SURFACE-GROUNDWATER FLOW NUMERICAL MODEL FOR COASTAL BARRIER BEACH

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INTRODUCTION

Fine-grain beaches are relatively common where the beach forms part of a larger coastal barrier system. In such a coastal system, different water levels could be present in the seaward side and back-barrier lagoon. The water level changes in the steady-state lagoon may potentially induce groundwater dynamics near the beach which would subsequently affect seepage flow into (or out of) the beach. The exchange of water could generate varying hydrodynamical and morphodynamical behaviour at the seaward boundary. Hence, it is important to gain insight into groundwater flow dynamics which results in exchange of water between sea, barrier and lagoon; especially for coastal engineers responsible for planning and managing such a coastal environment. In present work, a numerical model is developed to simulate flows through a coastal barrier and it is validated against prototype-scale experimental results, which can then be extended to model small time-scale groundwater flows that may be too expensive or impractical to set up in a lab.

NUMERICAL MODEL

Present numerical model is a fully-coupled groundwater-surface surface-groundwater flow model: it solves the non-linear shallow water equations using TVD-MCC scheme of Briganti et al. (2012) and uses the dependent variables of water depth and bed elevation from the surface flow model to determine the potential gradient on the seaward boundary using BIEM scheme (Liggett and Liu, 1983) solving 2-D Laplace equation for porous medium flow:

$$\nabla^2 \cdot \phi = 0, \tag{1}$$

where $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}$ in the horizontal direction x and vertical direction z, and potential head ϕ is combined water depth and bed-elevation obtained from the surface flow model. The model can also turn off the surface water waves using a switch, and simulate only the groundwater flow for a case of steady groundwater flow. The model is then independently verified by reproducing the steady-water flow cases in prototype-scale experiment BARDEX II (Turner et al., 2016). Next, the surface water waves are switched on and both surface and groundwater flows in the barrier beach are modelled and validated against results from the same experiment.

RESULTS

Two cases of groundwater flow are simulated using the present model: (a) lagoon water level $(4.3\ \mathrm{m}) >$ the sea level $(3\ \mathrm{m})$, (b) lagoon water level $(1.75\ \mathrm{m}) <$ the sea level $(3\ \mathrm{m})$, without and with surface water waves.

Firstly, groundwater flow in the barrier without surface water waves are compared against the BARDEX II prototype-scale experimental results (Turner et al., 2016), as shown in Fig. 1. The phreatic surface elevations from the numerical model are averaged over a time slot of $300\ \mathrm{s}$ and compared against the equivalent averaged phreatic surface elevations from the BARDEX II experiment. The results show excellent agreement with the experimental steady-state phreatic surface elevations, with root-mean square errors $\epsilon = 0.0369\ \mathrm{m}$ (Fig. 1(a)) and $\epsilon = 0.0324\ \mathrm{m}$ (Fig. 1(b)).

When the water level is higher at the lagoon side than the sea, exfiltration occurs at the sea side boundary as the groundwater is directed towards the sea, from higher potential head to lower potential head as shown in Fig. 2(a). On the other hand, decreasing water level at the lagoon side to smaller water level than the sea side is able to reverse the direction of groundwater flow towards the lagoon and cause infiltration at the sea side boundary, as shown in Fig. 2(b). This re-affirms that flow takes place from higher potential head to lower potential head in the absence of wave action.

Next, surface water waves at the sea side are also modelled along with the groundwater flow, and comparisons are made with the experimental results as shown in Fig. 3. The numerical model results show excellent agreement with the experimental results, with $\epsilon = 0.0281\ \mathrm{m}$ (Fig. 3(a)) and $\epsilon = 0.086\ \mathrm{m}$ (Fig. 3(b)). Corresponding pore water flow shown in Fig. 4 indicates that the groundwater flow direction is uninfluenced by the potential head differences between the sea side and the lagoon. Instead, the pore water flow is governed by the action of the surface water waves.

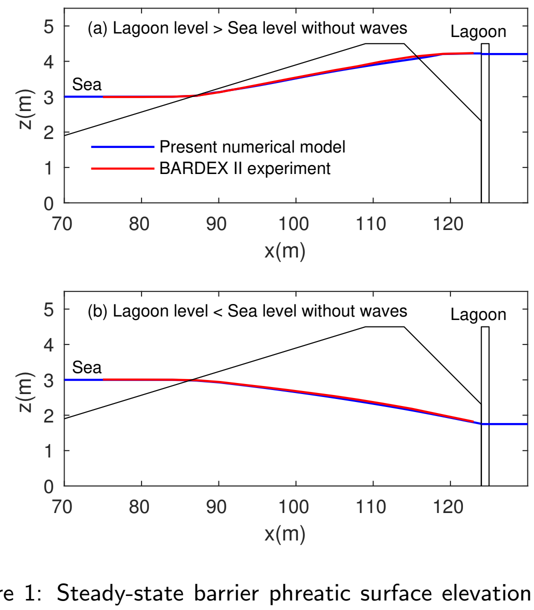

Figure 1: Steady-state barrier phreatic surface elevation averaged over a $300\ \mathrm{s}$ time slot.

