Towards fast large-scale flood simulations using 2D Shallow water modelling with depth-dependant porosity

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Session NH1.1 – Flood risk modelling and assessment (with a special focus on uncertainty)

Chat time: Wednesday, 6 May 2020, 8:30-10:15

Outline

1. The CASCADE project, main hypothesis and objectives.
2. Large scale flood modelling at high resolution: context and challenges.
3. Research question.
4. Study site and available data.
5. Model setup.
6. Results.
7. Conclusion.
8. References.

Grimma - Germany, 2013

Bangkok - Thailand, 2011

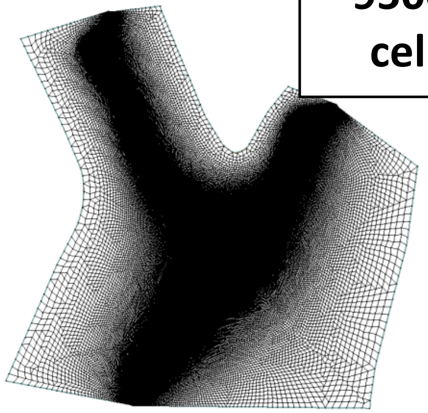
1. The CASCADE project

- A contribution to the CASCADE (Combining earth observation with a large scale model cascade for assessing flood hazard at high spatial resolution) project.
- The main working hypothesis of the CASCADE project: the joint use of Satellite Earth Observation (SEO) – derived soil moisture and flood maps will allow constraining model predictions, with a reduced need of in situ hydrometric data.
- Objective of the CASCADE project: the production of flood hazard maps over two to three test areas. This will contribute in establishing SEO-based early warning systems at a large scale by combining remote sensing and hydraulic modelling through data assimilation.

- Our objective: the development of modelling framework for large scale hazard mapping using a hydraulic model. The modelling suite SW2D (Shallow Water 2 Dimensions) under constant development at HydroSciences Montpellier since 2002 will be used with the Depth-Dependant Porosity (DDP).

2. Context and challenges

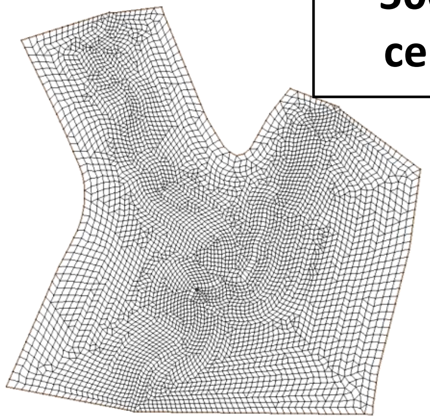
- A flood is a **multi-scale phenomena**: it occurs on a large scale. However, small scale features affect flood propagation. They thus need to be well represented in the model.
- Accurate results in conventional Shallow Water models require a fine meshing for representing complex topographic variations, which implies expensive computational costs.
- Porosity-based models solve the upscaled Shallow Water Equations with integrated porosity. The sub-grid features are dealt with even when using coarse meshing. This allows saving enormous processing times.



