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LWI

The State of the Art and Science of Coastal Engineering

Breaching of Coastal Barriers in A Changing Climate: Associated Processes and Implication for Contamination of Coastal Aquifers

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https://www.newsday.com/long-island/suffolk/fire-island-park-sandy-1.15524001

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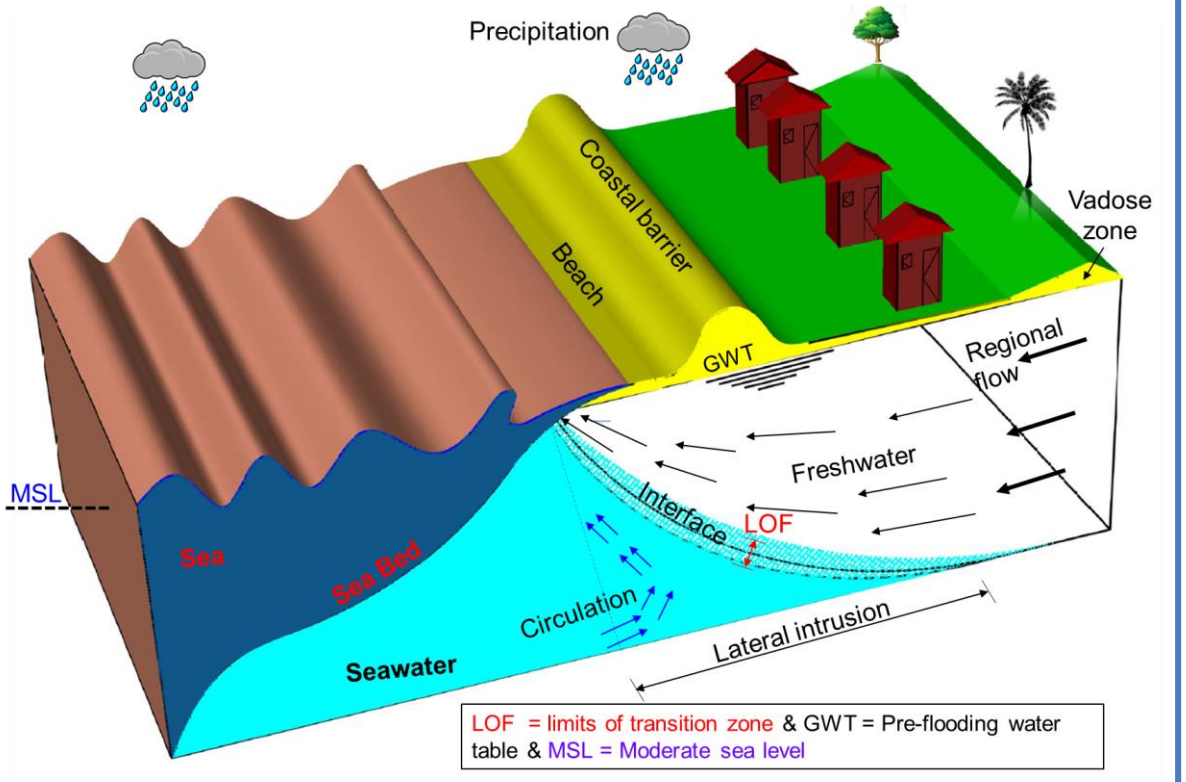
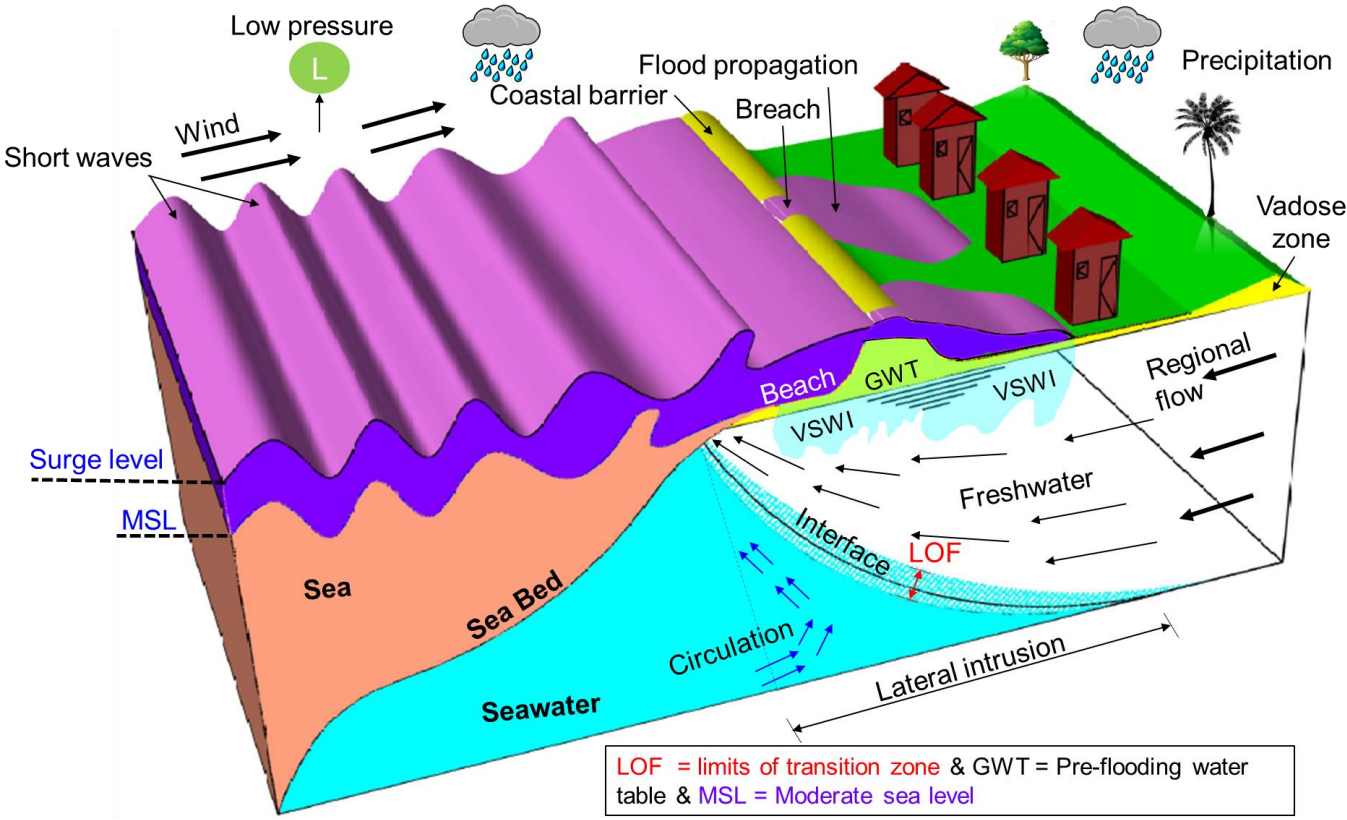
Motivations

Moderate sea conditions



Extreme storm surge conditions



Main motivation: Need for systematic research on coupling these processes to achieve a fully coupled model for the assessment of the safety of natural coastal barriers and possible implications for groundwater contamination.

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Objectives and Methodologies

Overall objective: Improve the knowledge of the processes associated with the breaching of dune systems, including the coupling of the breaching, inundation and saltwater intrusion models so that an integral model can be developed that accounts for the mutual interaction among them.

