

Salt Marshes in Coastal Flood Management: Experiment, Numerical Simulation and AI modelling

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Nature-based solutions workshop 16th December 2025

Swansea University Coastal and Water Engineering Research Group

<https://www.swansea.ac.uk/science-and-engineering/research/climate-action/research/extreme-weather/energy-environment/>

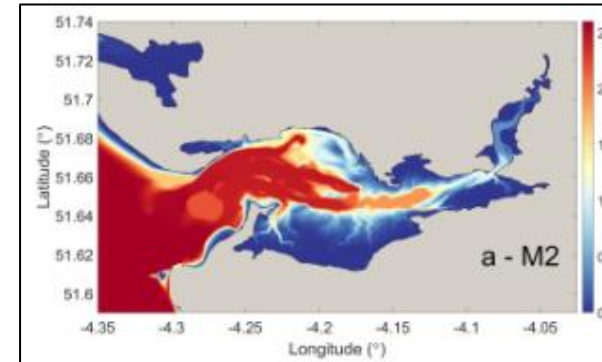
Sitting in the Climate Action Research Institute (<https://www.swansea.ac.uk/science-and-engineering/research/climate-action/>), we closely collaborate with Bioscience and Geography departments, doing very interdisciplinary research.

Recently, we held UK Saltmarsh Forum 2025.

Theoretical + numerical + experimental + AI research



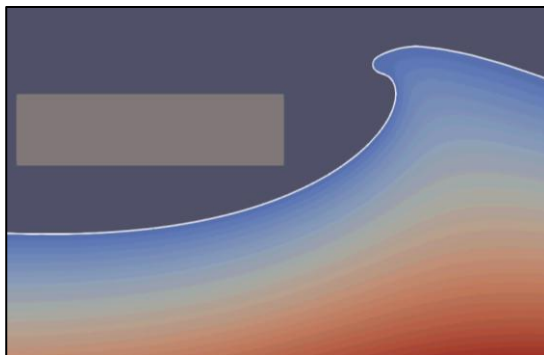
Climate change and flood management



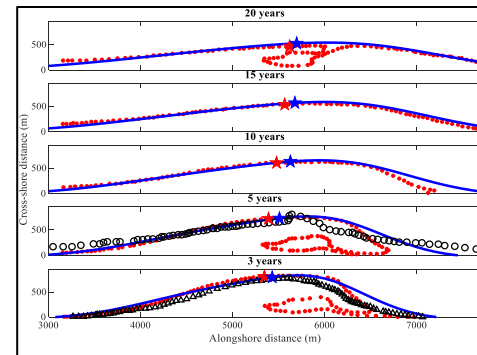
Nature-based solutions



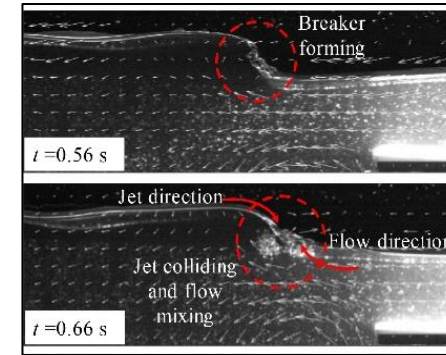
Wave-structure interaction



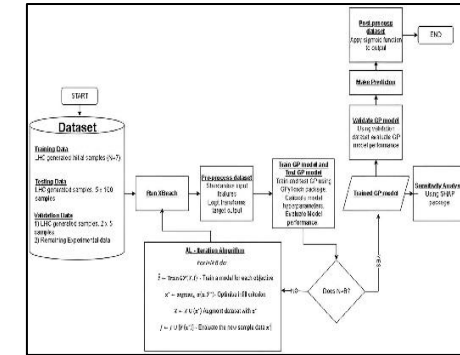
Coastal erosion and evolution



Coastal waves and tsunamis



AI modelling



Salt marsh: NbS in coastal flood management

01



Salt marsh in flood reduction: features and key benefits

02



How salt marsh attenuates flood: experimental exploration

03



Flood defence with salt marsh: numerical simulation

04



Accelerate the flood prediction: estuary idealisation and AI modelling

Salt marsh in flood reduction: features and key benefits



Salt marsh for flood reduction

Wave Attenuation: Break the wave energy and reduce the wave height

Tidal & Surge Reduction: Slowing down incoming tides and surges, reduce the tide levels inland.

Erosion Control: The root systems and the stem can stabilize the sediment.

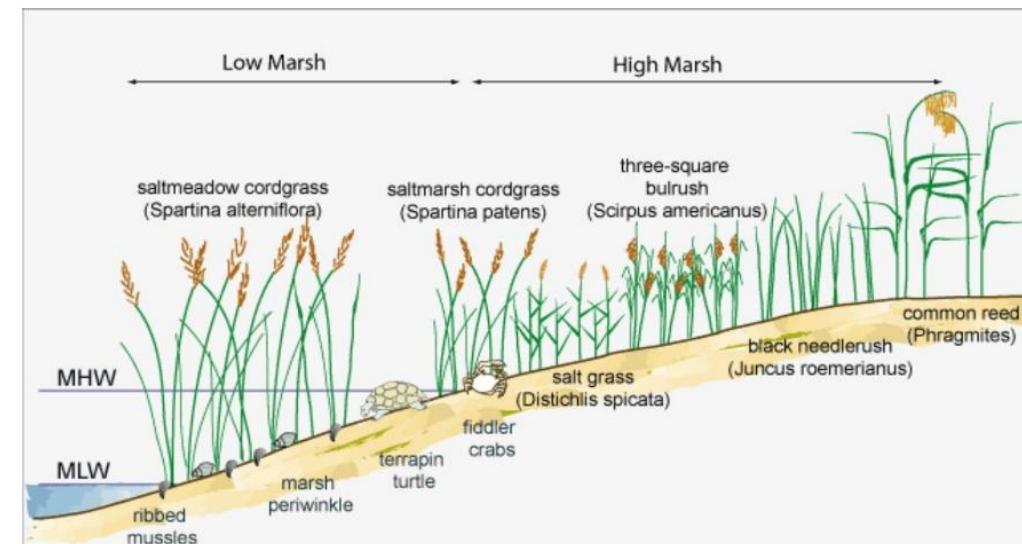


Challenges to salt marshes:

