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Modeling the effects of low flow on wood transport in the Piave River

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LW in rivers

Hydraulic risk

Italy – 2021 (IGV.it)

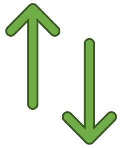
Germany – 2021 (The Guardian)

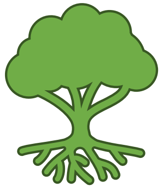
USA – 2018 (Chron.com)

Italy – 2018 (Il Gazzettino)

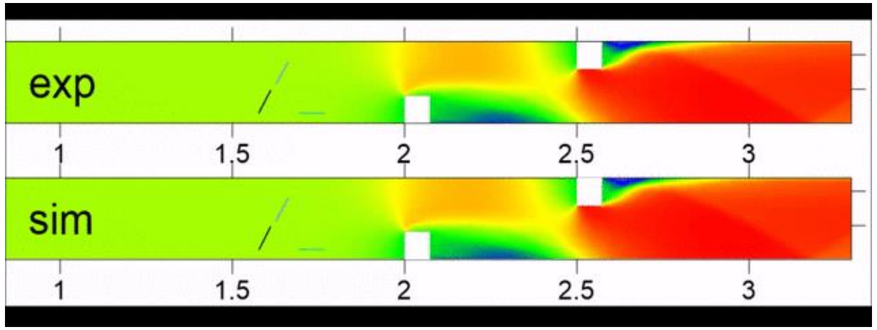
Geomorphology & habitat

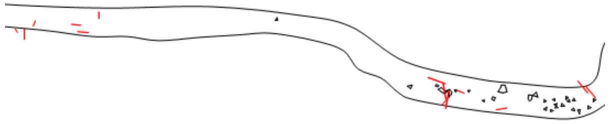
USA – 2015 (https://www.kittitasconservationtrust.org/projects/lower-cle-elum-river-restoration-project/)





LW modeling and flow regimes





ORSA2D_WT

- LW model that couples flow hydrodynamics and wood mobilization, transport and accumulation.
- Two-way coupled model.
- Application to flume and field test cases.

LW mobilized by high water levels and velocities
Modeling focus:
LW transport and accumulation at inline structures
Hydrulic risk prediction

High flow

Low flow

LW rarely mobilized
Modeling focus:
LW and LW jams stability
Effect of bed roughness, DTM accuracy
Effects of two-way coupling

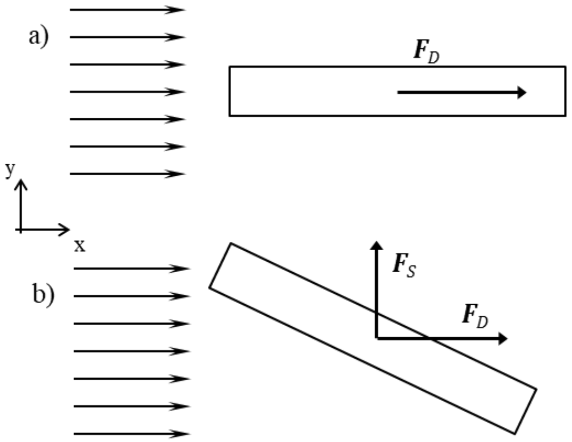
LW model ORSA2D_WT

- **Two-way coupled 2D hydrodynamic model**

$$\begin{cases} \dfrac{\partial h}{\partial t} + \dfrac{\partial q_x}{\partial x} + \dfrac{\partial q_y}{\partial y} = 0 \\ \dfrac{\partial q_x}{\partial t} + \dfrac{\partial\left(\frac{q_x^2}{h}\right)}{\partial x} + \dfrac{\partial\left(\frac{q_x q_y}{h}\right)}{\partial y} + g\cdot\dfrac{\partial\left(\frac{h^2}{2}\right)}{\partial x} = gh(S_{0x} - S_{fx}) + F_{X\_SORG} \\ \dfrac{\partial q_y}{\partial t} + \dfrac{\partial\left(\frac{q_x q_y}{h}\right)}{\partial x} + \dfrac{\partial\left(\frac{q_y^2}{h}\right)}{\partial y} + g\cdot\dfrac{\partial\left(\frac{h^2}{2}\right)}{\partial y} = gh(S_{0y} - S_{fy}) + F_{Y\_SORG} \end{cases}$$

F_{Y_SORG}: $-(\boldsymbol{F}_D + \boldsymbol{F}_S)_y$

F_{X_SORG}: $-(\boldsymbol{F}_D + \boldsymbol{F}_S)_x$



Drag force $\boldsymbol{F}_D = \dfrac{1}{2}\rho C_D A(\boldsymbol{V}_w - \boldsymbol{V}_b)^2$

Side force $\boldsymbol{F}_S = \dfrac{1}{2}\rho C_S A(\boldsymbol{V}_w - \boldsymbol{V}_b)^2 \times \hat{\imath}_z$

$A = LD$

- **Lagrangian approach for large wood transport**

Translation on water surface

$$(m_b + 0.5C_A m_w)\frac{d\boldsymbol{V}_b}{dt} = \boldsymbol{F}_D + \boldsymbol{F}_S + \boldsymbol{F}_{AM} + \boldsymbol{F}_{PG}$$

Rotation around vertical axis

$$I\frac{d\boldsymbol{\omega}_b}{dt} = \boldsymbol{T}_{CM} + \boldsymbol{T}_{AI}$$

Other forces and torques expressions

$$\boldsymbol{T}_{CM} + \boldsymbol{T}_{AI} = \sum \boldsymbol{r} \times \boldsymbol{F} + \frac{1}{2}C_{AI}I\left(\frac{D\boldsymbol{\omega}_f}{Dt} - \frac{d\boldsymbol{\omega}_b}{dt}\right)$$

$$\boldsymbol{F}_{MA} = \frac{1}{2}C_A m_w \frac{D\boldsymbol{V}_f}{Dt}, with\ C_A = 2$$

$$\boldsymbol{F}_{PG} = m_w \frac{D\boldsymbol{V}_f}{Dt}$$

Two-way coupling

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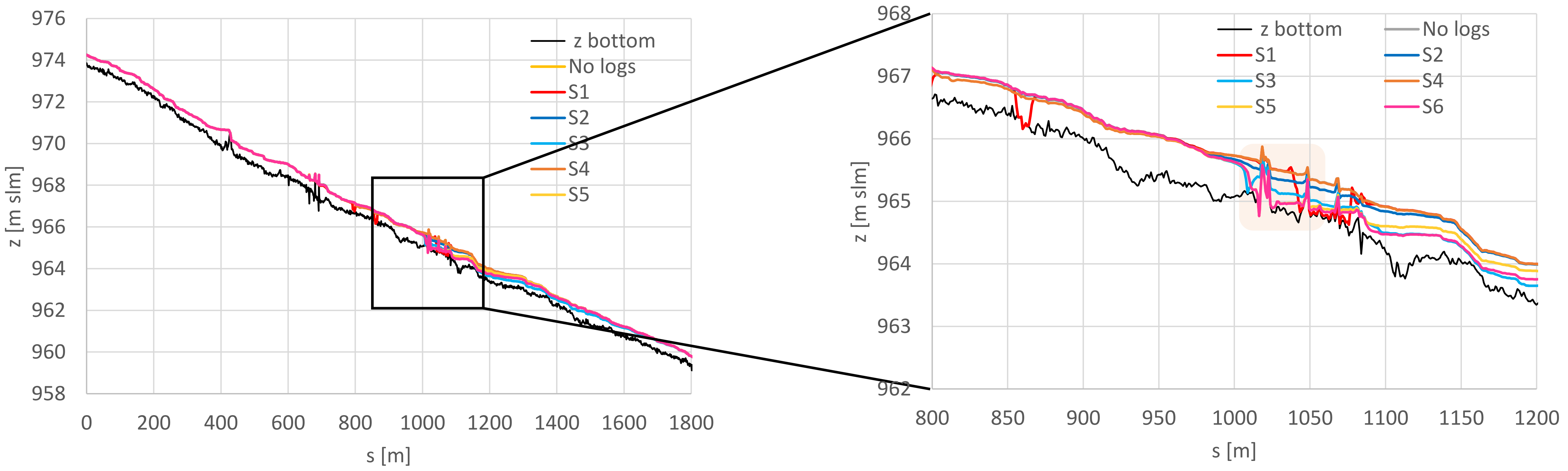
To what extent the logs affect the water level rise?

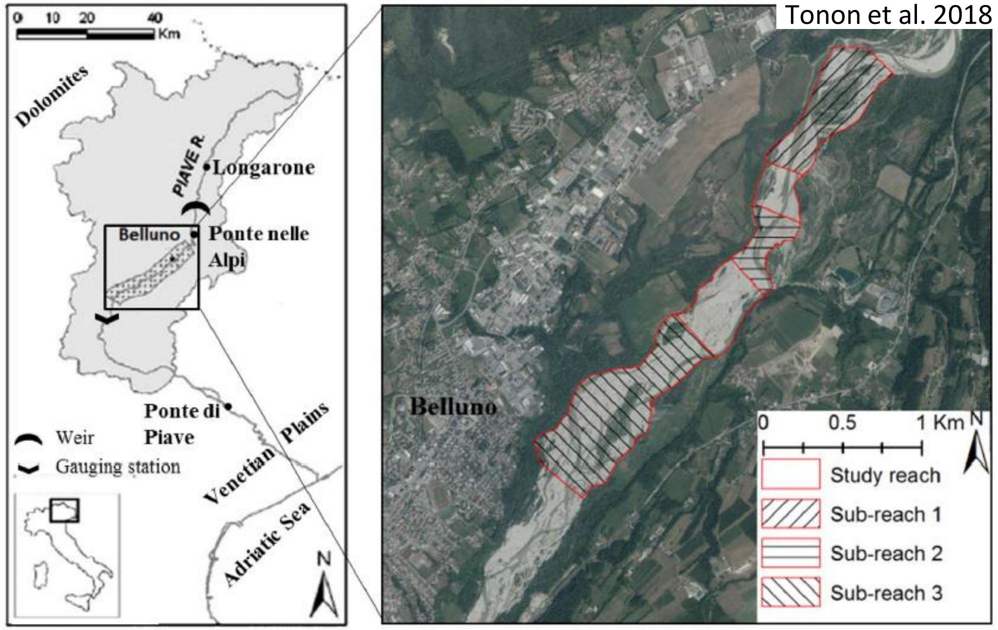
Different scenarios: same log numbers, different orientation → different local water levels.

