The Rio Rotiano event and its challenges to the mathematical and numerical modelling of debris flow phenomena

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Dipartimento di Ingegneria Civile, Ambientale e Meccanica

Flood hazard, mitigation works and residual risks: how can we manage changes over time?

OCTOBER 9-10 2023

Sala della Cooperazione, Trento (Italy)

The basin characteristics

geometry

- Area: $2.5\ km^2$
- Maximum elevation: $2050m\ AMSL$
- Minimum elevation: $840m\ AMSL$
- Average slope: $0.51\ m/m$
- Melton ratio: 0.78

geology

- Substrate outcrops in the upper and lower part
- Würmian sandy glacial deposits with large boulders in the middle part

(Data by CNR-IRPI)

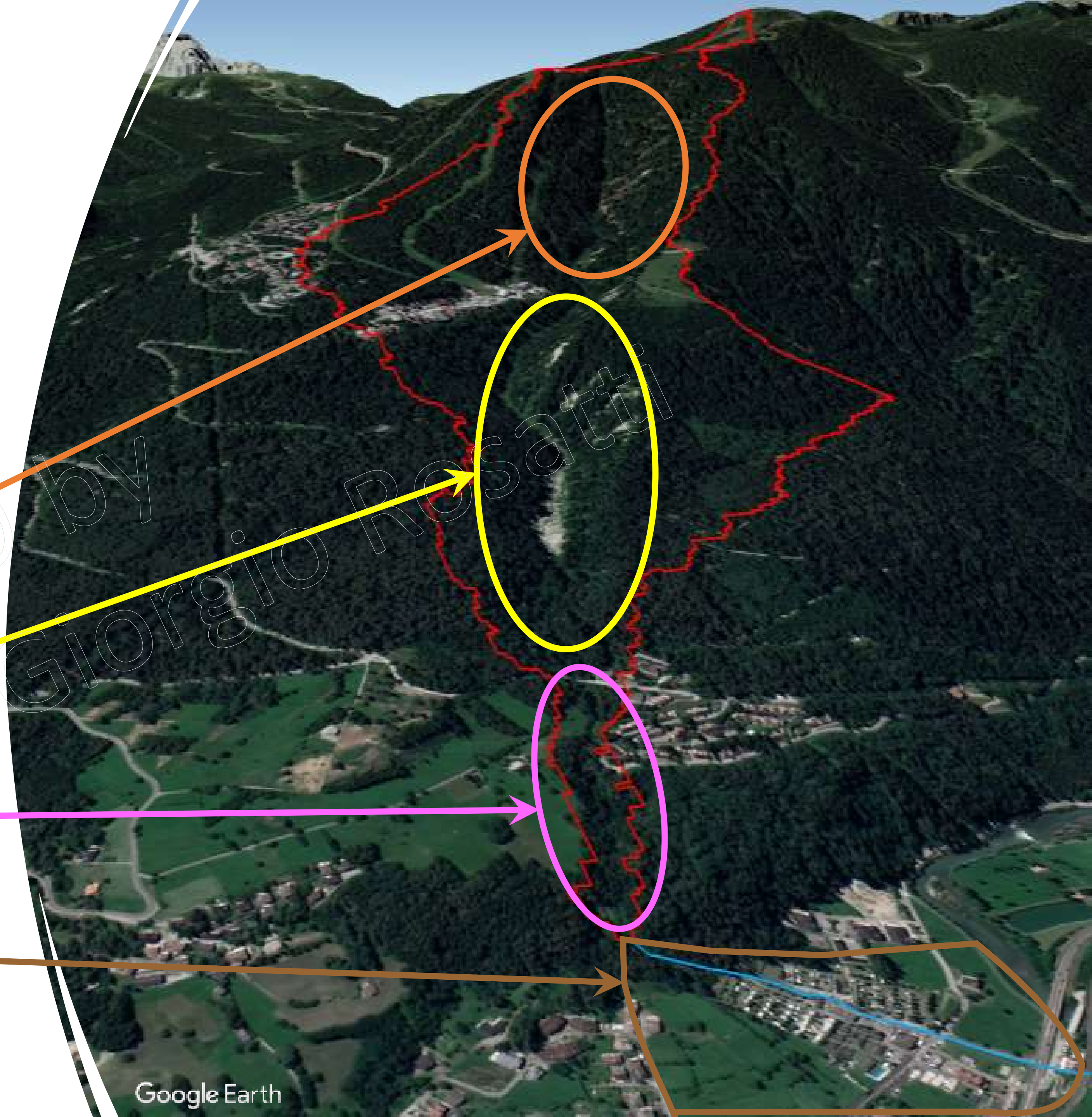
The creek characteristics

Upper part (40% ÷27%)

Middle stretch (~25%):

Rocky gorge with a small waterfall

Conoid



The system of protection works before the event

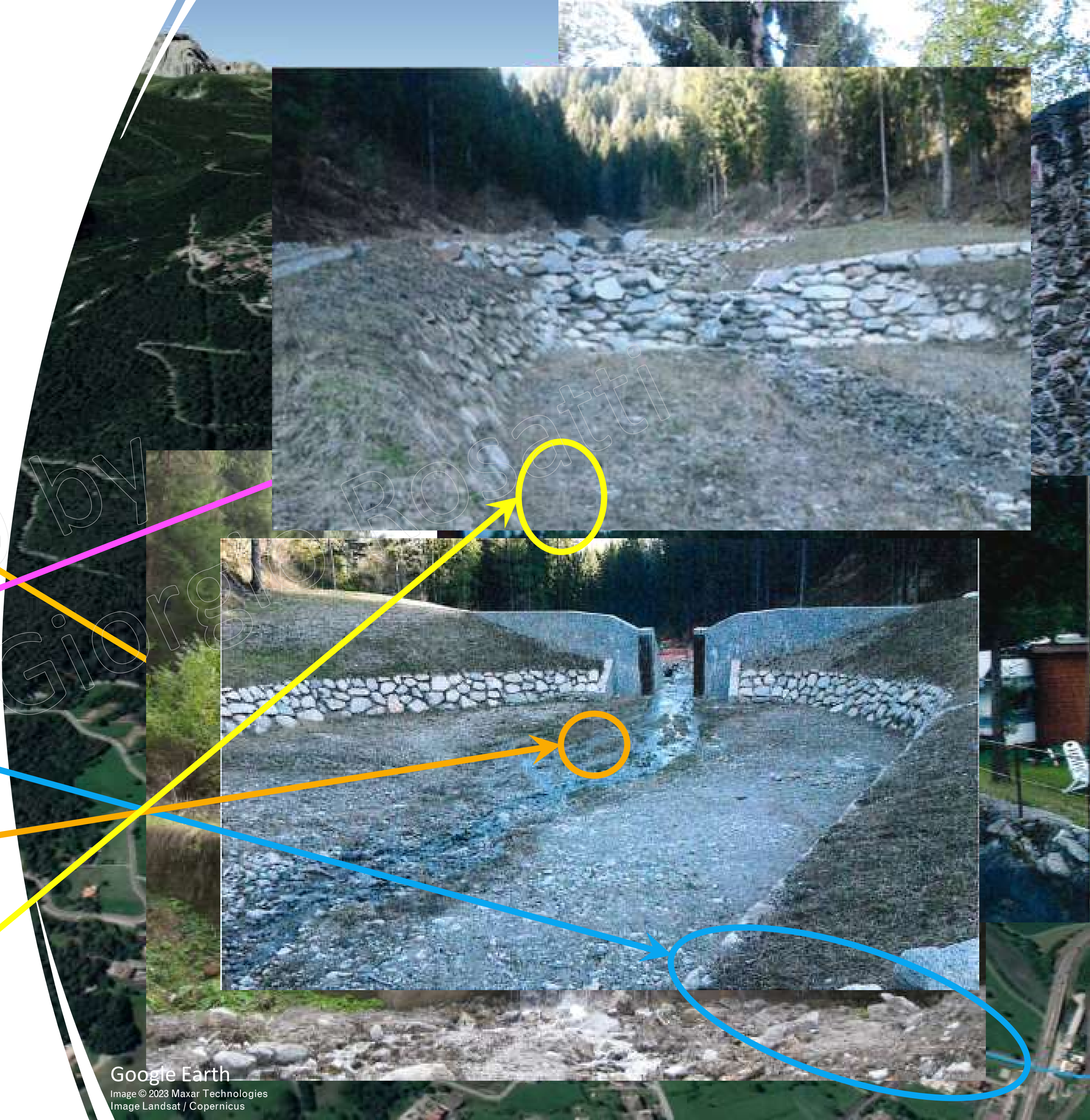
Diversion embankment (1882)

16 check dams (70s)

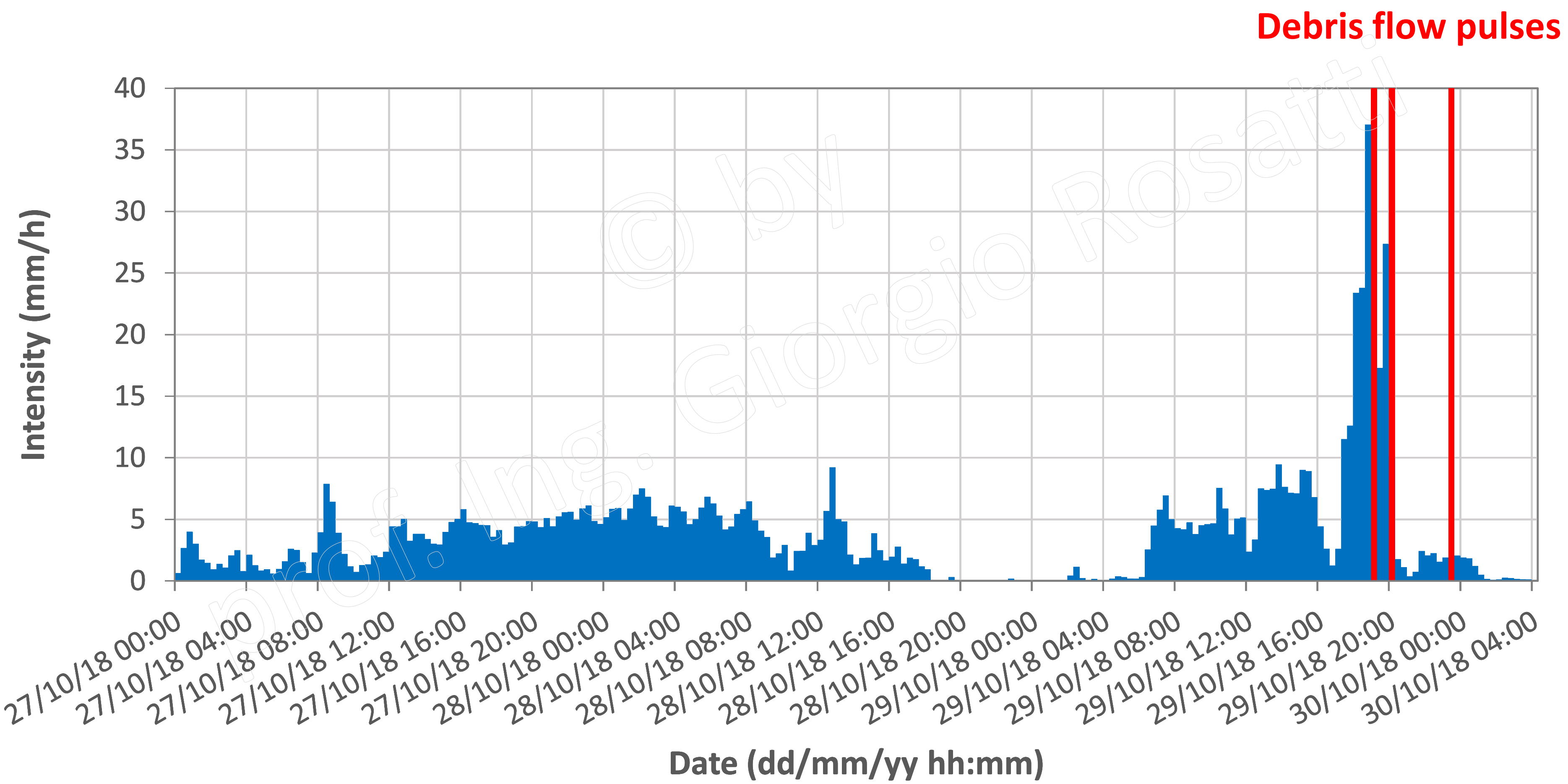
Paved channel (1986)

Slit check dam (1993)

Sediment storage area with a final open check dam (2012-2018)



27-30 October 2018
in the Rio Rotiano basin



(Data by TESAF)

The consequences

in the conoid

The consequences

in the conoid

The consequences

in the conoid

The consequences

in the conoid

~ **160.000 m³ of sediments deposited in the conoid**

(Data by CNR-IRPI)

The consequences

in the conoid

before...

