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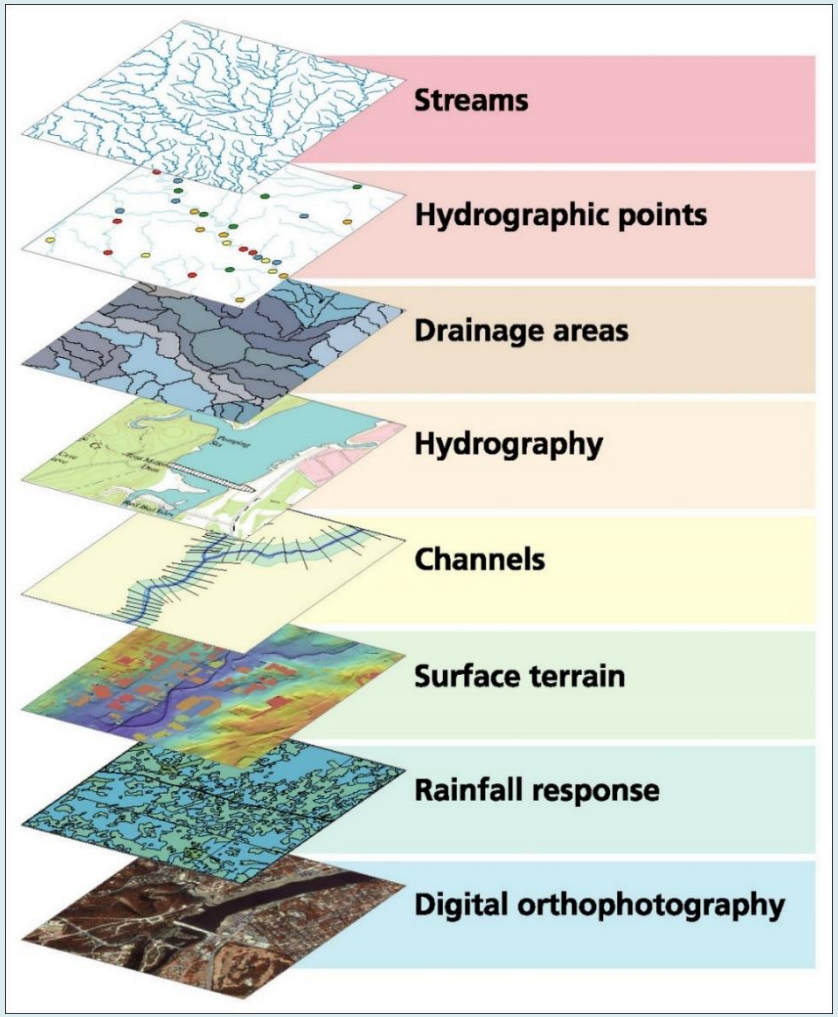
# Watershed and river network analysis with GIS:
## current applications




Virginia Ruiz-Villanueva

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Faculty of Geosciences and the Environment
Institute of Earth Surface Dynamics (IDYST)

# Fields of research (GIS-related)

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- Hydrology and morphometry: watersheds´ and rivers´ response to floods
- (Bio-)Geomorphology: physical processes-forest interactions
- Hillslopes-channel connectivity
- Sediment and large wood supply and transport
- Flood Hazards and Risks

# The watershed and river scales

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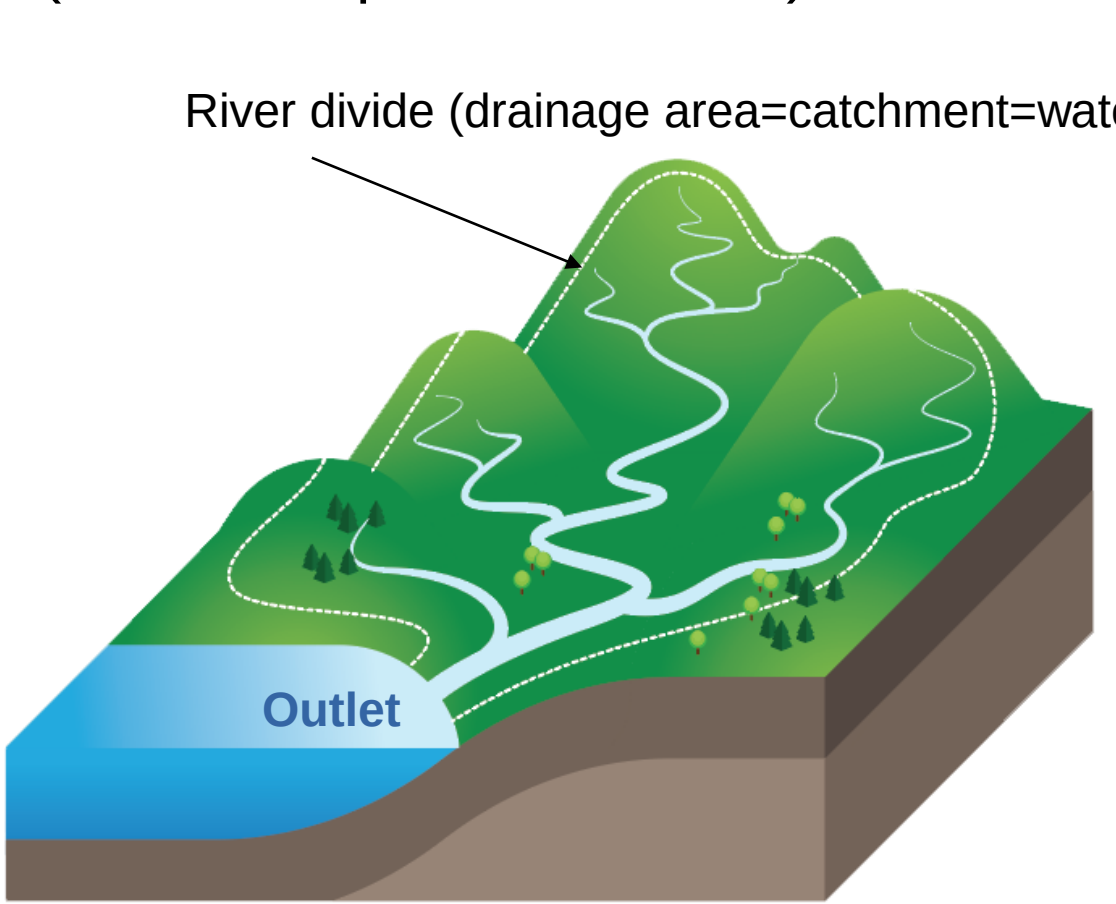
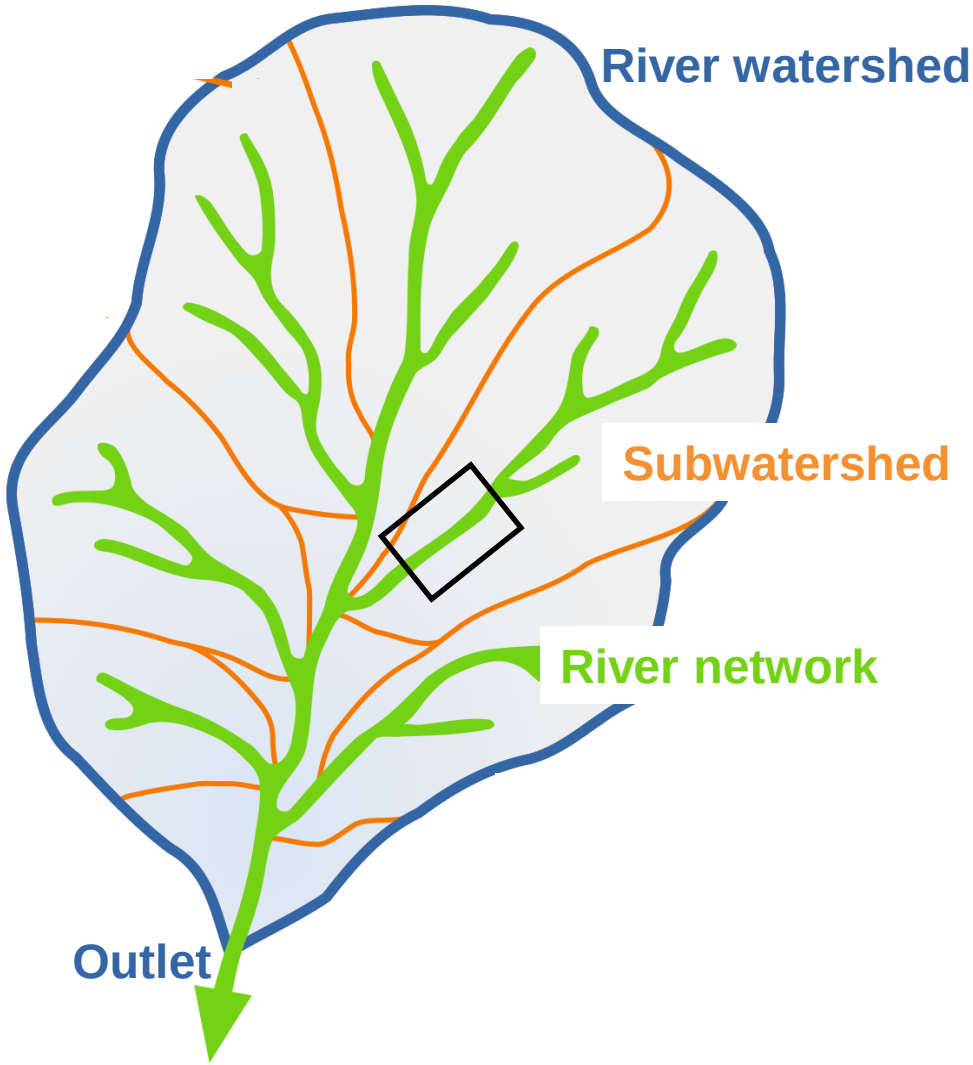
Landscape area drained by a river and its tributaries to a common point (i.e., outlet point, lake, sea)




Spatial scale: <1 $m^2$ up to > 1000 $km^2$

# GIS main applications

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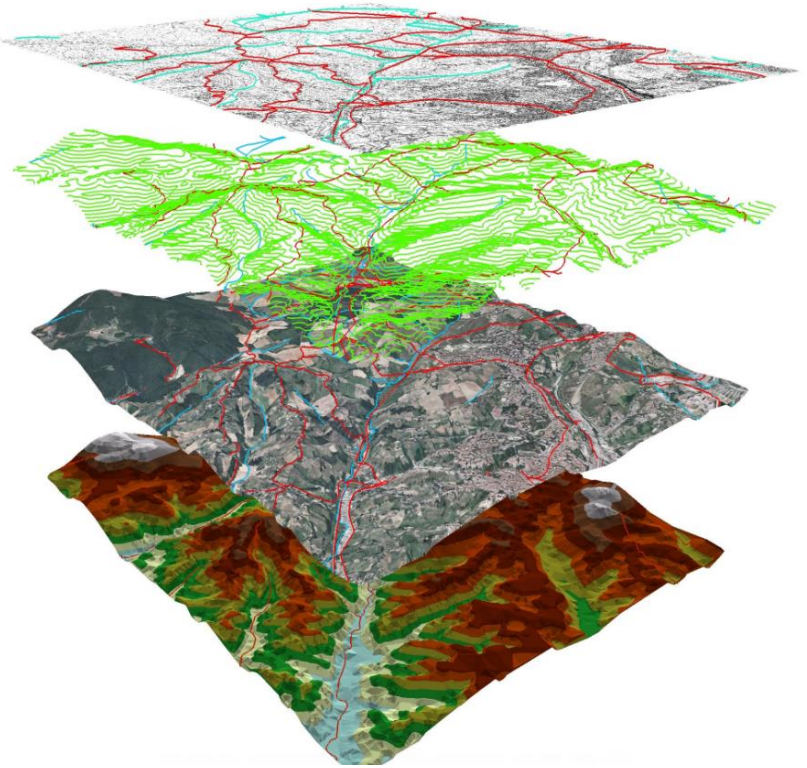
1) Data acquisition
2) Geoprocessing and spatially explicit modeling
3) Pre-processing of input data for numerical modelling
4) Post-processing and data (geo)visualization



*@yukti.aggarwal*

## Content

1. Use of drones to analyse geomorphic changes in rivers after floods
2. Hydrologic and Hydrodynamic modelling for flood hazard and risk assessment
3. Large Wood supply to the river network

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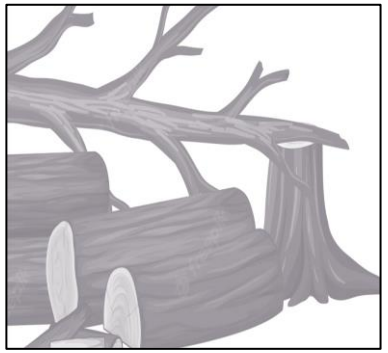

# Topographical and field surveys

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*Drone survey in the Spöl river (Graubünden) 2021*

Handling large datasets (high resolution aerial imagery)

