Sediment connectivity assessment through a geomorphometric approach: review of recent applications

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Outline

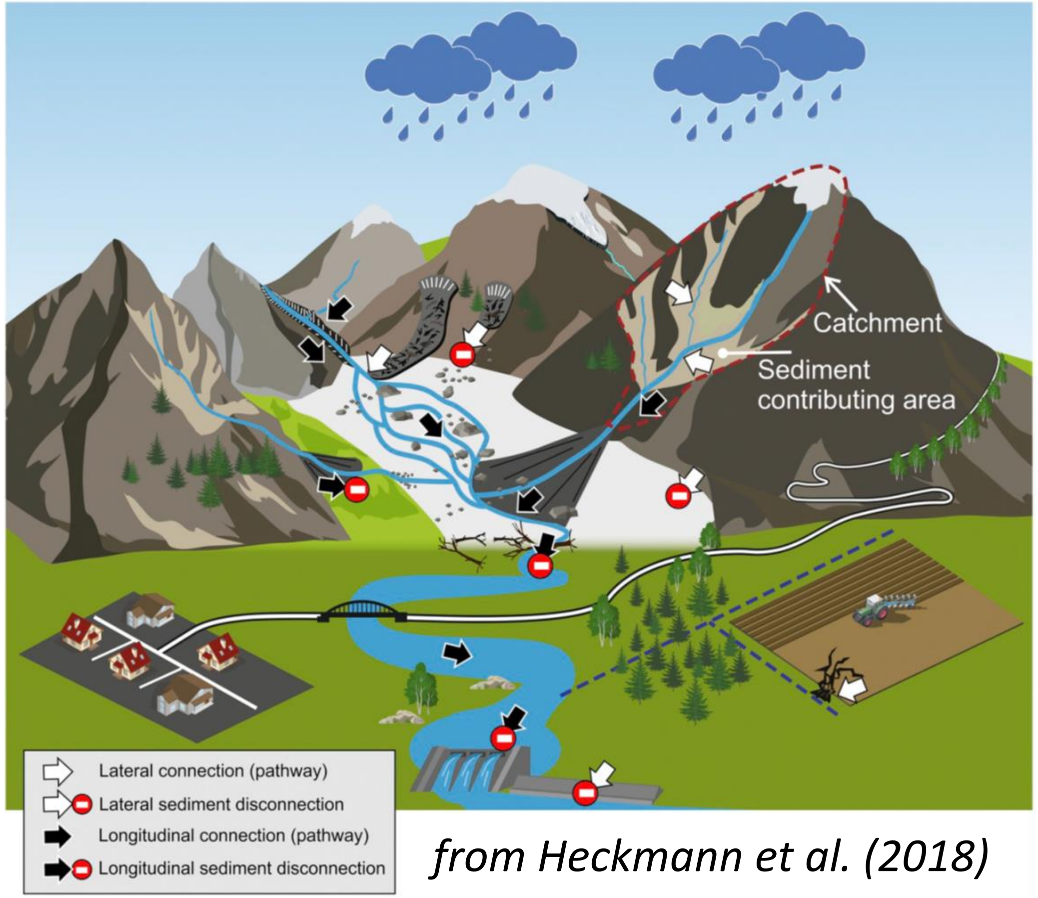
- Introduction
- Index of sediment connectivity and tools
- Overview on recent applications
- Considerations and perspectives

Connectivity concept

Hydrological and sediment connectivity: the degree to which a system facilitates the transfer of water and sediment through itself, through coupling relationships between its components (Heckmann et al., 2018).

Coupling

Decoupling

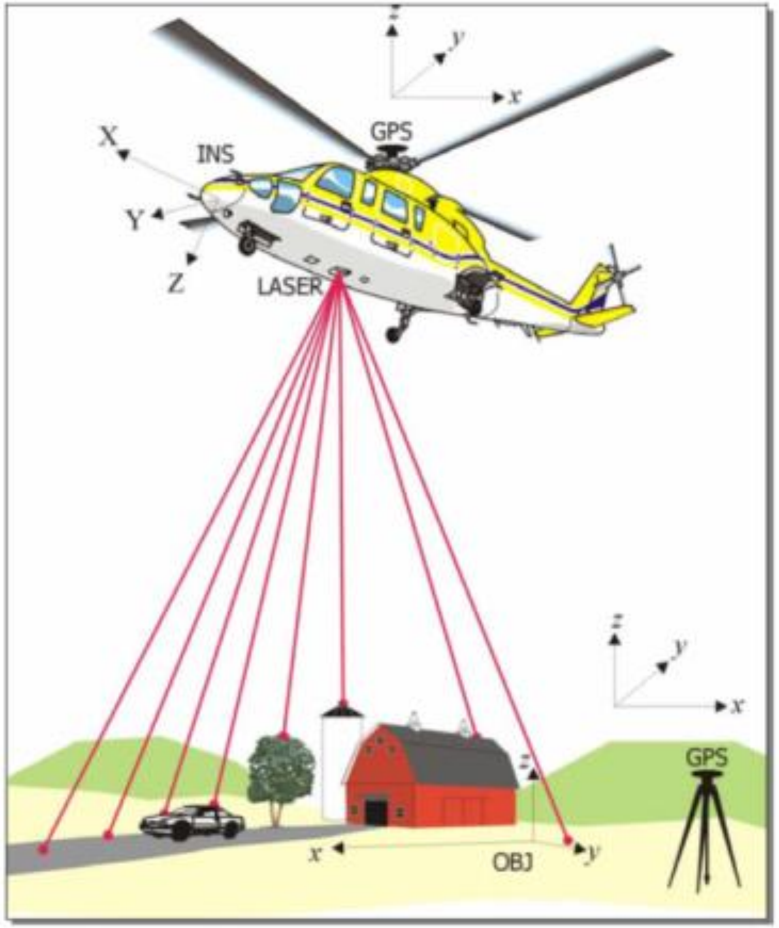


from Heckmann et al. (2018)

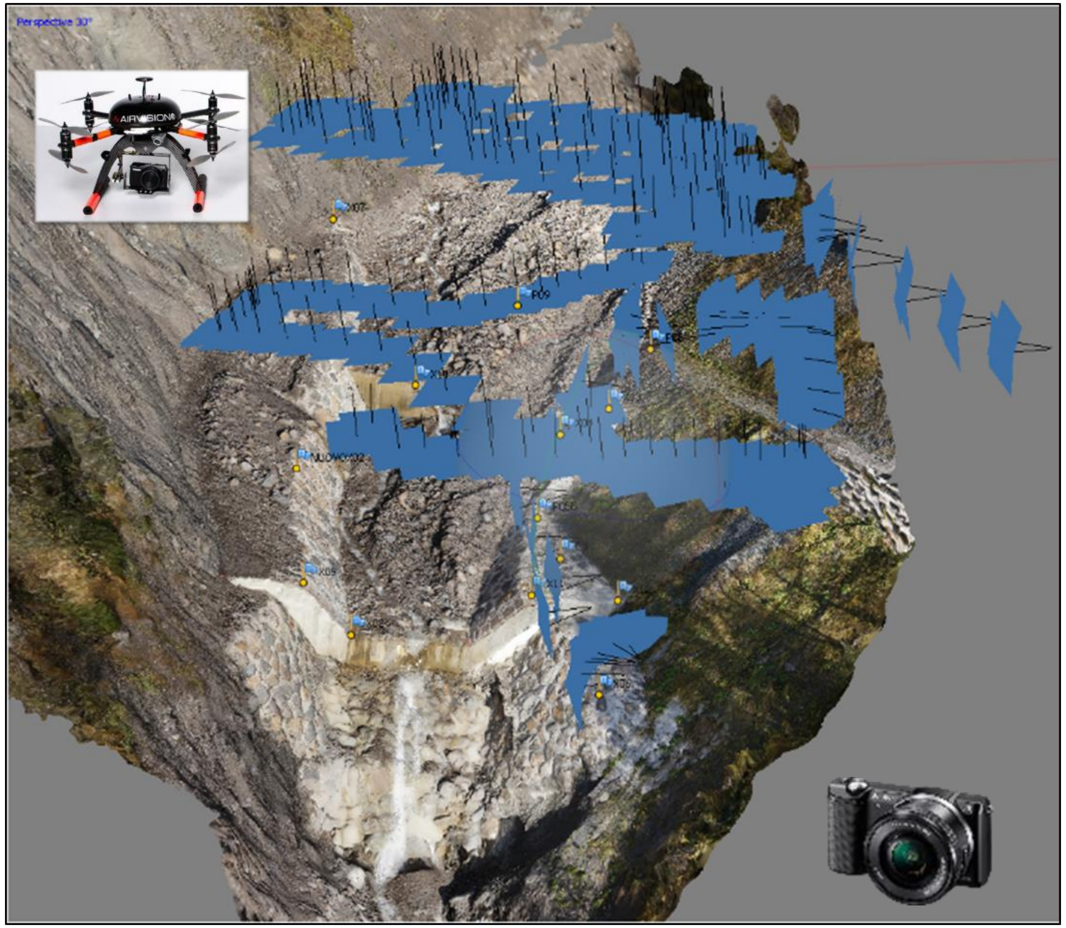
Heckmann T., Cavalli M., Cerdan O., Foerster S., Javaux M., Lode E., Smetanova A., Vericat D., Brardinoni B., 2018. Indices of sediment connectivity: opportunities, challenges and limitations. Earth-Science Reviews, 187, 77-108. DOI: 10.1016/j.earscirev.2018.08.004.