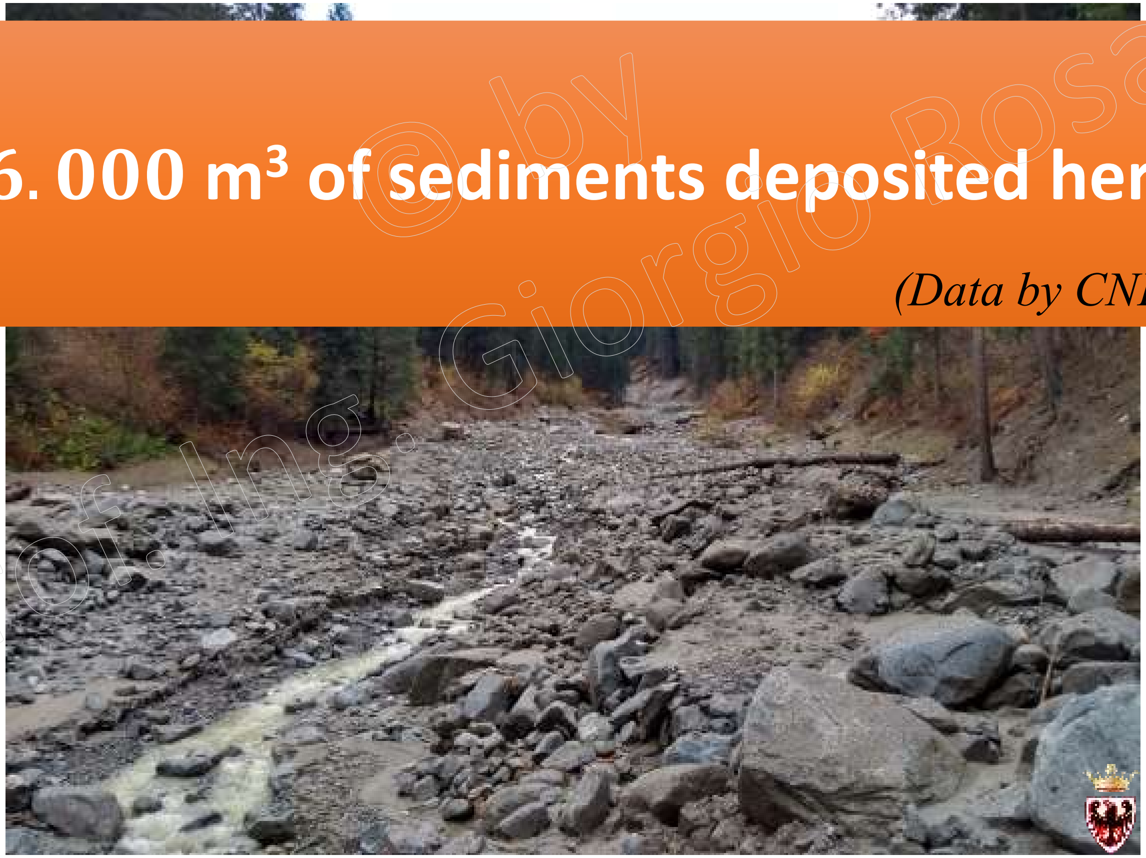
...after

The consequences

in the sediment storage areas

The consequences

in the sediment storage areas



~ 16. 000 m³ of sediments deposited here

(Data by CNR-IRPI)

The consequences

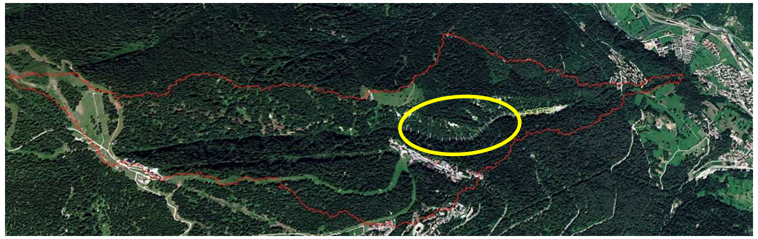
in the sediment storage areas

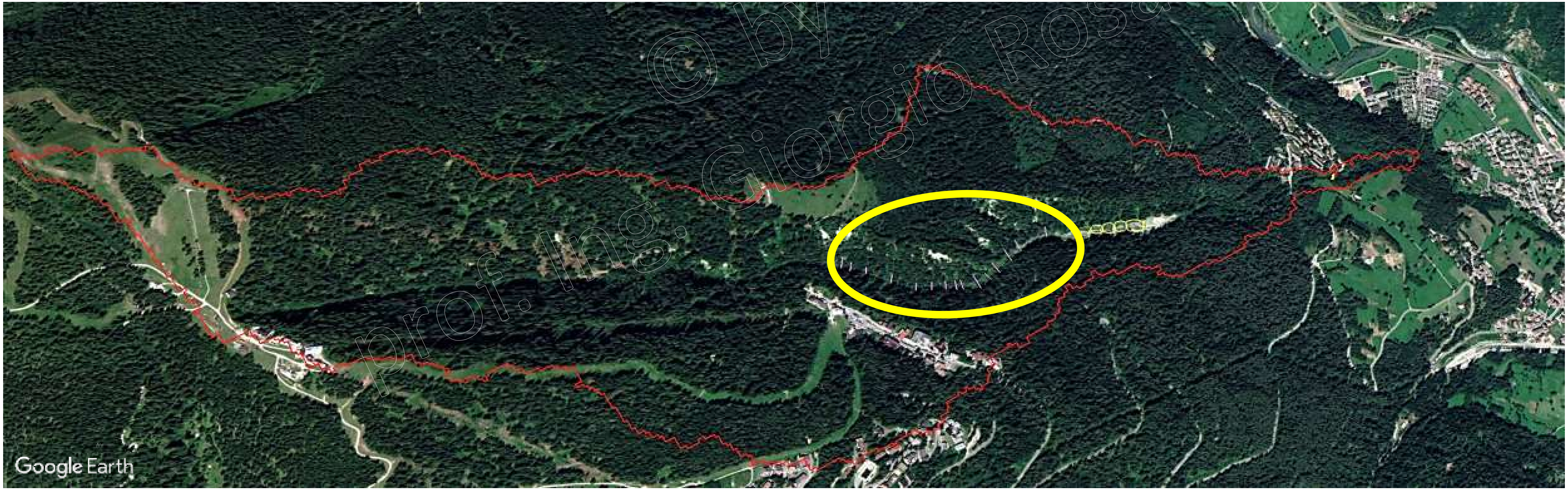
The consequences

Sediment storage areas

The consequences

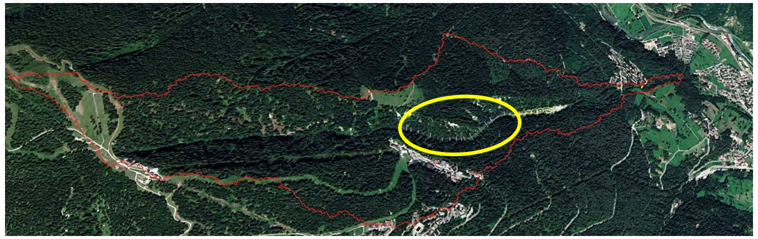
on the 16 check dams





The consequences

on the 16 check dams



before...

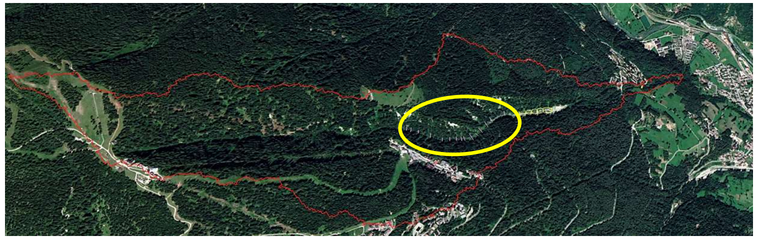
...after

~ 100. 000 m³ of sediments eroded here

(Data by CNR-IRPI)

The consequences

the 16 check dams



After the event…
the GPR Research Project

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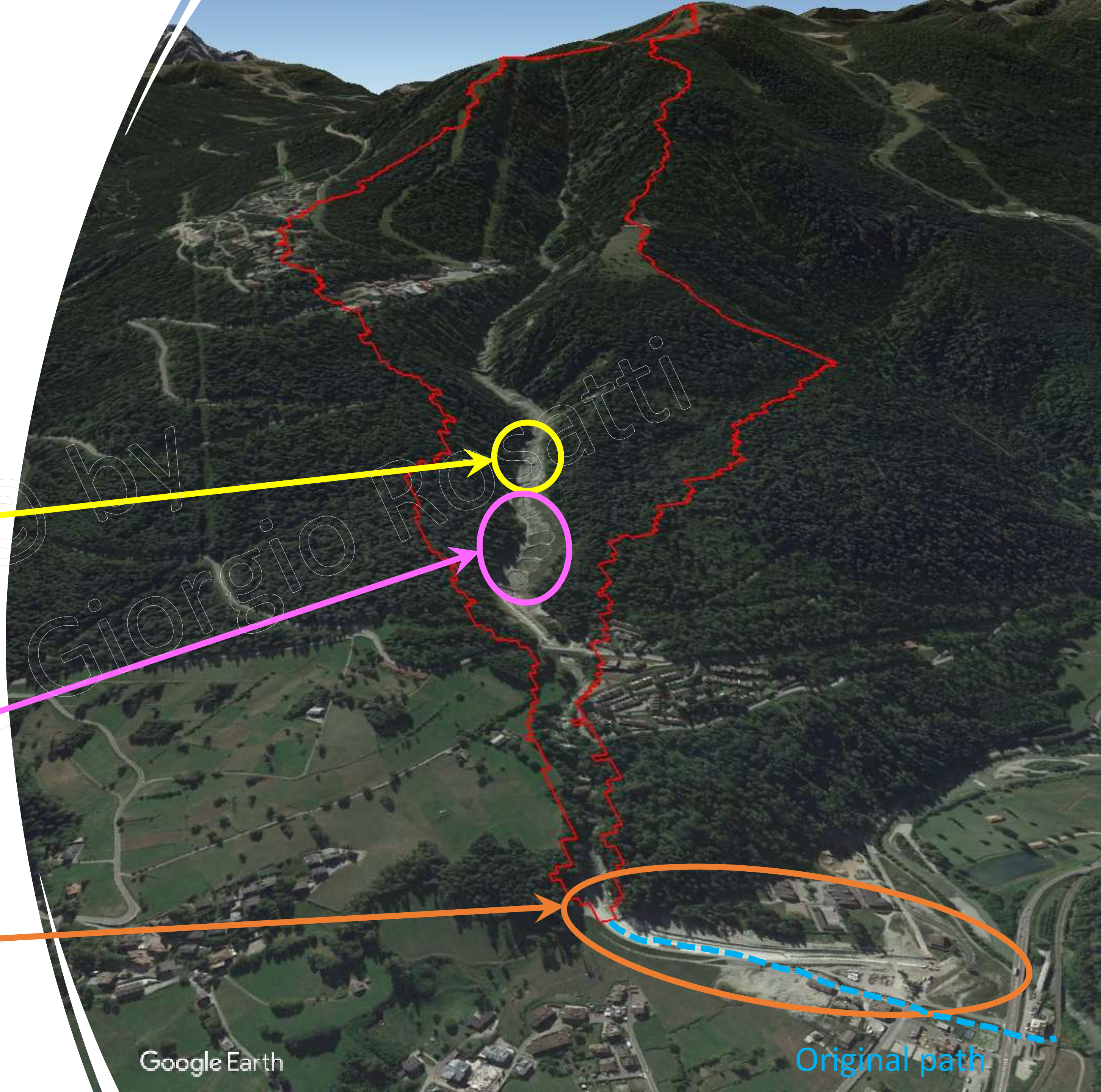
- assessing of the effectiveness of a new system of protection works
- trying to understand what happened