Specific objectives:

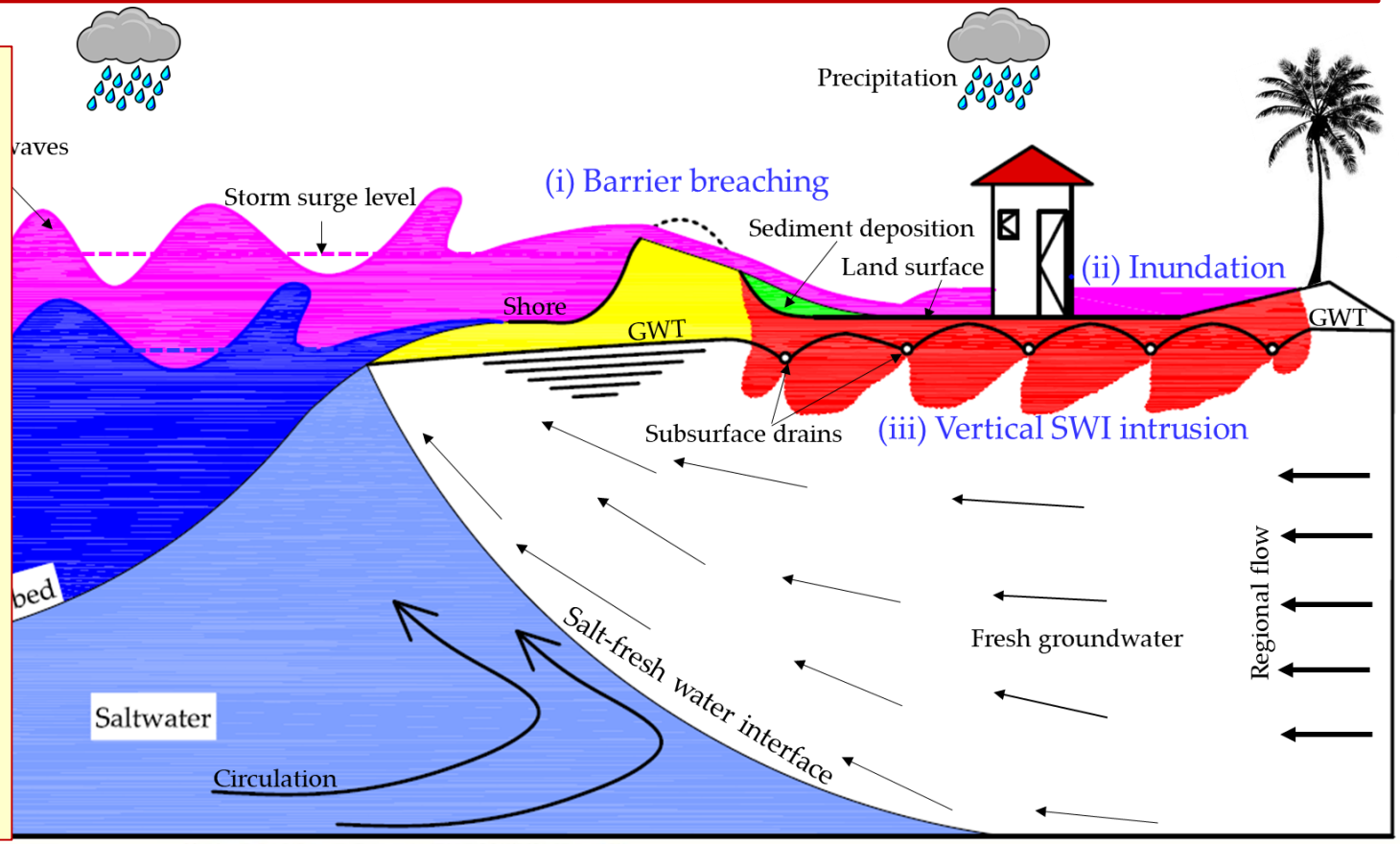
i) Assess XBeach performance based on reproduction of 17 GWK-tests (Wangerooge dune erosion).

ii) Improve/extend and validate XBeach to simulate both breaching and induced inundation.

iii) Couple XBeach with an infiltration model to simulate saltwater intrusion (SWI).

iv) Examine suitability of subsurface drainage as a counter-measure to shorten remediation time after contamination.

v) Apply the overall modelling approach to a pilot site.



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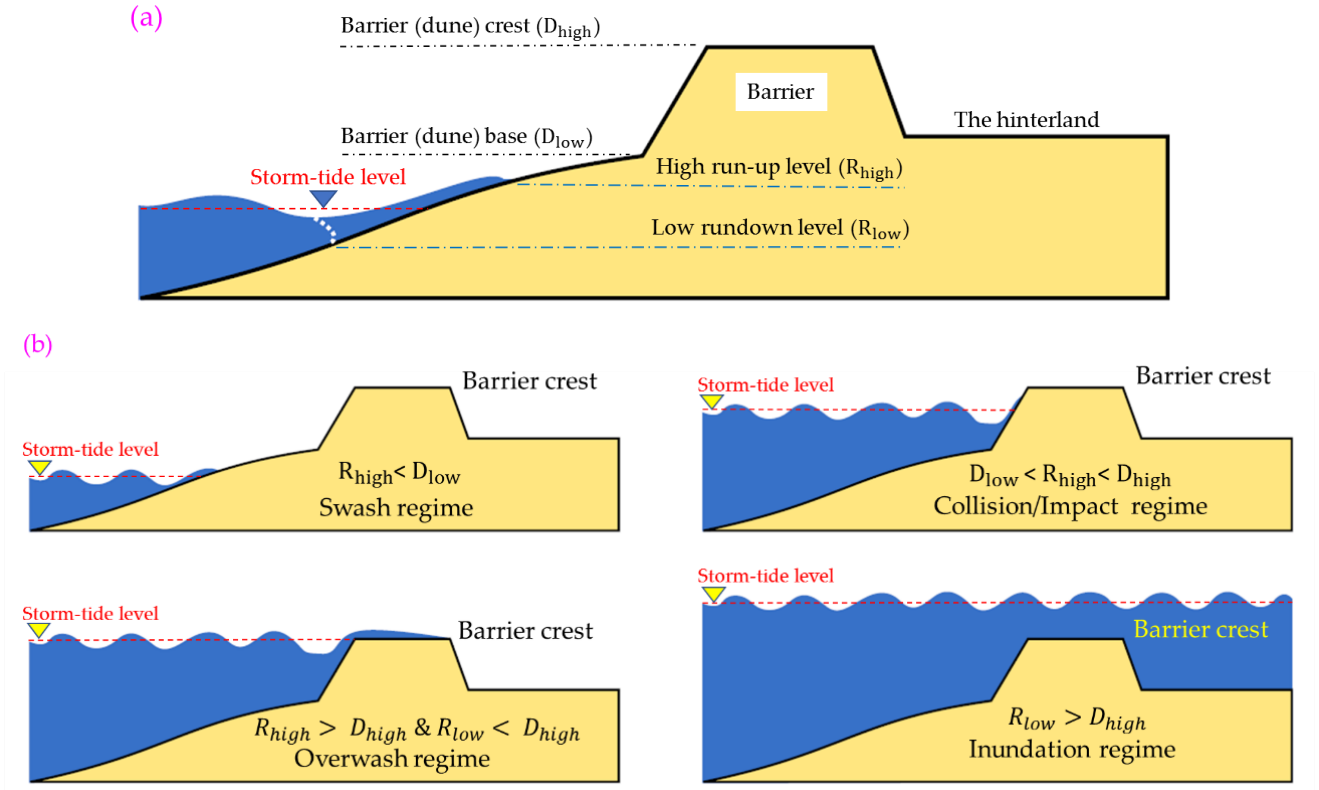
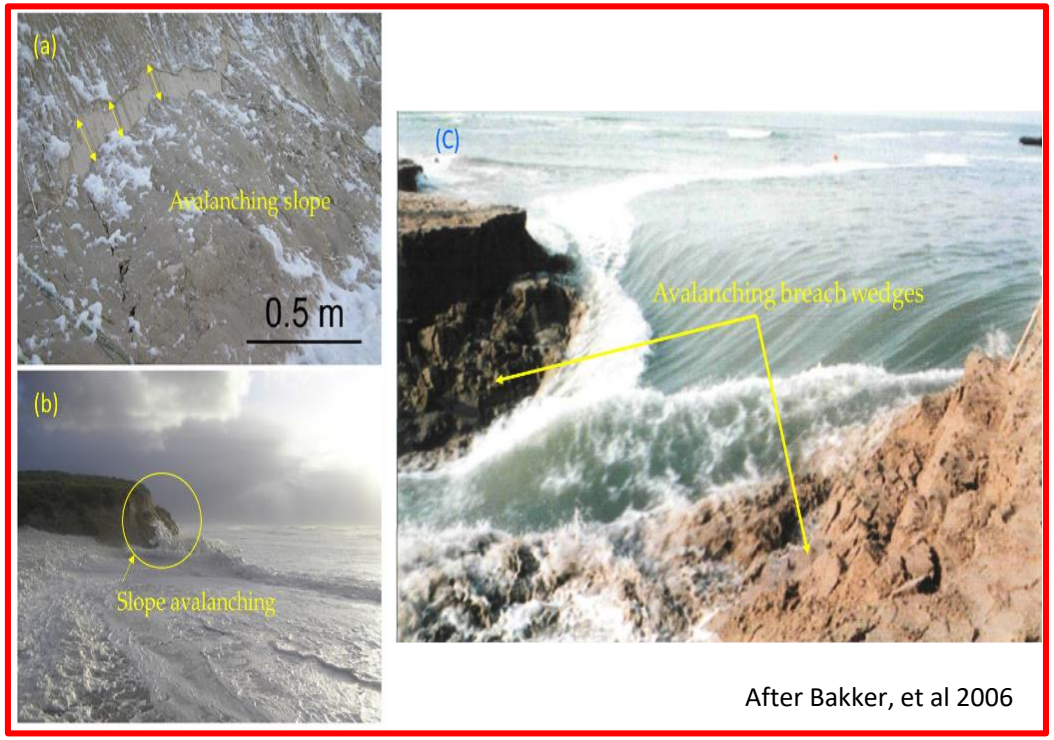
Phase 1: Selection of a breaching model

Main Purpose: Identify the **hydro-geo-morphodynamic processes** associated with breach initiation and development, so that the most appropriate breaching model can be selected.