- **85%** of saltmarsh in England has been lost since 1860 (UKCEH).
- In the UK, there are only **45,000 hectares** of saltmarsh remaining (UKCEH).
- **Overgrazing** is a key pressure on saltmarsh habitats (UKCEH).

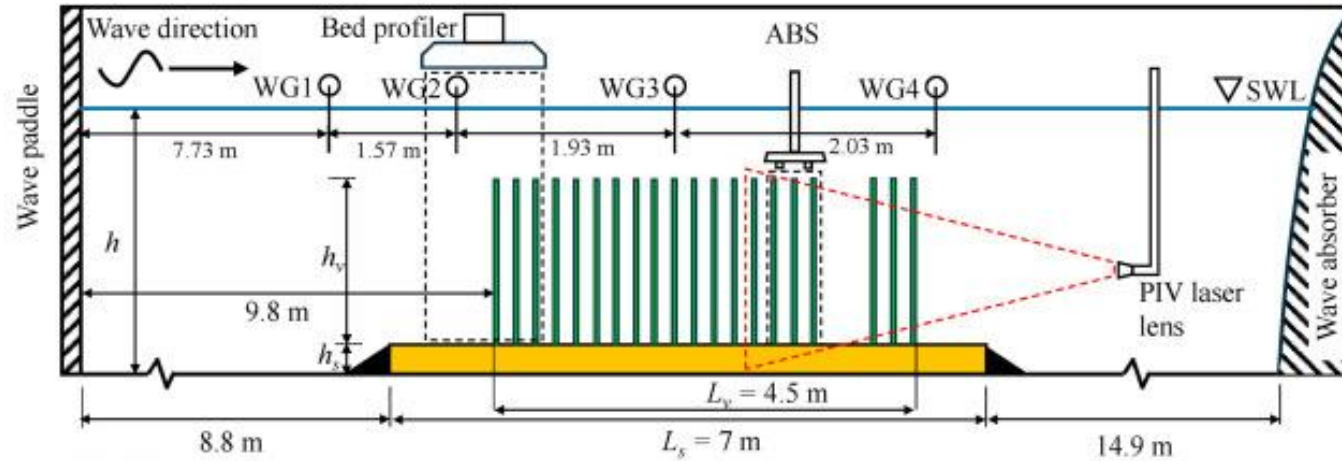


Salt marshes in Loughor estuary at high tide (photos taken in May, 2025)

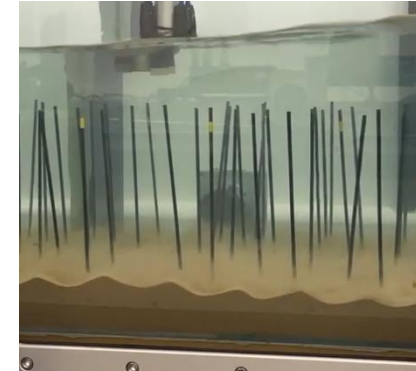


A sketch of salt marsh habitat (Source: CoastalWiki)

How salt marsh attenuates flood: experimental exploration



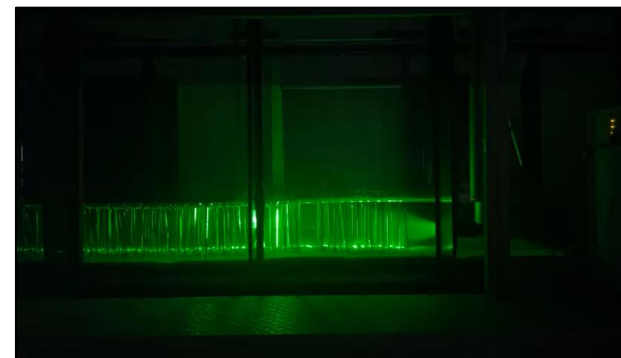
Laboratory experiment sketch



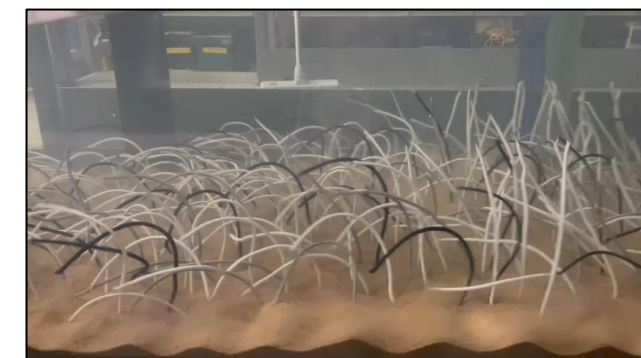
Salt marsh mimics
(rigid & flexible)

Study the influence of salt marsh:

- Wave energy dissipation
- Bed morphology change



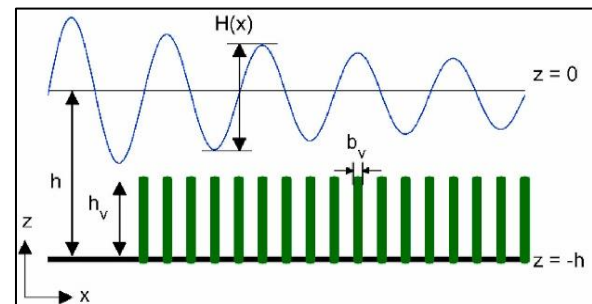
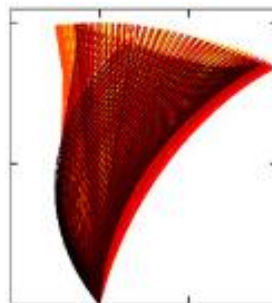
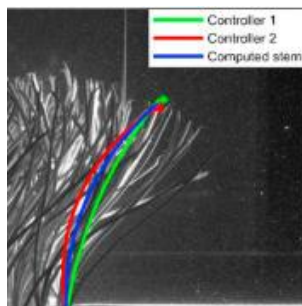
Measuring the flow field with PIV
(rigid stems)



Monitoring the vegetation movements
(flexible stems)

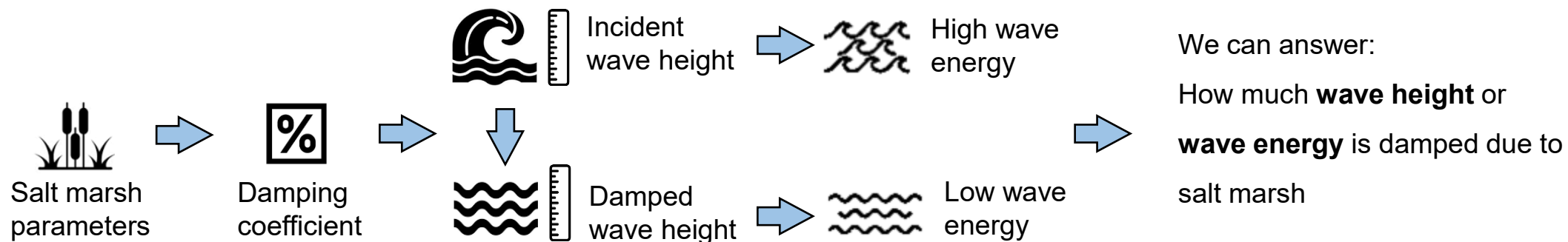
How salt marsh attenuates flood: experimental exploration

Monitor the vegetation stem and wave damping



Mathematical models of: 1) stem movement; 2) wave damping due to vegetation (damping coefficient)

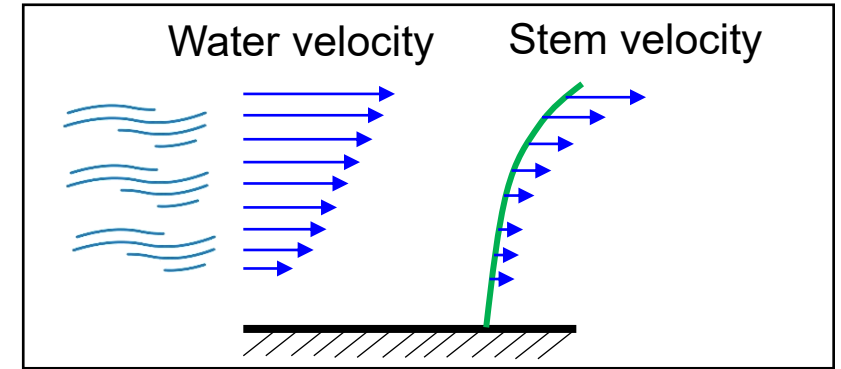
Applying the mathematical model:



How salt marsh attenuates flood: experimental exploration

What leads to the energy dissipation?

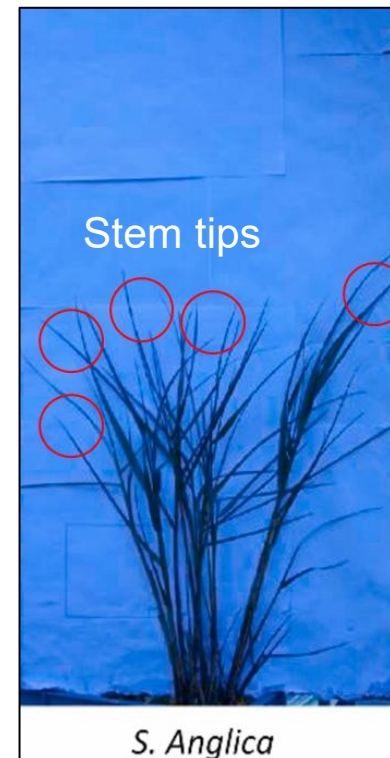
- The dominating factor is the **velocity difference** between water and stem
- The stem posture reconfiguration is NOT important



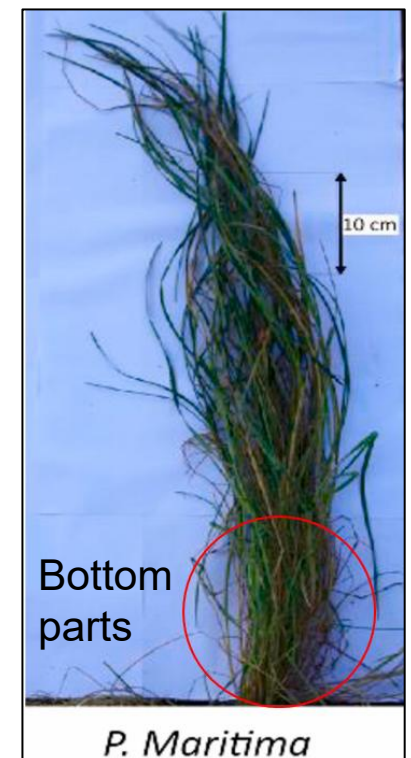
Sketch of a stem in the flow

Rigidity influences salt marsh behaviours:

- Rigid stems: maximum energy dissipation is at the **stem tip** (where the velocity difference is the largest).
- Flexible stems: maximum energy dissipation is at **upright bottom** section (where the stem motion was the smallest).