High-resolution Digital Elevation Models enable the quantitative modeling of sediment fluxes and connectivity via geomorphometric analysis.

LiDAR



Structure from Motion



Index of sediment connectivity

The connectivity index (IC) is computed using two components:

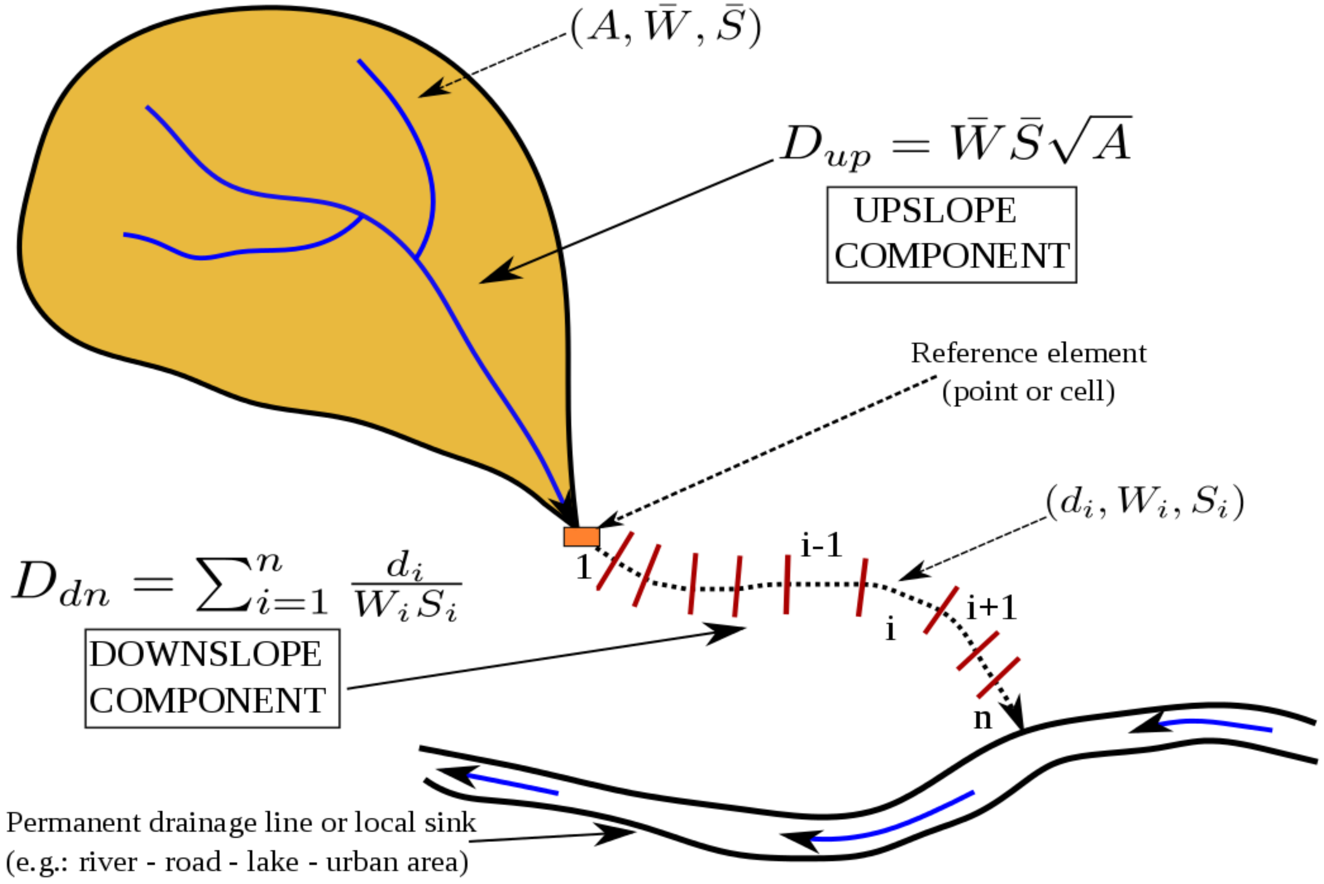
Upslope component D_{up}

potential for downward routing due to upslope area, mean slope and impedance factor.

Downslope component D_{dn}

flow path length that a particle has to travel to arrive to the nearest target or sink.

$$IC = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right)$$



Borselli L., Cassi P., Torri D., 2008. Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. Catena, 75(3), 268-277.

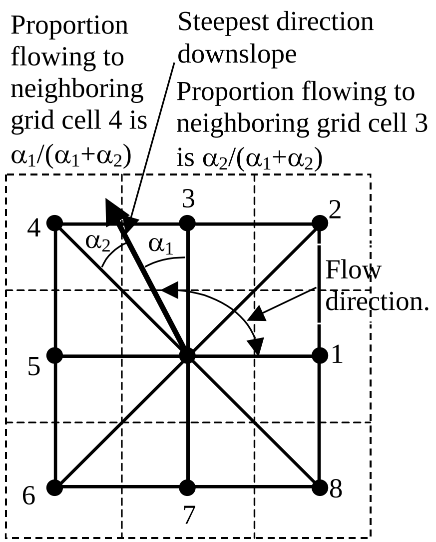
Cavalli M., Trevisani S., Comiti F., Marchi L., 2013. Geomorphometric assessment of spatial sediment connectivity in small alpine catchments. Geomorphology, 188, 31-41.

Slope S (m/m) (steepest descent direction)

