1D/2D porosity-like model for urban flood modeling

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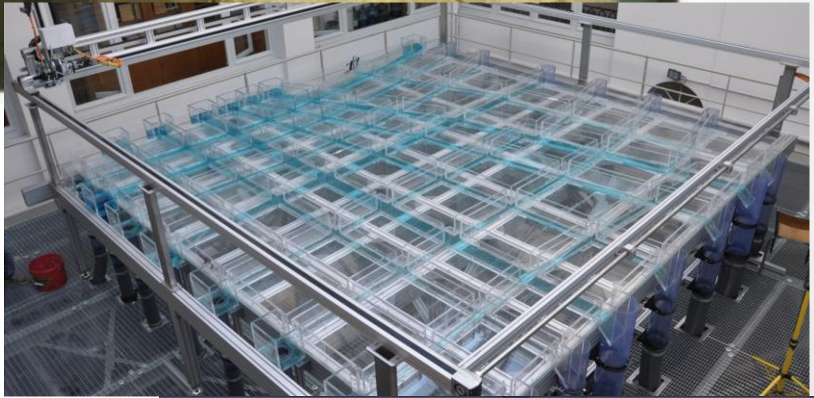
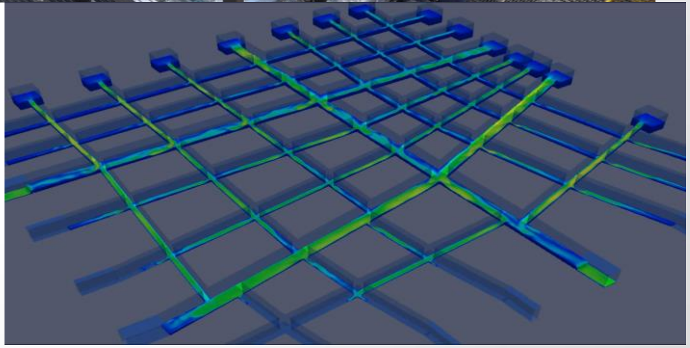
Introduction

- Urbanization of floodplains - increase urban areas vulnerability
- Numerical modeling needed for flood impact forecasting
- Common modeling approaches:
  - SWE with classical friction laws
  - SWE with macroscopic porosity
  - 3D Navier Stokes equations

  => Trade off between the modeling goals, computational cost, data requirements

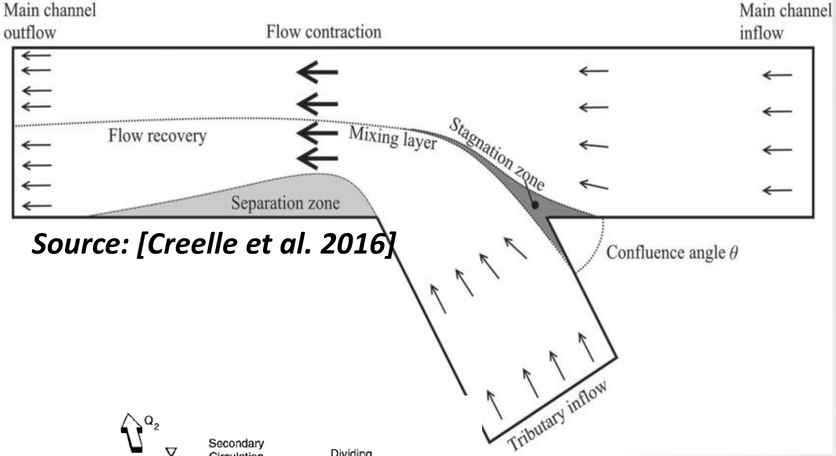
=> *Flood1D2D*: a 1D/2D hydraulic model taking into account the effect of 3D flow features using a parsimonious parametrization



