Surface-groundwater flow numerical model for coastal barrier beach

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Motivation and Goals

- To develop a surface-groundwater flow model to better understand the effects of seepage on swash hydro-morphodynamics.

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- Validation of the model is by comparing the numerical results against the BARDEX II prototype-scale experiment.

Governing Equations

Nonlinear shallow water equations

$$\frac{\partial h}{\partial t} + \frac{\partial hu}{\partial x} = 0 \qquad (1)$$

Variables involved

h is water depth, u is velocity, z_b is bed level, q is seepage, k is permeability, τ is bed shear stress, ρ_w is water density, x is horizontal axis, z is vertical axis, t is time

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Laplace's equation

$$\begin{aligned} \nabla \cdot \phi &= 0, & (3) \\ \phi &= h + z_b, \\ \nabla &= \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}. \\ q &= -k\frac{\partial \phi}{\partial n} & (4) \end{aligned}$$

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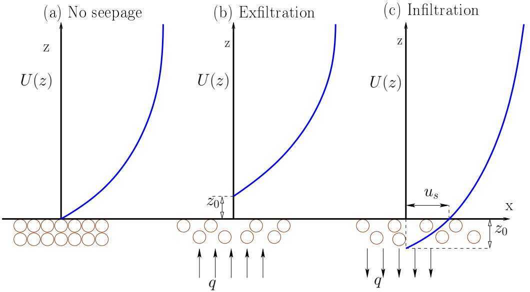
BBL sub-models with seepage



BBL model based on Cheng and Chiew (1998)

$$U(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right) + \frac{q}{4}\left[\frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right)\right]^2 \quad (5)$$

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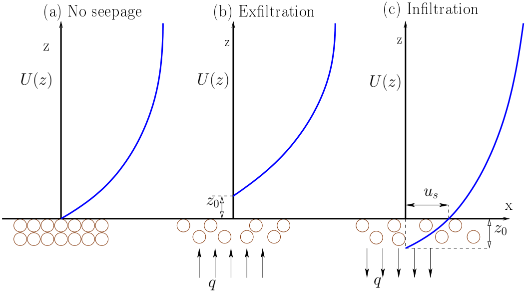

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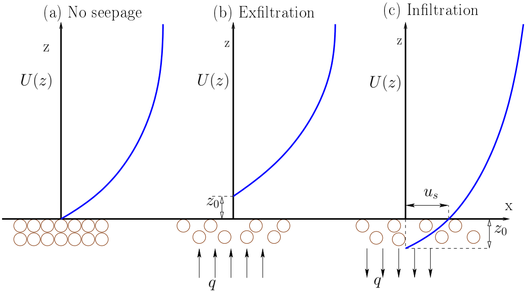

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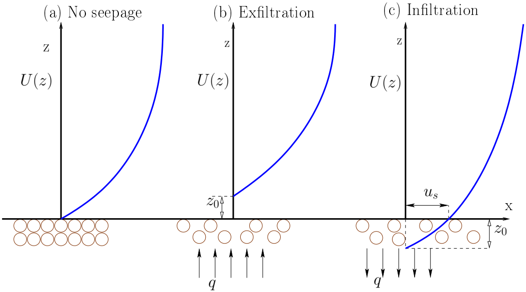

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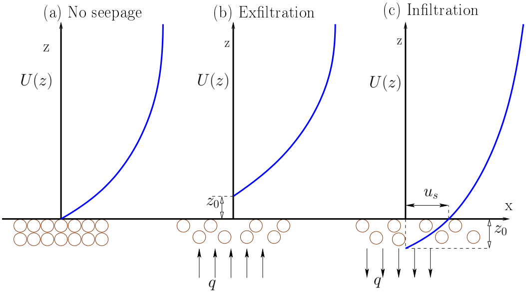

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$$\tau = \rho_w u_*^2 \quad (6)$$