95000 cells

Fine mesh in a conventional Shallow Water model

Number of cells reduced by a factor of 19

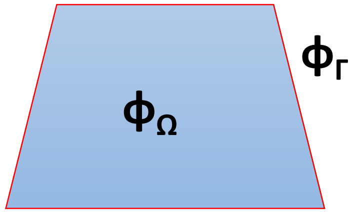


5000 cells

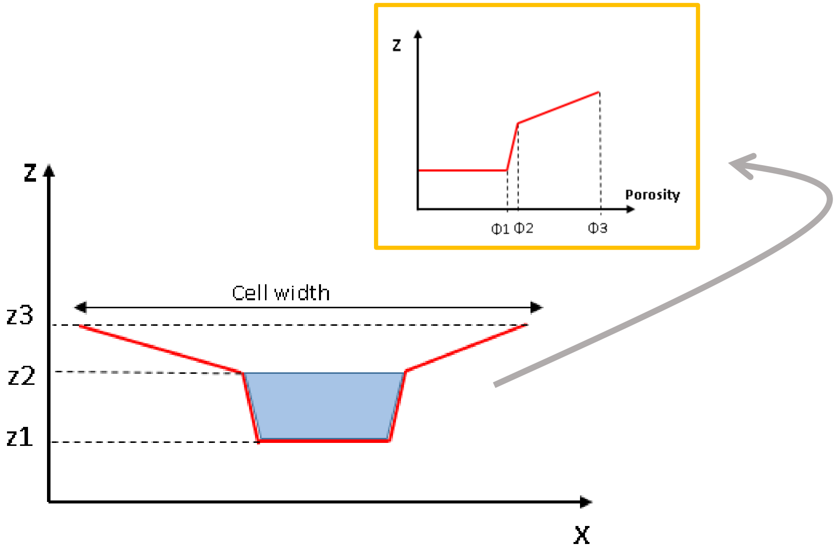
Coarse mesh in a Shallow Water model with porosity

3. Research question

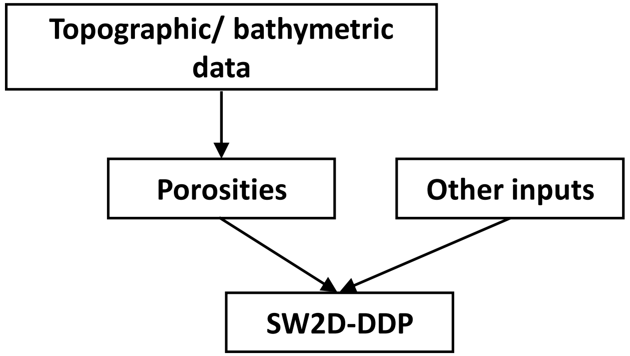
- Porosity = fraction of the cell (or edge) available to the water flow. It is equal to unity when the cell is completely wet, at its highest ground elevation.
- We distinguish storage porosity (ϕ_Ω) inside the cell from connective porosity (ϕ_Γ) on cell edges.
- **Research question:** How can porosity be represented through a grid cell in SW2D-DDP model?



Top view of a computational cell: storage and connective porosities.

