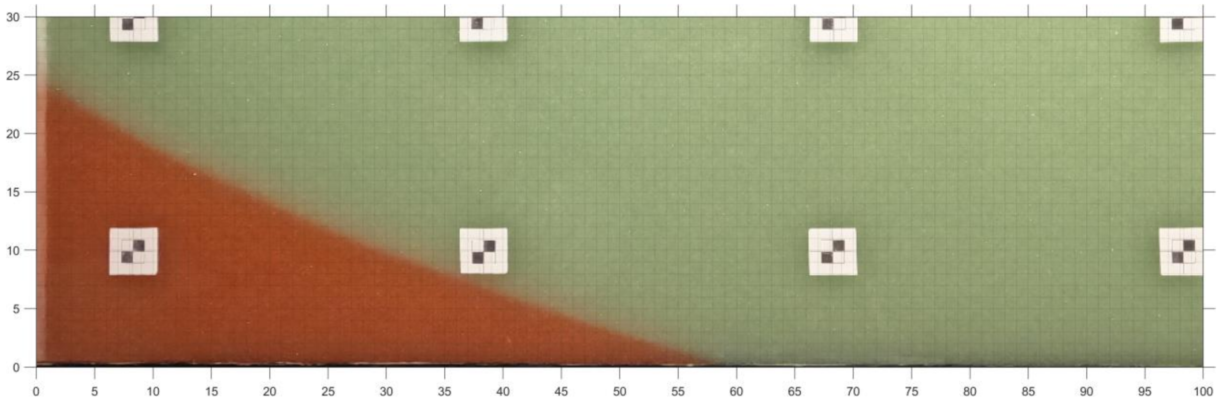

Figure 5 Laboratory experiment results in phase 2 after 100 min

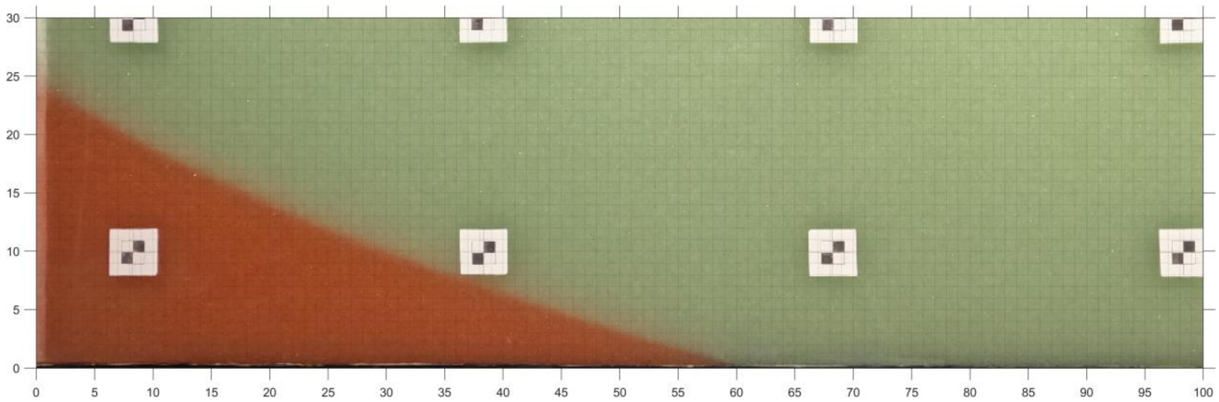

Figure 6 Laboratory experiment results in phase 2 after 180 min

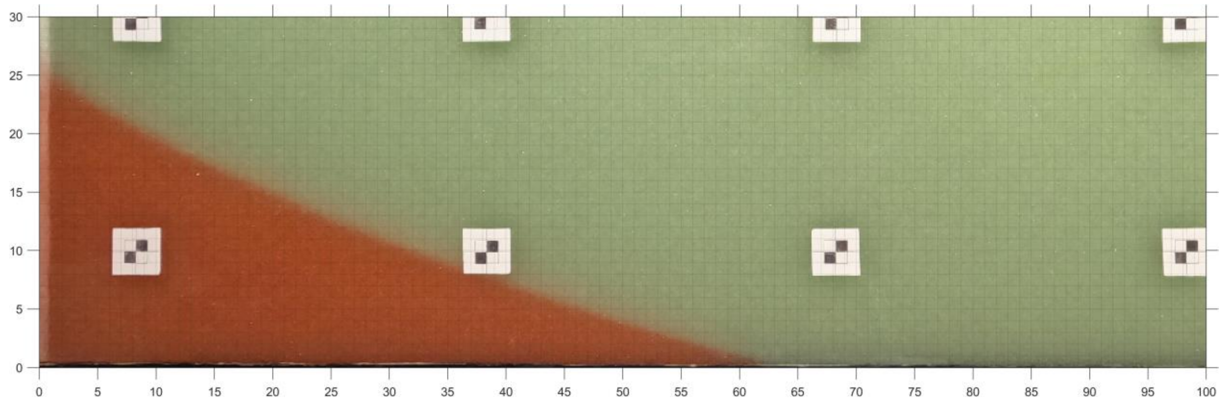

Figure 7 Laboratory experiment results in phase 3 after 10 min

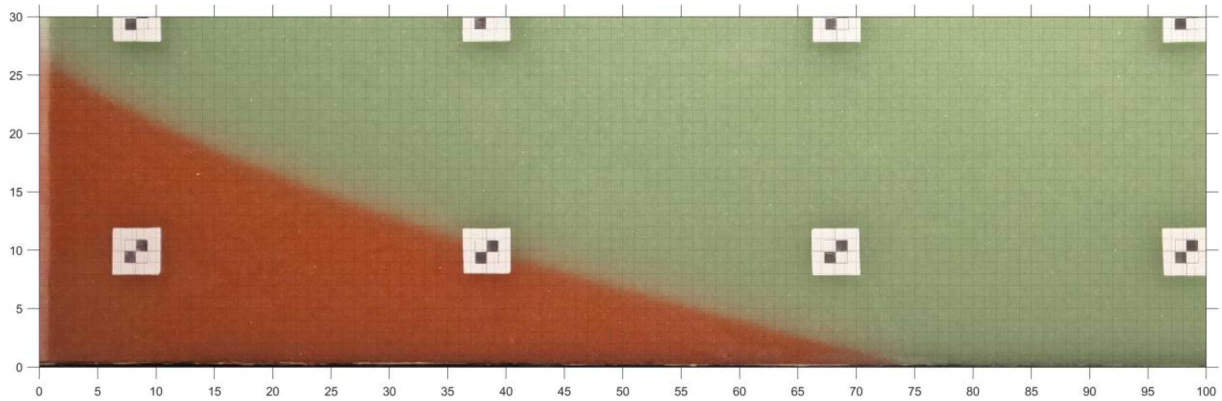

Figure 8 Laboratory experiment results in phase 3 after 100 min

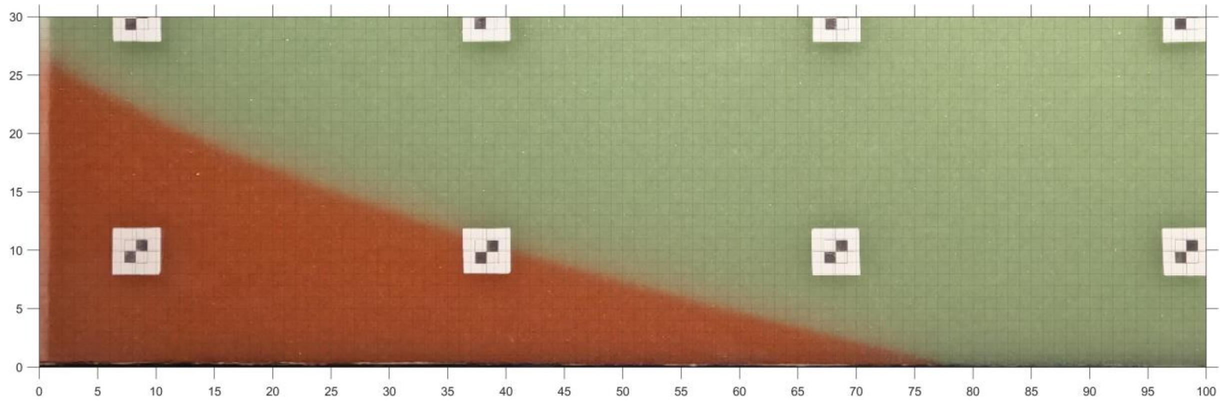

Figure 9 Laboratory experiment results in phase 3 after 170 min

Numerical model

The combination of laboratory scale models with numerical simulations was used in various research studies (Goswami and Clement, 2007; Guo et al., 2019; Kuan et al., 2019). The idea is to create such a numerical model of the flume experiment that mimics the laboratory experiment with the model domain, model parameters, and initial and boundary conditions. The results of such a numerical model can be used to validate and verify the results of laboratory scale experiments.

