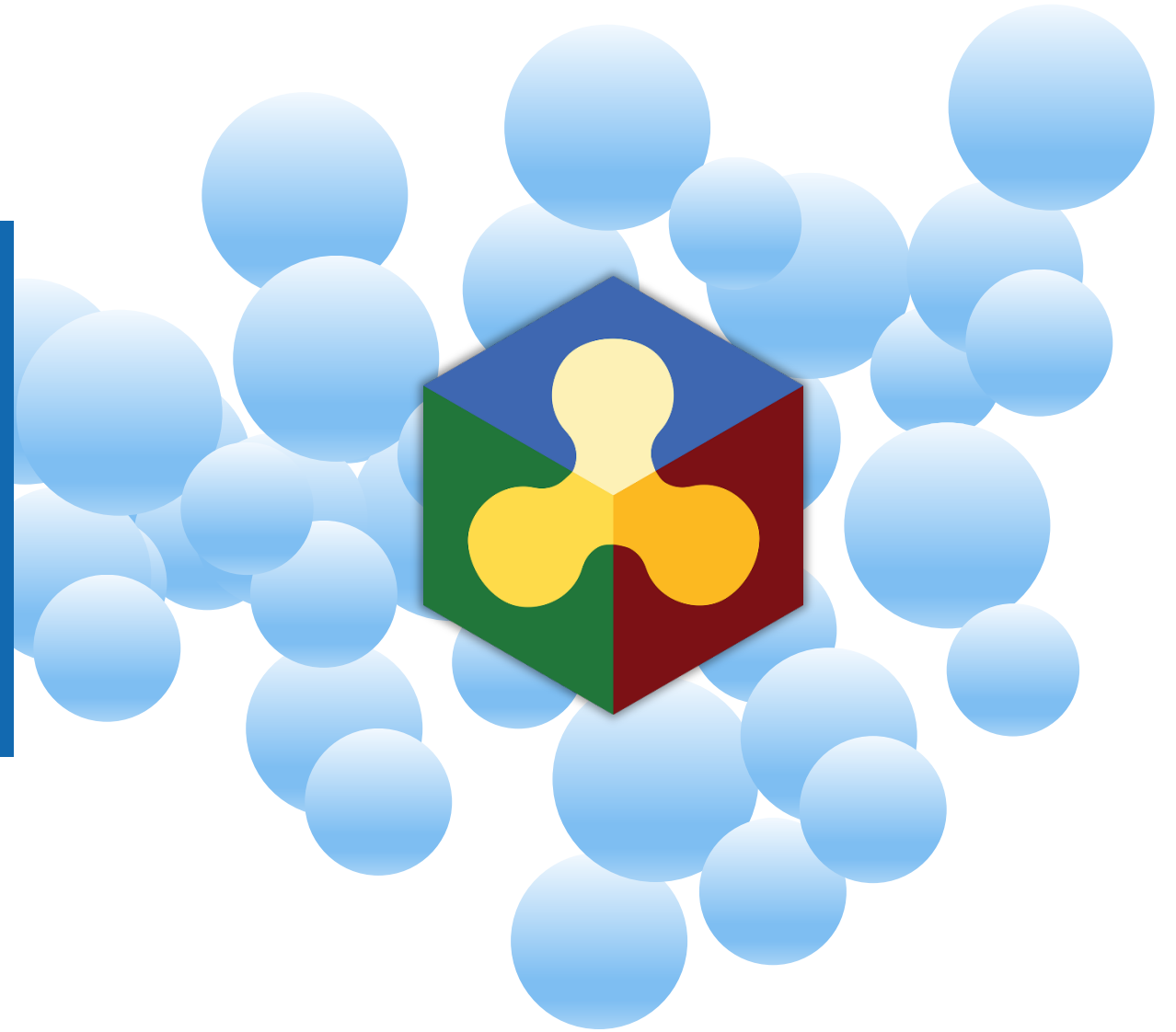


Lagrangian transport modelling

Dr. Francesco Caponi and Dr. Daniel
A.S. Conde
BASEMENT Users Meeting 2024



Outline

 Lagrangian modelling: motivation & background

 Applications: focus on eco-hydraulics

 Implementation within BASEMENT

 Modelling showcase

Introduction and Motivation

- Transport processes in rivers include
 - Pollutant
 - Sediments
 - Plastic
 - Organic material
 - Wood
 - ...



https://x.com/AGU_EPSP/status/1133411898081259526?s=20
<https://x.com/IEEPennState/status/1704532118808752350?s=20>
<https://x.com/LeicesterGeog/status/1269915845893017600?s=20>

Introduction and Motivation

Understanding mechanism of transport (and deposition) is key to quantify **fluxes** and **budgets**