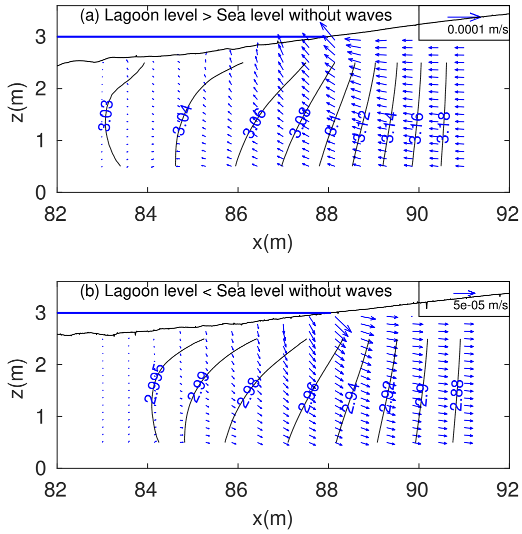

Figure 2: Pore water flow averaged over a 300 s time slot.

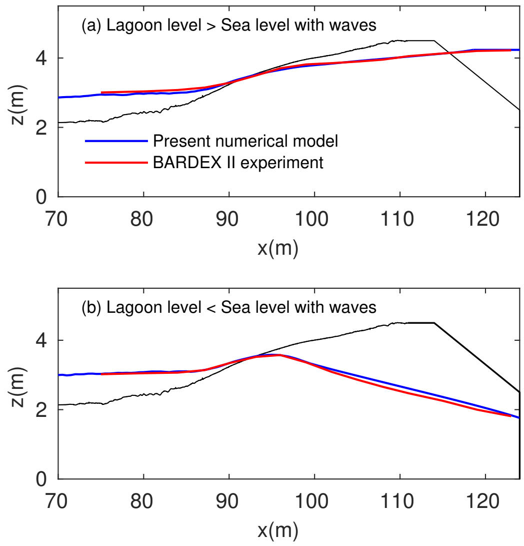

Figure 3: Barrier phreatic surface elevation with waves averaged over a 300 s time slot.

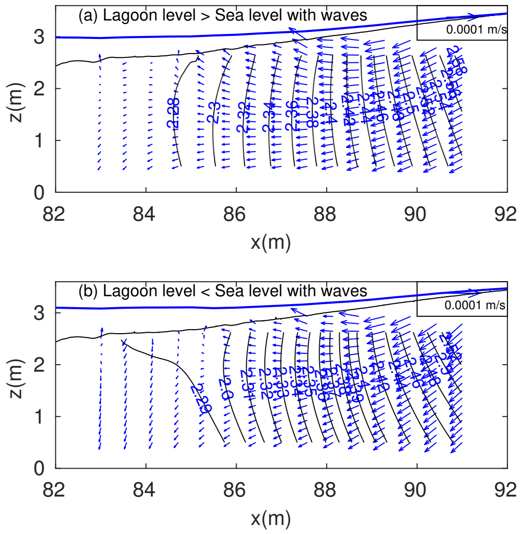

Figure 4: Pore water flow with waves averaged over a 300 s time slot.

CONCLUSION

This work presents a comprehensive numerical model which can show local swash in/exfiltration reversal from the global effect of the lagoon-sea level changes. The coupled surface-groundwater flow numerical model was validated against the prototype-scale BARDEX II experimental results with $0.03\ \mathrm{m} \leq \epsilon \leq 0.04\ \mathrm{m}$ for cases without waves and $0.03\ \mathrm{m} \leq \epsilon \leq 0.09\ \mathrm{m}$ for cases with waves. Pore water flow indicated that the wave action on the sea side is the dominant driving action of groundwater flow below the beach. The validation tests were carried out assuming a fixed beach, mainly to restrict focus on hydrodynamic processes in the barrier beach. Future work will include analysing the effect of seepage on bottom boundary layer and sediment transport, which would require a robust and dynamic sea side boundary for the groundwater flow model.

REFERENCES

Briganti, Dodd, Kelly and Pokrajac (2012): An efficient and flexible solver for the simulation of the morphodynamics of fast evolving flows on coarse sediment beaches, *International Journal for Numerical Methods in Fluids*, 69:859–877.

Liggett and Liu (1983): *The boundary integral equation method for porous media flow*, Volume 5.

Turner, Rau, Austin and Andersen (2016): Groundwater fluxes and flow paths within coastal barriers: Observations from a large-scale laboratory experiment (BARDEX II), *Coastal Engineering*, 113:104–116.