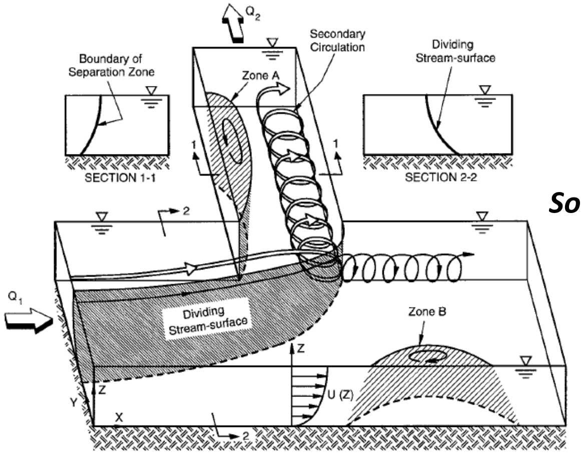


Introduction

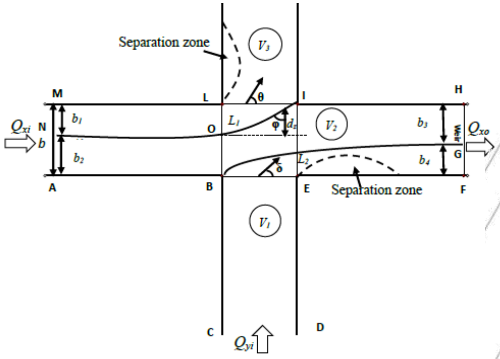
- Urban flood flows: combination of hydraulic intersections (junctions, bifurcations, crossroads)
- Experimental and numerical studies highlight the presence of recirculation areas downstream of intersections [Finaud-Guyot et al. 2018]



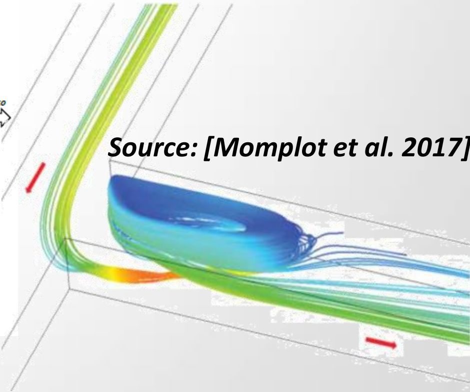
Source: [Creelle et al. 2016]



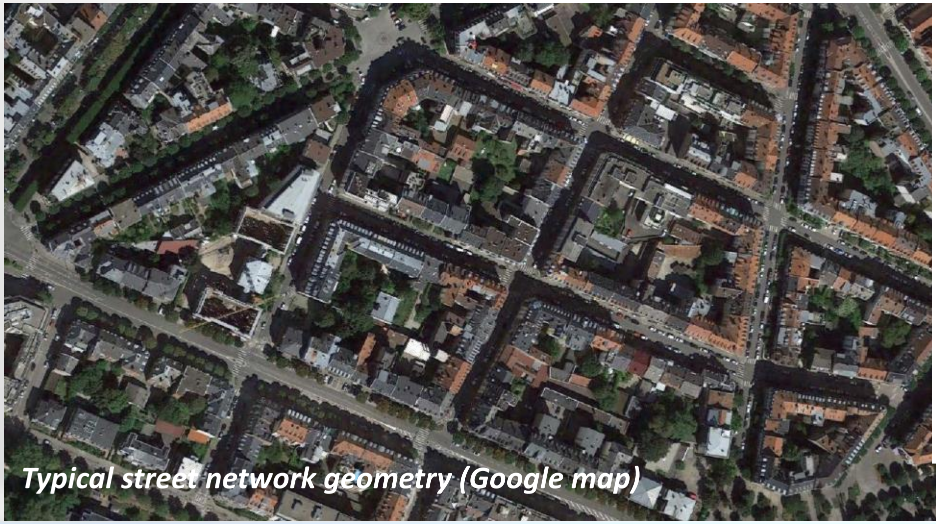
Source: [Neary et al. 1999]



Source: [Rivière et al. 2011]



Source: [Momplot et al. 2017]



Typical street network geometry (Google map)

Conceptual model

Operational requirements:

