Keynote lecture

Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm

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CONNECTEUR – Scientific Kickoff Meeting (COST Action ES 1306)
Wageningen, The Netherlands, on August 24-26, 2014

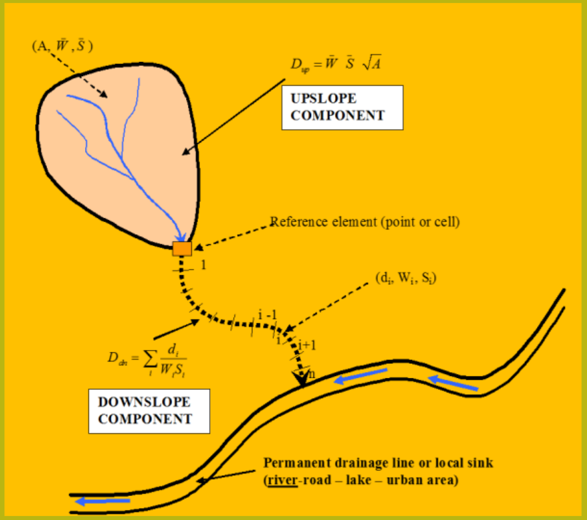
Why a need for Connectivity paradigm and modelling efforts?

Northern Appenines (Samoggia valley), ITALY, photo Borselli, autumn 2001

Flow Connectivity Approach (FCA)

Key points of this presentation :

- Connectivity basic concepts (my personal view)
- Development of index of connectivity (IC)
- Theoretical basis of IC index
- Examples of application
- Calibration of IC index and IC interpretation
- Second group of application examples
- Variants of IC index: applications and extension to mass movements
- Discussion on IC index, presents limits and possible future developments
- Highlights ad Speculations



Hydrological connectivity is a term often used to describe the internal linkages between runoff and sediment sources in upper parts of catchments and the corresponding sinks (Croke et al., 2005).

Connectivity paradigm has prominent importance also in geomorphology and ***landscape evolution:*** *processes and rates…*

SOURCE

SINK

MASS and Energy TRANSFER:
WATER , SEDIMENTS,….

(see definitions review in Bracken et al. (2013))

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Definition of connectivity for sediment flow:

Connectivity may be defined as the chances that a particle has to reach the nearest sink and it depends on: **distance to the sink; characteristics of the route; water available to transport from upslope; water that is gained/lost along the downslope route**

Erosion and connectivity in an old *biancana badland* levelled field (Tuscany, Italy 2001)

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Diffuse connectivity it is also influenced (Cammeraat ,2002) by :
1) soil surface irregularity (roughness), which could be very low at the patch scale, but higher at the hillslope and the catchment scales;
2) spatial organization of the vegetation at the hillslope scale and the spatial arrangement between land units at the catchment scale;
3) rainfall intensity, event duration, and thus the effective rainfall.!!!!

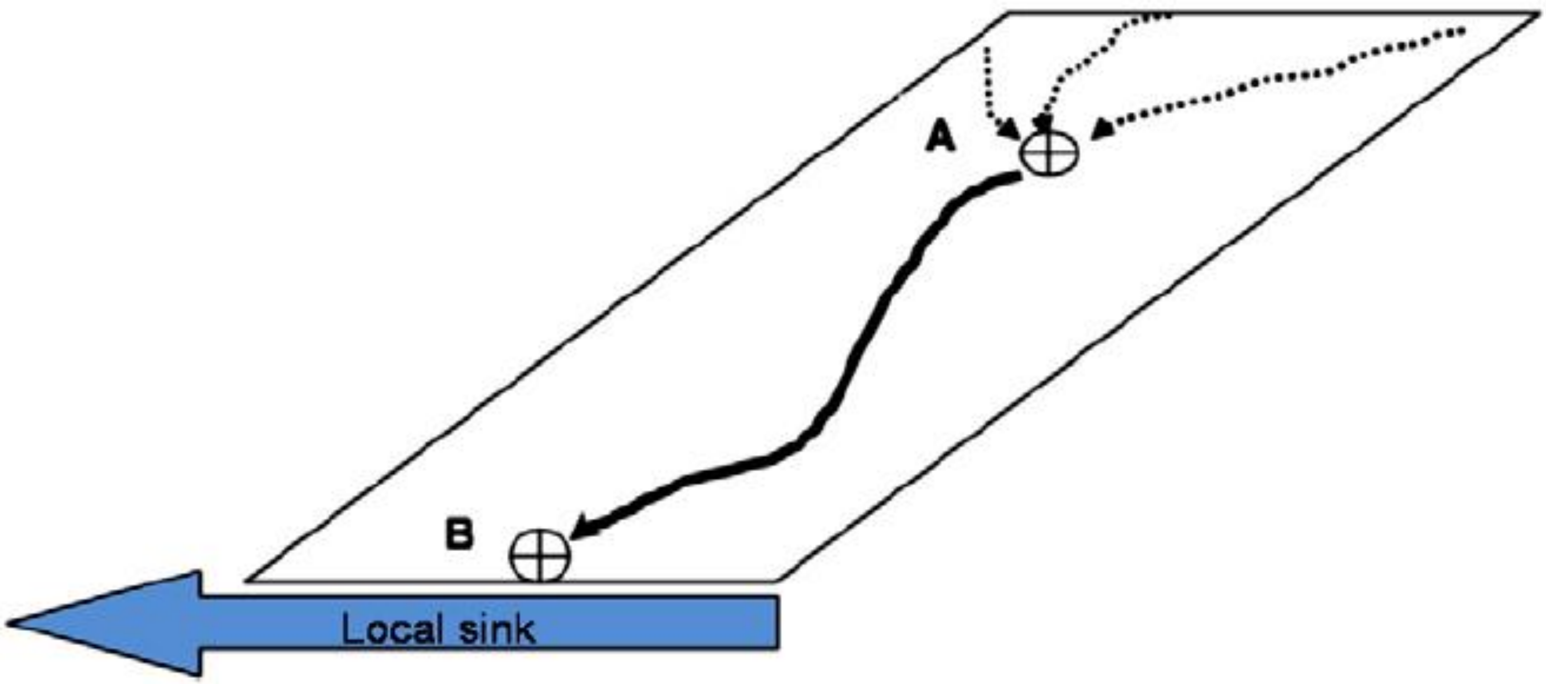

Fig. 1. Simple slope with flow path between the source area A and the local sink B.