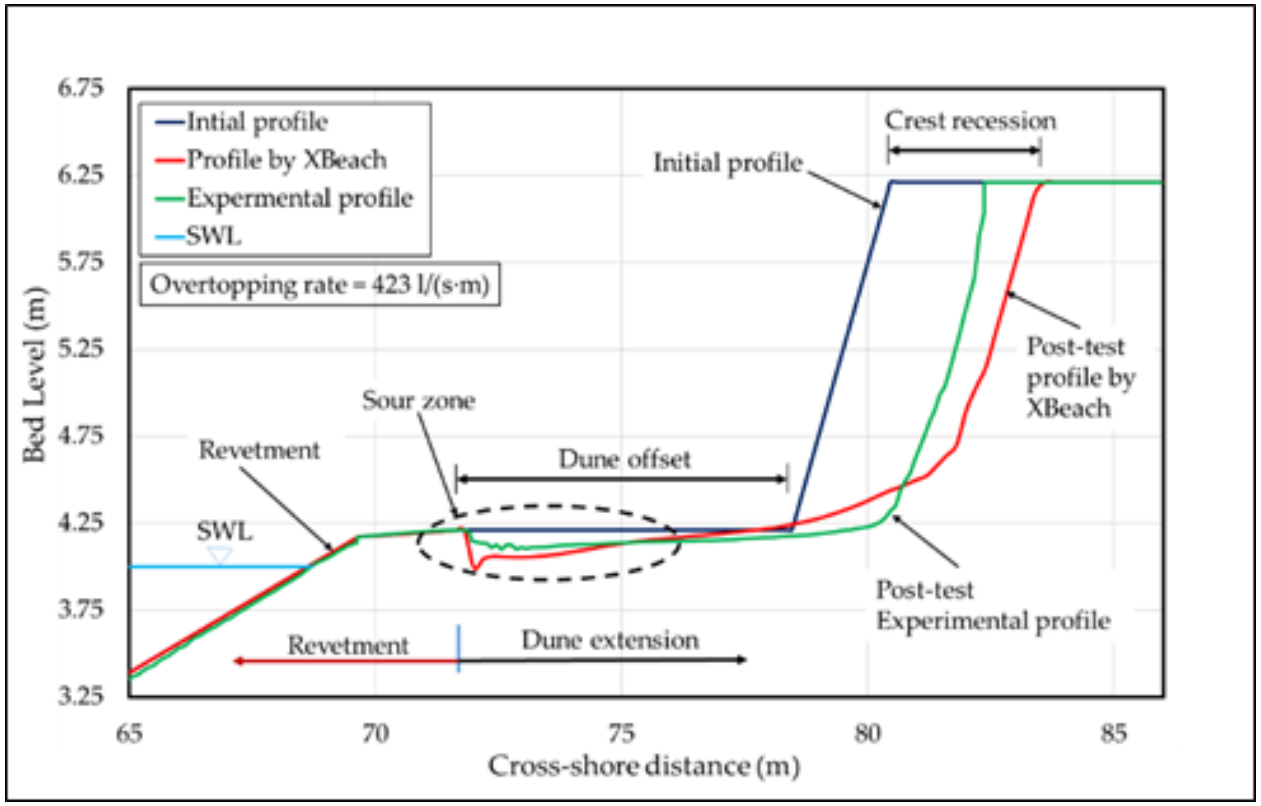


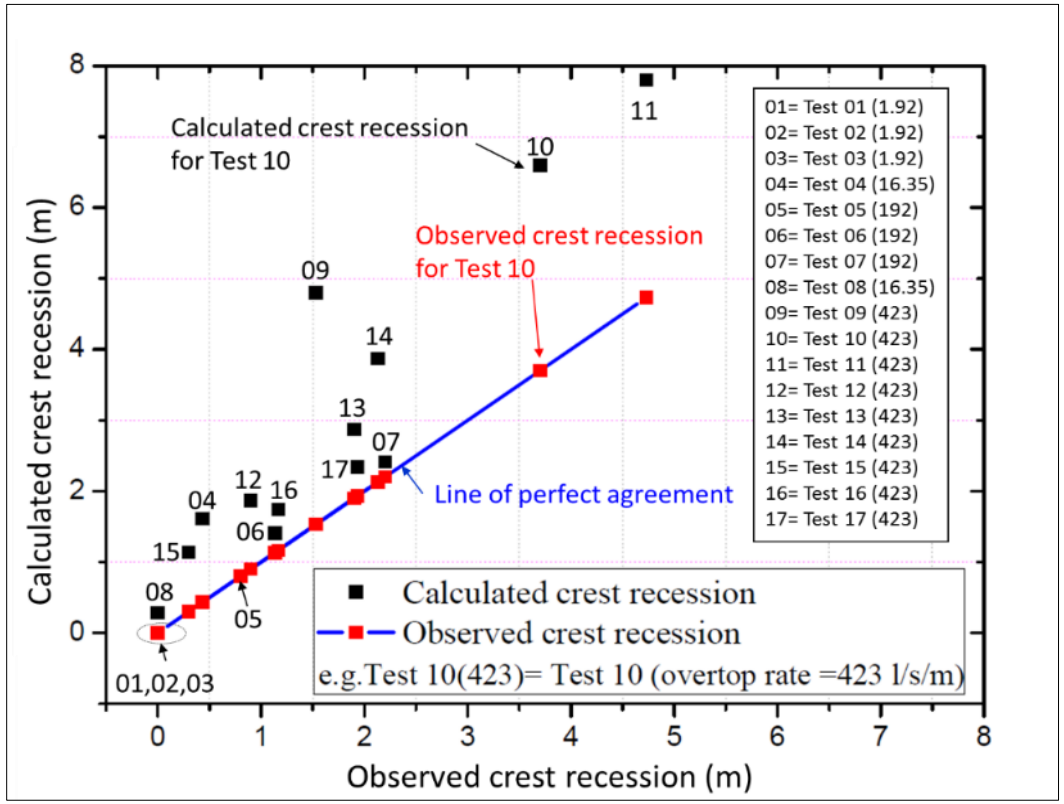
After Bakker, et al 2006

Result: XBeach (Roelvink et. al. 2009) is selected as the most appropriate model to simulate these processes.

Phase 2: Assessment of XBeach performance

Reproduction by XBeach of 17 laboratory large-scale tests (GWK) with a wide range of overtopping rates for Wangerooge Island





Result: **XBeach overestimates beach/dune erosion: Overestimation increases with higher overtopping rates and with less dune offset .**