Protection works: from the old… to the new system

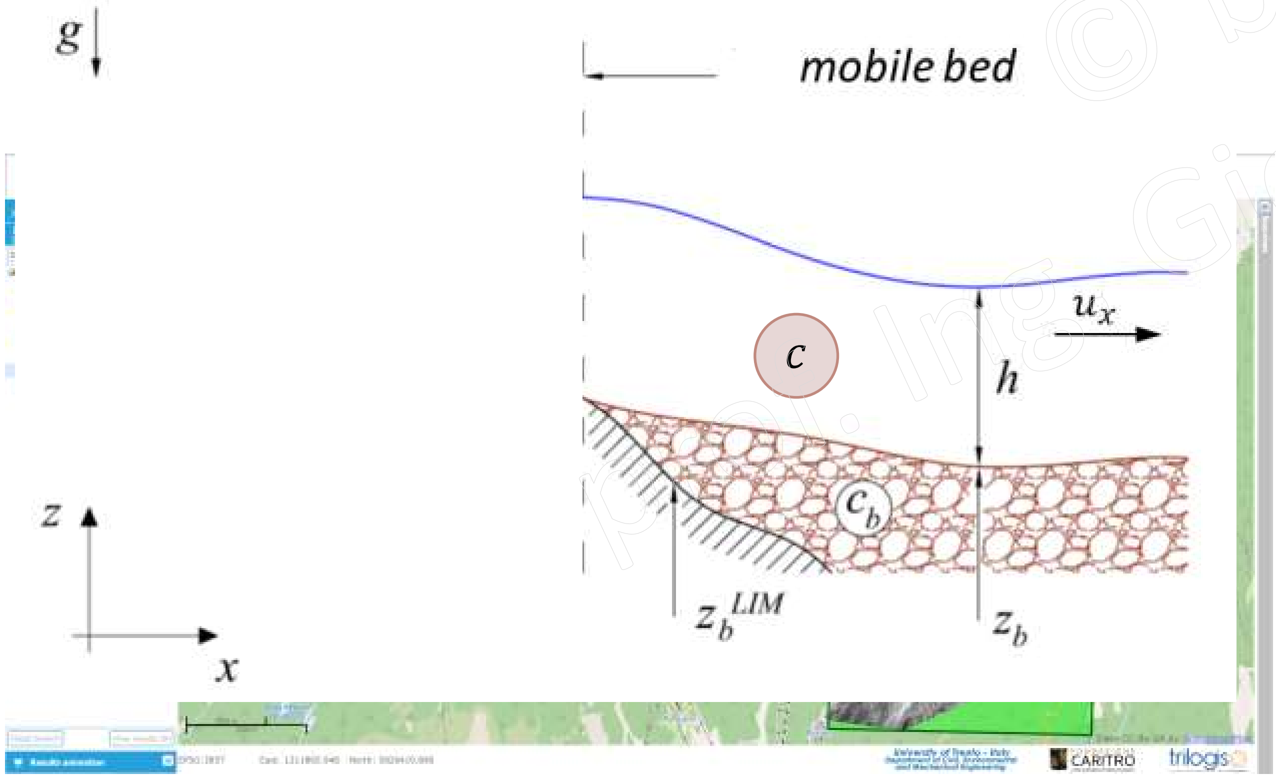
Restoration of the sediment storage areas and the open check dam

New sediment storage area with a final open check dam

New diversion embankment and paved channel



The available tool: the TRENT2D model

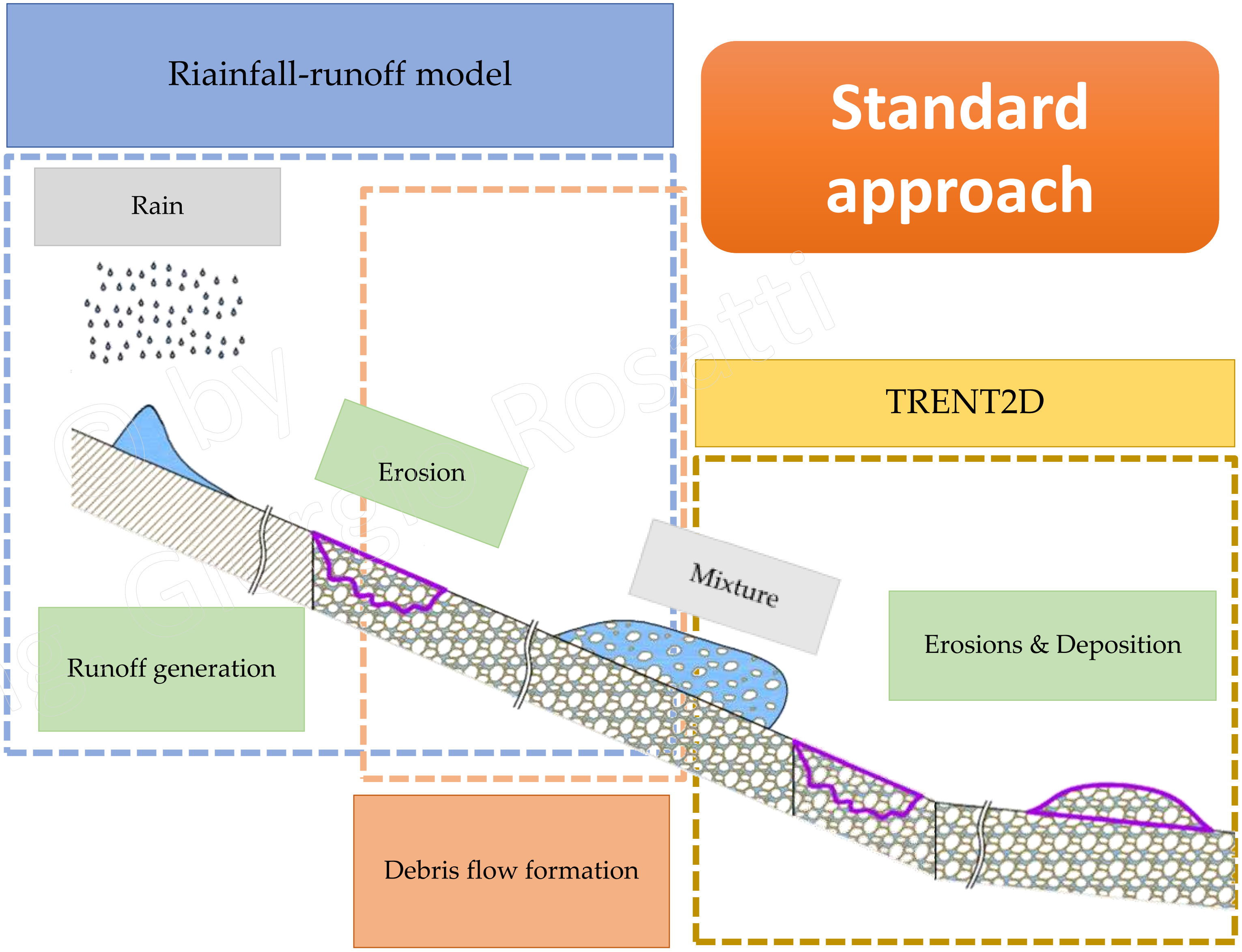


Main features:

- ✓ Two-phase, phase-averaged description (mixture theory)
- ✓ Basic assumptions:
  - Shallow-flow
  - Isokinetic behaviour
- ✓ 2D depth averaged PDEs
- ✓ Bed: mobile, non-erodible, and fixed bed
- ✓ Managed through WEEZARD (*https//tool.weezard.eu*)

The context of applicability

- Cascade modelling:
  - Evaluation of the liquid runoff
  - Estimate of the solid discharge (e.g., Takahashi amplification factor)
  - Propagation of the incoming debris flow (no additional rain contribute)



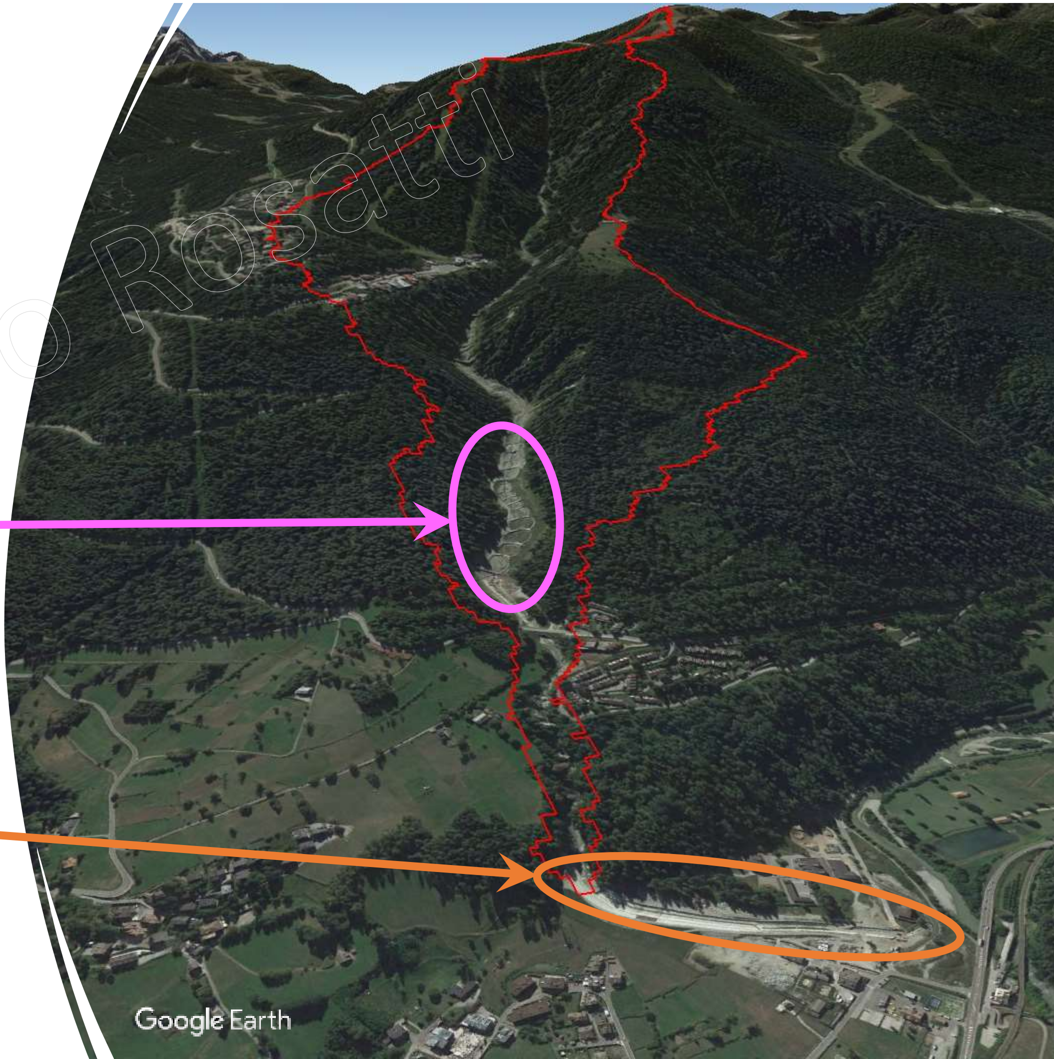
Assessment of the effectiveness of the planned protection works

Standard approach

- The old sediment storage area with a final open check dam
- The new sediment storage area with a final open check dam

Special features!