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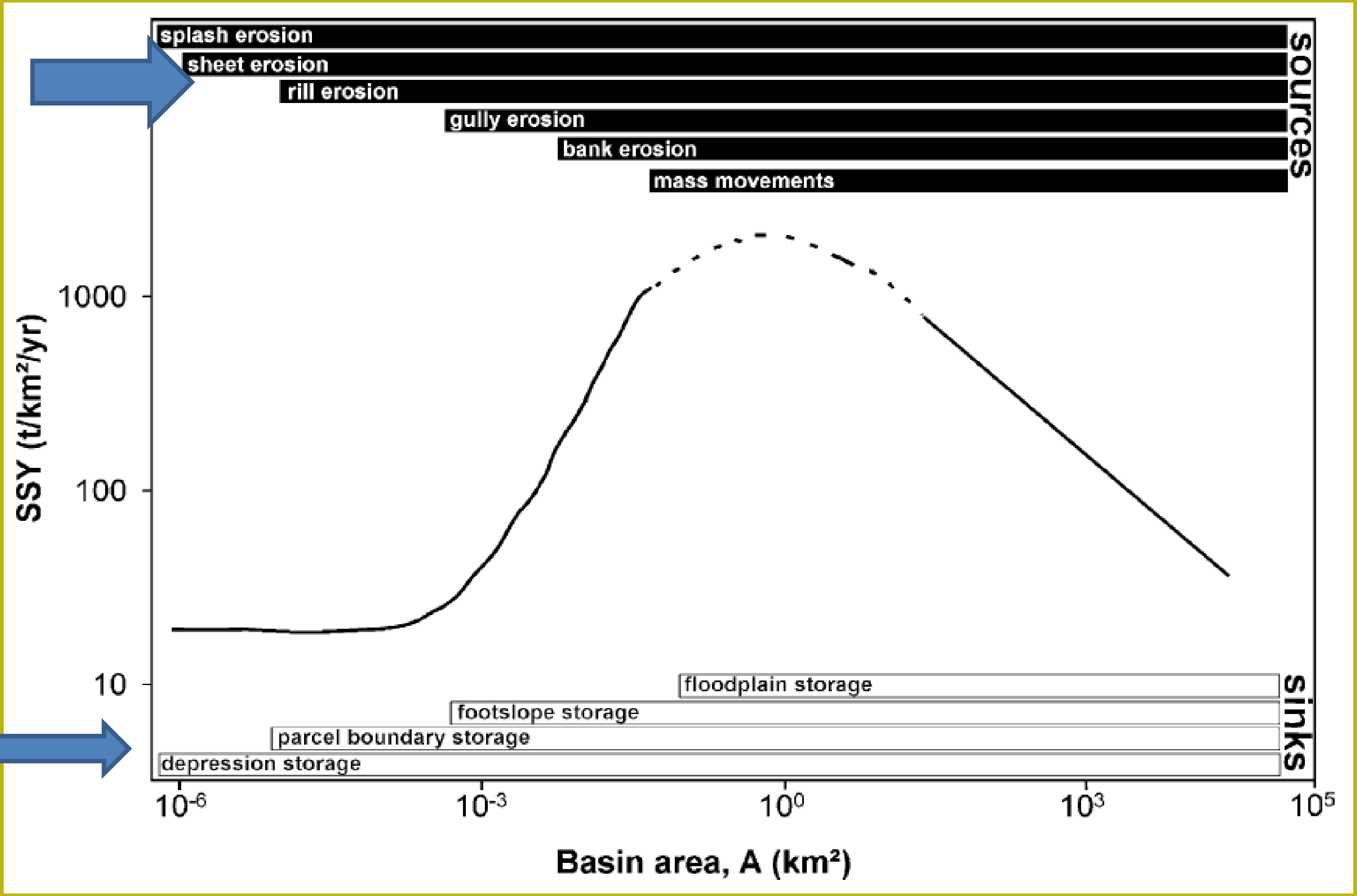
Influence of Connectivity on sediment yield (SSY).....from many sources.... (non only due to soil erosion....)

SOURCES

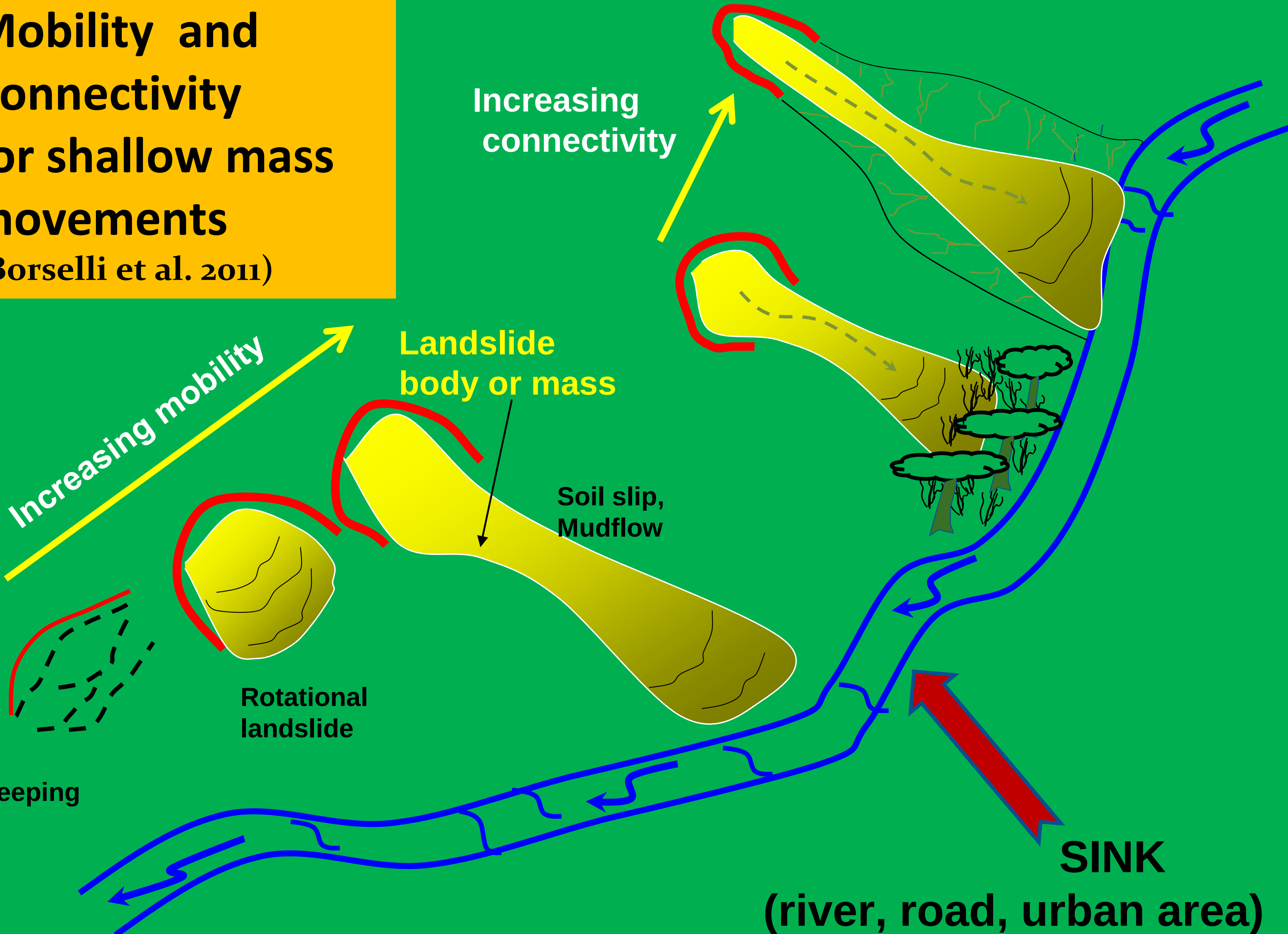
SINKS



Conceptual model of sediment yield at various scale and contributing sources and sinks (De Vente and Poesen, 2005)

Mobility and Connectivity for shallow mass movements

(Borselli et al. 2011)



