Parameterisation of Roughness Distribution on Floodplains in 2D Shallow-Water Simulations

J. Travert[1,2] C. Goeury[1,2] V. Bacchi[1]
F. Zaoui[1] S. Boyaval[2,3]

[1]EDF R&D, LNHE, [2]Saint-Venant Hydraulics Laboratory

[3]MATHERIALS, INRIA

LABORATOIRE D'HYDRAULIQUE SAINT-VENANT

eDF

IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China
Organized by: LNEC LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

Outline

Outline

Roughness parameterisation in flood modelling

Context

- 2D Flood modelling on floodplains
- Shallow-Water Equations:

$$\begin{cases} \dfrac{\partial h}{\partial t} + \dfrac{\partial (hu)}{\partial x} + \dfrac{\partial (hv)}{\partial y} = 0 \\ \dfrac{\partial (hu)}{\partial t} + \dfrac{\partial (hu^2)}{\partial x} + \dfrac{\partial (huv)}{\partial y} = -gh\dfrac{\partial \eta}{\partial x} - \dfrac{1}{\rho}\tau_{bx}(K) + \dfrac{h}{\rho}F_x + \nabla \cdot (h\nu_e \nabla u) \\ \dfrac{\partial (hv)}{\partial t} + \dfrac{\partial (huv)}{\partial x} + \dfrac{\partial (hv^2)}{\partial y} = -gh\dfrac{\partial \eta}{\partial y} - \dfrac{1}{\rho}\tau_{by}(K) + \dfrac{h}{\rho}F_y + \nabla \cdot (h\nu_e \nabla v) \end{cases}$$

- Influence of the roughness parameter K on hydraulic variables

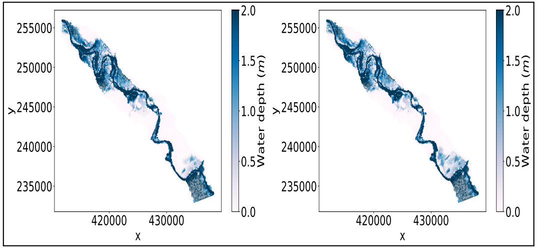


Figure 1: Example of two simulations with different sets of coefficients on the floodplains.

Objectives

- Quantify roughness parameter based on observations
  - Determine the optimal spatial distribution of roughness

Roughness parameterisation in flood modelling

Current method for quantifying roughness coefficients

- River: Calibration using hydrometric stations
- Floodplains: Subdomains splitting based on land cover + Expert opinions

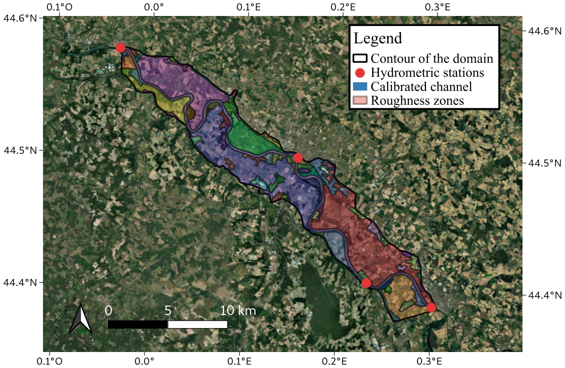


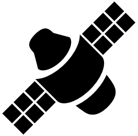
Table 1: Strickler values for each land cover in the floodplain for 2D models.

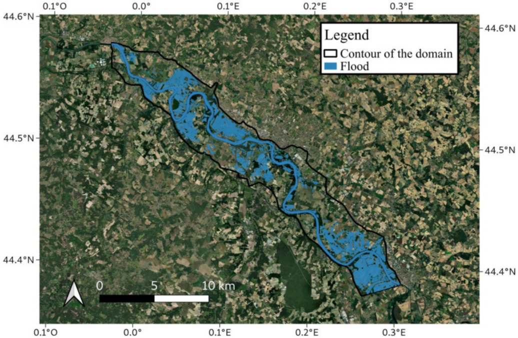
Land cover	Strickler coefficient ($m^{1/3} \cdot s^{-1}$)
Fields and meadows without crops	20
Cultivated fields with low vegetation	15 to 20
Cultivated fields with high vegetation	10 to 15
Shrubland and undergrowth areas	8 to 12
Areas of low urbanisation (town)	8 to 10
Highly urbanised areas (agglomeration)	5 to 8

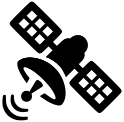
Roughness parameterisation in flood modelling

Calibrate roughness floodplain zones with more information?