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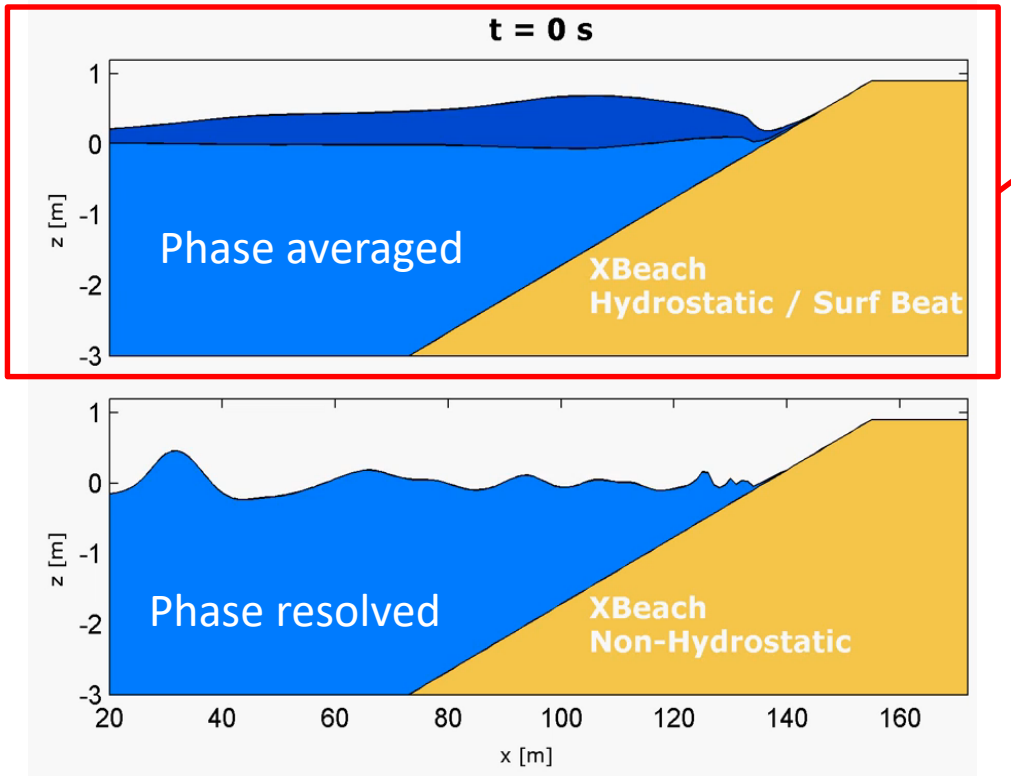
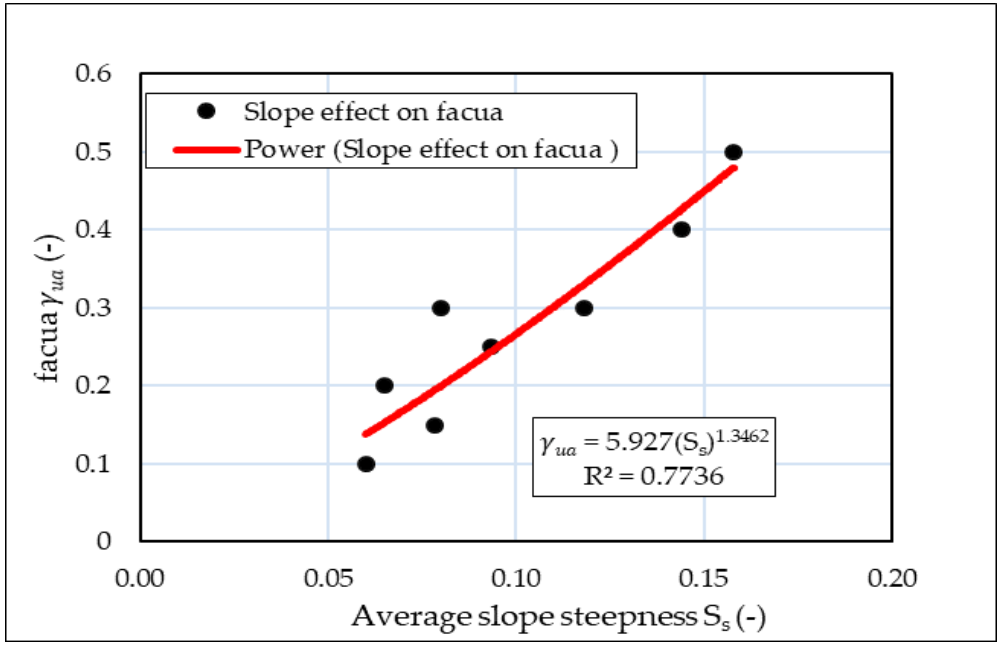
Phase 3: Improvemnt of XBeach

First Improvement: Nonlinearity effect on sediment transport in the surf-beat mode of XBeach



The surf-beat mode implicitly included using a virtual flow velocity u_a

$$u_a = \gamma_{ua} u_{rms}(S_k - A_s) \qquad \gamma_{ua} = 0.1$$

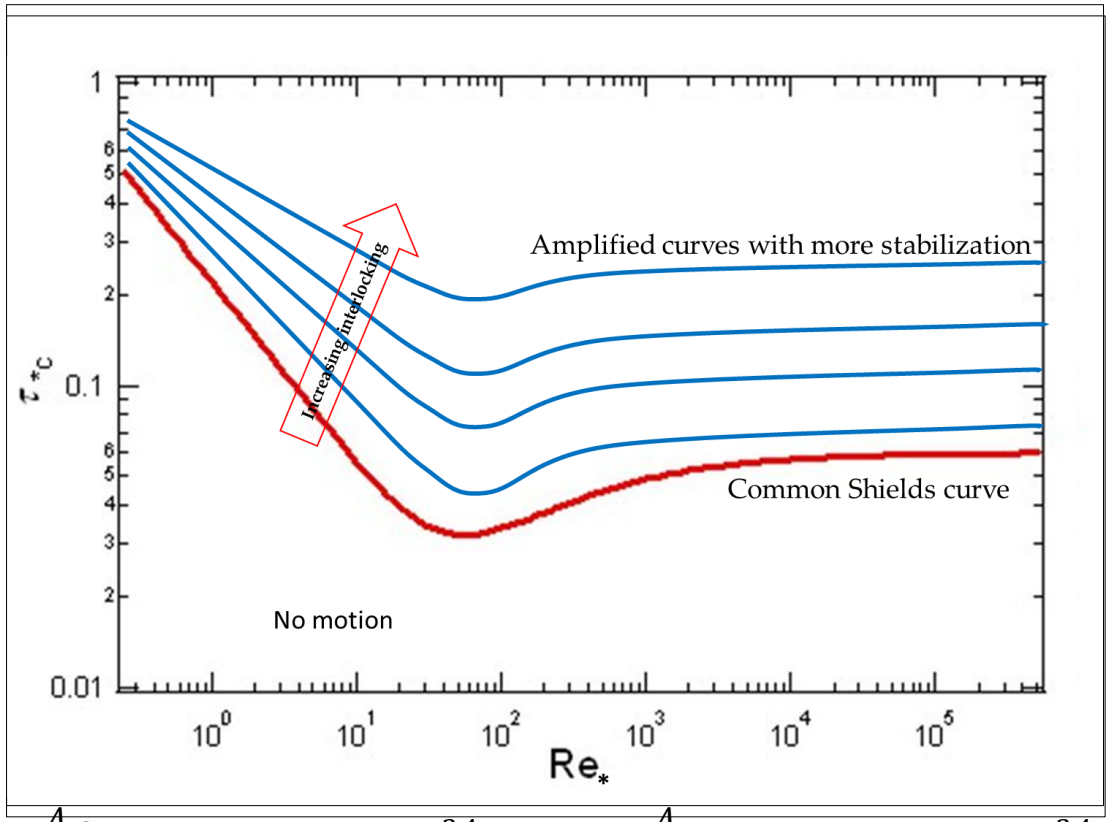


$$u_a = 5.93 s_s^{1.35} . u_{rms} (S_k - A_s)$$

Onshore sediment transport depends on the average beach steepness Ss.

Phase 3: Improvemnt of XBeach

Second Improvement: **implementation of stabilizing effects on critical shear stress for incipient sediment motion**



$$C_{eq,b} = \frac{A_{sb}}{d}\left(U_{stirring} - \gamma_{pi}.U_{cr}\right)^{2.4} \;\&\; C_{eq,s} = \frac{A_{ss}}{d}\left(U_{stirring} - \gamma_{pi}.U_{cr}\right)^{2.4}$$