*Tourneret, 2022; Ruiz-Villanueva et al., unp*

# Mapping, temporal and spatial changes

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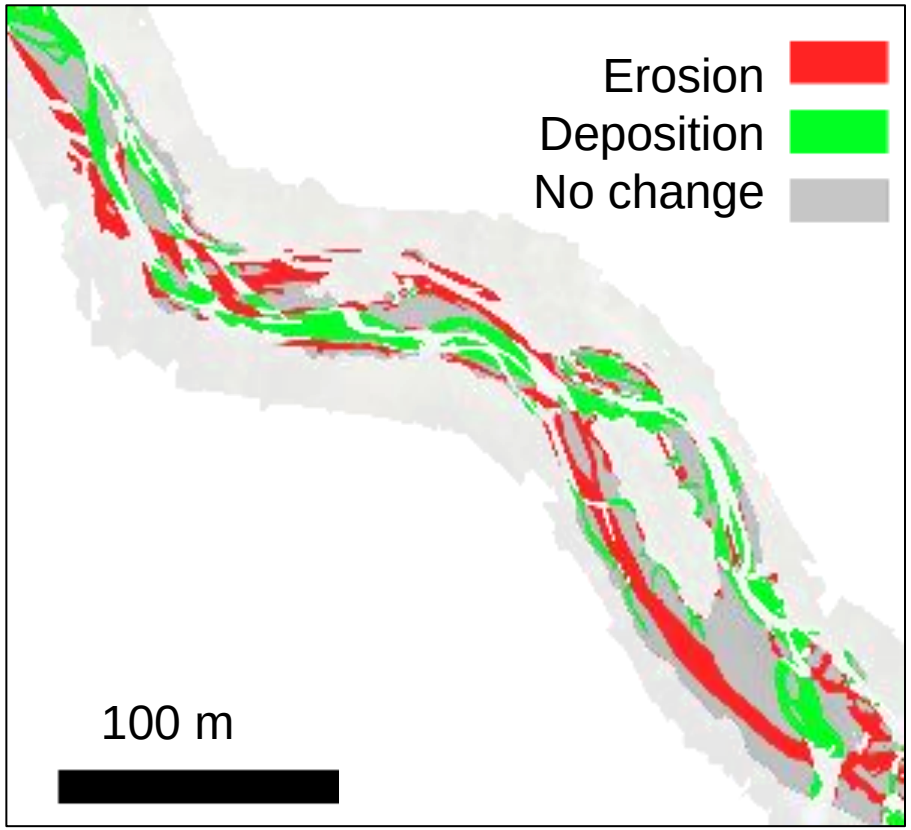
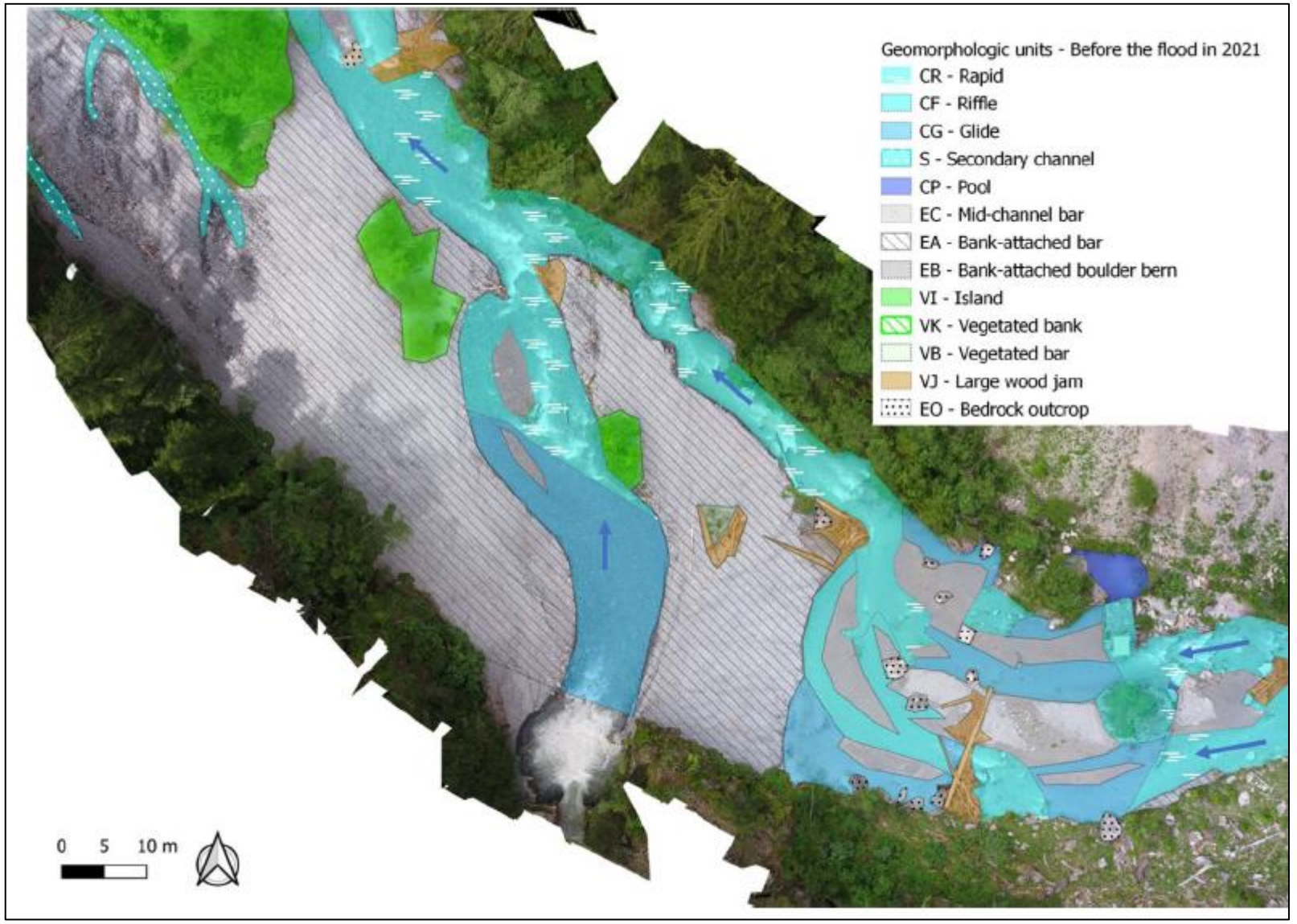
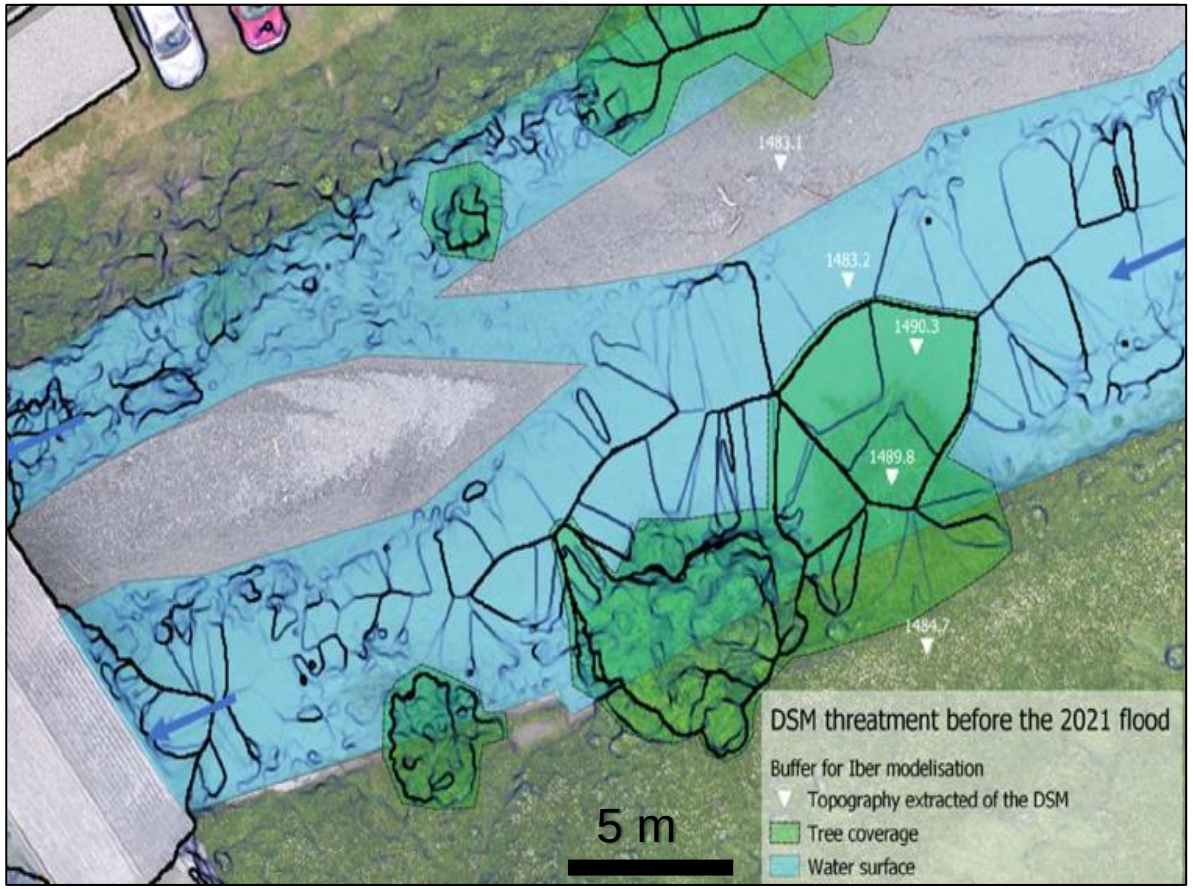



*Tourneret, 2022; Ruiz-Villanueva et al., unp*

# High resolution digital terrain models

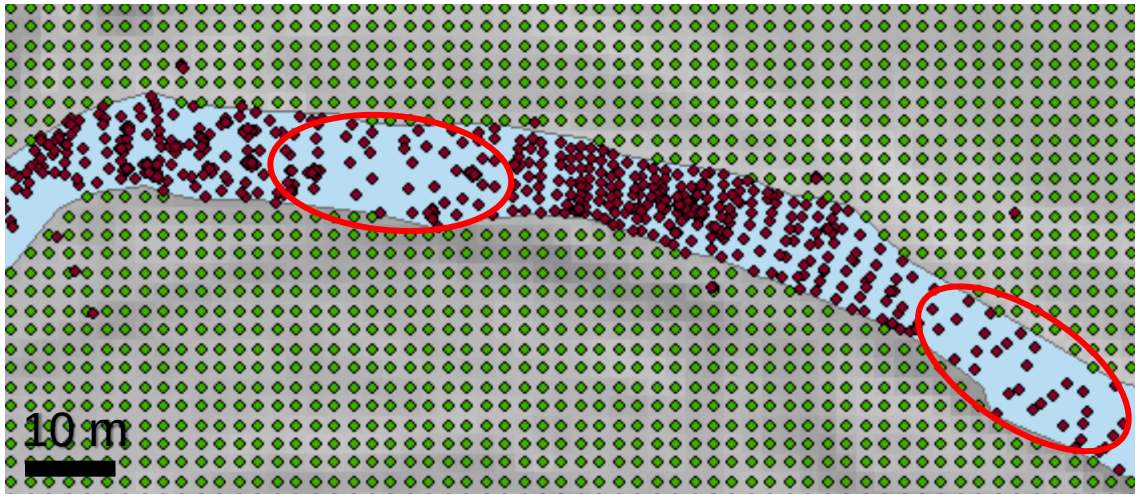
Combining topographical surveys and DEMs or Structure from motion derived DTMs




*Tourneret, 2022*

Agisoft Metashape

*Topographical survey, Spöl river 2022*




Regular grid from DEM (x2m) and topographical survey with dGPS

Spatial interpolation often results in artifacts

# High resolution digital terrain models

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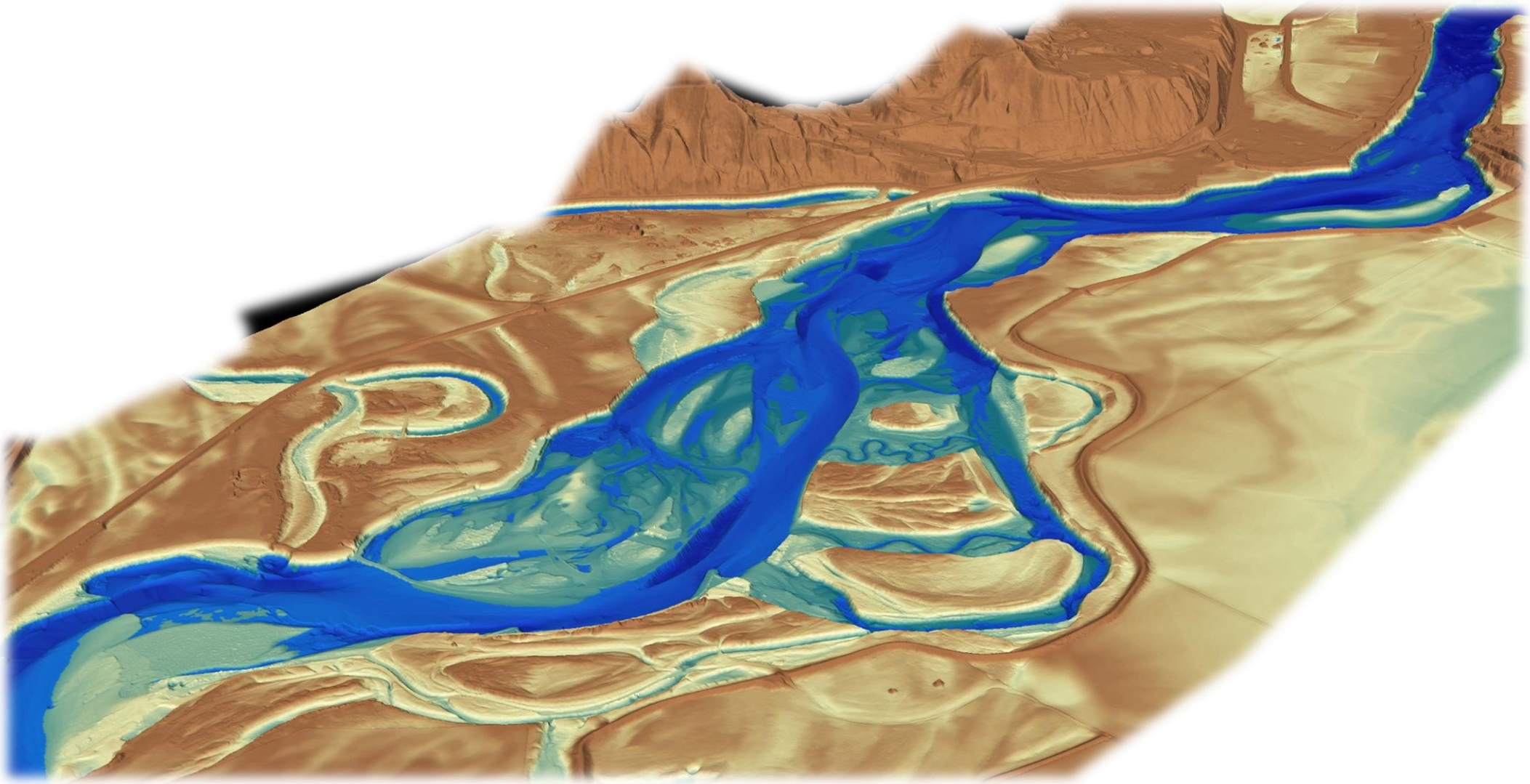