- Water depth and velocity profile in streets

=> coherent with a 1D modeling approach of the streets

- Street discharge repartition

Crossroad flow complexity are at least 2D

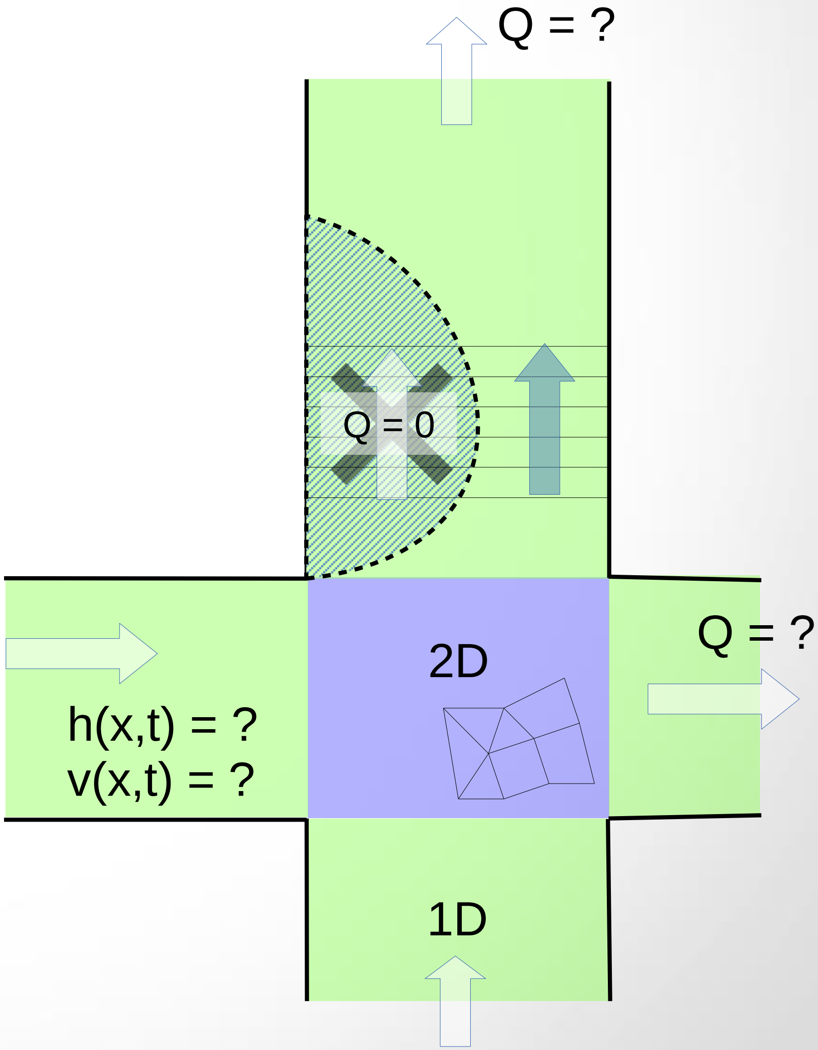
Proposed model

- 1D in street => cell width = street width
- 2D in crossroad = classical 2D unstructured mesh

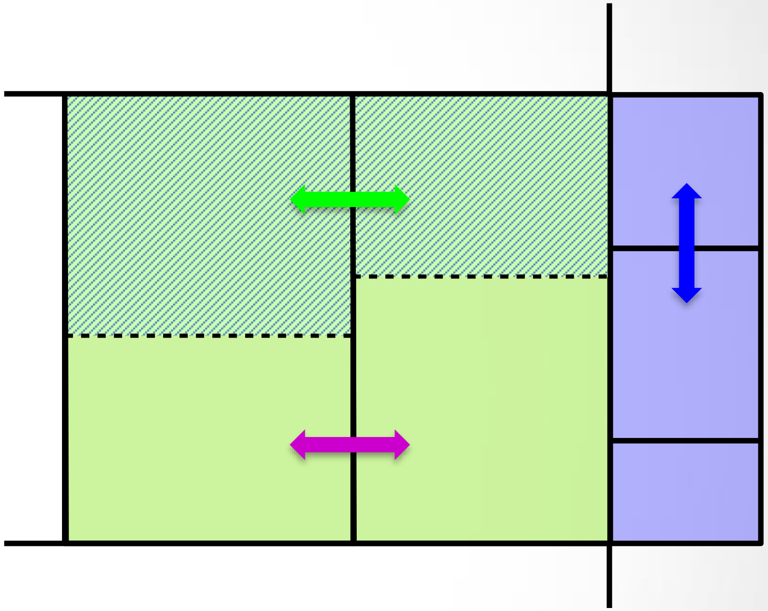
Recirculation effect in 1D cell not accounted by the classical shallow water equations

=> Introduction of a subcell model in the 1D cells:

- ineffective flow area => no velocity
- effective flow vein



Numerical approach



Classical 2D SWE in all cells

- Account for direction change
- Simplified coupling at 1D/2D edge

Finite Volume Method

$$\boldsymbol{U}_i^{n+1} = \boldsymbol{U}_i^n - \Delta t \left[\frac{1}{A_i} \sum_{j \in N(i)} \boldsymbol{P}_{i,j} L_j \boldsymbol{F}_j^n + \boldsymbol{S}(\boldsymbol{U}_i^n) \right]$$

1D1D and 1D2D edge :

$$\boldsymbol{F}_j^n = \frac{L_{j,u} \boldsymbol{F}_{j,u}^n + L_{j,v} \boldsymbol{F}_{j,v}^n}{L_j} = (1 - \phi_j) \boldsymbol{F}_{j,u}^n + \phi_j \boldsymbol{F}_{j,v}^n$$

$$\phi_j = \frac{\phi_L + \phi_R}{2}$$

Riemann flux computation : PorAS solver $\mathcal{P}(\dots)$ [Finaud Guyot et al. 2010]