- New diversion embankment and paved channel

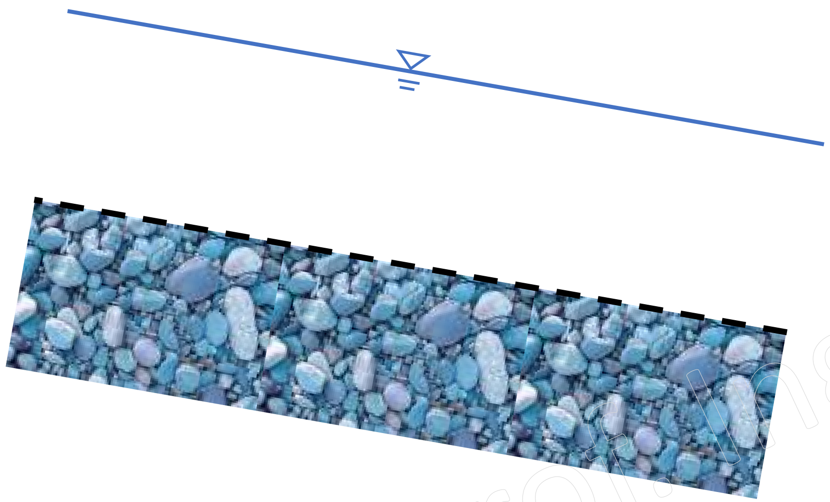


Assessment of the effectiveness of the paved channel

Challenge 1:
careful simulation of debris flow along this stretch

Uniform flow conditions with collision-dominated solid flow

Mobile bed

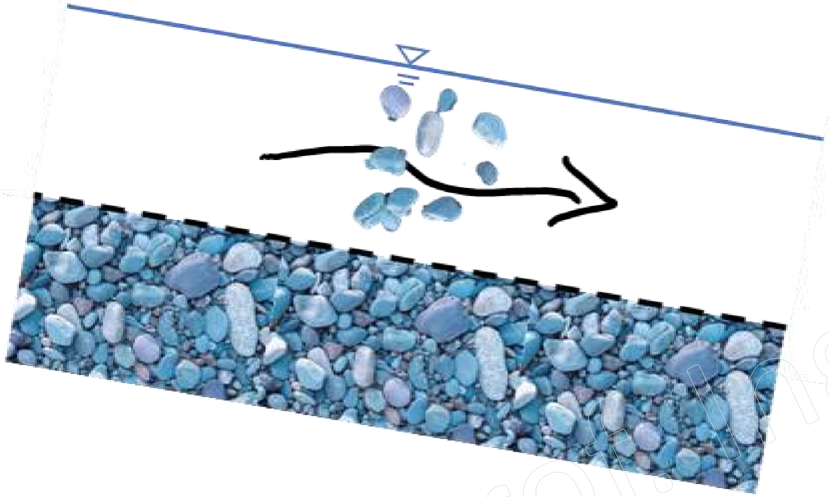


q_s, c } Univocal value!

Transport capacity function

Uniform flow conditions with collision-dominated solid flow

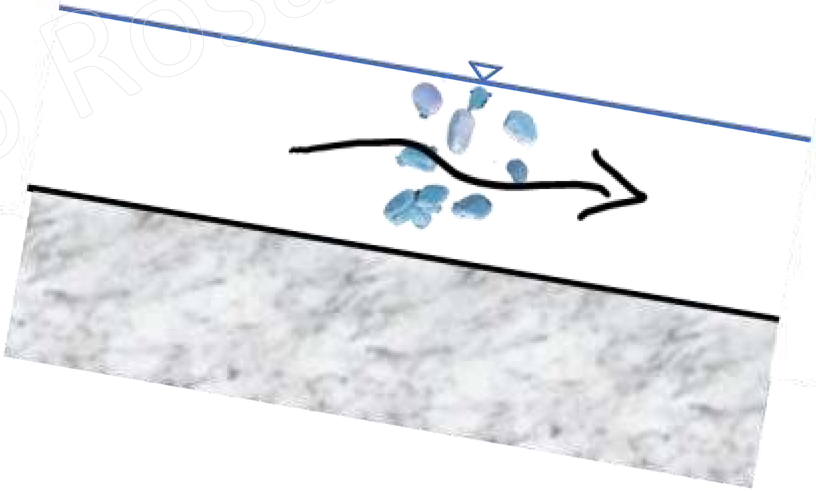
Mobile bed



q_s, c } Univocal value!

Transport capacity function

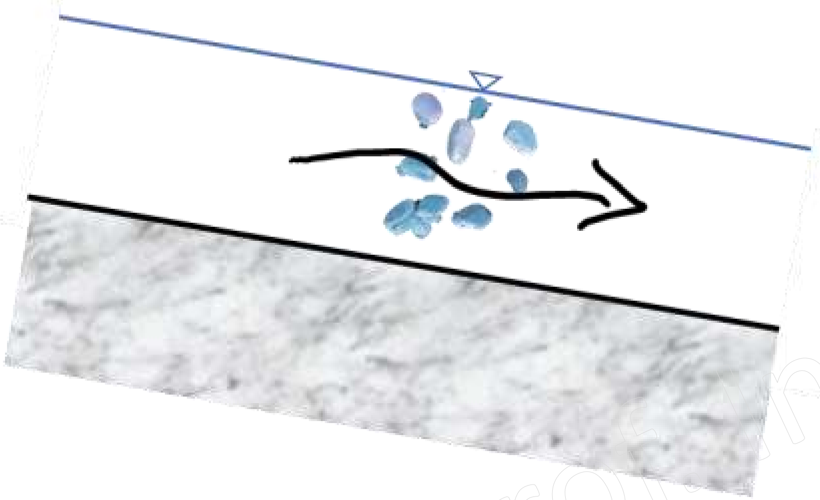
Non-erodible bed



q_s, φ } Non-univocal value!

Uniform flow conditions with collision-dominated solid flow

Non-erodible bed



q_s, φ } Non-univocal value!

- Does a solid discharge limit exist?
- Is this limit equal to the transport capacity on a mobile bed subjected to the same uniform flow conditions?
- What happens if I exceed this limit?

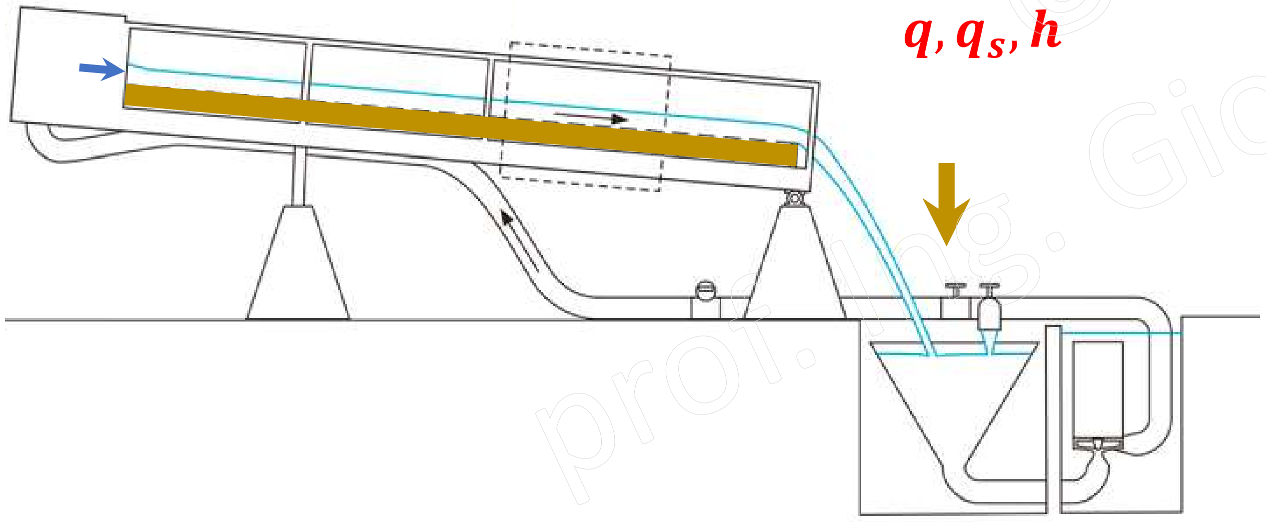
Empirical approach

The lab experiment

$$\begin{cases} \hat{q}_s = \dfrac{\mathbf{q_s}}{d\sqrt{g\,\Delta d}} \\ \hat{\tau} = \dfrac{\tau_0}{\gamma \Delta d} = \dfrac{(1 + c\Delta)\mathbf{h} \sin\psi}{\Delta d} \end{cases}$$

Measures:

$\boldsymbol{q, q_s, h}$



where

d = sediement diameter

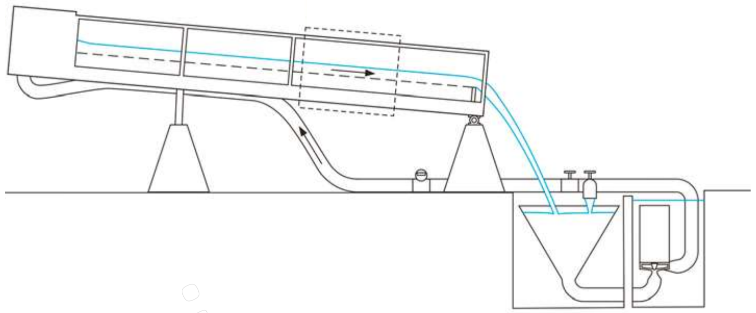
$$\Delta = \frac{\rho_s - \rho}{\rho}$$

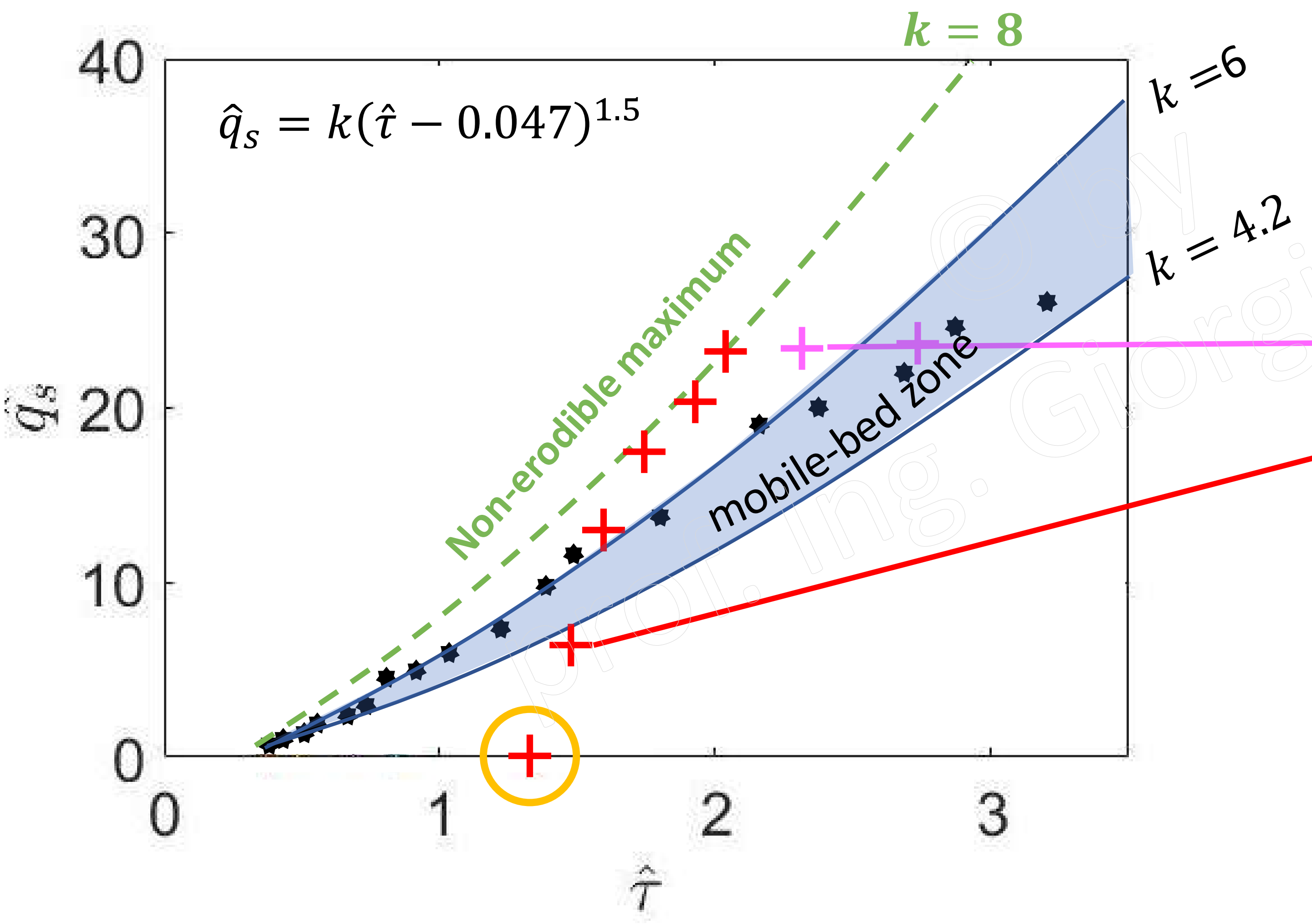
$$c = \frac{q_s}{q}$$

q = mixture discharge (per unit width)

ψ = bed inclination angle

Results





$$\begin{cases} \hat{q}_s = \dfrac{q_s}{d\sqrt{g\,\Delta d}} \\ \hat{\tau} = \dfrac{(1 + c\Delta)\,h \sin\psi}{\Delta d} \end{cases}$$

$\hat{q}'_s = \hat{q}'_s(\hat{\tau}, d_{50})$ / $f(\hat{\tau}), f_s(\hat{\tau})$

Solid discharge limit over non-erodible bed

Uniform flow conditions with collision-dominated solid flow

?

- A solid discharge limit $\hat{q}'_s$ does exist

$$\begin{cases} \hat{q}'_s(\hat{\tau}) > \hat{q}_s(\hat{\tau}) \;\; \mathit{if} \;\; (e_s/d_{50}) \ll 1 \\ \hat{q}'_s(\hat{\tau}) \approx \hat{q}_s(\hat{\tau}) \;\; \mathit{if} \;\; (e_s/d_{50}) \approx 1 \end{cases}$$

- If I exceed this limit, we have quick transition to mobile-bed and an increase of bed slope

$\hat{q}'_s(\hat{\tau})$: solid discharge limit over non-erodible bed
$\hat{q}_s$ $(\hat{\tau})$: transport capacity function over mobile bed

We implemented the relation in the model

The need for a physical model

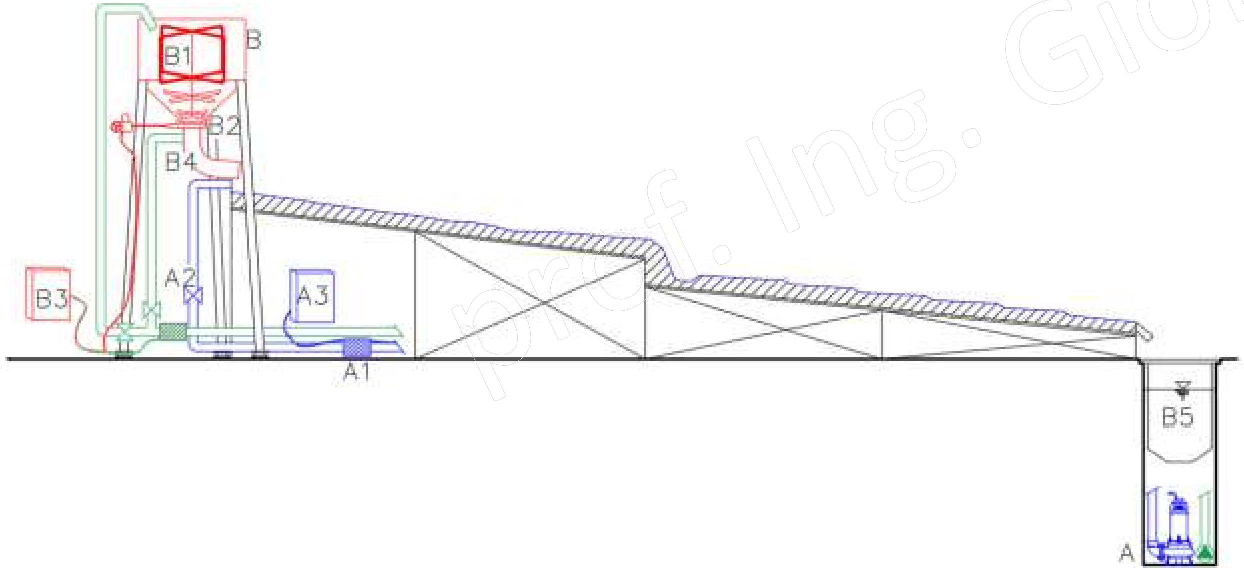
1. To validate the capabilities of the numerical model to simulate a DF in the paved channel and in the rocky gorge;
2. To understand the behaviour of the freefall, hard to reproduce by a 2D model

The need for a physical model

1. To validate the capabilities of the numerical model to simulate a DF in the rocky gorge and paved channel;
2. To understand the behaviour of the freefall, hard to reproduce by a 2D model

Features of the physical model

- Geometric scale: $\lambda = 1/30$
- Froude similitude



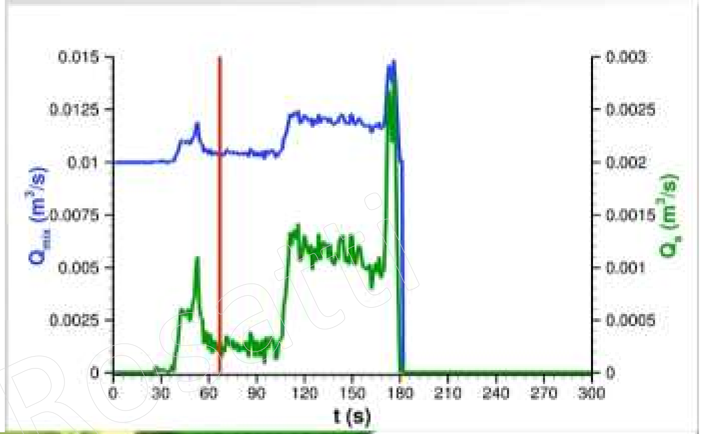
Feeding tank

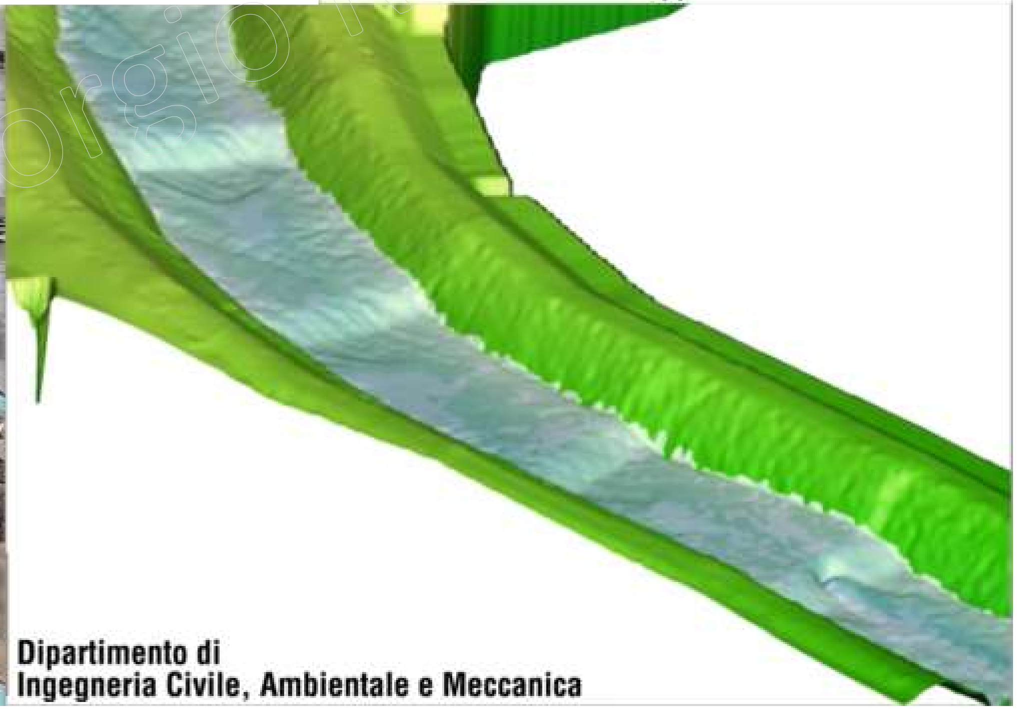
Roky gorge

Paved channel

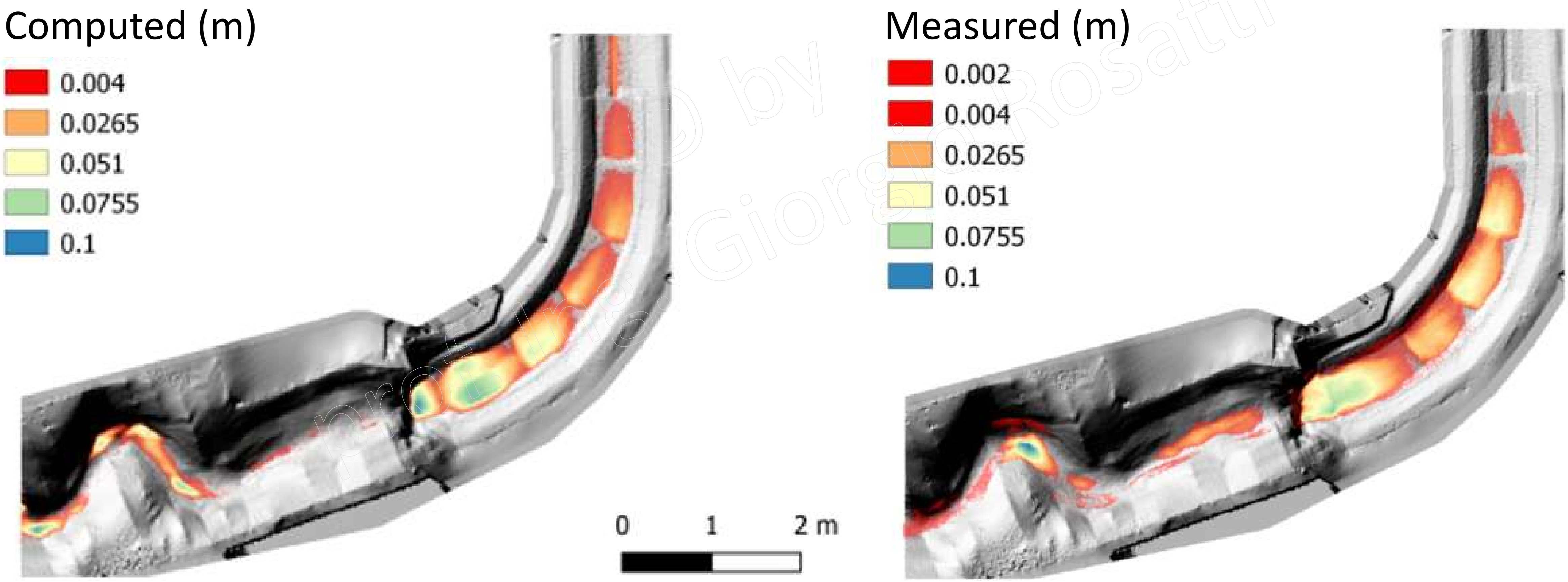
Some tests

Comparison 1: dynamics





Comparison 2: final deposits



Application to the lower part of the Rotiano
(effectiveness, hazard assessment)

