1-D Shallow water model for industrial practice
Application to the River Romanche

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Context

The Romanche, a river in the French Alps, is currently facing large changes. A new hydropower facility is being built in order to replace older power plants. For this project, as well as for many others around the World, it is important to be able to simulate quickly and efficiently the behavior of the river under a range of discharges consecutive to some human or natural inputs.

1-D models have low computational costs. In order to reach appreciable precision, equivalent 1-D cross sections were generated from previously calibrated 2-D steady simulations. This approach leads to richer information than local 1-D measures, based on validated data.

1-D shallow water model

A first steady solution can be obtained thanks to (Kerger et al. 2011)

$$\frac{\partial \Omega}{\partial \tau} - \left[\frac{\partial \beta u Q}{\partial x} + g\Omega\left(\frac{\partial Z}{\partial x} + J\right) - \theta u q_L\right] = 0$$

Saint-Venant equations are used for time solving:

$$\begin{cases} \frac{\partial \Omega}{\partial t} + \frac{\partial Q}{\partial x} = q_L \\ \frac{\partial Q}{\partial t} + \frac{\partial \beta u Q}{\partial x} + g\Omega\left(\frac{\partial Z}{\partial x} + J\right) = \theta u q_L \end{cases}$$

where Ω [m²] is the cross section area, Q [m³/s] the discharge, q_L [m²/s] the lateral input discharge, u [m/s] the velocity in the direction of the discretization axis, β [-] a coefficient for unequal velocity distribution across the section, g [m/s²] the gravity acceleration, Z [m] the position of the free surface, J [-] the friction slope and θ [-] a coefficient which allows to take into account or not the velocity of the lateral discharge. The domain is descretized using finite volumes method. Barr-Bathurst is used as friction law (Machiels et al. 2011), k_s being the characteristic size of the bottom roughness, R_h the hydraulic raédius and Re* a Reynolds number.

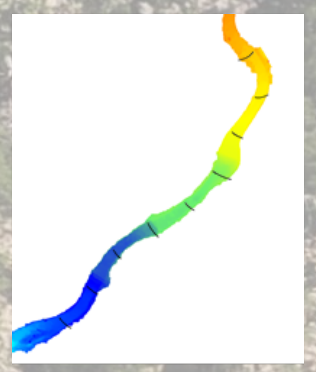
For $k_s/R_h <= 0.05$ For $0.05 < k_s/R_h <= 0.15$ For $k_s/R_h > 0.15$

$$\frac{1}{\sqrt{\lambda}} = 1469.76\left(\frac{k_s}{R_h}\right)^3 - 382.83\left(\frac{k_s}{R_h}\right)^2 + 9.89\left(\frac{k_s}{R_h}\right) + 5.22$$

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{1.1295\log\left(\frac{Re*}{1.75}\right)}{Re*\left(1+\frac{Re*^{0.52}\left(\frac{k_s}{R_h}\right)^{0.7}}{37.22}\right)} + \frac{k_s}{14.8R_h}\right)$$

$$\frac{1}{\sqrt{\lambda}} = 1.987\log\left(\frac{1}{5.15}\min\left(\frac{k_s}{R_h}, 1\right)\right)$$

1-D cross sections



DEM

Domain divided using Fast Marching Method (FMM)

2-D steady simulations with several discharges

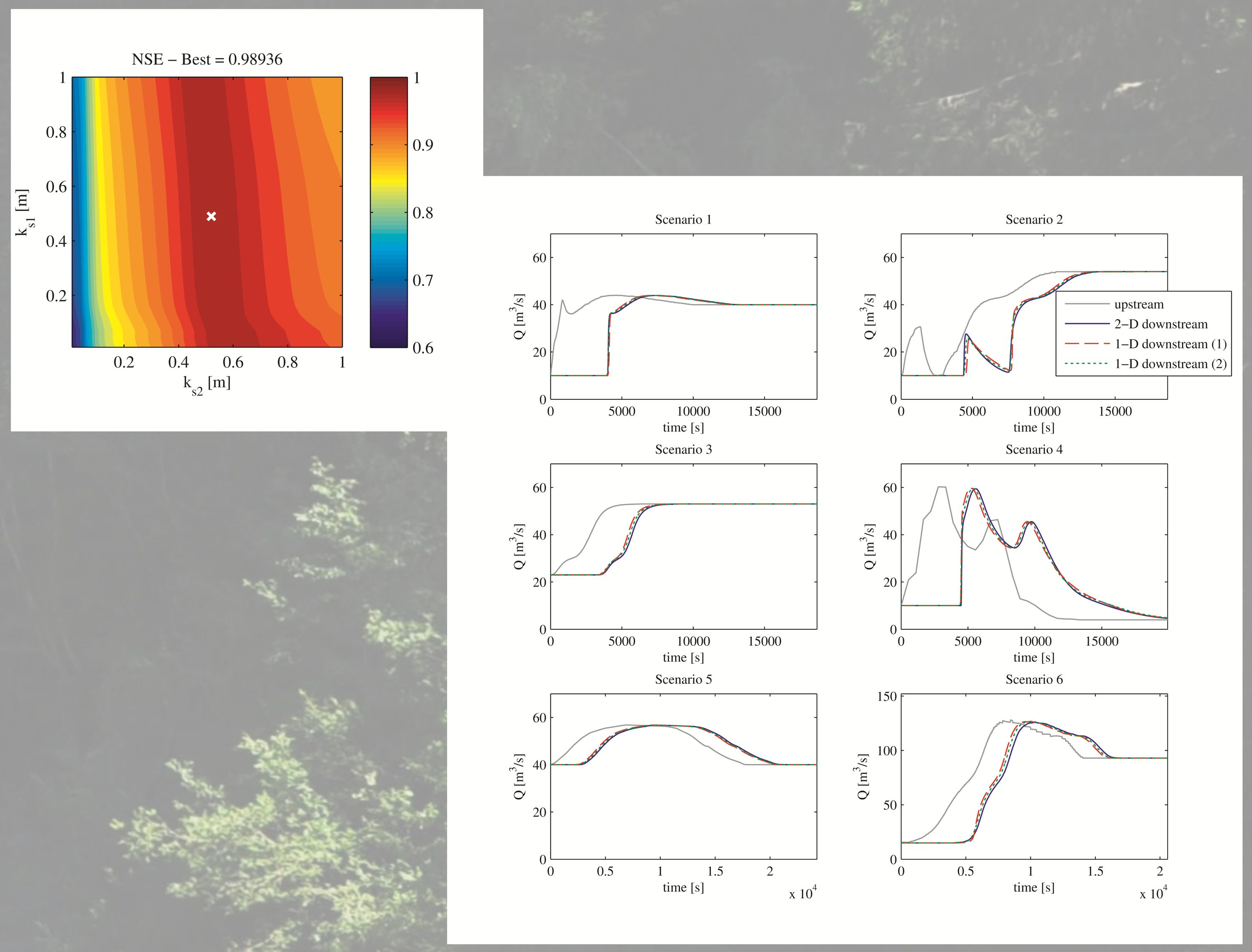
Cross section	Wet perimeter	Water depth
$\Omega = \frac{V}{\Delta x_{1D}}$	$\chi = \frac{S}{\Delta x_{1D}}$	$h = z_s - z_h$