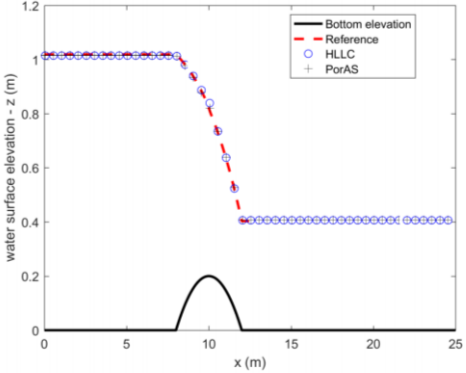
- $\boldsymbol{F}_j^n = \mathcal{P}([h_L \quad q_L \quad r_L]^T, [h_R \quad q_R \quad r_R]^T)$
- $\boldsymbol{F}_{j,u}^n = \mathcal{P}([h_L \quad 0 \quad 0]^T, [h_R \quad 0 \quad 0]^T)$
- $\boldsymbol{F}_{j,v}^n = \mathcal{P}([h_L \quad q_L/\phi_L \quad r_L/\phi_L]^T, [h_R \quad q_R/\phi_R \quad r_R/\phi_R]^T)$

SWE variables
h: water depth
q: x unit-discharge
r: y unit-discharge

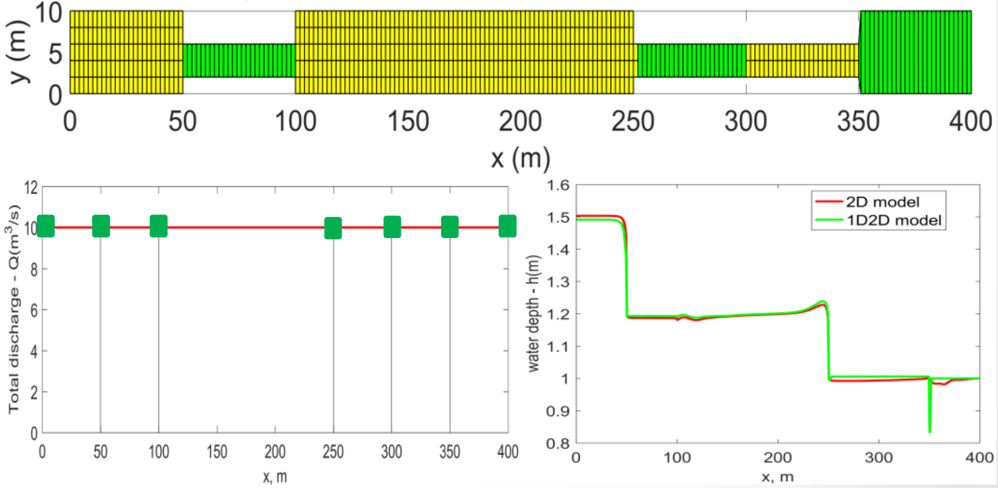
Flood1D2D

- C/C++ software
- Validated on various test cases [Chen 2018 PhD]
  - Academic
  - Experimental

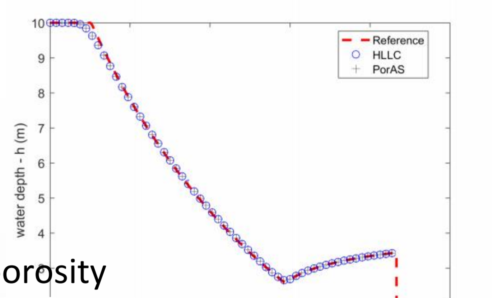
Steady flow over a bump



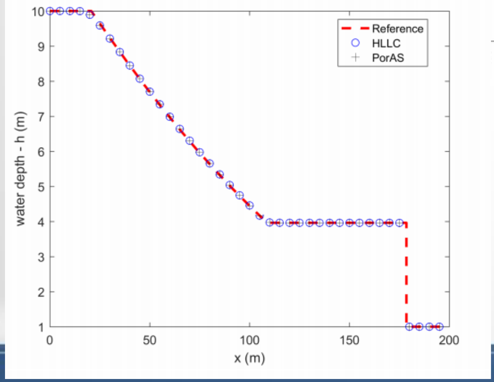
Steady flow in a variable width 1D2D channel