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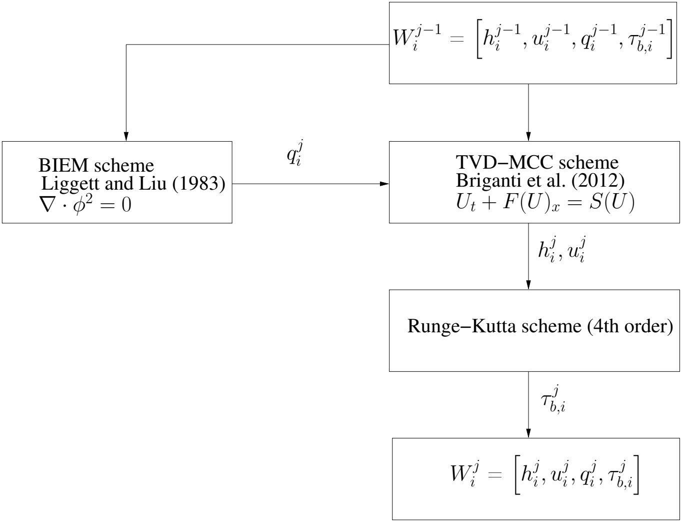
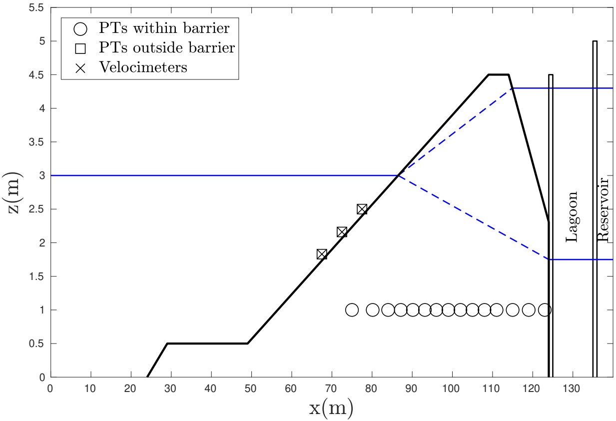
Coupled surface-groundwater flow model



The BARDEX II experimental set-up (Delta flume, Deltares, Netherlands)



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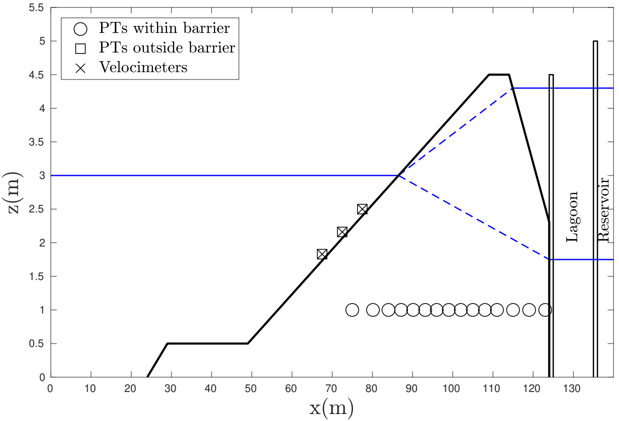
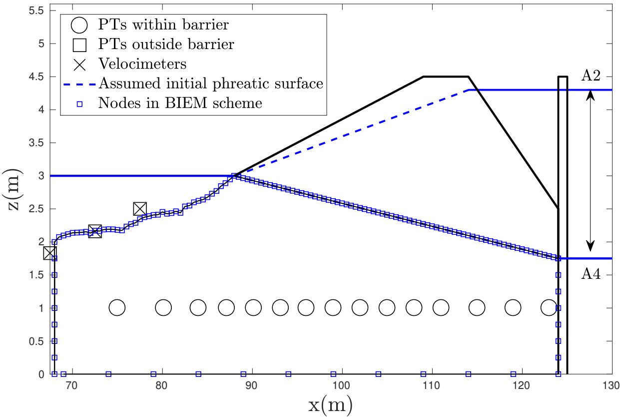


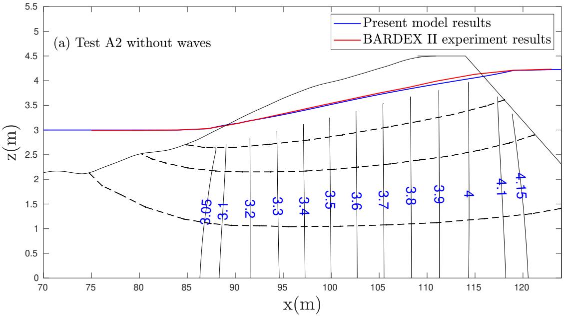
- Wavemaker at $x = 0$ m, $H_s = 0.8$ m and $T_p = 8$ s
- 2 test cases: A2 (sea level < lagoon level), A4 (sea level > lagoon level)

Numerical model set-up



- Surface flow model: $\Delta x = 0.01$ m, $L_x = 56.5$ m, $CN = 0.5$, $h_{min} = 1 \times 10^{-3}$ m , $d_{50} = 0.43$ mm, $p_b = 0.4$, $k = 8 \times 10^{-4}$ ms^{-1}
- Groundwater flow model: $\Delta l \cos\alpha = 50\Delta x$ m where $\tan\alpha = \frac{dz_b}{dx}$ (sea-side), $\Delta l = 0.5, 0.25, 0.5$ m (other sides)