Large wood dynamics

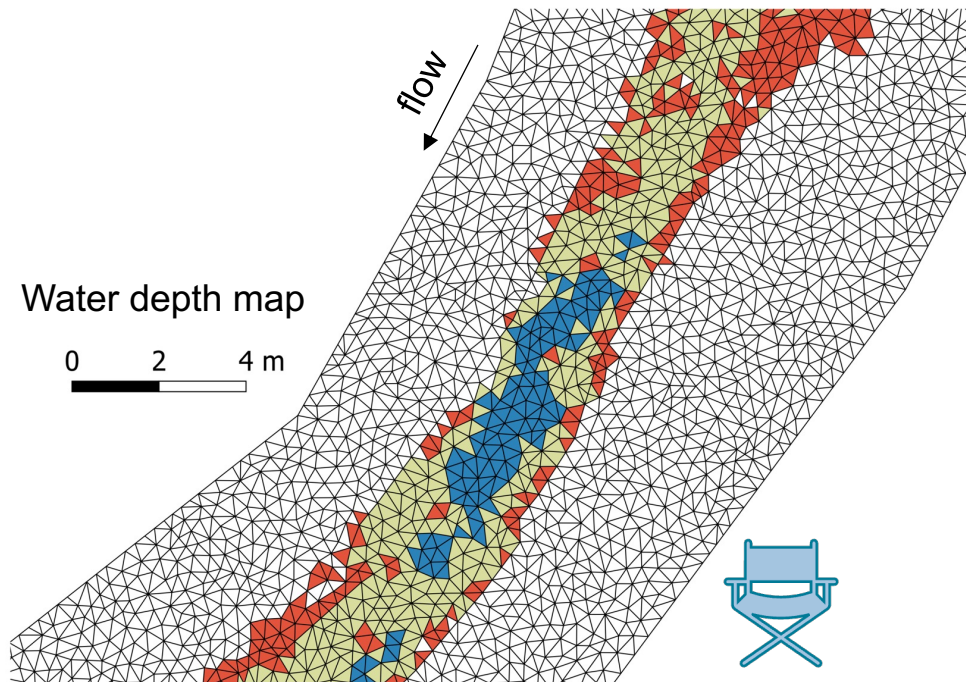


Organism migration

Eulerian vs Lagrangian approaches

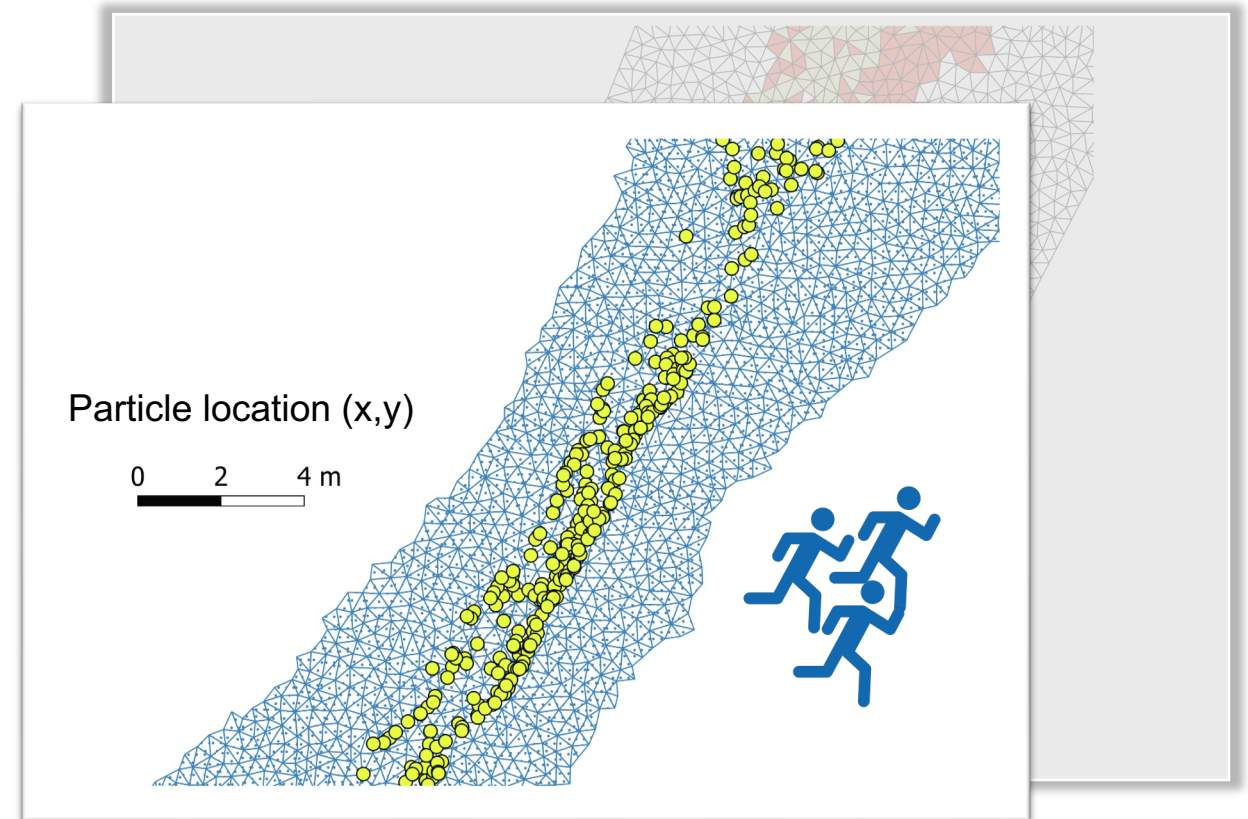
