# Modeling groundwater-driven morphodynamic evolution of a gravel bed river in presence of riparian vegetation

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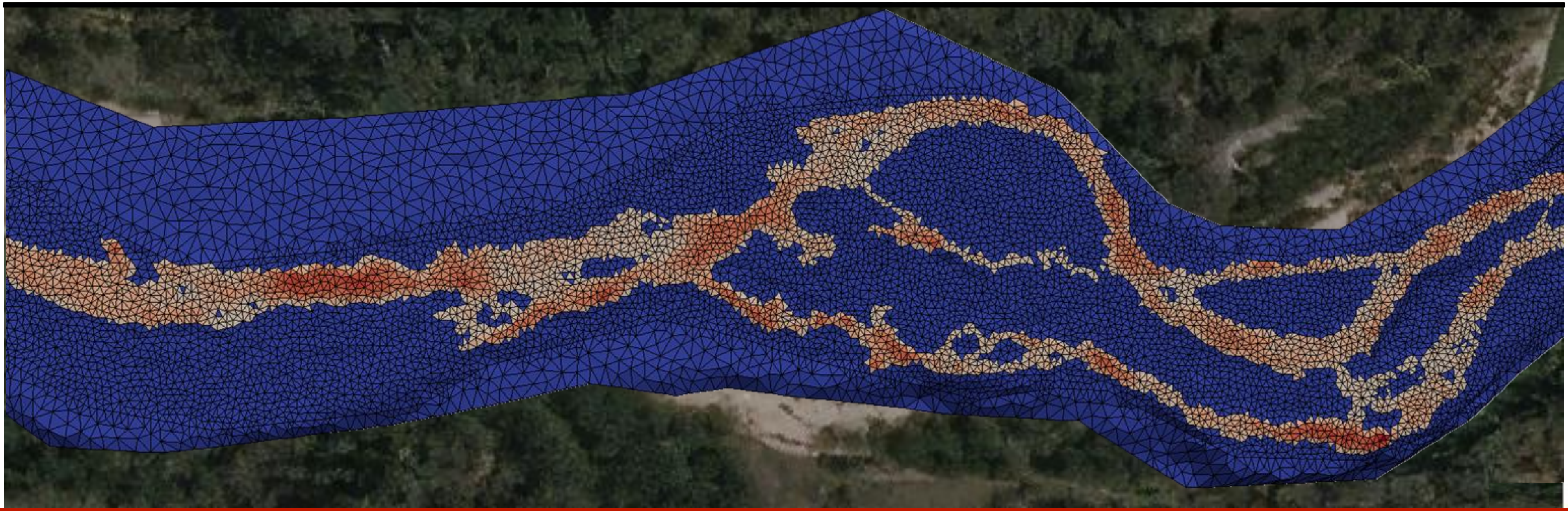


# Goal & outline

**Eco-morpho-hydro paradigm:** Riparian vegetation, flow field and sediment transport are interconnected by non-linear complex relations, which remain, nowadays, still unclear

**Goal:** Investigate the relations among riparian vegetation, flow field and sediment transport in a gravel bed river, analyzing different vegetation spatial distributions associated with different groundwater depths, by means of a numerical model

**Outline:**

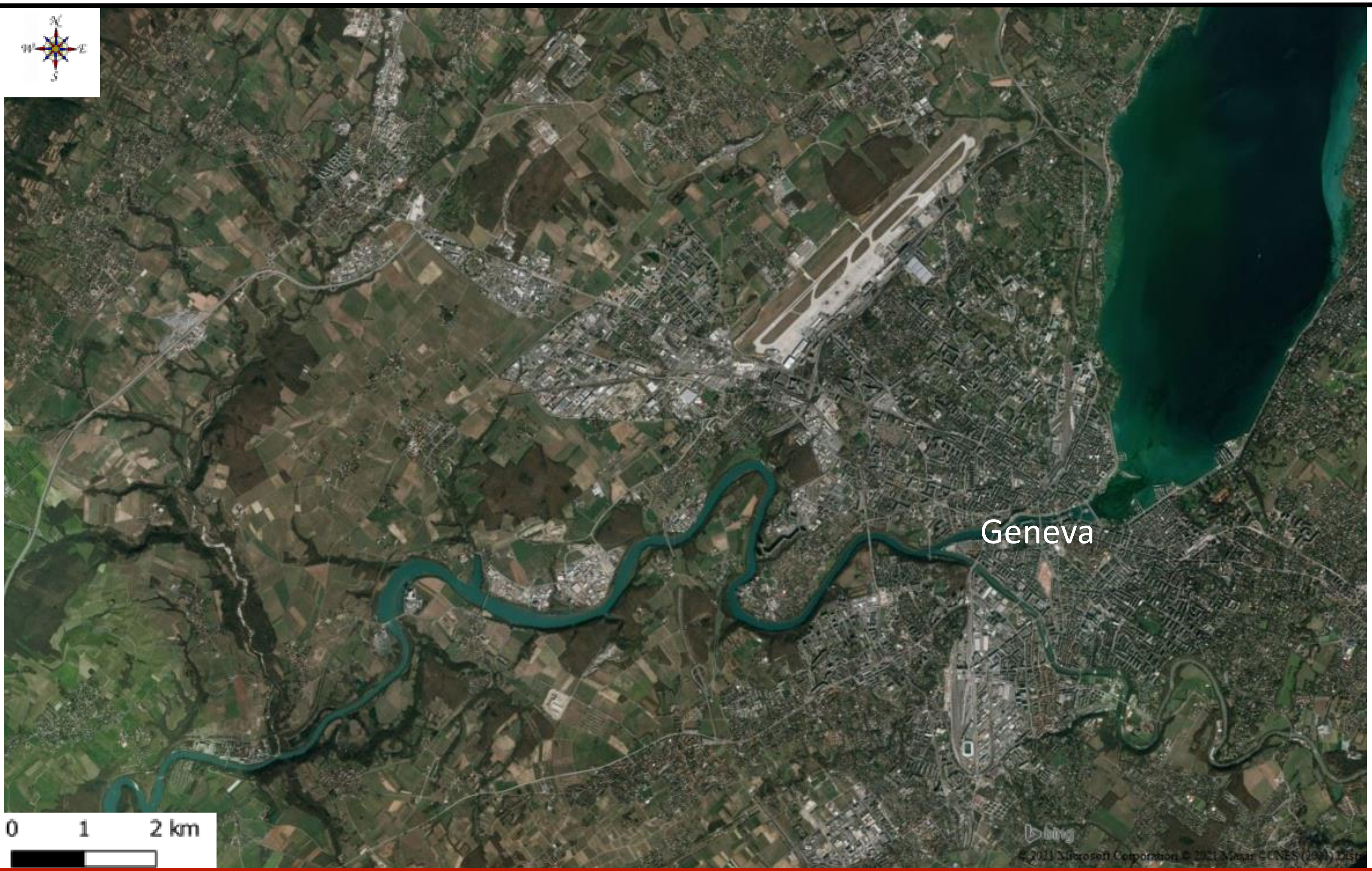
- Introduction
- The case study area
- Numerical model & specifications
- Results & Conclusions

# *Introduction*

Revealing the complex relations among vegetation dynamics and morphodynamics can help quantify the different processes involved and predict the river morphological trajectories to implement efficient restoration projects and to conceive resilient rivers

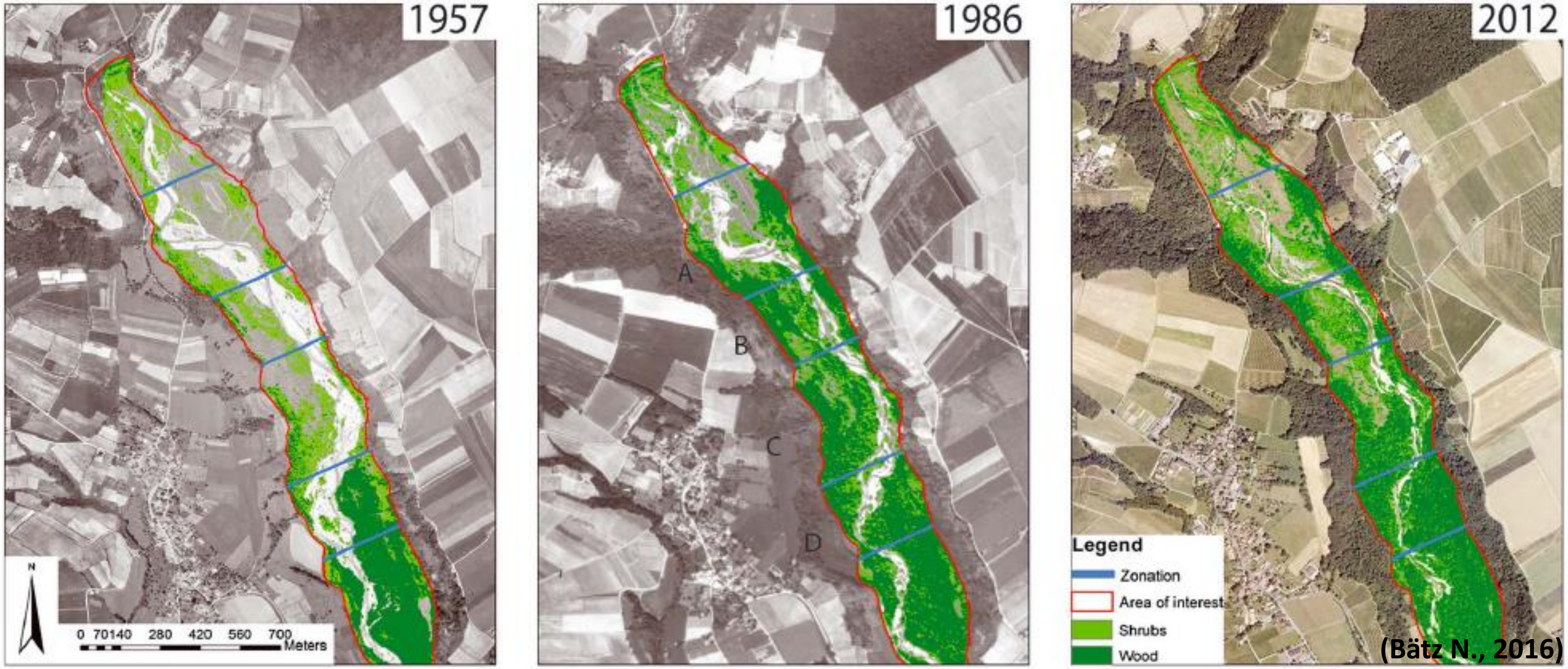
(Bertoldi W., 2010)