Example: rigid stem



Example: flexible stem

van Veelen, T. J., Karunaratna, H., & Reeve, D. E. (2021). Modelling wave attenuation by quasi-flexible coastal vegetation. *Coastal Engineering*, 164, 103820.

Salt marsh and near-bed morphology

What does salt marsh do to near-bed sand?

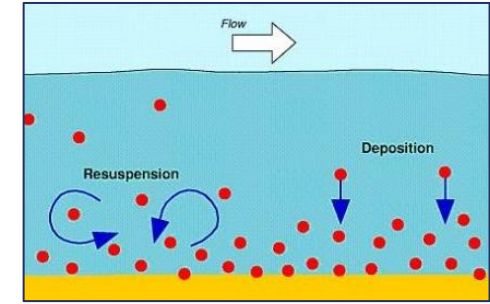
- Reduce the near-bed velocity, sediment re-suspension and concentration.
- Stronger effect for more densely distributed and more rigid stems (may totally remove the ripples!).

Why salt marsh is crucial to the sandy bed?

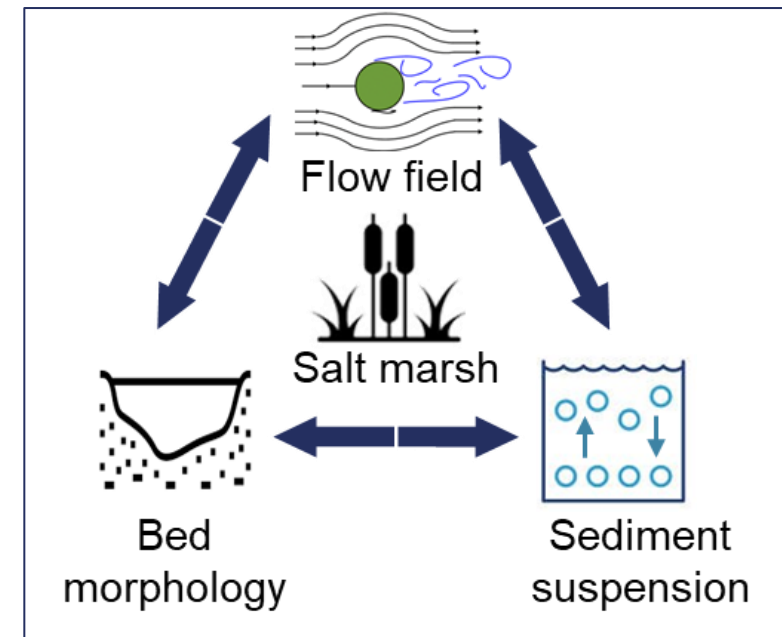
- The roots hold the sand.
- The stems reduce the near-bed velocity and sediment suspension.
- Leading to a 'salt marsh-friendly' local environment.



Ripples on sandy seabed



Sediment re-suspension

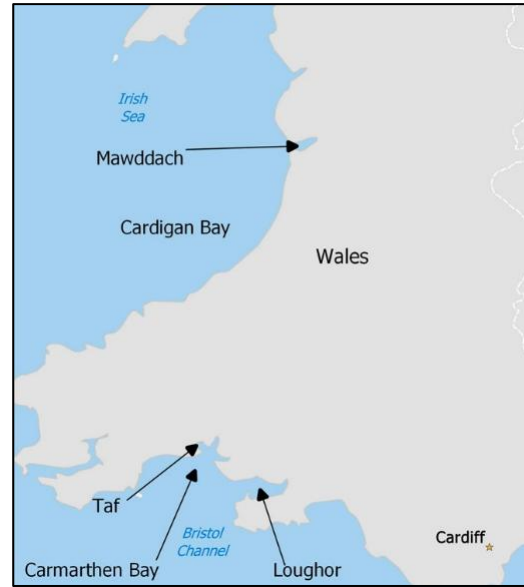


Salt marsh influences the near-bed processes

Then from a broader range, what's the influence of salt marsh on the whole estuary scale?

Flood defence with salt marsh: numerical simulation

The influence of salt marsh on tide:

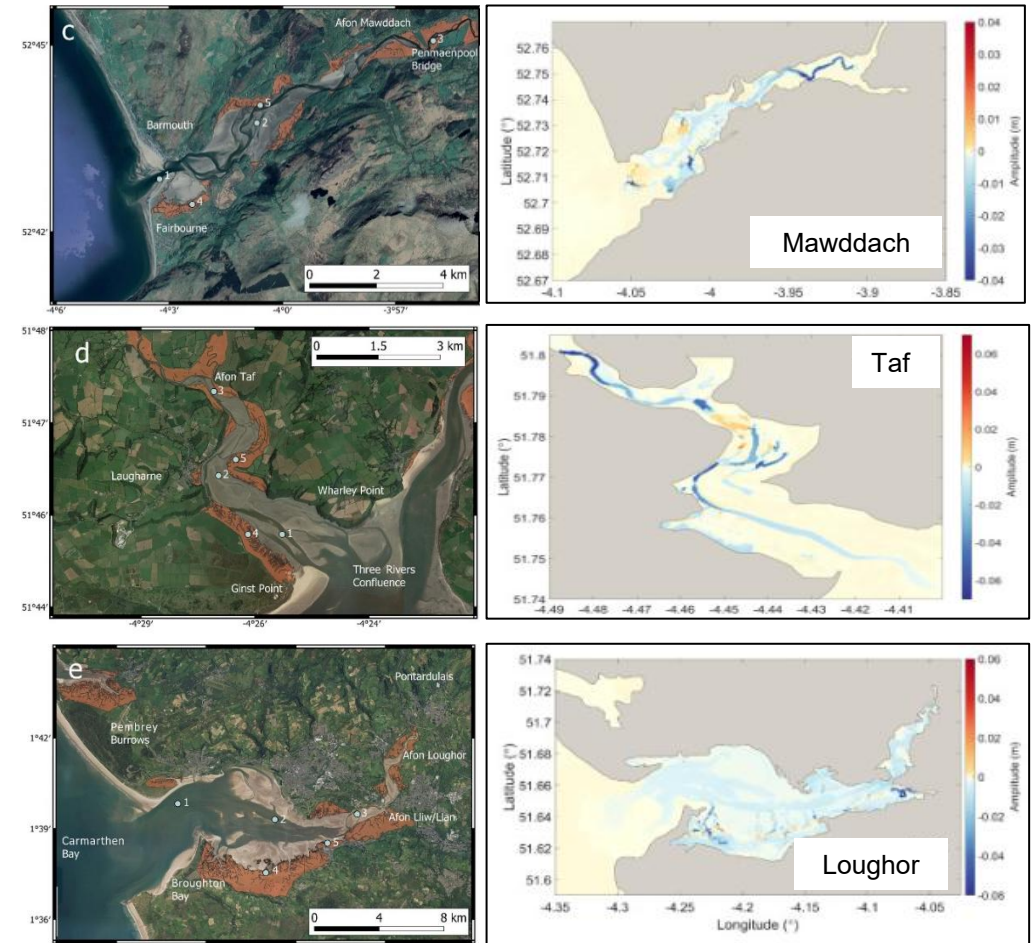


Wales map and locations of the 3 estuaries



Comparison: vegetated VS no salt marsh

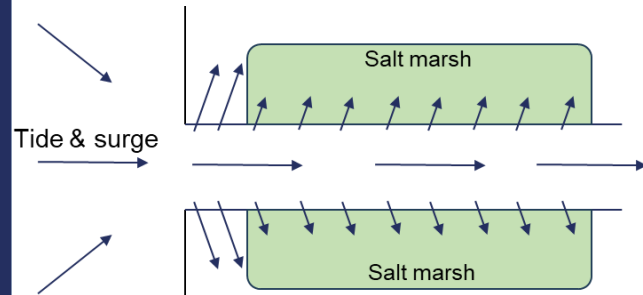
- Tide constituent amplitudes are reduced
- Higher reduction inland



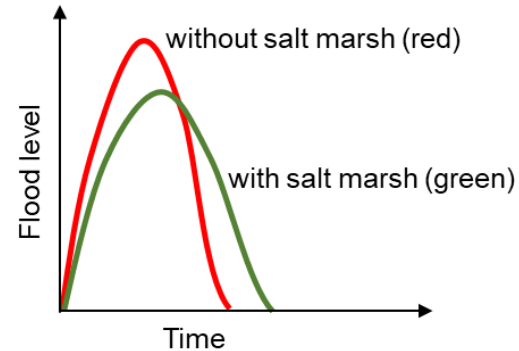
Satellite maps and reduction of M2 tide amplitudes of the 3 estuaries

Flood defence with salt marsh: numerical simulation

More extreme: the influence of salt marsh on tide & surge



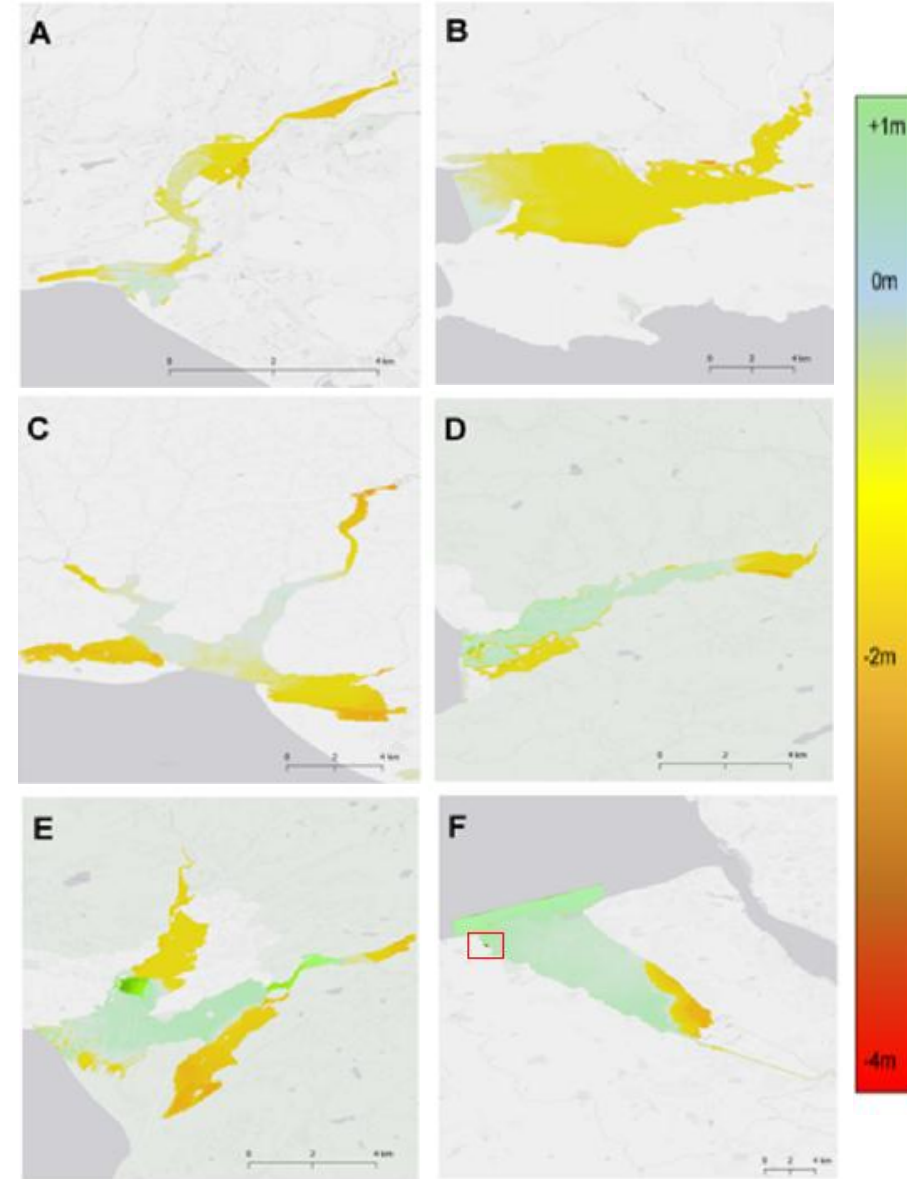
A sketch of the water flow during a flood