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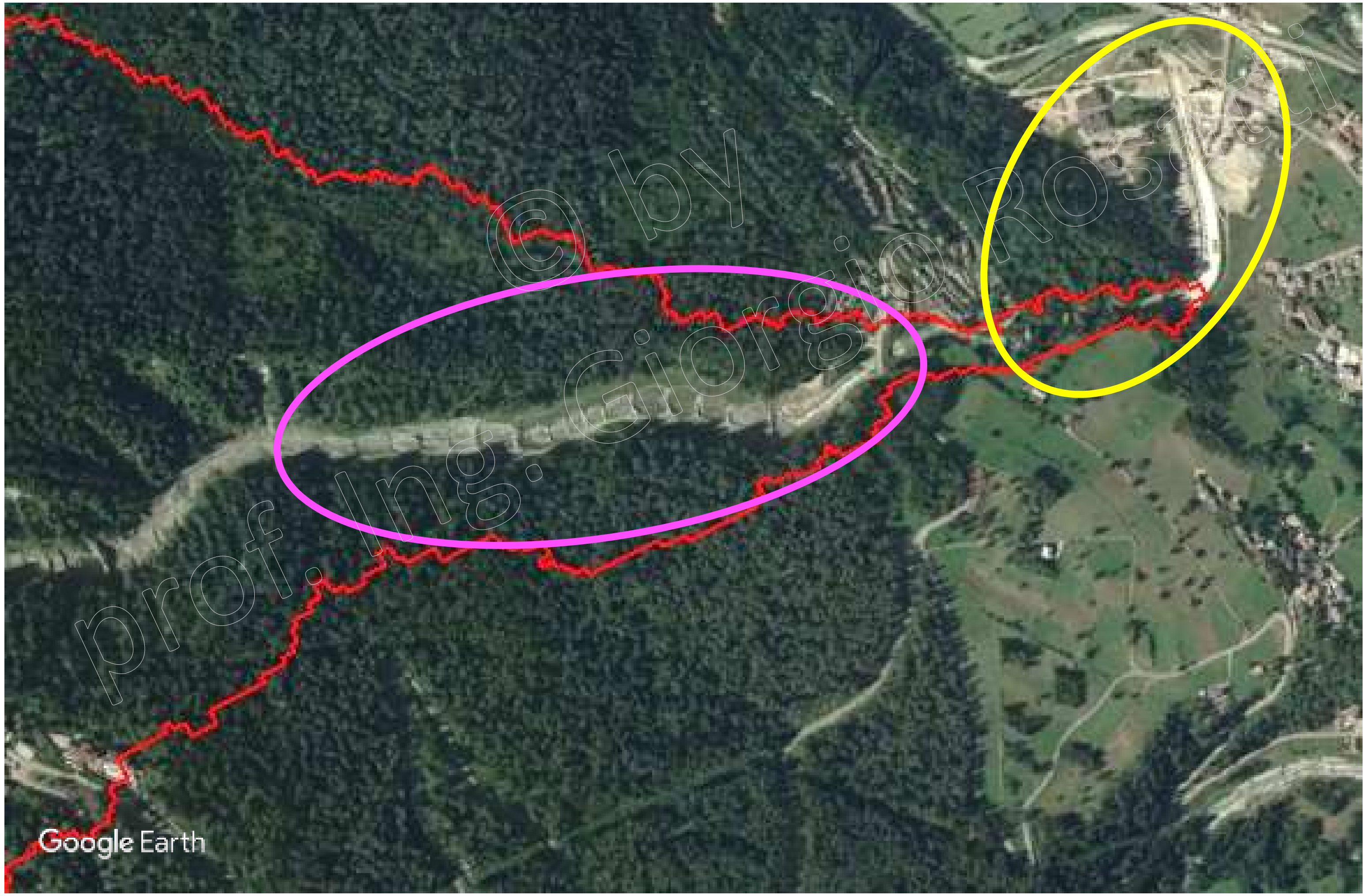
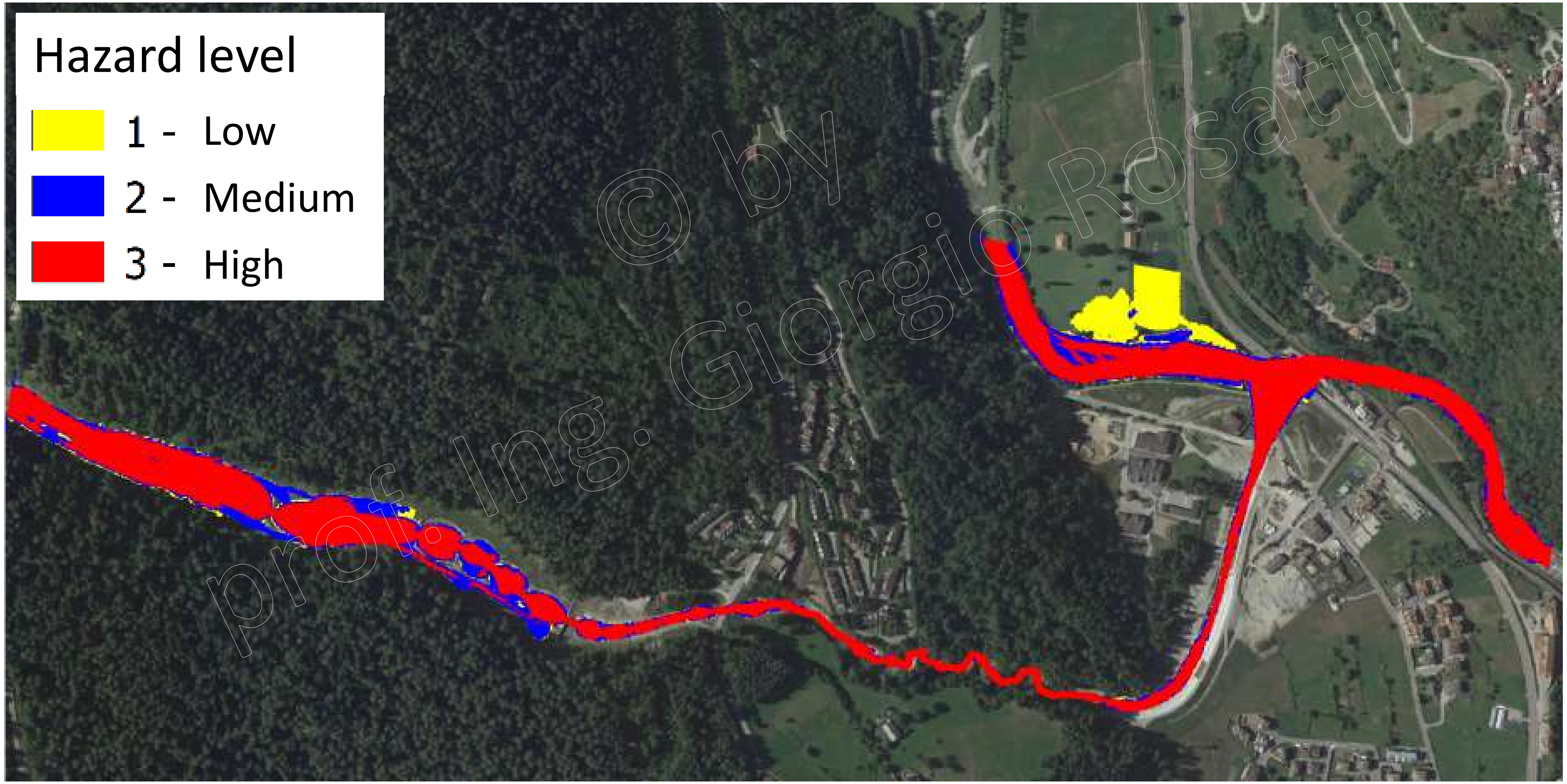
(effectiveness, hazard assessment)



Hazard map



Hazard level
1 - Low
2 - Medium
3 - High
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Residual hazard scenarios

1. Sudden collapse of the residuals of the closed check dams; 200-years RP hydrograph as upstream forcing.

2. Sudden collapse of the residuals of the closed check dams with the old slit check dam in clogged conditions; 200-years RP hydrograph as upstream forcing.

3. Slope collapse and consequent remodelling of the riverbed in the part upstream of the old storage area; 200-years RP hydrograph as upstream forcing.