# *The case study area*

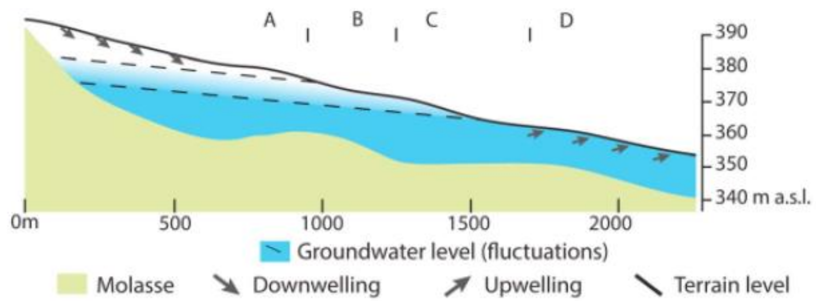


# The case study area

# *The case study area*




(Bätz N., 2016)




(Bätz N., 2016)

- Upstream (A,B reaches): deep groundwater, limited vegetation growth, larger active width and dynamic behavior
- Downstream (C,D reaches): shallow groundwater, well developed vegetation, narrower active width and channel stabilization

# Numerical model

PROBLEM

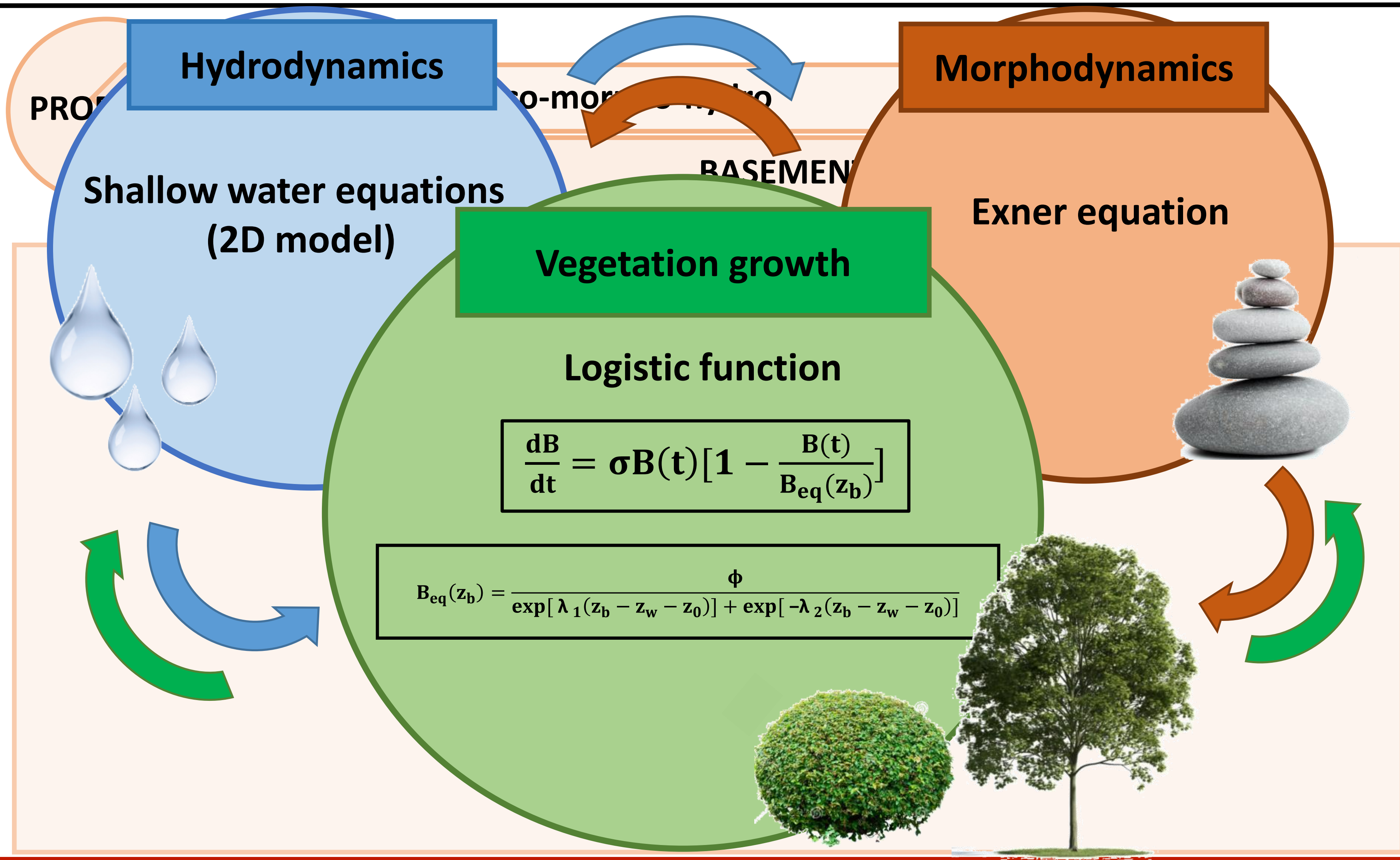
Eco-morpho-hydro

NUMERICAL MODEL

BASEMENT (Version 2.8)

Mathematical formulation

# *Numerical model*

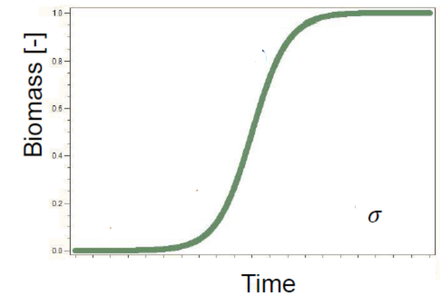


# Numerical model

**Vegetation growth**

**Logistic function**

$$\frac{dB}{dt} = B\sigma(t)\left[1 - \frac{B(t)}{B_{eq}(z_b)}\right]$$




- Vegetation is described by a biomass, B
- $\sigma$ represents the timescale of vegetation growth
- The growth is inhibited during high flows, when sediment transport takes place (i.e. $\theta > \theta_{cr}$)
- $B_{eq}$ is the carrying capacity (maximum vegetation biomass that can grow at a given bed level)

$$B_{eq}(z_b) = \frac{\phi}{\exp[\lambda_1(z_b - z_w - z_0)] + \exp[-\lambda_2(z_b - z_w - z_0)]}$$

- Carrying capacity distribution is a bell-shaped function of the bed elevation $z_b$
- $z_b$ is the bed elevation
- $z_0$ is the optimal elevation above the mean water table level $z_w$
- $z_w$ is the mean water level
- $\lambda_1$ and $\lambda_2$ control the rate at which fitness diminishes away from its maximum
- $\phi$ is a parameter normalizing the maximum value of $B_{eq}(z_b)$ to 1

(Siviglia A., 2019)

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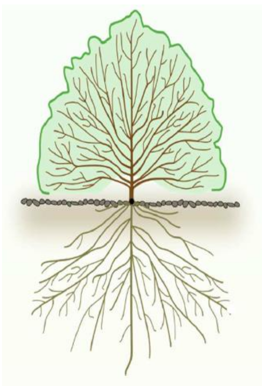
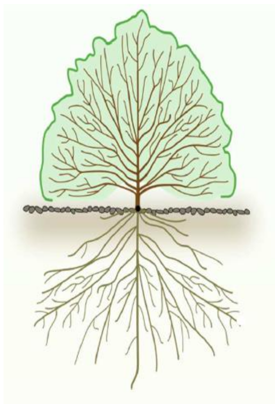
# *Numerical model*