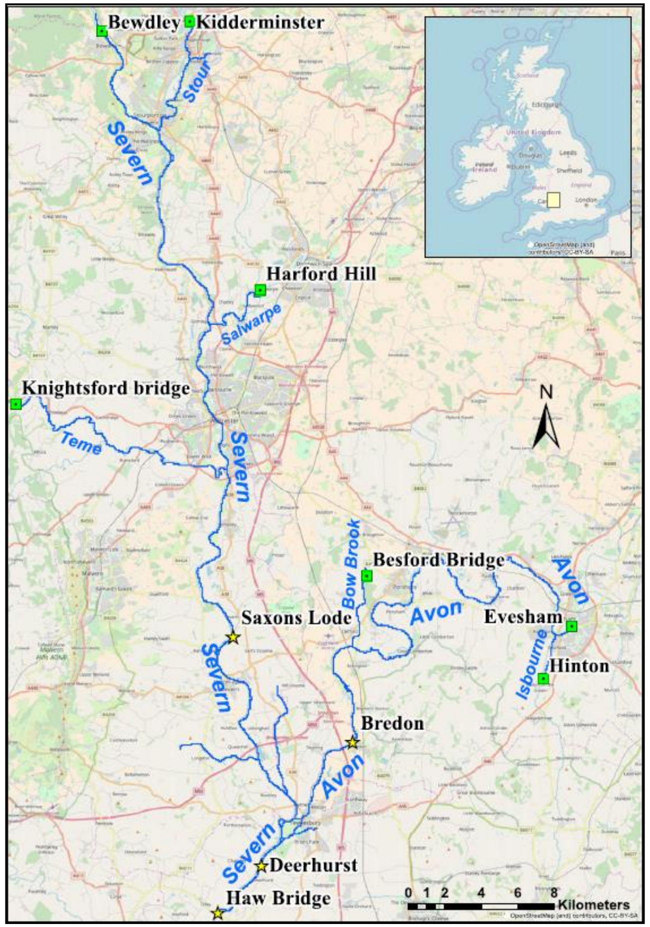


Cross-sectional view of a computational cell



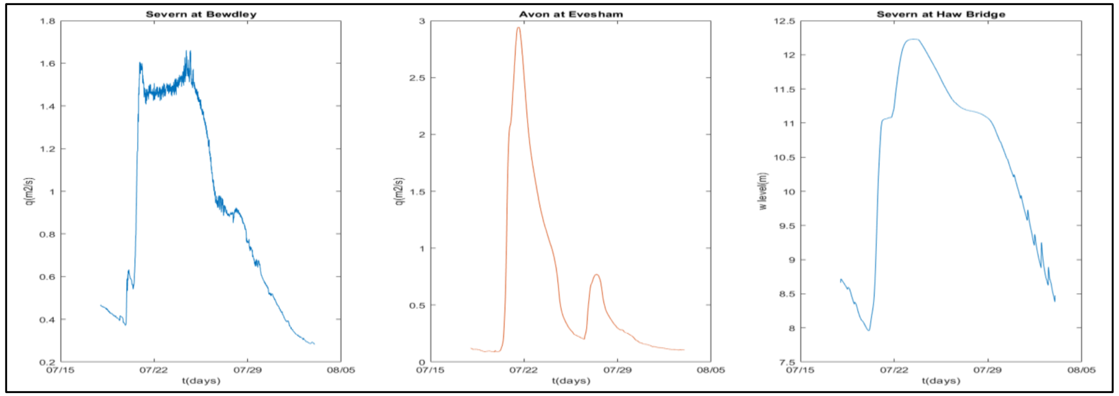
=> Coarse grid cells simulation with sub-grid scale features data.

4. Study site and available data

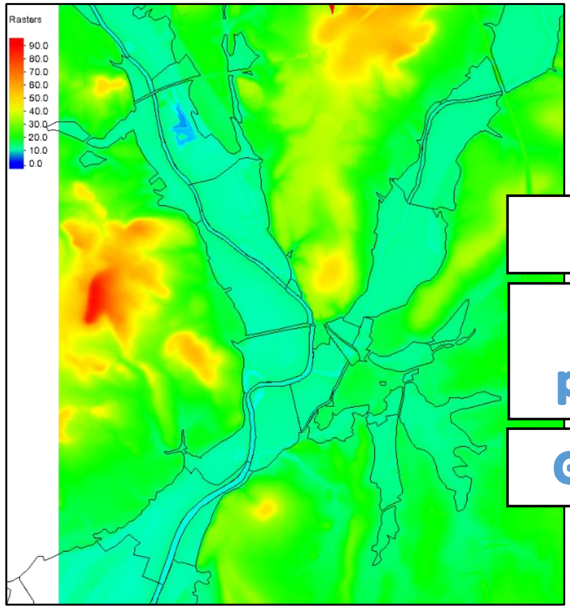


Study site

- Area covering approximately 50*30 km^2 of the Severn and Avon catchments.
- Two main rivers and six main tributaries.
- Regularly experiences severe flooding and for which a comprehensive history of information is already available.
- Flood event of July 2007 used as a test case.
- An aerial photography close to the peak time is available.
- A LiDAR Digital Terrain Model (DTM) is available.
- Gauging stations represented by stars.



Hydrometric data



LiDAR

Aerial photography

Google earth

5. Model setup

Topography

Determine overbank flow level => river banks (highest points)