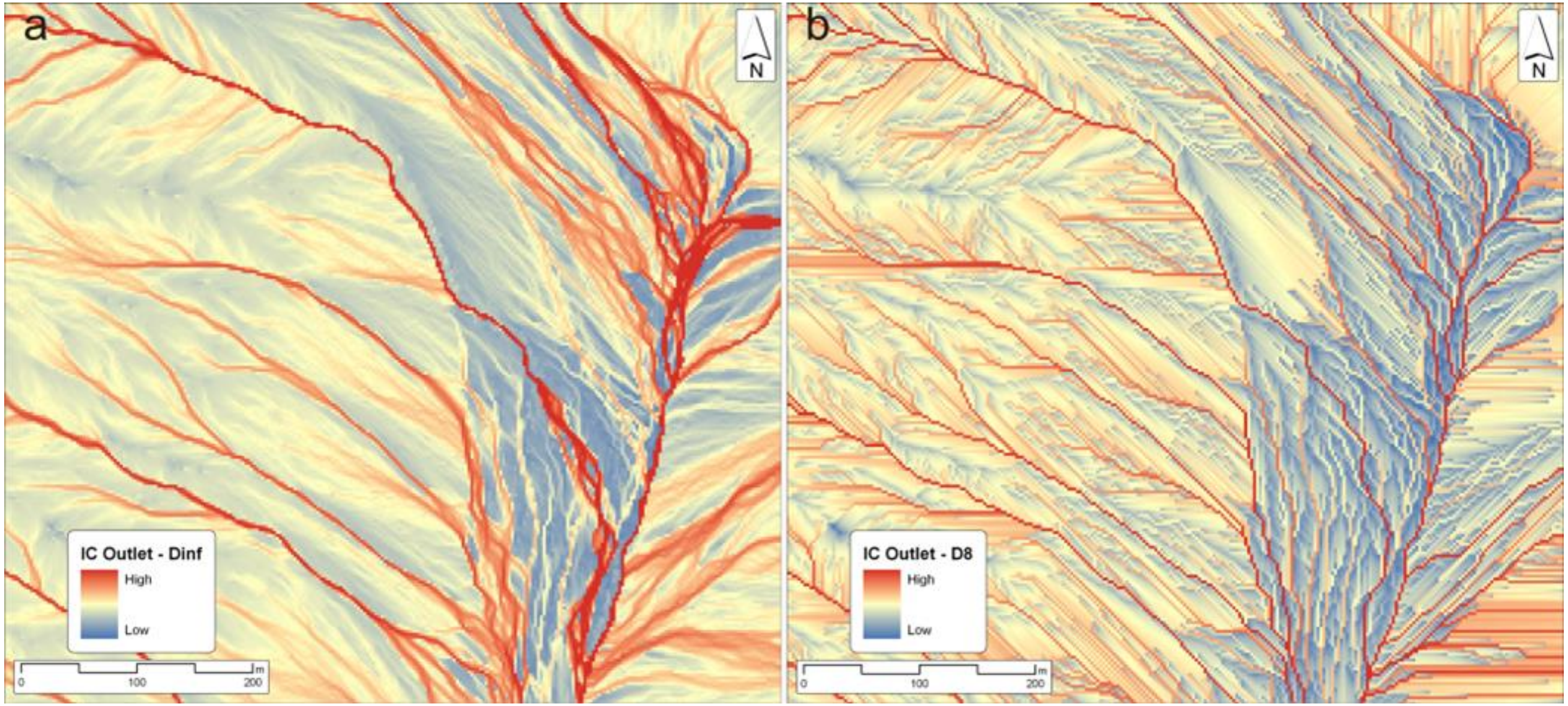
S < 0.005 ➡ S = 0.005 to avoid ∞ in the downslope component equation

S > 1 ➡ S = 1 to limit the bias due to very high values of IC on steep slopes (e.g. rocky outcrop)

Flow Direction (D∞ algorithm)



Tarboton, 1997. Water Res. Research, 33(2): 309-319.



Weighting factor (W)

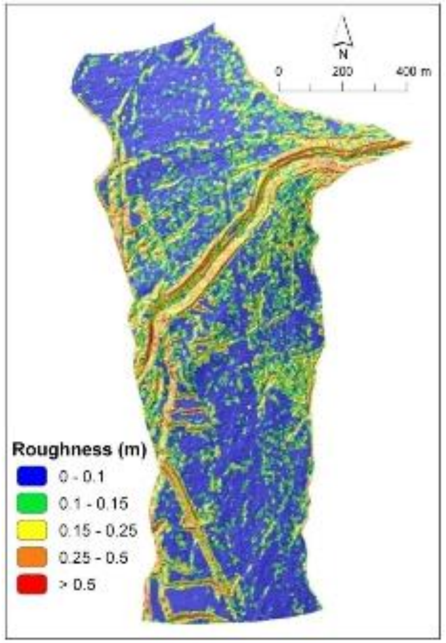
- The weighting factor W is intended to model the impedance to runoff and sediment fluxes;
- W ranges from 0 to 1. Based on the C-factor of USLE-RUSLE models in Borselli et al. (2008).

C-factor for the Bilancino watershed, Florence, Italy

Level 1	Level 2	Level 3	C-factor
1. Artificial surfaces	1.1 Urban fabric		n.c.
	1.2 Industrial fabric		n.c.
	1.3 Mines, dumps and construction sites	1.3.1 Mineral extraction sites	1
		1.3.3 Construction sites	1
	1.4 Artificial non agricultural vegetated areas	1.4.1 Green urban areas	0.05
		1.4.2 Sport and leisure facilities	0.05
2. Agricultural areas	2.1 Arable land	2.1.1 Non irrigated arable land	0.1
		2.1.4.1 Vegetables cultivation[a]	0.1
		2.1.4.2 Nursery cultivation and cultivation under plastic[a]	0.001
	2.2 Permanent crops	2.2.1 Vineyards	0.451
		2.2.2 Fruit trees and berries plantations	0.296
		2.2.3 Olive groves	0.296
	2.3 Pastures	2.3.1 Pastures	0.15
		2.3.2 Pastures with shrubs[a]	0.13
	2.4 Heterogeneous agricultural areas	2.4.4 Agro-forestries	0.05
3. Forest and seminatural areas	3.1 Forest	3.1.3.1 Mixed forests[a]	0.001
		3.1.3.2 Discontinuous forests[a]	0.006
		3.1.4 Riparian vegetation[a]	0.006
	3.2 Shrub and/or herbaceous vegetation associations		0.04
	3.3 Open spaces with little or no vegetation	3.3.2 Bare rocks	0.9
4. Wetlands	4.2 Coastal wetlands	4.2.3 Intertidal flats	1
5. Water bodies	5.1 Continental waters	5.1.1 Stream courses	n.c.
		5.1.2 Water bodies	n.c.

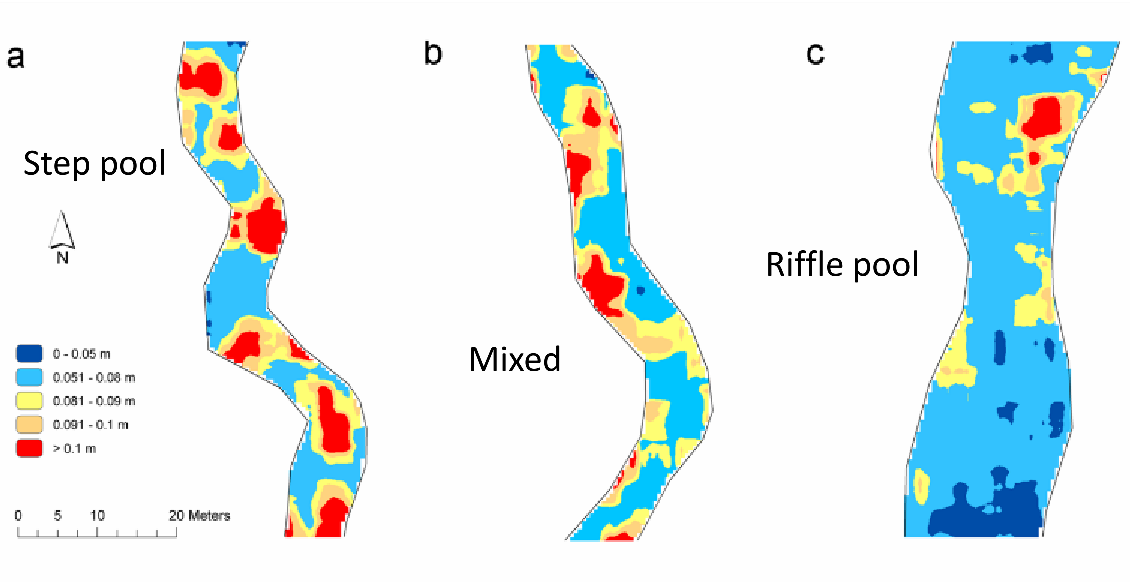
[a] Based on CORINE Land Cover (modified) assigned from literature data ERSO (1990).