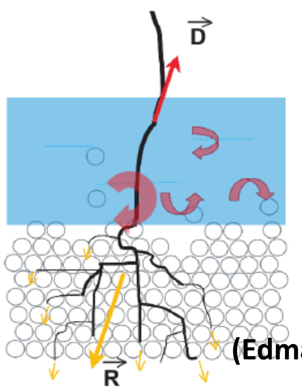


1 Hydro-morphodynamics ⇄ Vegetation 2



**1**

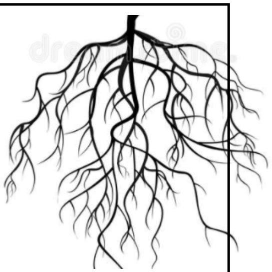
- **Availability of water for plant growth**
- **Uprooting of vegetation during flood events**

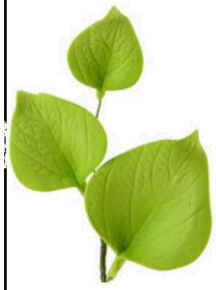



**(Edmaier et al., 2011)**

**2**

- **Increase of soil cohesion (modification of the Shields critical parameter and solid transport)**





- **Increase of flow resistance (modification of the roughness)**

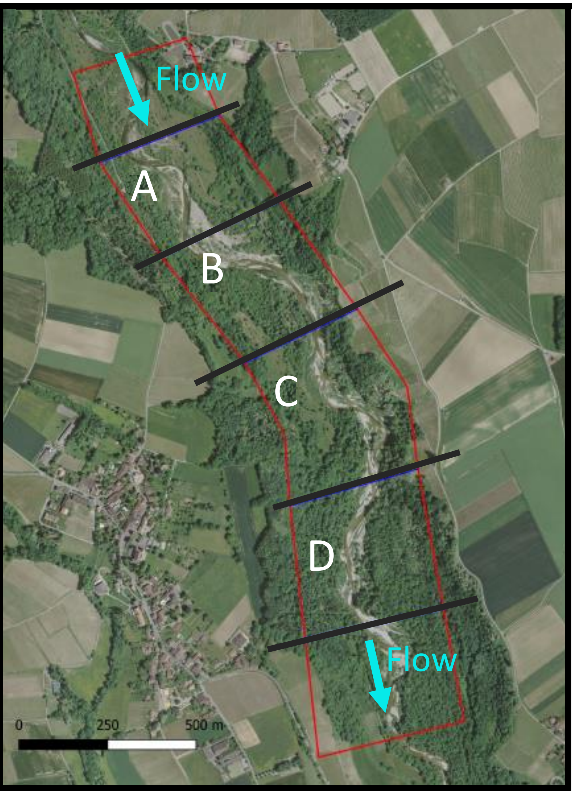
# *Numerical model*

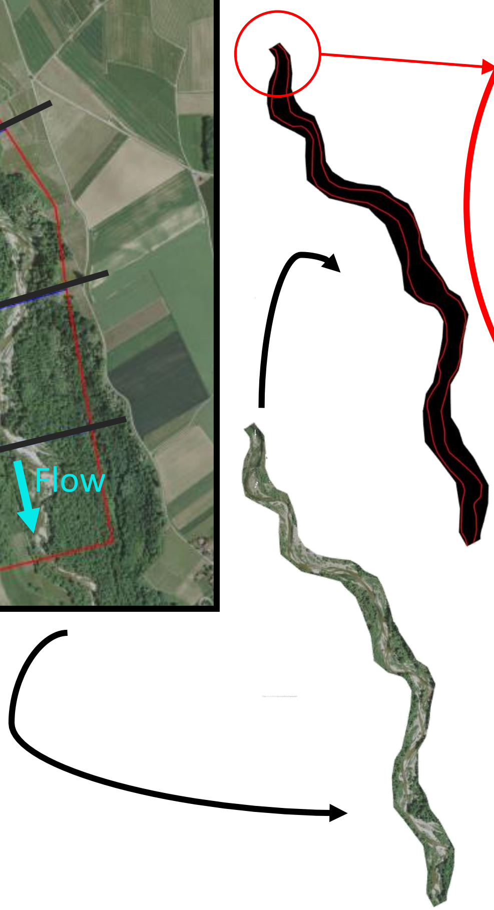
Hydro-morphological processes have a significant impact of vegetation distribution determining plant removal by uprooting, which occurs when the resistance provided by the plant roots equals the pull-out forces on the canopy

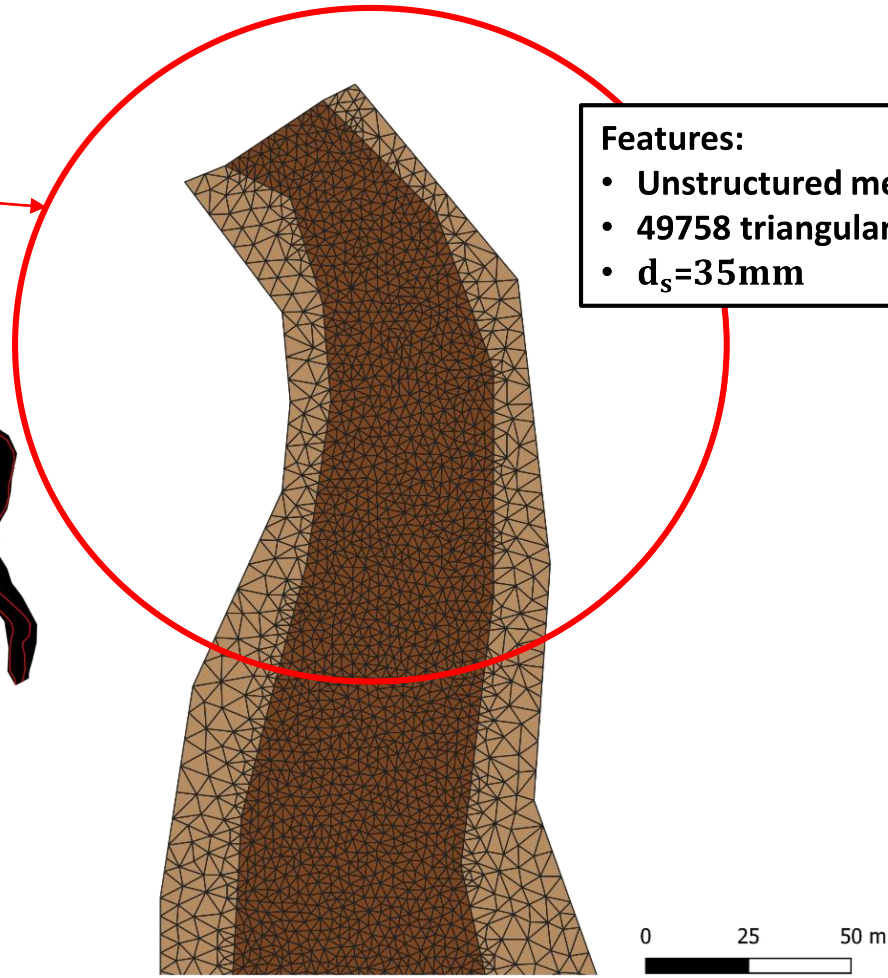
(Bertoldi W, 2010 )

In the model is assumed that the biomass disappears as soon as the total erosion, during a flood event, reaches a given value of uprooting resistance ($\boldsymbol{Zup}$)

# *Model domain*

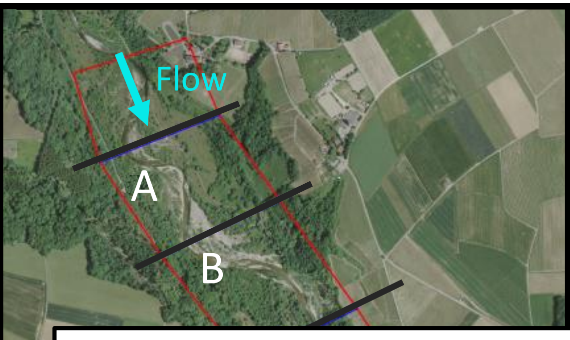


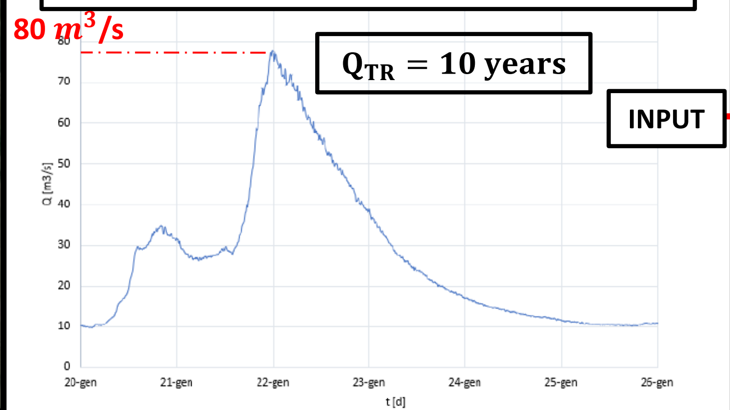



**Features:**
- **Unstructured mesh**
- **49758 triangular elements**
- $\mathbf{d_s=35mm}$

# *Model domain*




Flood event, hydrographic station (Dardagny )