Sediment stabilisation increases the critical shear stress

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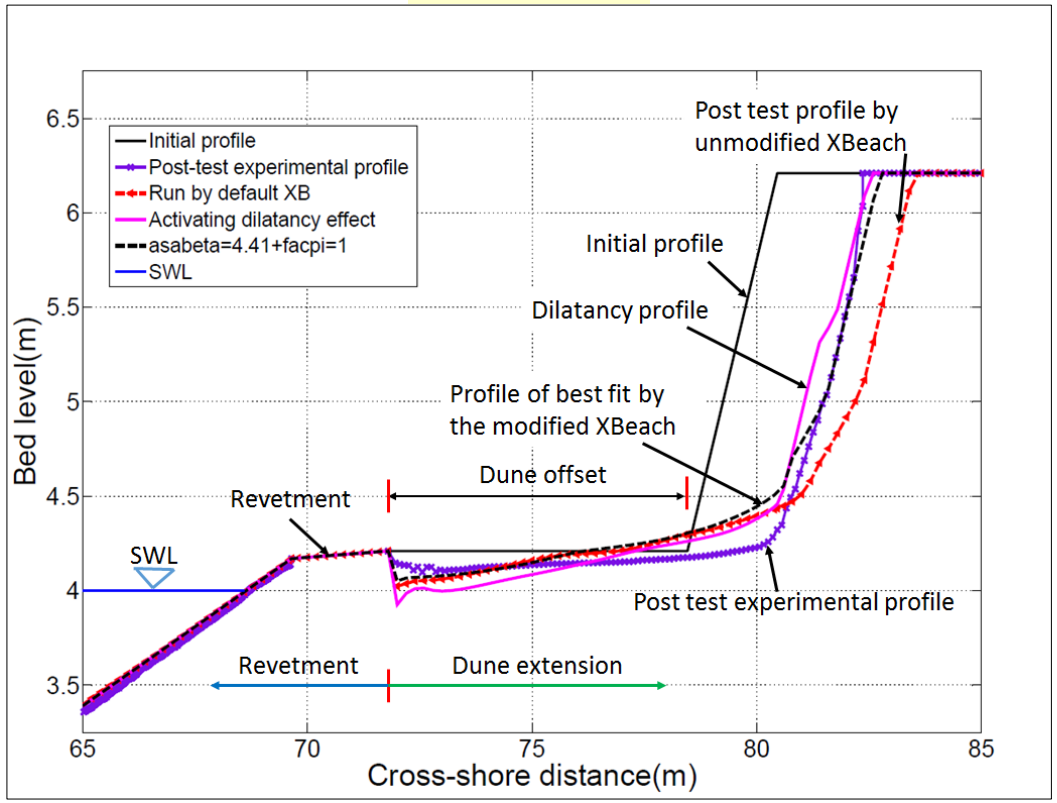
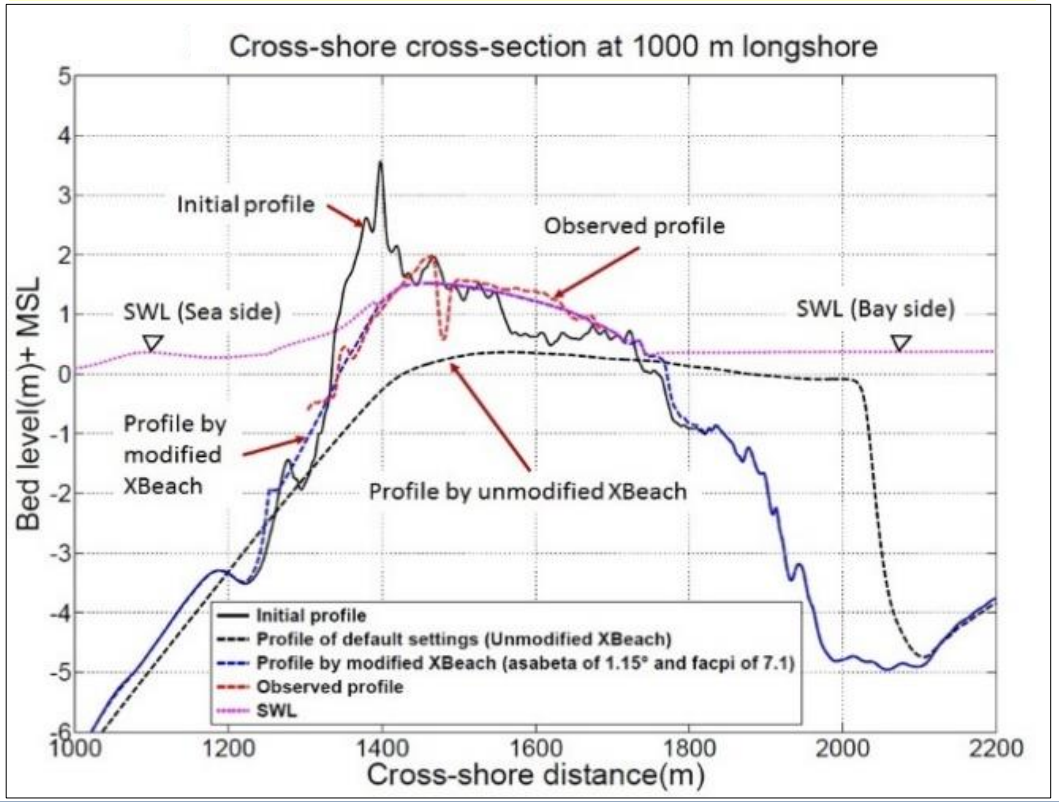
Phase 3: Improvemnt of XBeach

Validation of Improvements : **3 validation cases. Here only two of them**

GWK tests



Erosion of Santa Rosa Island under Hurricane Ivan



Result: Improved XBeach model can adequately predict erosion rates, breaching dimensions and thereby inland discharges.

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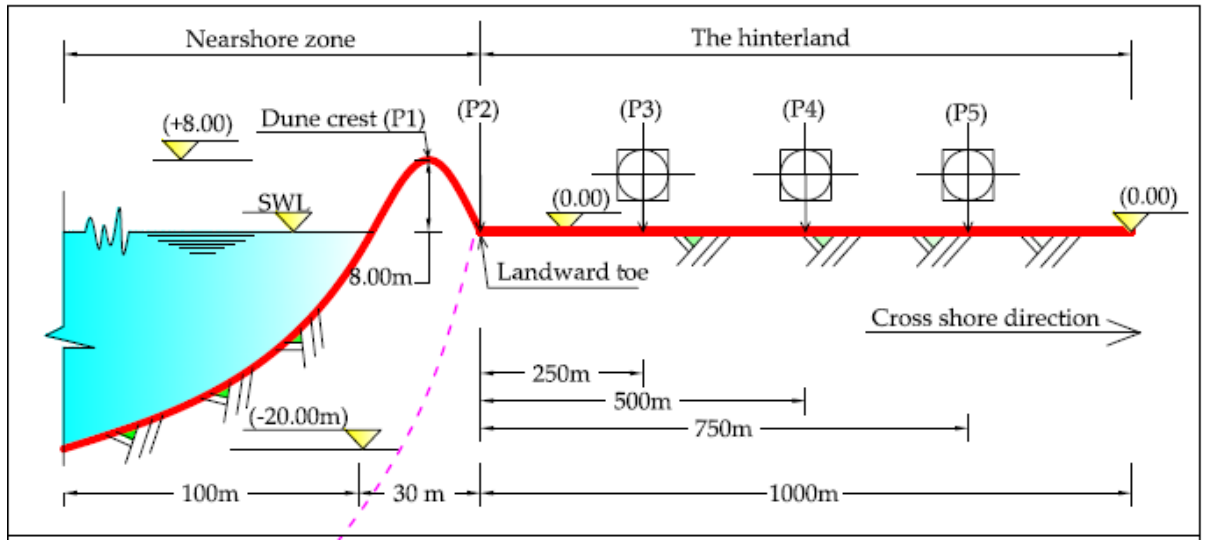
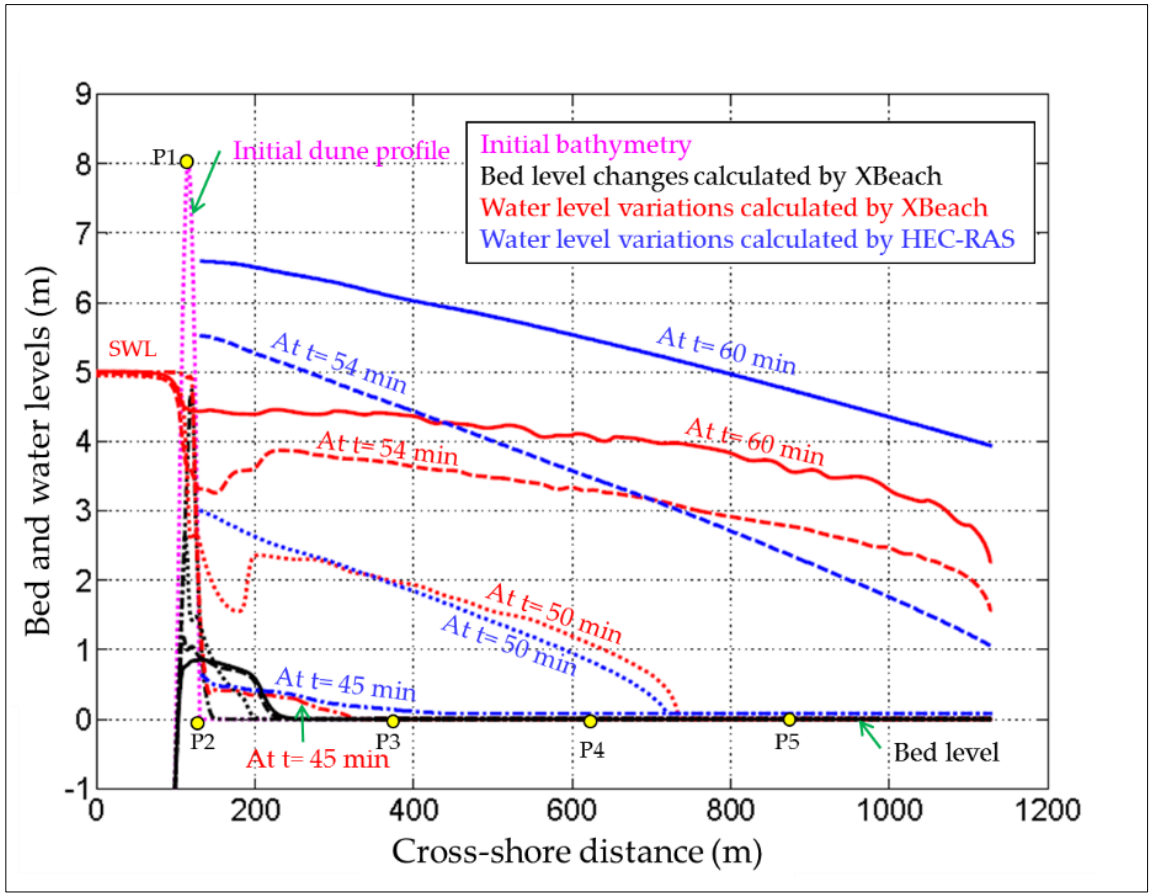
Phase 4: Combined modelling of breaching and induced inundation

