Analysis of the hydrological safety of dams using numerical tools: Iber and DualSPHysics

José González-Cao, Orlando García Feal, Alejandro Crespo, José Domínguez, Moncho Gómez-Gesteira

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SCHEME OF PRESENTATION

1.- INTRODUCTION

2.- NUMERICAL CODES

2.1.- Iber

2.2.- DualSPHyics

3.- ANALYSED CASE: Maximum expected inflow in Belesar dam

4.- RESULTS

5.- CONCLUSIONS

1.- **INTRODUCTION**
2.- NUMERICAL CODES
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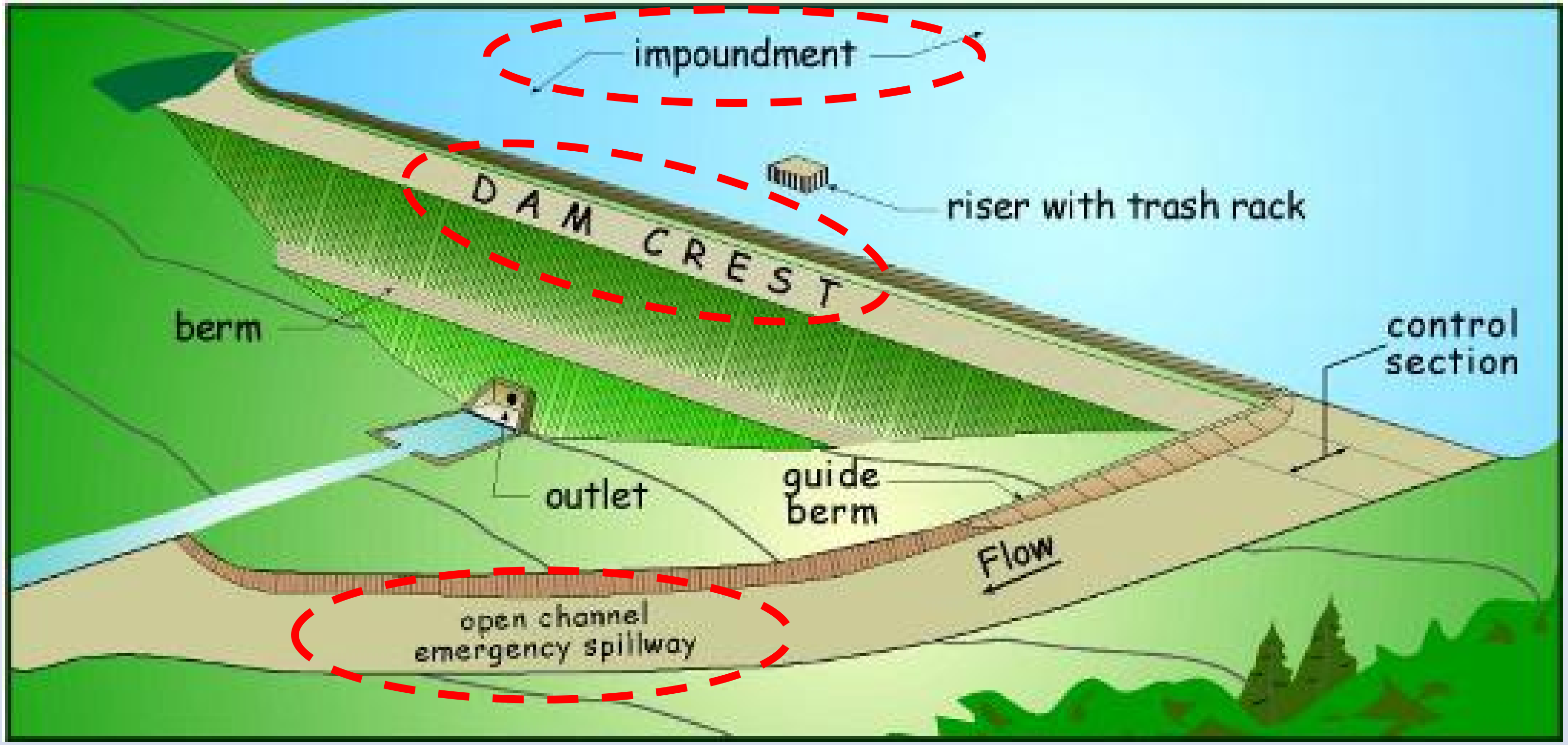
WHAT IS A DAM?

A barrier to obstruct or control the flow of water, built across a stream or river

Three Gorges dam in China:
the world's largest dam (by structure volume)

PRINCIPAL COMPONENTS OF A DAM



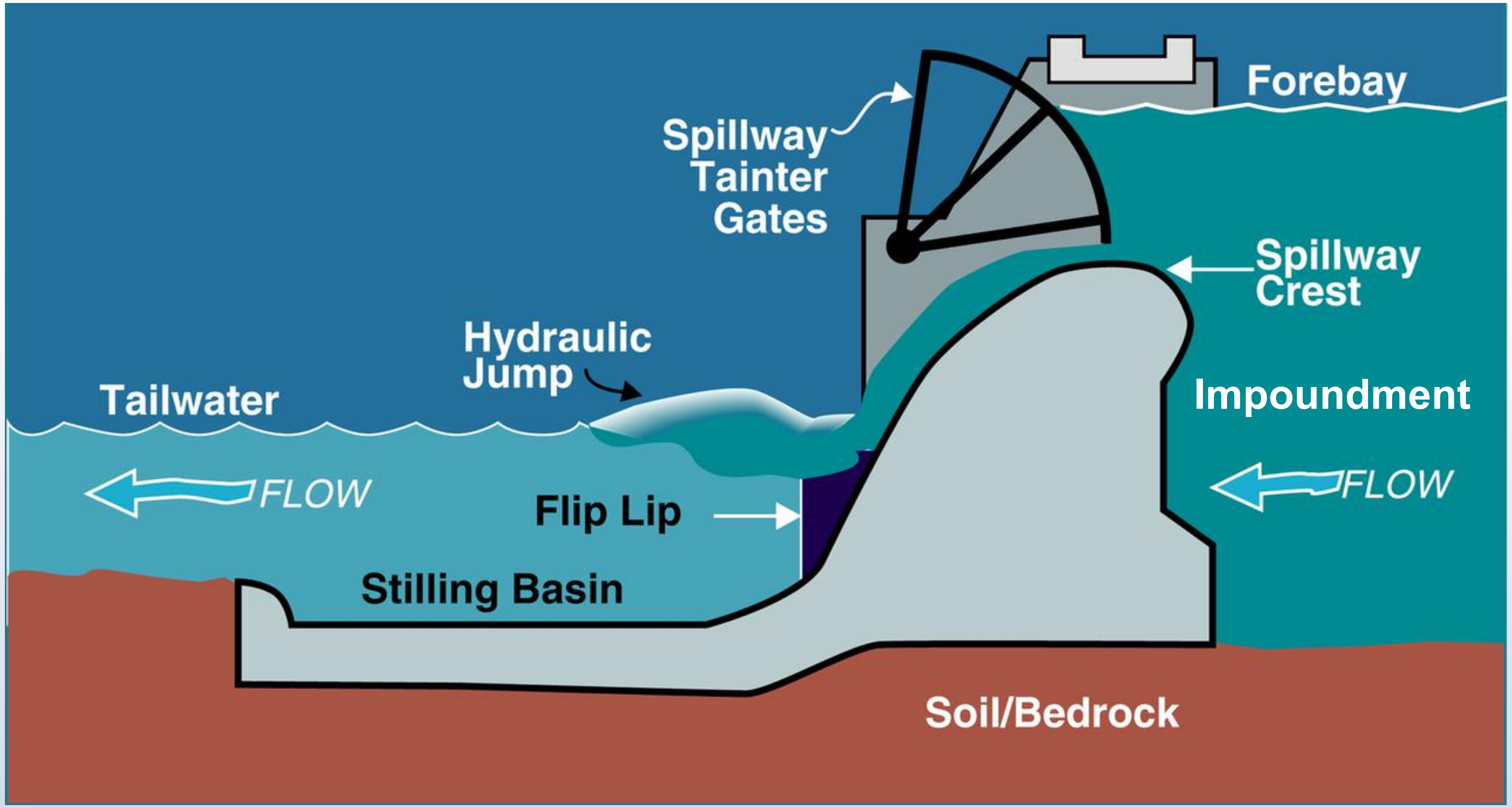
H < Crest elevation
OK

H ≈ Crest elevation
Release water: SPILLWAY

H > Crest elevation
OVERFLOW

(Picture taken from: http://water.ohiodnr.gov/safety/dam-safety)

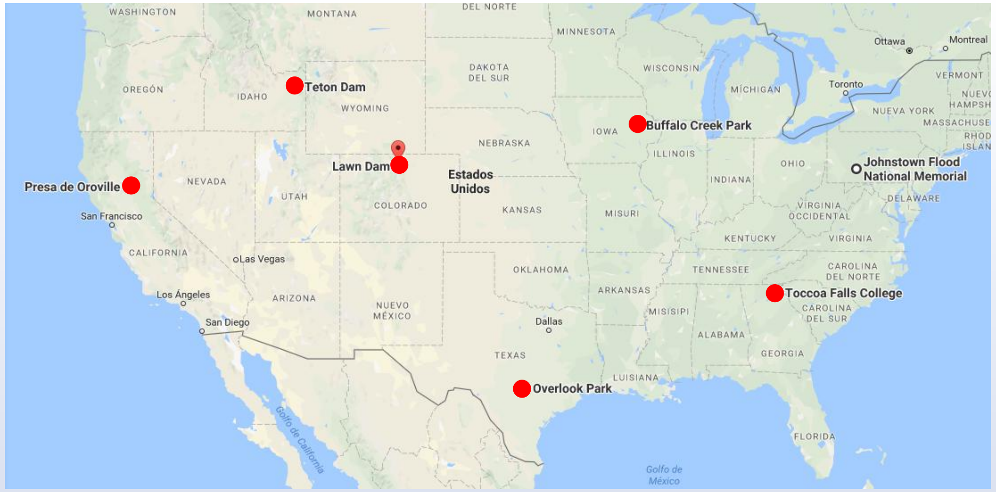
Cross section of a spillway



(Picture taken from: https://en.wikipedia.org/wiki/Spillway)

WHY STUDY SAFETY OF DAMS?