$$\chi = \frac{S}{\Delta x_{1D}}\left(\alpha\left(\frac{h}{h_{max}}\right) + 1\right)$$

Model fitting

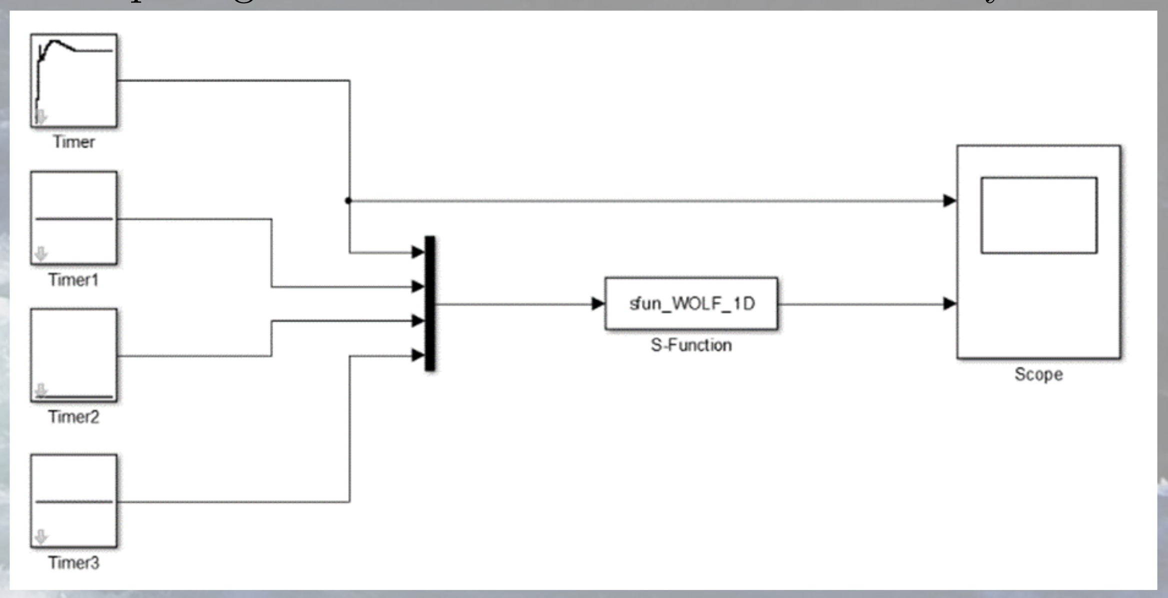
Fitting is performed upon downstream hydrographs. Several Goodness-of-fit factors can be computed: NSE, index of agreement, R^2, etc.
Optimization methods:
1. Scanning N-dimensional space of parameters
2. Simulated Annealing Method (heuristic)

Optimzation over:
(a) Roughness in several zones of the river
(b) Tuning factors on the wet perimeter formula



Integration into Simulink

Fotran or C codes can be integrated into Matlab or Simulink (D-Functions). Fast computing routines can be used in a user-friendly environment.



This poster is inspired from Goffin L., et al., 2016. Non-linear optimization of a 1-D shallow water model and integration into Simulink for operational use. *Sustainable Hydraulics in the Era of Global Change: Proceedings of the 4th IAHR Europe Congress*, Liège, Belgium.
References:
Kerger, F. et al., 2011. A fast universal solver for 1D continuous and discontinuous steady flows in rivers and pipes. International Journal for Numerical Methods in Fluids, 66(1), pp.38–48.
Machiels, O. et al., 2011. Theoretical and numerical analysis of the influence of the bottom friction formulation in free surface flow modelling. Water SA, 37(2), pp.221–228.