Eulerian approach

→ Flow field cell-wise

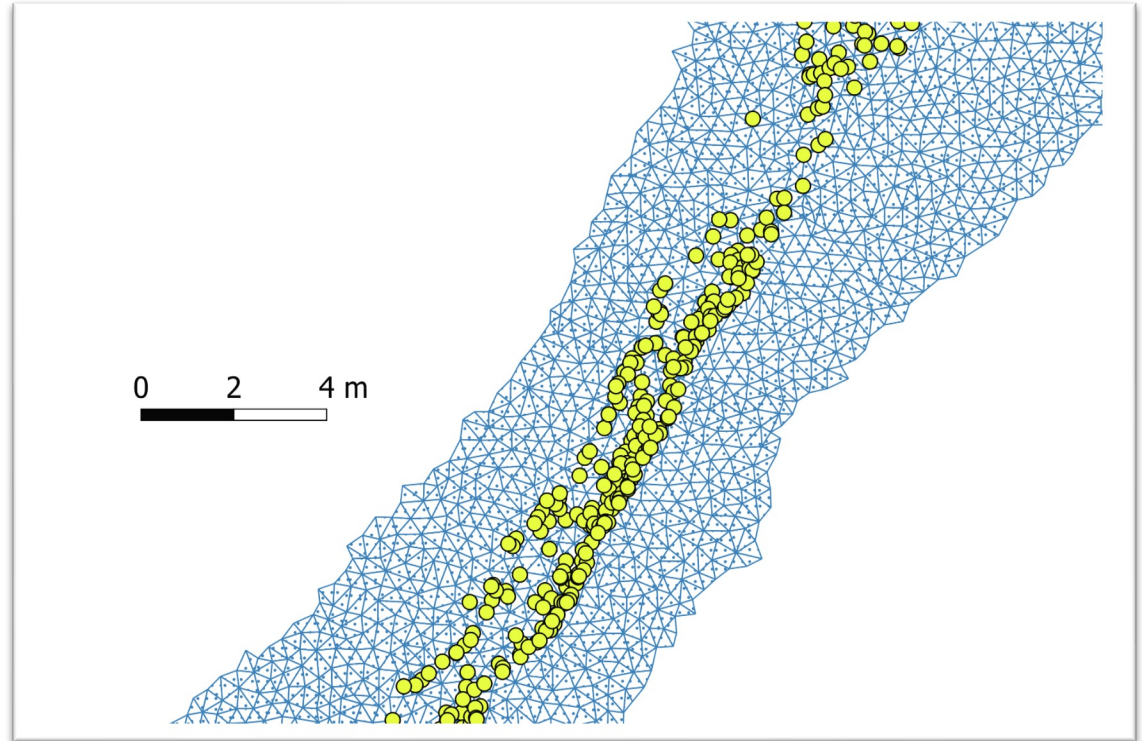
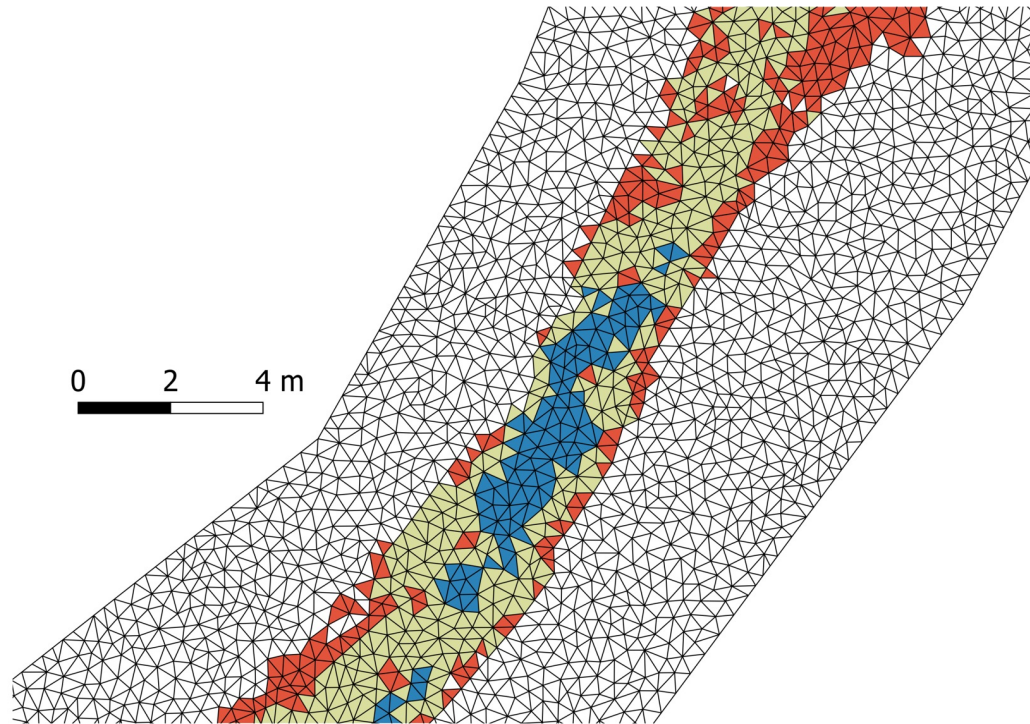