Notable dam failures (USA)



Year	Name of	Dece.	Damag e
1889	South Fork	2,209	17
1972	Buffalo Creek	125	400
1972	Canyon Lake	139	60
1976	Teton	11	400
1977	Taccoa Falls	39	30
1982	Lawn Lake	3	21

(millions of $)

(Data obtained from: http://water.ohiodnr.gov/safety/dam-safety)

WHY STUDY SAFETY OF DAMS?

Ribadelago dam break in January 1959

More than 140 people dead or missing


LA VANGUARDIA ESPAÑOLA

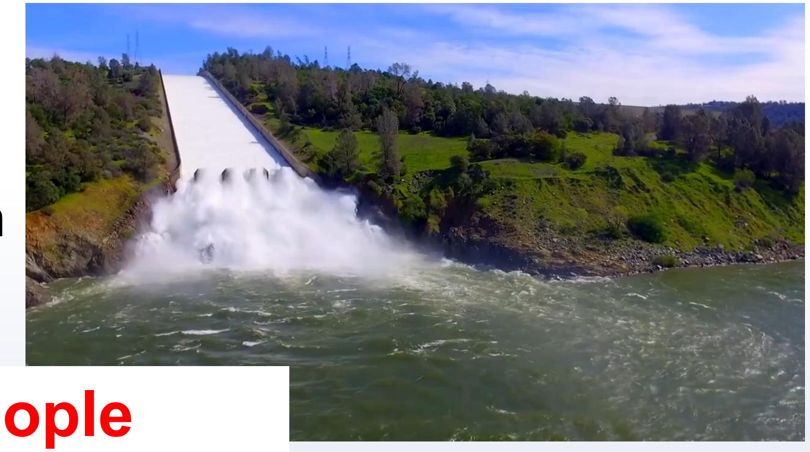
BARCELONA

LA CATASTROFE DE RIBADELAGO

WHY STUDYSAFETY OF DAMS?

Oroville dam crisis in February 2017

Correct operation of the spillway



More than 150,000 people were evacuated

Population of Lijiang (丽江市): 155,540

Spillway operation during the crisis

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AIM OF THIS WORK

TO DEVELOP A METHODOLOGY

Design components of dams

Prevent the incorrect operation of the components of dams

Predict the consequences of dam breaks

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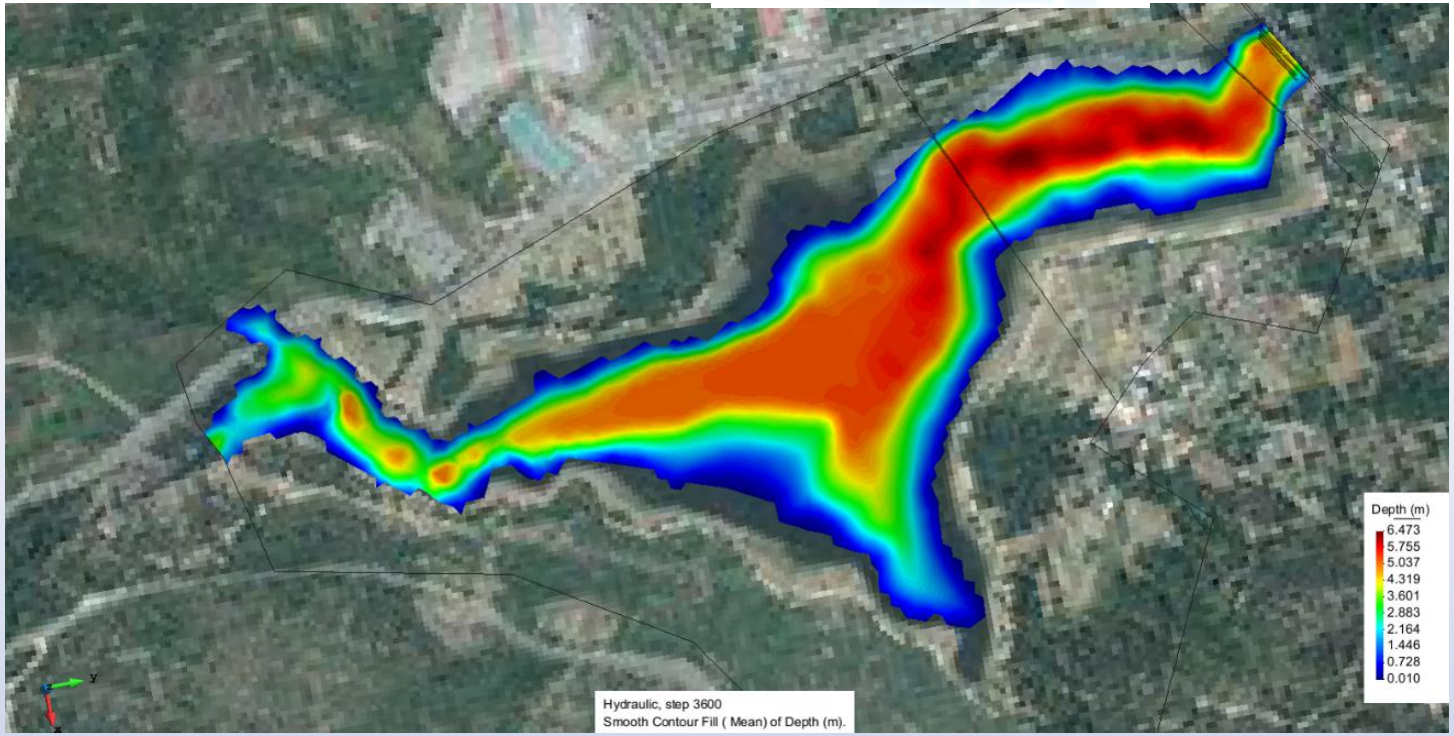
Mesh-based CFD:

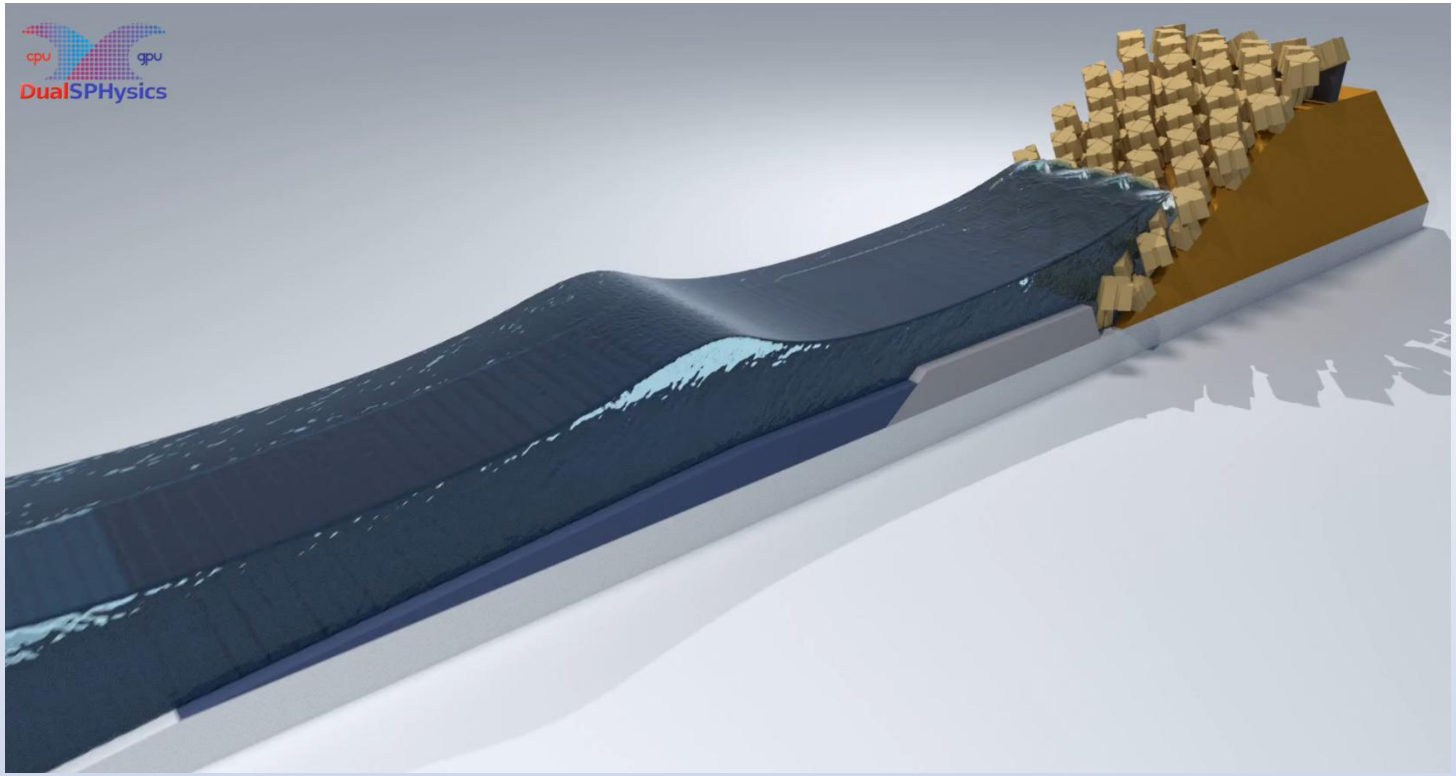
Mesh-free CFD:

Mesh-based CFD:



- Solves 2D Shallow Water Equations
- Robust but rigid
- Suitable to deal with large domains where 3D effects can be neglected
- Developed by the groups:
  - GEAMA (U. de Coruña)
  - Flumen (U. Pol. de Cataluña)
- Freely downloaded: http://iberaula.es/web/index.php

Mesh-free CFD: DualSPHysics



- Flexible and adaptable
- Suited to deal with complex 3-D fluxes
- Run in CPU and GPU → acceleration
- Developed by:
  - EPHYSLAB (U. de Vigo)
  - Uni. of Manchester
  - …
- Freely downloaded: http://www.dual.sphysics.org.

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DualSPHysics

References Downloads Validation Animations SPHysics GPU Computing
GUI Visualization Developers Contact News FAQ Forums

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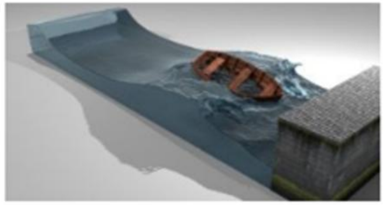
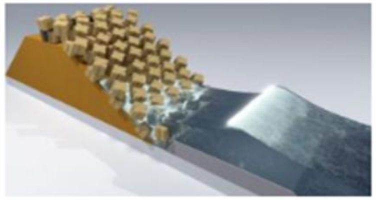
MANCHESTER 1824
The University of Manchester



DualSPHysics is based on the Smoothed Particle Hydrodynamics model named SPHysics (www.sphysics.org).

The code is developed to study free-surface flow phenomena where Eulerian methods can be difficult to apply, such as waves or impact of dam-breaks on off-shore structures. **DualSPHysics** is a set of C++, CUDA and Java codes designed to deal with real-life engineering problems.



Contact E-Mail: dualsphysics@gmail.com

Youtube Channel: www.youtube.com/user/DualSPHysics

Twitter Account: @DualSPHysics

VALIDATIONS

- **Wave generation and propagation**
  Altomare C, Domínguez JM, Crespo AJC, González-Cao J, Suzuki T, Gómez-Gesteira M, Troch P. 2017
  wave generation and absorption for SPH-based DualSPHysics model. Coastal Engineering,
- **Active wave absorption system**
  Altomare C, Domínguez JM, Crespo AJC, González-Cao J, Suzuki T, Gómez-Gesteira M, Troch P. 2017
  wave generation and absorption for SPH-based DualSPHysics model. Coastal Engineering,
- **Estimation of sea wave impact on coastal structures**
  Altomare C, Crespo AJC, Domínguez JM, Gómez-Gesteira M, Suzuki T, Verwaest T. 2015. Applicability
  Particle Hydrodynamics for estimation of sea wave impact on coastal structures. Coastal En
  1-12.
- **Study of the run-up in an existing armour block sea breakwater**
  Altomare C, Crespo AJC, Rogers BD, Domínguez JM, Gironella X, Gómez-Gesteira M. 2014. Numerica
  armour block sea breakwater with Smoothed Particle Hydrodynamics. Computers and Struc
  45.
- **Simulation of an Oscillating Water Column (OWC-WEC)**
  Crespo AJC, Altomare C, Domínguez JM, González-Cao J, Moncho Gómez-Gesteira M. 2017. Towards simulating
  floating offshore Oscillating Water Column converters with Smoothed Particle Hydrodynamics. Coastal
  Engineering, 126: 11-16

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2.- NUMERICAL CODES
2.2.- DualSPHysics

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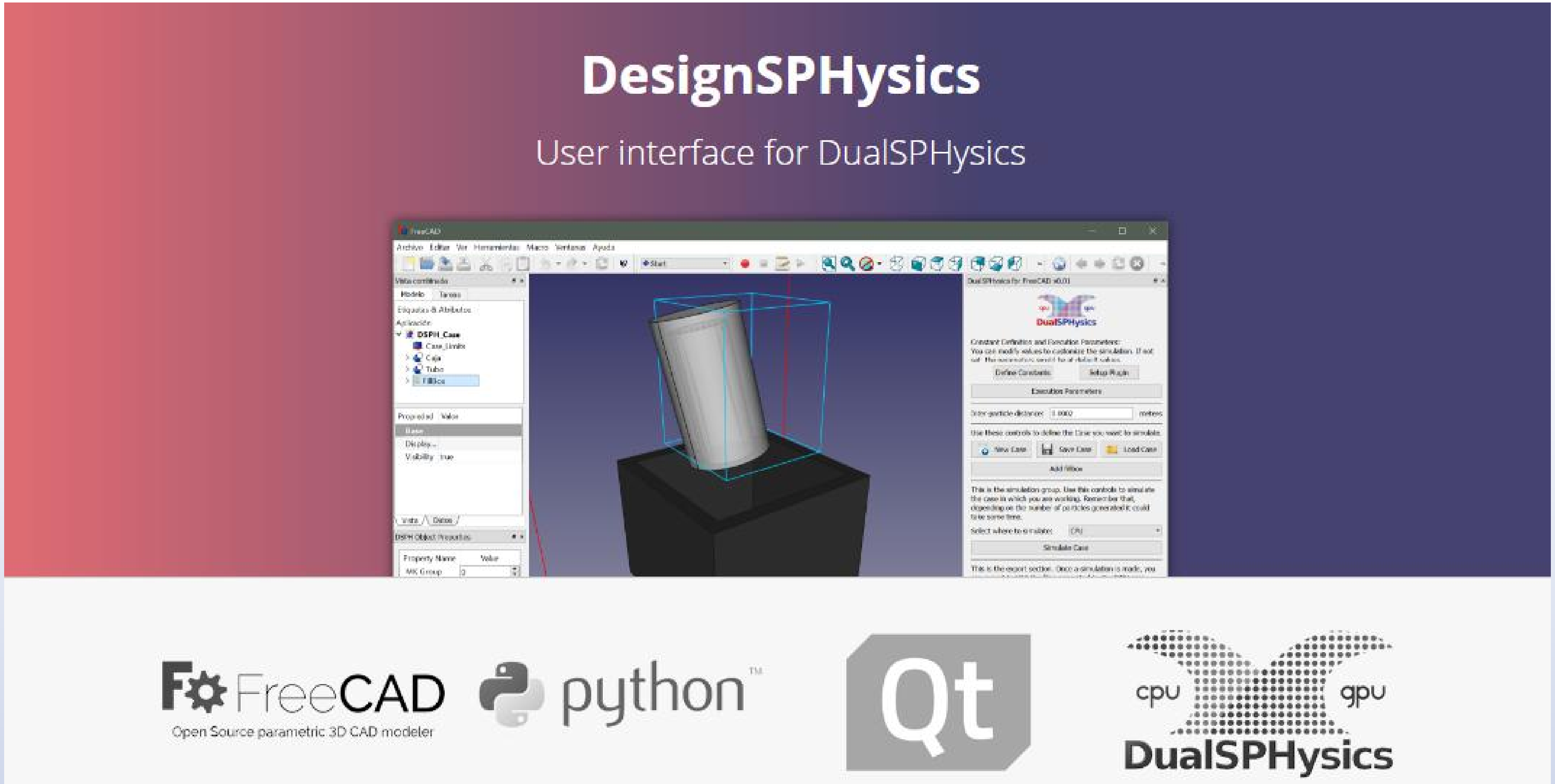