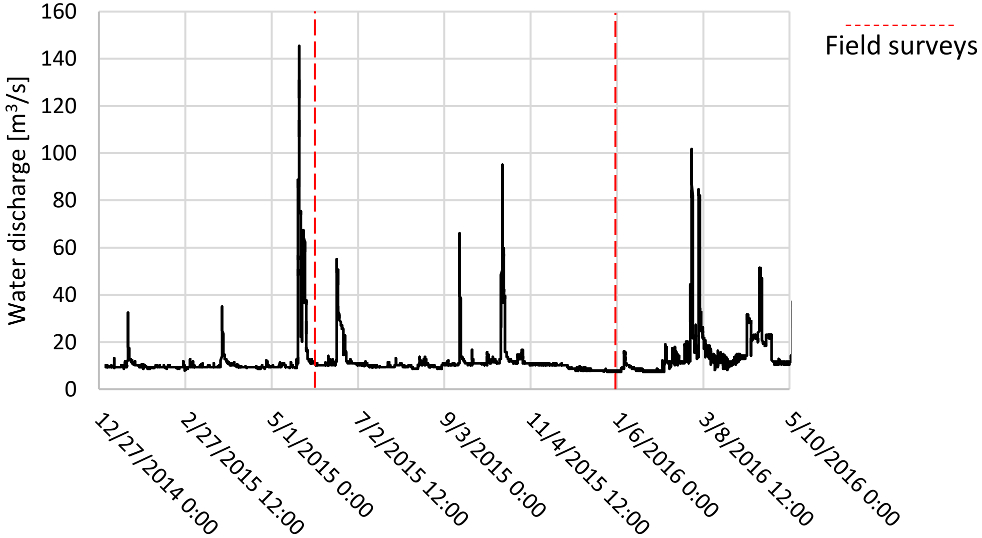
Longitudinal profile of water levels – global scale

Longitudinal profile of water levels - detail



Piave river case study





- Northeast of Italy, 3899 km^2 basin.
- Study reach: 3.7 km, in the middle section of the river, with wide, gravel-bed valley, single and multiple thread channel patterns.
- Highly disturbed river, large human impacts.
- Surveys: June 2015 – June 2016
- LW input from bank erosion and effects of fluvial transport.
- Bankfull discharge: 700 m^3/s.
- Maximum discharge between surveys: 95 m^3/s (RT < 1yr)

Wood mobilization related to very low flow events: only 1.43% of surveyed logs moved…
…but they moved!

Data & initial conditions (1)

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Low flow

- Hydraulic data for upstream and downstream BC
- Channel morphology (DTM & ortophoto)
- Bed roughness (Ortophoto & grain-size analysis)
- LW data (dimension, orientation, shape, presence of branches or roots, density, decay level)
- LW jams relations (number of logs)

2011

Data & initial conditions (1)

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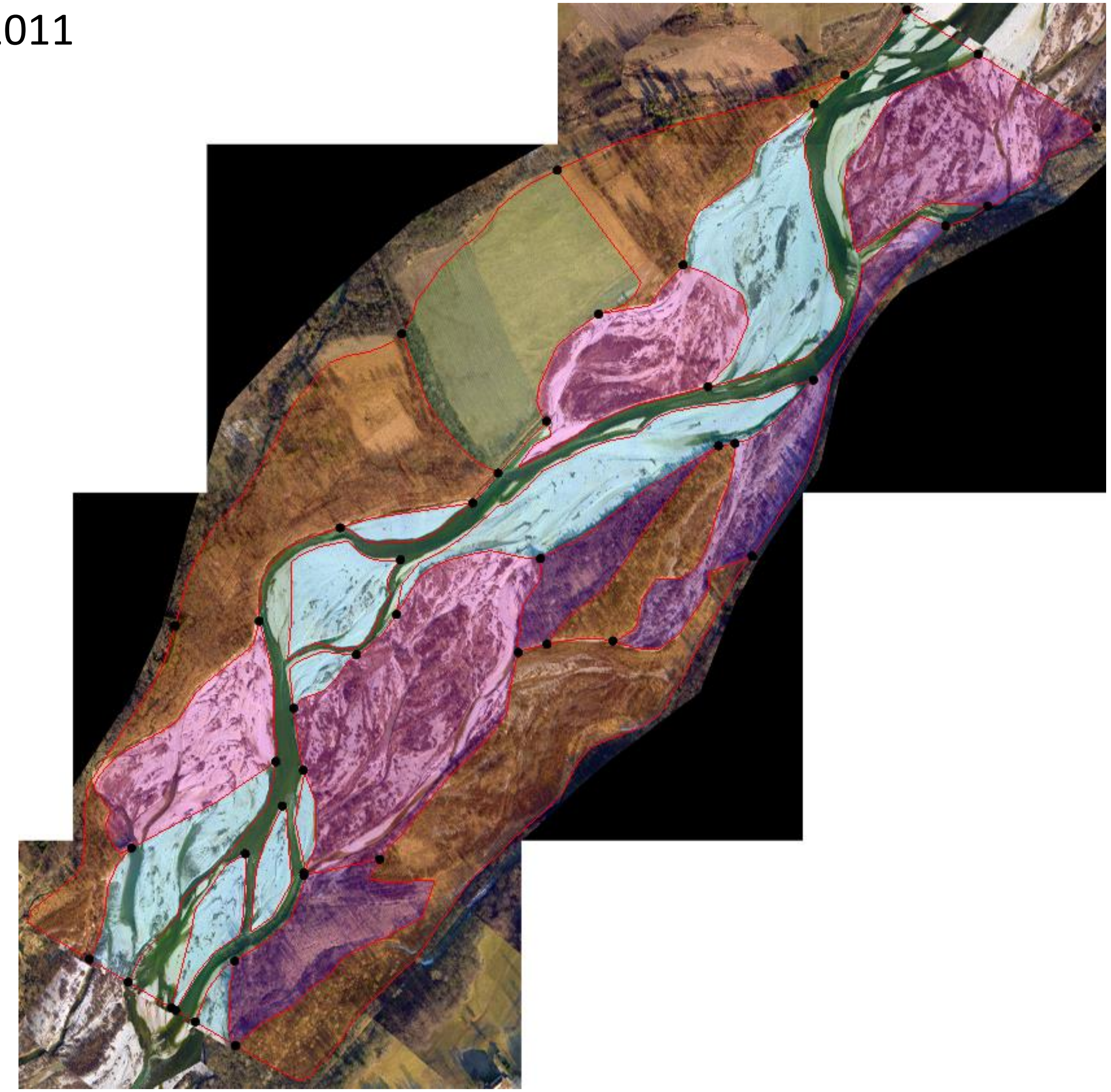

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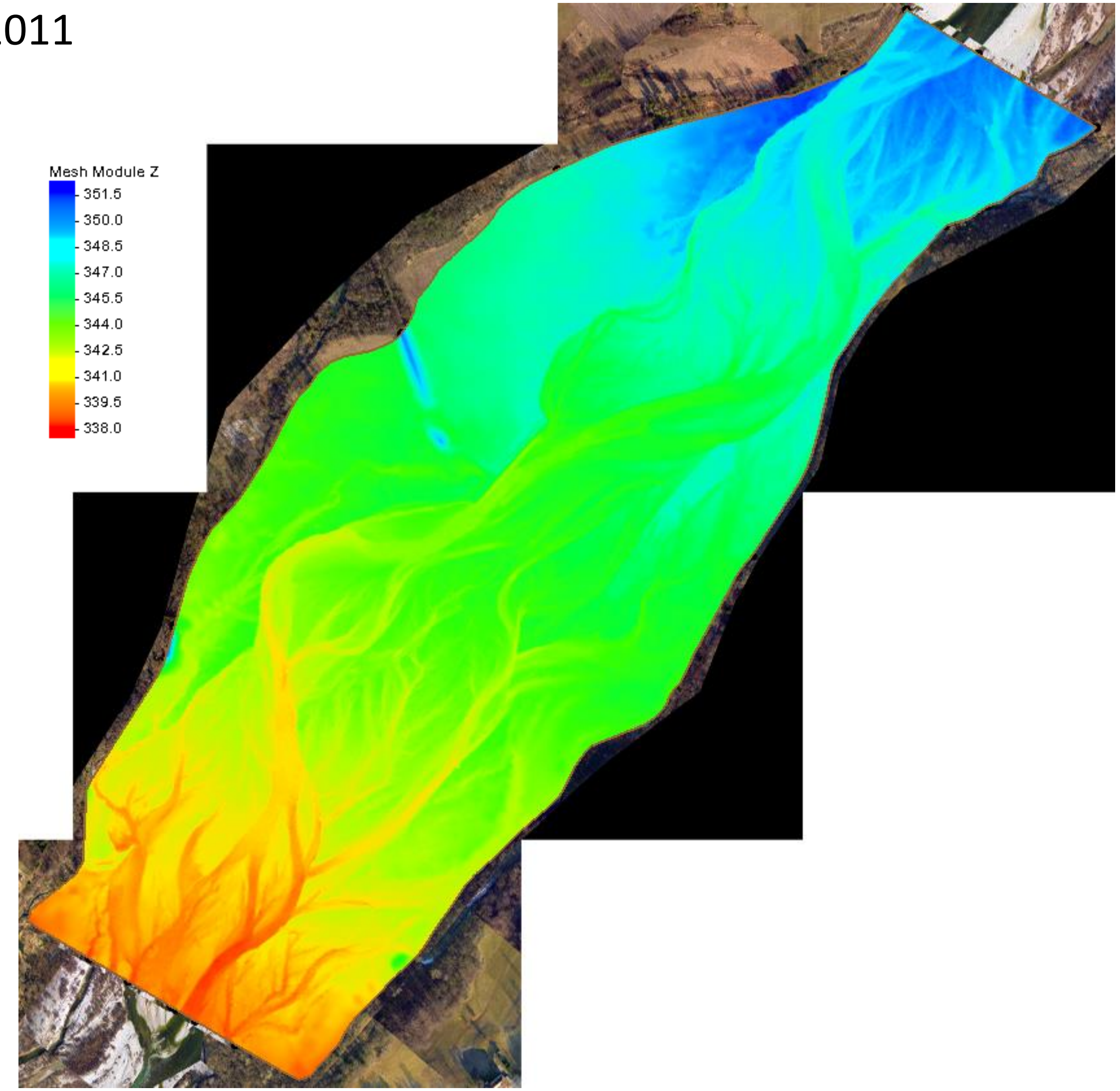