Computational mesh

Floodplain cell

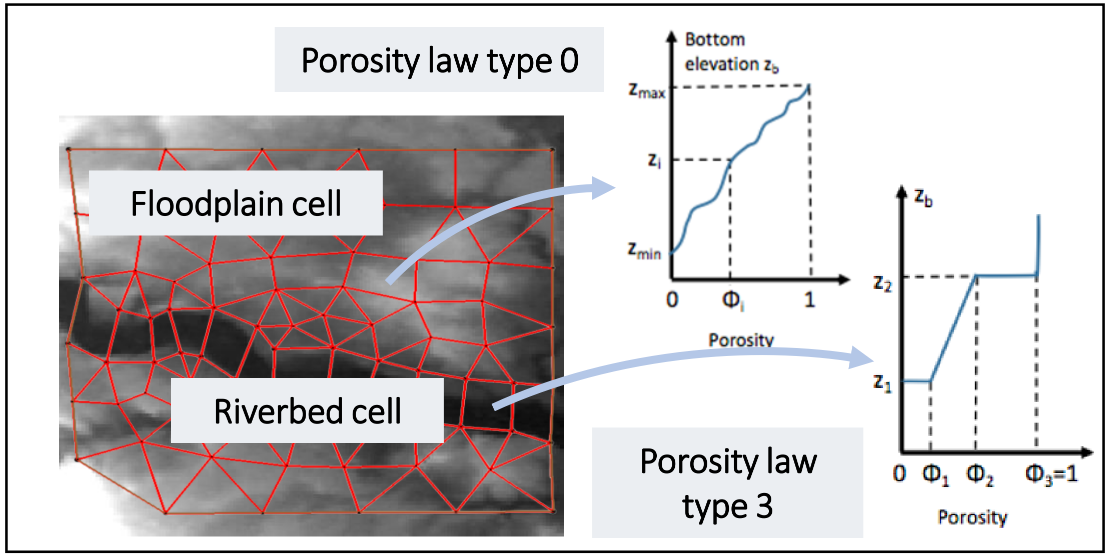
Riverbed cell

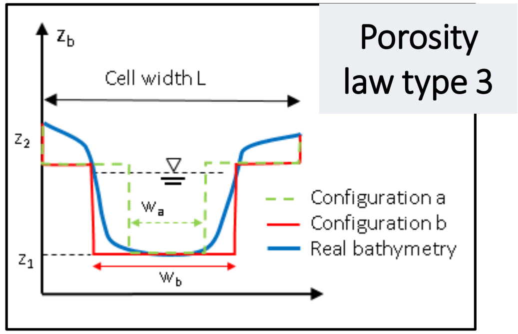
Porosity law type 0:

- The ground elevations are first estimated from the Digital Terrain Model (DTM).
- From this, N equidistant values are taken to define the elevation-porosity function.

Porosity law type 3:

- Used in the riverbed according to a simplified rectangular riverbed shape assumption.
- Z1 is derived from punctual bathymetric measurements. Z2 corresponds to the bank elevation (given by the DTM).