The numerical simulations from the flume experiment were performed using state-of-the-art software (SEAWAT) based on efficient coupling of flow (MODFLOW) and transport (MT3DMS) in saturated porous media with capability of working with dual density fluids (Levanon et al., 2019; Luyun et al., 2009).

Model domain and parameters

Domain of the numerical model (1.89m x 0.38m x 0.12m) (Figure 10) was set to mimic the dimensions of the laboratory scale model (1.89m x 0.38m x 0.125m). A uniform cell size Δx = 1cm, Δy = 1cm, and Δz = 1cm was used to create the model grid, with a total of 86,184 number of cells in the model domain.

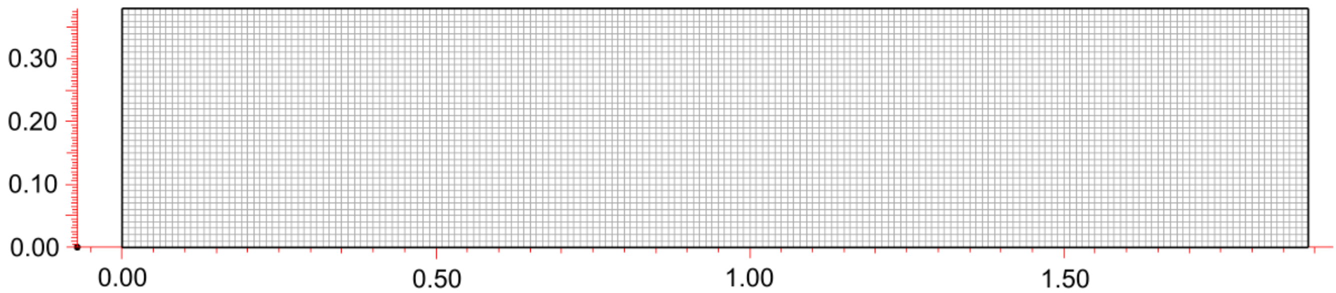

Figure 10 Model size and grid

Longitudinal dispersivity (α_L) was determined based on the Peclet number (Pe) criterion (Voss and Souza, 1987):

$$Pe \approx \frac{\Delta L}{\alpha_L} \leq 4$$

α_L of 0.5cm results in a Pe value of 2. The transverse dispersivity α_T is assumed to be one tenth of α_L (Badaruddin et al., 2015). A molecular diffusivity (Dm) of 10^{-9} m^2/s was also assumed in the numerical modeling (Badaruddin et al., 2015).

Model parameters such as specific storage (Ss) and porosity (n) were determined based on the material properties used in the laboratory experiment. Accordingly, values of 10^{-5} m^{-1} for Ss and 0.38 for n were used in the numerical simulation.

The horizontal hydraulic conductivity (k_h) of the material used in the laboratory experiment was calculated to be 42 m/h, while the k_h used in the numerical simulations corresponds to a value of 48 m/h. The k_h value in the numerical model is determined based on the comparison between the results observed in the laboratory experiment and the results of the numerical model. In the same way, the ratio between horizontal and vertical hydraulic conductivity (k_h/k_v) is determined, or a value of 3.40.

Initial and boundary conditions

The initial values of head were set to the same height as the top of the cell elevation, while the initial concentration values were set to 0.2 g/l as measured in the freshwater chamber in the flume experiment in the laboratory.

The boundary conditions on the left (x=0m) correspond to seawater with a salt concentration of 36.24 g/l, while the right boundary condition corresponds to freshwater with a concentration of 0.2 g/l. Due to the expected movement of the freshwater above the seawater wedge towards the left region, the concentration in the left boundary condition is variably adjusted as follows:

$$c = 36.24\,\frac{g}{l}, \qquad v > 0$$

$$c = 0.00\,\frac{g}{l}, \qquad v < 0$$

Head values in seawater and freshwater boundary conditions were corrected in all three phases due to the expected reading error from the laboratory model.