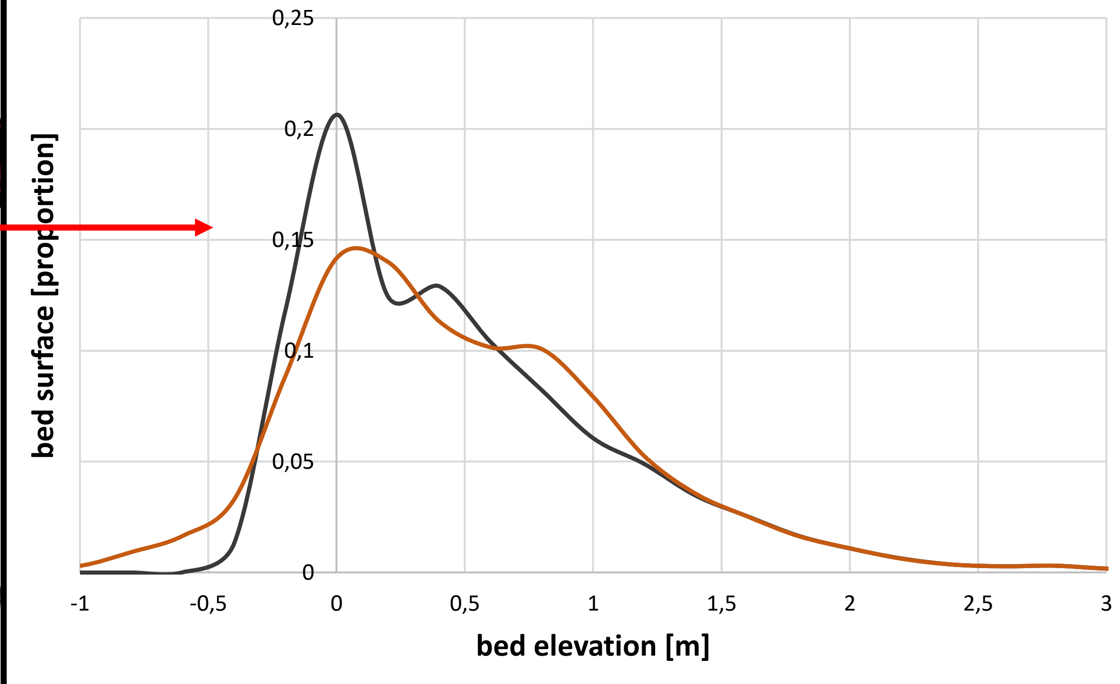



$Q_{TR} = 10$ years

INPUT


M0 is the frequency distribution of bed elevation before the flood event (initial stationary condition)

M1 is the frequency distribution of bed elevation after the flood event



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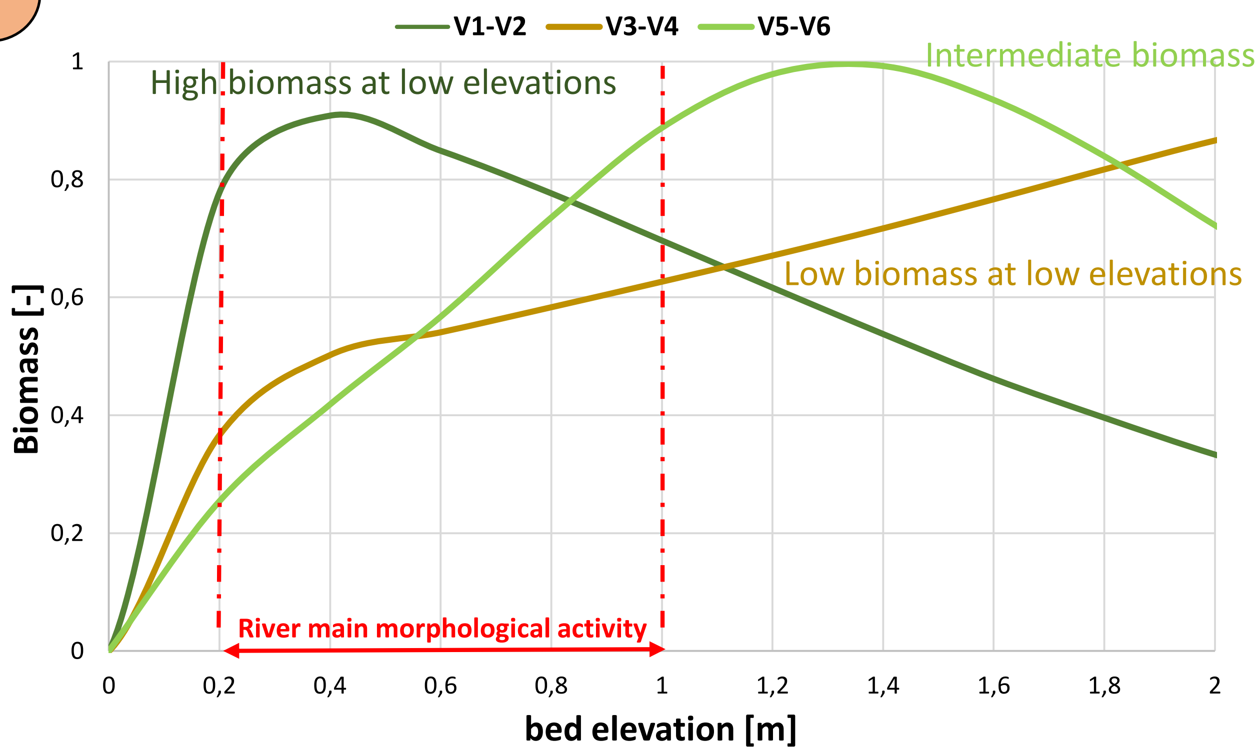
# *Model parameters set up*

| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
| V2 | 1 | 0.4 | 0.3 | 0.5 |
| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

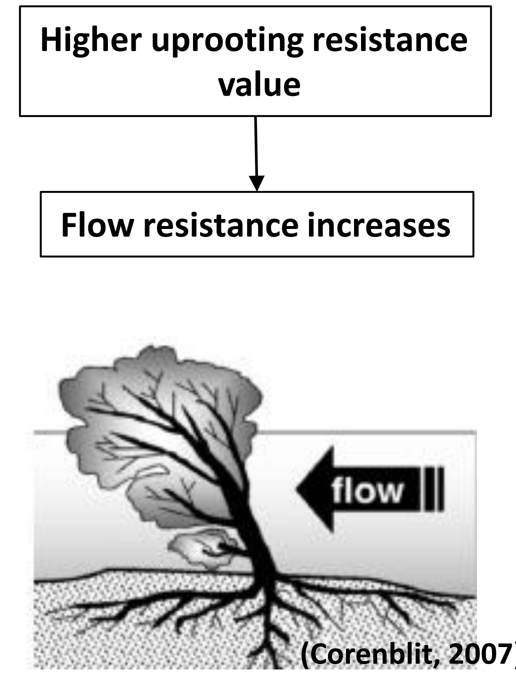
## Vegetation parameters:

1. Different vegetation spatial distributions ($\lambda_1$, $\lambda_2$) **associated with different groundwater depths ($z_0$)** are simulated
2. Different vegetation uprooting resistance are simulated (*Zup*)