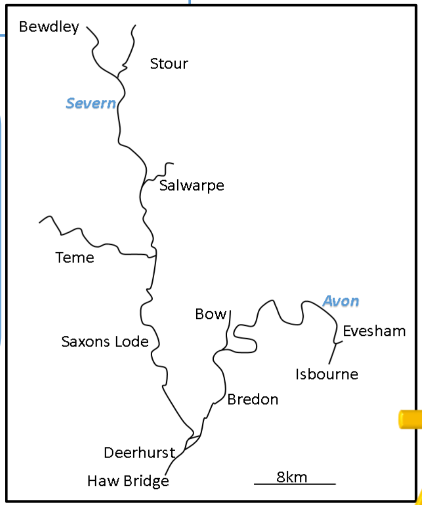
Porosities

Hydrometric data

Initial and boundary conditions

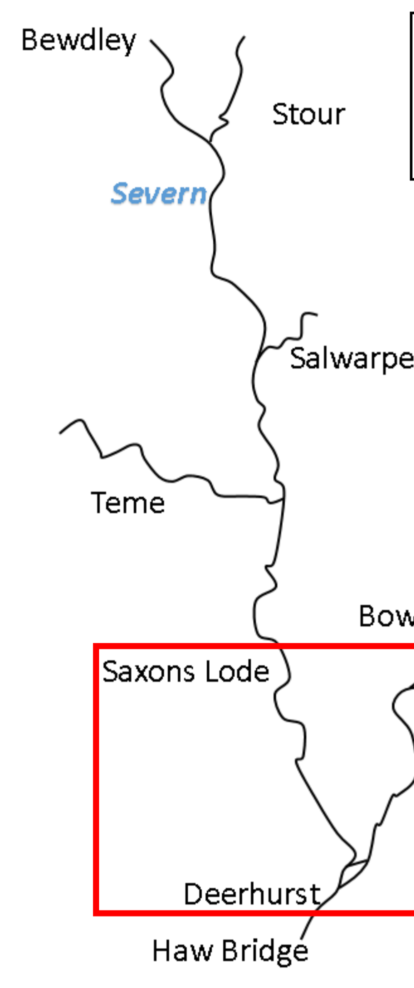
Model Parameters

- Upstream boundary conditions: two hydrograms at Bewdley and Evesham.
- Downstream boundary condition: a limnigram at Haw Bridge.
- Initial condition: constant water level over the entire domain.
- A uniform friction coefficient is set to $Ks=50s/m^{1/3}$ as a first estimation.
- Two configurations of uniform porosity are tested where:
  - Configuration a: $\Phi=0.3$ => river width represents 1/3 of cell width.
  - Configuration b: $\Phi=0.6$ => river width represents 2/3 of cell width.



6a. Water level assessment

Comparison of water levels in the downstream part of the river to assess the hydraulic model performance while changing the global porosities in two configuration tests, using the Root Mean Square Error (RMSE) metric.



Global porosities:

Configuration (a): Φ=0.3
Configuration (b): Φ=0.6

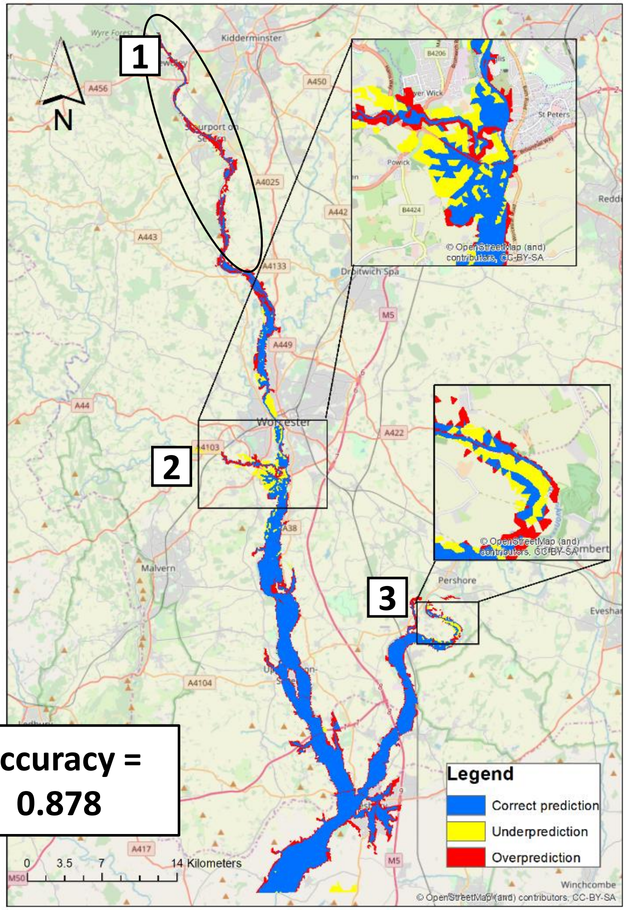
	Saxons Lode	Bredon	Deerhurst
RMSE (a)	0.854	0.886	0.261
RMSE (b)	+13 % 0.987	-6 % 0.824	+16 % 0.419

- Porosity change is influential on the model performance.
- Results are slightly better in configuration (a) for Saxons Lode and in configuration (b) for Bredon => parameters other than porosity affect the model's behaviour.
- The model is globally less sensitive to porosity at the downstream (Deerhurst). However the porosity change induces a bigger increase gap of 16%. This is probably due to the backwater effects.