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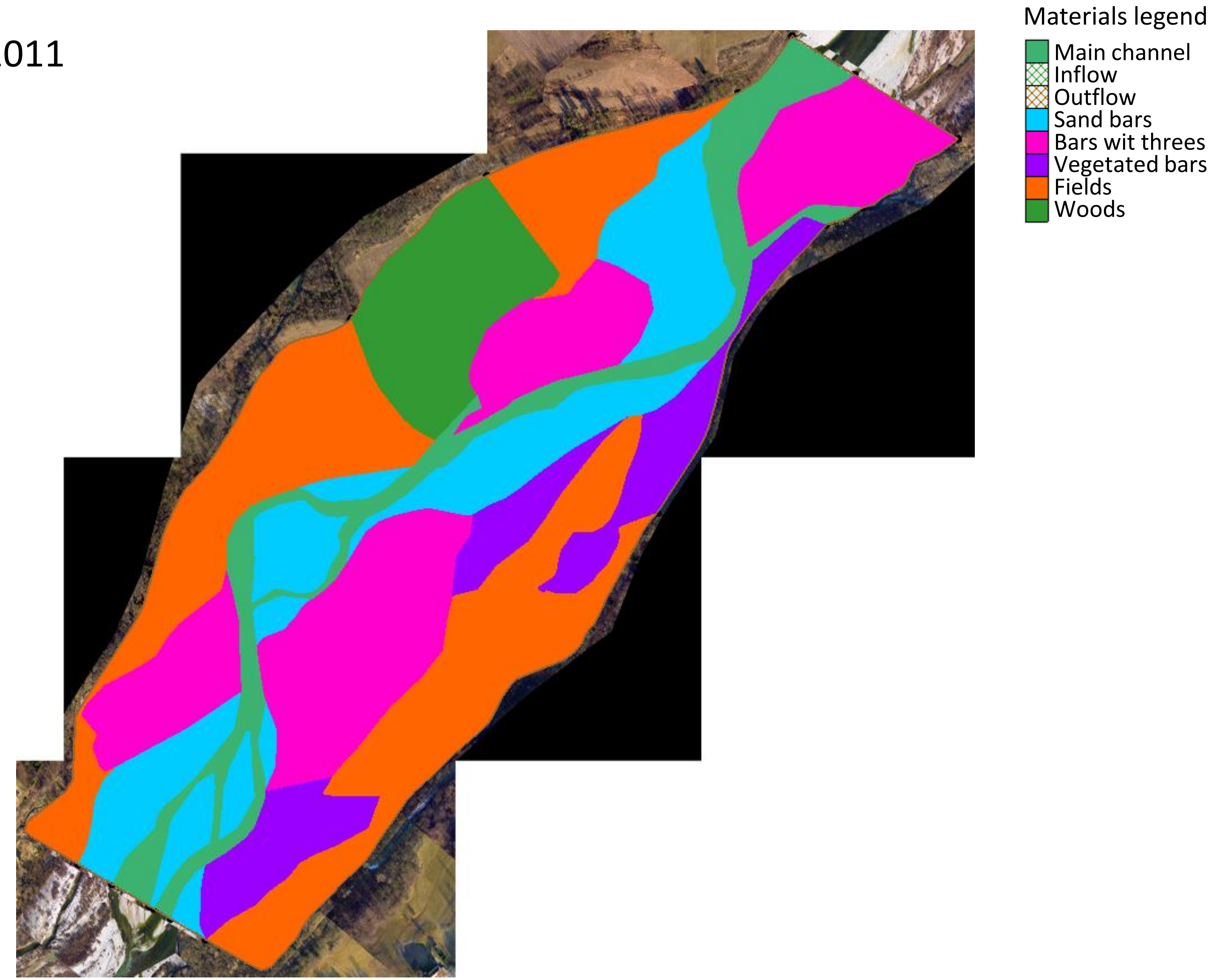

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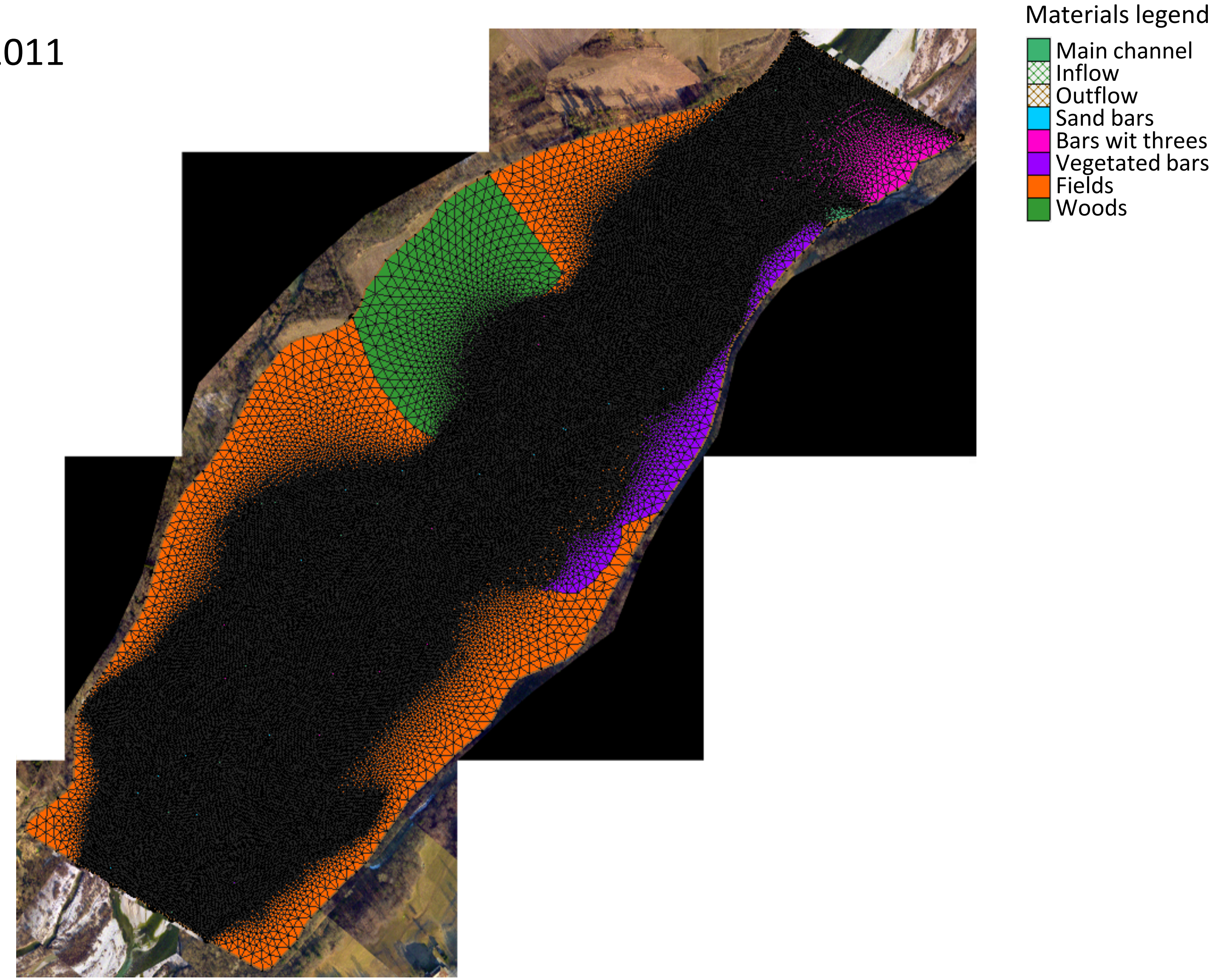