Table 1 Boundary conditions for head in all three phases in laboratory experiment and in numerical model

	$h_{seawater}$	h_{fresh} (phase 1)	h_{fresh} (phase 2)	h_{fresh} (phase 3)
Lab	0.4 m	0.422 m	0.419 m	0.416 m
SEAWAT	0.4 m	0.4208 m	0.418 m	0.4154 m

Calibration of model and verification

The first phase of the laboratory experiment is used for parameter calibration of the numerical model. The comparison of the first phase results from the laboratory and the numerical model was used for the determination of the parameters k_h and k_h/k_v and for the adjustment of the head values in the boundary conditions. The second and third phases were used for parameter validation. The head values of the freshwater boundary conditions in the second and third phases were also corrected by comparing the laboratory and numerical model results. Due to the measurement accuracy of the head values in the laboratory model, differences between the head values of the boundary conditions in the laboratory and in the numerical model are expected. However, the difference between the head values of the boundary conditions in the laboratory and in the numerical model is not expected to be more than ±1.5 mm.

Results

The experiment conducted in the laboratory lasts a total of 540 minutes. The first phase lasts 190 minutes. After the first phase, the head in the freshwater chamber is adjusted to a new value and then phase 2 begins. The second phase lasts 180 minutes and the third phase lasts 170 minutes. In these three phases, only the value of the water column in the freshwater chamber changed, as you can see in Table 1. The same experiment is repeated with SEAWAT.