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2.- NUMERICAL CODES

2.1.- Iber

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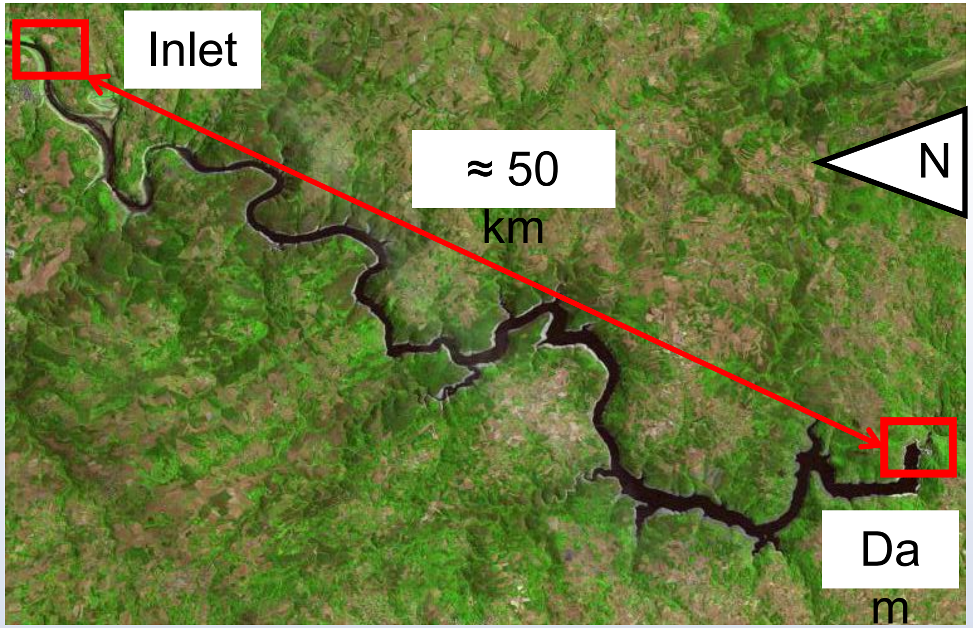
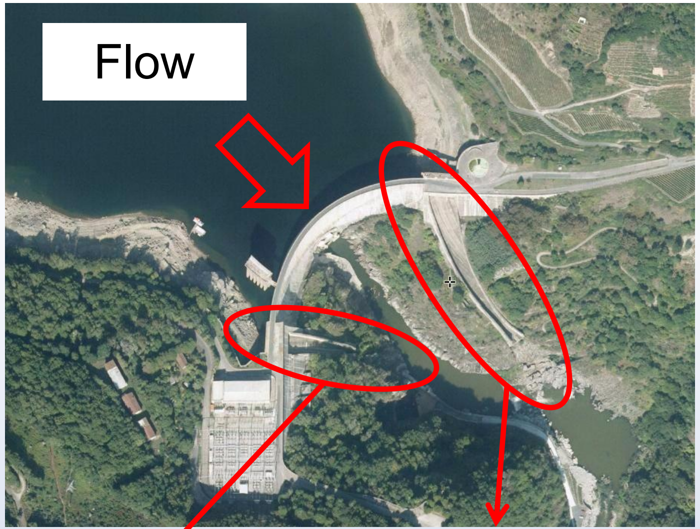
Belesar dam

Location of Belesar Dam

Reservoir associated to the Belesar Dam



Belesar Dam



Rigth spillway (operated with gates)

Left spillway ≈ 200 m long (operated with gates)

(Figures taken from: http://www.ign.es/iberpix2/visor/#)

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Belesar dam features:

(Figure taken from: http://www.ign.es/iberpix2/visor/#)

- Built in 1962
- Main purposes:
  - Hydroelectric generation
  - Basin regulation
  - Control of floods of Miño river
- Hydrological data:
  - Area of the basin: 4,000 km^2
  - Maximum expected flow: 4,000 m^3/s
  - Maximum water depth: 330 m
  - Dam crest elevation: 332 m
  - Dam crest length: 500 m

SIMULATION PROCESS

FIRST: Simulation of the reservoir

Input to Iber:

- Real geometry of the impoundment
- Maps of land uses: Manning's coefficients
- Maximum expected flow of the Miño river
- Initial water depth

Output of Iber:

- Outflow in the spillways (only the left spillway)
- Water depth near the spillways of the dam

SECOND: Simulation of the left spillway

Input to DualSPHysics:

- Geometry of the left spillway
- Outflow obtained with Iber

Output of DualSPHysics:

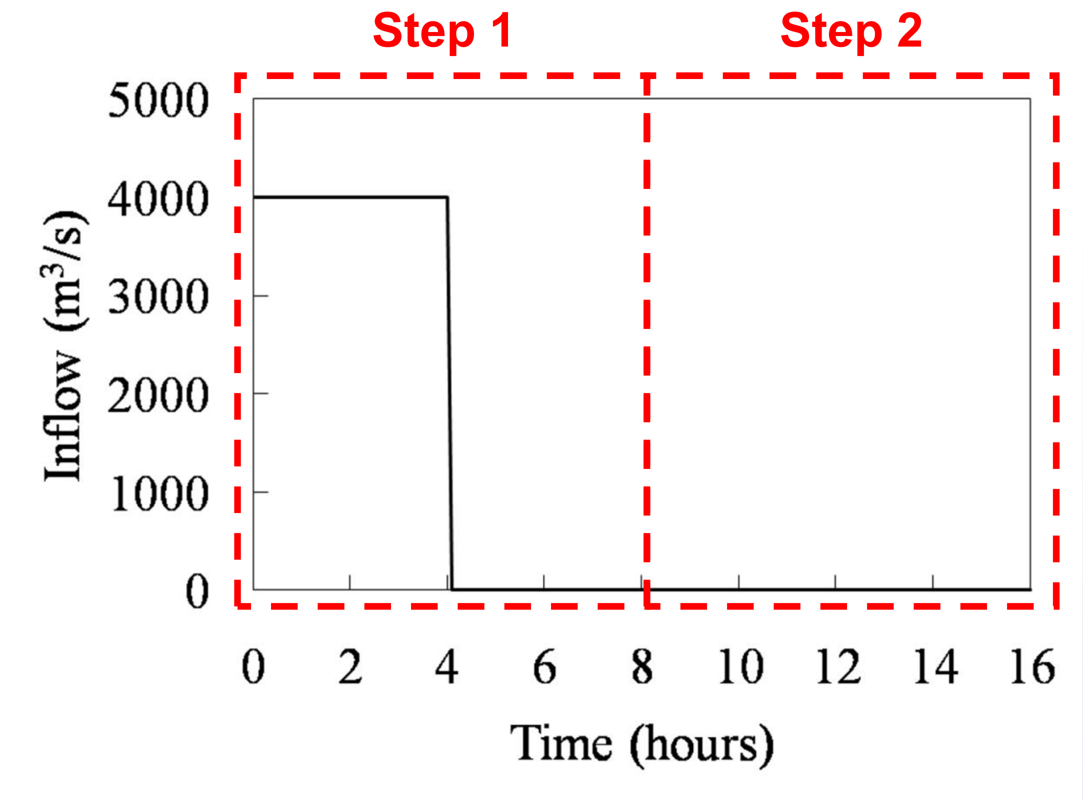
- Operation conditions of the spillway

SIMULATION PROCESS

FIRST: Simulation of the reservoir

Step 1: Crest elevation increased to 350 m and gates closed

Step 2: Gates opened



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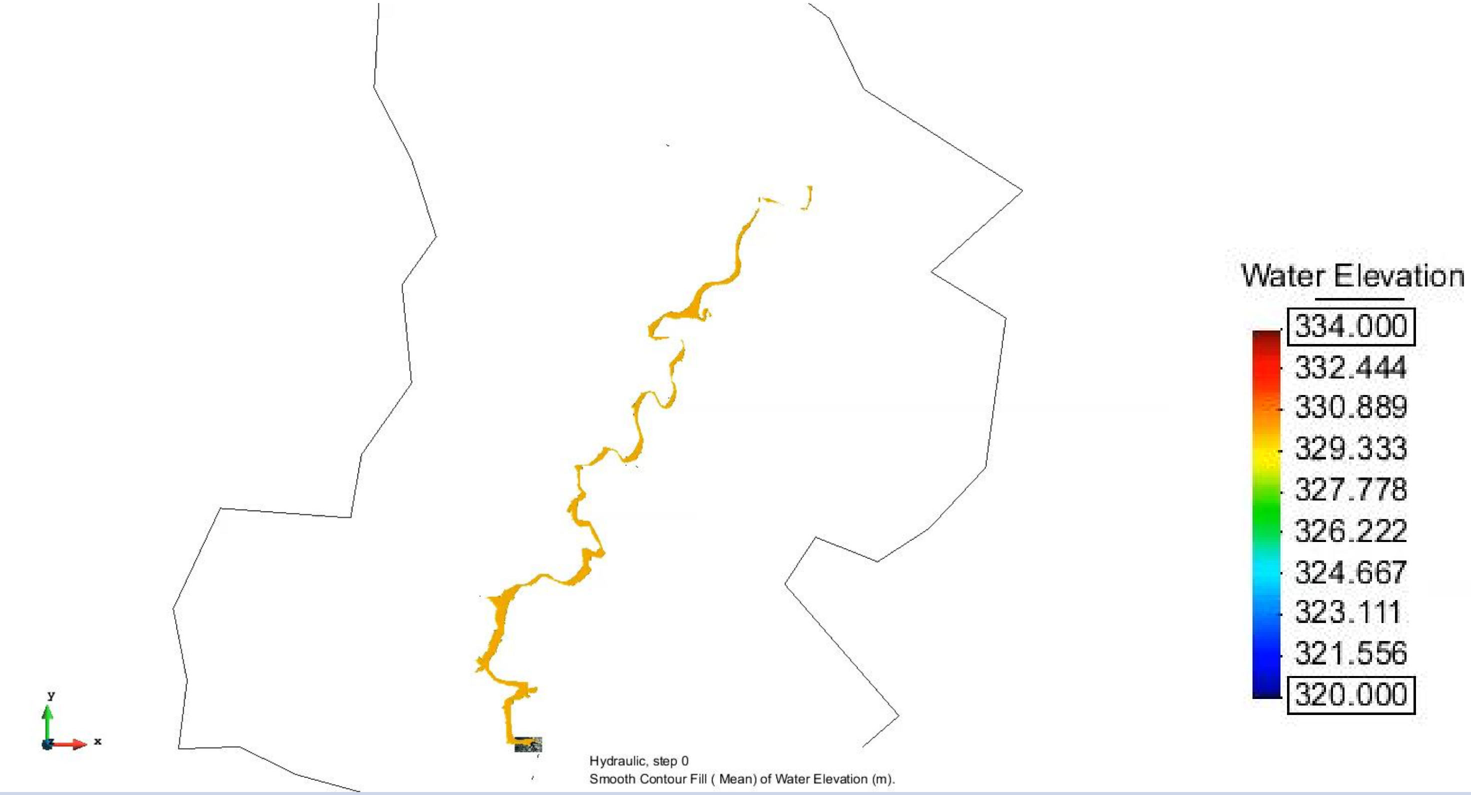
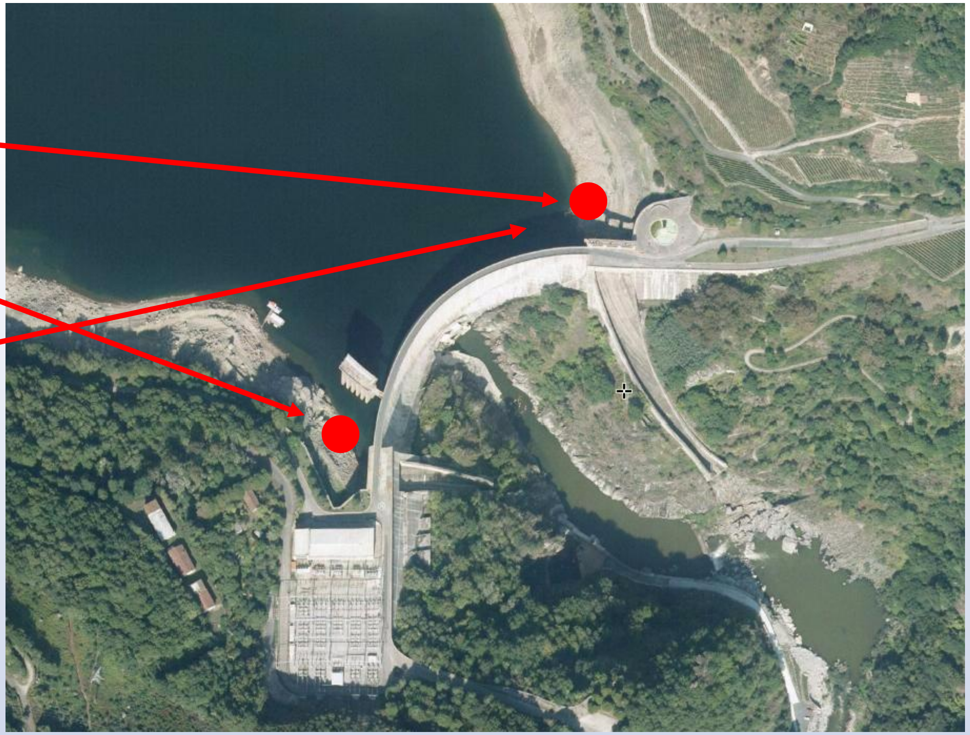
FIRST: Simulation of the reservoir