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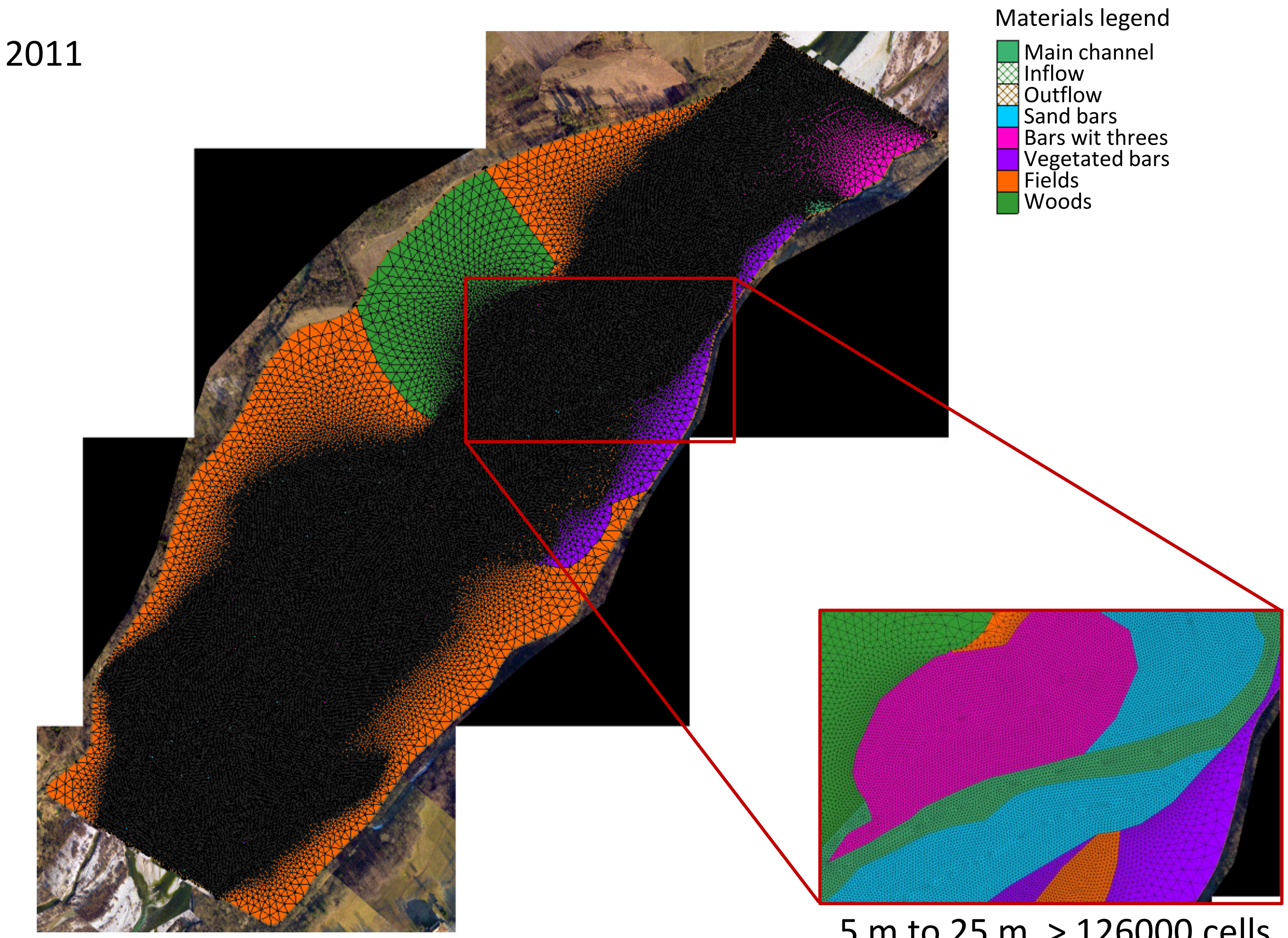
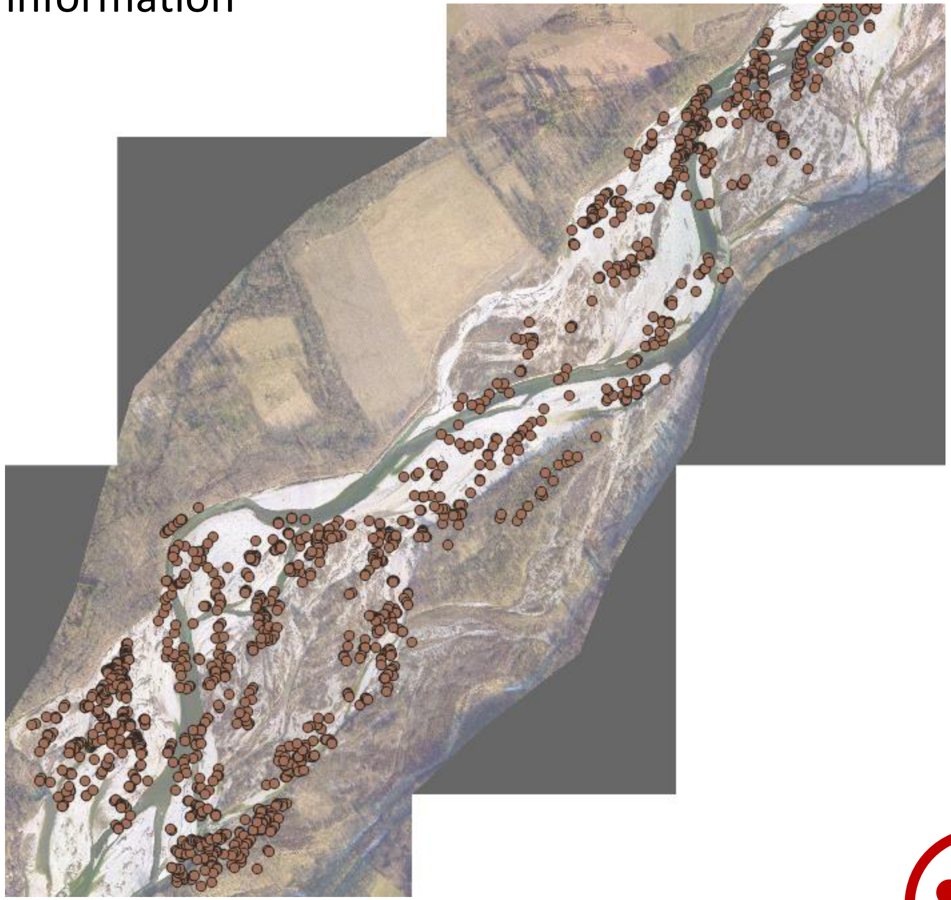


5 m to 25 m, > 126000 cells

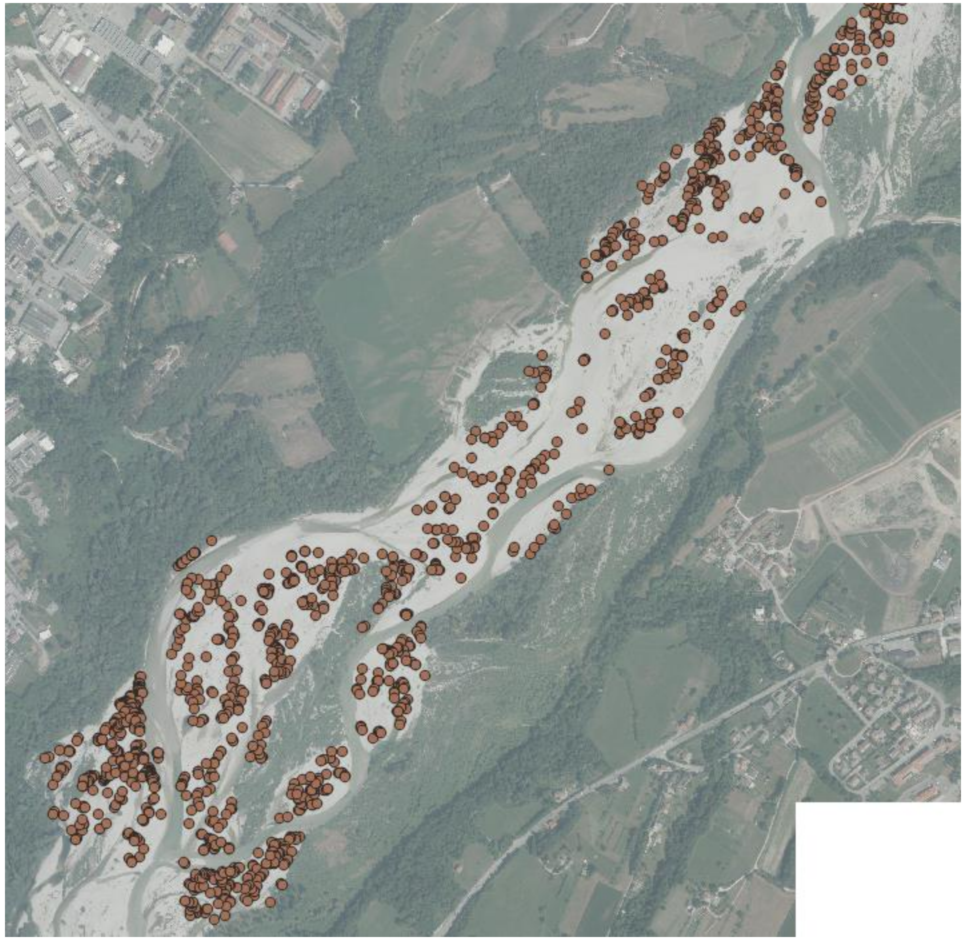
Data & initial conditions (2)