What occurs when breaching and induced inundation are simulated separately?





Separate modelling leads to incorrect results of flood propagation in the hinterland.

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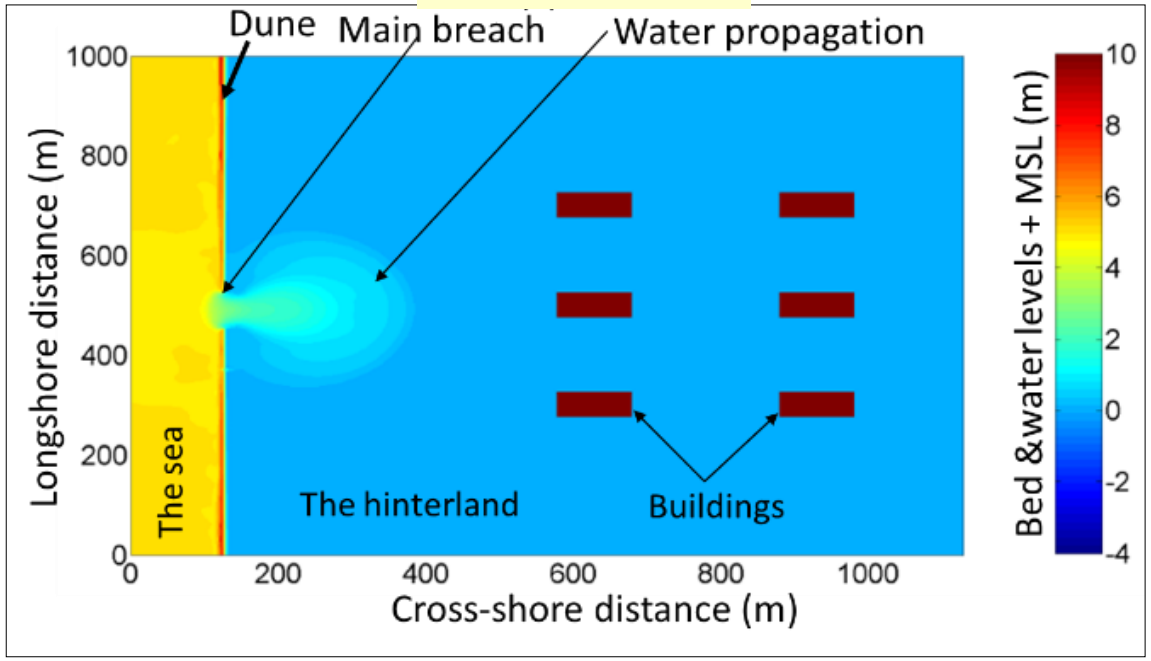
Phase 4: Combined modelling of breaching and induced inundation

Is XBeach able to simulate both breaching & subsequent inundation?

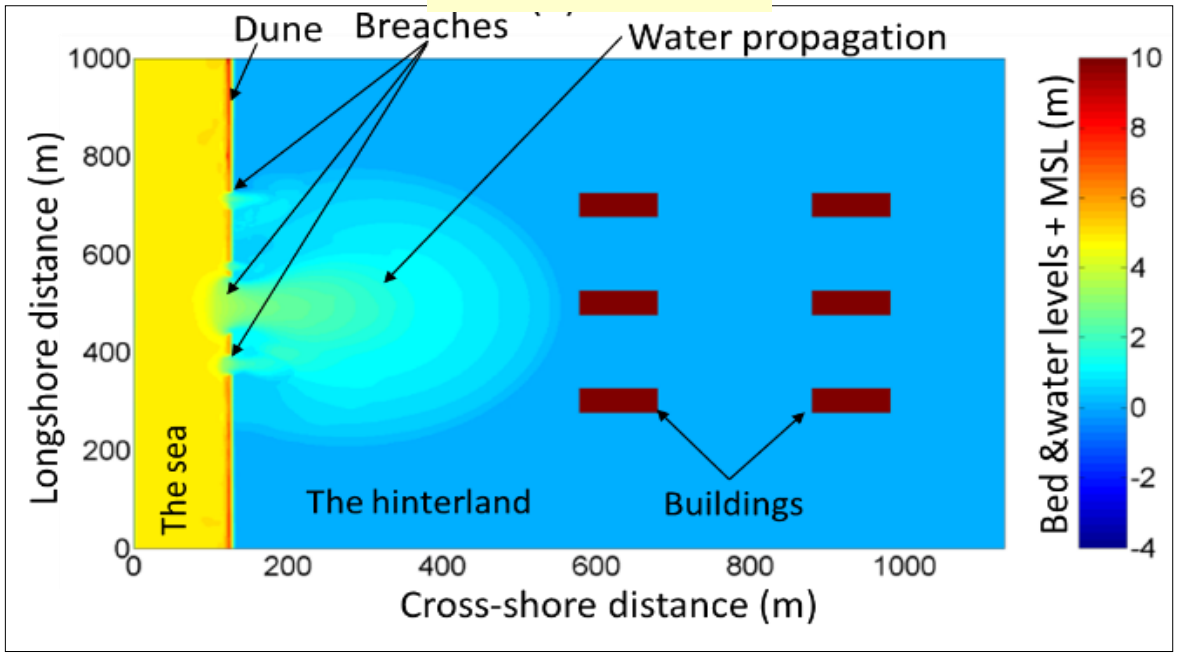
Yes, the study has demonstrated the applicability of the Generalized Lagrangian Mean (GLM) for both nearshore hydrodynamics and flood propagation in the hinterland