*lidarmag.com*

# Geomorphometry and terrain analysis

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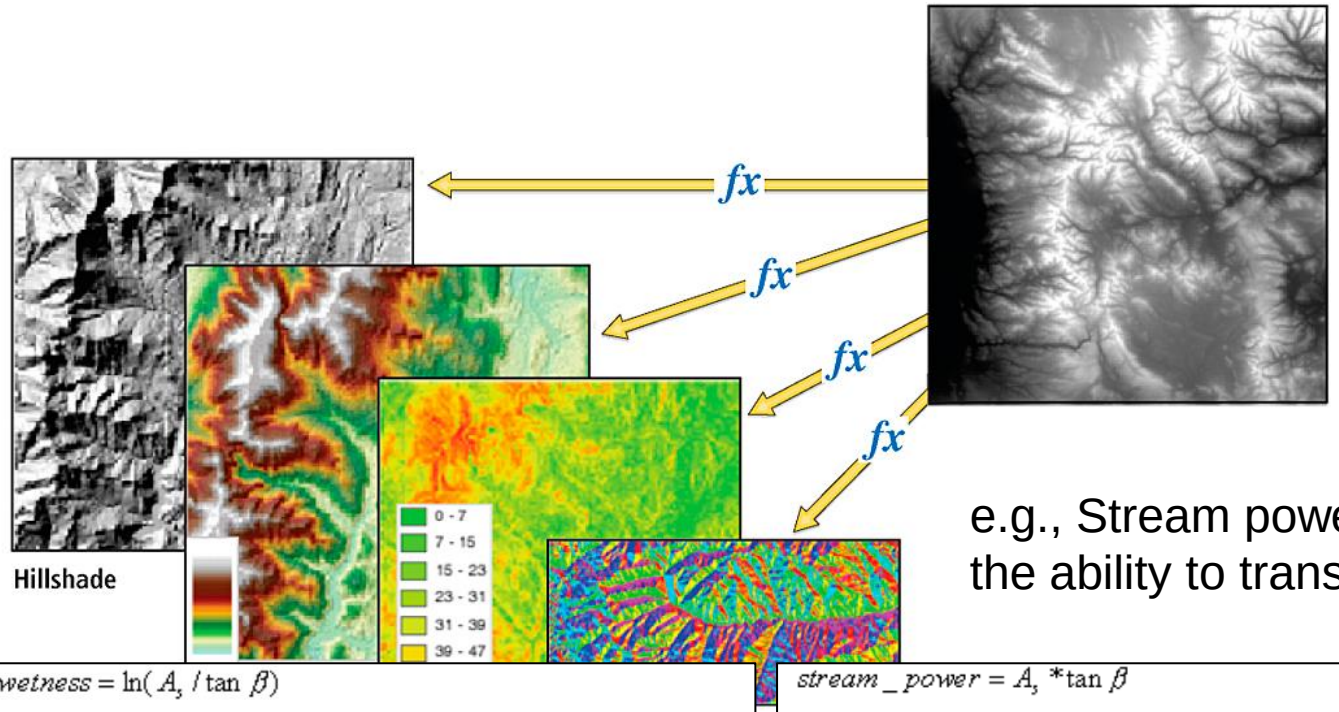
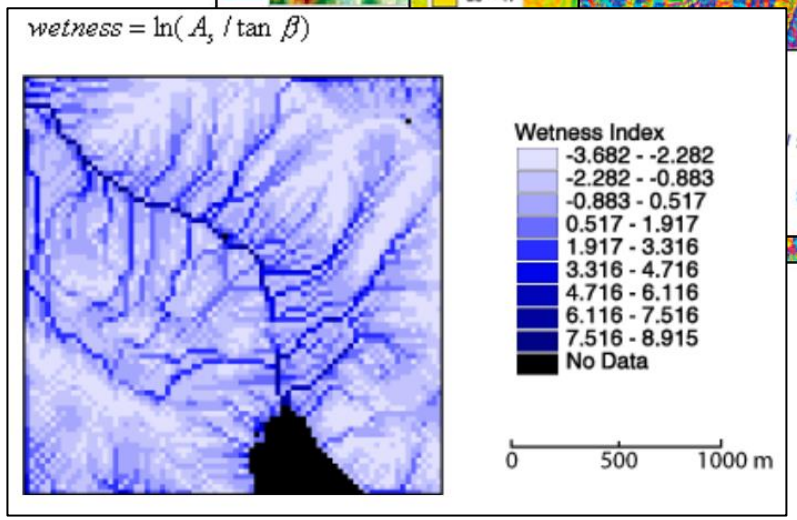
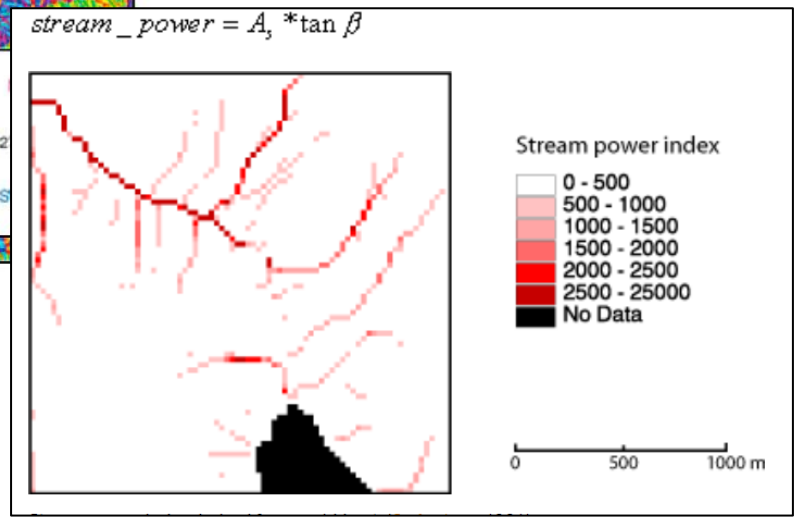
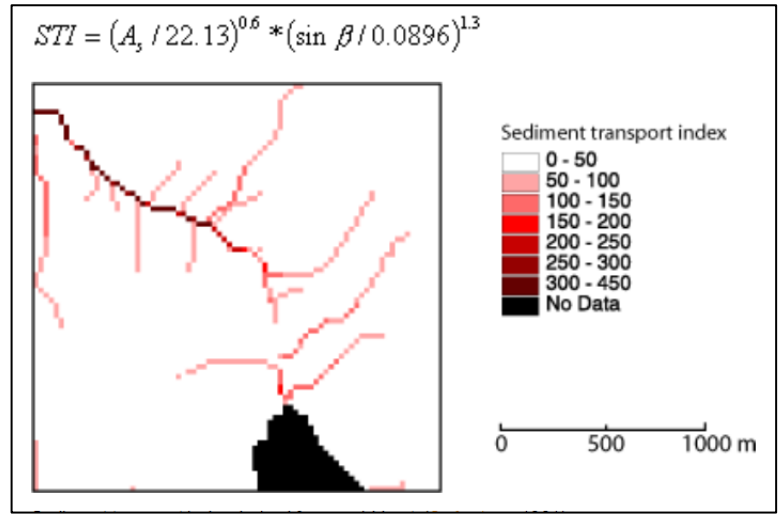



e.g., Stream power index: energy of a stream channel, related to the ability to transport sediment, ...




*Swisstopo, 1991*

# Geomorphometry and terrain analysis

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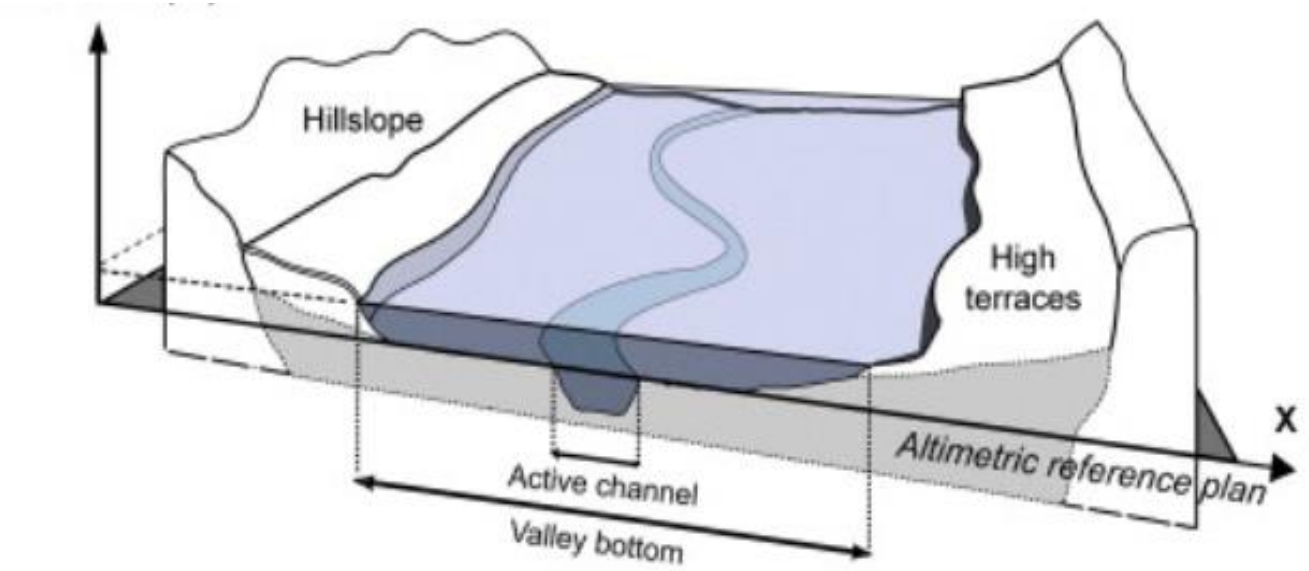
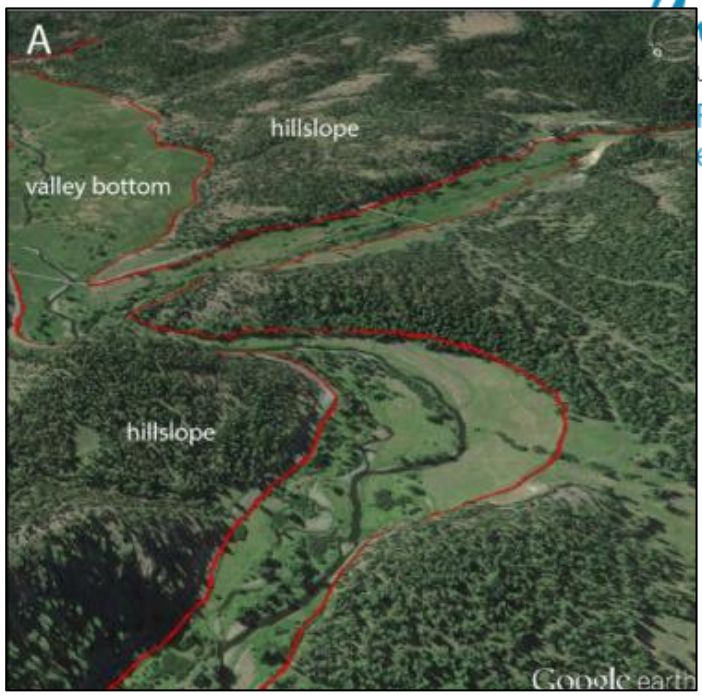
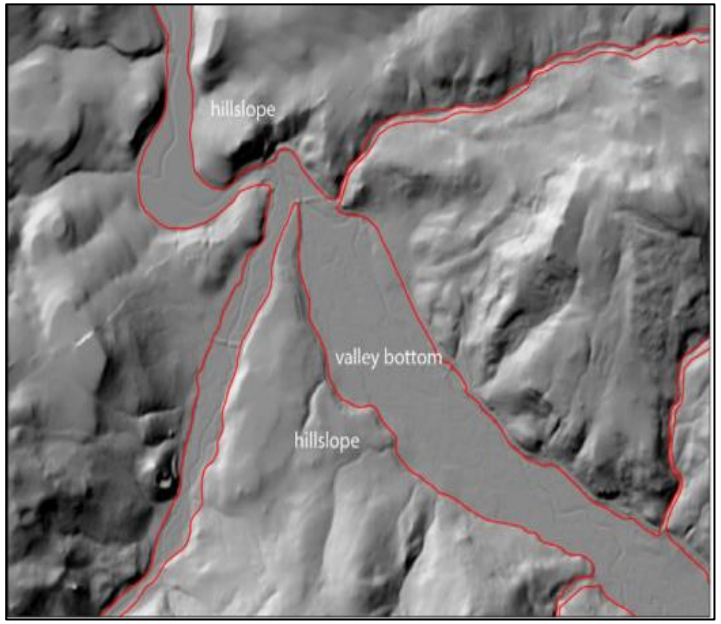
## Physiography and geomorphic units semi-automatic delineation

The **valley bottom** includes the contemporary floodplain and/or its **channel**(s) within **confining margins**