Borselli et al. (2008)



Moscardo Creek alluvial fan

Cavalli and Marchi, 2008

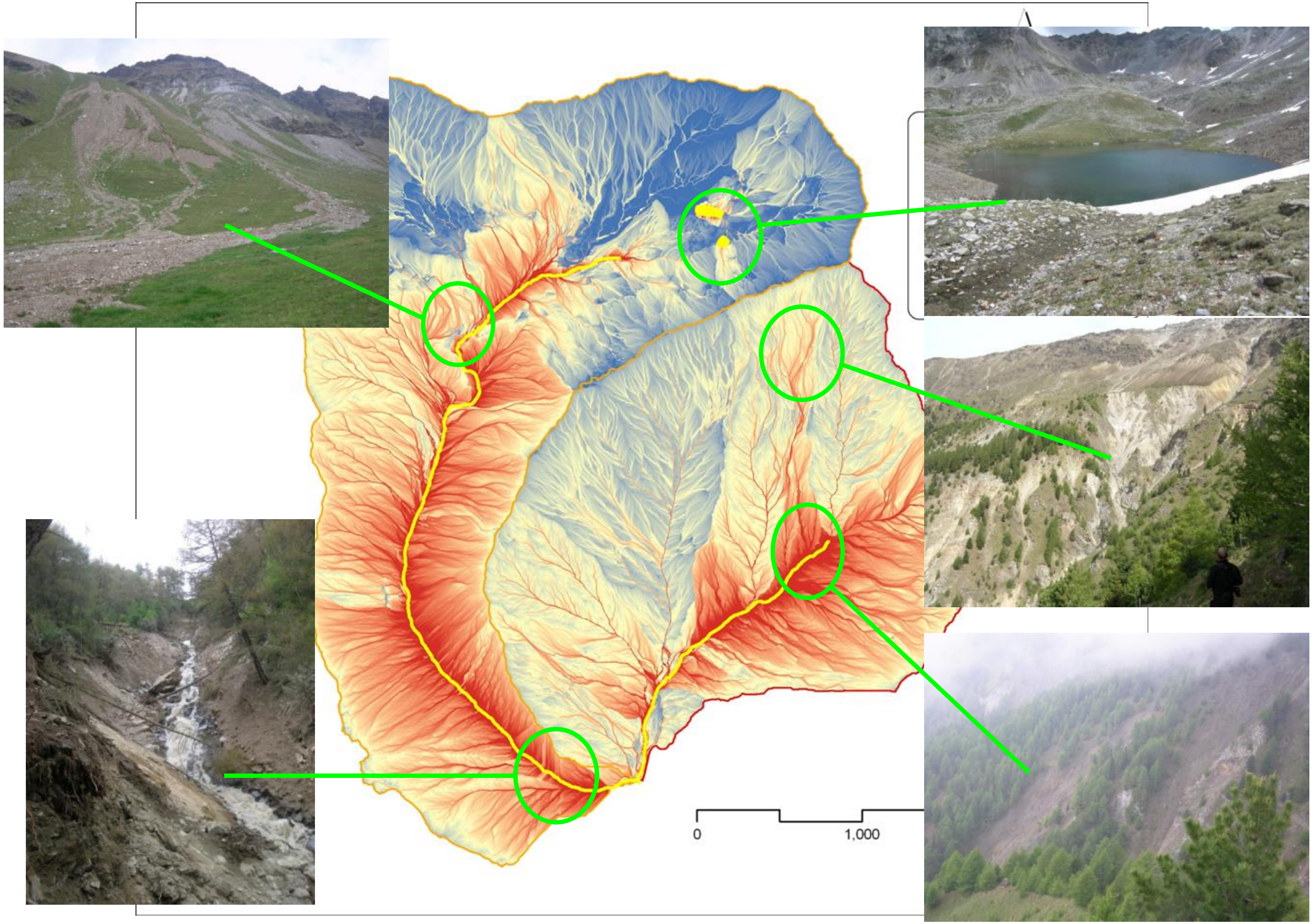


Rio Cordon main channel

Cavalli et al., 2008

Cavalli M., Tarolli P., Marchi L., Dalla Fontana G., 2008. The effectiveness of airborne LiDAR data in the recognition of channel-bed morphology. Catena, 73(3), 249-260. doi: 10.1016/j.catena.2007.11.001.

Cavalli M., Marchi L., 2008. Characterisation of the surface morphology of an alpine alluvial fan using airborne LiDAR. Natural Hazards and Earth System Science, 8, 323-333. doi:10.5194/nhess-8-323-2008.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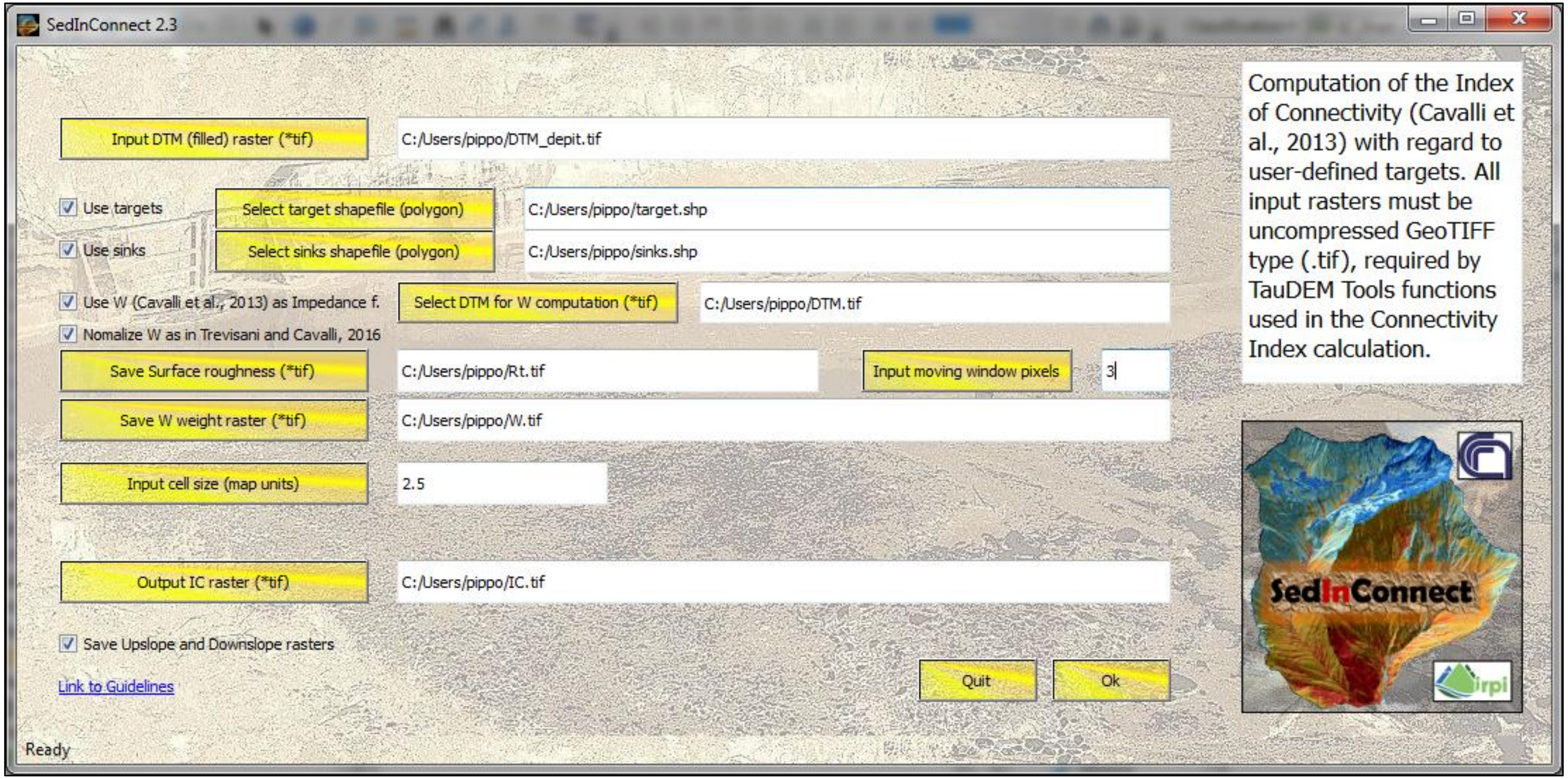
Open-source implementation (**SedInConnect 2.3**) (Crema & Cavalli, 2018)