6b. Flood extent maps assessment

A pixel to pixel comparison of flood extent maps derived from the aerial photography (observation) and the simulation (while changing the global porosities in two configuration tests). Evaluation using the overall accuracy metric.

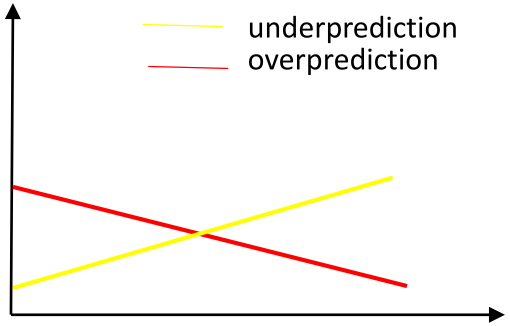
Contingency map	Predicted as flooded	Predicted as non-flooded
Observed as flooded	Correct prediction: true positives (blue)	Underprediction (yellow)
Observed non-flooded	Overprediction (red)	Correct prediction: true negatives

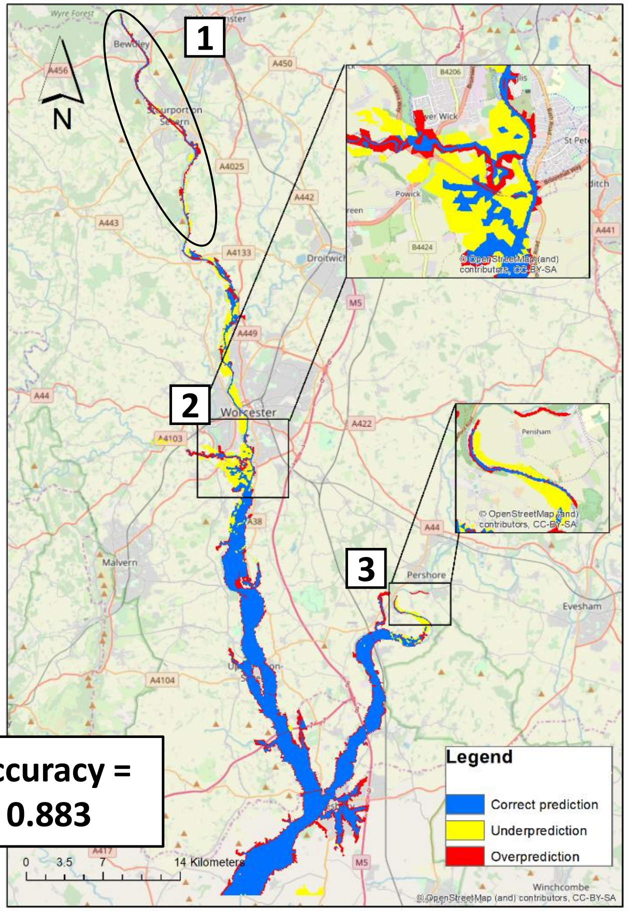


Accuracy = 0.878

Contingency map for configuration a (with Φ = 0.6).

- Good results in both configurations (high accuracy).
- Increasing porosity implies the river is wider and the required overbank flow is higher, which explains:
  - How increasing porosity leads to an increase in underprediction at the Teme-Severn confluence (2) and the upstream part of the Avon (3).
  - How Increasing porosity reduces overprediction in the upstream part of the Severn (1).
- Using spatially parameterized porosity with respect to river widths, instead of a globally uniform porosity, is very likely to improve predictions.