Phreatic surface validation - without waves



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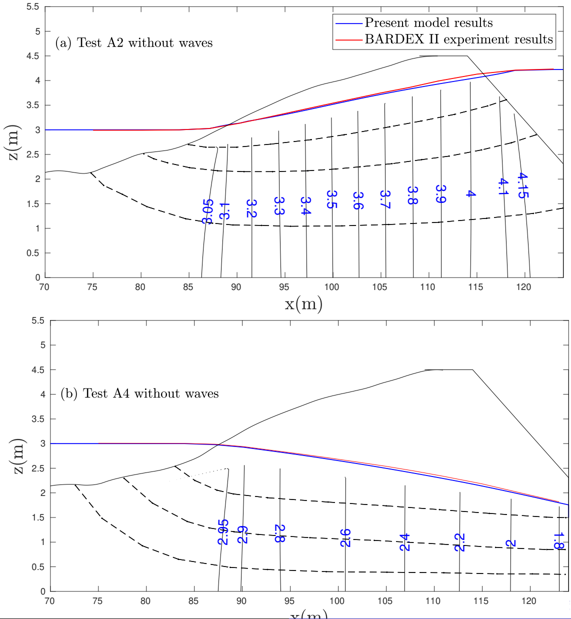
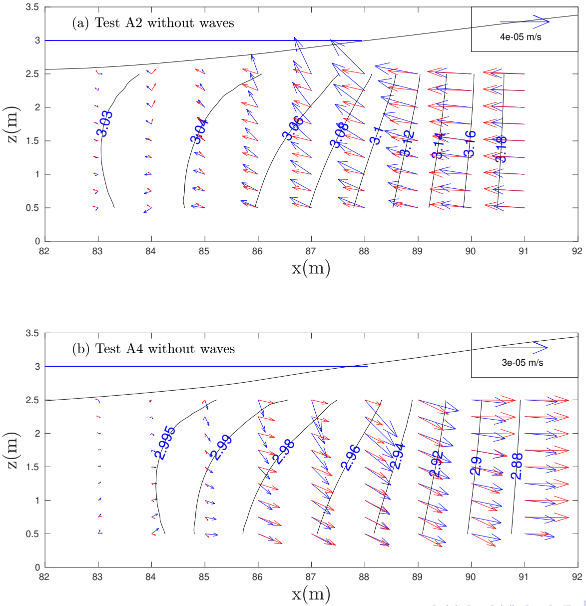


Pore velocities below the beach - without waves



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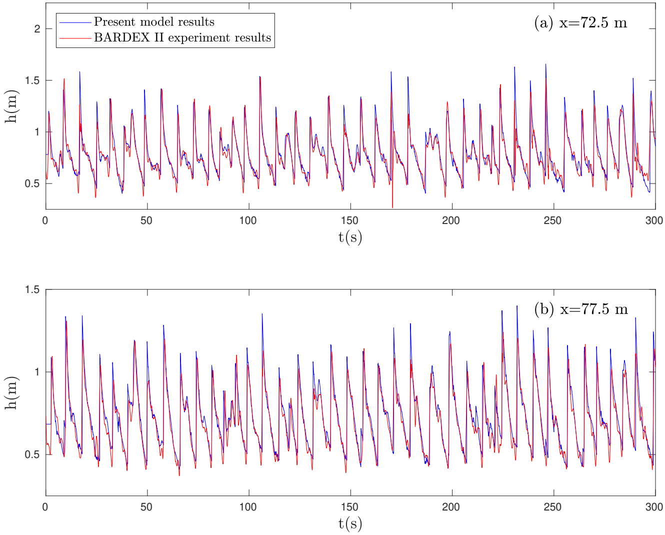

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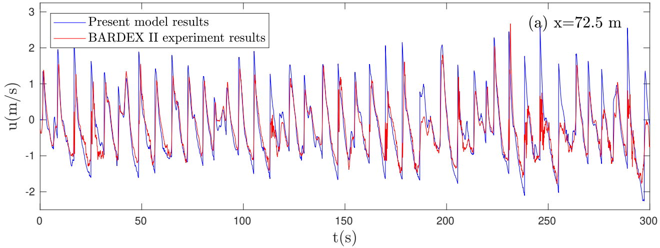

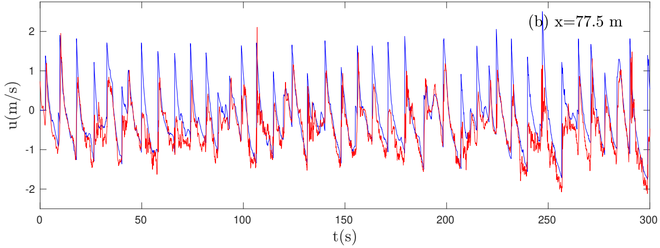

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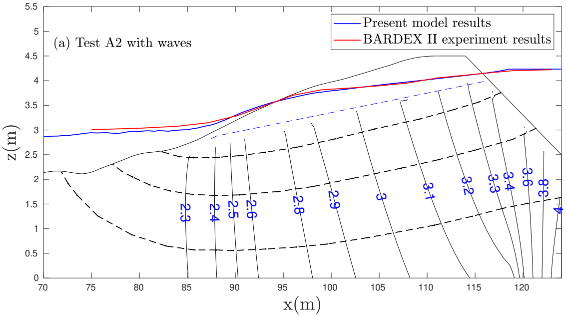