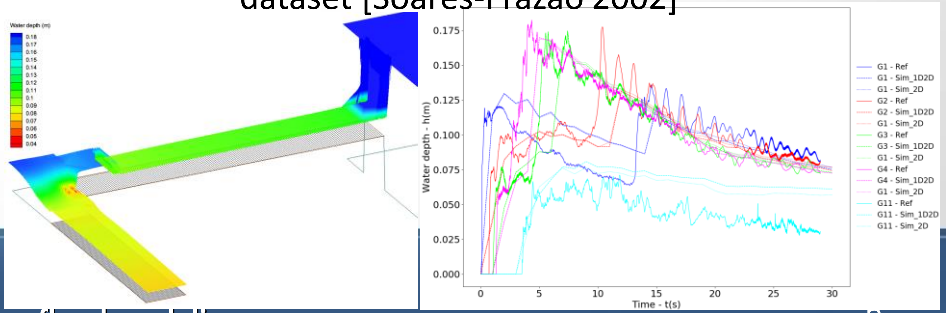
Dambreak with porosity



Dambreak without porosity



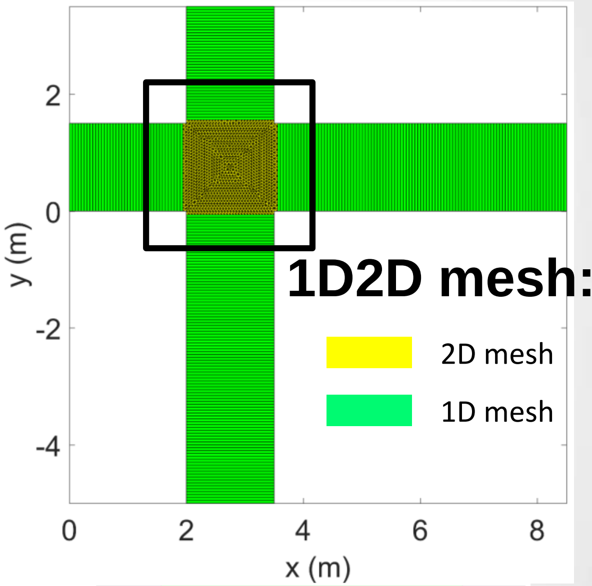
Comparison of Flood1D2D results with Soares-Frazao's dataset [Soares-Frazao 2002]

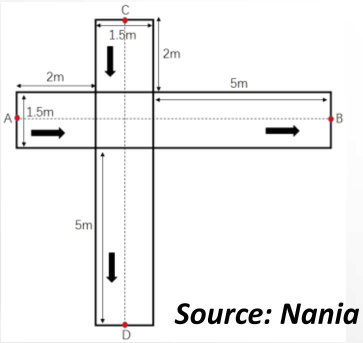


Flood1D2D - Local scale validation

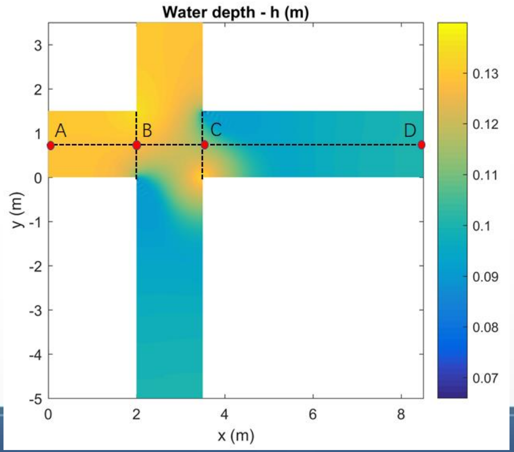
- Four branch junction flow [*Nania et al., 2011*]
  - $Q_{up,x} = Q_{up,y} = 75L/s$
  - Downstream water depth $h = 0{,}1m$
  - Friction : $\mathrm{K} = 100\ \mathrm{m}^{1/3}/s$

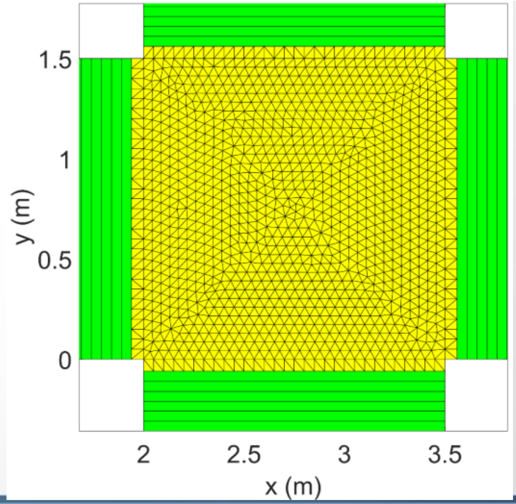
- Simulations:
  - Reference = Telemac 2D
  - Flood1D2D parameterized with a supposed porosity profile