1




2



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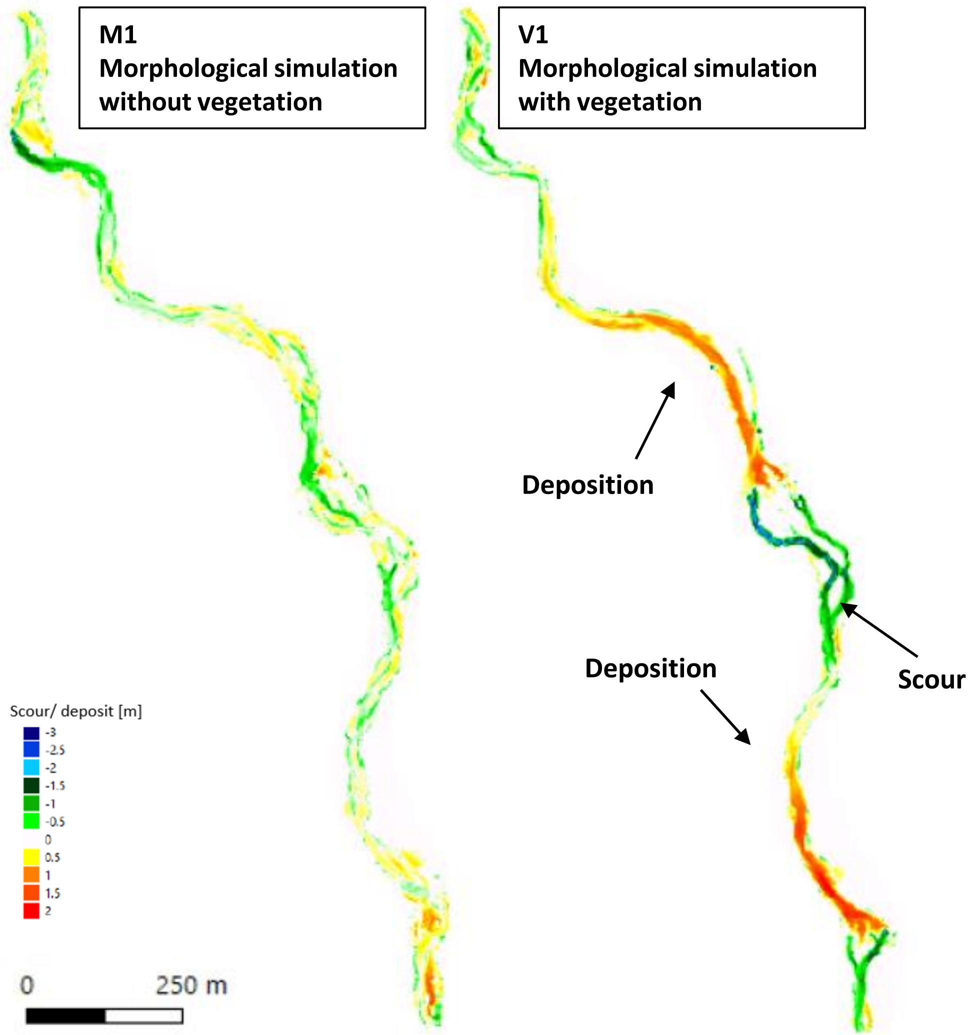
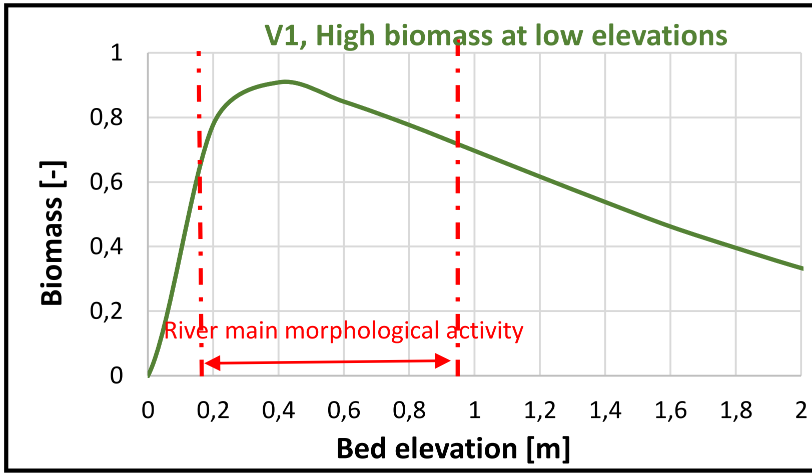
# Simulations results: M1 vs V1




**Vegetation (V1) effects:**

- Reduction of river active width and channel stabilization
- Local deposition/scour effect but total higher deposition

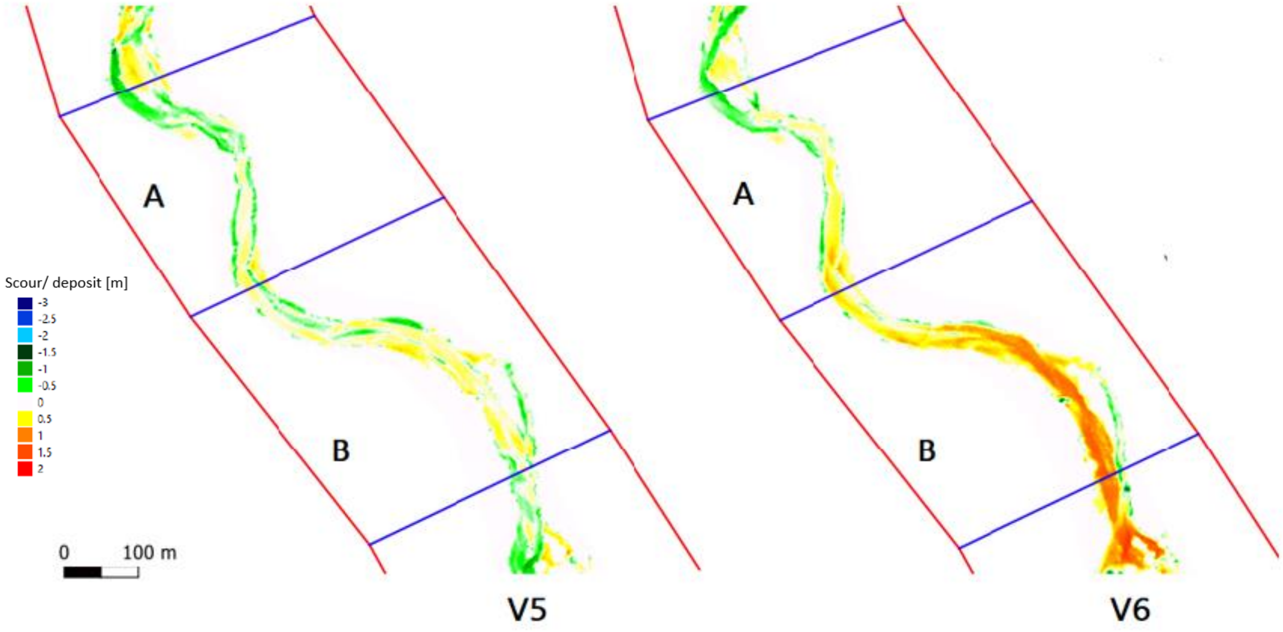
# Simulations results: V5 vs V6

## Sensitivity analysis of vegetation uprooting resistance

| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
| V2 | 1 | 0.4 | 0.3 | 0.5 |
| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

**Uprooting resistence Zup=0.1**

**Uprooting resistence Zup=0.3**

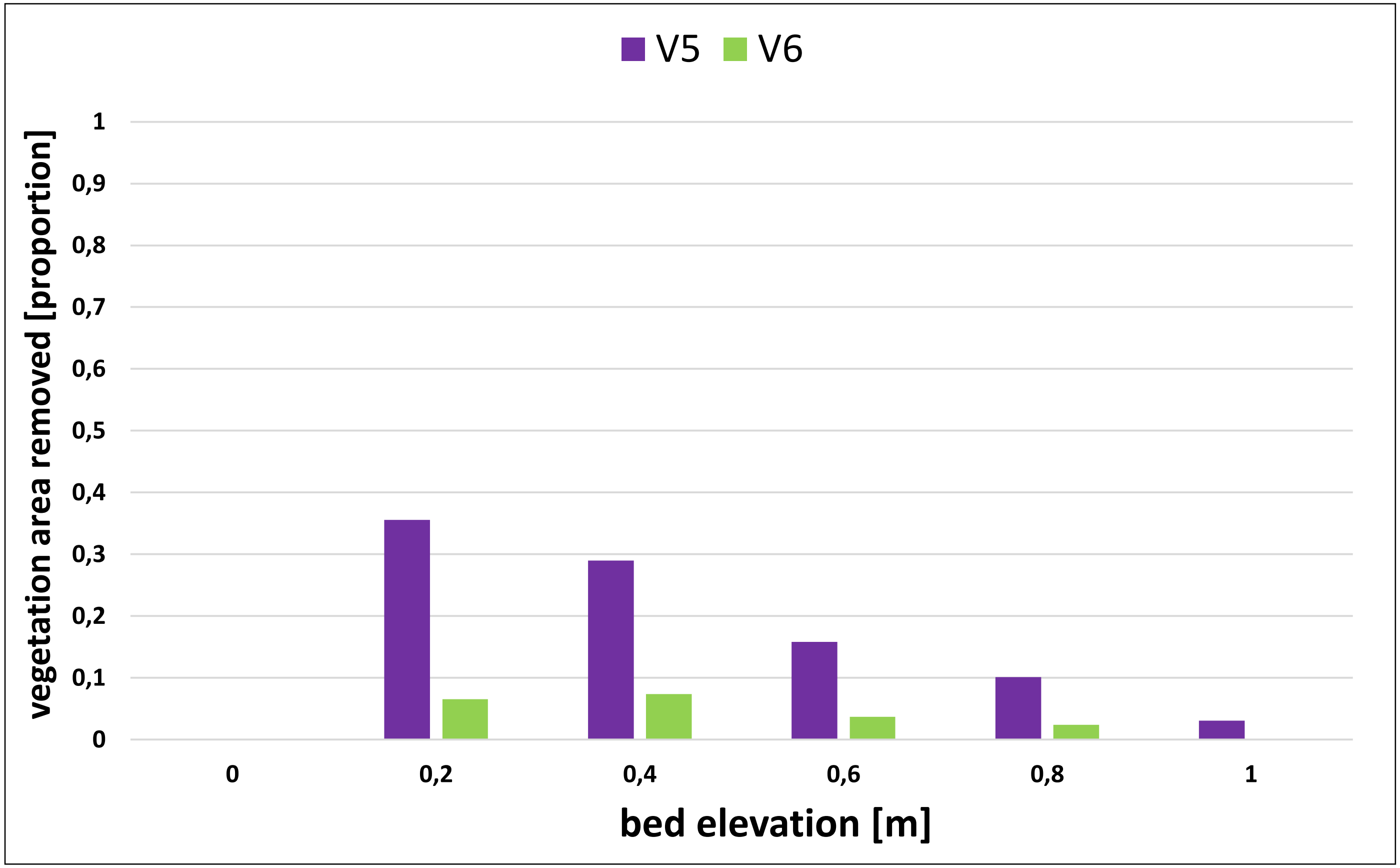



**Equal vegetation distribution (intermediate biomass) but different values of uprooting resistance**

**Higher value of uprooting resistance (V6) induces higher sediment deposition, instead lower value of uprooting resistance (V5) shows not relevant morphological effects**