> 2000 logs, with detailed information

2011

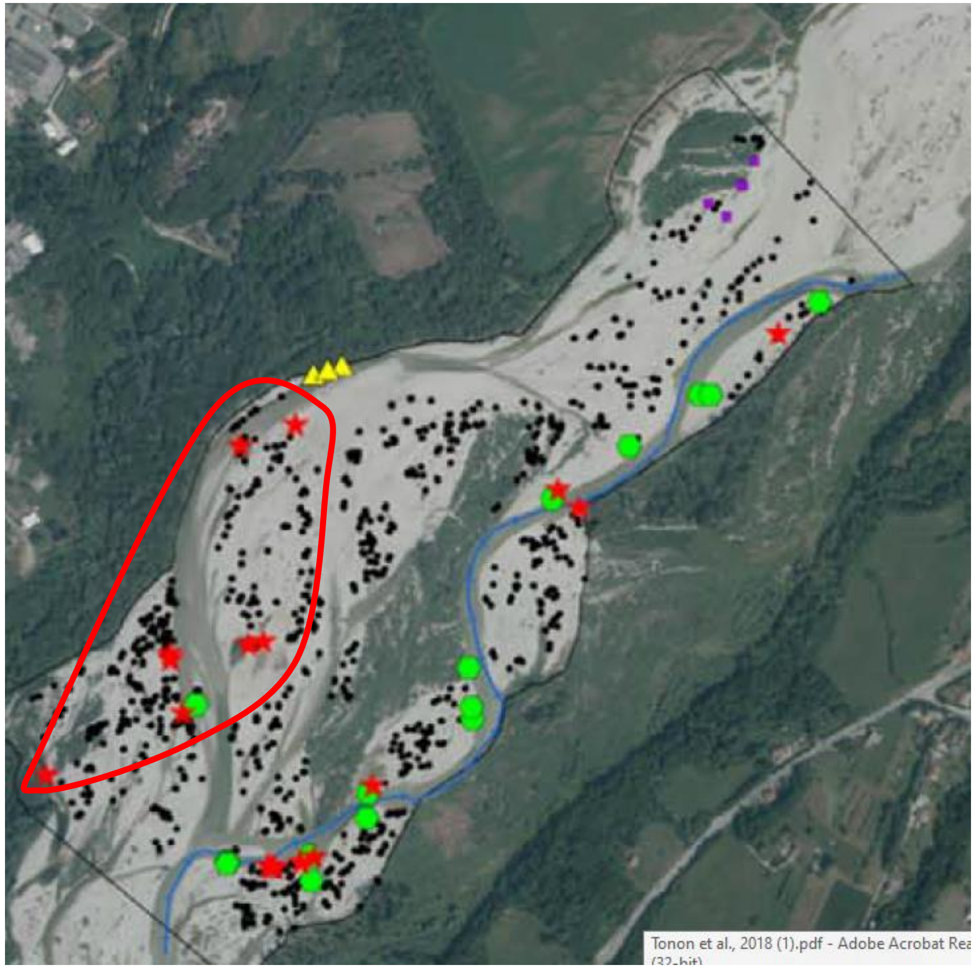


2015-2016



«Temporal» mismatch between logs and ortophoto/DTM!

Modeling approach - test



Tonon et al. 2018 – ortophoto 2015-2016

★ Exiting LW

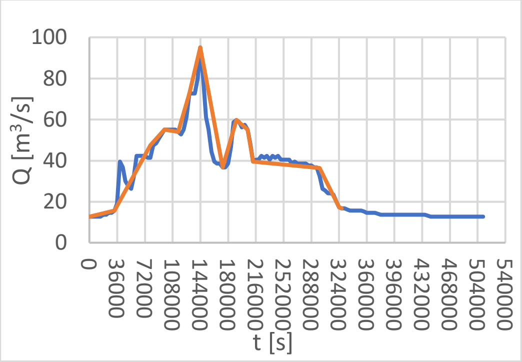
● New LW

● Stored LW

Ortophoto 2011 (& DTM)

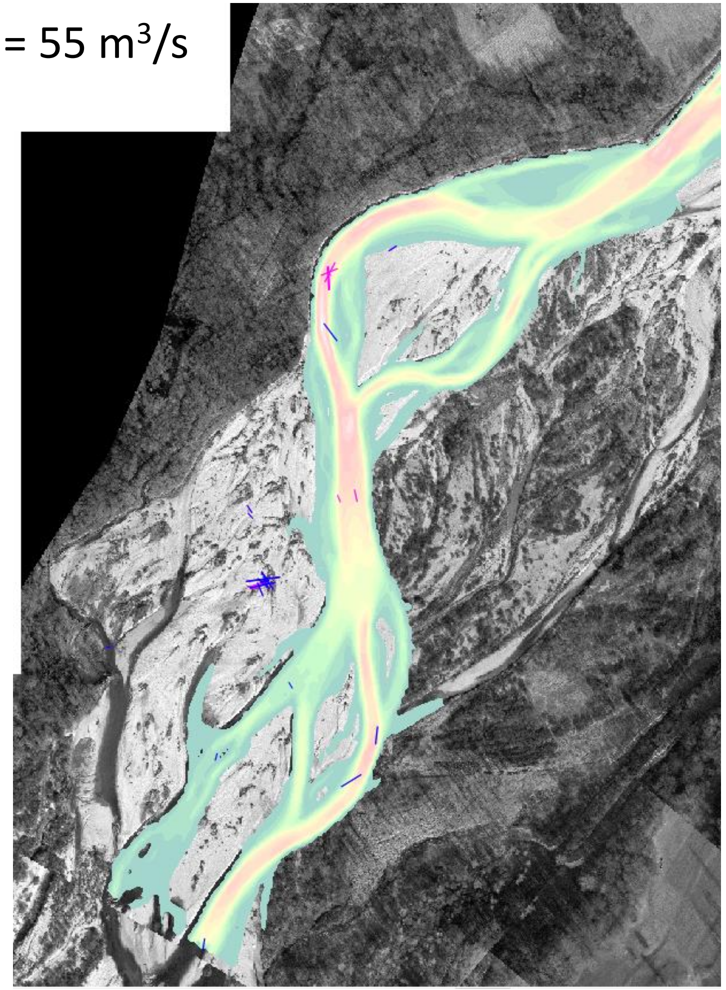
- Limit attention to the area circled in red
- Select 1 minor peak event
- Limit to 8 + 12 logs
- Check mobility for the rising and the falling limb of the hydrograph

Results (1)

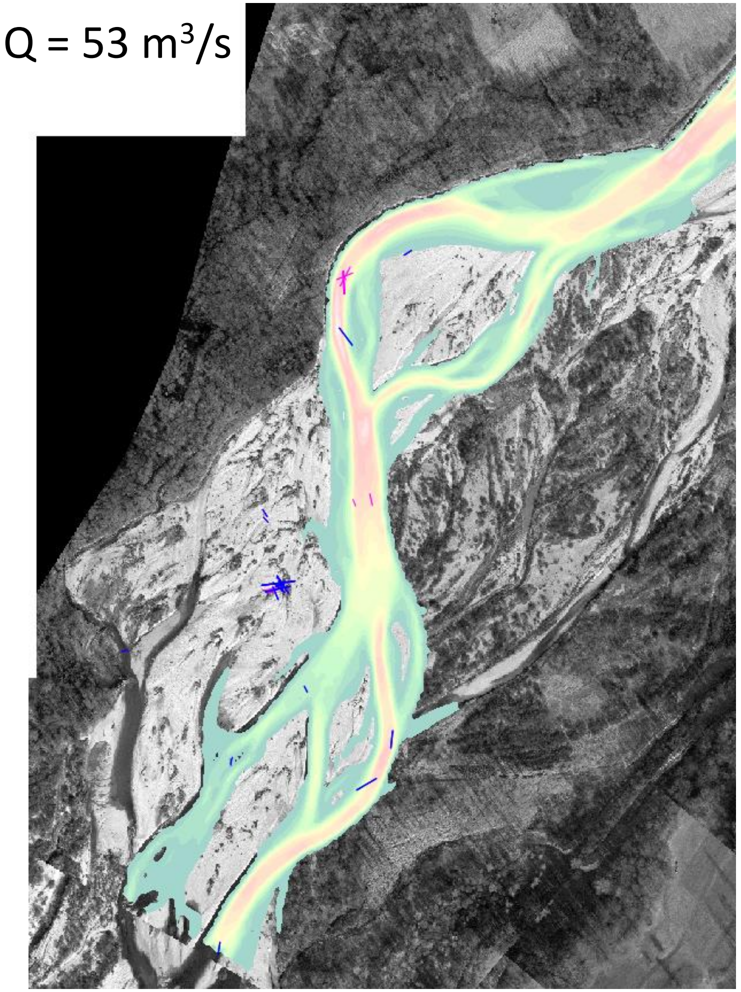


Rising limb - plateau

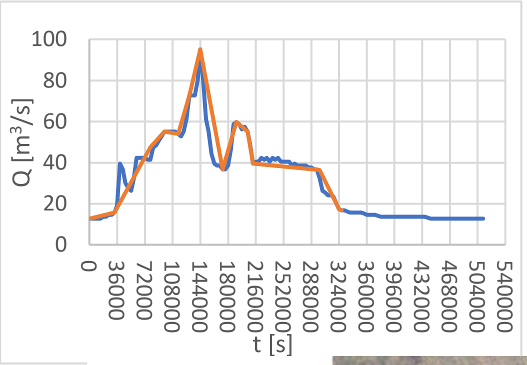
Q = 55 m³/s



Q = 53 m³/s

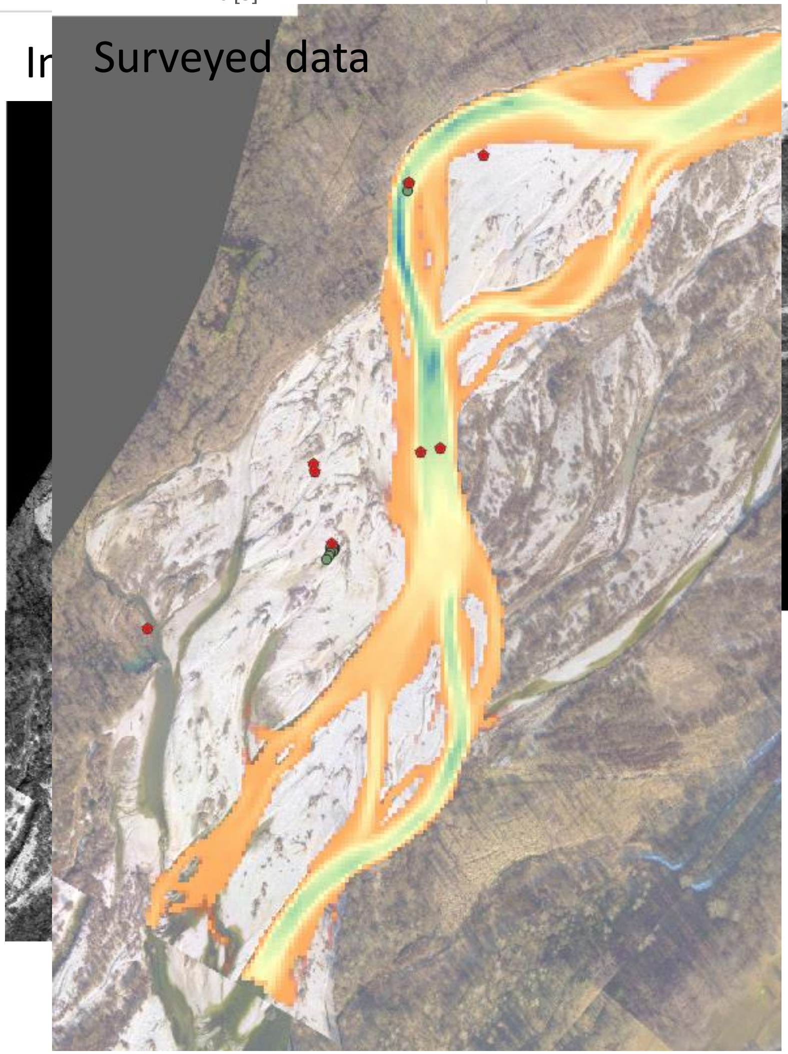


Results (2)