*Fryirs et al., 2015*



# Geomorphometry and terrain analysis

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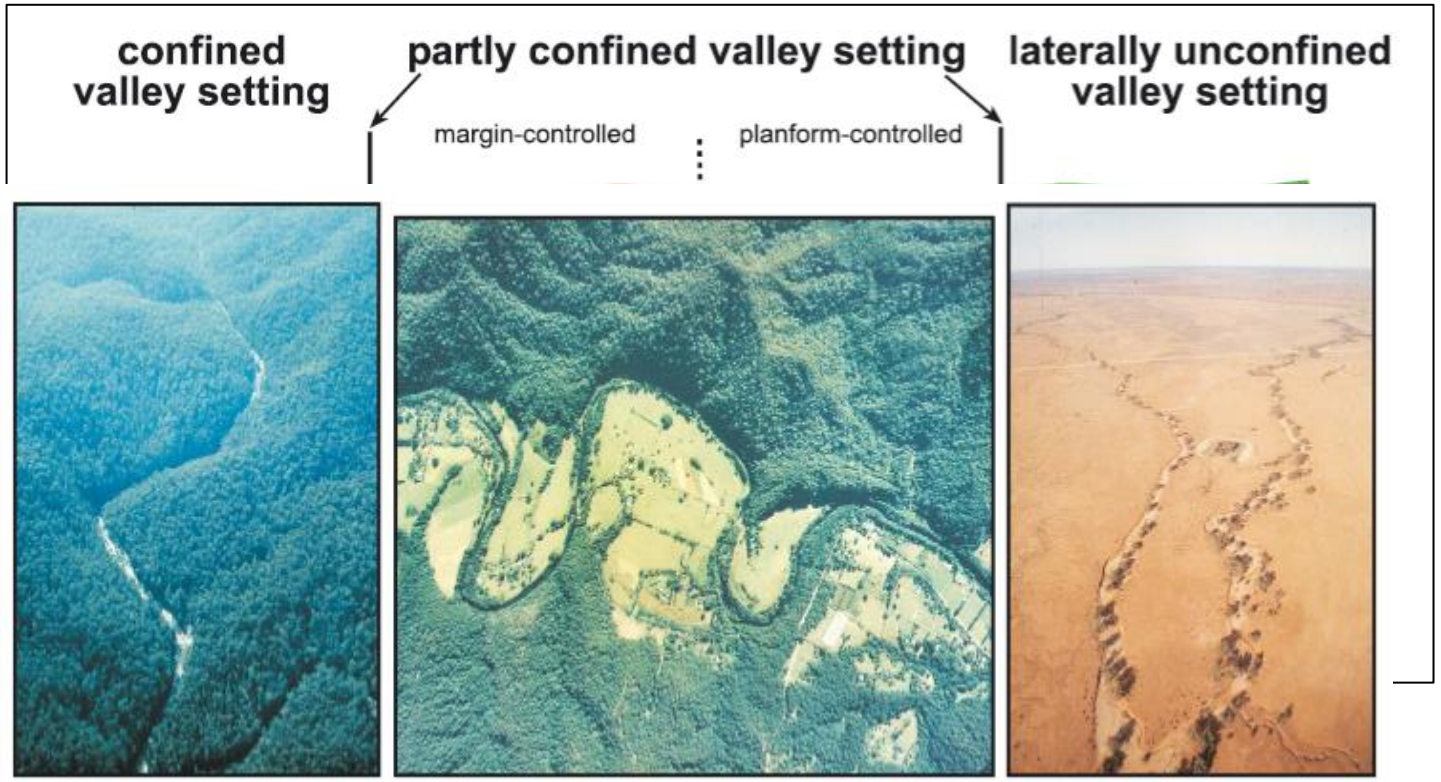
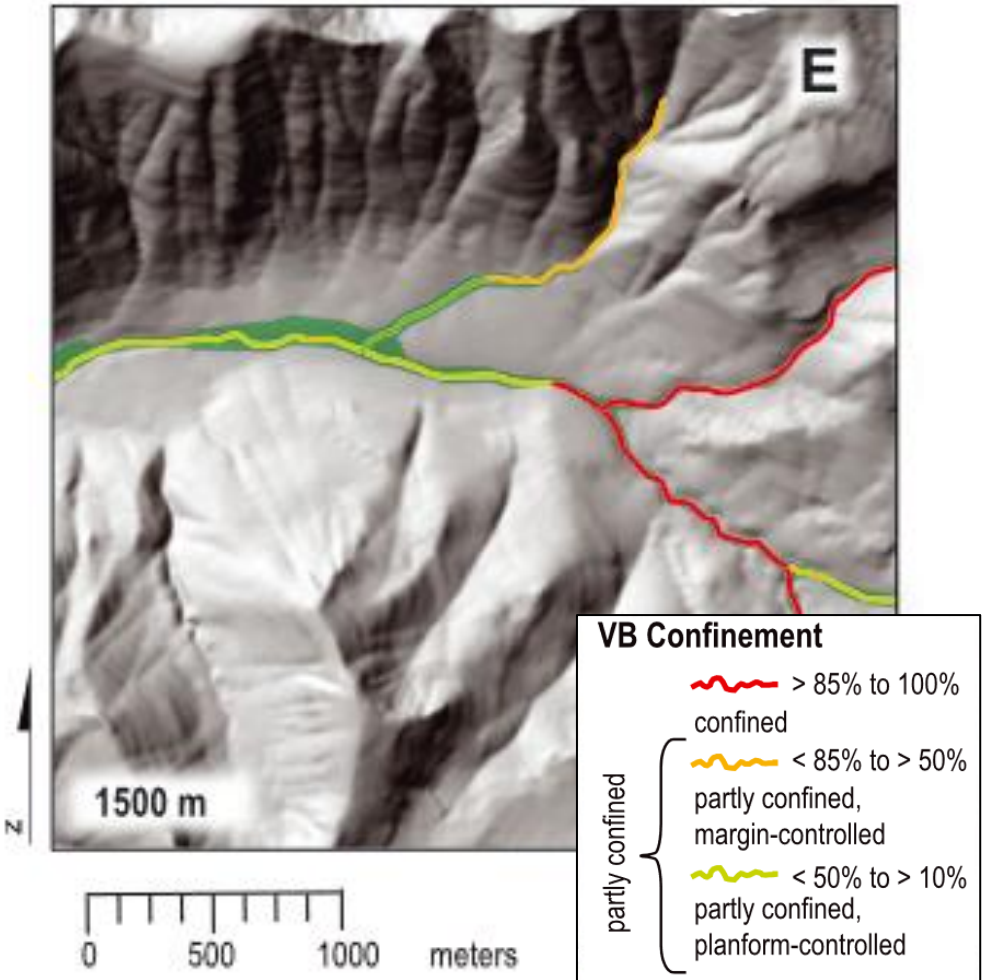
## River confinement



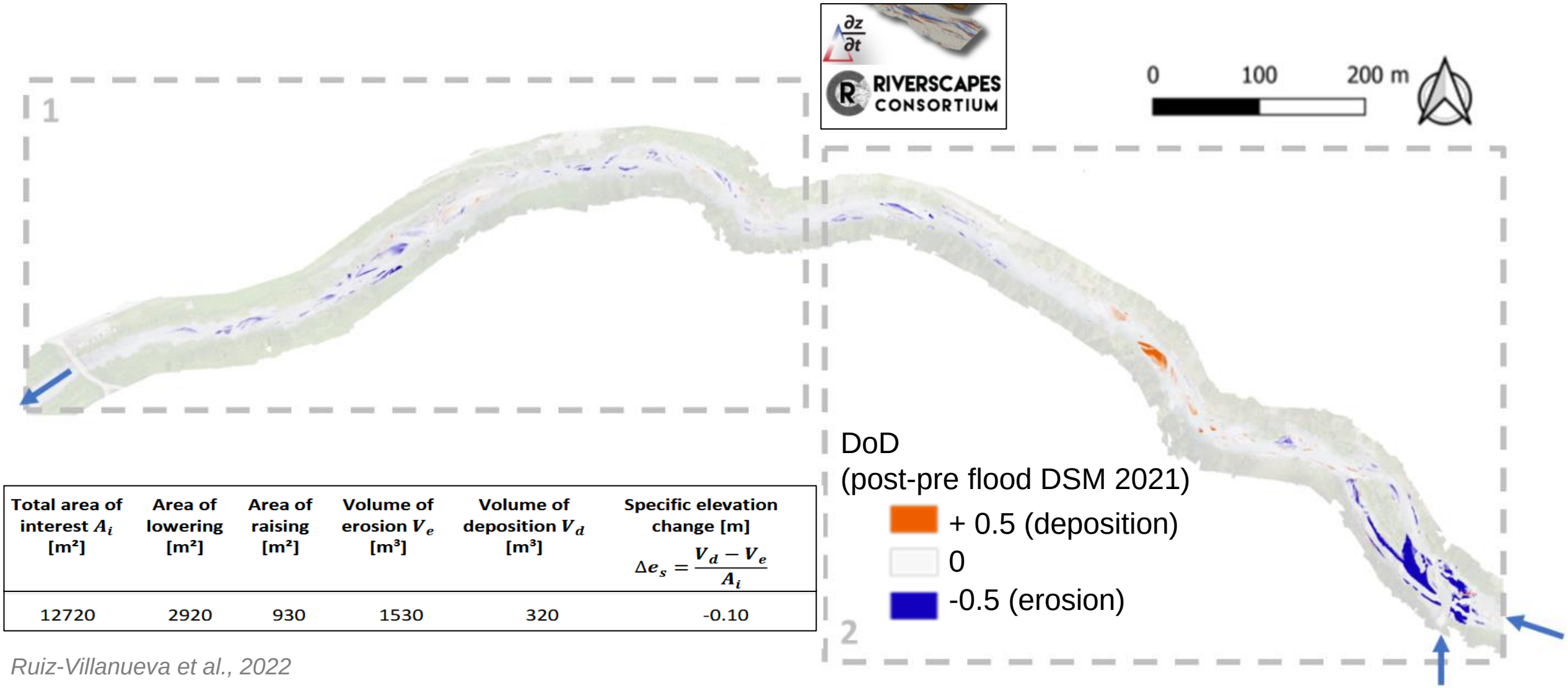




Valley confinement as a control on patterns of rivers, evolutionary trajectory, sediment flux and the geomorphic effectiveness of floods

*Fryirs et al., 2016*

https://onlinelibrary.wiley.com/doi/epdf/10.1002/esp.4615

# Quantitative geomorphological changes: erosion and deposition




| Total area of interest $A_i$ [m²] | Area of lowering [m²] | Area of raising [m²] | Volume of erosion $V_e$ [m³] | Volume of deposition $V_d$ [m³] | Specific elevation change [m] $\Delta e_s = \frac{V_d - V_e}{A_i}$ |
|---|---|---|---|---|---|
| 12720 | 2920 | 930 | 1530 | 320 | -0.10 |

*Ruiz-Villanueva et al., 2022*

**DoD**: DEM of difference= cell-by-cell change in elevation between two DEMs

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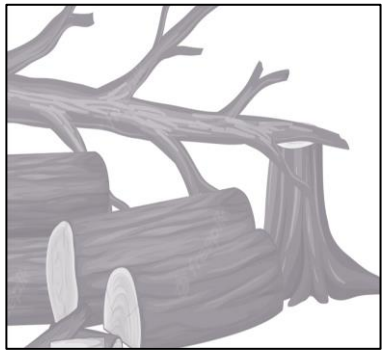

# Hydrology: watershed´s response

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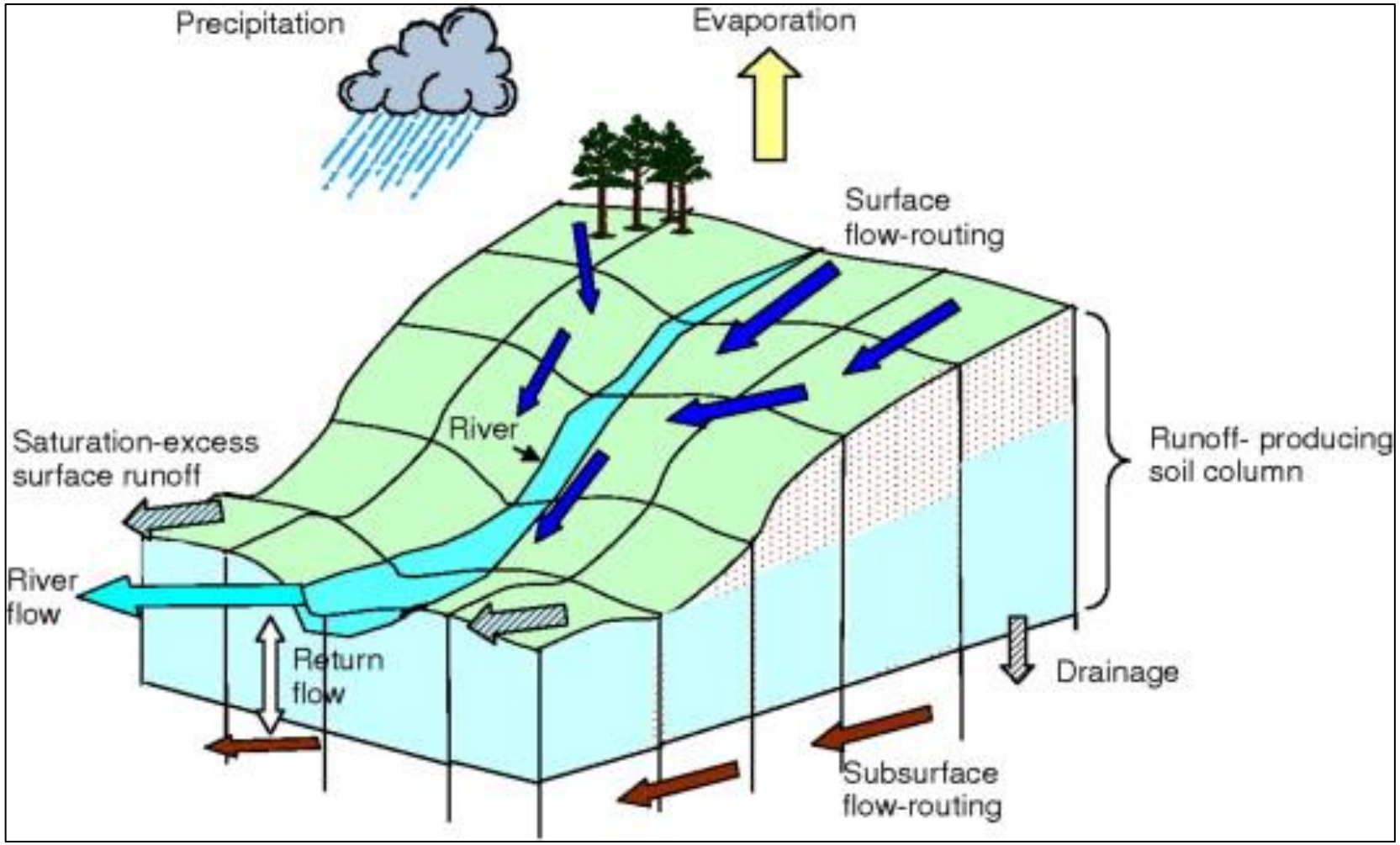