- Using spatialised data in space and time (eg. satellites, drones, etc.)







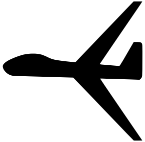


Figure 2: Extracted flood extent on the Garonne River in France (on the 2nd of Feruary at 6pm) from Sentinel-1 satellite.

Outline

Distribution of the roughness

- Issue: Calibrating too much parameters is a challenging optimisation problem

Calibration simplification

Objective: Reduce the number of parameters to calibrate based on the available observations

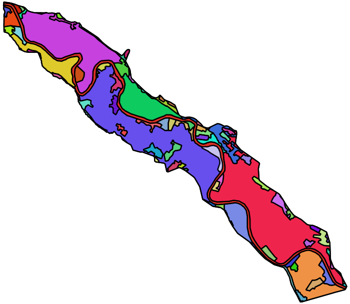


Figure 3: A priori zoning based on land cover.

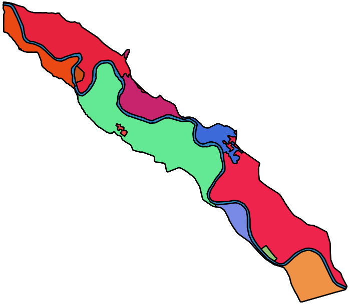


Figure 4: Possible new zoning of the roughness parameter.

Sensitivity analysis framework

- Study how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in its inputs

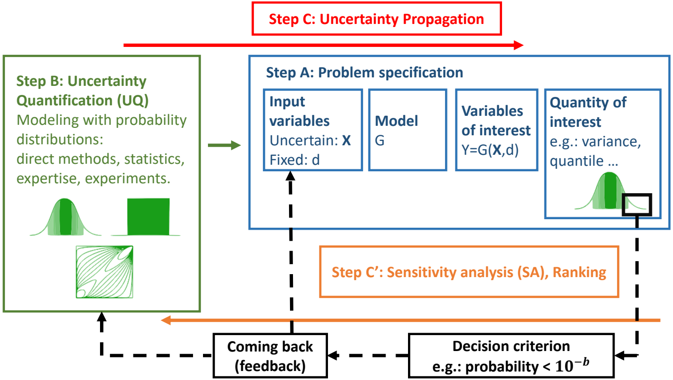


Figure 5: Uncertainty management methodology.

A - B: Problem specification and UQ

- Fixed d: Topography, flood hydrograph, and rating curve
- Uncertain inputs $\mathbf{X}$: K in the subdomains and channel (around calibrated values C)

Table 2: Range of roughness values for the subdomains.

Subdomains	**K** $(m^{1/3} \cdot s^{-1})$
Channel	$\mathcal{U}(C-2.5, C+2.5)$
Waterbodies	$\mathcal{U}(32.5, 37.5)$
Fields and meadows without crops	$\mathcal{U}(17.5, 22.5)$
Cultivated fields with low vegetation	$\mathcal{U}(15, 20)$
Cultivated fields with high vegetation	$\mathcal{U}(10, 15)$
Shrublands and undergrowth areas	$\mathcal{U}(8, 12)$
Areas of low urbanisation	$\mathcal{U}(8, 10)$
Highly urbanised areas	$\mathcal{U}(5, 8)$

- Model G: TELEMAC-2D from the opentelemac suite of solvers

- Variables of interest $\mathbf{Y}$: 290 Water depths locations every hour

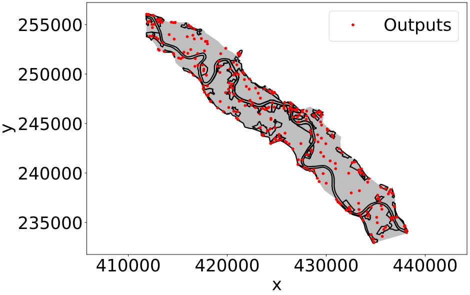


Figure 6: Water depths sampling locations.