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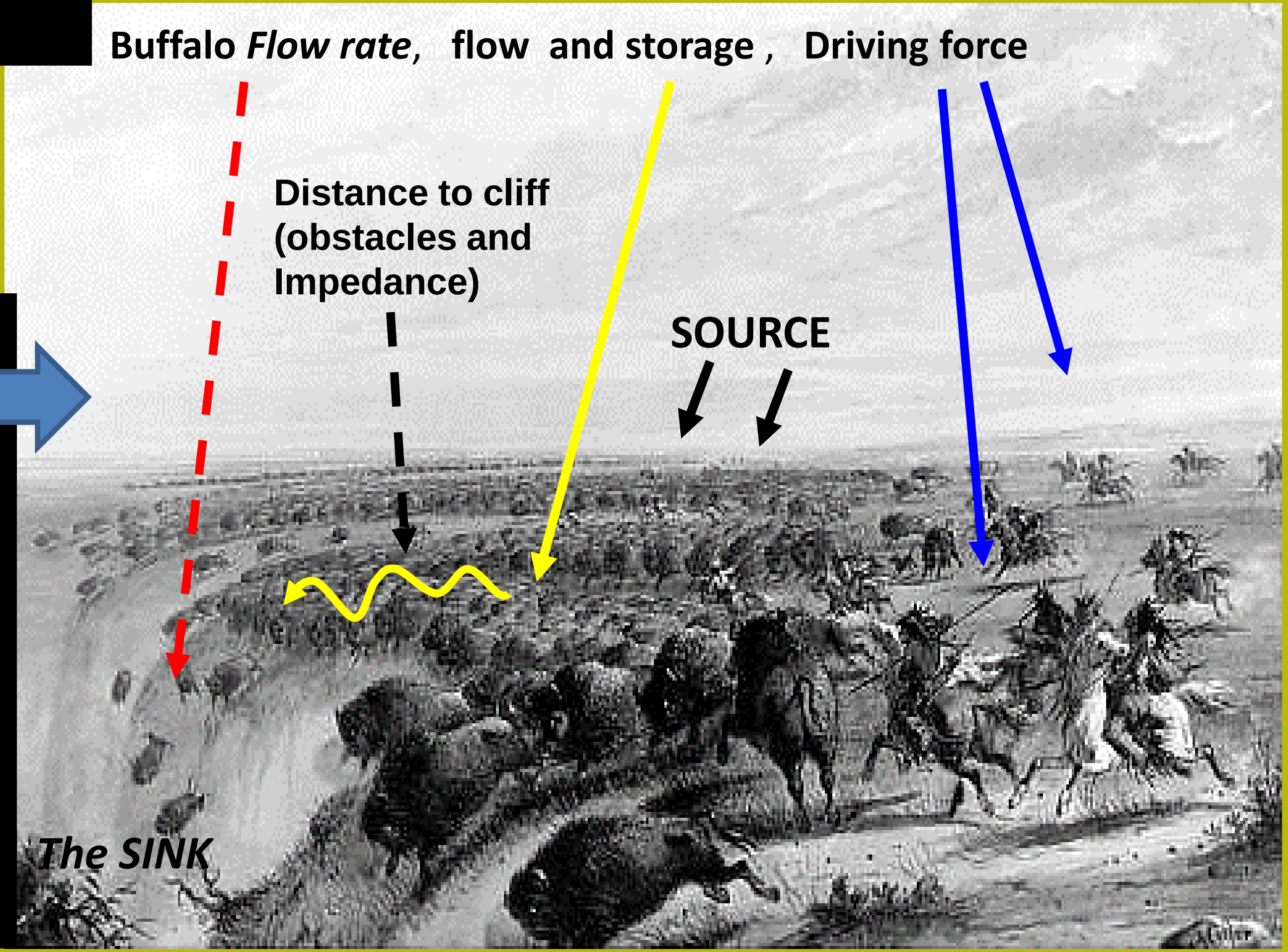
The previous characteristics are defined and used, by many soil erosion distributed models in modelling and computation of erosion and deposition in whole catchments

A conceptual example… importance of connectivity…

The ***Buffalo jump.***
A Native Americans hunting technique that has some similitude with soil erosion /runoff processes….
e.g. The chance of each buffalo to fall …. die,
.. or escape and survive….



Source: Alfred J. Miller 1887 from National Archives of Canada

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Connectivity Indexes, a local metric for flow connectivity approach (FCA).

If an ideal model, able to simulate perfectly mass and energy transfer, redistribution and storage in the landscape, existed, probably we would not need Connectivity metrics.
(*e.g. A perfect, event based soil erosion model that could simulate erosion, transport and deposition rate on the landscape)*

But this type of models does not exist yet, and many of the existing soil erosion models are not easy to use…sometimes models are extremely complex and are affected by **parametric and modeling uncertainty, numerical problems, and occasionally by numerical instabilities** (e.g. violation of principle of mass an energy conservation).

A set of new tools are needed to consider Connectivity as stand alone metric which can be put in relation to various processes (e.g. runoff, erosion, mass movement mobility, etc...)

To do this we need to develop Connectivity indexes, as local Metrics, representing the local connectivity status.

But a preliminary and exhaustive *verification in field* of the evidences of the linkage between connectivity and the intensity of certain processes (e.g. soil erosion, soil deposition, landslide mobility, runoff concentration, etc.) is required….

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Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment

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An attempt to develop a new tool in order to represent a <u>connectivity local metric</u>

The index of connectivity IC

From Borselli et al. 2008

In the paper :

Two indices of connectivity were operatively defined:

1) (**IC**) that can be calculated in a GIS environment and represents a map potential connectivity between two different parts of a catchment (assessment based on landscape's information);

2) Another index that can be evaluated in the field (**FIC**) through direct assessment of connected flow path after a flow or erosion event.

IC and FIC indices were designed to complement each other and their combined use was shown to improve accuracy.

The study was based also on field observation in a 150km2 watershed Italy and was funded by the European Commission, Directorate- General of Research, **Global Change and Desertification Program, RECONDES project (2004–2007) "Conditions for Restoration and Mitigation of Desertified Areas using Vegetation"** and by **Autorità di Bacino del fiume Arno-Italy; BABI project** (2003–2007)

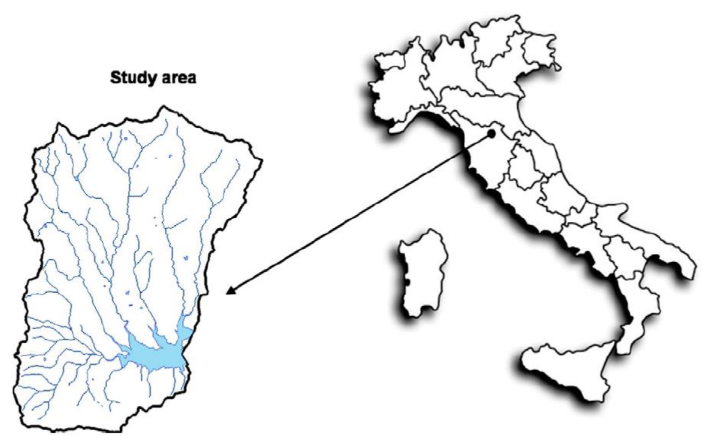

Fig. 3. Study site—Bilancino watershed (Tuscany, Italy).