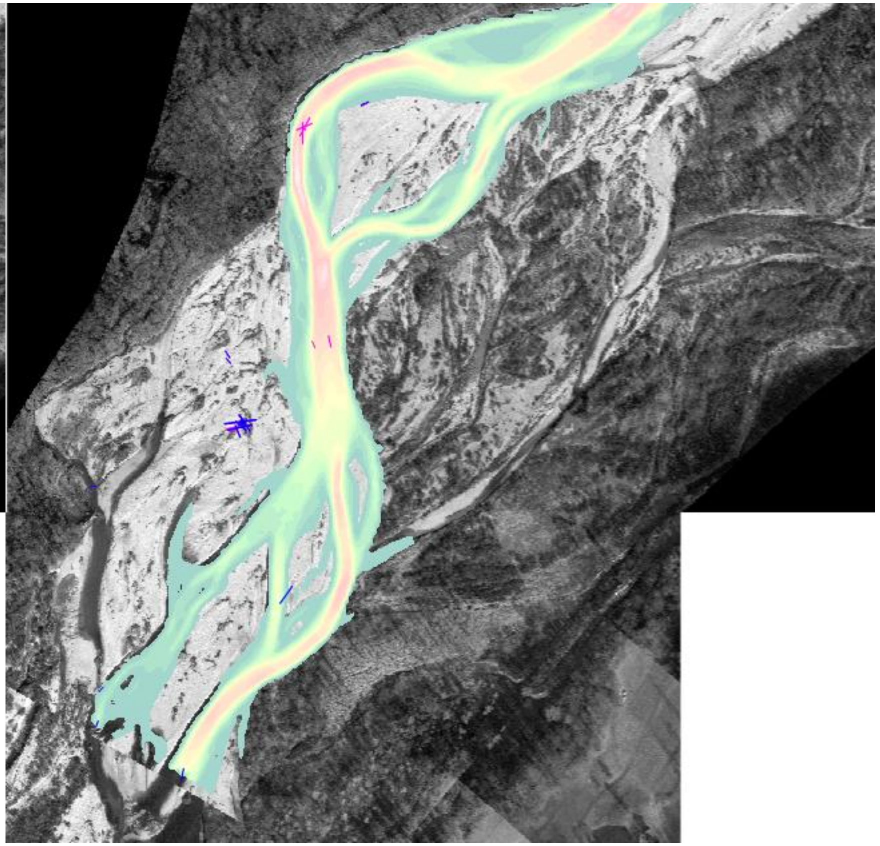
Rising limb
Q=70 m^3/s

In



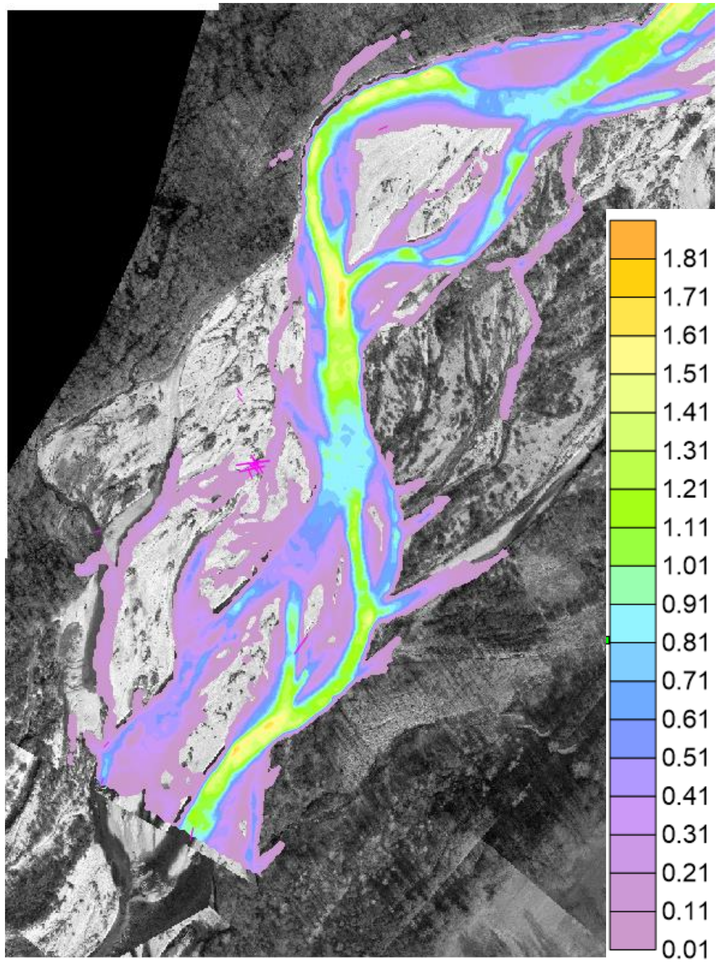
Initial positions + specific discharge

Final positions + specific discharge

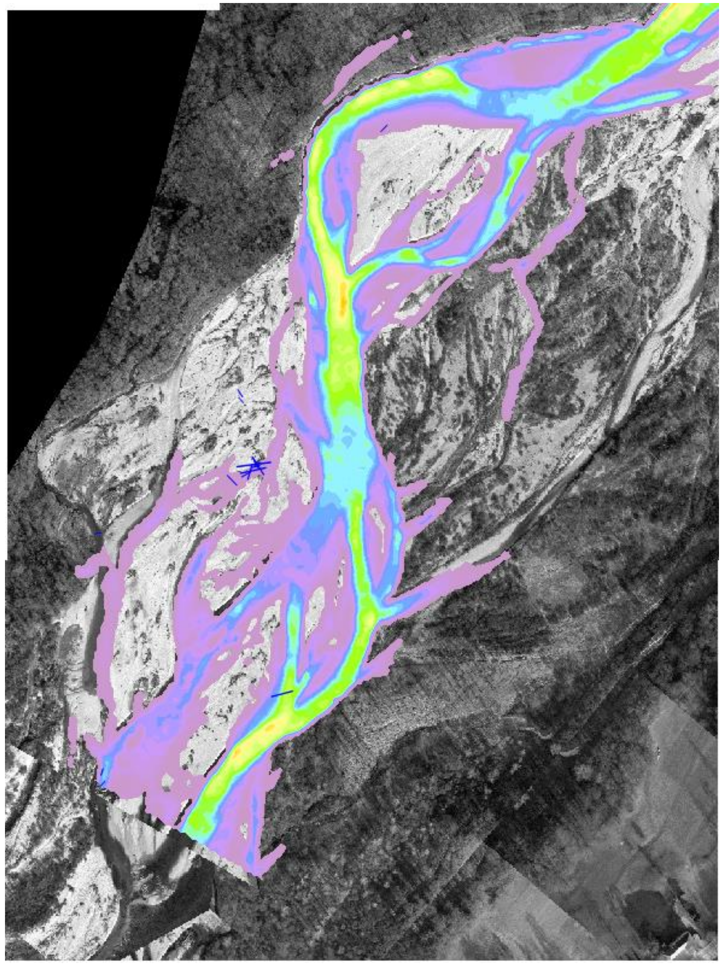


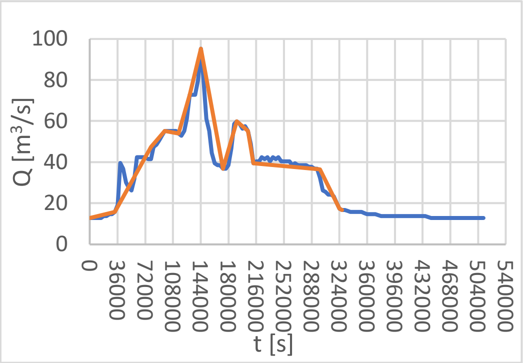
Results (3)

Initial positions (17 logs, after Res. 2) + max. water levels



Position after start (every 60s) + max. water levels





Falling limb

From Q = 95 m^3/s to 36 m^3/s in 8h

Results (3)

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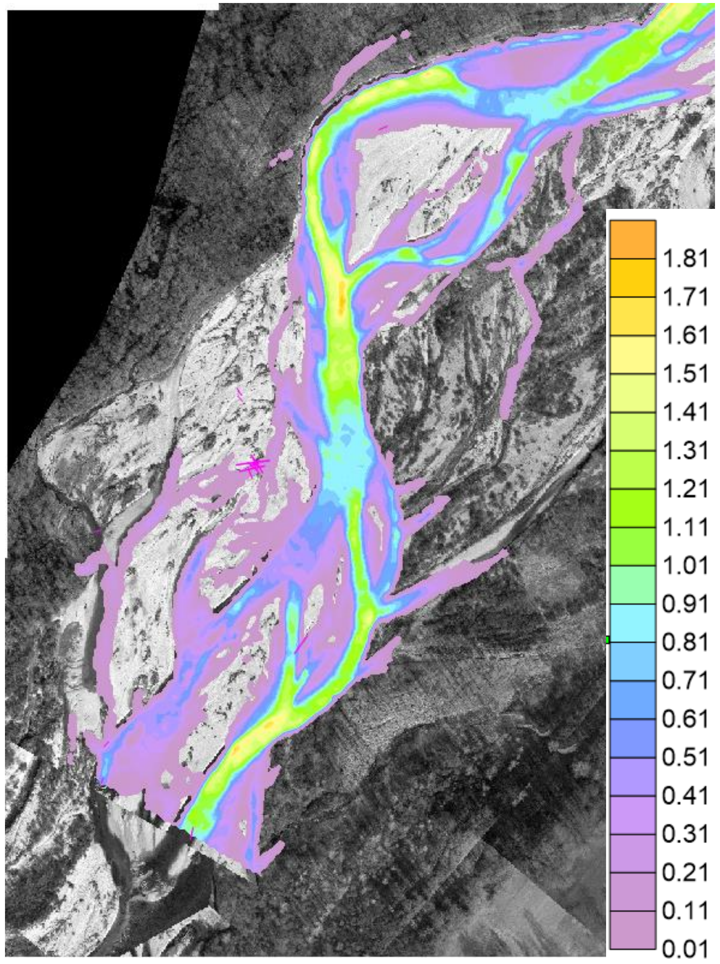