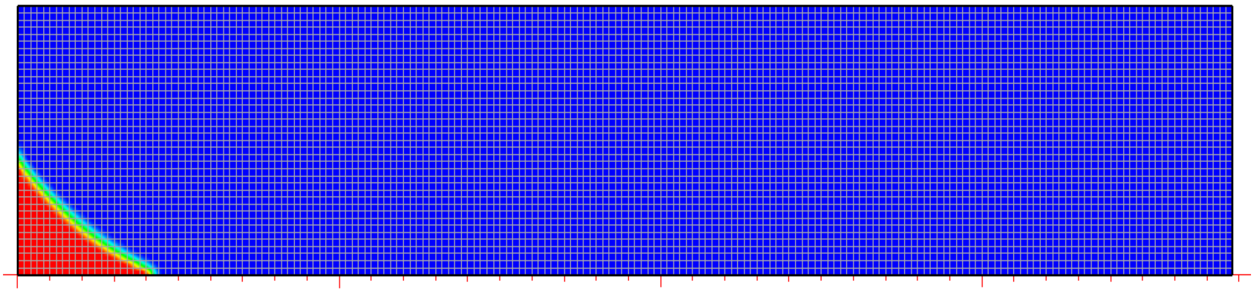

Figure 11 SEAWAT results in phase 1 after 10 min

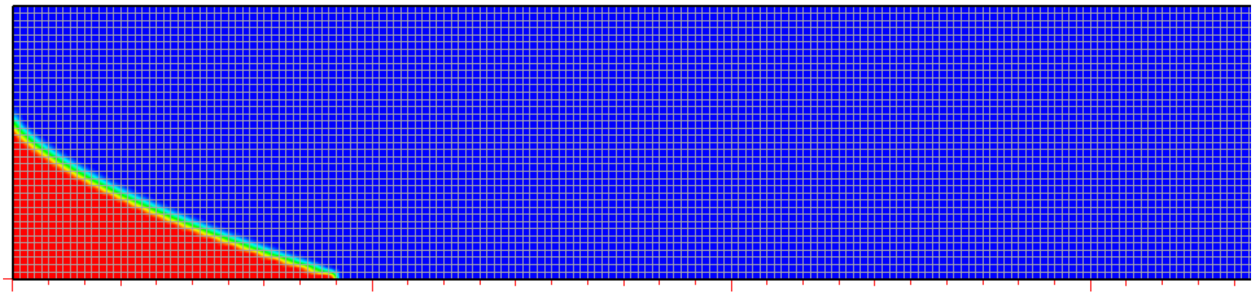

Figure 12 SEAWAT results in phase 1 after 100 min

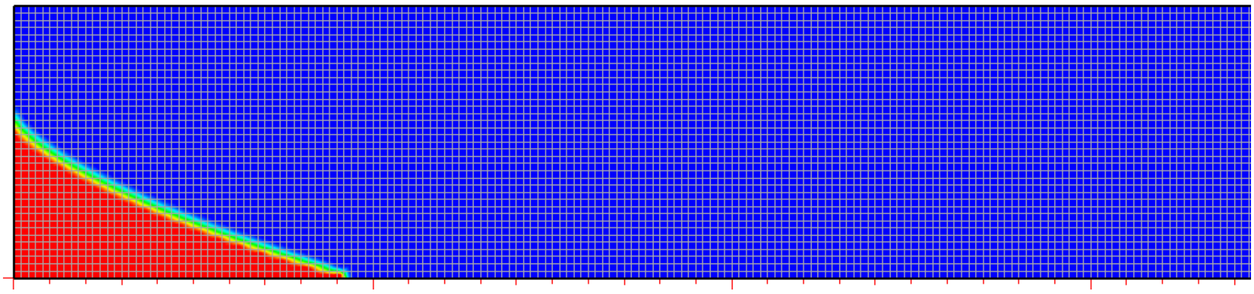

Figure 13 SEAWAT results in phase 1 after 190 min

Lab experiment and SEAWAT simulation in phase 1 reached steady state after 190min.

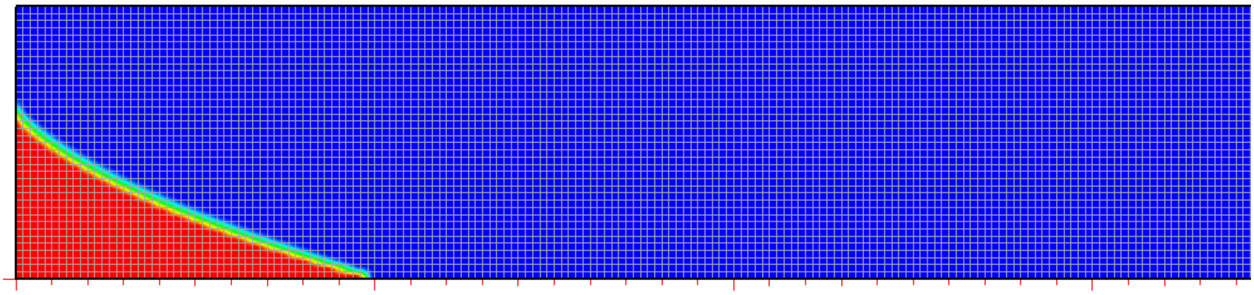
Figure 14 SEAWAT results in phase 2 after 10 min

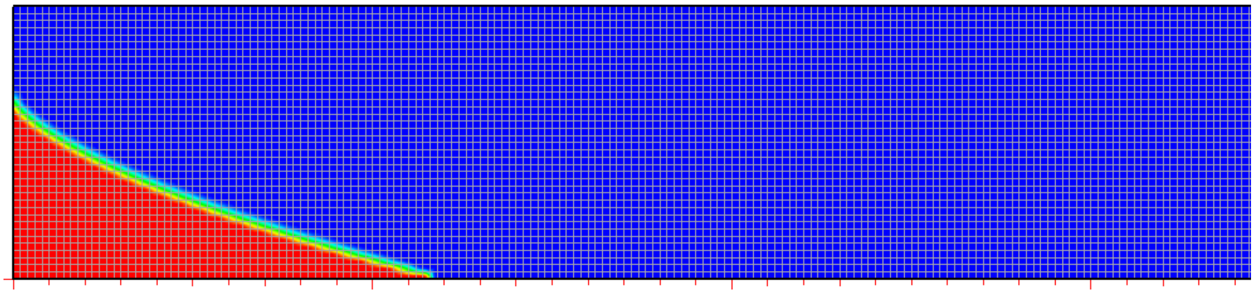
Figure 15 SEAWAT results in phase 2 after 100 min

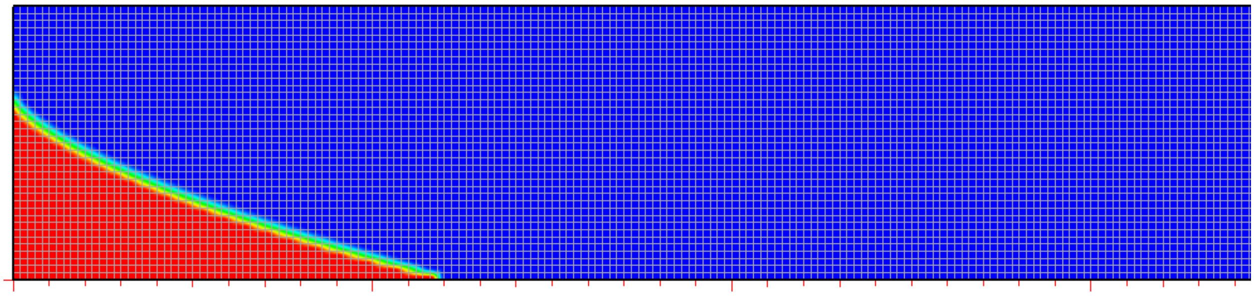
Figure 16 SEAWAT results in phase 2 after 180 min

Lab experiment and SEAWAT simulation in phase 2 reached steady state after 180min.