Lagrangian approach

→ single particles motion through a flow field



Eulerian vs Lagrangian approaches



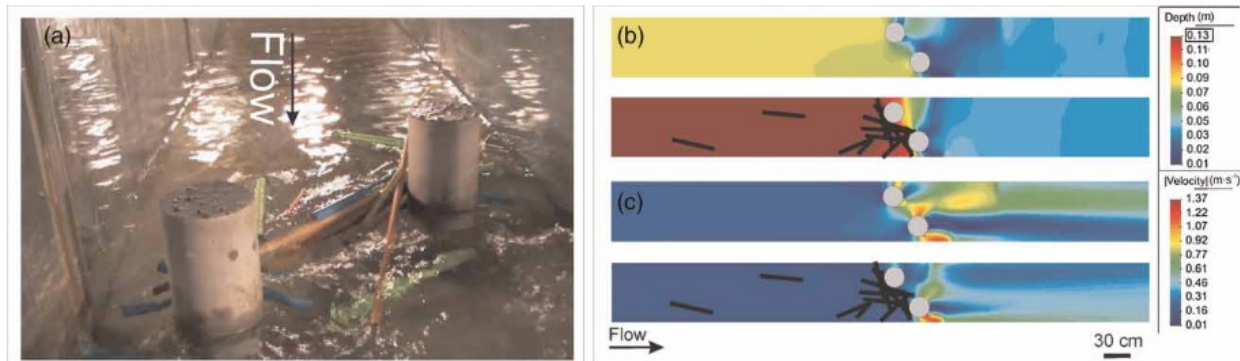
- Calculate budget and fluxes ✓
- Spatially-explicit variables ✓



- Residence times
- Calculate trajectories
 - 3D motion of particle with interactions

Some applications

- Use of Lagrangian approaches find applications in
 - River-floodplain connectivity
 - Organism (e.g. larval) drift
 - Macro- and micro-plastic transport
 - Wood transport and accumulation



Two-dimensional modelling of large wood transport during flash floods

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ABSTRACT: Large woody material (LWM) transported by rivers may be entrapped at critical stream geometry configurations (e.g. bridges) and therefore dramatically increase the destructive power of floods. This was the case in a Spanish mountain river where a flood event with a high degree of LWM transport took place in 1997. The aim of this study was to simulate a bridge clogging process and reconstruct the wood deposit patterns, modelling individual pieces of wood moving with the water flow and interacting among them and with the bridge. A two-dimensional numerical model was developed to simulate the transport of LWM and its effect on hydrodynamics. Different scenarios for the wood transport rate allowed us to study the influence of inlet boundary conditions on bridge clogging. For the studied event, the scenario which best reproduced the bridge clogging effect and flood characteristics was one in which 60% of the total wood entered before the peak discharge. This dropped to 30% at the peak itself, and finally fell to 10% during the recession curve. In addition, the accumulation patterns of LWM along the reach were computed and compared with post-event field photographs, showing that the model succeeded in predicting the deposition patterns of wood and those areas prone to form wood jams. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS: large woody material; 2D model; bridge clogging; hydrodynamics; woody debris

Introduction

Large woody material (LWM) plays an important role in river ecosystems by influencing hydrology, hydraulics, sedimentology, and morphology (Lasseine and Harris, 2001; Carwell et al., 2002; Montgomery, 2003; Seo et al., 2008). In addition, an extensive literature now exists describing the influence of wood on stream ecology (Gippel and White, 2006; Martin and Bondi, 2001; Gregory et al., 2003), since wood may provide a habitat for fish and riverine species (Carlson et al., 1990; Jackson and Sturm, 2002; Langford et al., 2012), and references cited therein) and regulates water flows and nutrient flows (Wolby et al., 2002).