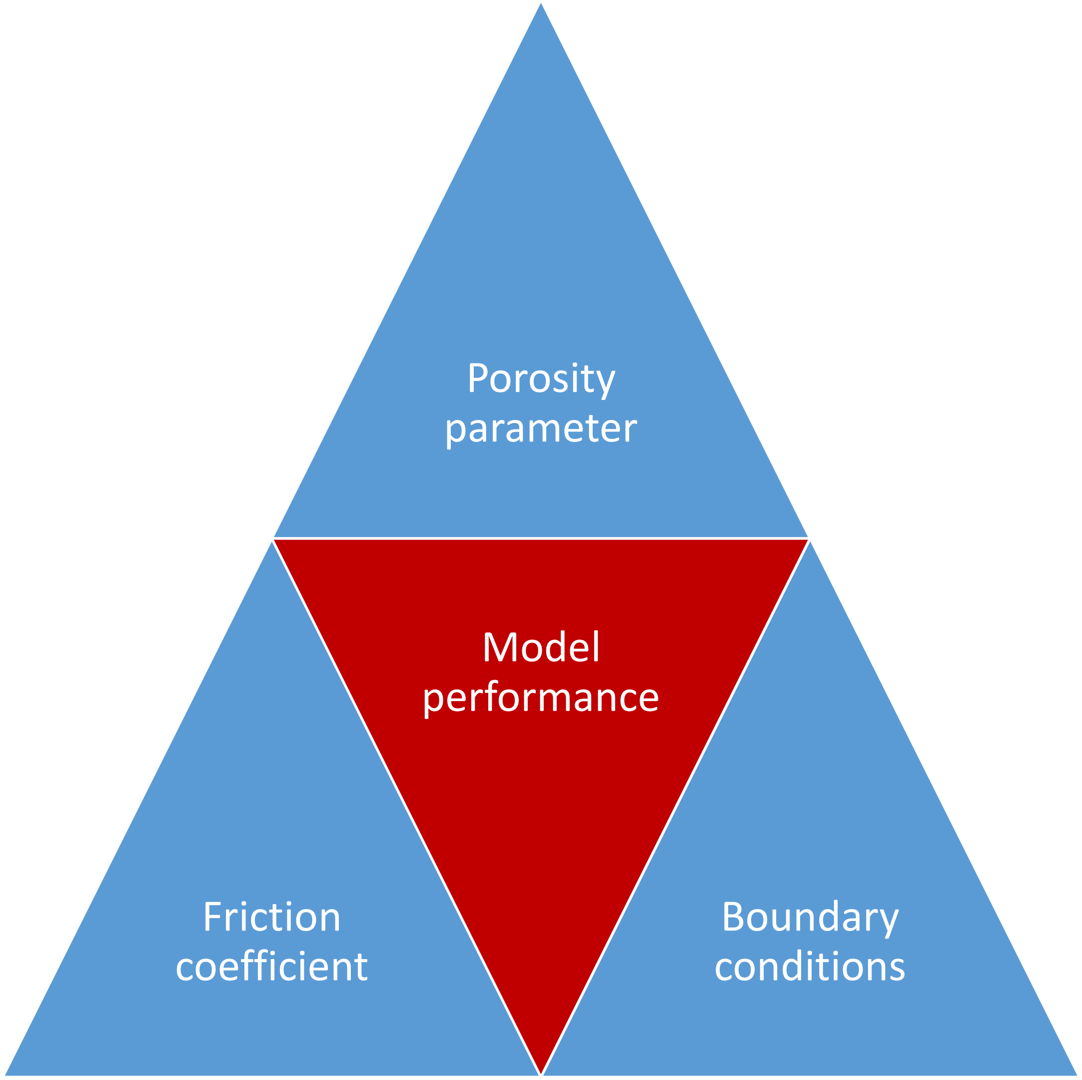




Accuracy = 0.883

Contingency map for configuration b (with Φ = 0.6).

7. Conclusion



- Flood extent maps derived from water depth maps generated by the model, have shown **a rather good agreement with the aerial photography-extracted flood map**.
- At certain locations the porosity parameter can be more influential on the model’s behaviour. **Observing underestimations and overestimations at certain locations suggests the porosity influence on the model is affected by the space parameter and boundary conditions => Porosity should be parameterized spatially in order to improve predictions.**
- A correction algorithm of local porosity parameterization is to be further tested.
- **In order to further investigate the parameters influence on the model, it would be interesting to also estimate model uncertainties coming from boundary conditions and friction coefficient => equifinality problem.**
- Overall, the study shows the use of SW2D-DDP holds promising results with **rather satisfying performance levels at a lower computational effort**.

8. References

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Thank you for your attention

Questions?

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