Any hydrological model needs spatial datasets on terrain, soil, land-use and land-cover properties as physiographic input; and spatially distributed climatic data: radiation, temperature, precipitation

*https://www.sciencedirect.com/science/article/pii/S0309170809000177*

# Hydrology: watershed´s response

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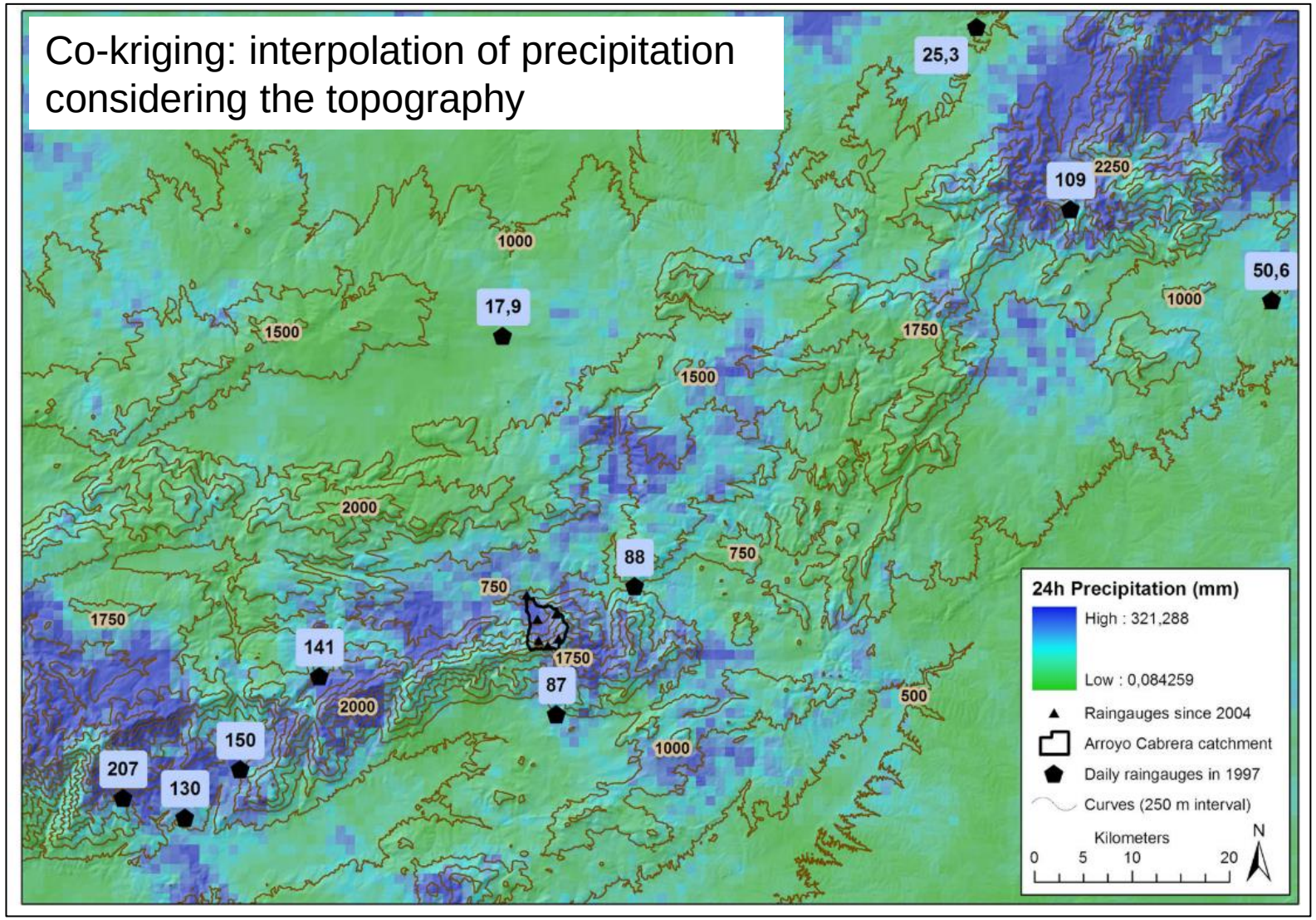


Interpolation (i.e., using known data values to estimate unknown data values) of climatic variables: from station (point)-based to spatially distributed

Interpolation methods: from IDW, spline…, to geostatistics (e.g., kriging and co-kriging)

*Ruiz-Villanueva et al., 2013*

# Hydrology: watershed´s response

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Hydrology tools to extract watershed and river network

Handling different datasets with different spatial resolution

**Digital terrain analysis catchment to global datasets**

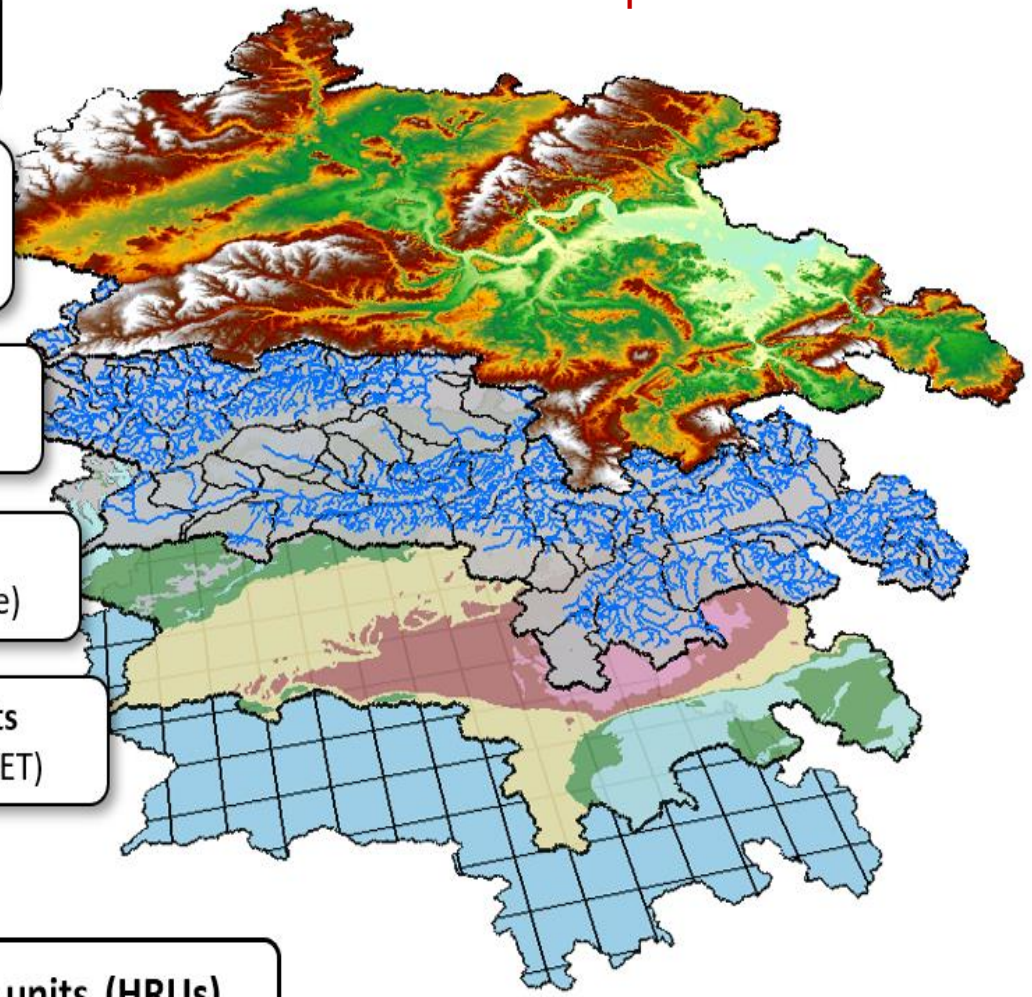
**Topographic information**
(elevation, slope, accumulated area, topographic index)

**Gauge and river network**
(gauged or ungauged points)

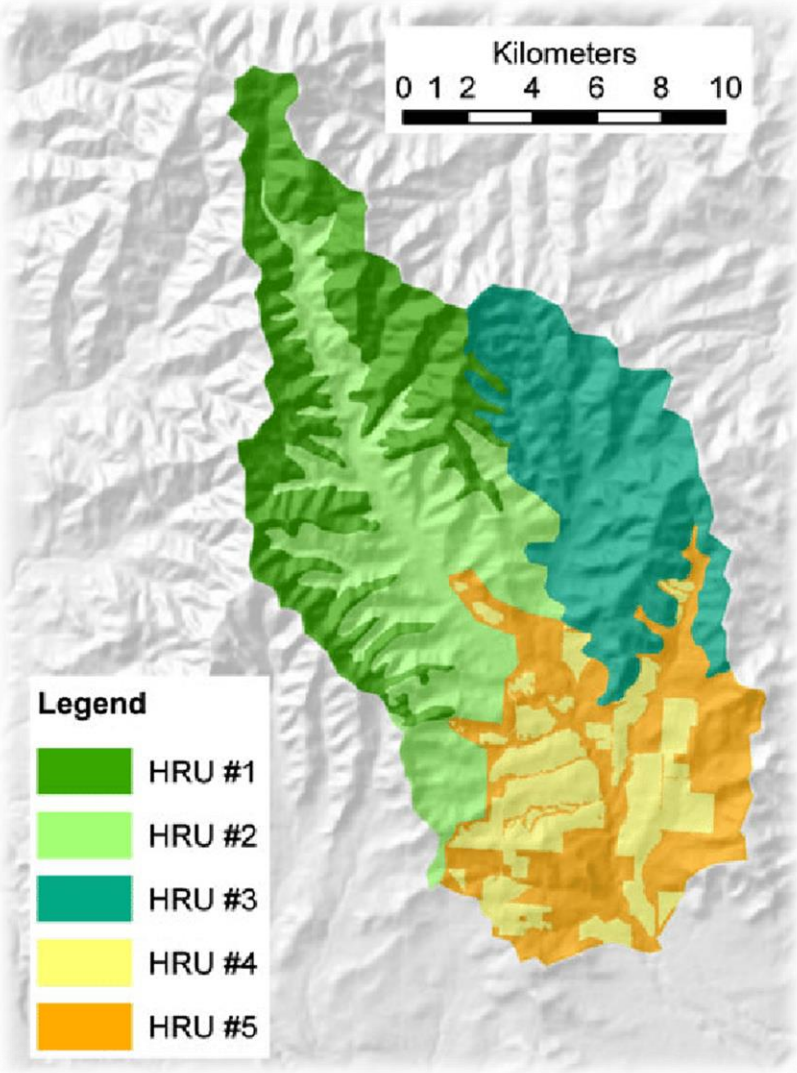
**Landscape layers**
(e.g. geology, soils, land use)

**Spatially varying inputs**
(e.g. gridded rainfall or PET)

**Hydrological response units (HRUs)**



Interpolation tools




*Forbes et al., 2011*

# Hydrodynamics: river´s response

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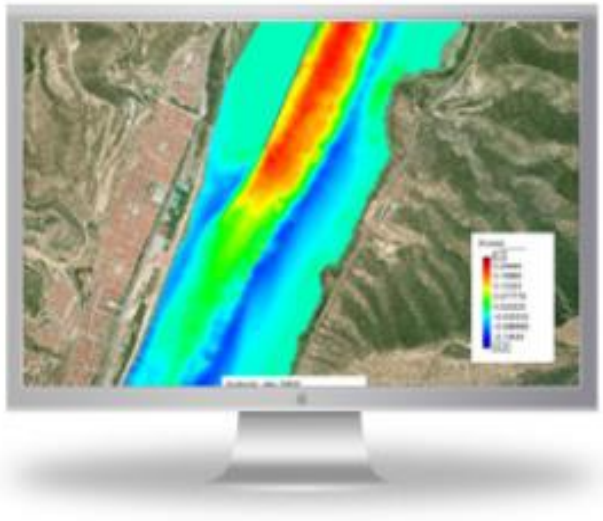

Water Depth
Flow velocity
Energy
Sediment transport

©Iberaula

Any hydraulic or hydrodynamic model needs spatial datasets as: terrain (DEM), land use and land cover…

Pre-process and input data acquisition and post-process and visualization of results