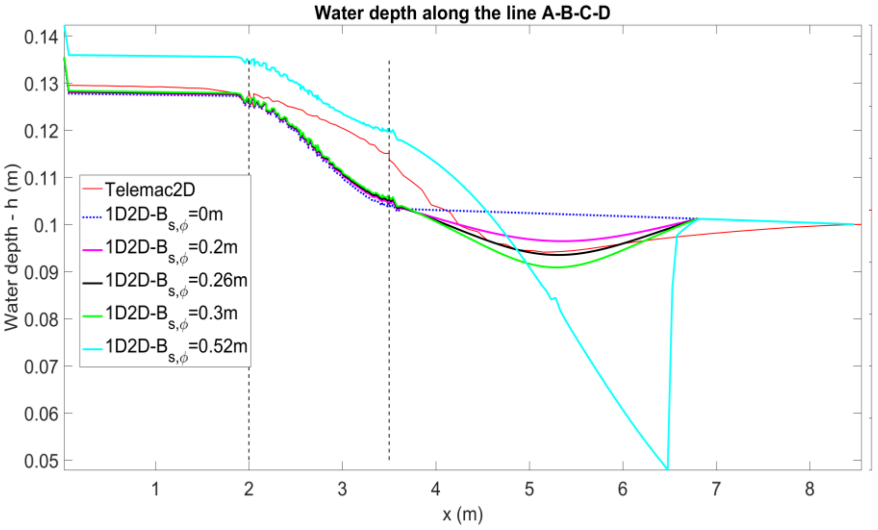
Source: Nania et al. 2011





Flood1D2D - Local scale validation

- Water depth profile inflexion in flow throat (due to recirculation) not predicted by friction parameterized SWE
- Adding a porosity parameterization allows to reproduce the water depth profile in the downstream street
- Porosity estimated from 2D model (recirculation width) leads to incorrect 1D/2D flowlines
  - Different modeled physics (friction effect, turbulence, …)
  - Potentially equifinality problem between friction and porosity



New 1D2D shallow water model with porosity like parameterization able to reproduce complex 2D flow features.