Scenario 3
maximum deposits map

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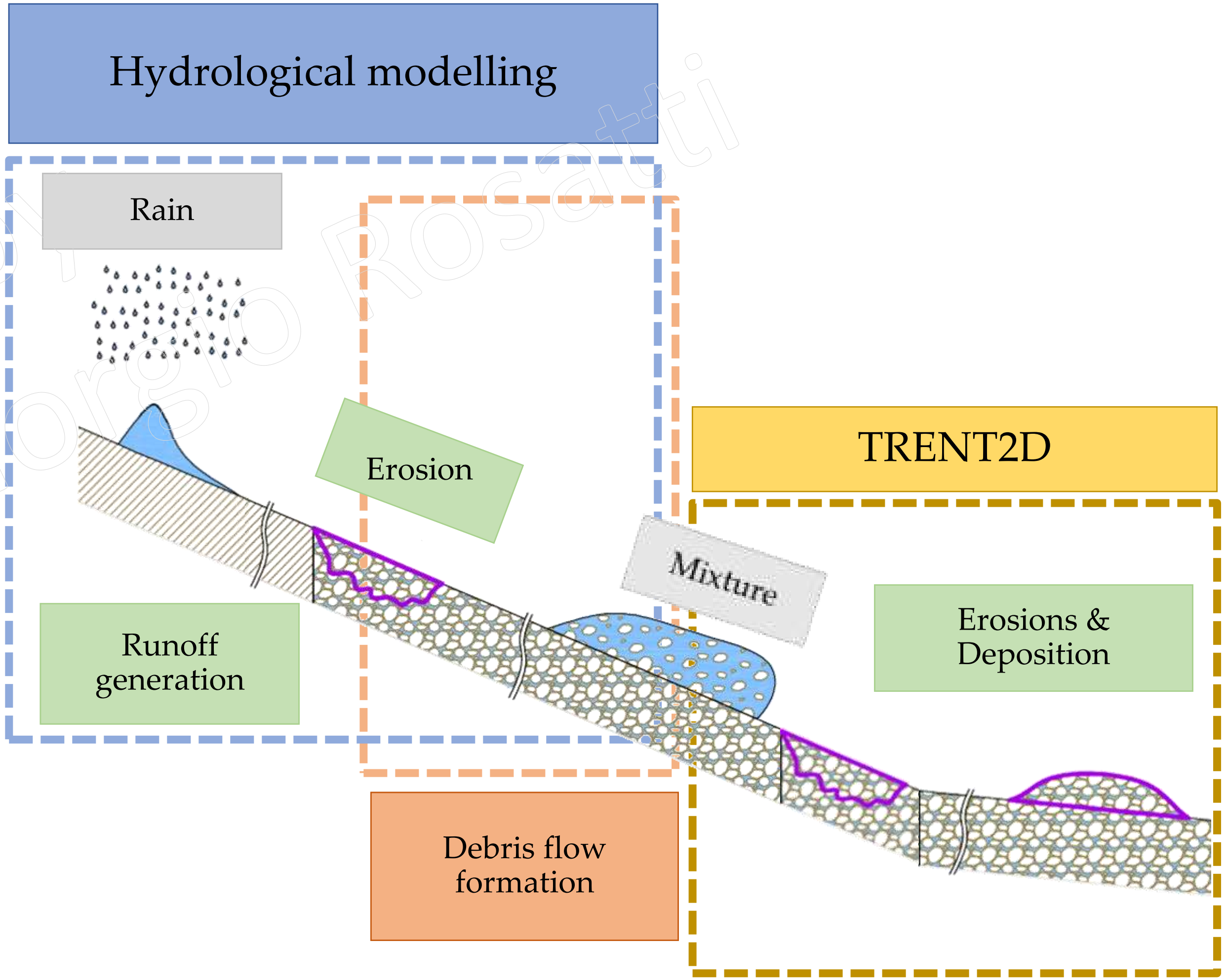
- assessing of the effectiveness of a new system of protection works
- trying to understand what happened

The features of the event

1. The debris flow affected almost the entire length of the creek;

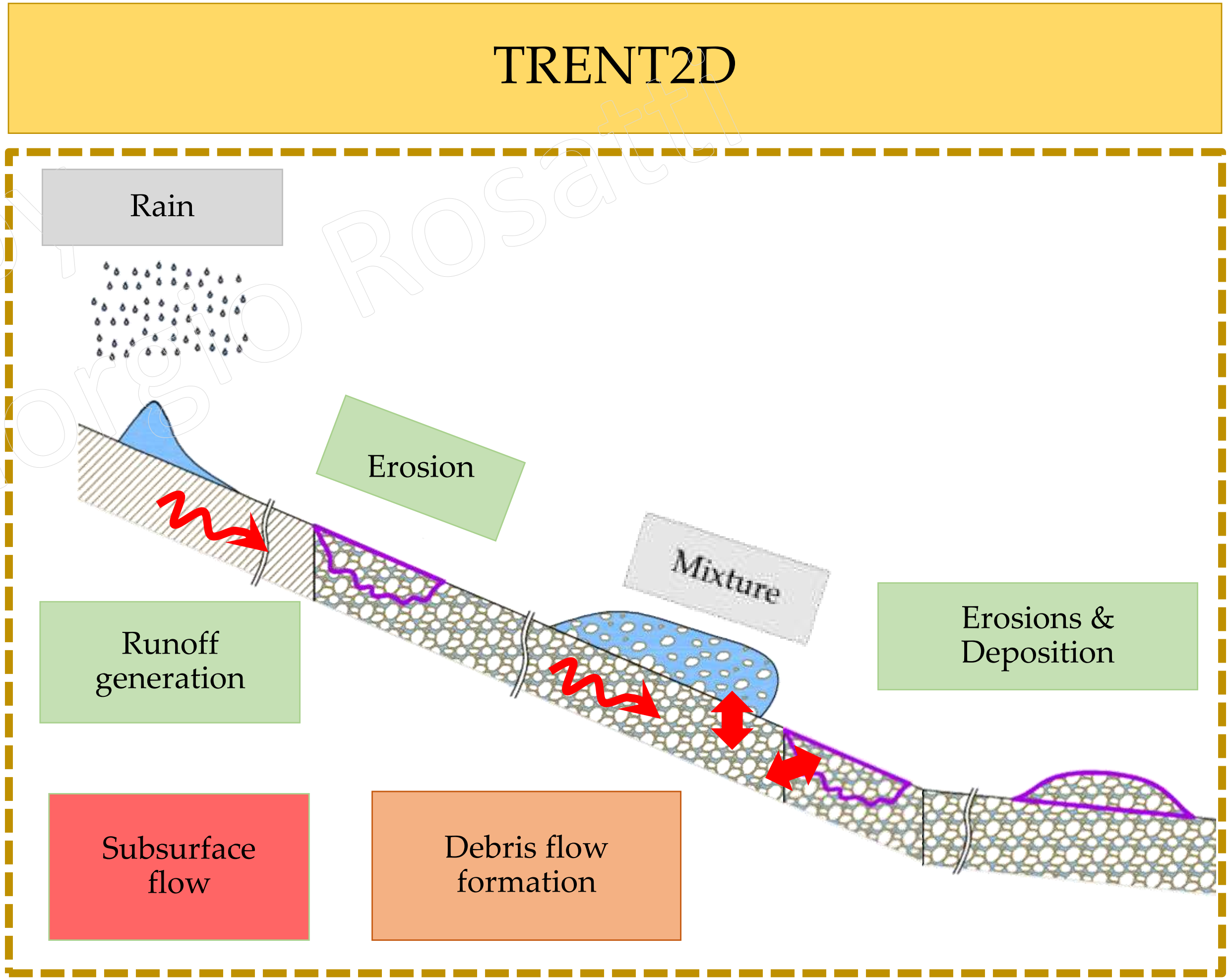


The features of the event

1. The debris flow affected almost the entire length of the creek;

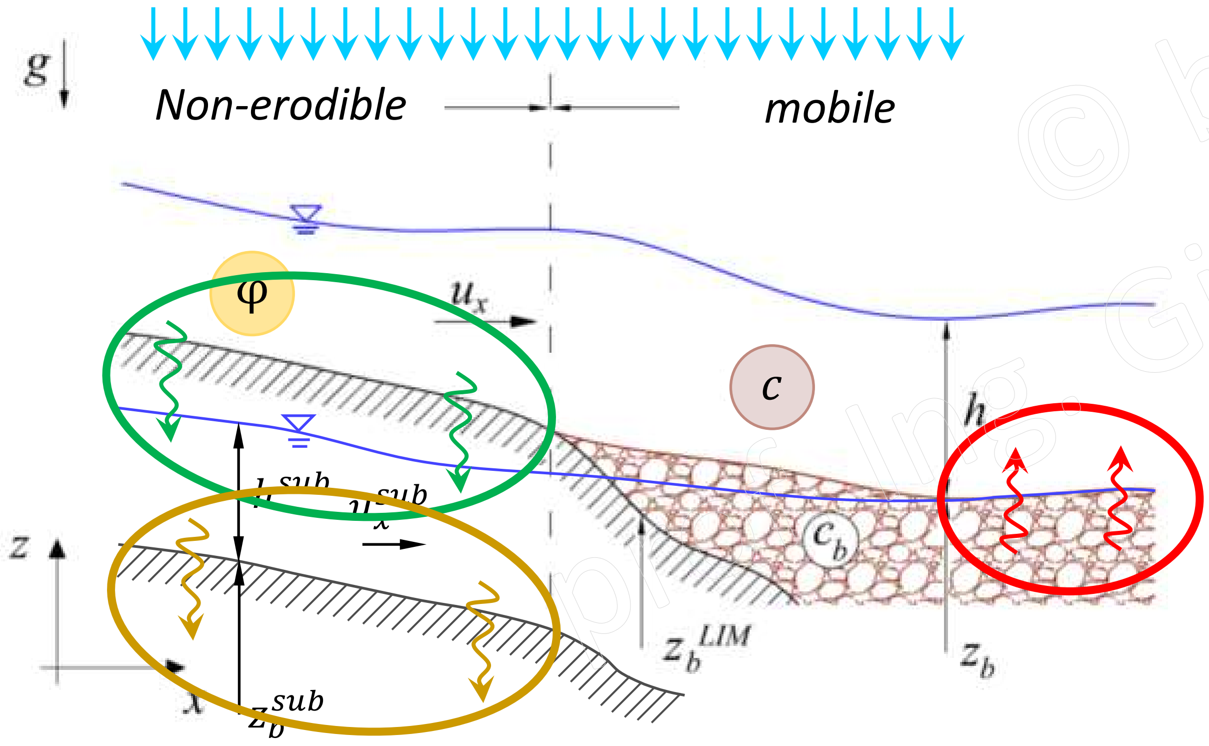
Challenge 2:
a mobile-bed rainfall-runoff distributed model