C- C': Design of Experiment and SA

- **Sampling procedure:** Nested Latin Hypercube Sampling (space filling DoE) with $N_{samples} \in \{500, 1000, 2000, ...\}$
- **Spatio-temporal Sensitivity Analysis** on $\mathbf{Y} = \{Y_i^t\}_{1 \leq i \leq 290}^{1 \leq t \leq 310}$
- Sensitivity Analysis methods: Variance-based and density-based methods

Outline

Illustration with Sobol indices

Polynomial Chaos Expansion based Sobol indices

Let $Y \in \mathbb{R} \subset \mathbf{Y}$ with $\mathbb{V}ar(Y) < \infty$ then:

$$Y = \sum_{\alpha \in \mathbb{N}^p} y_\alpha \psi_\alpha(\mathbf{X})$$

- $\{\psi_\alpha\}_{\alpha=0}^{p}(.)$ is a polynomial orthonormal basis
- $\{y_\alpha\}_{\alpha=0}^{p}$ are the coordinates of Y in the basis

$$S_i^1 = \frac{\sum_{\alpha \in \mathcal{A}_i} y_\alpha^2}{\sum_{\alpha \in \mathcal{A}, \alpha \neq 0} y_\alpha^2}$$

$$S_i^T = \frac{\sum_{\alpha \in \mathcal{A}_i^T} y_\alpha^2}{\sum_{\alpha \in \mathcal{A}, \alpha \neq 0} y_\alpha^2}$$

where $\mathcal{A}_i = \{\alpha \in \mathcal{A}, \alpha_i > 0, \alpha_{j \neq i} = 0\}$ and $\mathcal{A}_i^T = \{\alpha \in \mathcal{A}, \alpha_i > 0\}$

Sensitivity analysis - One location

- First step: Temporal sensitivity for one control point

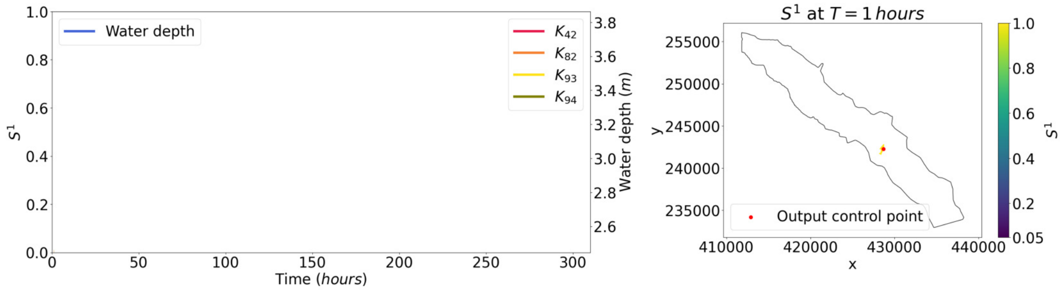


Figure 7: Evolution of the S^1 indices with time for a given location.

Sensitivity analysis - Multi locations

- Step 2: What if several water depths are available?

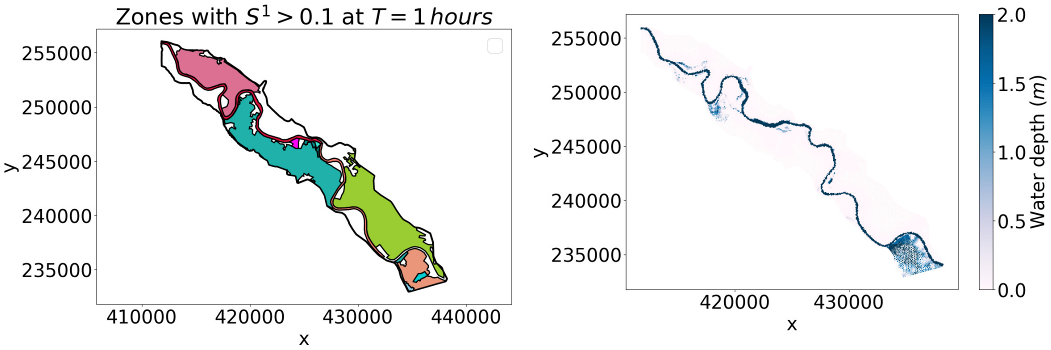


Figure 8: Visualisation of the zones with an influence on at least one of the control point with time.