Recent research has focused on the mobilization of woody material during floods, since transported woody material can represent a substantial increase in the destructive power of floods (Diehl, 1997; Fischer, 2006; Tyn et al., 2007; Waldner et al., 2007; Coniti et al., 2008; Mao et al., 2008; Mazzonara et al., 2009; Coniti et al., 2012). LWM may reduce the capacity of bridge openings, contribute to scour, and increase lateral forces on bridges. The main results of these phenomena are a quick succession of backwater effects with bed aggradation, flow diversions and local scouring processes, ultimately evolving towards embankment/bridge collapse and floodplain inundations. As a result, flooded areas may be different from those predicted in the absence of wood (Ruiz-Villanueva et al., 2012a).

In this context, it has been demonstrated that wood removal could fail, in part because of new inputs of wood (Young, 1991; Gippel, 1995; Dudley et al., 1998). For this reason, the problem has been redefined as the inability of infrastructure to allow LWM to pass (Lasseine and Kondolf, 2012).

In forested mountain catchments, most trees fall into the stream as a result of a variety of mechanisms such as mass wasting, channel migration and bank undercutting (May and Greenwell, 2001; Swanson, 2003; wildfire and fire (Bernta and Siao, 2003; Rosso et al., 2007) or natural tree mortality (Bernta et al., 2003). During floods, the number of wood pieces likely to be transported may increase significantly (Nakamura et al., 2000). A better understanding of LWM entrainment, or the process by which woody material is transported to the river, is therefore needed (May and Greenwell, 2001; Bragg and Kenner, 2004; Mazzonara et al., 2009; Rigon et al., 2012; Ruiz-Villanueva et al., 2012b).

There are few direct observations and/or measurements of the conditions of wood entrainment and transport during floods (see pioneering studies in MacVicar et al., 2009). Physical models and flume experiments have been used to overcome these constraints, contributing greatly to our present knowledge of LWM transport (Braudrick and Grant, 2000; Braudrick et al., 2001; Becchiola et al., 2002; Haga, 2002; Schroeder and Hager, 2011). Some others have used one-dimensional (1D)

Water Resources Research
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A Lagrangian particle-tracking approach to modelling larval drift in rivers

Richard R. McDonald and Jonathan M. Nelson

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Plant dispersal by water

- Key mechanism for maintaining **plant biodiversity** in freshwater systems
- It allows plant to colonize new areas and connect distant communities
- Seeds as of *Tamarix* and *Salix* are adapted to be transported in water