# Simulations results: V5 vs V6

## Sensitivity analysis of vegetation uprooting resistance

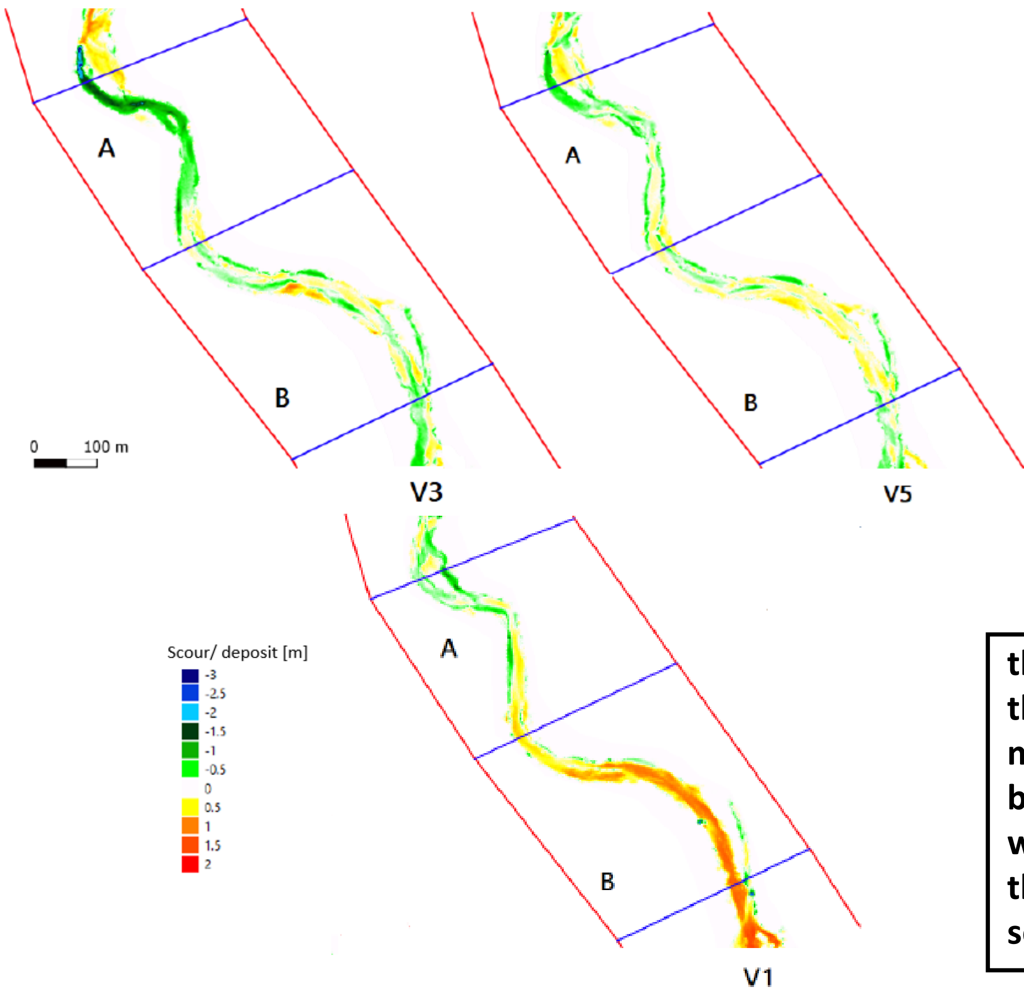


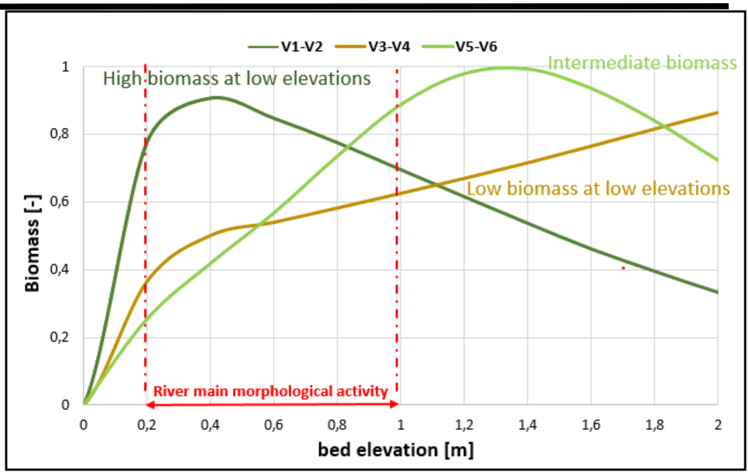

| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
| V2 | 1 | 0.4 | 0.3 | 0.5 |
| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

**Flood event removes more vegetation during the simulation with a lower value of uprooting resistence (V5)**

# Simulations results : V1, V3, V5

## Sensitivity analysis of vegetation distribution

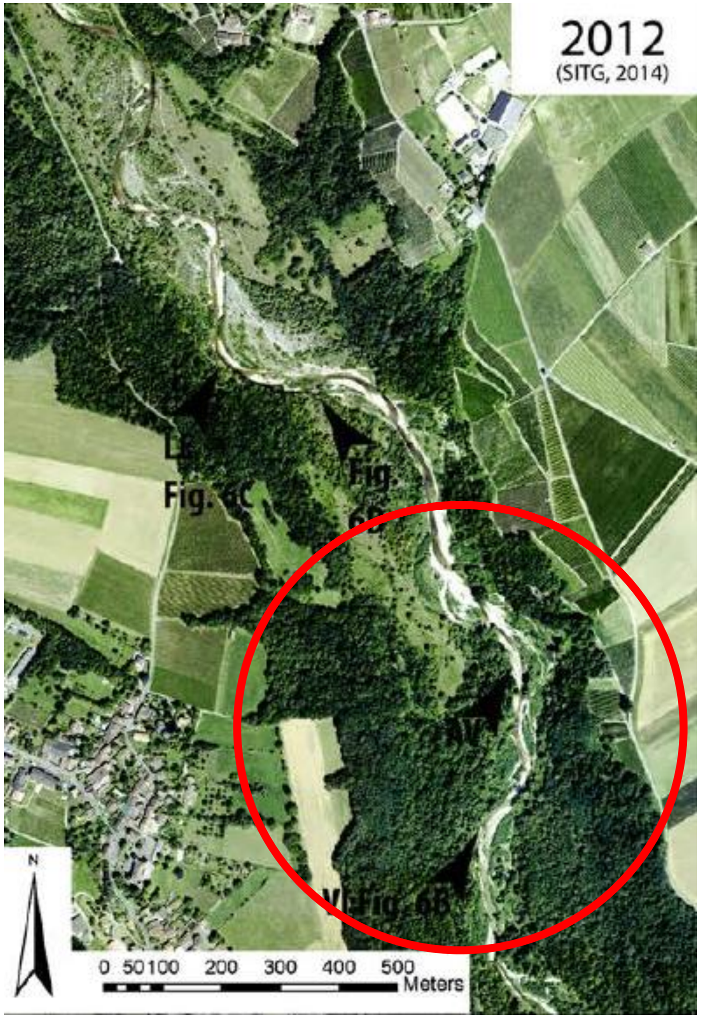



**Equal value of uprooting resistance (Zup=0.1) but different vegetation distributions**

**the high biomass at low elevations (V1) induces the highest depositated sediment volume. The main morphological activity takes place between bed elevation 0.2 m and 1 m, which is the range where vegetation V1 is more developed and therefore intereferes most with the flow field and sediment transport.**