Sensitivity analysis - Influencial zones

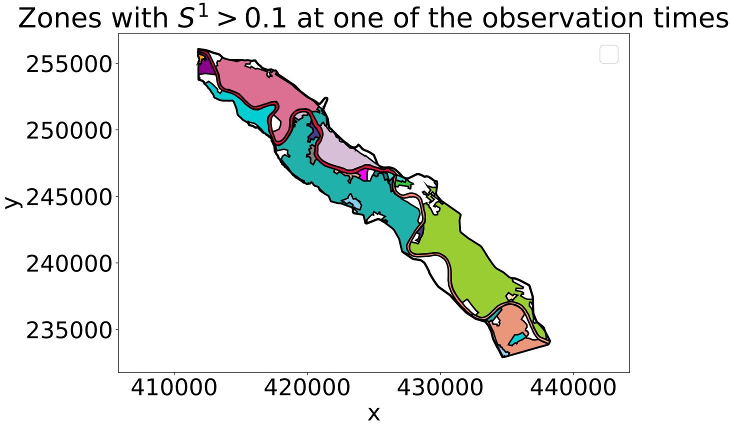


Figure 9: Zones with $S^1 > 0.1$ at least once.

Sensitivity analysis - Satellite flood extent

- Control points locations within the flooded regions for two satellite images during the flood

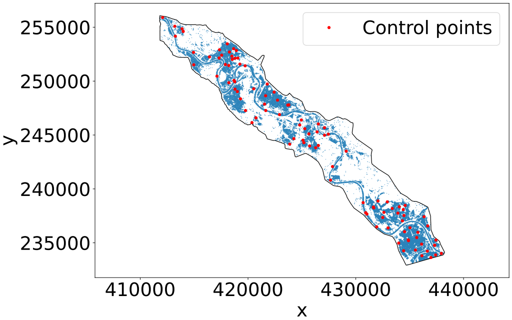


Figure 10: Flood extent on the 2nd of February 2021 at 5:55pm extracted from Sentinel-1 and possible control points.

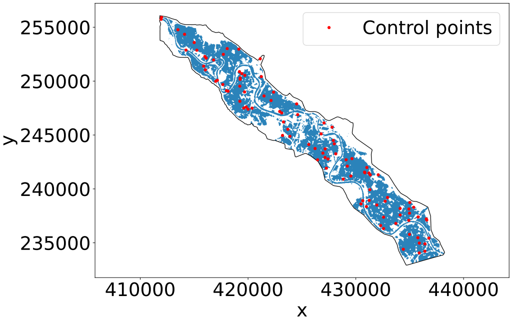


Figure 11: Flood extent on the 3rd of February 2021 at 5:48pm extracted from Sentinel-1 and possible control points.

Sensitivity analysis - Satellite flood extent

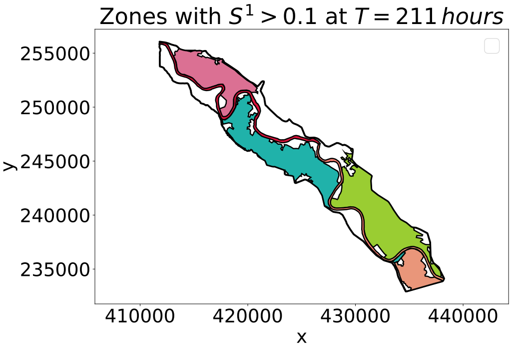


Figure 12: Zones with an influence on at least one of the control points for the first satellite image.

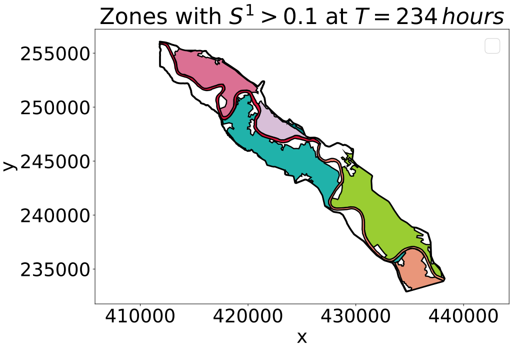


Figure 13: Zones with an influence on at least one of the control points for the second satellite image.

Outline

Conclusions and perspectives

Conclusions:

- Reduction of the number of parameters (from 95 to 30)
- Only a few zones (the larger ones) are influential at the times of observation

Perspectives:

- Create a new zoning of the roughness based on the sensitivity analysis and a data-driven approach
- Calibration of the roughness zones with data assimilation strategies

Thank you for your attention!

Contact: jean-paul.travert@edf.fr