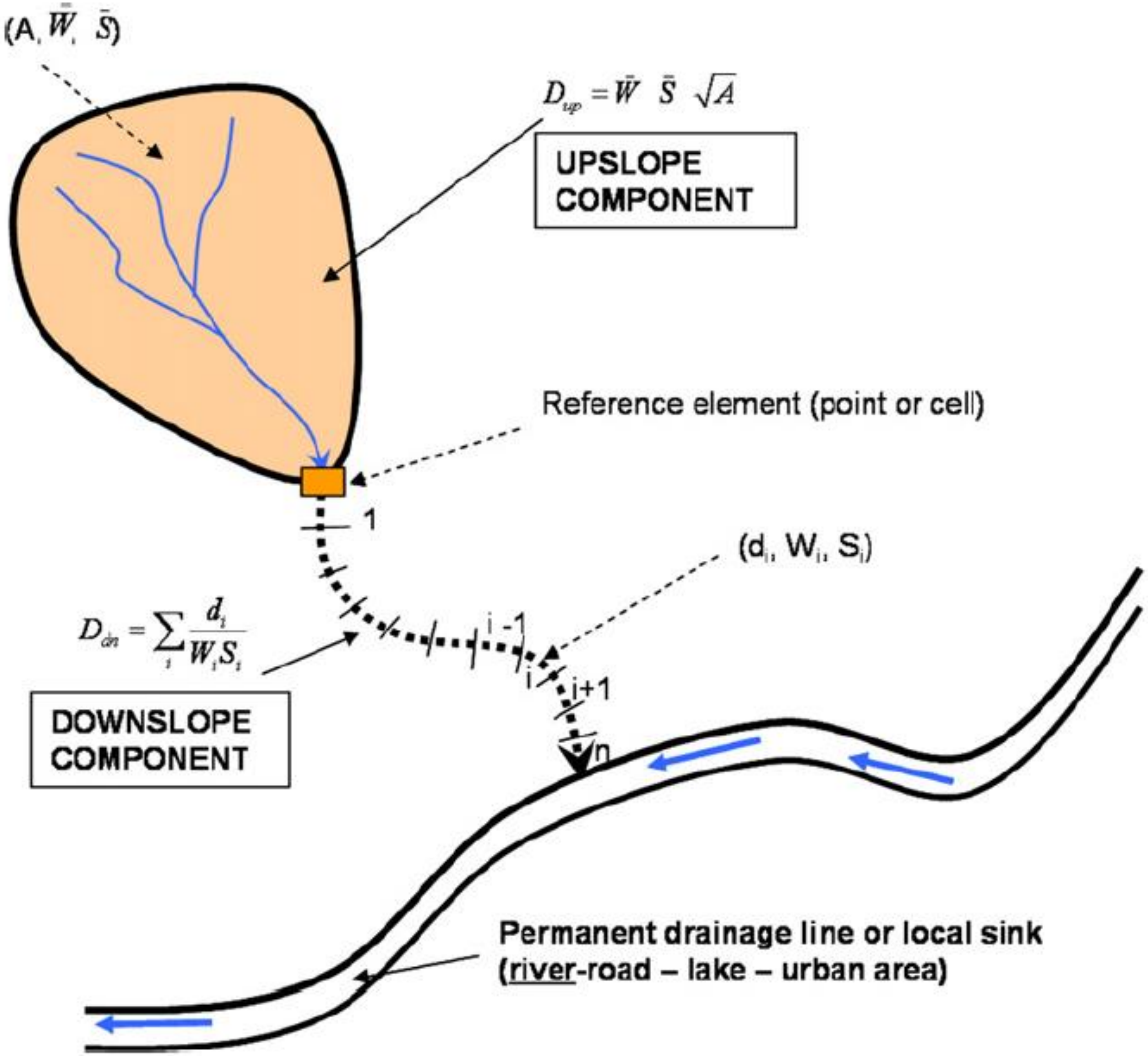

Fig. 2. Definition of IC upslope and downslope component in the landscape for index of connectivity (IC).

IC Index

The Connectivity Index (IC) value is computed using two components:

Upslope component: is the potential for down routing due to upslope catchment's areas, mean upslope and land use.

Downslope component: is the sinking potential due to the path length, land use and slope along the downslope route.

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$$D_{up} = \bar{W}\,\bar{S}\,\sqrt{A}$$

UPSLOPE Component

$\bar{W}$ **= average Weigthing factor in the upslope contributing area (adimensional);**

$\bar{S}$ **= average slope gradient of the upslope contributing area (m/m)**

A **= upslope contributing area (m^2)**

$$D_{dn} = \sum_i \frac{d_i}{W_i S_i}$$

DOWNSLOPE Component

d_i = length of cell *i* along the downslope path (in m)
W_i = Weighting factor of cell *i* along the downslope path (adimensional)
S_i = slope gradient of cell *i* along the downslope path (m/m)

Final IC calculation <u>in each pixel</u>

$$IC = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right) = \log_{10}\left(\frac{\bar{W}\,\bar{S}\,\sqrt{A}}{\sum_i \frac{d_i}{W_i S_i}}\right)$$

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$$IC = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right) = \log_{10}\left(\frac{\bar{W}\,\bar{S}\,\sqrt{A}}{\sum_i \frac{d_i}{W_i S_i}}\right)$$

Orders of magnitude of IC

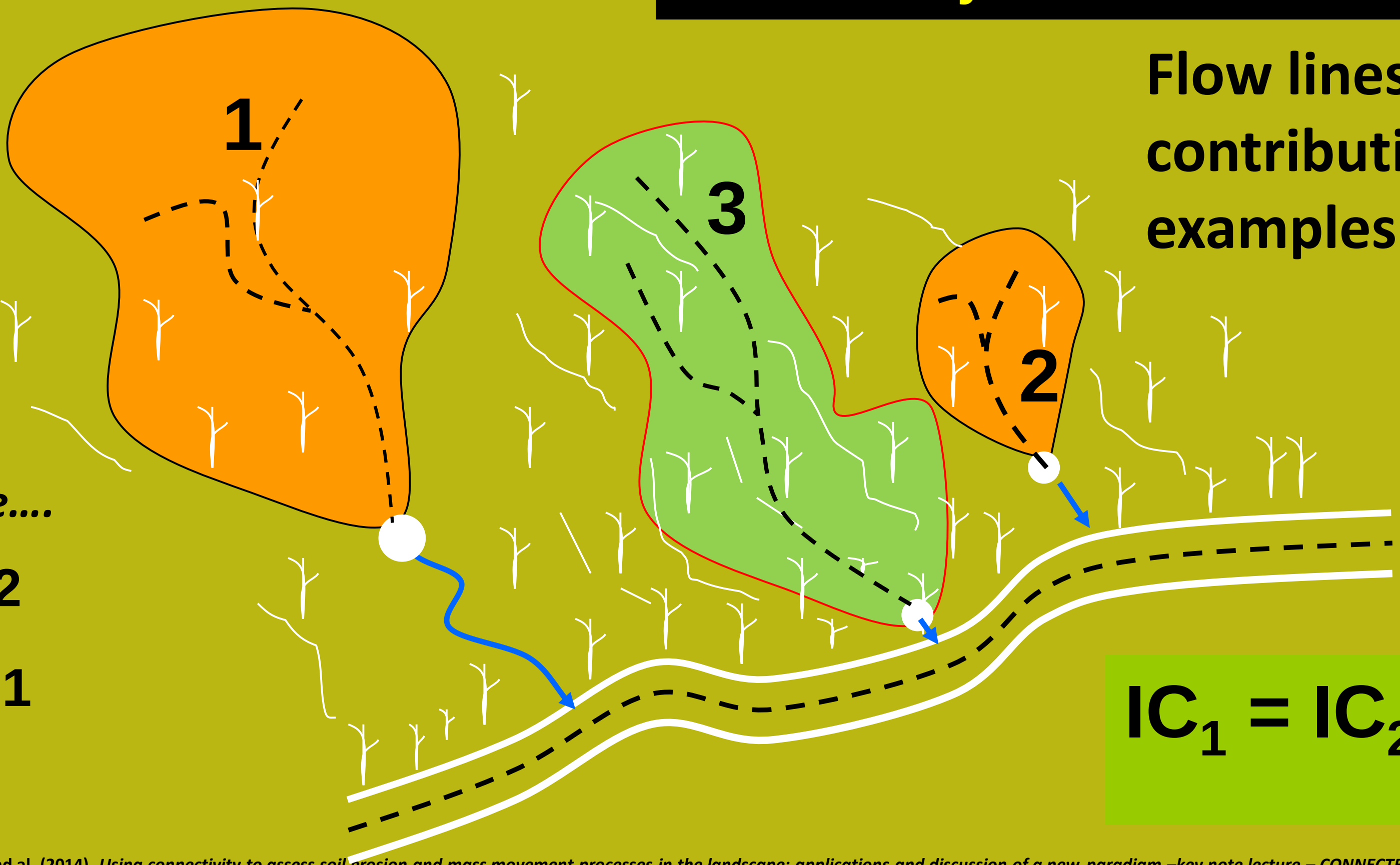
***Under this definition the local level of connectivity to permanent drainage lines/sinks is inversely proportional to IC*:**

Values *IC* > 0 high connectivity

Values *IC* < 0 medium to low connectivity

***IC* range:** $\left[-\infty, +\infty\right]$

Flow lines and contribution area examples



A special case….