An example

At t = 45 min



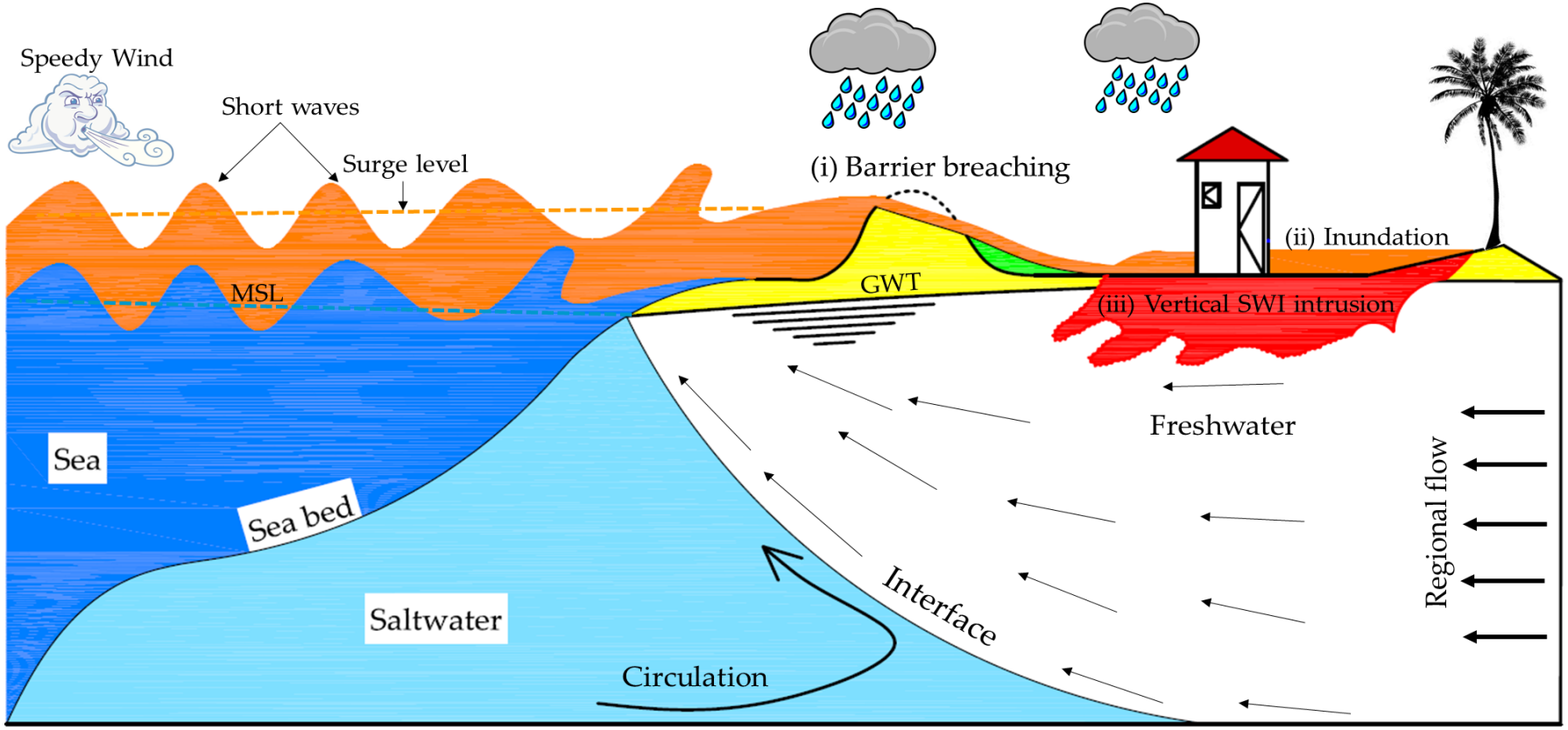
At t = 60 min



XBeach can be applied for both breaching & subsequent inundation in coastal and fluvial environments.

Phase 5: Implications of coastal floods for aquifers contamination

In the previous research phases, infiltration of saltwater into freshwater aquifers was omitted



Besides direct/indirect damages induced by coastal floods, infiltrating seawater contaminates the originally freshwater aquifers

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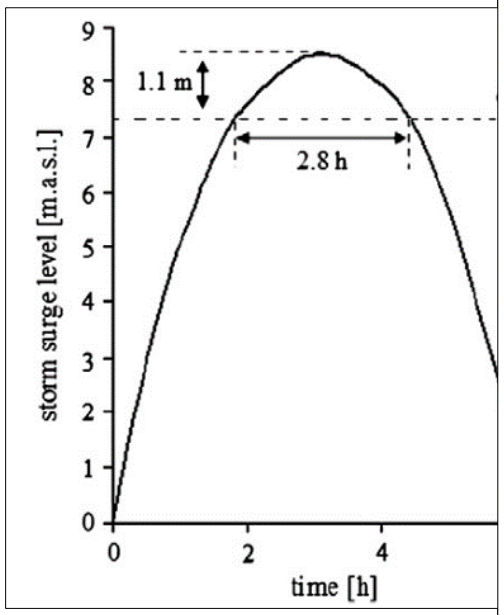
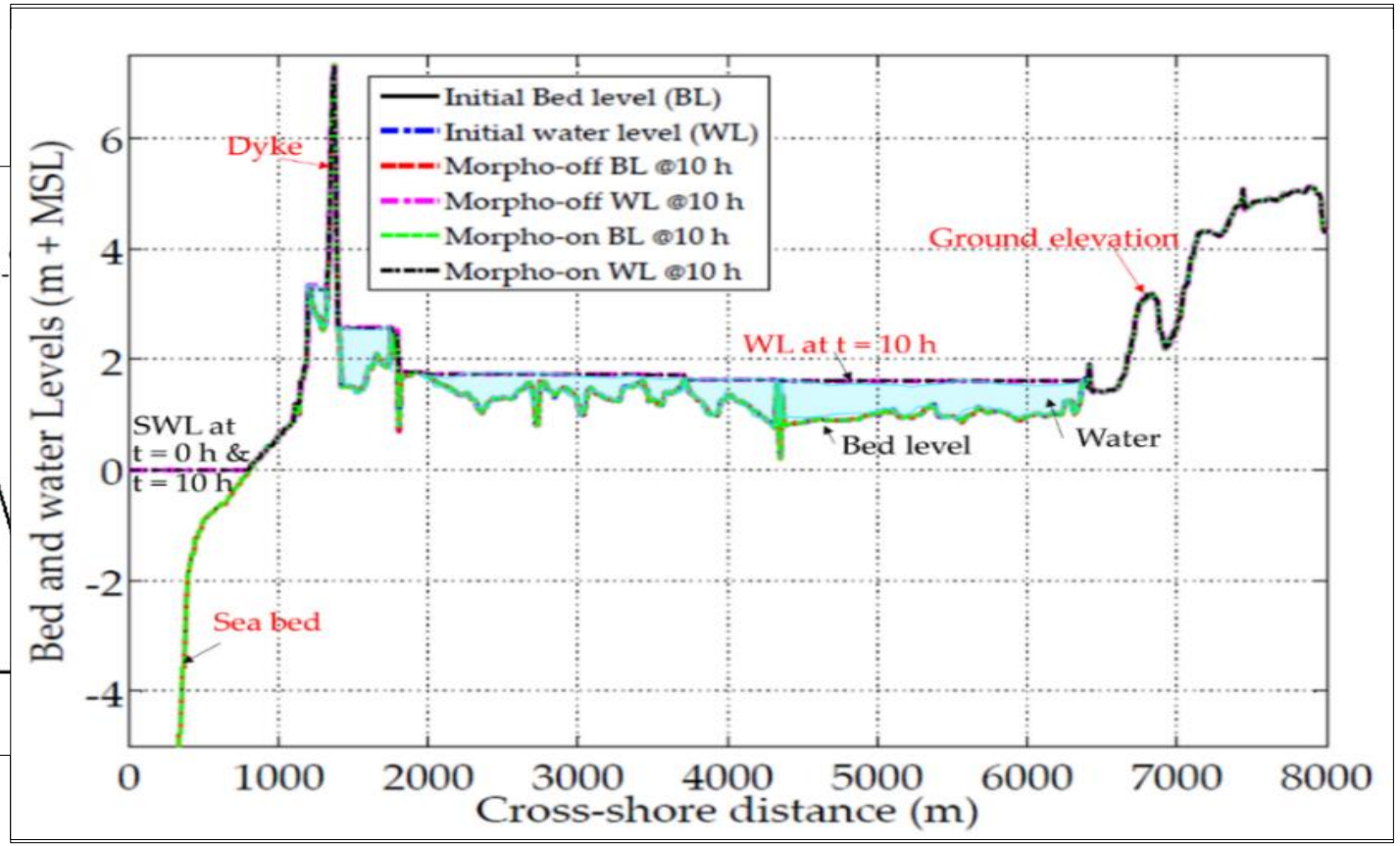
Phase 5: Implications of coastal floods for aquifers contamination

Case study near Bremerhaven





Due to storm surge water level, seawater overflow the dyke causing hinterland inundation (5 km behind dyke)