# Input data and pre-processing for hydrodynamic modelling

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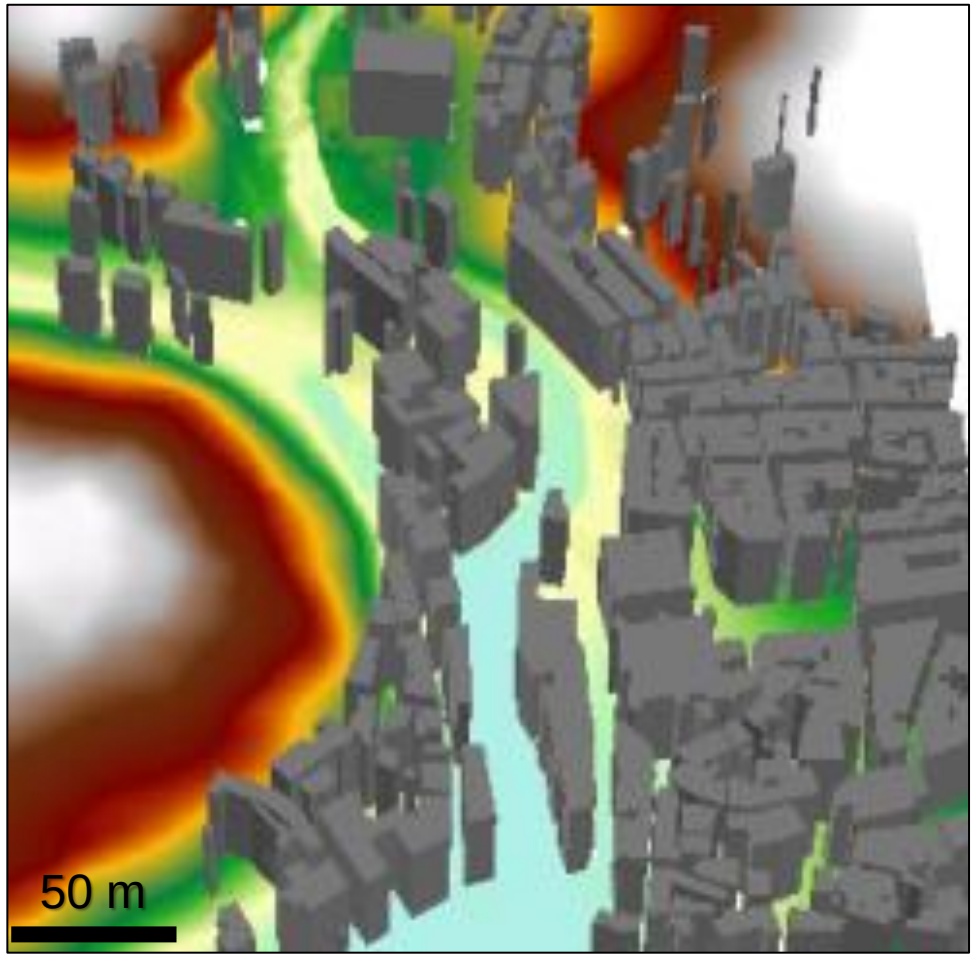
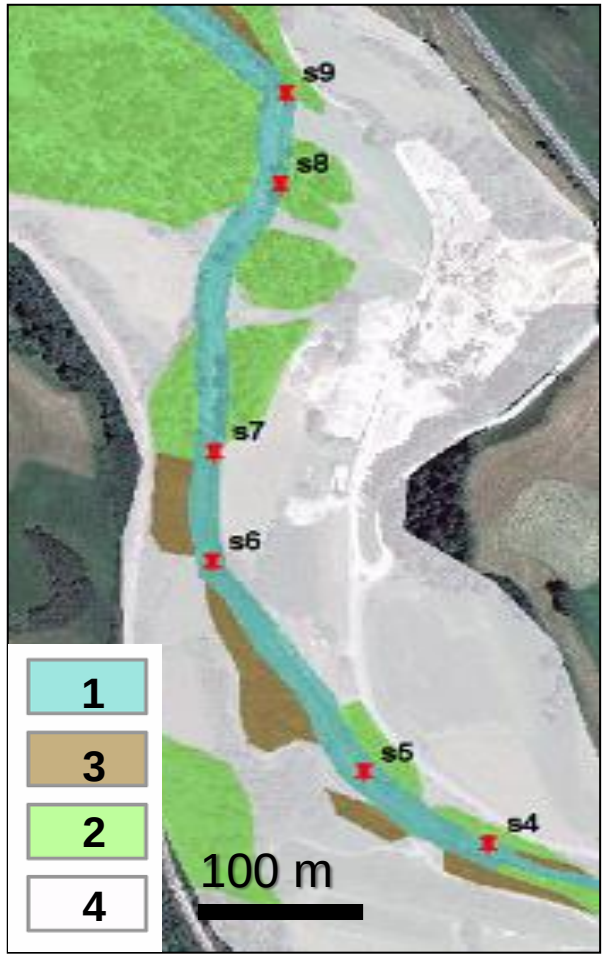
## High resolution topography




*Ruiz-Villanueva et al., 2014*

## Homogeneous Roughness Units




*Ruiz-Villanueva et al., unp*

*Schneider et al., 2015*


| ID | Name | Description | N |
|---|---|---|---|
| 3 | Shrubs | Medium to dense shrubby | 0.06 |
| 4 | Meadows /cultivated | Crops | 0.02 |
| 2 | Trees | Medium to dense forest | 0.1 |
| 1 | Gravel | riverbed | 0.04 |

# Hydrodynamic modelling post-process

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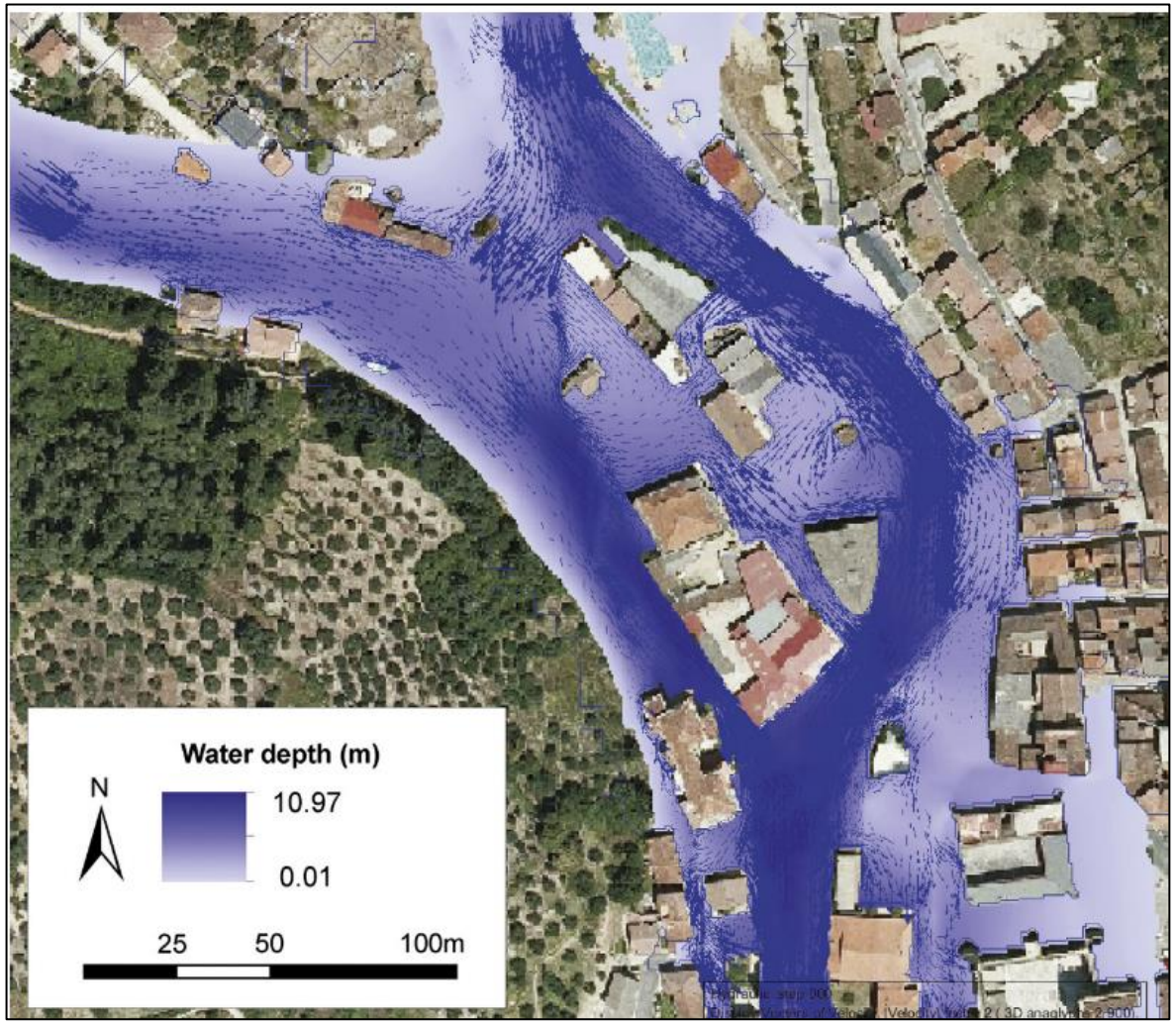
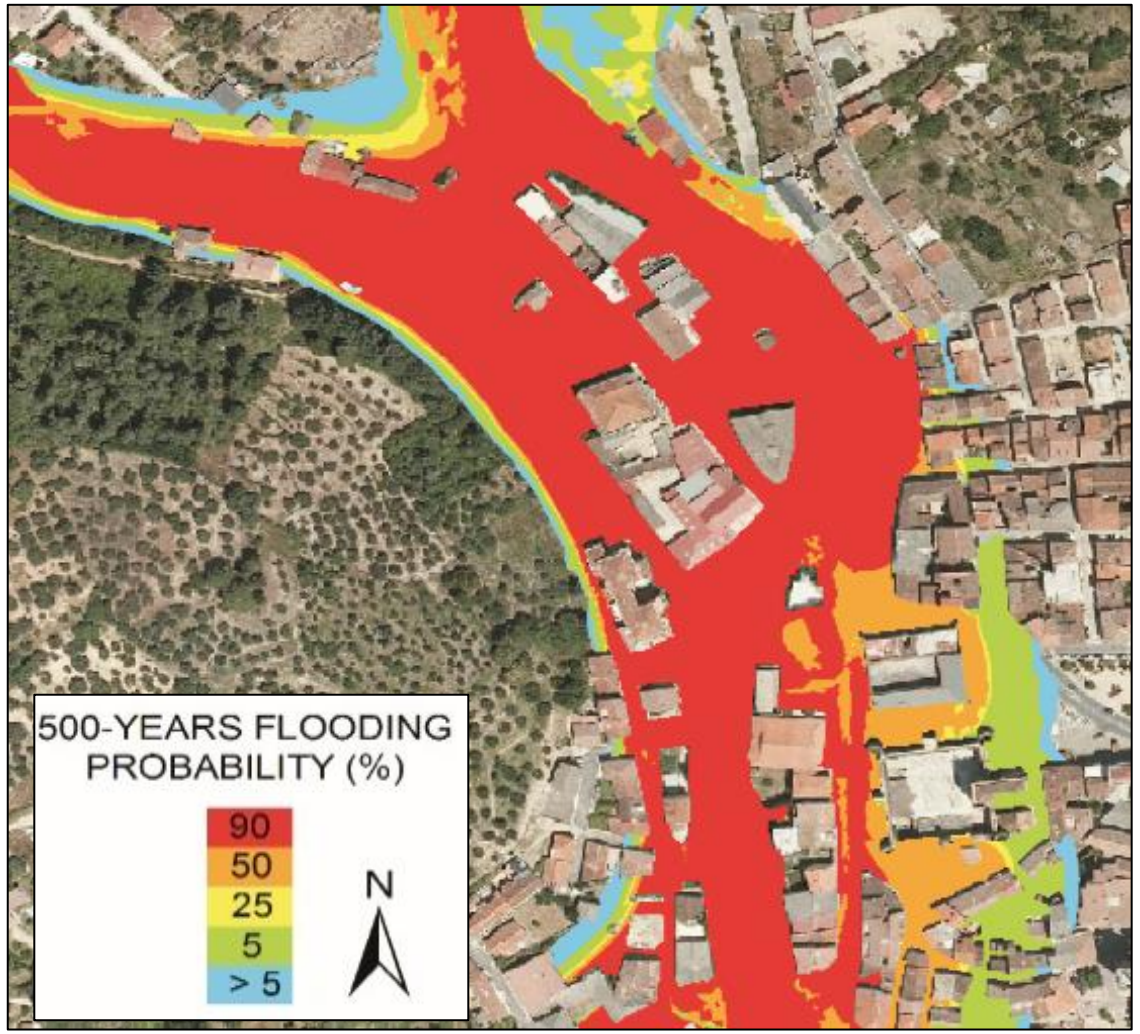
## Hydrodynamic modelling output: water depth




## Flooded area (probabilistic)




*Bodoque et al., 2015; Ruiz-Villanueva et al., 2014*

# Hydrodynamic modelling post-process

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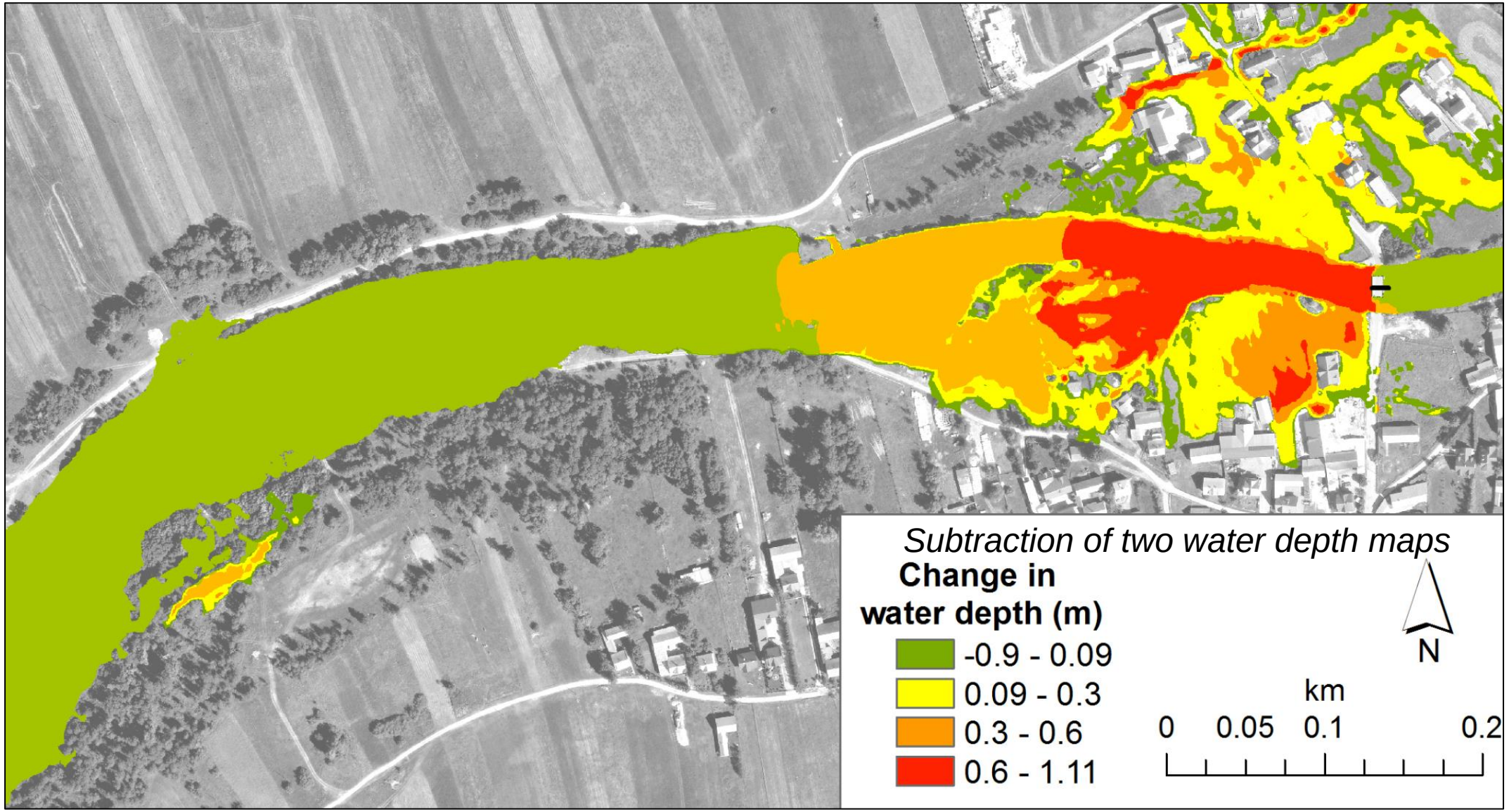