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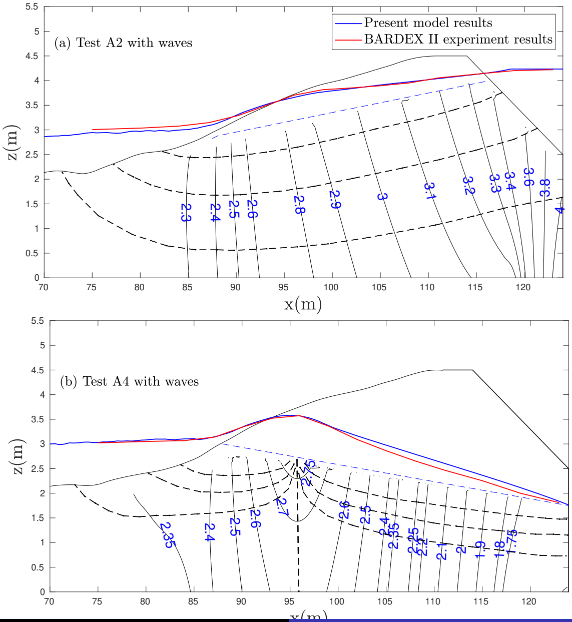

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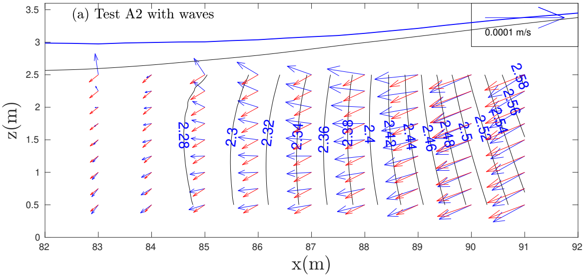
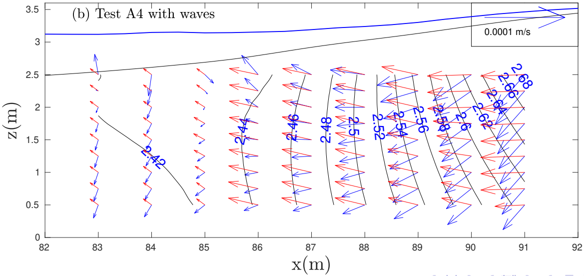
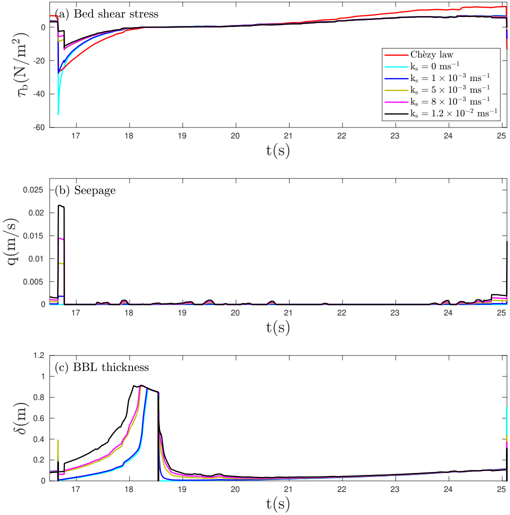




Exfiltration on BBL



- Increase of exfiltration rate:
  1. increases BBL thickness,
  2. decreases bed shear stress.

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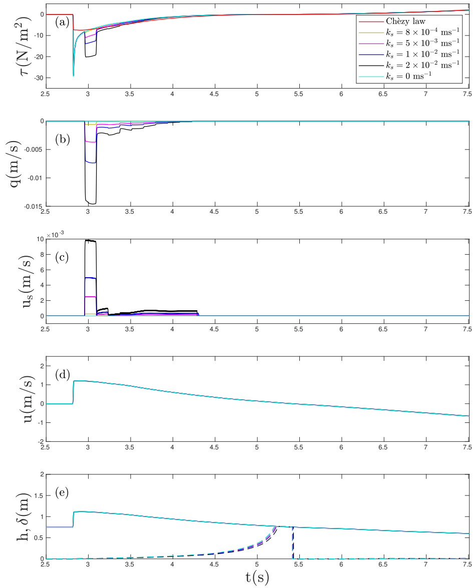

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Conclusion

- Model is capable of simulating barrier beach groundwater dynamics with reasonable accuracy.

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- Exfiltration reduces bed shear stress due to thickening of boundary layer.
- Infiltration increases bed shear stress due to thinning of boundary layer.

References

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Thank you for your attention!

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