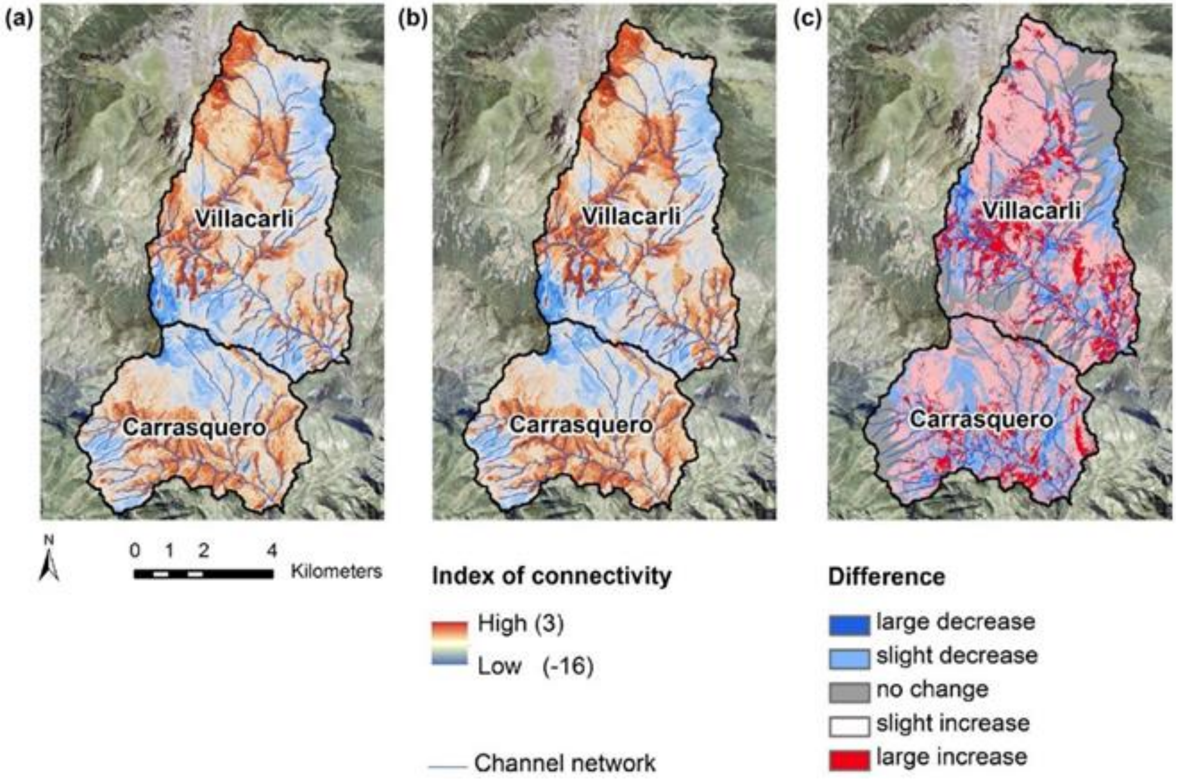
- It avoids the use of commercial GIS;
- It implements the "Sink" function.

https://github.com/HydrogeomorphologyTools/SedInConnect_2.3

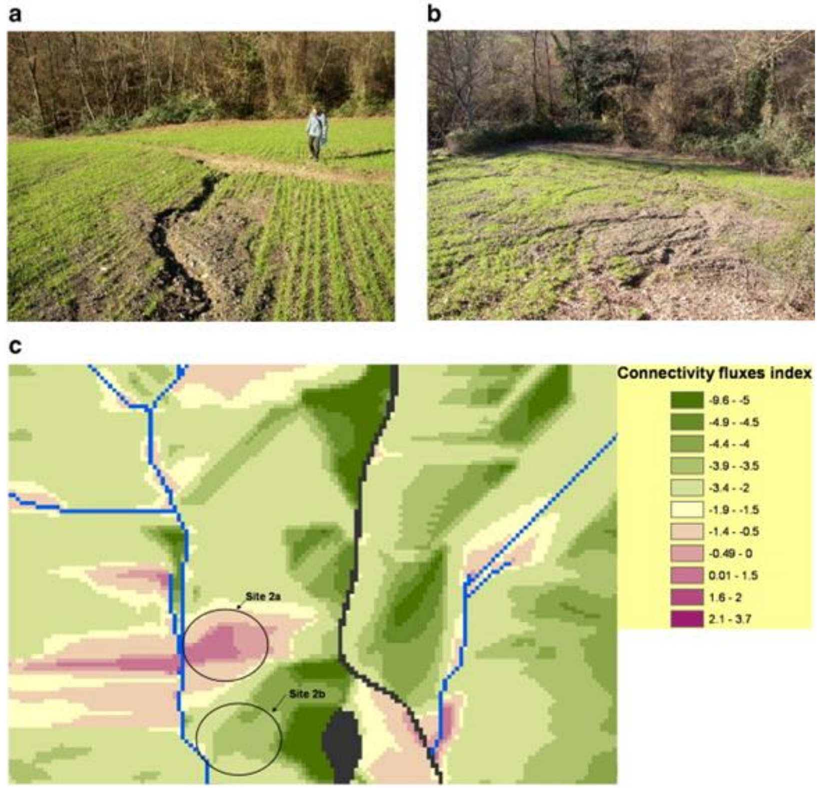
http://www.sedalp.eu/download/tools.shtml

Applications of IC using the C-factor

- The IC by Borselli (2008) was successfully applied in other catchments in the Mediterranean region (López-Vicente et al., 2013, 2014, 2015; Sougnez et al., 2011) to estimate erosion rates and different scenarios of land use and land abandonment;
- It has proven useful also for estimating hillslope sediment delivery ratio (SDR) (Vigiak et al., 2012; Jamshidi et al., 2014).