3. Due to the large erosions, subsurface flow was influenced by bed variations.



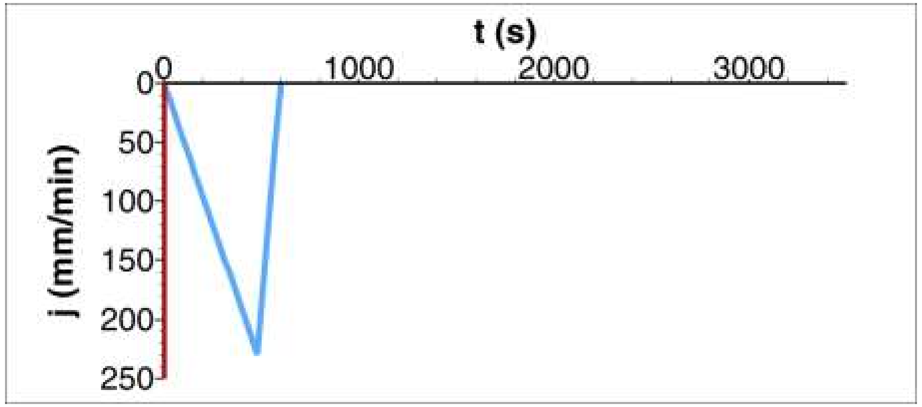
The TRENT2D^{MBRR}

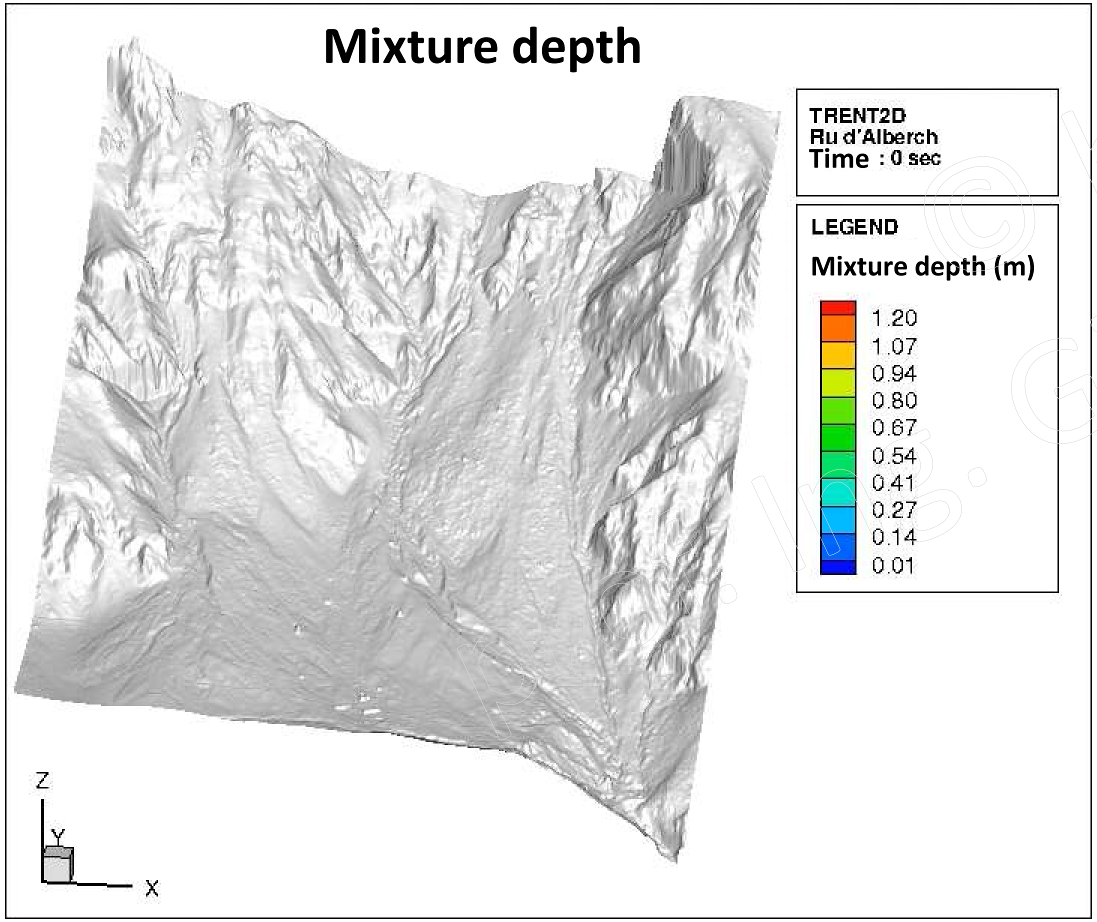
a debris flow model at basin scale

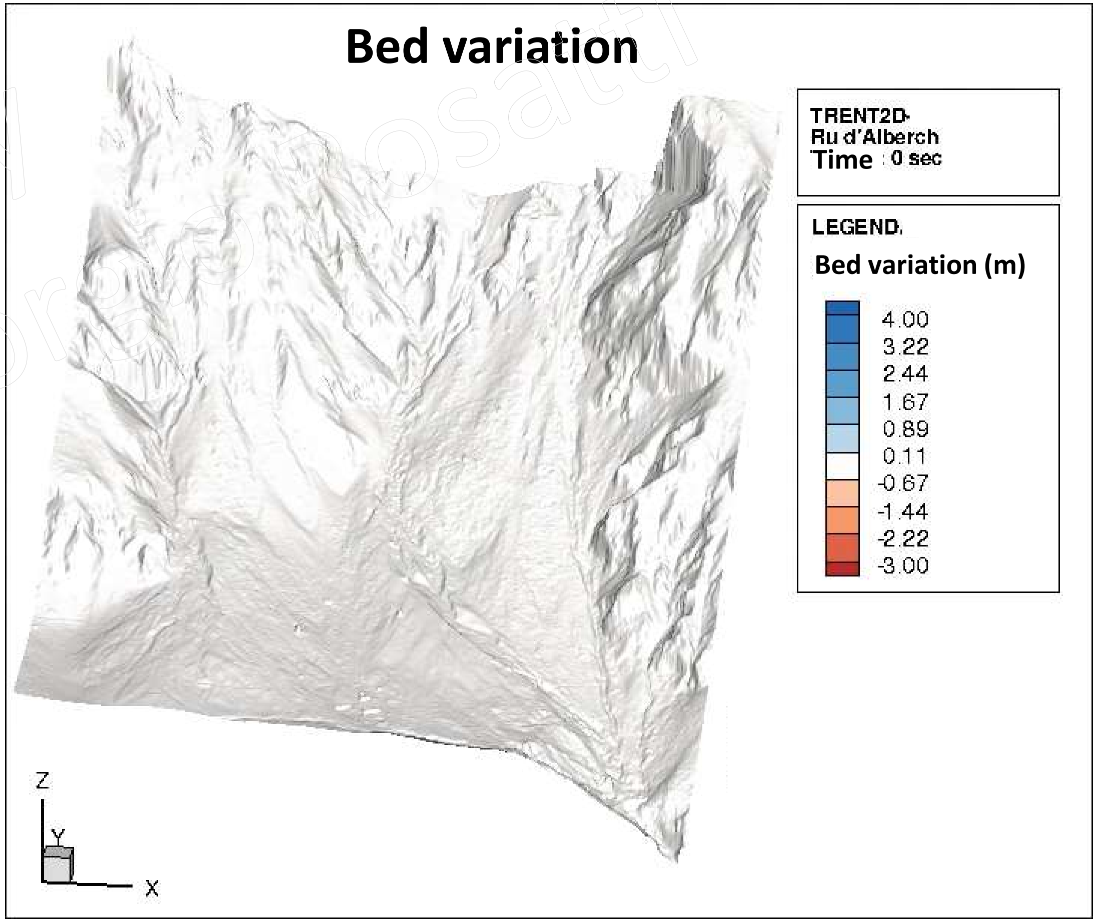


Physic process	Modelled by…
Rainfall	Source term
Subsurface flow	• Mass balance equation • Velocity by Dupuit-Forchheimer expression
Vertical fluxes *(coupling)*	• Infiltration term *(simplified Green-Ampt)* • Upwelling term • Deep infiltration term

Preliminary application: the Ru d'Alberch basin

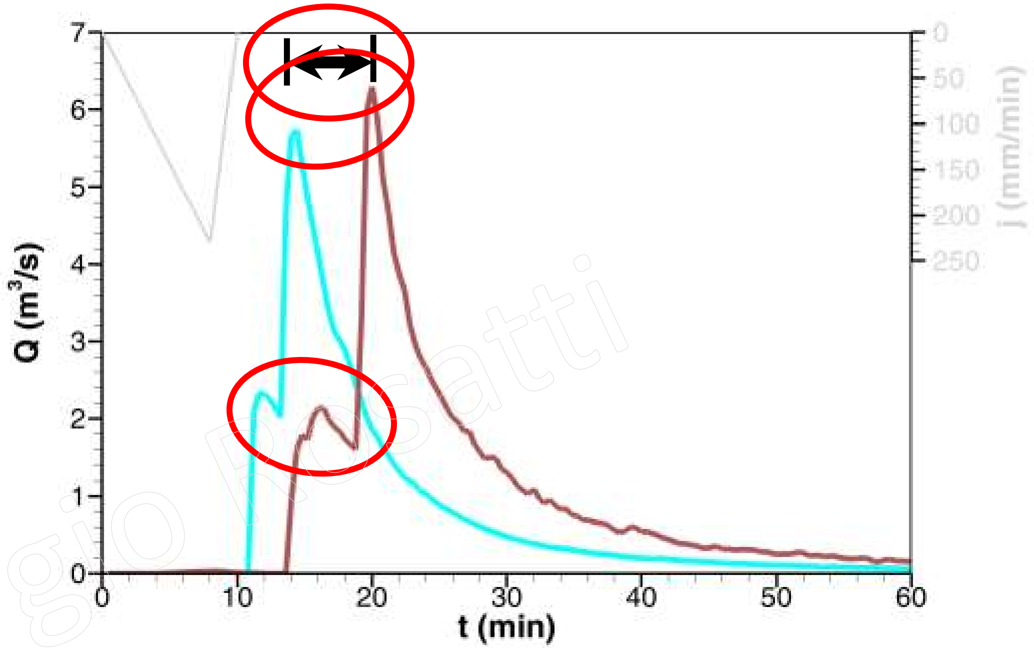






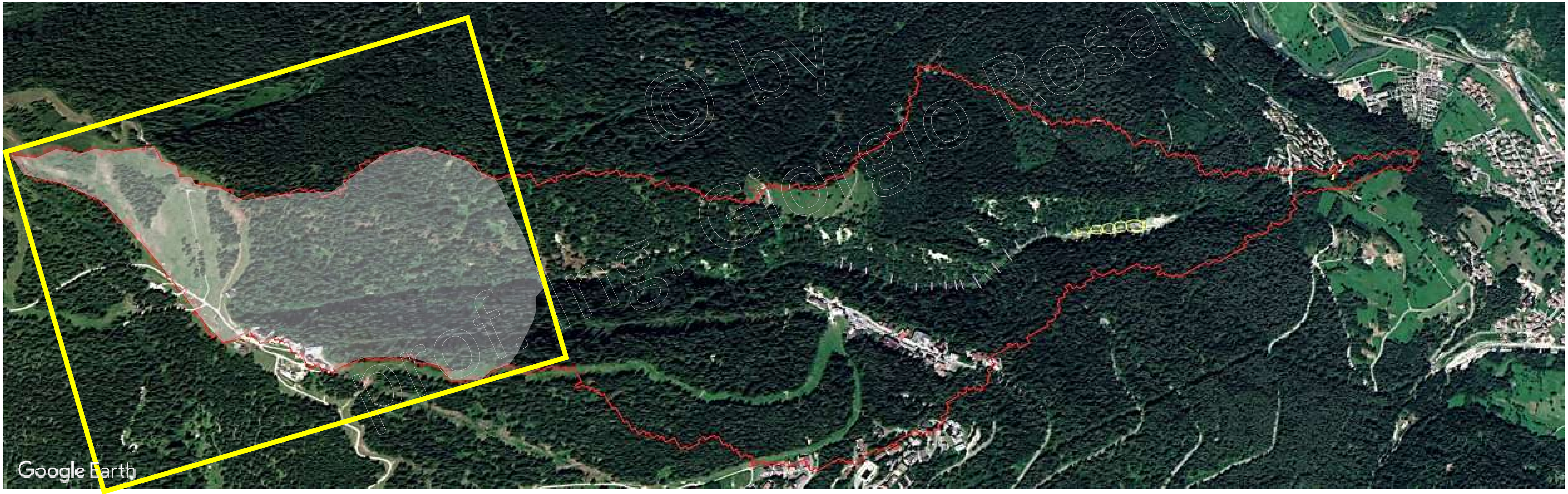
Preliminary application: the Ru d'Alberch basin

Liquid phase behaviour in the case of
fixed bed ↔ mobile bed



Feature	Reason
Time lag	Different flow resistance (function of c)
Different maxima	a) Water in bed b) Upwellings

Application to the upper part of the Rotiano *(back analysis)*



Application to the upper part of the Rotiano *(back analysis)*

Computed

From DoD

(Data by CNR-IRPI)

Erosion and deposition [m]

red	- 8
salmon	- 4
white	0
light blue	4
blue	8

TRENT2D^{MBRR}
difficulties in practical application

1. Need for a lot of distributed data
2. Large uncertainties in these distributed data
3. Estimate of physically based distributed parameters
4. Calibration of distributed parameters is costly, and not always easy to do (e.g., for lack or poor quality of surveyed data)
5. Non-negligible computational cost
6. Not all the possible phenomena are yet included in the model (e.g., shallow hillslope instabilities, check dam collapses…)

Complexity!

Conclusions

✓The event raised challenges from a modelling point of view:

- accurate modelling of debris flow over non erodible bed
- development of a new paradigm: modelling a debris flow at a basin scale

✓TRENT2D^{MBRR}

- first attempt to face the challenges
- results show promises
- several aspect can/should be improved
- much work remains to be done to make it an effective tool for back and forecast analyses (e.g. hazard mapping)

Acknowledgements

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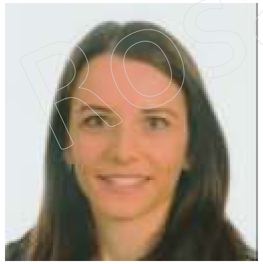
Dott. Ing. Marta Martinengo

Dott. Ing. Atousa Ataieyan



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Thanks for the attention!

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