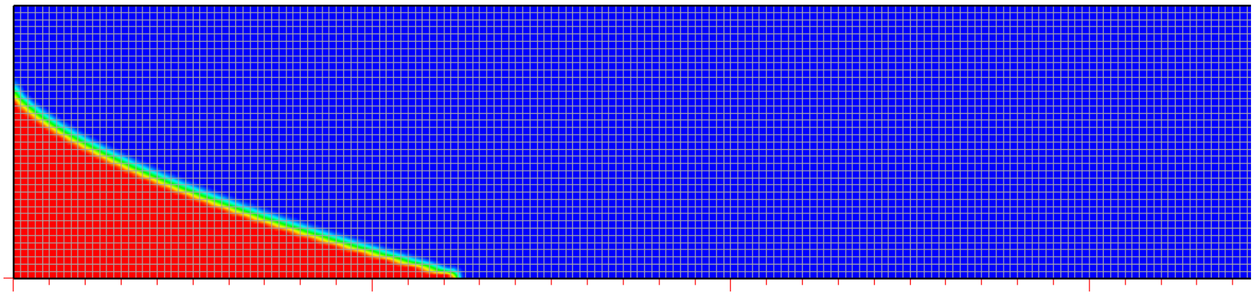

Figure 17 SEAWAT results in phase 3 after 10 min

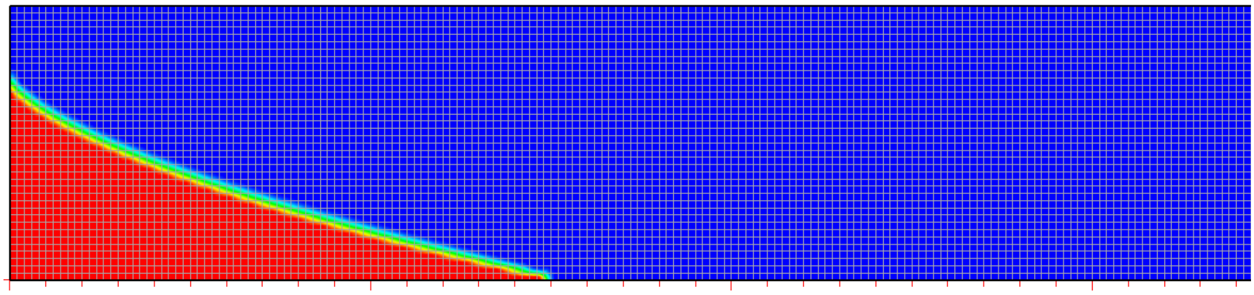

Figure 18 SEAWAT results in phase 3 after 100 min

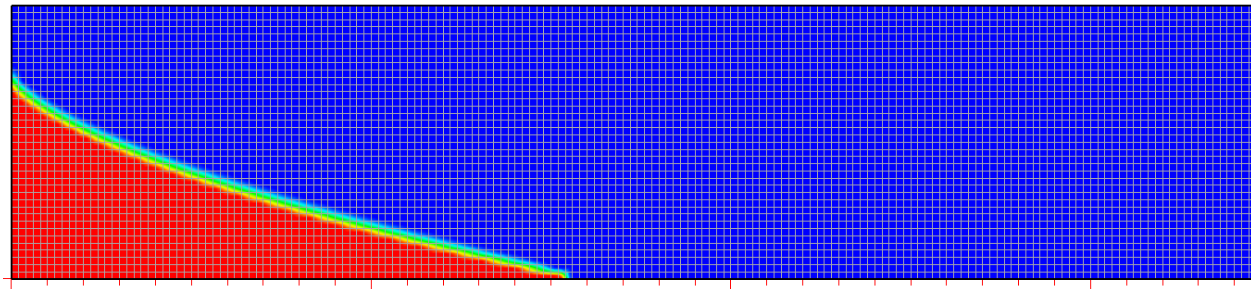

Figure 19 SEAWAT results in phase 3 after 170 min

Lab experiment and SEAWAT simulation in phase 3 did not reached steady state after 170min.