$D_{up}1 > D_{up}2$

$D_{dn}2 < D_{dn}1$

$IC_1 = IC_2 < IC_3$

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IC methodology requirements (classical approach):

- High quality and high resolution DTM are preferred. Ideal resolution variable between 2 and 5X5 m
- Resolution of DTM at least 10x10m my be sufficient
- But in some case may be acceptable until 20X20 depending from local availability and from the type of application we want to generate
- Raster map of slope gradient
- Detailed Land use to obtain the local weighting (W) factor map
- No data value layer (internal local sink): river mask, roads, urban area, lakes, etc..
- River mask must be generated starting from a maximum accumulation area (it defines permanent drainage lines) - usually 1-2.5 ha.

IC Index computation notes

Permanent drainage lines, roads, urban areas, and water bodies, as well as pixels outside of the considered watershed, are usually set as no data value MASK.

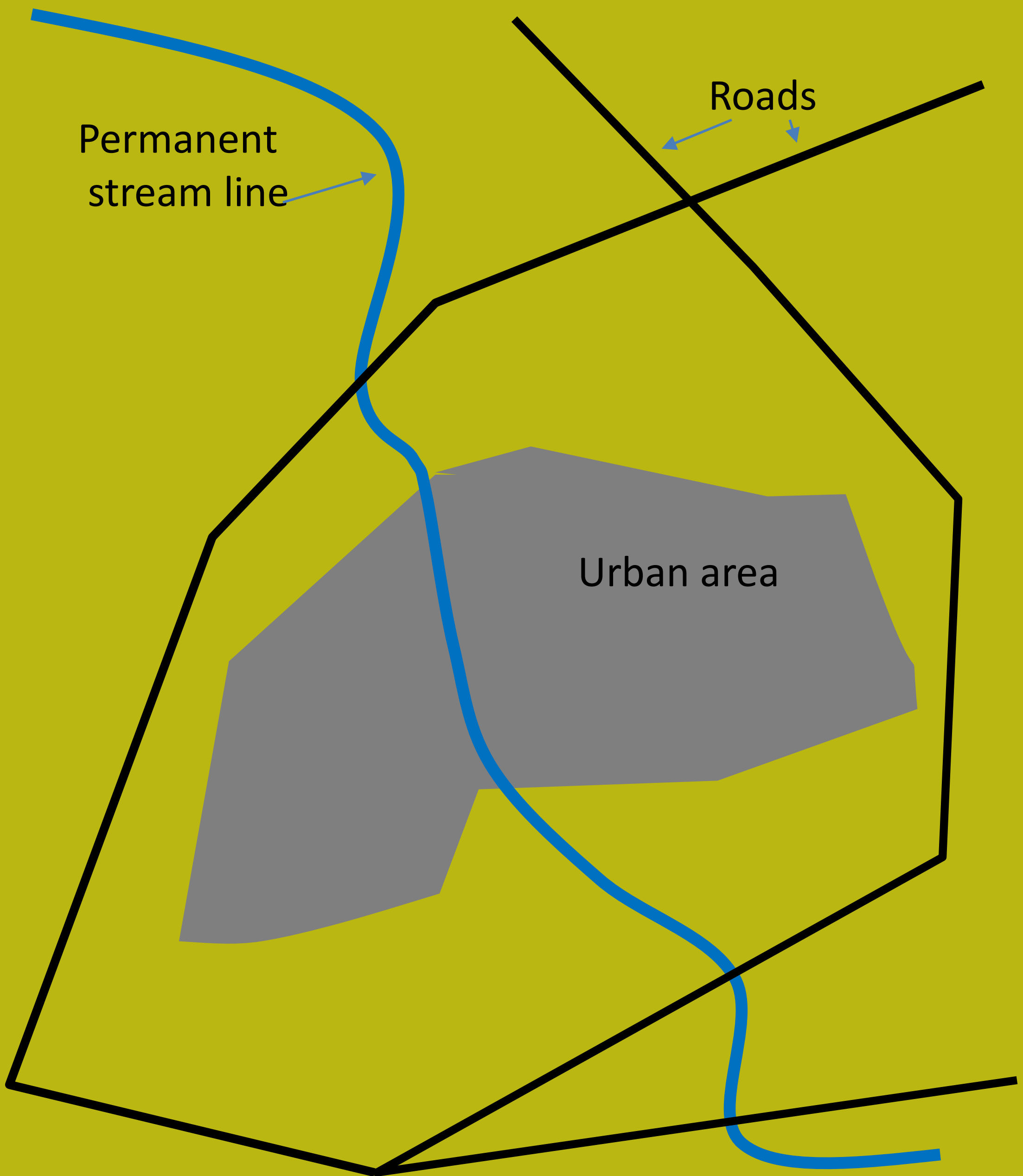
ALL internal *no data value* pixels are considered as local SINKs

The concept of local sink is fundamental…

Of course you can choose to not consider road or urban areas as local SINK, but in this case you will generate an new type of connectivity pattern and values…

DTM quality and resolution is fundamental… !!!! In any case and at any resolution

Types of no data value masks



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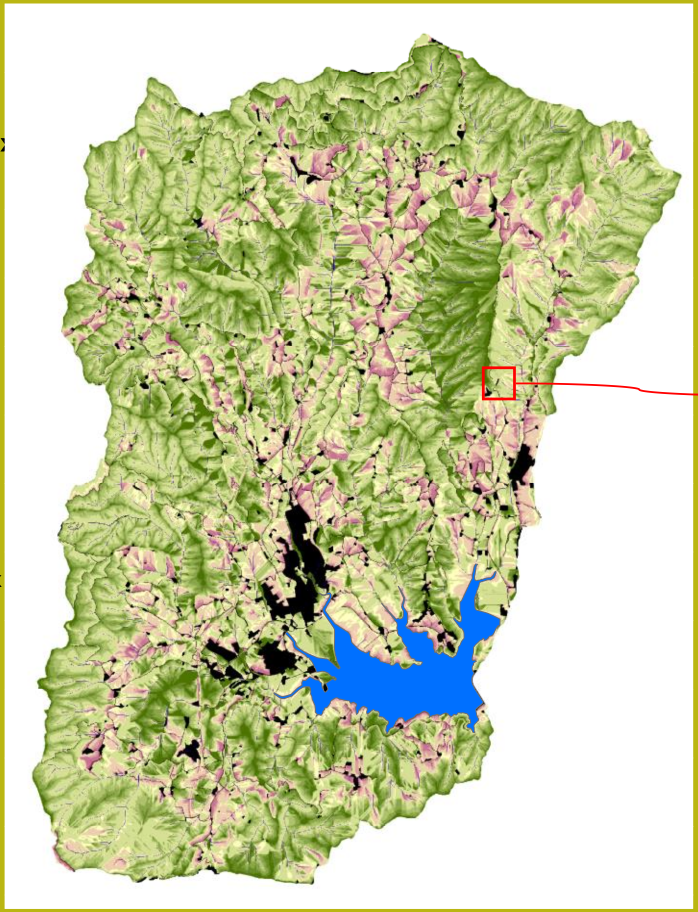
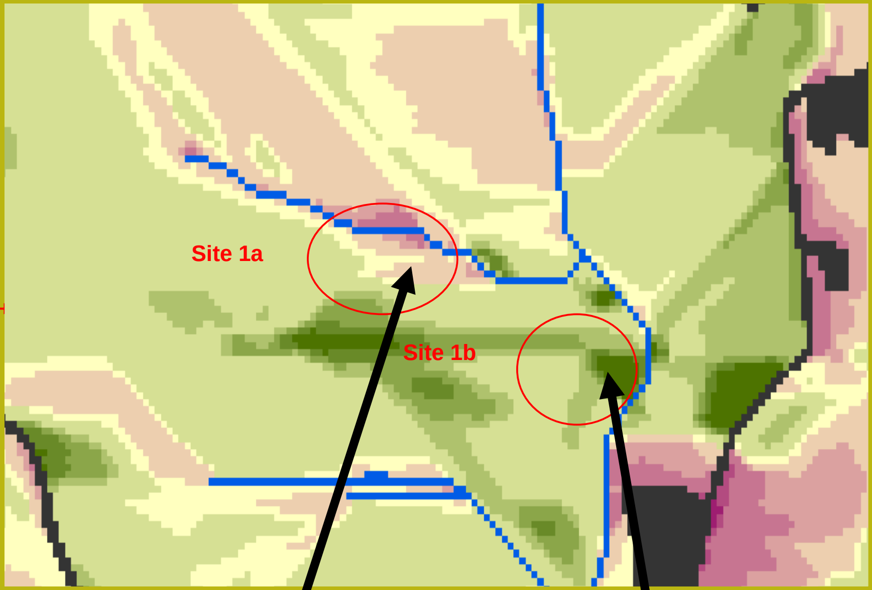
Connectivity fluxes index