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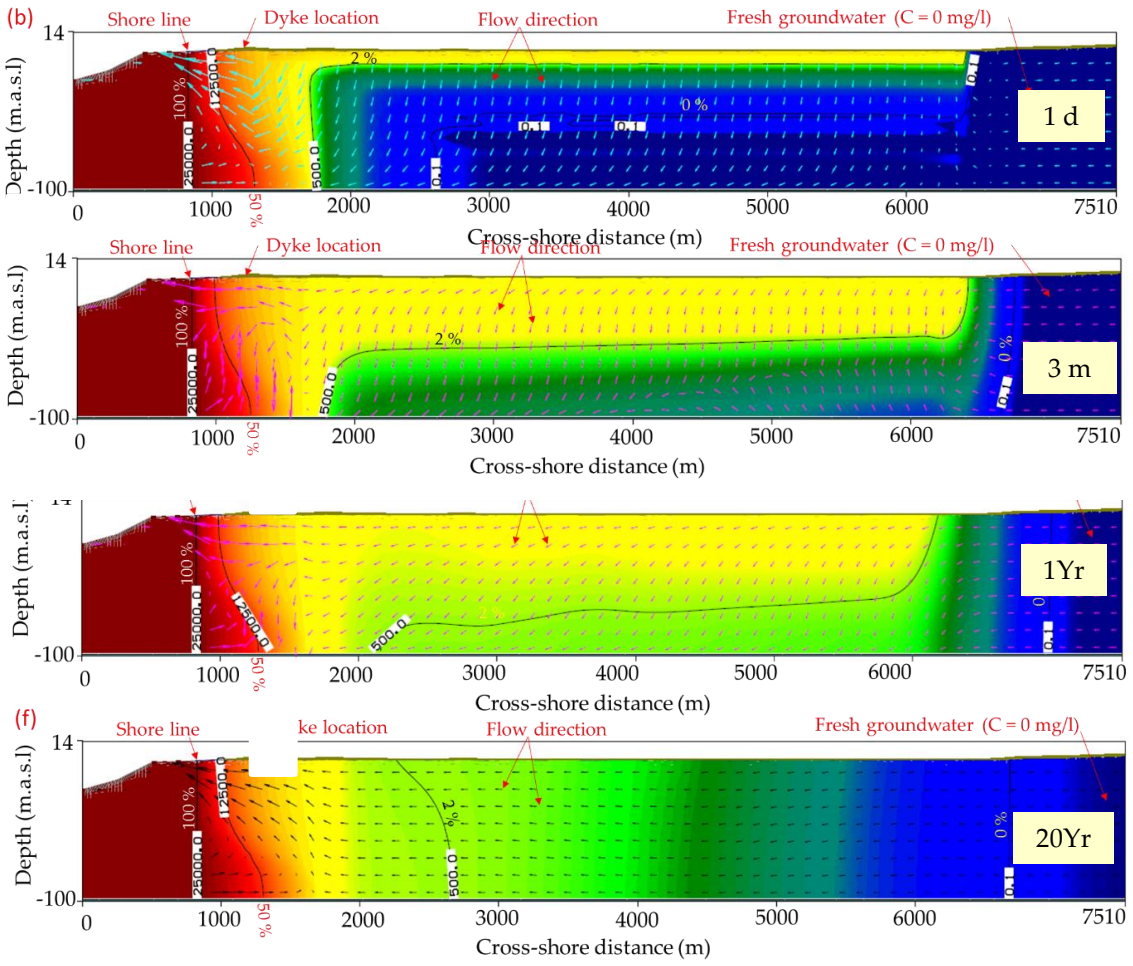
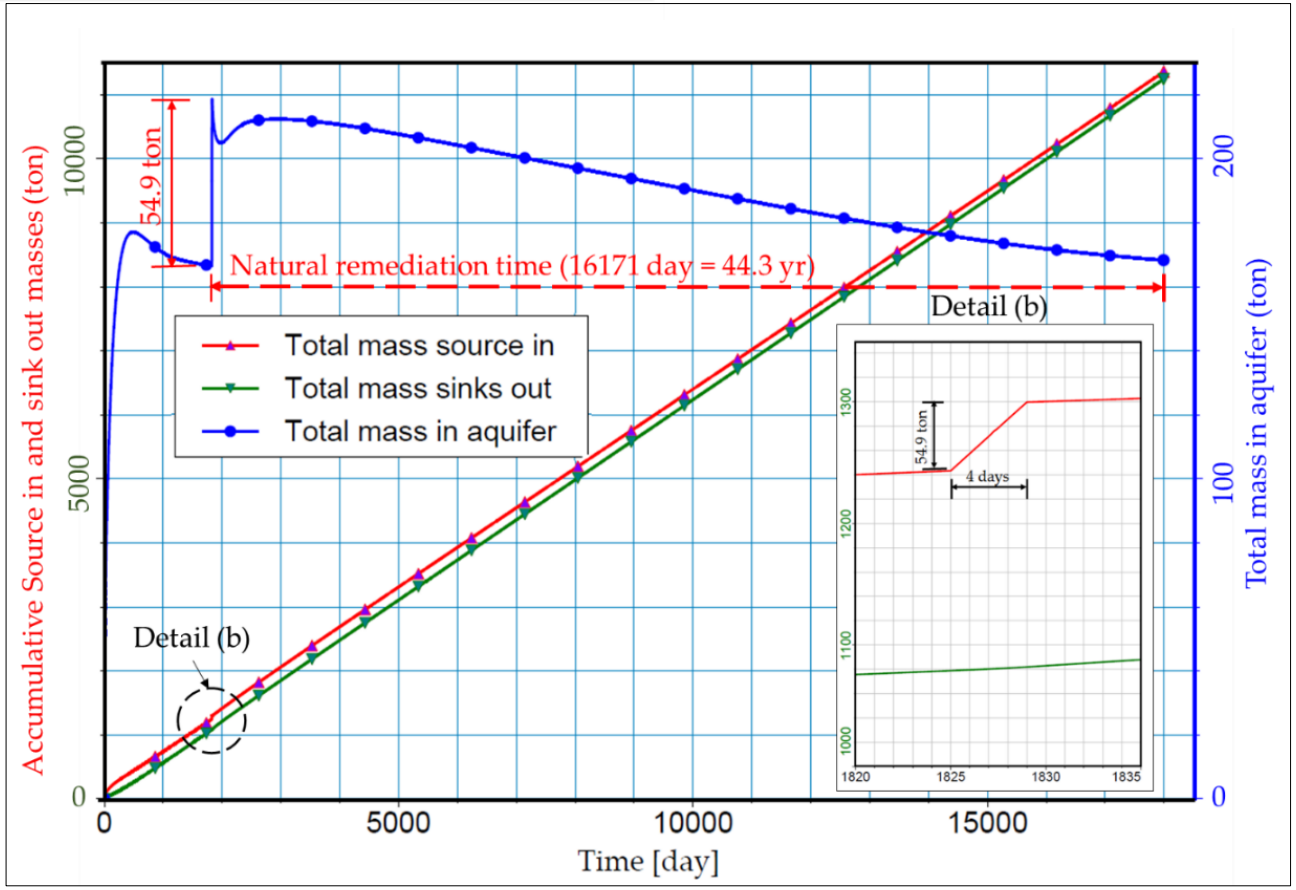
Phase 5: Implications of coastal floods for aquifers contamination





Result: Coastal floods might contaminate freshwater aquifers for decades.

Conclusions (Take Home Messages)

1. Onshore sediment transport depends on skewness and asymmetry of nearshore waves.
2. Moreover, it depends on beach slope steepness as demonstrated in this study.
3. Sediment transport depends also on the degree of sediment stabilization
4. Critical shear stresses calculated using the common Shields criterion are often underestimated for highly stabilized soils, leading to overestimation of erosion.

5. Breaching of coastal barriers results in widely extended marine floods that lead to direct and indirect damages.
6. Coastal floods might lead to significant environmental damages due to infiltration of seawater into groundwater aquifers.

7. A coastal flood for a few hours might contaminate coastal aquifers for decades.

8. Costs of SDSWI as an environmental damage should be considered in future flood risk assessments as SDSWI might hinder the sustainable development in coastal zones.

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References

Work presented here is published in three main journal papers

Elsayed, S.M.; Oumeraci, H. **(2018)**: Modelling and Mitigation of Storm-Induced Saltwater Intrusion: Improvement of the Resilience of Coastal Aquifers Against Marine Floods by Subsurface Drainage. Environmental Modelling & Software, volume 100 (C) pages 252-277, https://doi.org/10.1016/j.envsoft.2017.11.030.

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Elsayed, S.M.; Oumeraci, H. **(2016)**: Combined Modelling of Coastal Barrier Breaching and Induced Flood Propagation Using XBeach. Hydrol. Spec. Issue Floods Landslide Predict. 3, 34. doi:10.3390/hydrology3030032

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