They can be modelled
as tracer or very small
particles



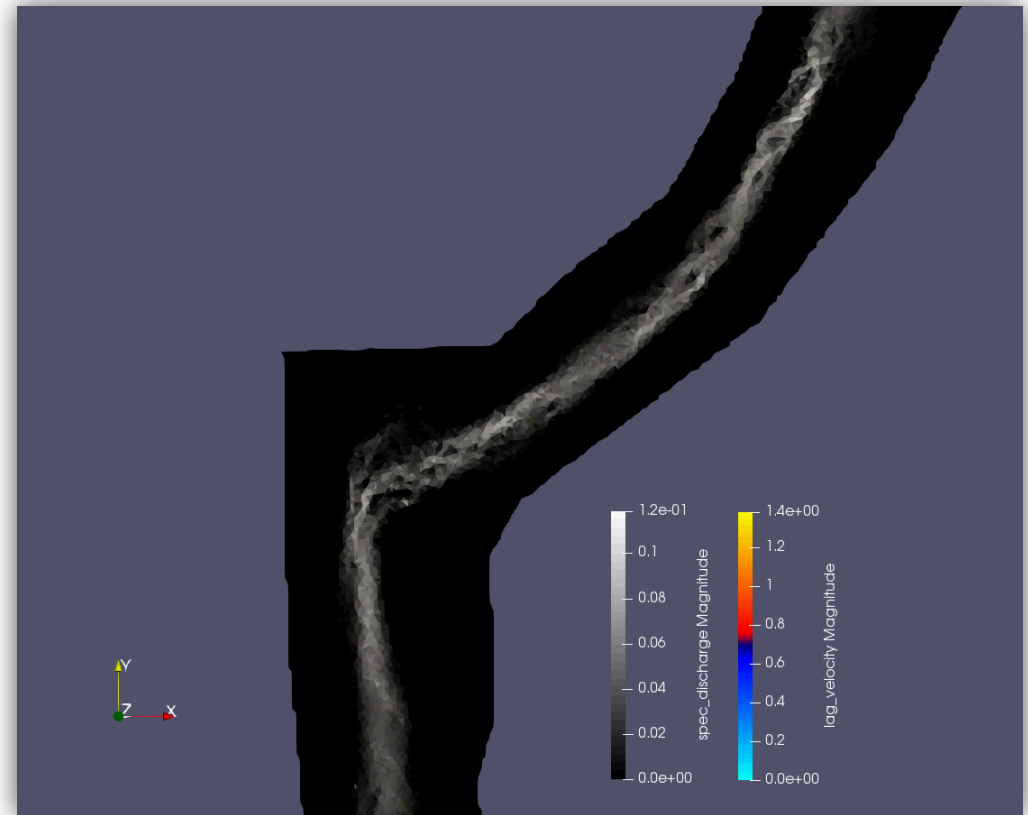
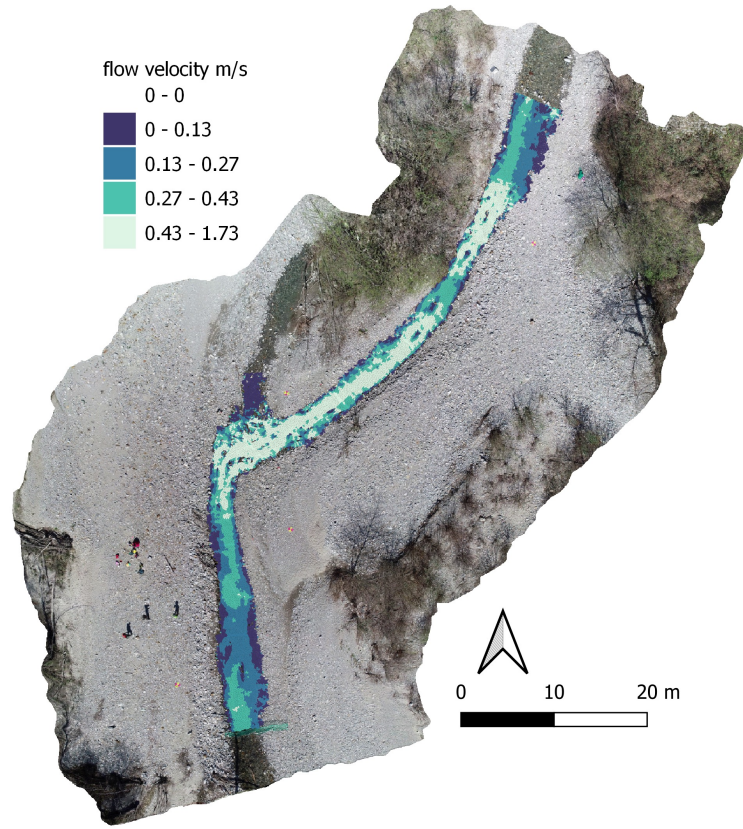
Floodplain vegetation at Moesa river, Graubünden (photo: Sabine F.)

Modelling plant seed dispersal

BASEMENT v3.2
(Eulerian)



Lagrangian module



Implementation in BASEMENT and showcase

Daniel A. S. Conde

Implementation in BASEMENT

- Governing equations:
 - **One-way coupling:** size is low enough to disregard momentum transfers between them and the surrounding fluid
 - **Tracer approach:** particles advected according to the fluid velocity field (2DH)

$$\boxed{\vec{x}_p} = \boxed{\vec{u}_f}$$

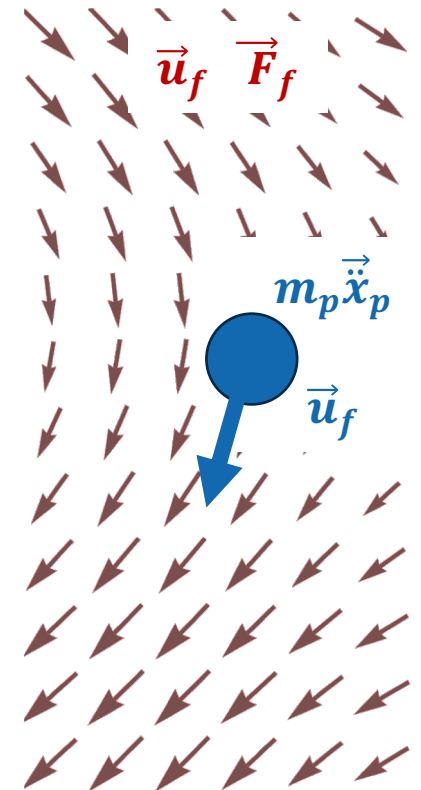
Lagrangian Eulerian

- **Particle approach:** particles with momentum conservation (2DH + 1DV)