*Ruiz-Villanueva et al., 2017*

# Hydrodynamic modelling post-process

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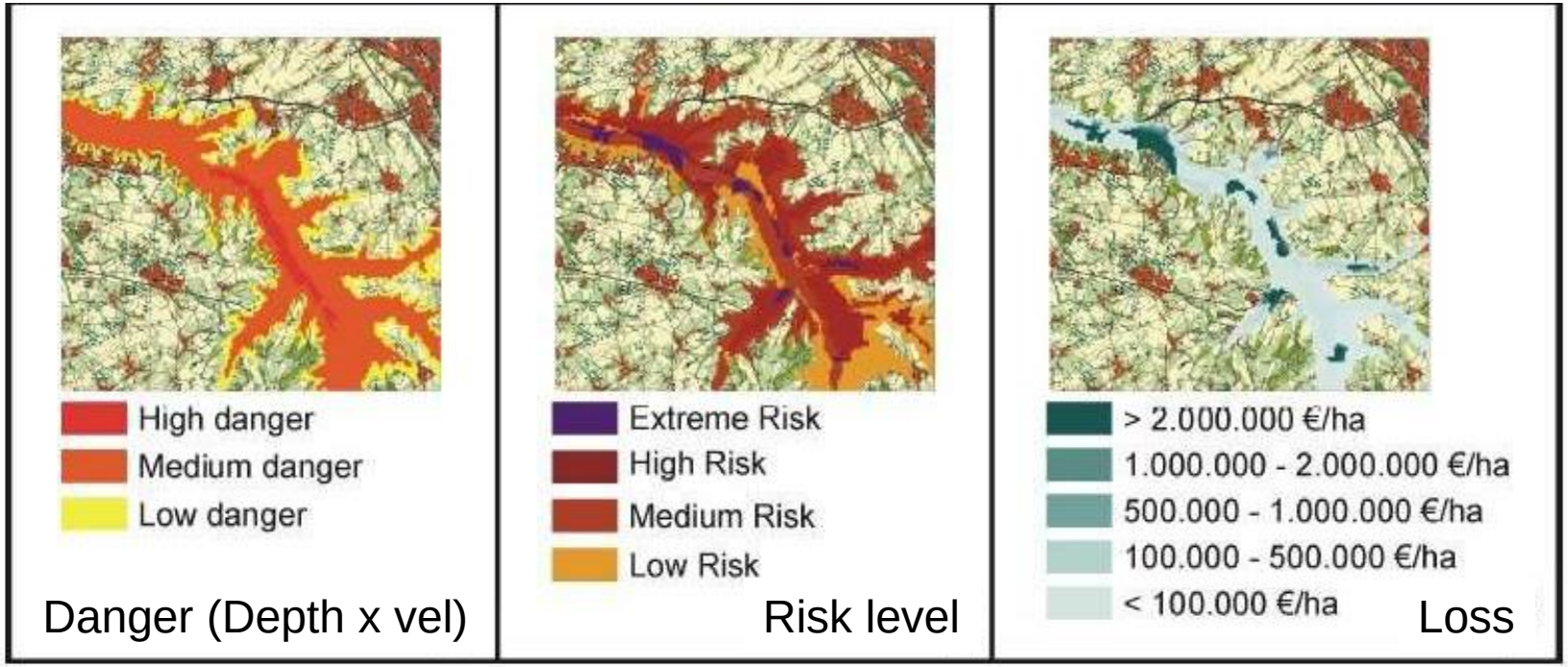
**Cadastral data (land use)**

*Ruiz-Villanueva et al., 2014*

**+ depth-damage functions** and the **types of elements** at risk




*Ochege et al., 2016*

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# Large wood supply to the river during extreme events

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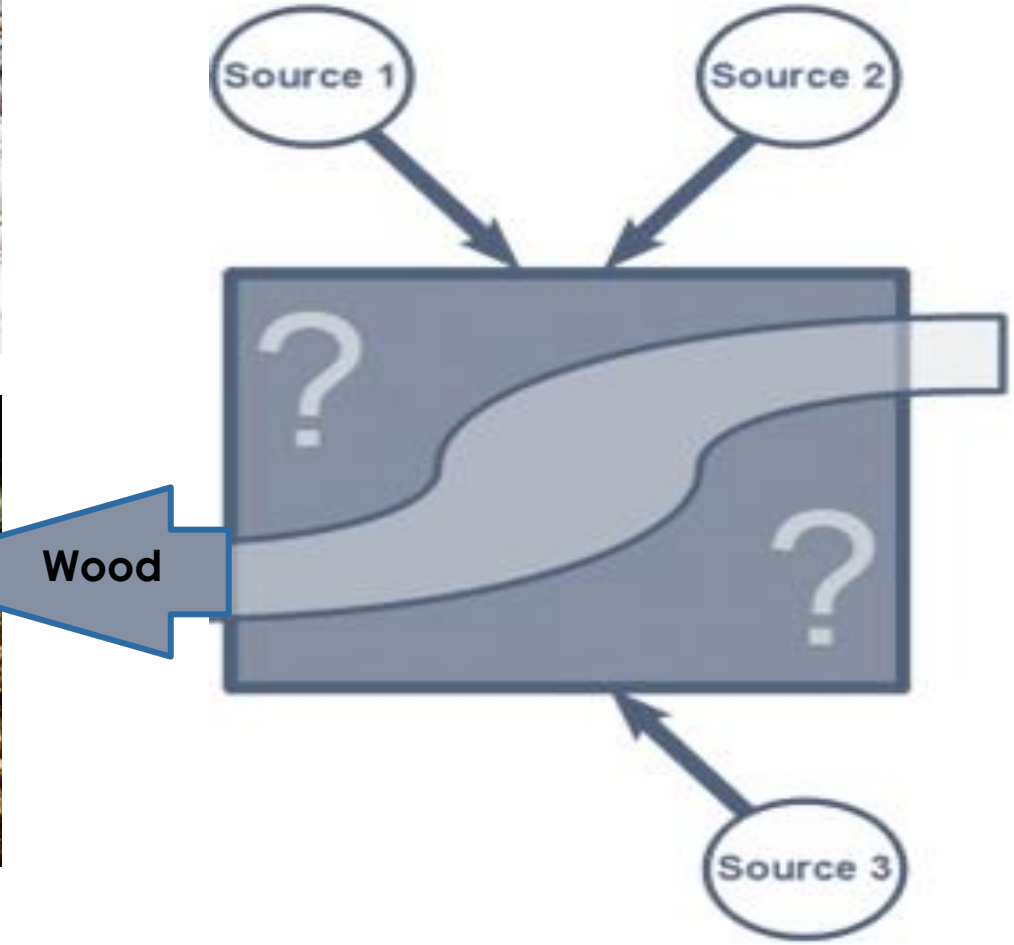

# Large wood supply to the river during extreme events

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Landslides

Flooding and bank erosion

# Large wood supply to the river network

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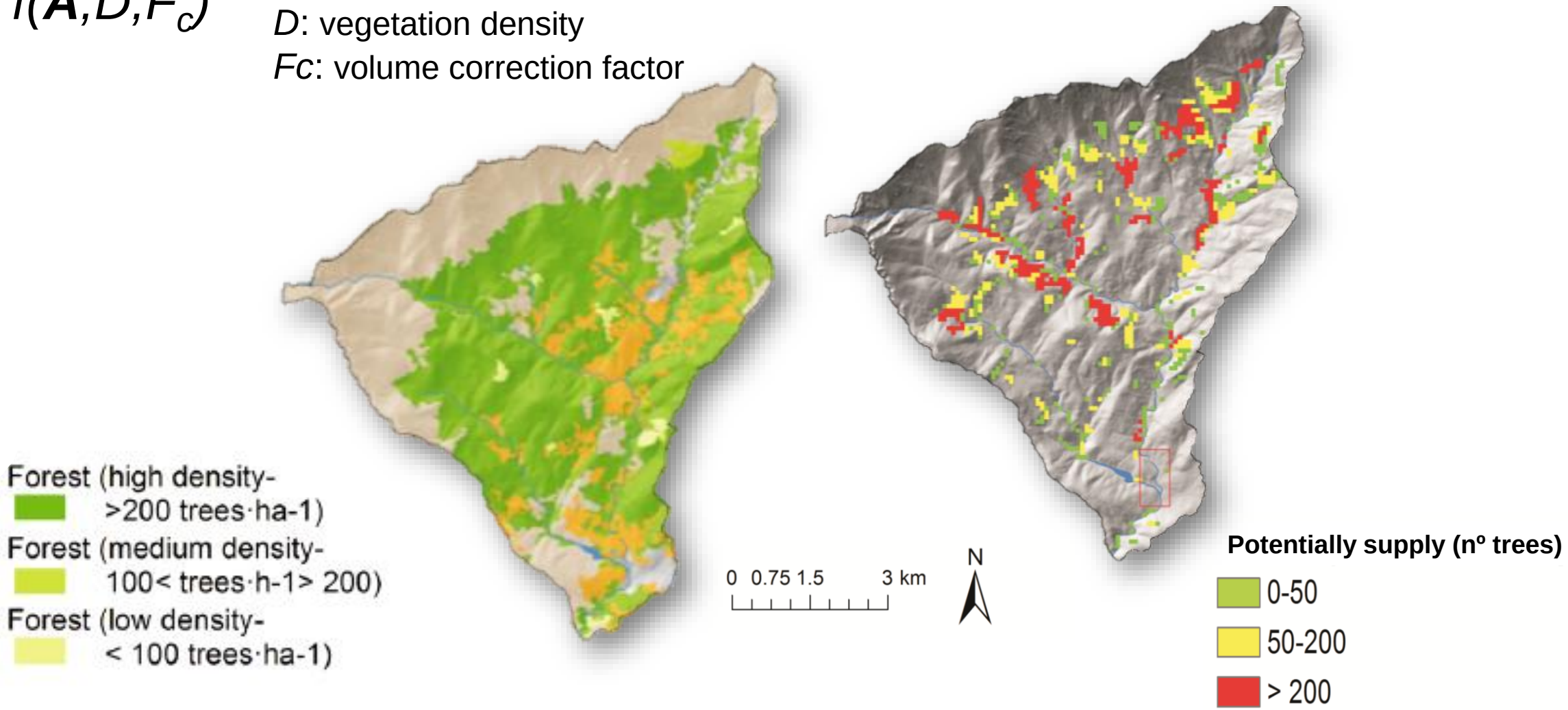
$V_w = f(\mathbf{A}, D, F_c)$

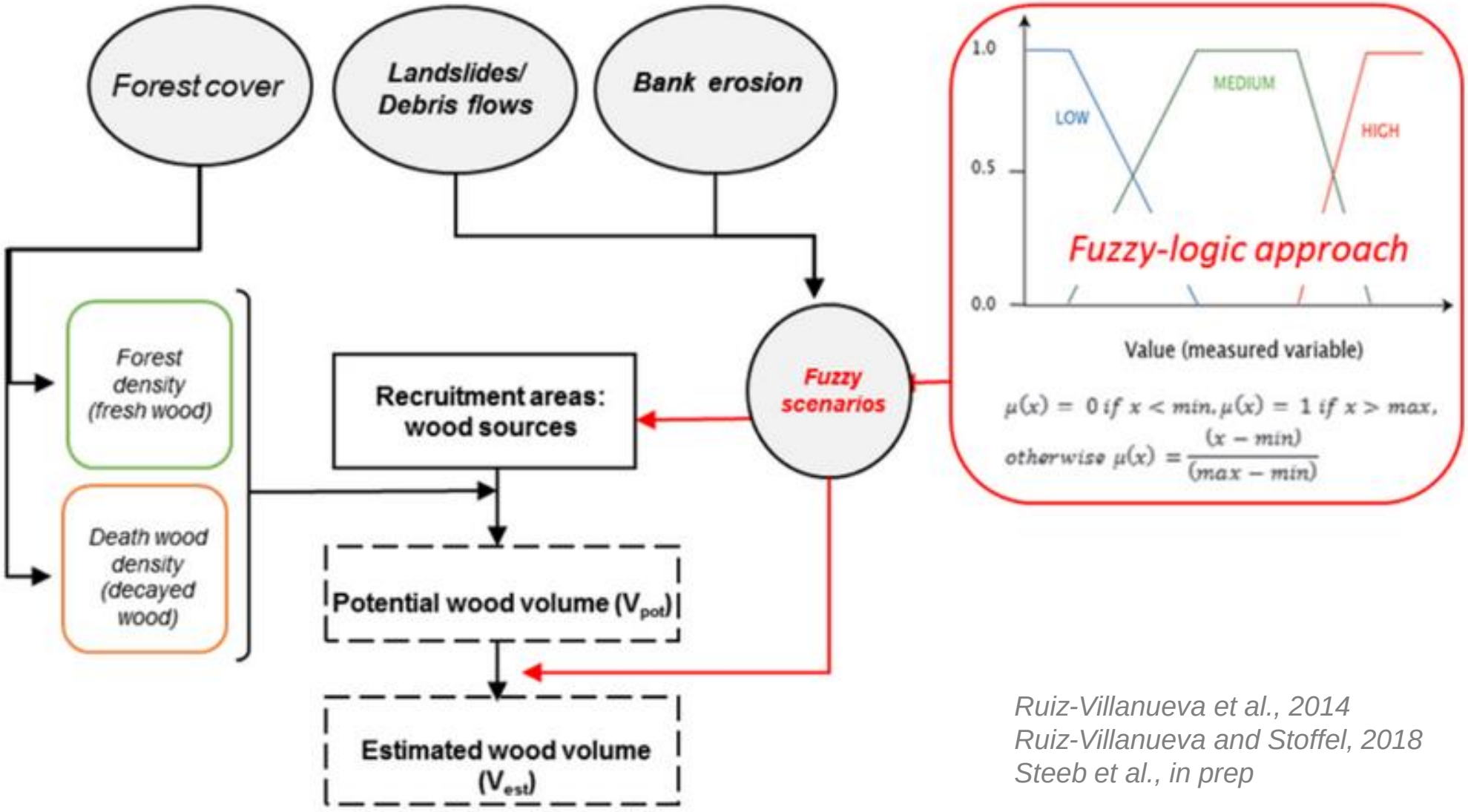
$V_w$: Volume of wood (nº logs)
***A:* contributing area** (areas susceptible to landslides, debris flows, floods…)
$D$: vegetation density
$Fc$: volume correction factor