- -9.6 - -5
- -4.9 - -4.5
- -4.4 - -4
- -3.9 - -3.5
- -3.4 - -2
- -1.9 - -1.5
- -1.4 - -0.5
- -0.49 - 0
- 0.01 - 1.5
- 1.6 - 2
- 2.1 - 3.7

In black the road/urban mask



IC map of deposition and connection areas evidenced in red



Site1a -Area in proximity of local sink at field bottom: direct connection of rill system without appreciable sedimentation

Site1b-Area in proximity of local sink at field bottom: direct connection of rill system relevant sedimentation

Application at watershed scale (Bilancino – Tuscany - Italy): hot spot identification of primary sediment sources area.
From Borselli et. Al. (2007,2008)
Area: 150 km2
DTM 5x5m

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Other evidences in field. Borselli et al. (2008)

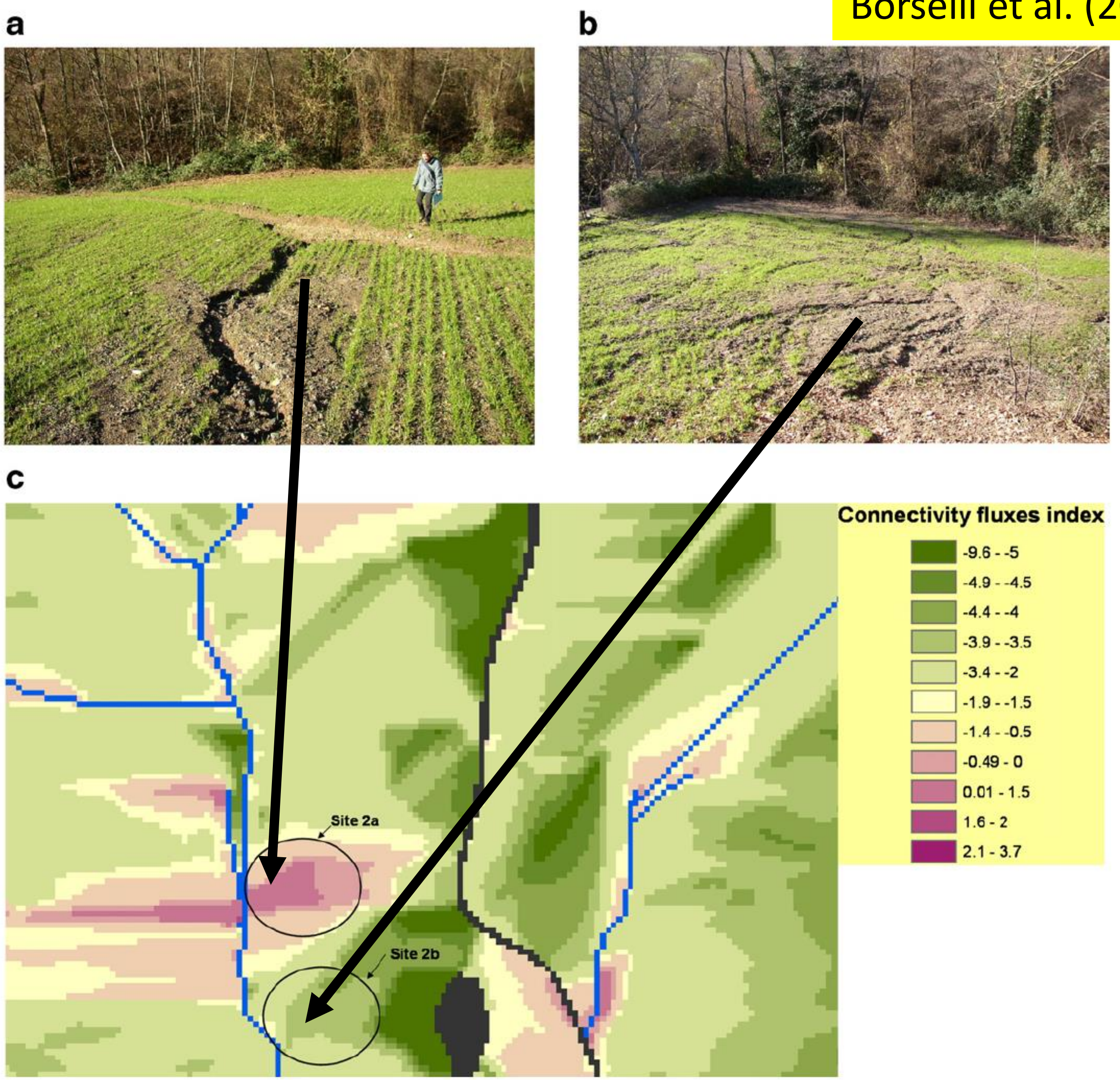


Fig. 5. a: Site 2—Area close to a local sink at the bottom of a field: direct connection of rill system without detectable sedimentation. b: Site 2—Area in proximity of local sink at the bottom of a field: direct connection of rill system with intense sedimentation. c: IC map of Site 2: deposition and connection areas are evidenced inside circular areas.

FIC – THE FIELD APPROACH

The field assessment of connectivity is evaluated using the same approach of Ic, i.e. estimating the upslope and the downslope component. A well defined field connectivity index (*FIC)* can permit an evaluation of the GIS-based *IC*. As *FIC* is strictly related with the event that produced the connectivity evidence, it is also a way of representing ground truth. Hence a comparison between the two indexes will allow for a validation of IC.