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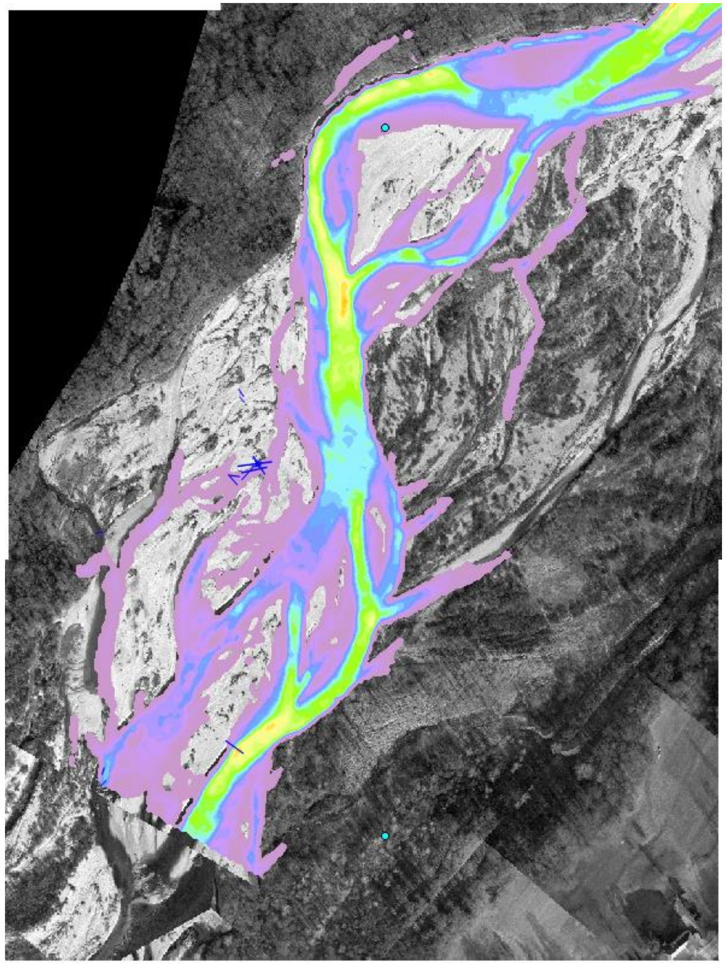

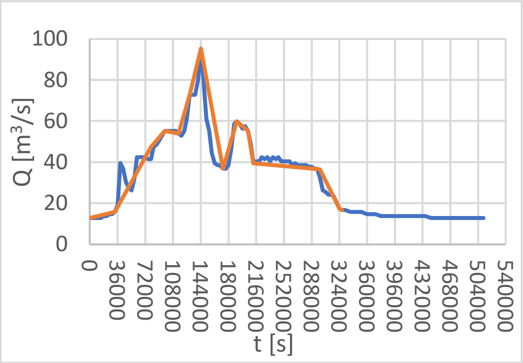

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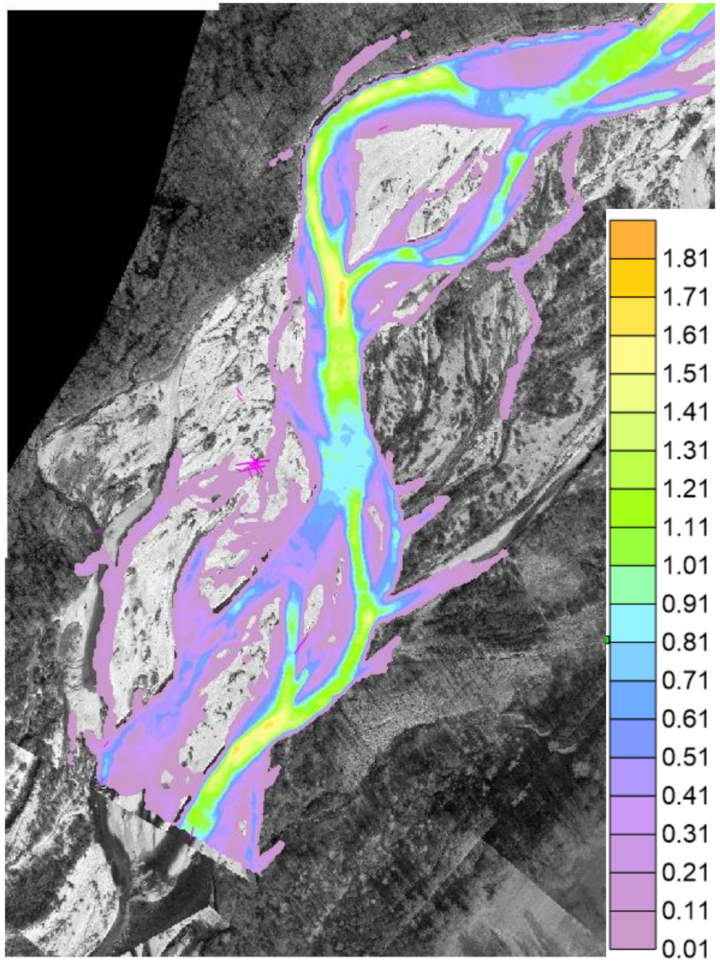

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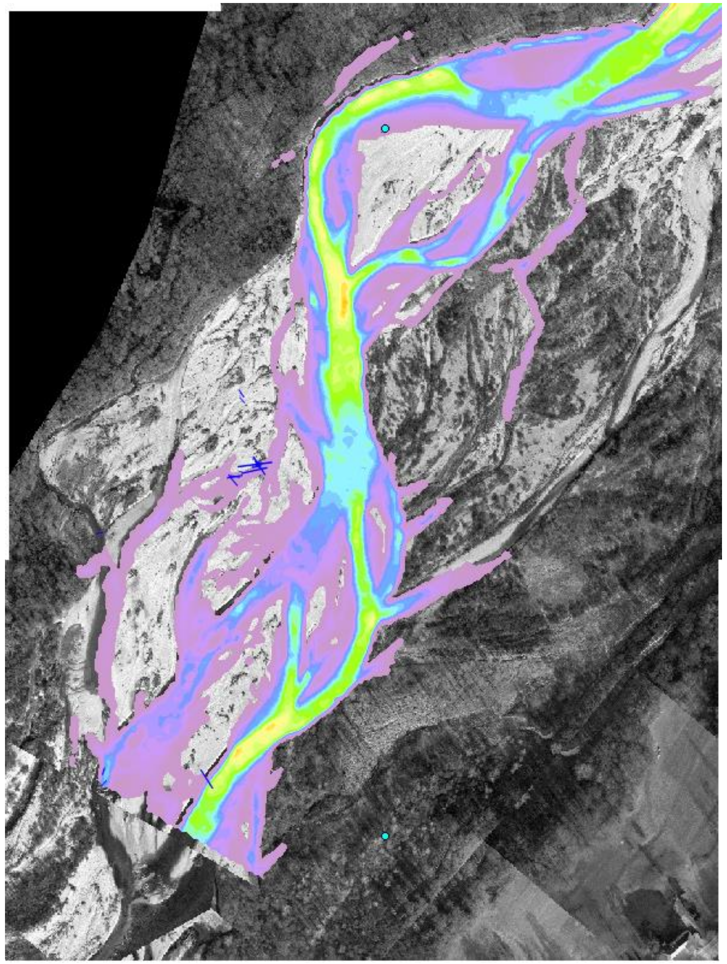

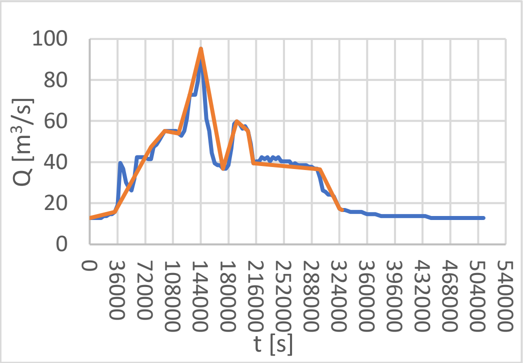

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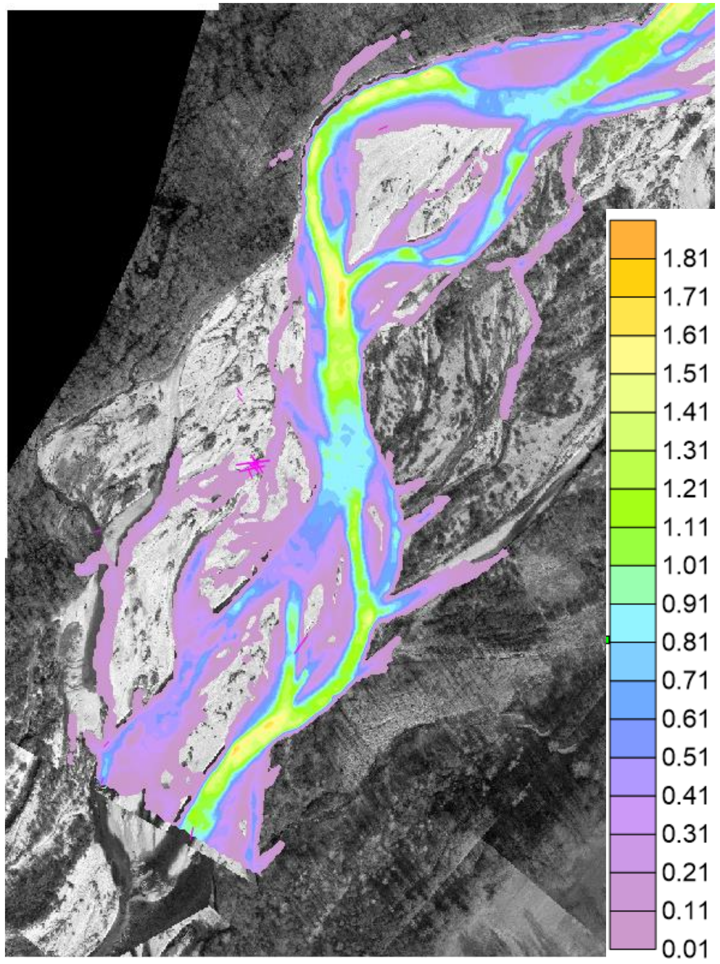