$$m_p \ddot{\vec{x}}_p = \vec{F}_{p,g} + \vec{F}_f$$

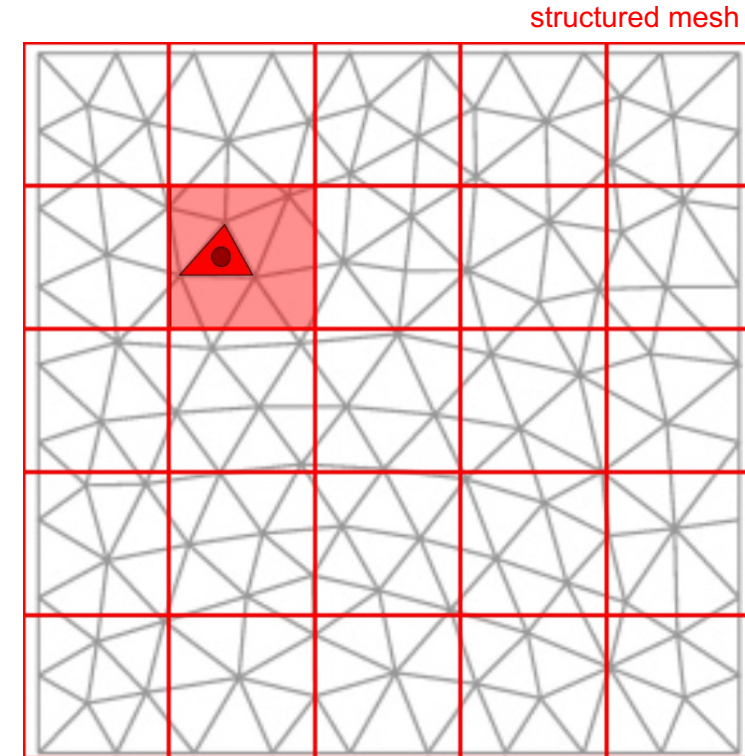
- **Vertical motion:** computed from settling and suspension closures (1DV)

$$\dot{z}_p = w_s + r_s$$



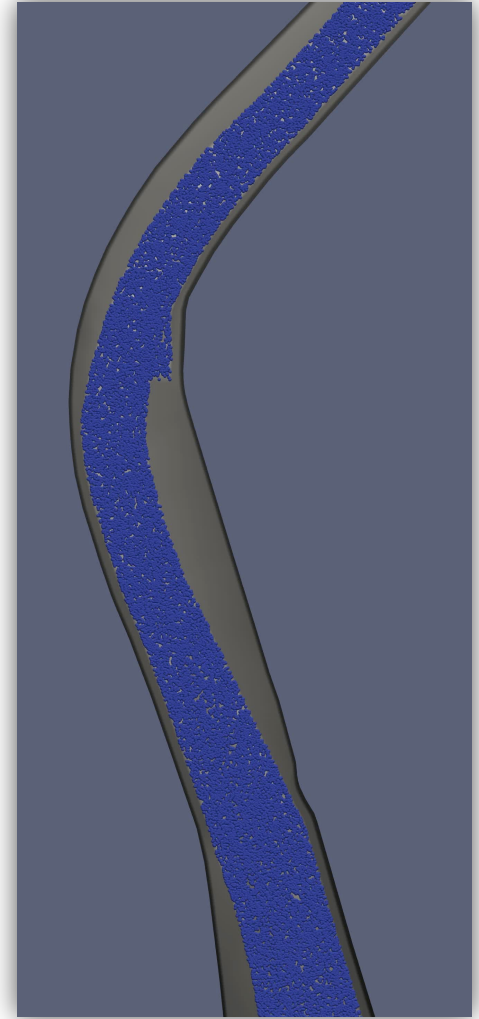
Implementation in BASEMENT

- Technical implementation:
 - BASEMENT is an **unstructured mesh solver**: including **meshless** methods requires considerable adaptation of the existing code base
 - A **structured ‘virtual’ mesh** is used in order to index the underlying triangular mesh, acting as a **proxy** between the **Lagrangian kernels** and **Eulerian data**
 - Lagrangian **particle position** can be **directly** mapped to the **structured mesh**, then a geometrical search algorithm probes the **triangular cell** for flow data



Implementation in BASEMENT

- Technical implementation:
 - **Fully parallelized** in all backends of BMv3
 - **Low memory requirement**, thousands of particles can be used with <1GB of additional memory
 - **Low computational overhead**, less than 25% increase in CPU simulations and less than 20% increase for GPU (comparable number of particles and cells)
 - **Dedicated output** (xdmf) for particle-based results



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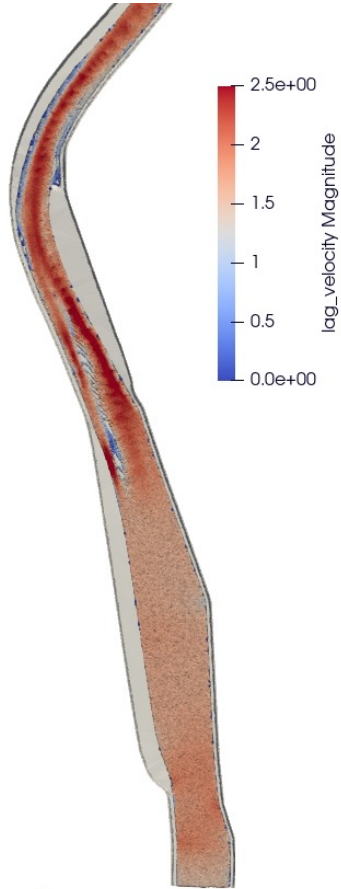
Eulerian velocity field