$$\mathbf{FIC} = \frac{\mathbf{Su} + \mathbf{Sd}}{\mathbf{2}}$$

FIC is subdivided into an upslope (Su) and a downslope subfactor (Sd); FIC varies between 1 and 100 and increases with connectivity

$$\mathbf{Su = Au + Bu + W_u Cu_1 + (1 - W_u) Cu_2}$$

Upslope subfactor

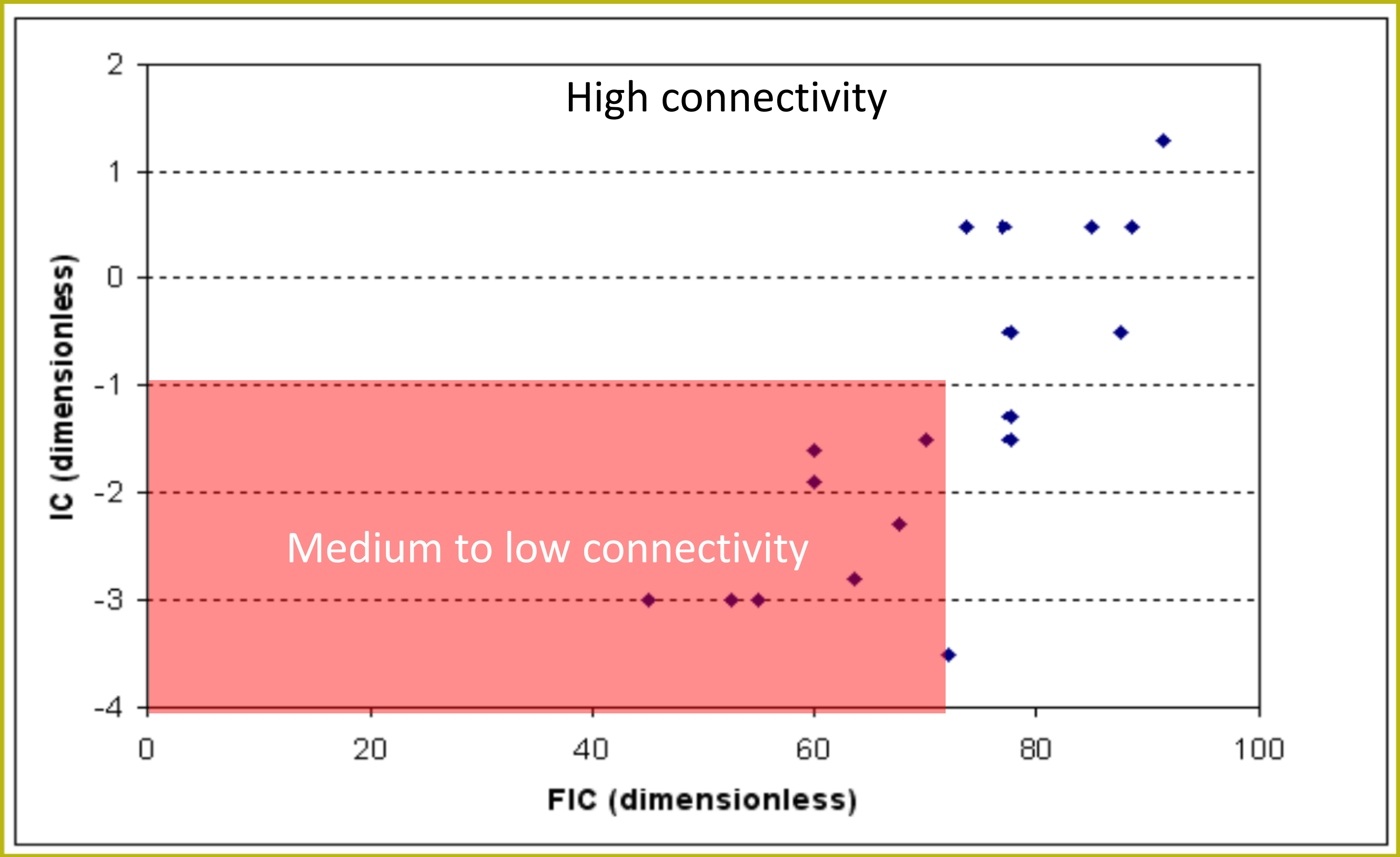
$$\mathbf{Sd = Ad + Bd + Cd + W_{d1} Dd_{1\_} + (1 - W_d) Dd_2}$$

Downslope subfactor

Au and **Ad**- Upslope area and the downslope distance to local sink;
Bu and **Bd** - Presence of sedimentation features along the upslope and downslope flow paths;
Cd presence and wideness of buffer-bush strip area before or along the flow path to the local sink;
Cu1, Cu2, Dd1, Dd2 - Subfactors opposing resistance to fluxes (surface roughness and vegetation cover crop, plant basal area) in the upslope area and the downslope flow path;
Wu and **Wd** – Fraction of arable land in the upslope area and in downslope flow path.

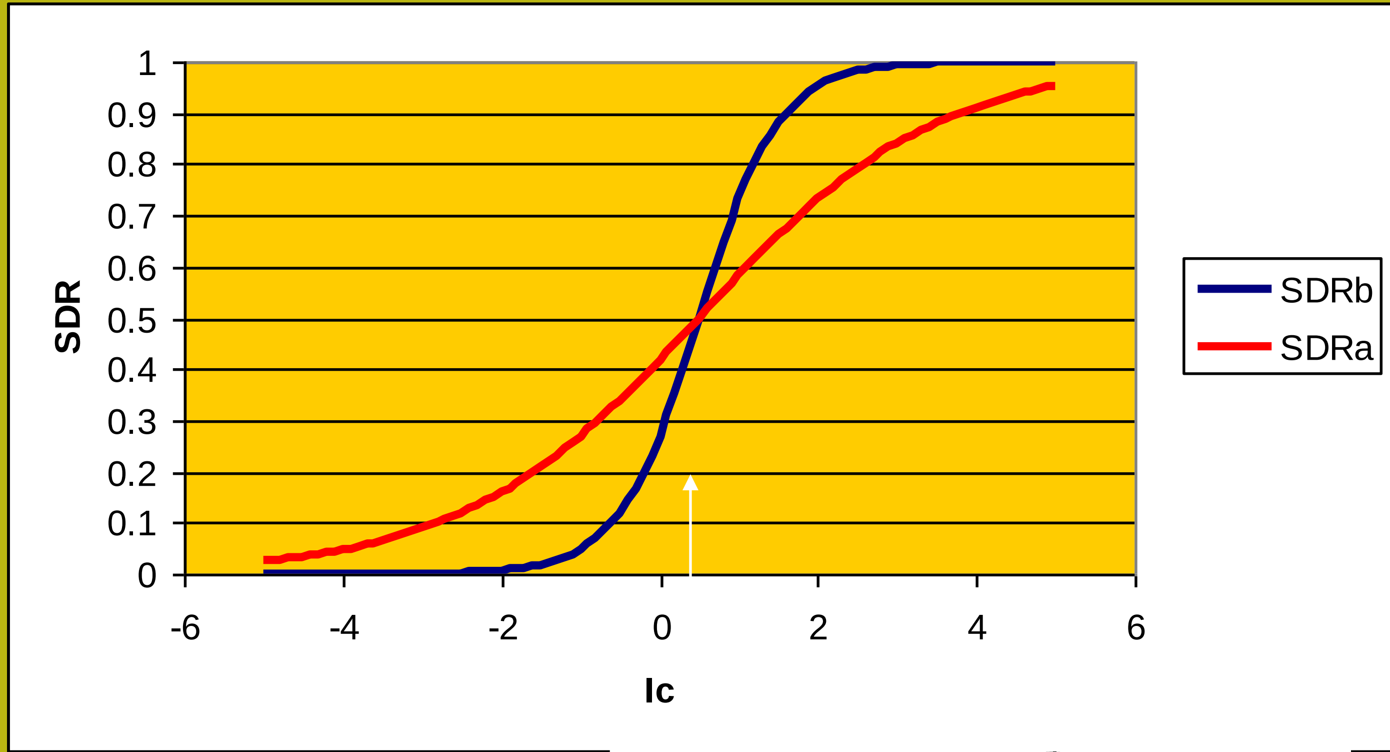
From Borselli et al.(2008)

Please see the original paper for details and examples of application…



The FIC values have been compared to the IC flux map obtained with the ArcGIS procedure for the entire study site