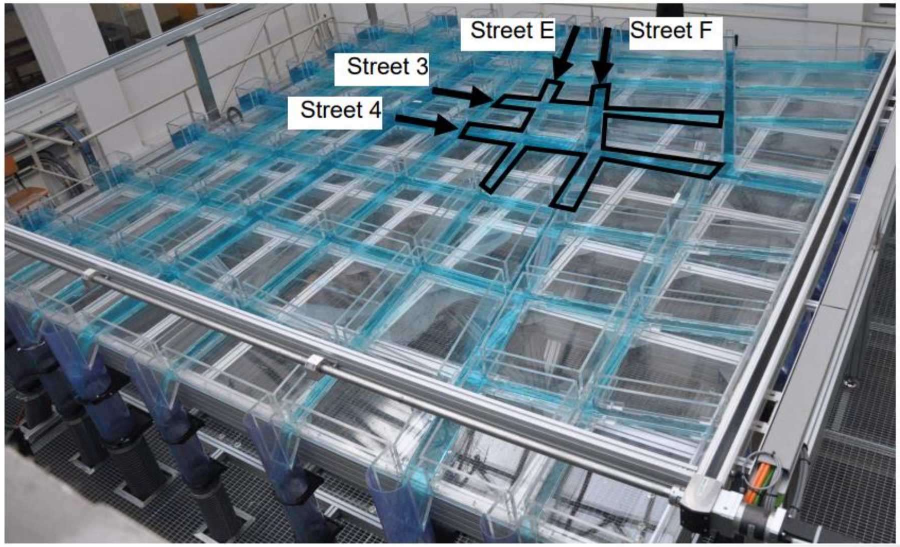
Flood1D2D - Global scale validation

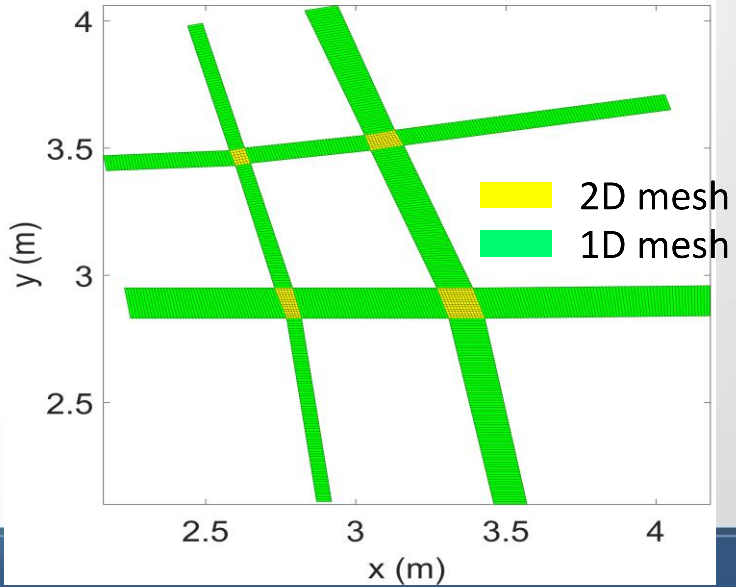
Icube urban flood experimental rig

- Water depth profile
- Street discharge repartition

Simulation with Flood1D2D

- Boundary conditions
  - Upstream : Q_{exp}
  - Downstream: h(Q)
- Run 1 : K_{cross} and K_{street}
  - $K_{cross} \in [25, 50, 75, 100, 125, 150]$
  - $K_{street} \in [25, 50, 75, 100, 125, 150]$
- Run 2 : K, ϕ_{large} and ϕ_{narrow}
  - $K = 75 m^{1/3}/s$
  - $\phi_{large} \in [0.25, 0.50, 0.75, 1.00]$
  - $\phi_{narrow} \in [0.25, 0.50, 0.75, 1.00]$





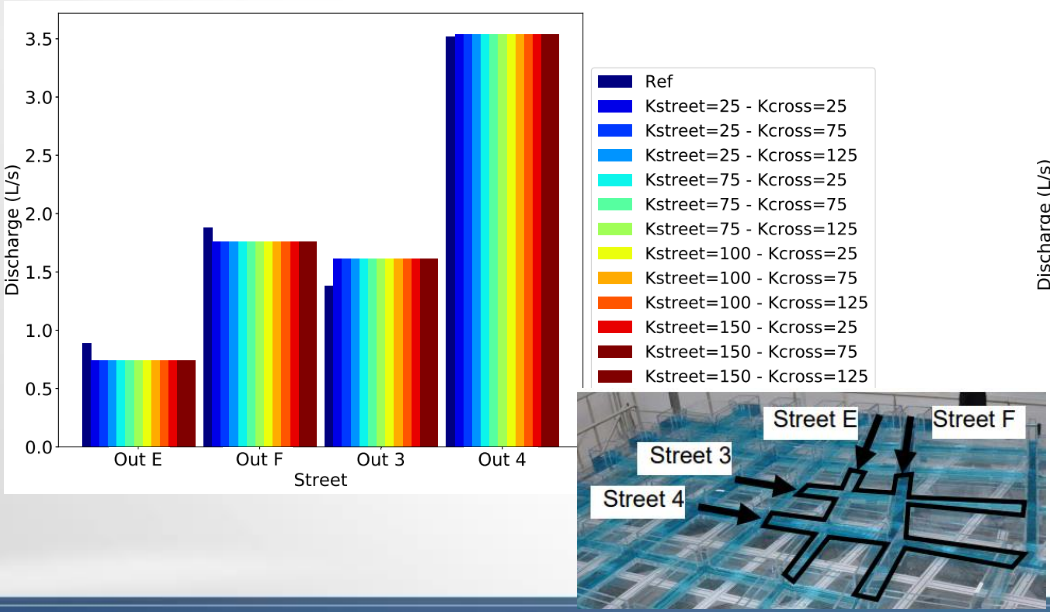
Flood1D2D - Global scale validation

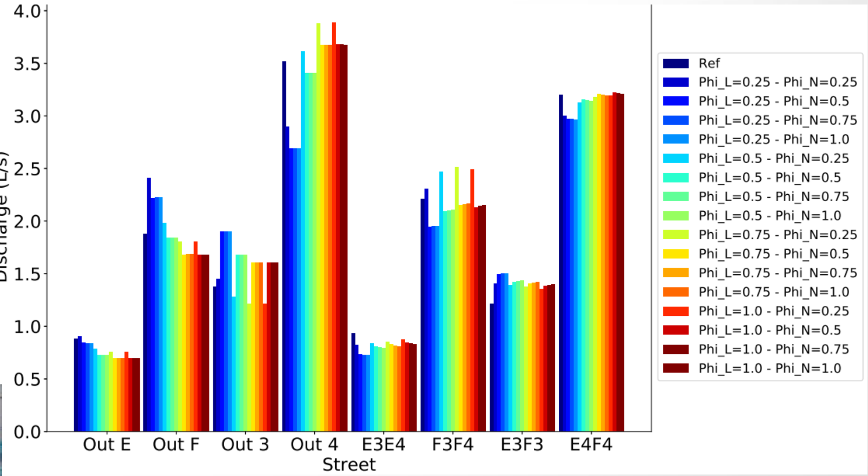
Run 1 : K_{cross} and K_{street}

- Downstream discharge unsensitive to friction coefficient
- Over or underestimation of the experimental discharge