A conceptual description of the flood level histories

Saltmarsh vegetation:

- Slows flood water spreading.
- Reduces the water level and speed.
- Reduces the flood water volume.
- Stronger impact in the inland area.

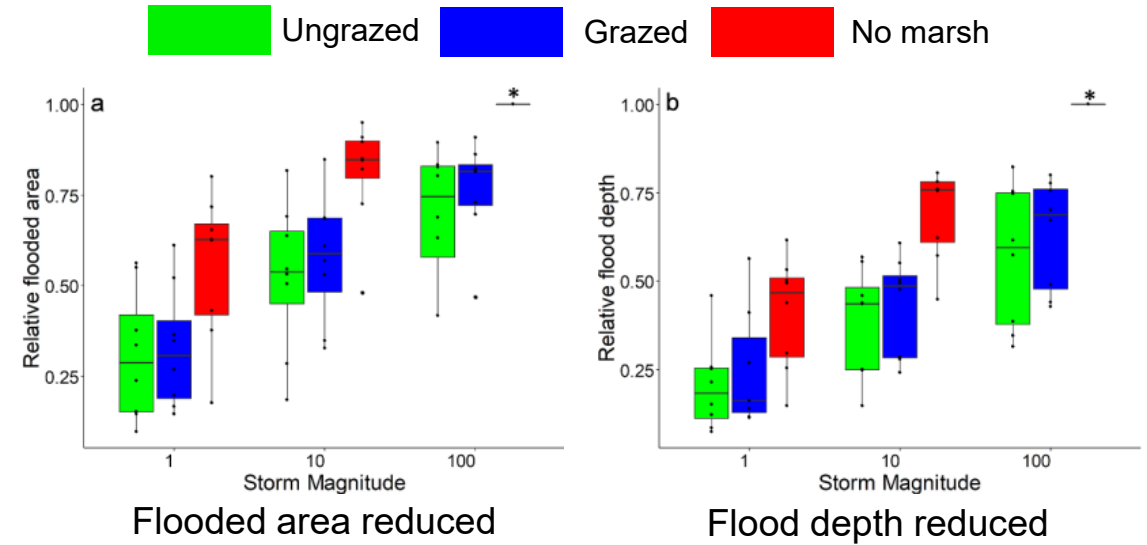


Differences in water level between unvegetated and vegetated scenarios for a 1 in 100 Storm

Flood defence with salt marsh: numerical simulation

Will salt marsh still be functionable if grazed?

- Still very useful for flood protection!
- Lower impact for salt marsh during stronger storm.



Considering the economic values of salt marsh...

- Significant benefits!
- Flood saving varies between \$ 34 to \$ 11,162.
- \$ 4772 VS \$ 41 annually per hectare.

Economic benefits: annual flood damage saving with salt marsh

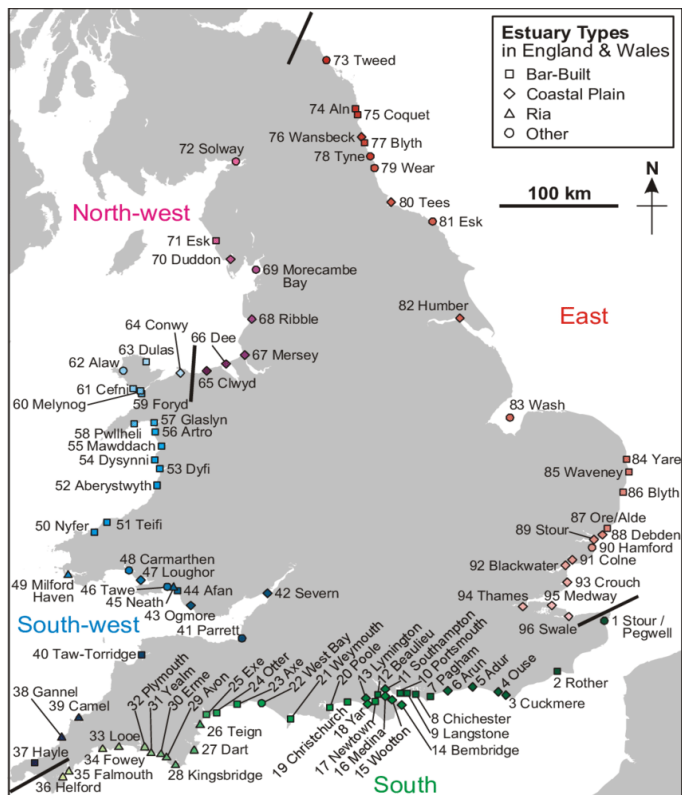
	Flood Saving (ha/yr)	Carbon Value (ha/yr) ^A	Grazing Value (ha/yr) ^B
Dee	\$ 34		
Glaslyn	\$ 7,557		
Gwendaerth	\$ 5,676		
Loughor	\$ 5,813		
Mawddach	\$ 2,733	\$64-220	\$41
Neath	\$11,162		
Taf	\$ 873		
Towy	\$ 4,331		
Average	\$ 4,772	(SE±\$1285)	