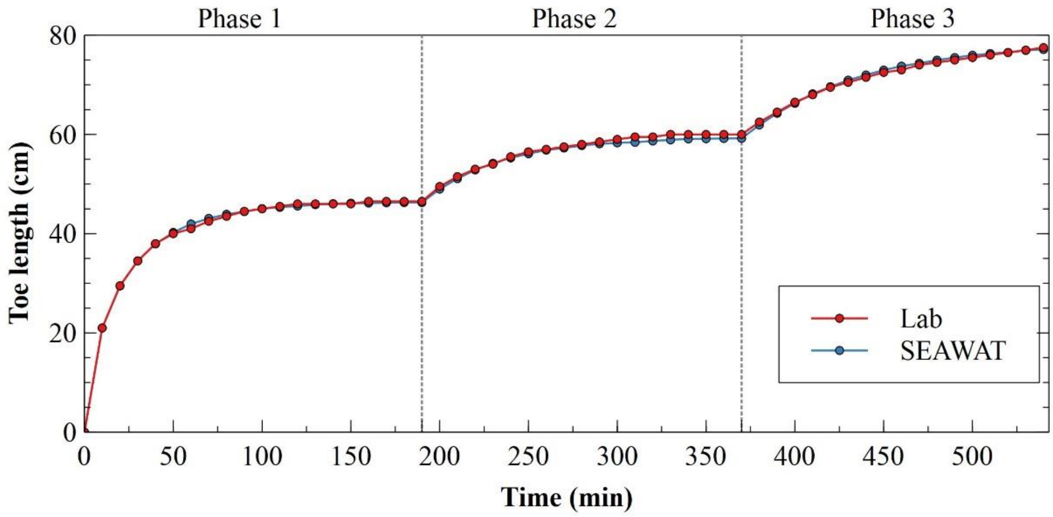

Figure 20 Comparison of results from SEAWAT and Lab for Toe length

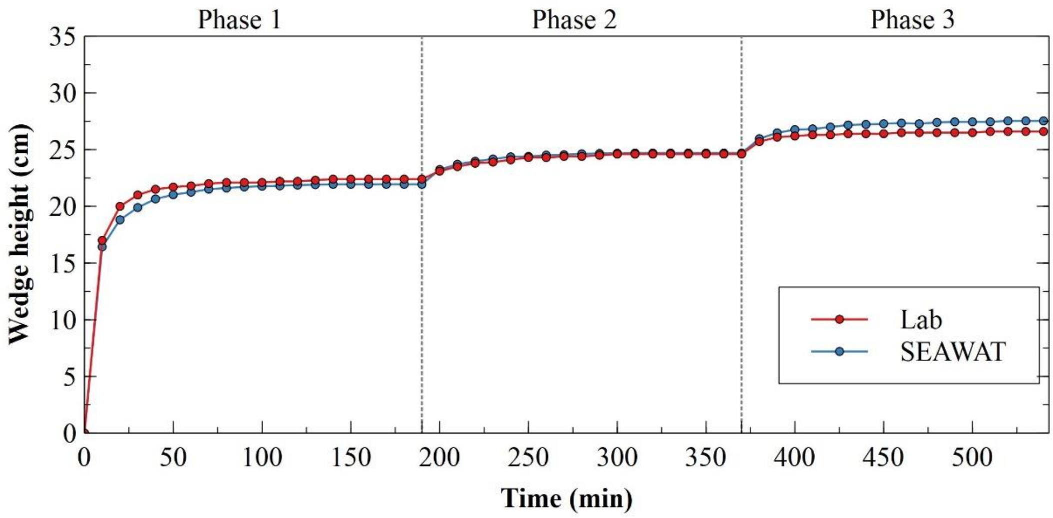

Figure 21 Comparison of results from SEAWAT and Lab for Wedge height

Figure 20 and Figure 21 show that the numerical model is able to successfully simulate seawater intrusion at the laboratory scale. Moreover, Figure 20 and Figure 21show that the difference between the measured values of the boundary conditions in the freshwater chamber in the laboratory model and the corrected values in the numerical model (Table 1) is consistent with the reading accuracy. Difference between calculated k_h from the laboratory model and the k_h value used in the numerical model is negligible.

Literature

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