# *River trajectory: downstream evolution*


**(Bätz N., 2020)**

# River trajectory: downstream evolution (past)

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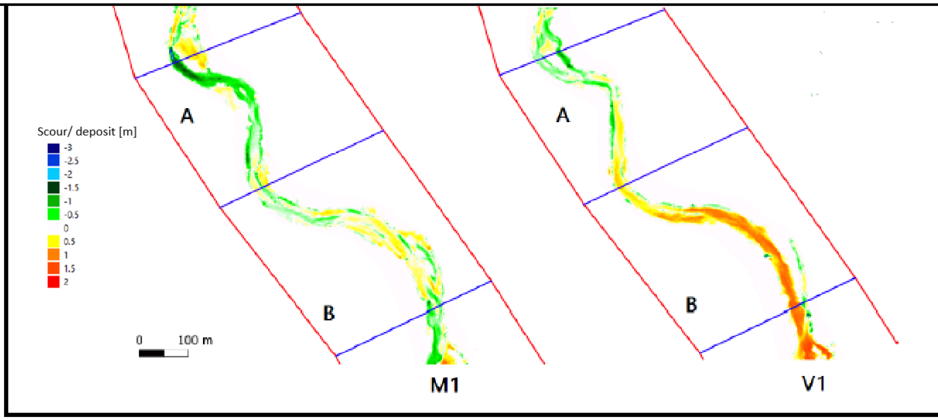
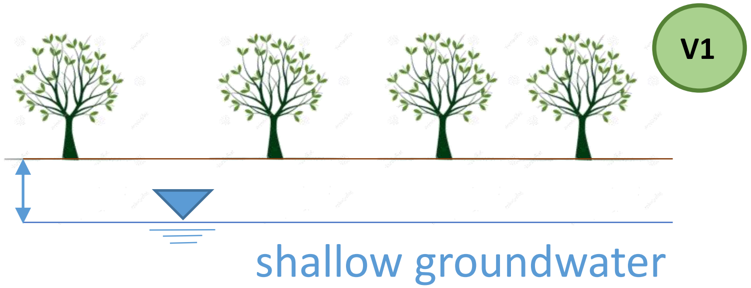
The downstream reach past situation can be assimilated to the current morphological upstream topography




V1

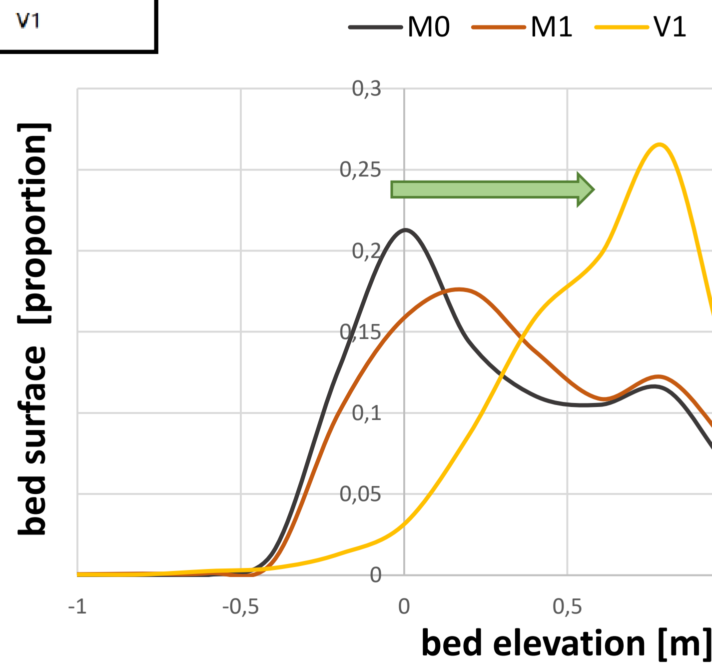
**Well developed vegetation but not uprooting resistant**

↓

**Deposition of sediments, narrower active width and channel stabilization**

↓

**Current downstream configuration and vegetation development (V2)**




| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
| V2 | 1 | 0.4 | 0.3 | 0.5 |
| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

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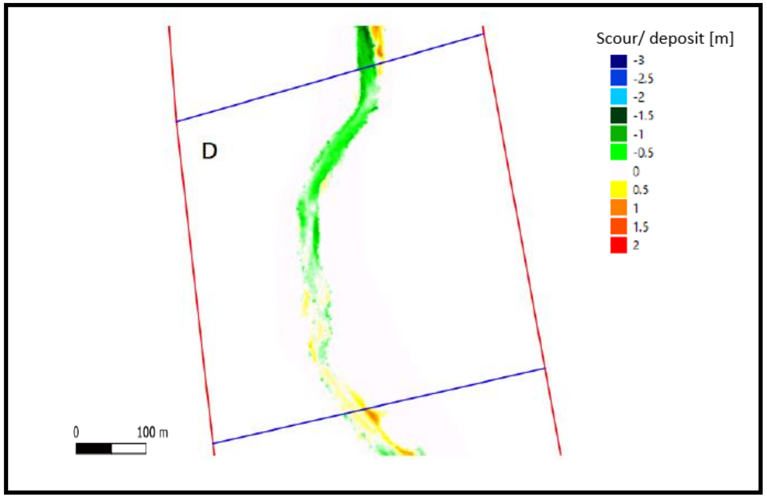
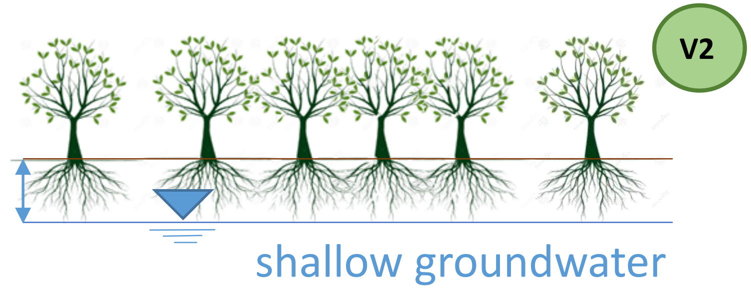
# River trajectory: downstream evolution (present)