^AFrom Beaumont et al., 2013²⁷; ^BFrom King and Lester, 1995²⁸. In 2020 values, accounting for inflation.



We have to think about the balance between flood protection and grazing!

Accelerating the flood prediction: estuary idealisation



A map of the estuaries in England and Wales

- 160+ estuaries in the UK.
- Multiple scenarios needed for an estuary.
- Massive time and computational resources!

As it is unrealistic to simulate every estuary...



Any possibility to simulate less estuaries?



Try to find some 'representative' estuaries!



Is that reasonable to use representative estuaries?



Estuaries may share similarities and same underlying physical mechanisms!

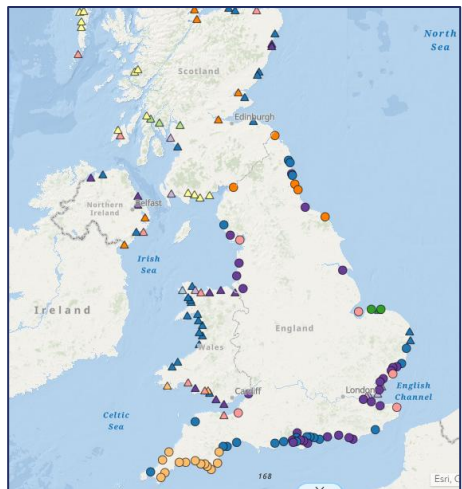


Then how to find 'representative' estuaries?



Due to the site-specific features, we choose to create rather than select!

Accelerating the flood prediction: estuary idealisation



Estuary database

- Coastal plain
- Ria
- Fjord/fjord
- Bar built
- Etc.

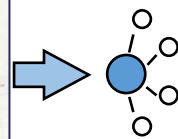
Estuary type classification



Example: Loughor (coastal plain)

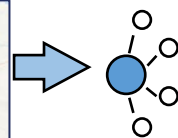


Example: Milford heaven (Ria)



Key parameters

Idealised estuary (Coastal plain)

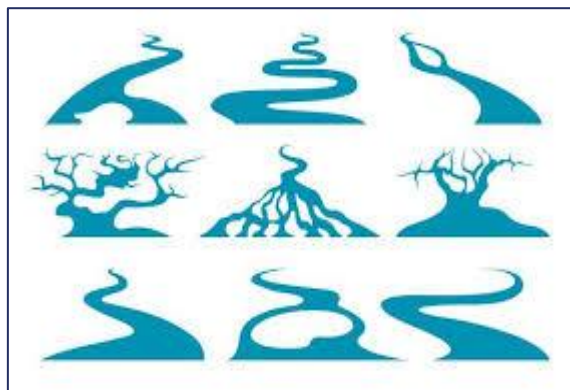


Key parameters

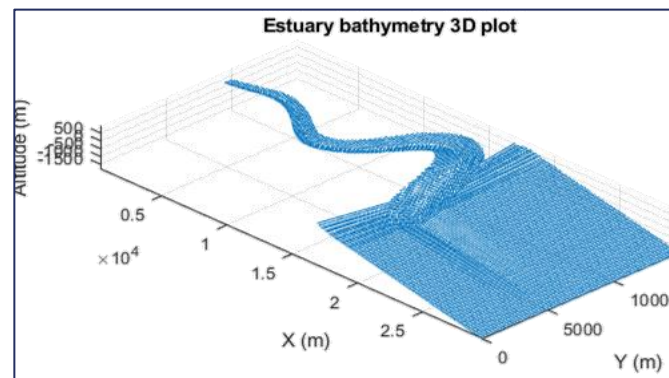
Idealised estuary (Ria)