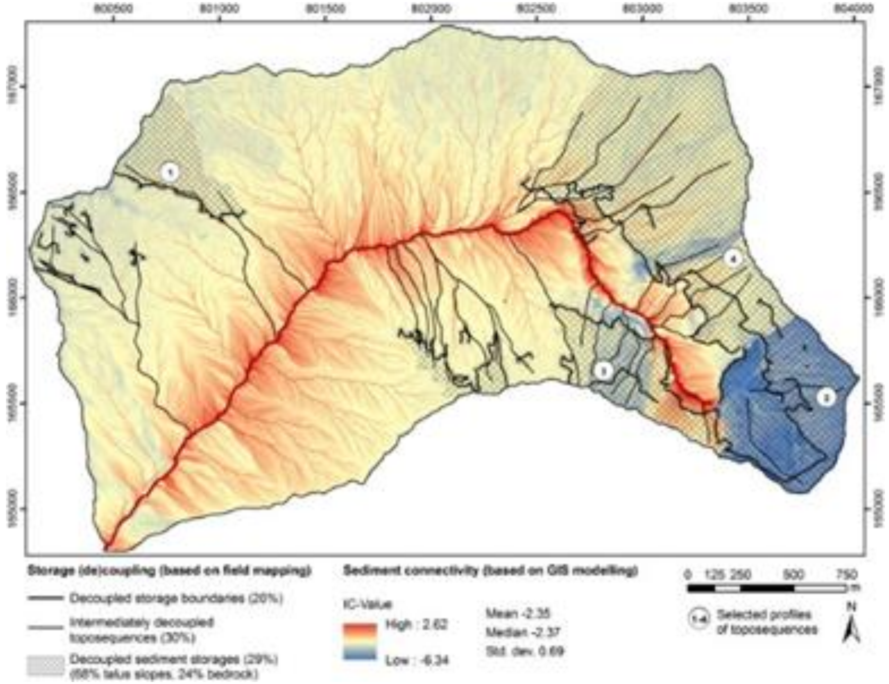
Foerster et al., 2014



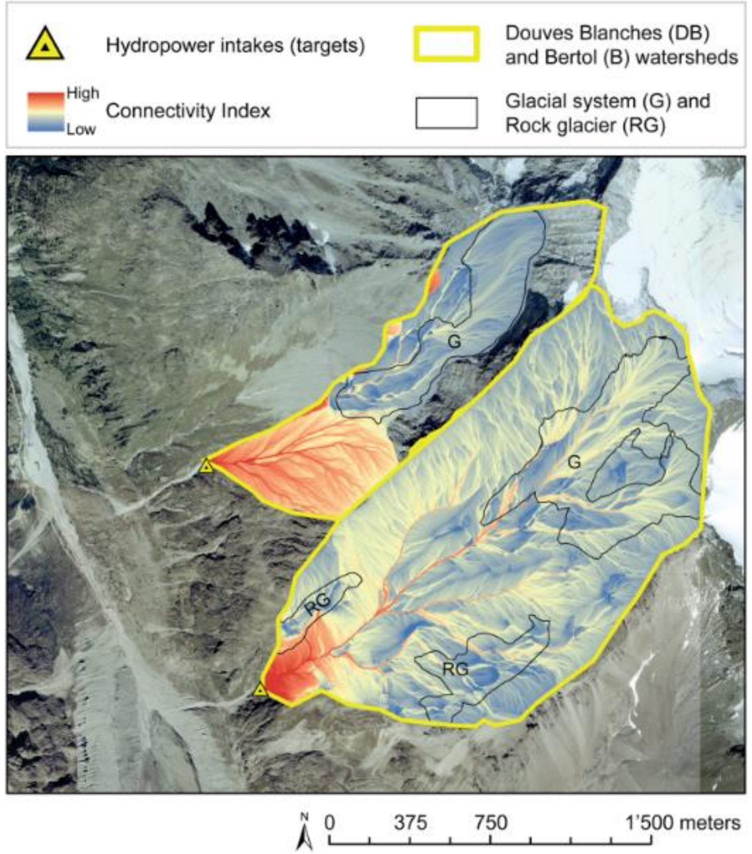
Borselli et al., 2008

Applications of IC using the Roughness

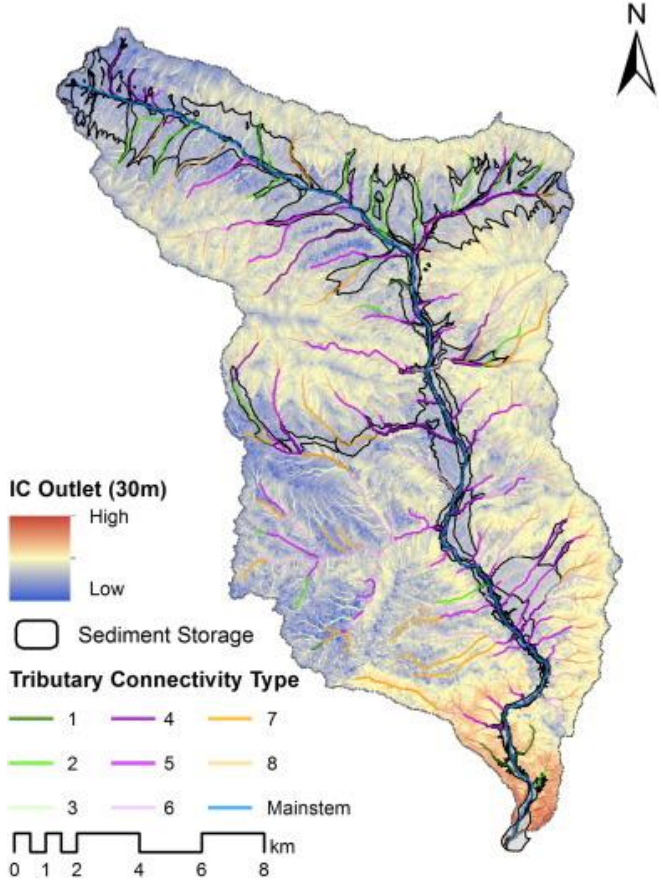
- IC to evaluate the connection of sediment source inventories to the channel network in order to prioritize sediment sources or to assess sediment supply (Cavalli et al., 2016; Surian et al., 2016; Tiranti et al., 2016);
- IC supported the interpretation of radioactive dose rate measurements after the Fukushima nuclear accident in nearby catchments (Evrard et al., 2013)



Messenzehl et al. (2014)