FIRST: Simulation of the reservoir

Water elevation
- Left spillway
- Right spillway

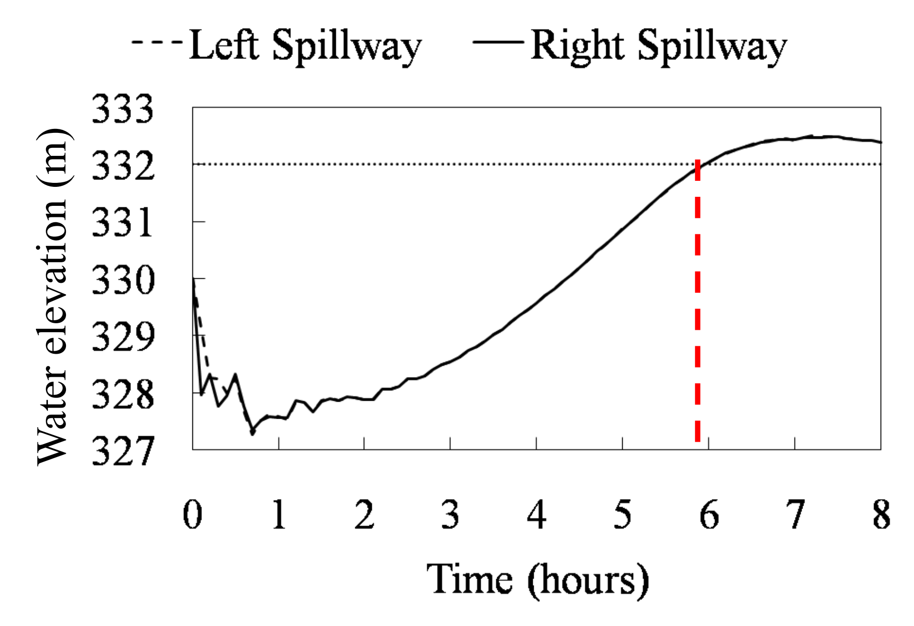
Outflow
- Left spillway



FIRST: Simulation of the reservoir

Step 1

Water elevation near spillways



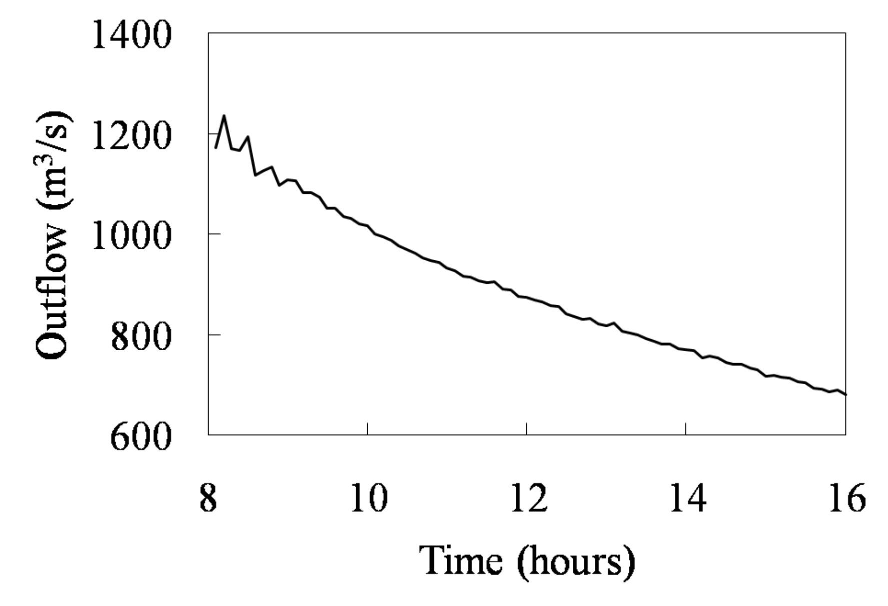
Runtime
≈ 20 hours

Nº of cells
≈ 220 000

CPU:
Intel Core i7
940 2.93GHZ

Step 2

Outflow in the left spillway



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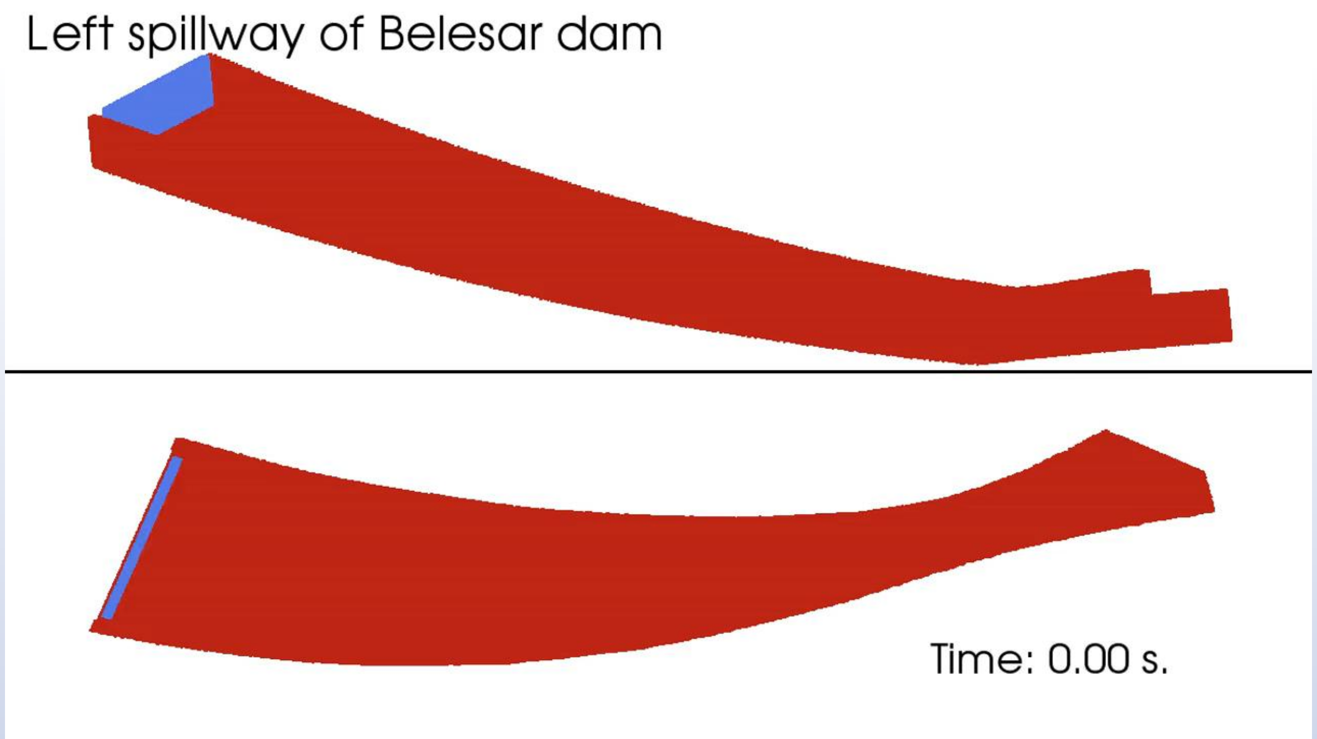
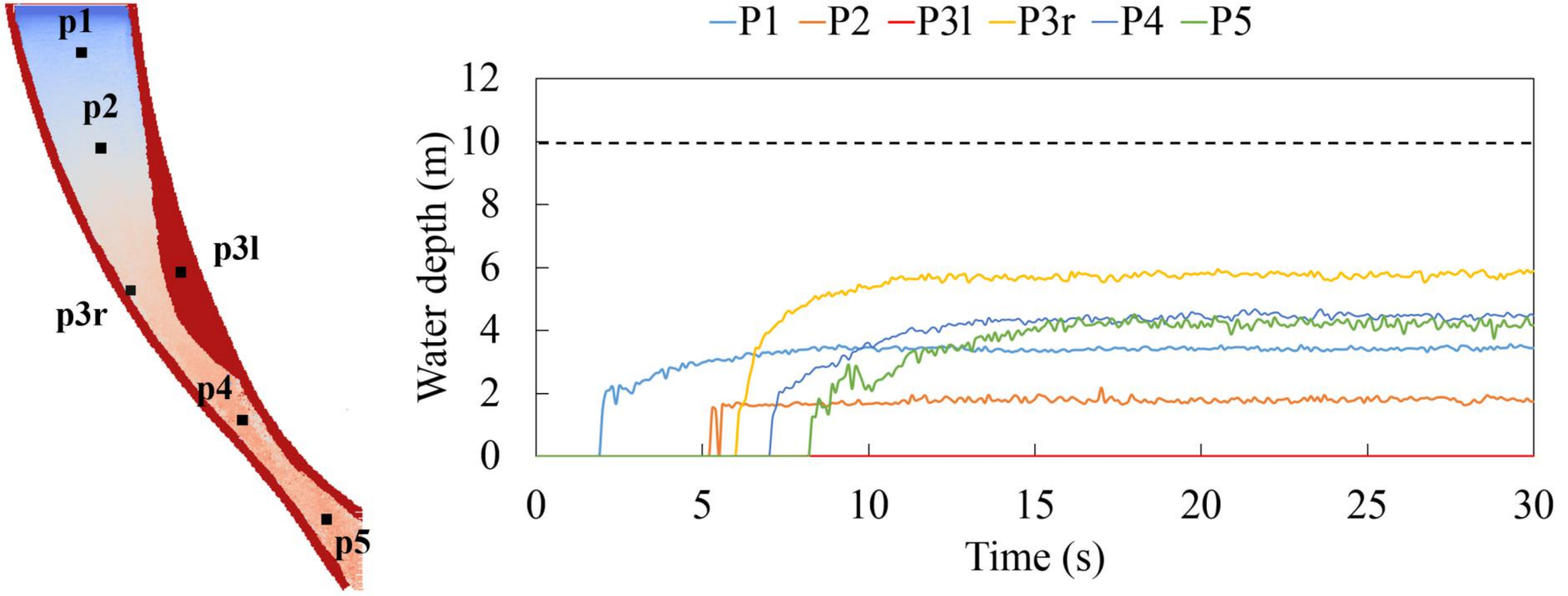
Second: Simulation of the left spillwa