*Ruiz-Villanueva et al., 2014*

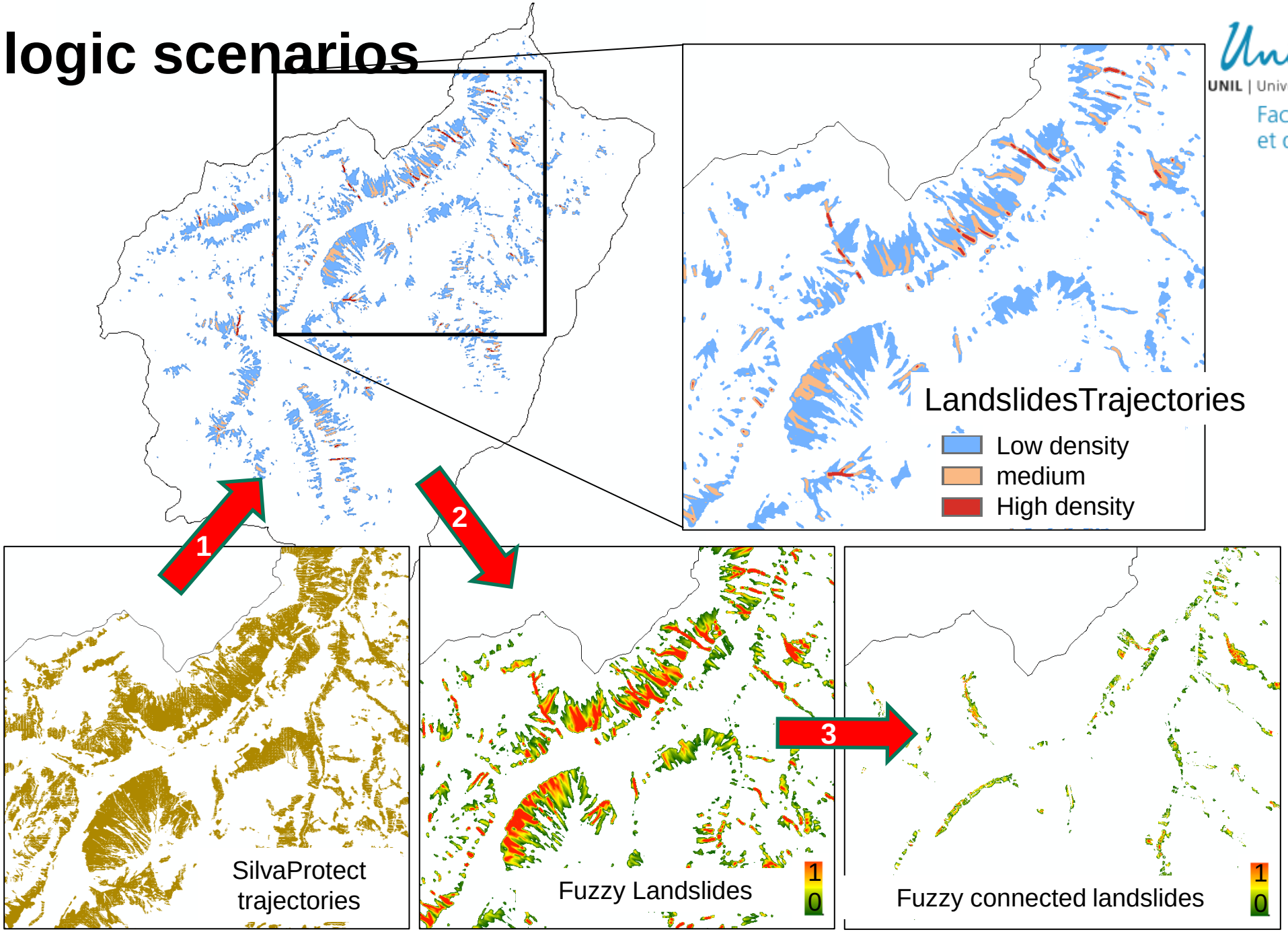
# Large wood supply to the river network

## GIS and fuzzy logic




*Ruiz-Villanueva et al., 2014*
*Ruiz-Villanueva and Stoffel, 2018*
*Steeb et al., in prep*

# Fuzzy logic scenarios



# Large wood supply to the river network

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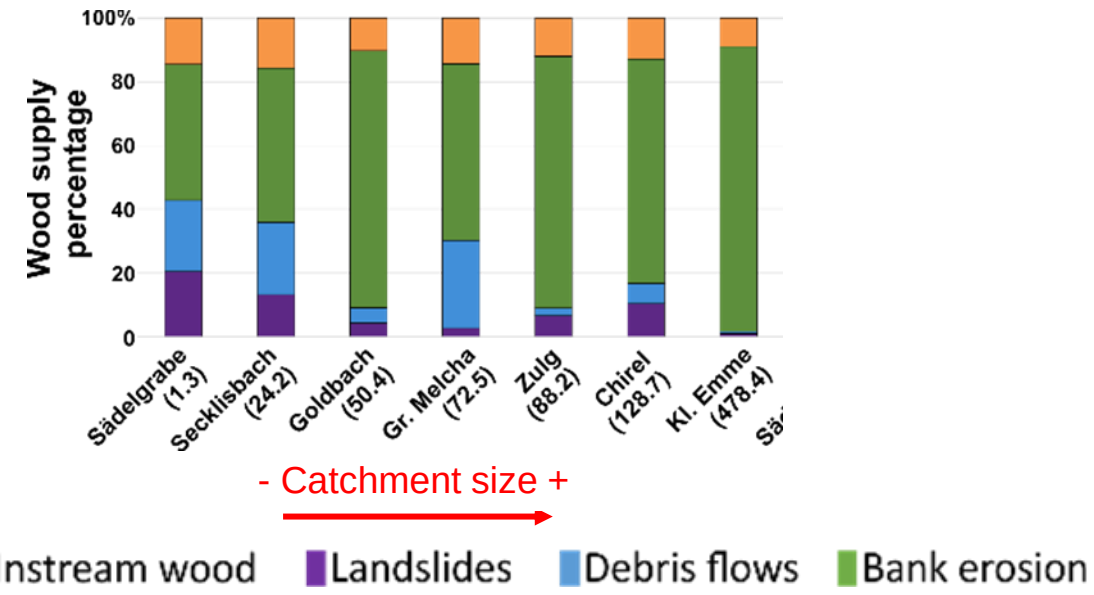
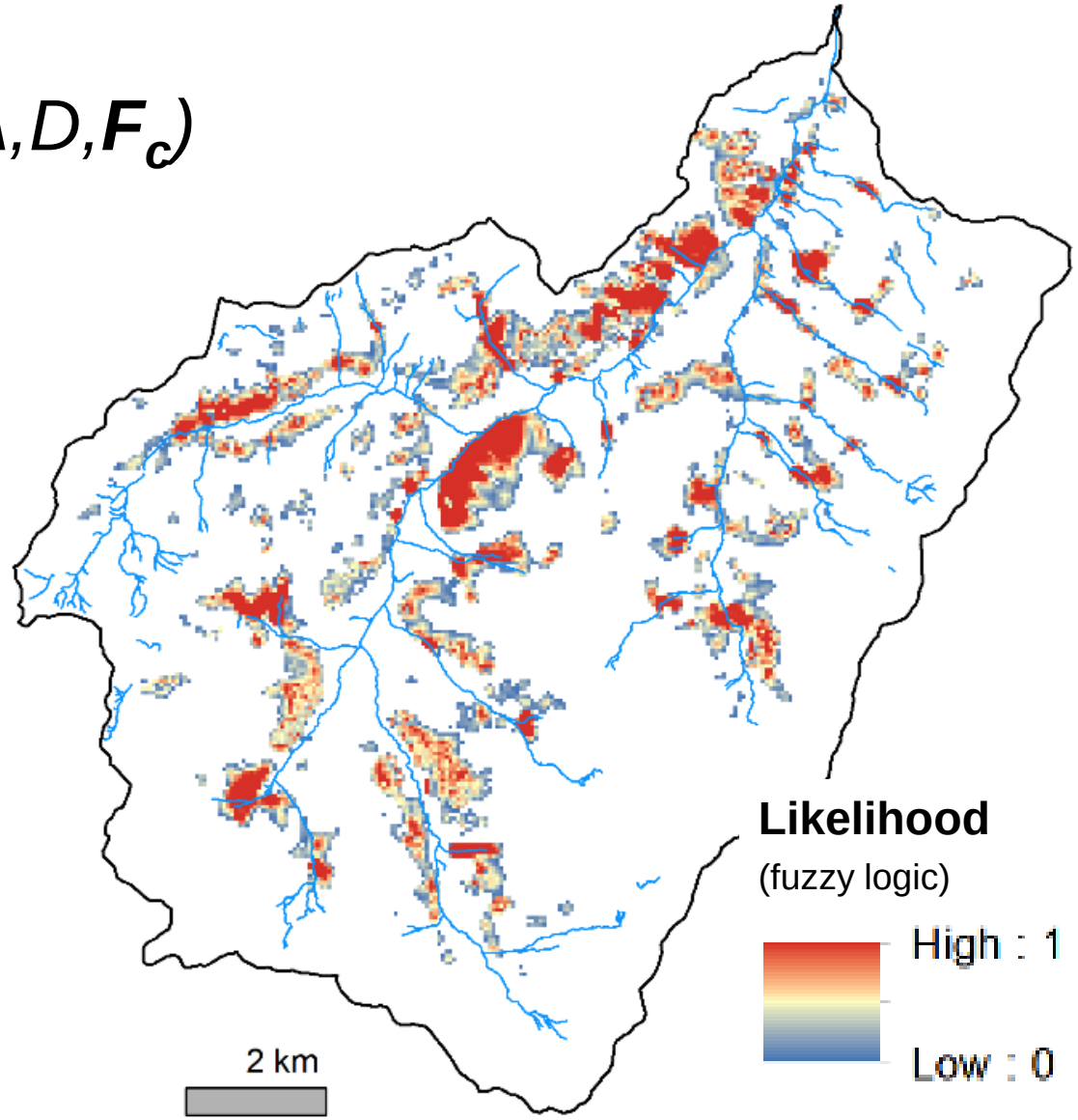
$V_w$: Volume of wood (nº logs)
$A$: contributing area
$D$: vegetation density
***Fc*: volume correction factor**

$$V_w = f(A, D, \boldsymbol{F_c})$$

Contribution (%) of each process to wood supply




*Ruiz-Villanueva and Stoffel, 2018; Steeb et al., in prep*

# River networks as graphs

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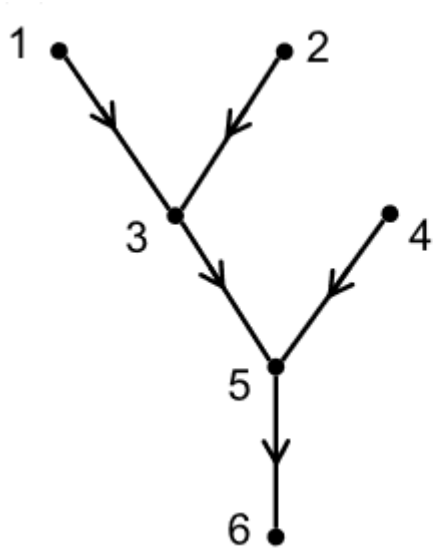
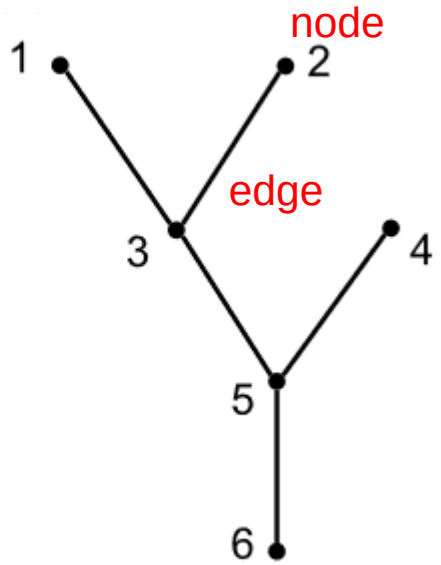
*directed graph representation*




*undirected graph*




**Graph theory** is a branch of mathematics that is concerned with the **structure and function of networks**

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

*asymmetric adjacency matrix*

$$B = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

*symmetric adjacency*

Graphs are systems that comprise *n* nodes (or vertices) connected by *m* edges (or links/arcs) *(Newman, 2010)*. Nodes can represent any physically- or process-based system component, while edges represent any kind of connection between nodes, which may be physical, statistical, temporal, behavioural, etc. *(Heckmann et al., 2015)*

*Abed-Elmdoust et al., 2017*

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