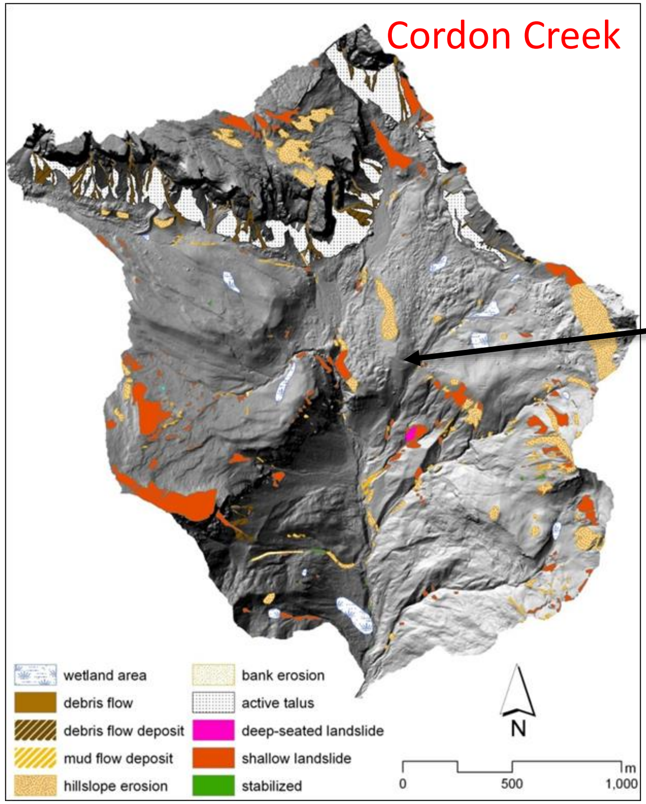


Micheletti and Lane, 2016

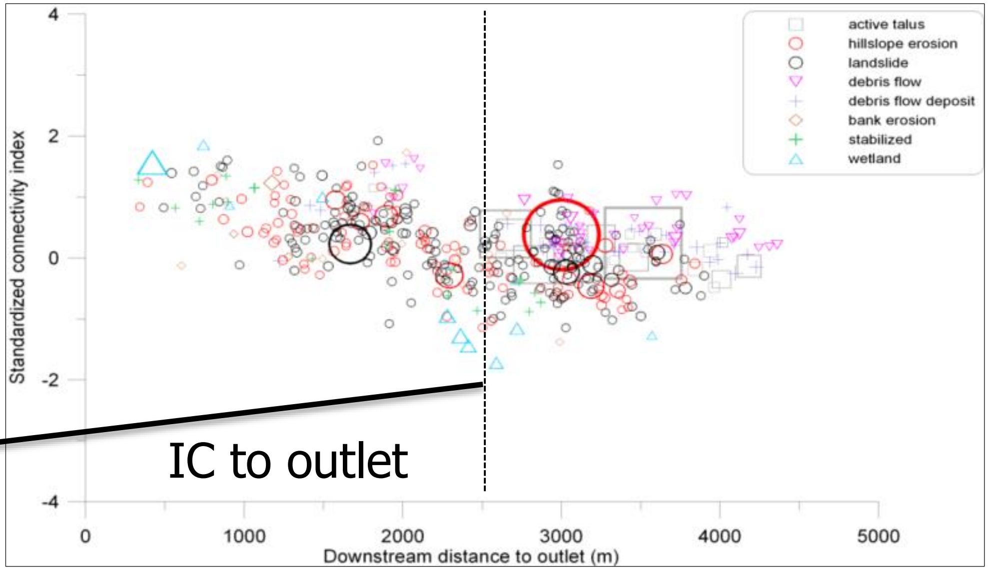


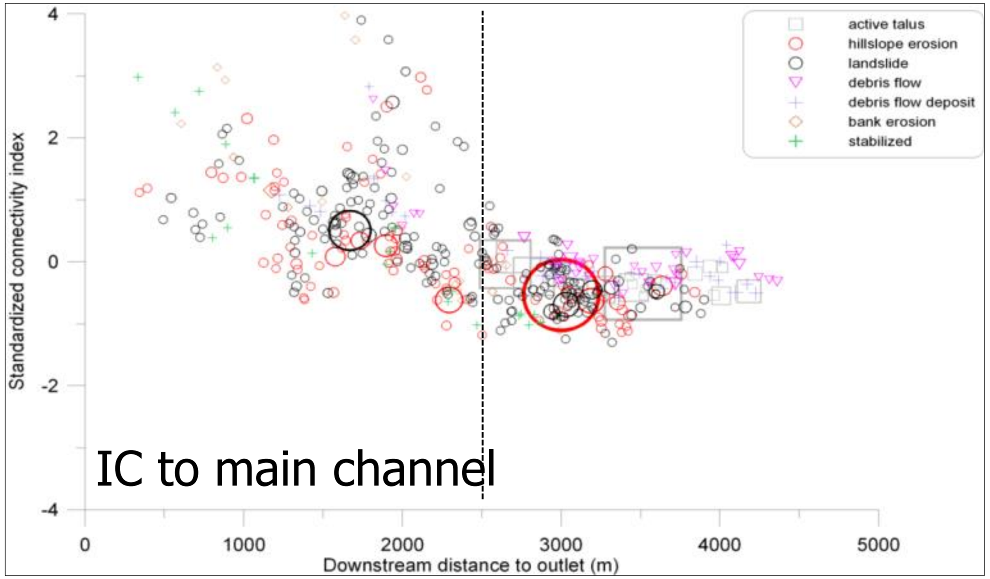
Nicoll and Brierley, 2016

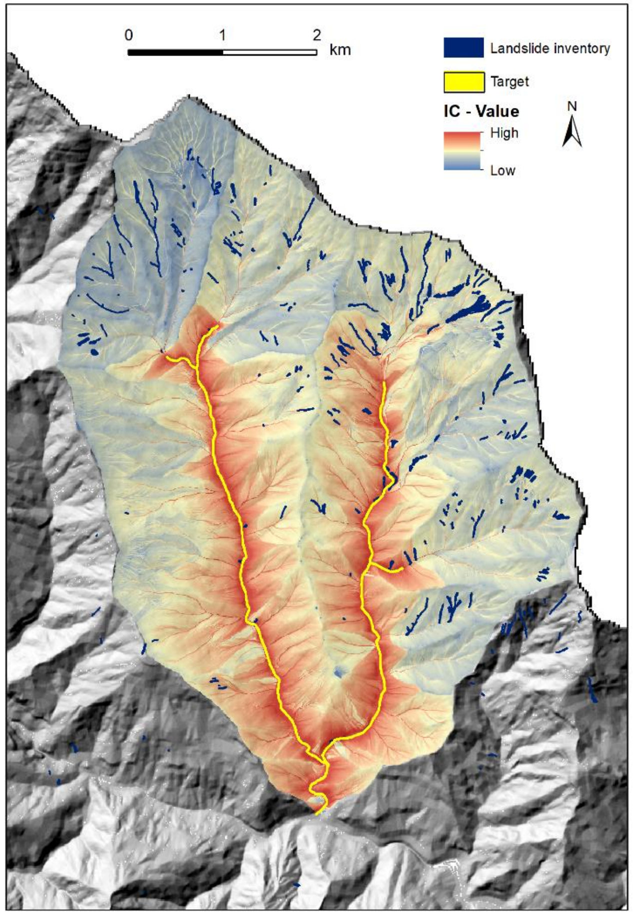
IC and sediment source areas



Cavalli M. et al., 2016.



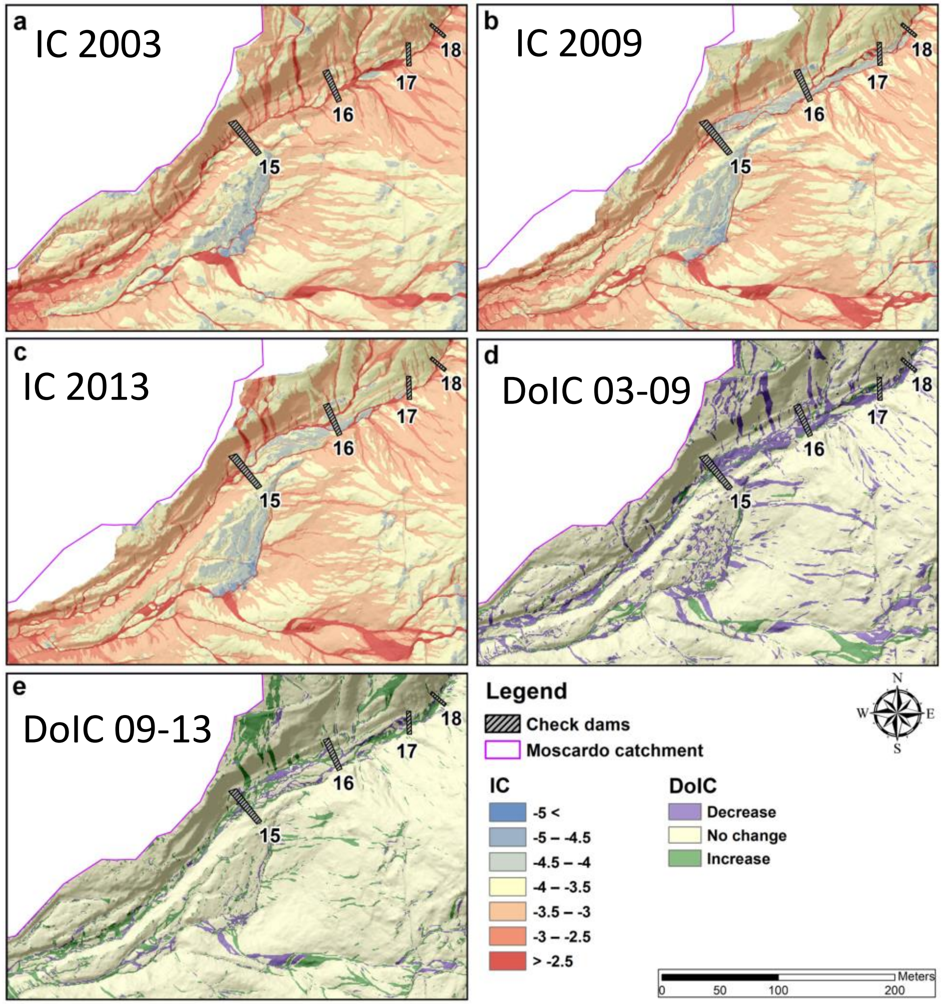




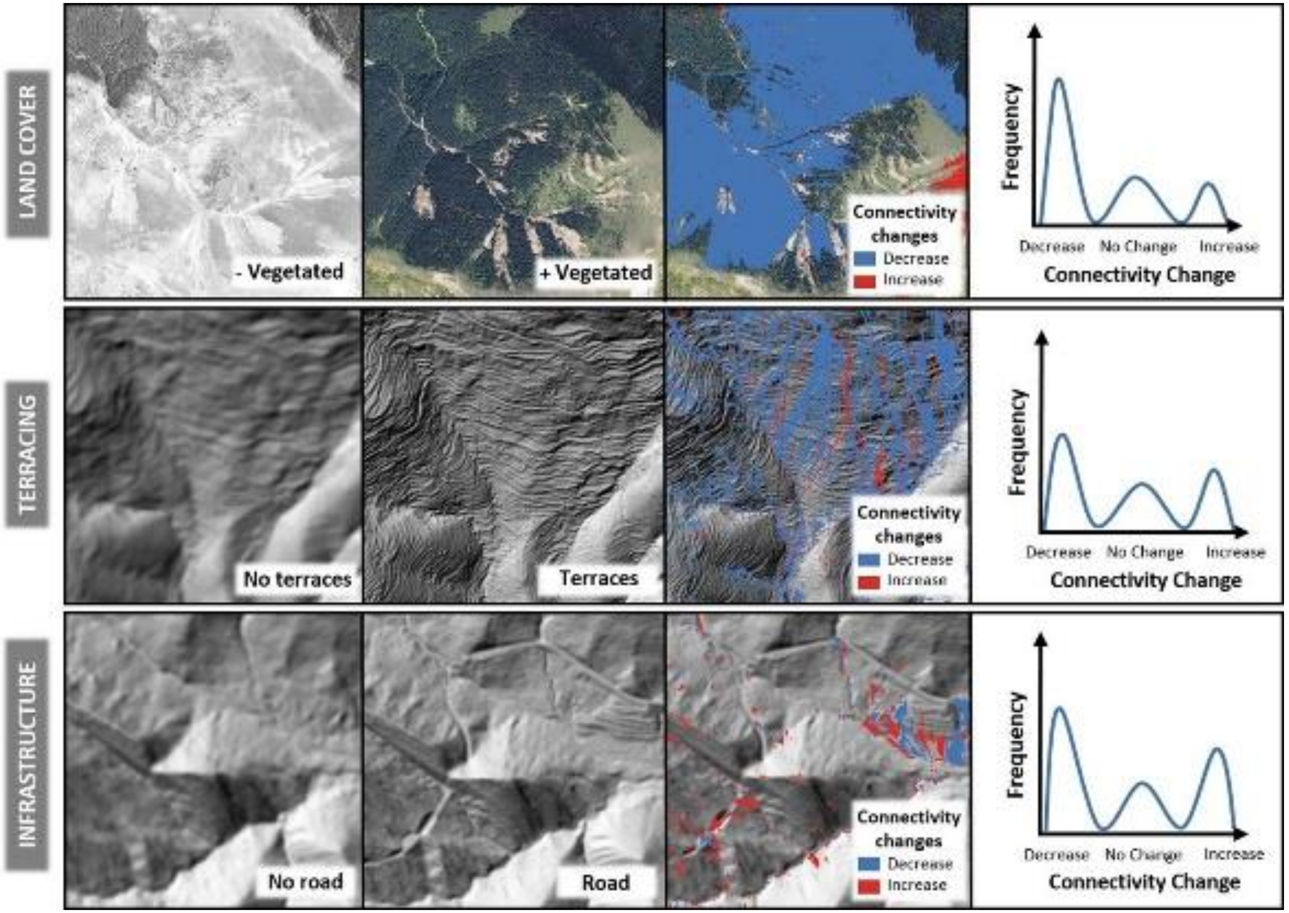
- alta Valle Argentina (IM)
- 'Alex' event 2-3 october 2020
- Collaboration with IRPI PG.