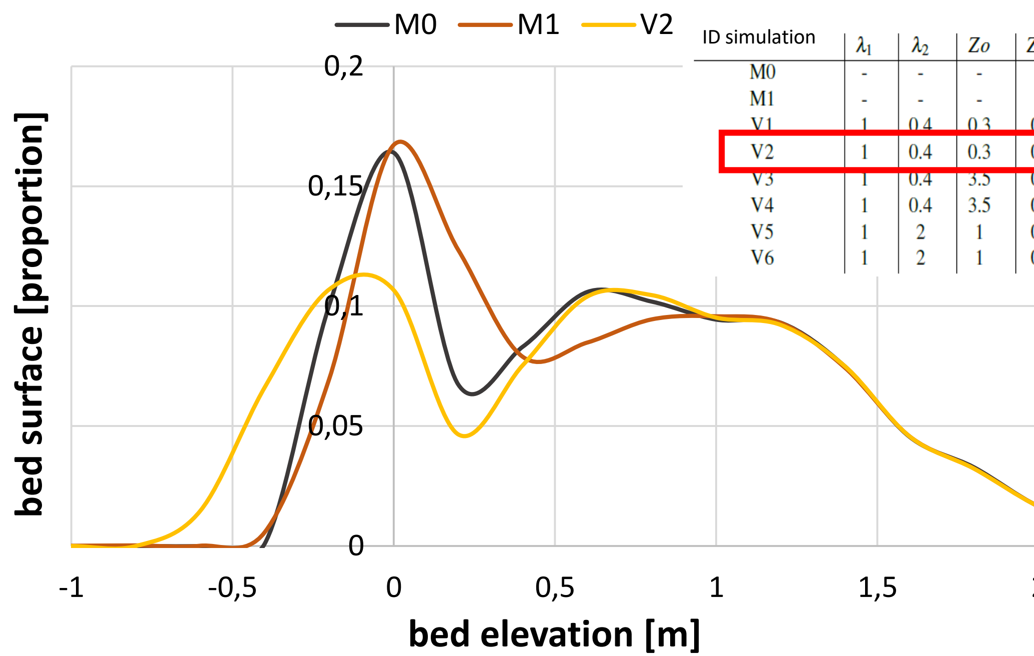

V2 Well developed vegetation and uprooting resistant

↓

Encroachment of vegetation on the riverbed

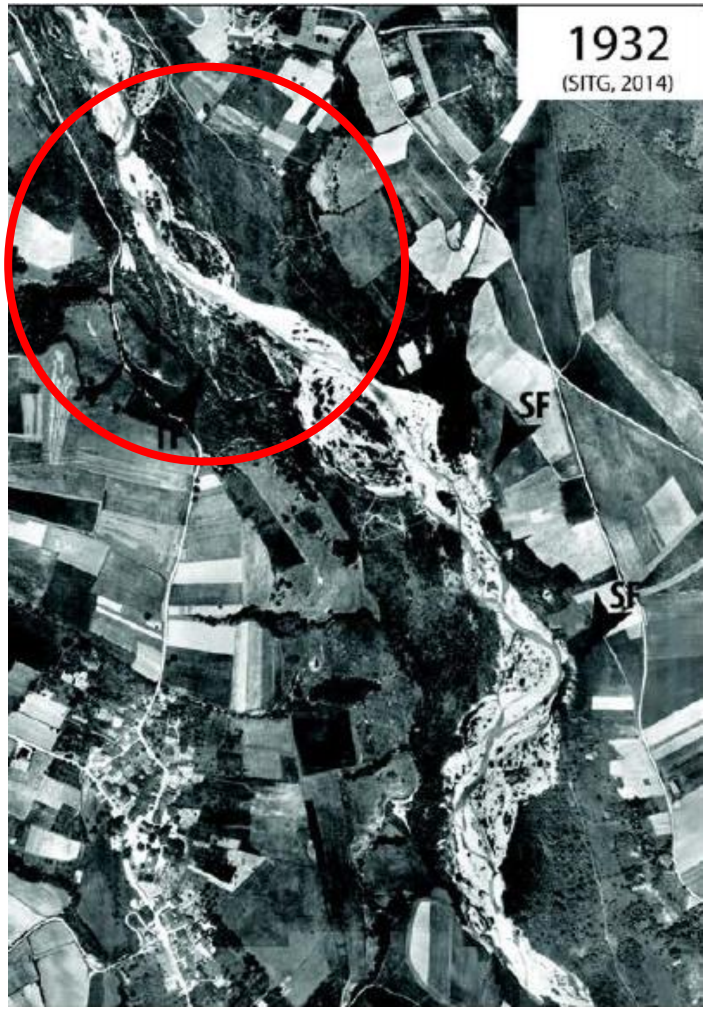
↓

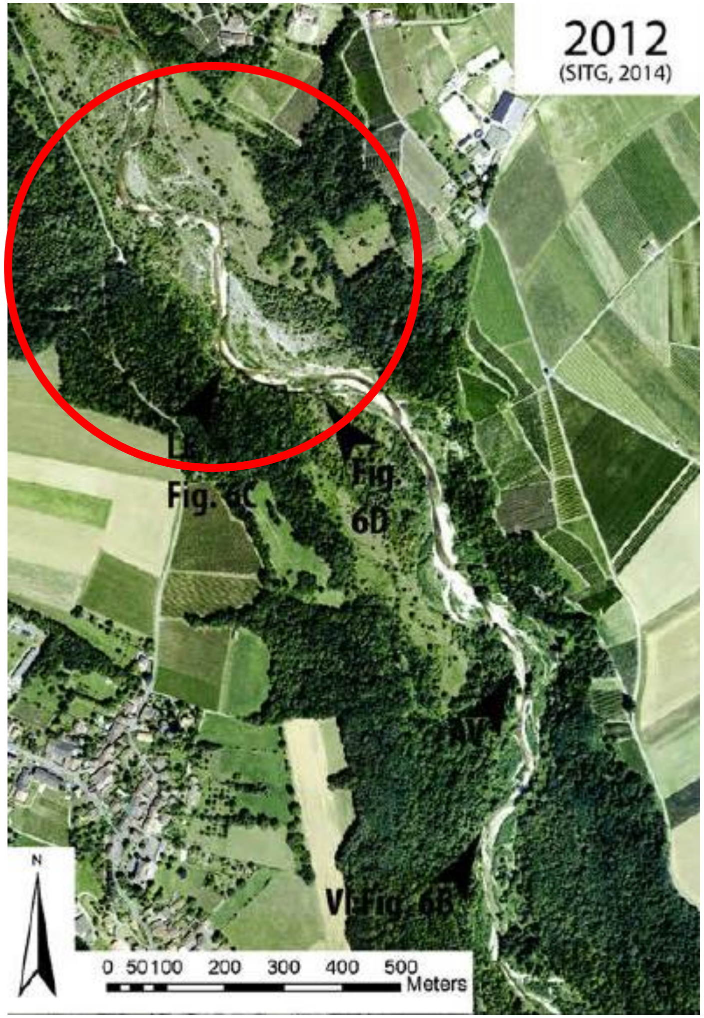
Stabilized channel, narrow active width and low river dynamic morphological behavior




| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
| V2 | 1 | 0.4 | 0.3 | 0.5 |
| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

# *River trajectory: upstream evolution*




**(Bätz N., 2020)**

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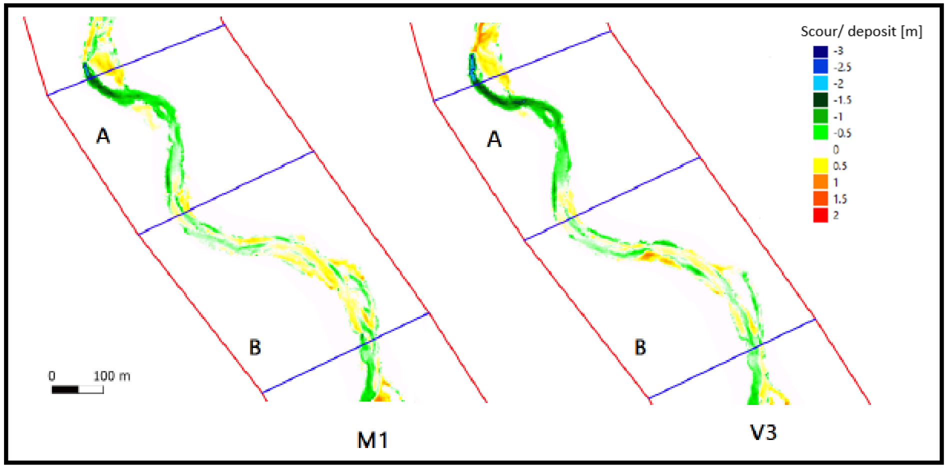
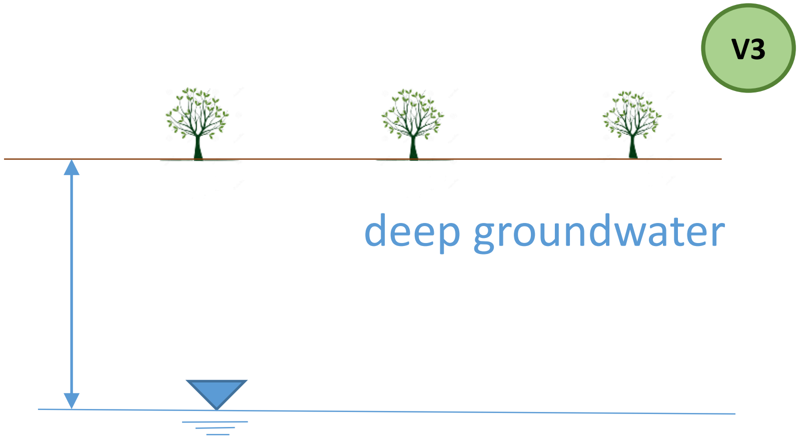
# River trajectory: upstream evolution




**V3**

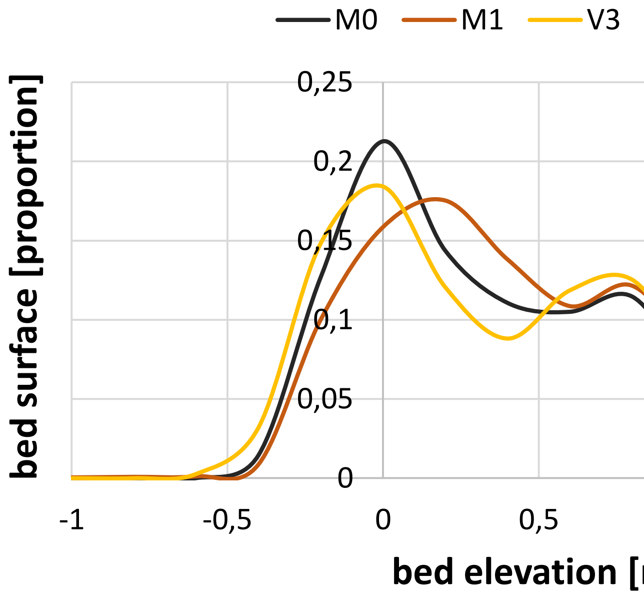
Limited vegetation growth, not uprooting resistant

↓

Doesn't interfere significantly with the morphological activity of the river

↓

Large active width and high river dynamic morphological behavior




| ID simulation | $\lambda_1$ | $\lambda_2$ | $Zo$ | $Zup$ |
|---|---|---|---|---|
| M0 | - | - | - | - |
| M1 | - | - | - | - |
| V1 | 1 | 0.4 | 0.3 | 0.1 |
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| V3 | 1 | 0.4 | 3.5 | 0.1 |
| V4 | 1 | 0.4 | 3.5 | 0.5 |
| V5 | 1 | 2 | 1 | 0.1 |
| V6 | 1 | 2 | 1 | 0.3 |

**Conclusions:**

- The uprooting resistence, associated with intermediate biomass vegetation distributions, can influence the morphological activity of the river

- Low vegetation biomass density at low elevations doesn’t interfere significantly with the morphological activity of the river, favoring a dynamic behavior and a large active width. High biomass density at low elevations, encroaches the riverbed, reducing channel mobility and river active width

- Groundwater dynamics and position can influence the spatial distribution of vegetation and its growth, modifying also the morphological activity of the river

- Ecomorphodynamic modeling is a useful tool to represent the complex dynamics among riparian vegetation, flow field and sediment but further research and model improvements are needed to better understand and quantify

# Thanks for the attention

*“You could not remove a single grain of sand from its place without thereby … changing something throughout all parts of the immeasurable whole.” -Fichte,1800-*

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