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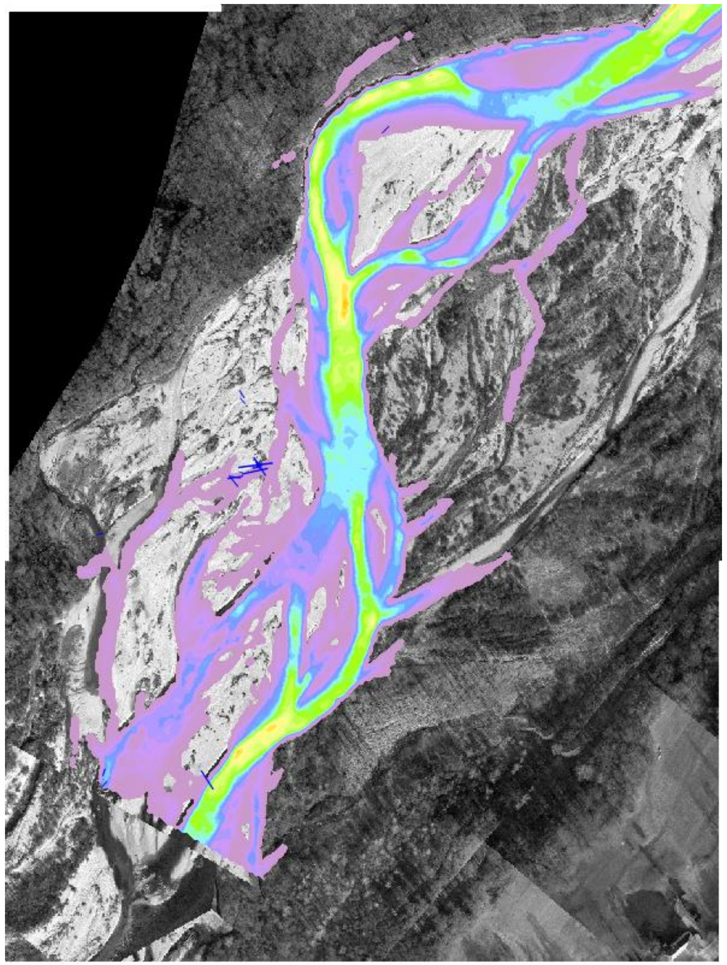

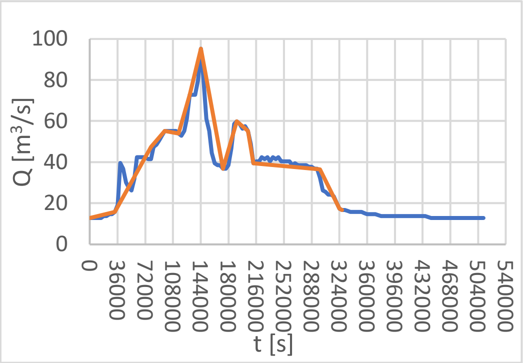

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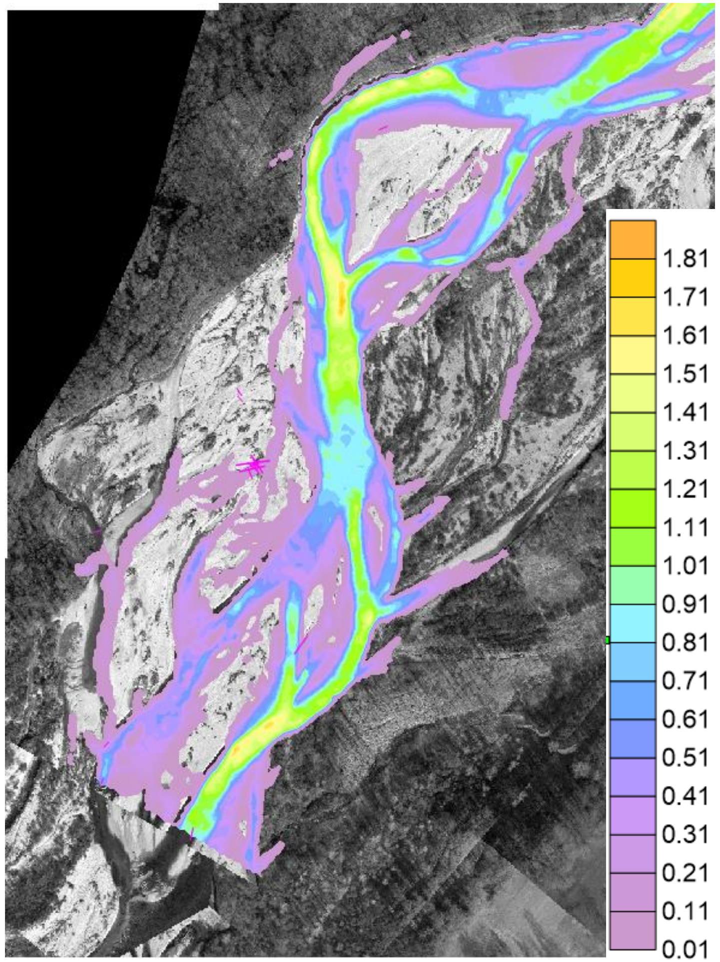

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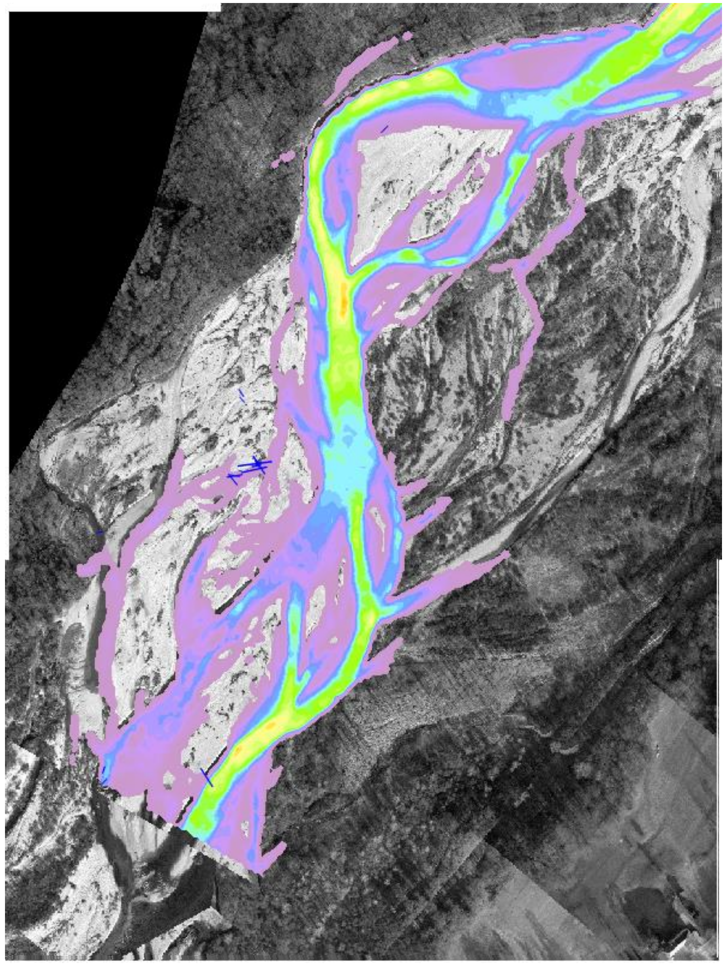

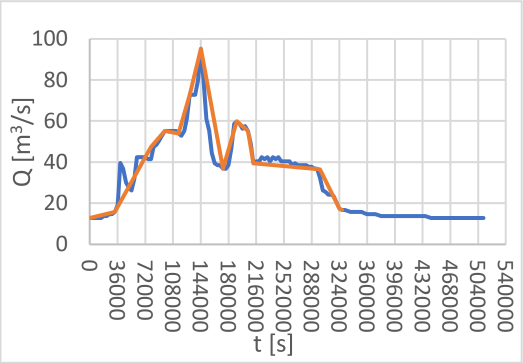

Falling limb

From Q = 95 m^3/s to 36 m^3/s in 8h

→ Stable condition reached after 180s

→ 3 more logs out of the mesh

LW in low flow…work in progress!

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Basic observations

- In-channel LW is mobilized even during low-flow events
- With the highest water discharge, 6/20 logs are exiting the domain.
- Different mobilization depends on different DTM geometry.

Tips for **the perfect LW survey** (☺) for low-flow events

- Temporal consistency of data.
- Maximum detail for orientation (not just parallel/ perpendicular/oblique).
- Wood type and decay levels to estimate density.

Lessons learnt for numerical modeling

- Manage LW shape and position complexity.
- LW jams are mobilized correctly?
- Model optimization to cope with large LW number.

Another option: scenario-based approach to cope with model and data uncertainties

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