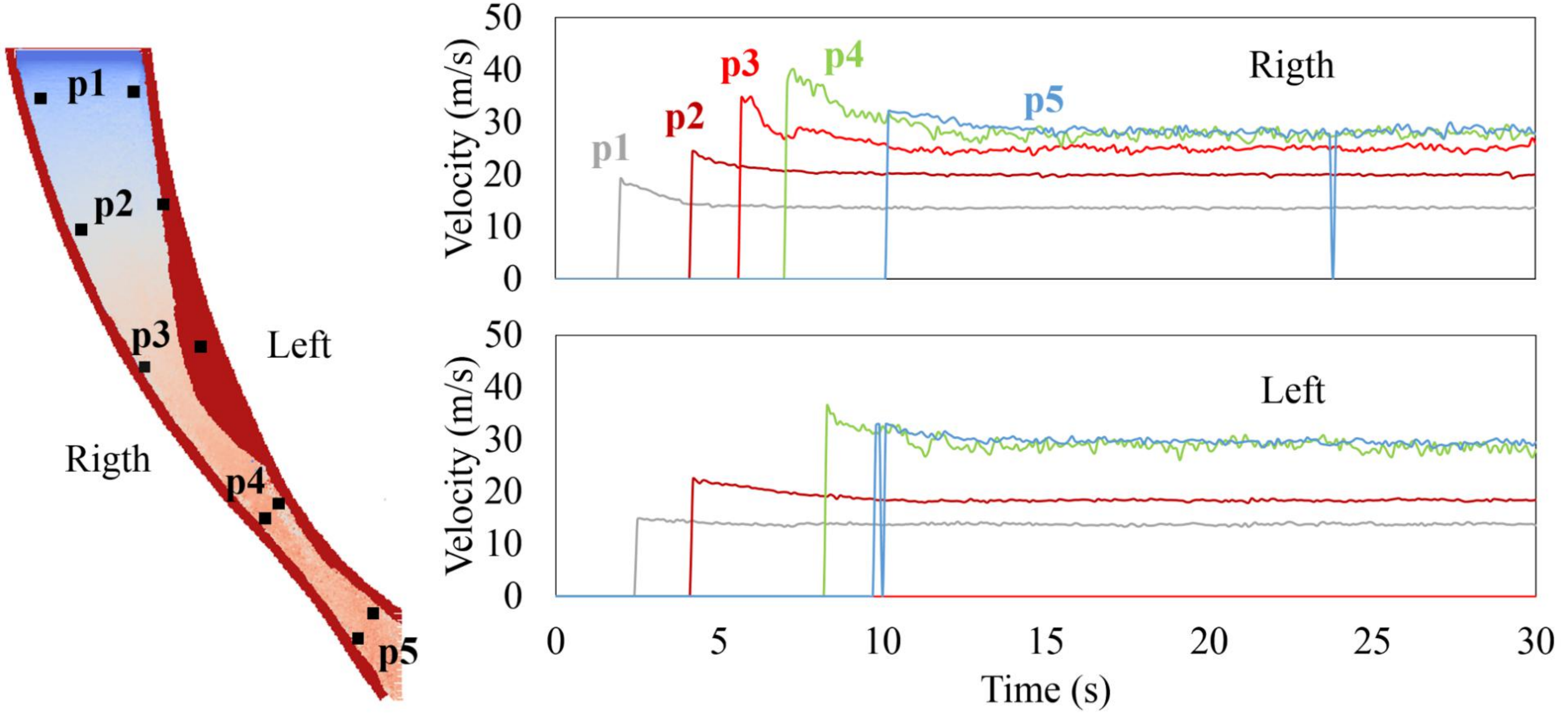
Second: Simulation of the left spillwa

Time series of Water depth



Second: Simulation of the left spillwa

Time series of velocity



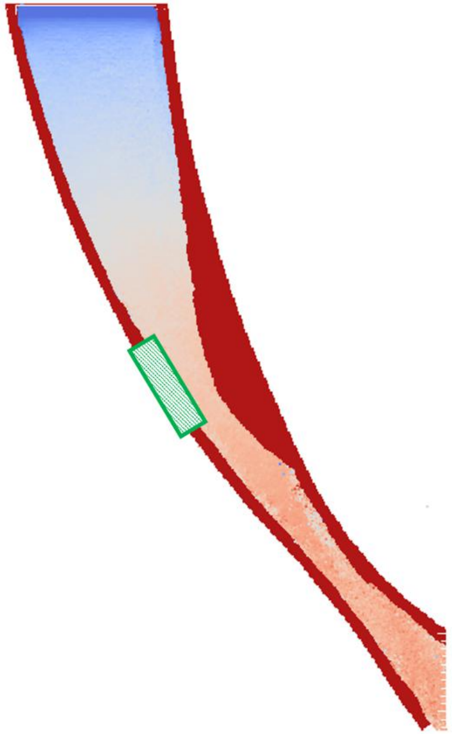
Second: Simulation of the left spillwa

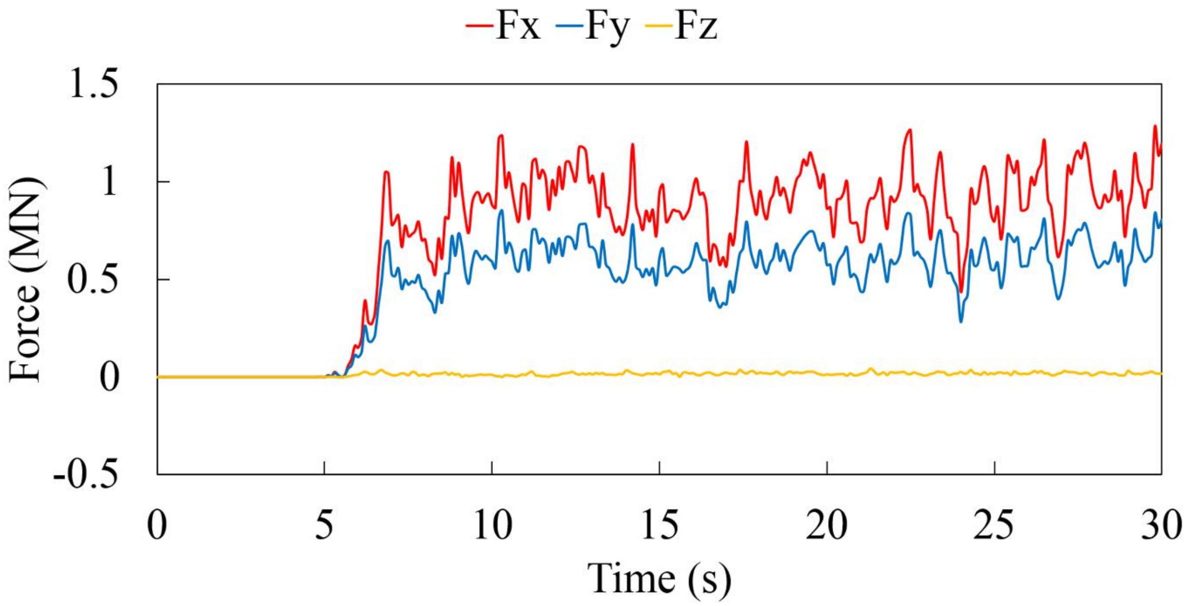
Time series of force: curve of the spillway

Runtime
≈ 1 hour

Nº of particles
≈ 180 000

GPU: NVIDIA GeForce GT 730





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2.- NUMERICAL CODES

2.1.- Iber

2.2.- DualSPHyics

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Conclusions

- The numerical simulations of the **impoundment** carried out with Iber show that **no overflow** is observed if gates are open up 6 hours after the inflow starts.

- The numerical simulation of the left **spillway** carried out with **DualSPHysics** shows that the **spillway works properly** with the conditions defined in this work. The water elevation inside the spillway is less than the height of the lateral walls of the spillway so **no overflow is observed in the spillway**.

This work shows the **benefits** of using Iber **and DualSPHysics altogether** to analyse the **safety of dams** although some limitations were found…

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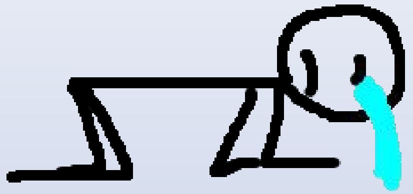
Some limitations (only for the analysed case)…

- the actual bathymetry of the impoundment was not considered
- experimental data of the spillway obtained in laboratory tests or in real working conditions are not available: velocity, pressure, force…



Future work

- Implementation of Iber using C++
- Implementation of Iber using CUDA: GPU cards ⇒ Acceleration
- Hybridization of Iber with **DualSPHysics**

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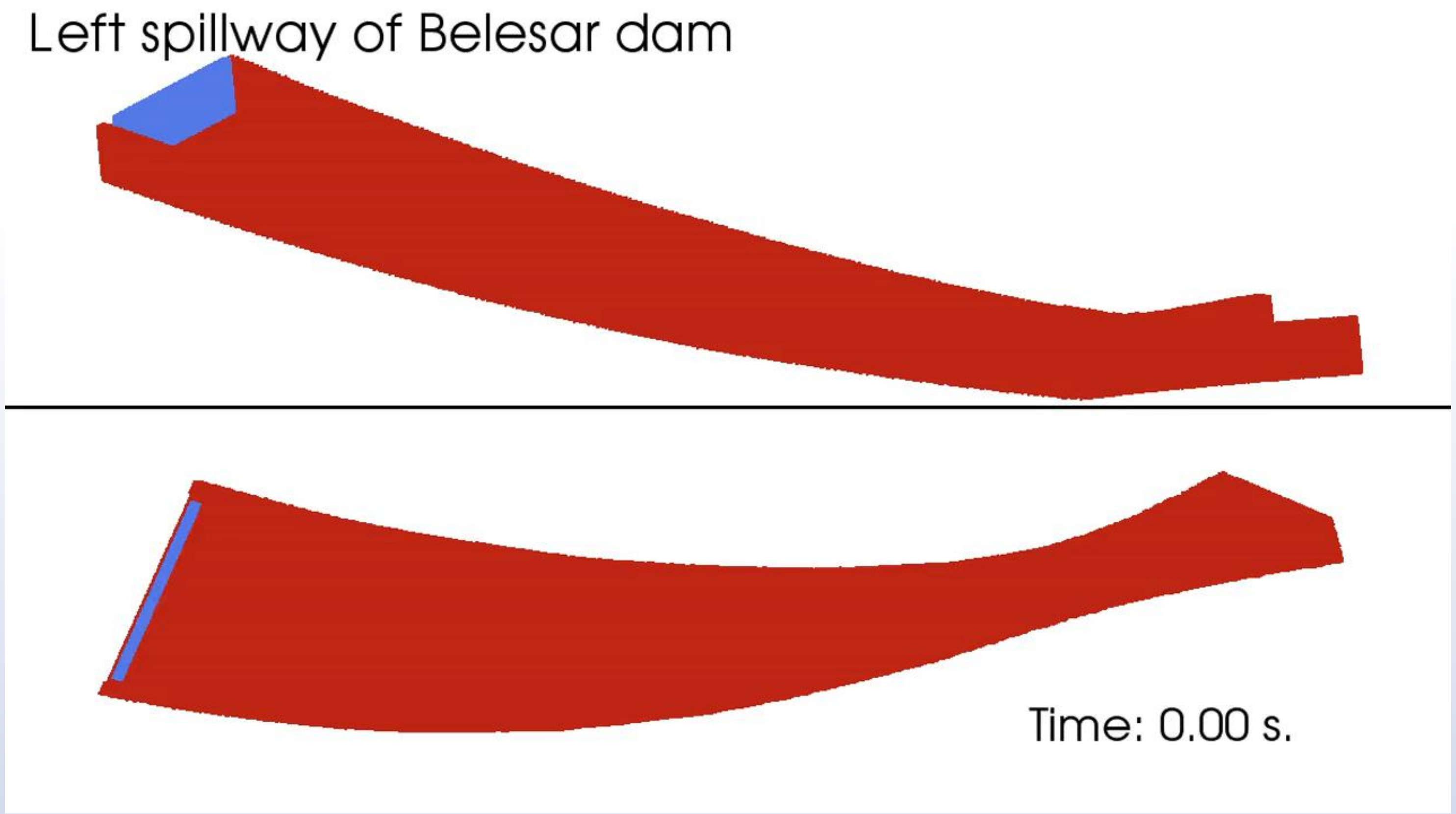

谢谢

Supported by the project
“IMDROFLOOD”
(Water JPI - WaterWorks 2014)

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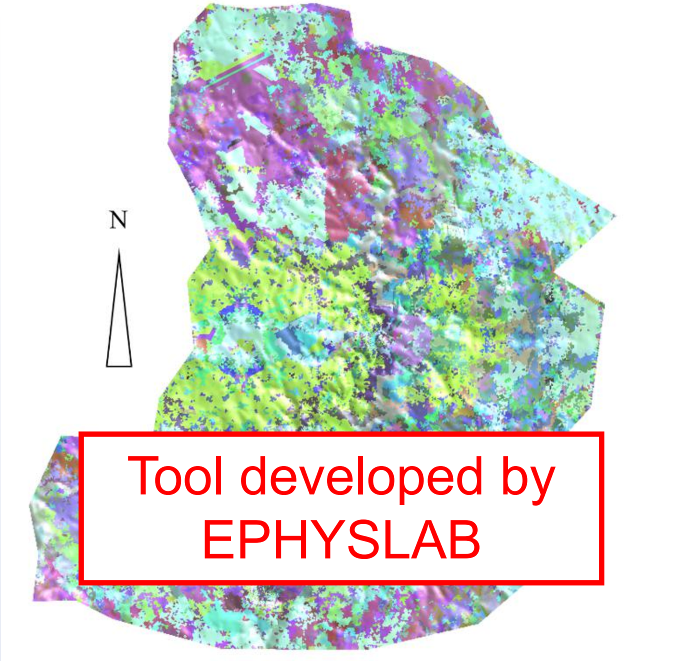
Belesar dam features:

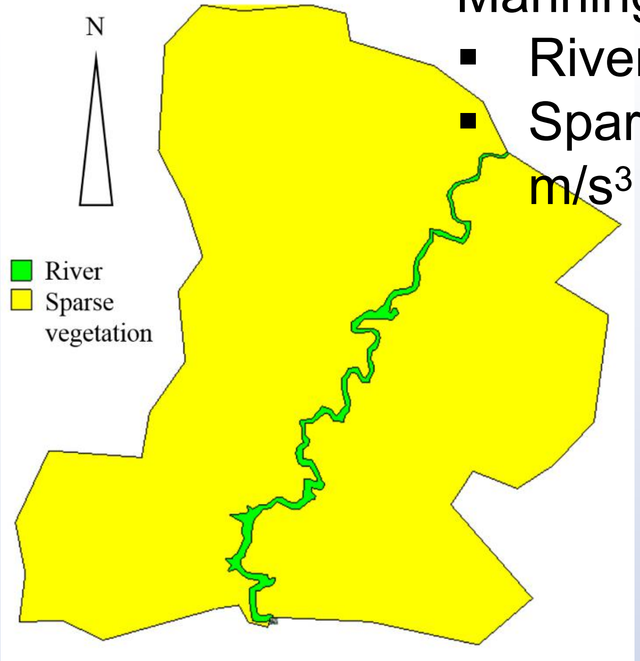
Automatic land uses assignment: runoff process



Tool developed by EPHYSLAB

Manning's coefficient definition

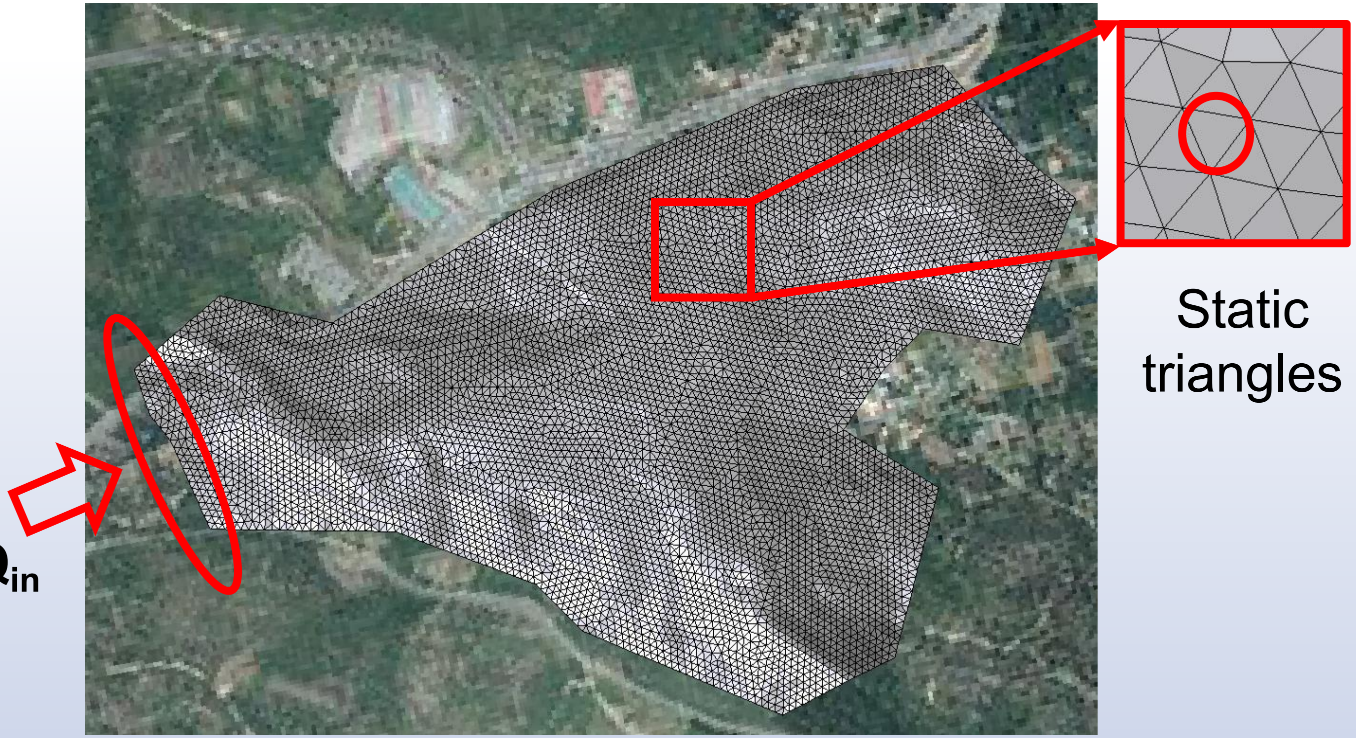
Manual land uses assignement



Manning's coefficients

- River: 0.025 m/s³
- Sparse V.: 0.080 m/s³

Mesh-based CFD: Iber



Shallow Water Equations

$$
\begin{cases}
\dfrac{\partial h}{\partial t} + \dfrac{\partial hU_x}{\partial x} + \dfrac{\partial (hU_y)}{\partial y} = 0 \\
\dfrac{\partial (hU_x)}{\partial t} + \dfrac{\partial}{\partial x}\left(hU_x^2 + g\dfrac{h^2}{2}\right) + \dfrac{\partial}{\partial y}(hU_xU_y) = \\
-gh\dfrac{\partial Z_b}{\partial x} - \dfrac{\partial \tau_{s,x}}{\rho} - \boxed{\dfrac{\partial \tau_{b,x}}{\rho}} + \dfrac{\partial}{\partial x}\left(h\nu_t\dfrac{\partial U_x}{\partial x}\right) + \dfrac{\partial}{\partial y}\left(h\nu_t\dfrac{\partial U_x}{\partial y}\right) \\
\dfrac{\partial (hU_y)}{\partial t} + \dfrac{\partial}{\partial x}\left(hU_y^2 + g\dfrac{h^2}{2}\right) + \dfrac{\partial}{\partial y}(hU_xU_y) = \\
-gh\dfrac{\partial Z_b}{\partial y} - \dfrac{\partial \tau_{s,y}}{\rho} - \boxed{\dfrac{\partial \tau_{b,y}}{\rho}} + \dfrac{\partial}{\partial x}\left(h\nu_t\dfrac{\partial U_y}{\partial x}\right) + \dfrac{\partial}{\partial y}\left(h\nu_t\dfrac{\partial U_y}{\partial y}\right)
\end{cases}
$$

Manning coeficcien
t

h, U_x and U_y in each triangle

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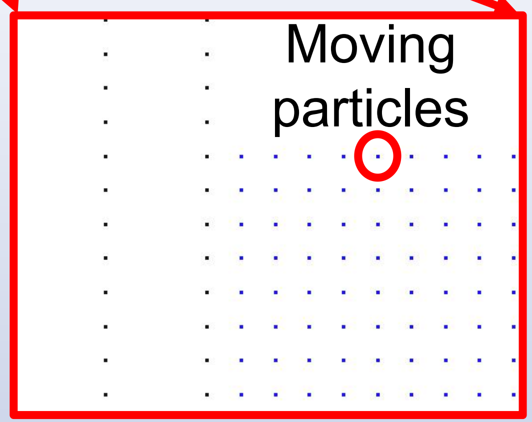
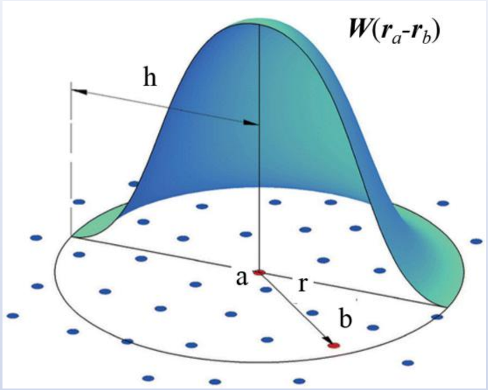
DualSPHysics

Mesh-free CFD:

Wave impacts onto structure

Kernel functions



(h: smoothing length)

Discrete SPH Lagrangian system of equations & Tait´s equation

$$\frac{d\rho_a}{dt} = \sum_b m_b (\boldsymbol{v}_a - \boldsymbol{v}_b)\nabla_a W_{ab}$$

$$\frac{d\boldsymbol{v}_a}{dt} = -\sum_b m_b \left(\frac{P_b + P_a}{\rho_b \cdot \rho_a} + \Pi_{ab}\right)\nabla_a W_{ab} + \boldsymbol{g}$$

$$\frac{d\mathbf{r}_a}{dt} = \mathbf{v}_a$$

Interaction neighbouring

$$P = B\left[\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1\right] \qquad \sum_b W(\boldsymbol{r}_a - \boldsymbol{r}_b, h) \approx 1$$