Run 2 : K, ϕ_{large} and ϕ_{narrow}

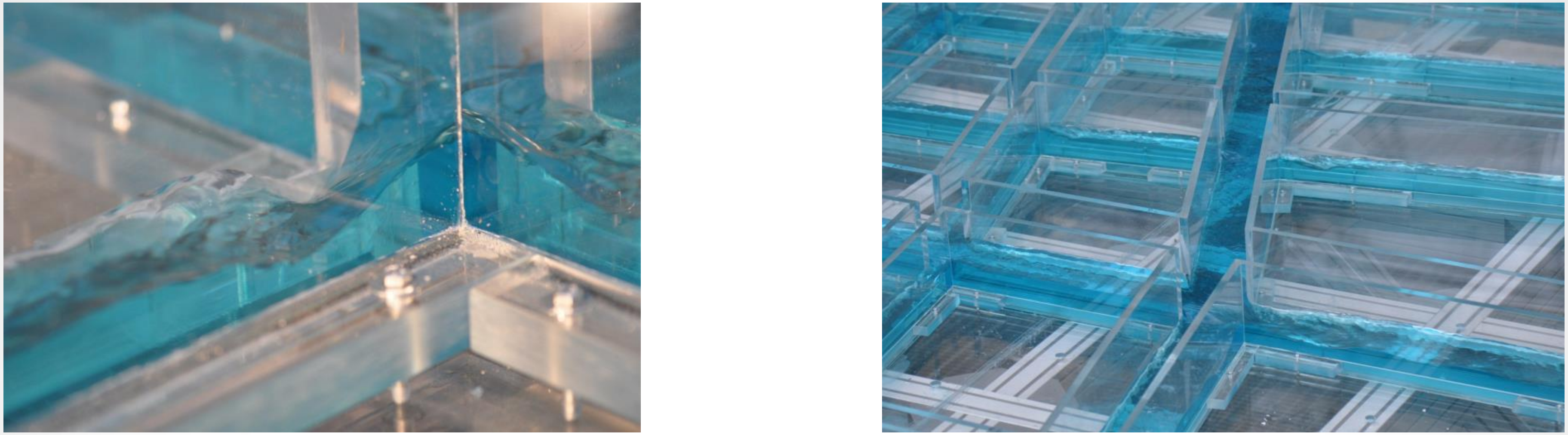
- Sensitivity of the street/outlet discharge to the porosity
- Allows to surround the experimental value



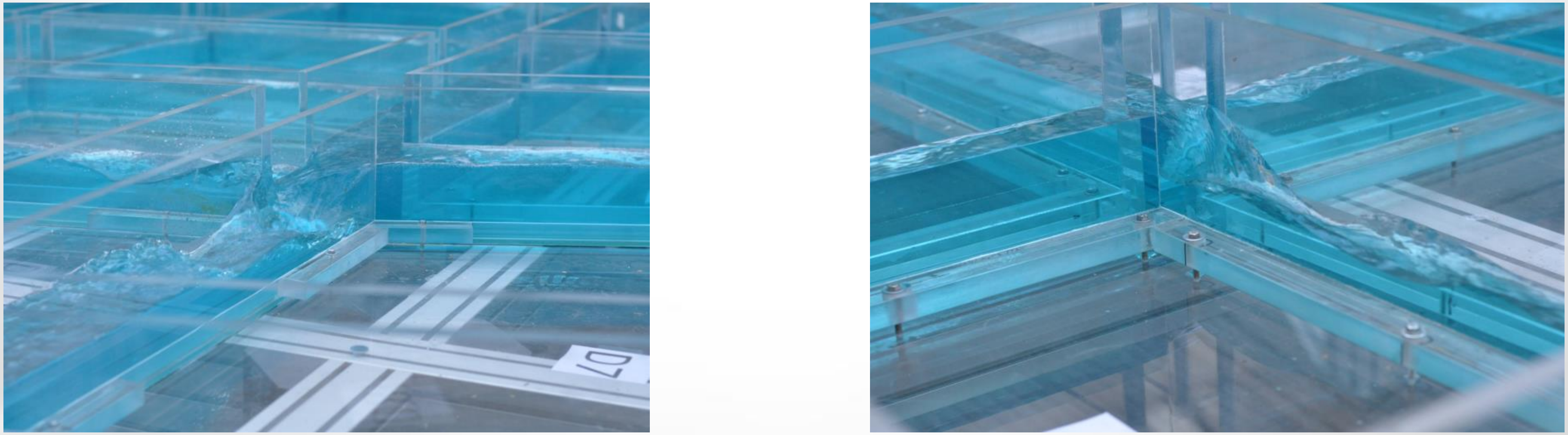


Conclusion

- Flood1D2D - New modeling paradigm using SW equations and porosity like approach proposed for urban flood flows
- Predictive capabilities and accuracy demonstrated on various steady and unsteady test cases
- Ongoing studies:
  - Application of the model to larger scales
  - Calibration method based on flow features



Thanks for your attention



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