Characteristics summarization

Idealised estuary establishment



Sketch of different types of estuaries

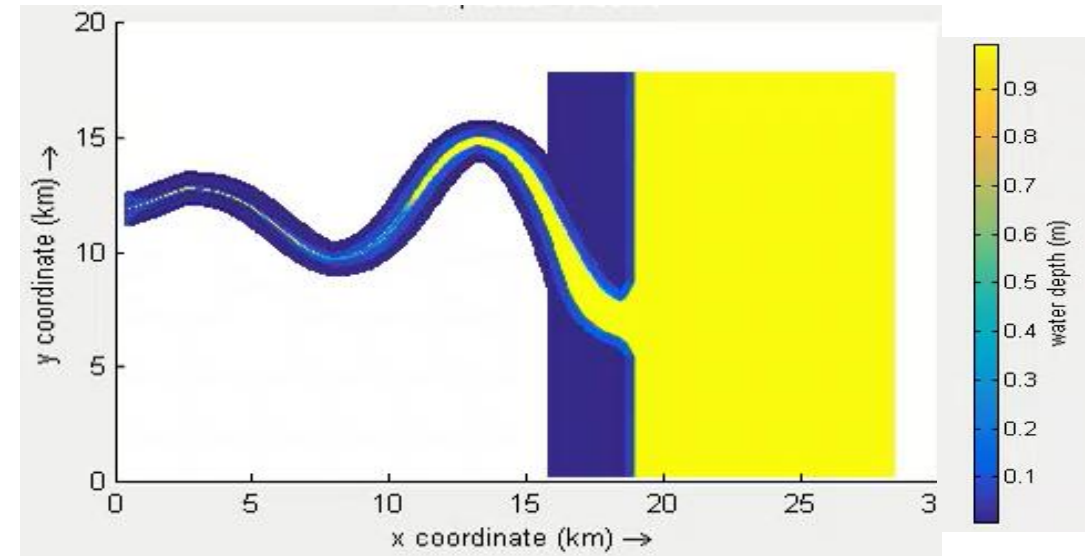


Example of idealised coastal plain estuary

Accelerating the flood prediction: estuary idealisation

Applying the idealised estuary model...

- Highly simplified morphology
- No site-specific characteristic
- Representative result



Water depth contours under tide and surge

😊 Benefits

- Significantly reduces the simulation cases
- High applicability, acceptable accuracy and representability
- Controllable parameters
- Less complexity

😞 Limitations

- Multiple idealised estuaries are still needed
- Ignorance of site-specific features
- Lower accuracy
- Not considering some estuaries

Accelerate the flood prediction: estuary idealisation + AI modelling

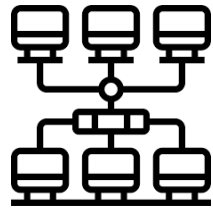


Even with idealised estuaries, we still need to simulate multiple cases!

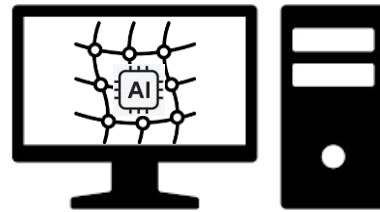
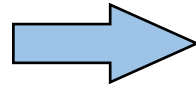
(various scenarios considering the management strategy, climate change, etc.)



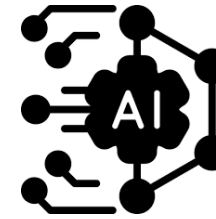
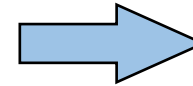
Faster and more efficient: AI-powered simulation and strategy making



Mass simulations with
idealised estuary



AI model training
(Gaussian process)



AI-based estuary
flooding model

Using the AI-based flooding model, we expect to get the flooding estimation within 1 minute!

Less data requirement

Less resource requirement

Higher efficiency modelling



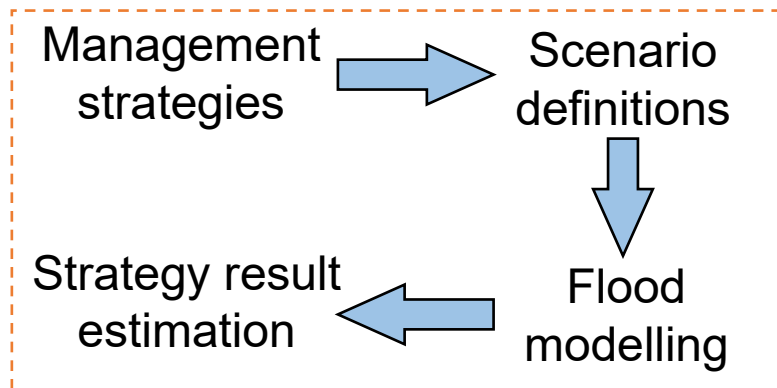
Research findings summary

- The flood reduction ability of salt marsh is stronger when the stem is rigid and densely distributed
- Salt marsh deeply influences the interactions among local flow field, sediment re-suspension and bed morphology
- Salt marsh (even grazed) significantly reduces the flood over the whole estuary, especially inland.
- Balance between flood protection and grazing is suggested.

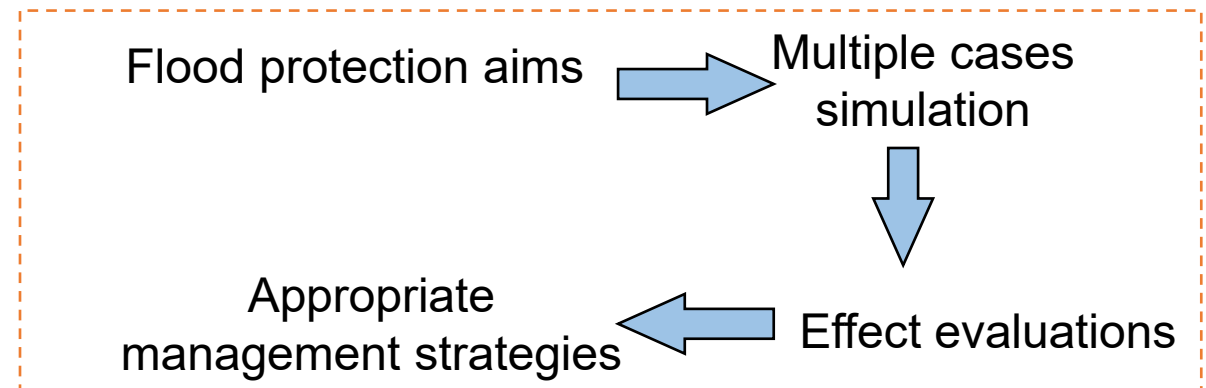


Supporting the strategy-making with our research

Fast estimation of management strategies



Optimization of management strategies



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Thank you!
Diolch!

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