Multitemporal analysis of IC

- Understand the check dams' effects on sediment dynamics in a debris flow catchment;
- Investigating the impact of different disturbances on connectivity.



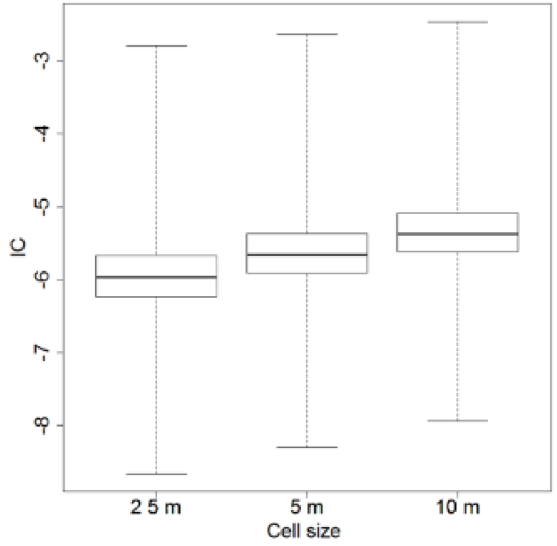
Cucchiaro et al., 2019



Llena et al., 2019

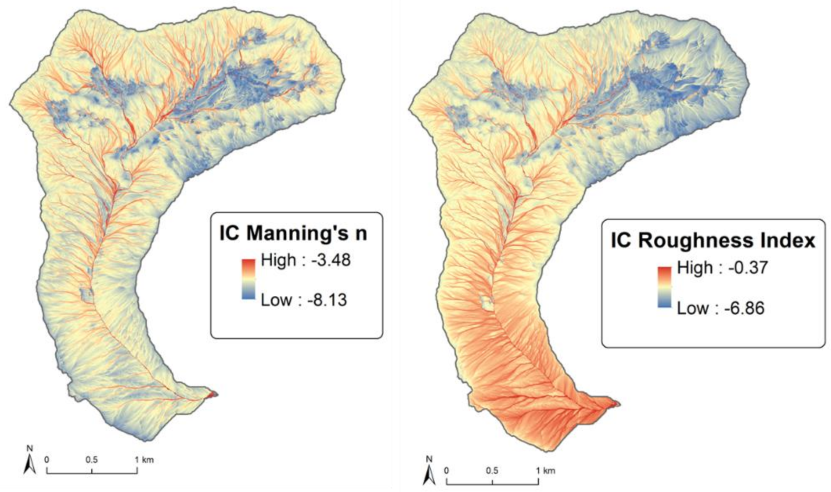
Index sensitivity

IC vs. DTM resolution



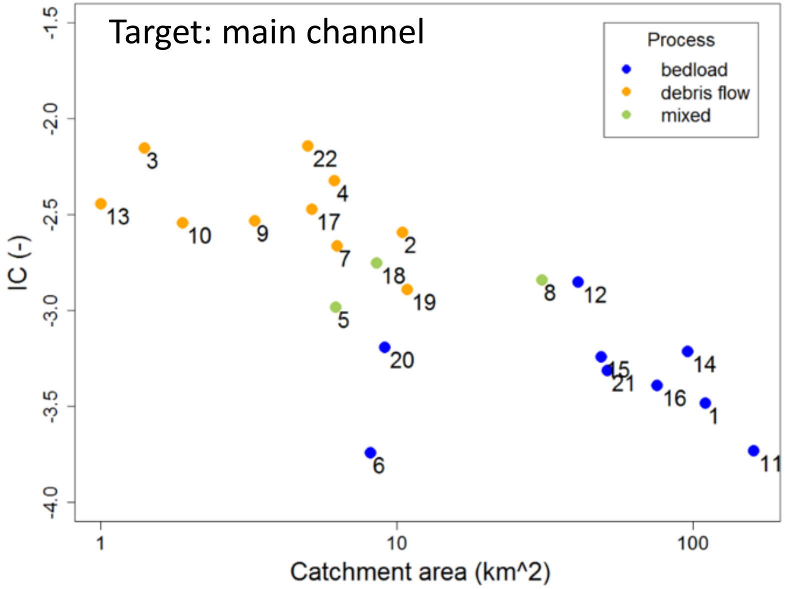
- slight increase in IC values with decreasing resolution;
- simplification of the flow paths due to increased cell size leads to an increase of IC values.

Manning's n vs. roughness



- different pattern when different impedance factors are used;
- overall lower IC values with Manning's n.

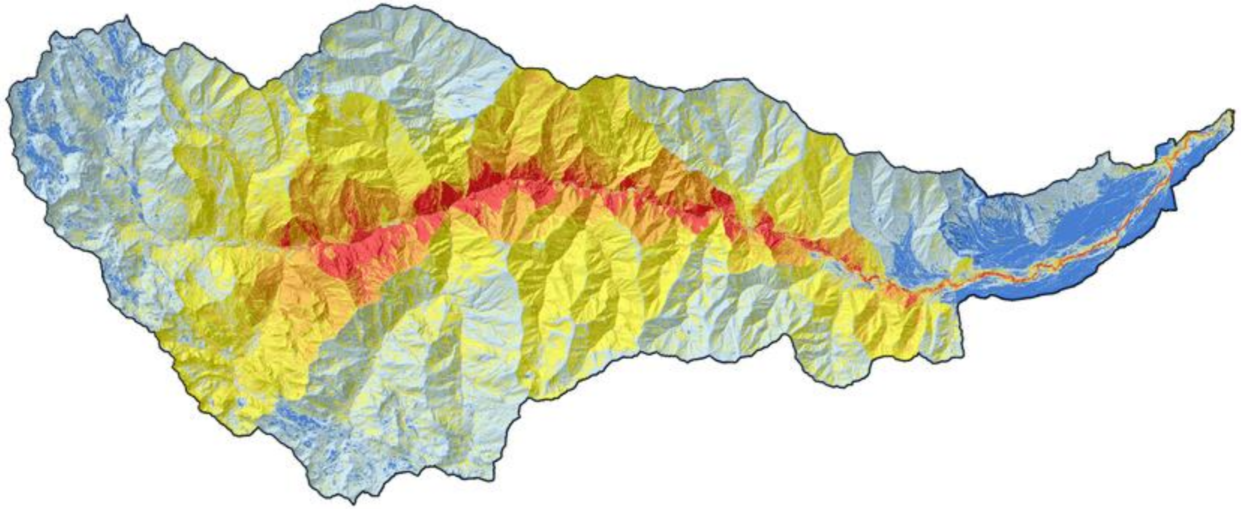
IC vs. catchment size



- data show a positive correlation between IC and catchment area mainly due to Ddn.
- IC useful to determine the dominant flow process types for steep headwater catchments.

Final remarks and perspectives

- ✓ IC has proved very promising for a rapid spatial characterization of sediment dynamics both at catchment and regional scales;
- ✓ The reported applications demonstrate that a reliable assessment of sediment connectivity via a geomorphometric approach, especially when integrated with a sediment sources inventory, is useful for giving management priorities;
- ✓ DEM quality and resolution and weighting factor choice have a strong effect on IC results;
- ✓ Future development should also consider process-based connectivity and incorporate temporal variability.



Thank you for your attention!

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