Lagrangian velocity field

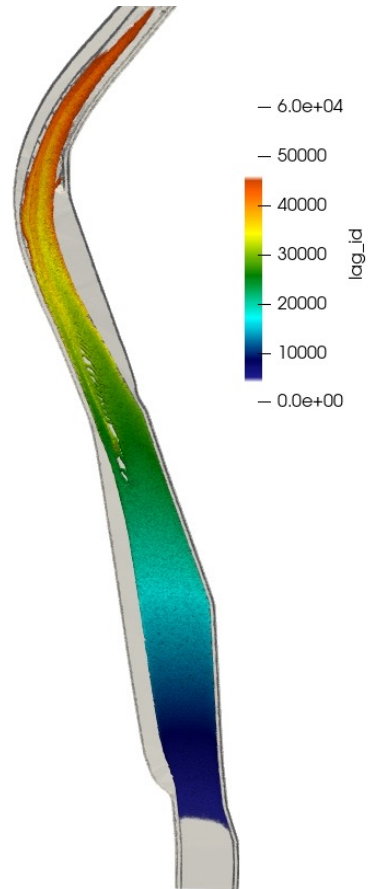
Alpine Rhine case



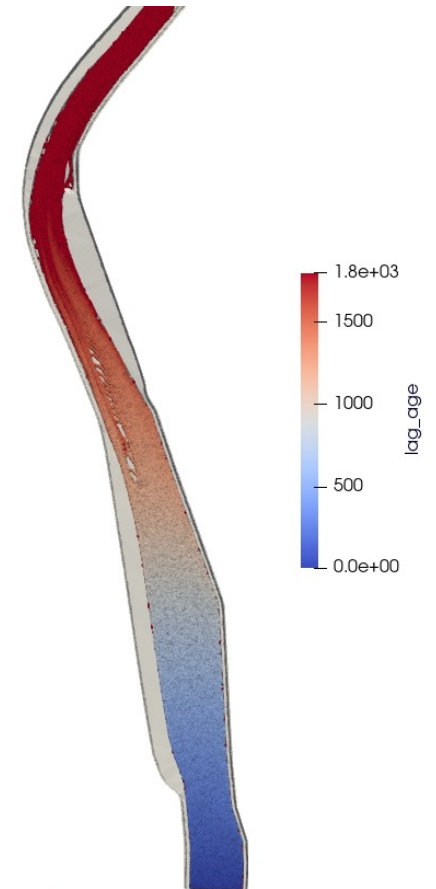
Alpine Rhine case – output quantities



particle velocity (m/s)



unique particle ID

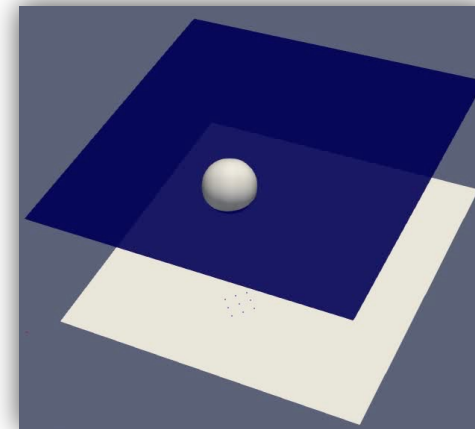
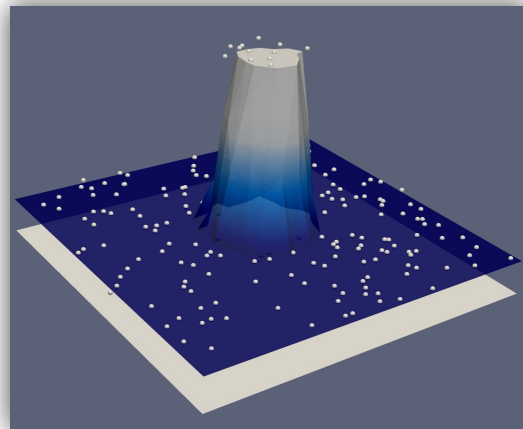


particle age (s)
since insertion

Conclusion and outlook

- Combination of **Eulerian and Lagrangian** approaches
- Generalizable for **several particle types**
- **Low computational overhead**, normally less than 10% increase in compute time
- **Dedicated output** format for particles (e.g. in ParaView)
- The implementation of a Lagrangian framework in BMv3 will bring **advanced capabilities for fluvial debris modelling**:

small particles
one-way coupling



large debris
two-way coupling
(early tests)

Thank you for your attention!

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