Possible functional relationships between IC and SDR…

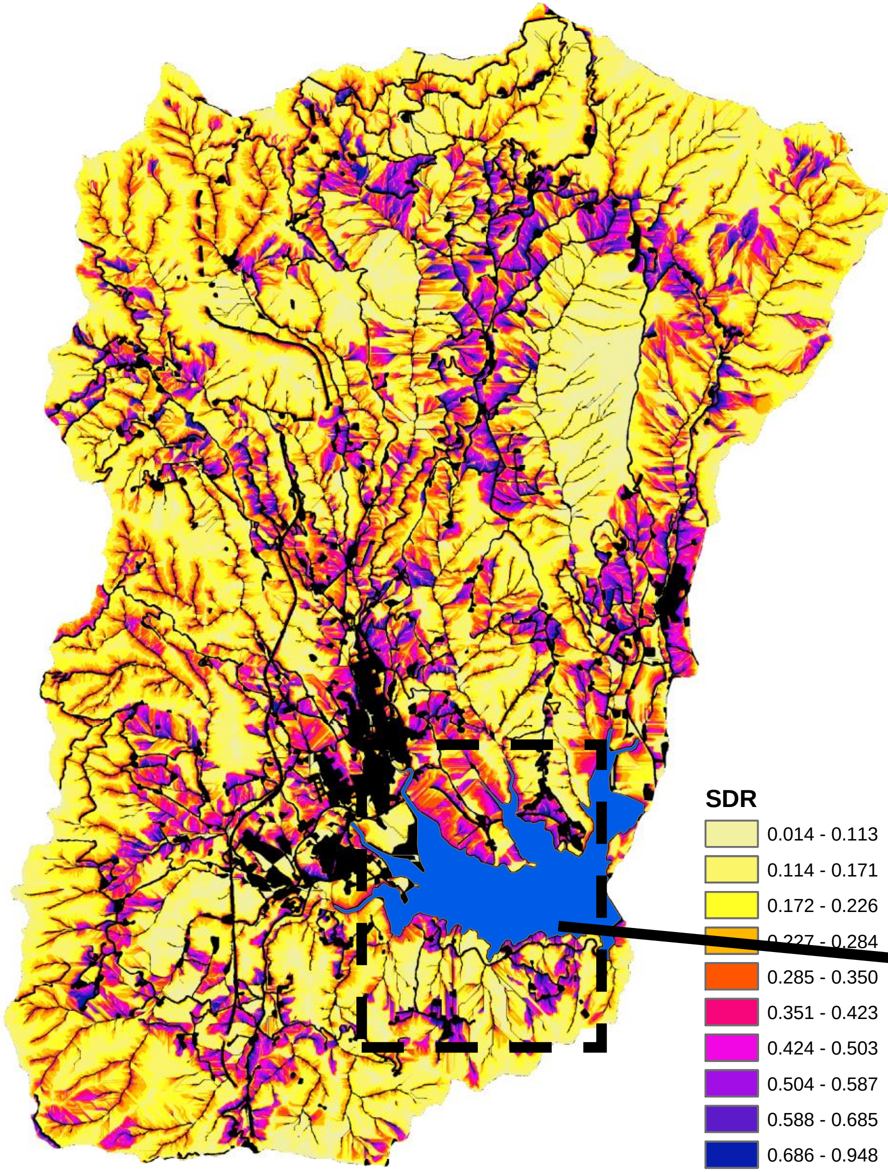


$$SDR = \frac{1}{1 + \exp\left(\frac{Ic_0 - Ic}{k}\right)}$$

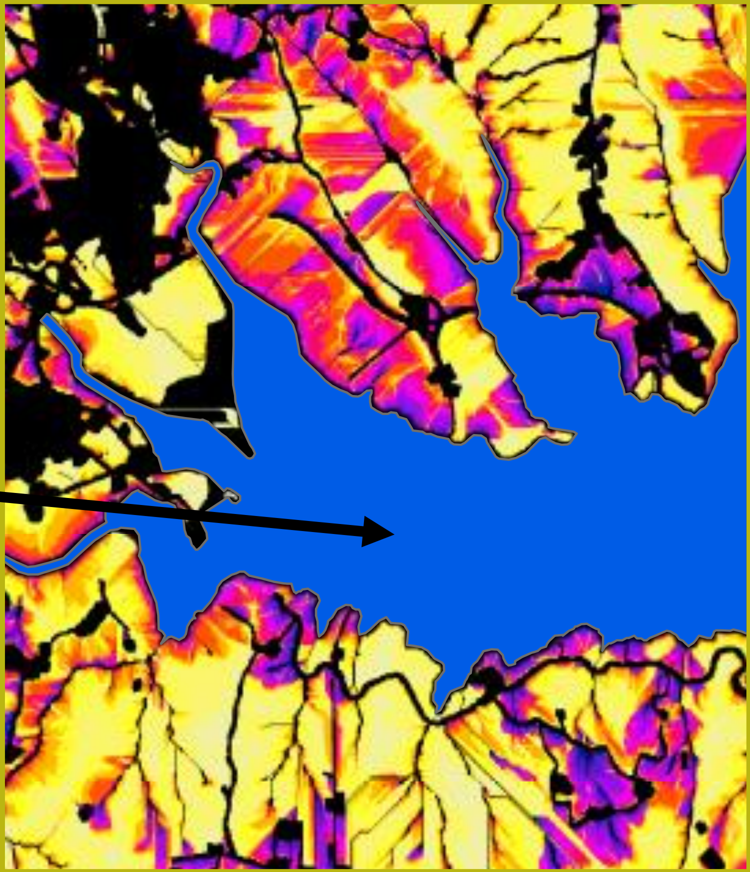
Boltzmann type function: SDR=f(IC, IC0, k)
(Borselli et al. 2007)

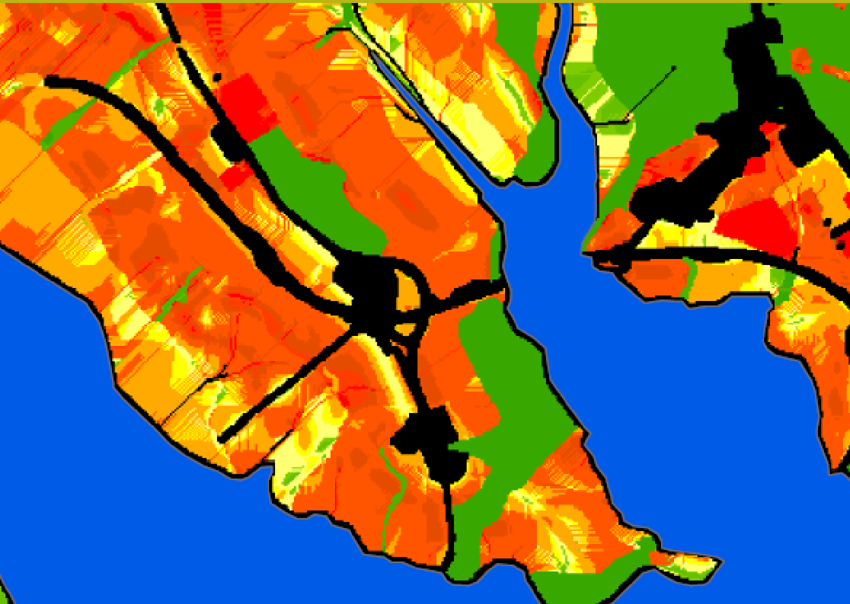
In this first application (2007) to Bilancino watershed we speculated on a possible relationship between IC and SEDIMENT DELIVERY RATIO (SDR) and developed it as SDR=f(IC) at the hillsope scale.
This analysis was not officially published until 2012
after the verification made by Vigiak et al. (2012) in another catchment (in Australia).

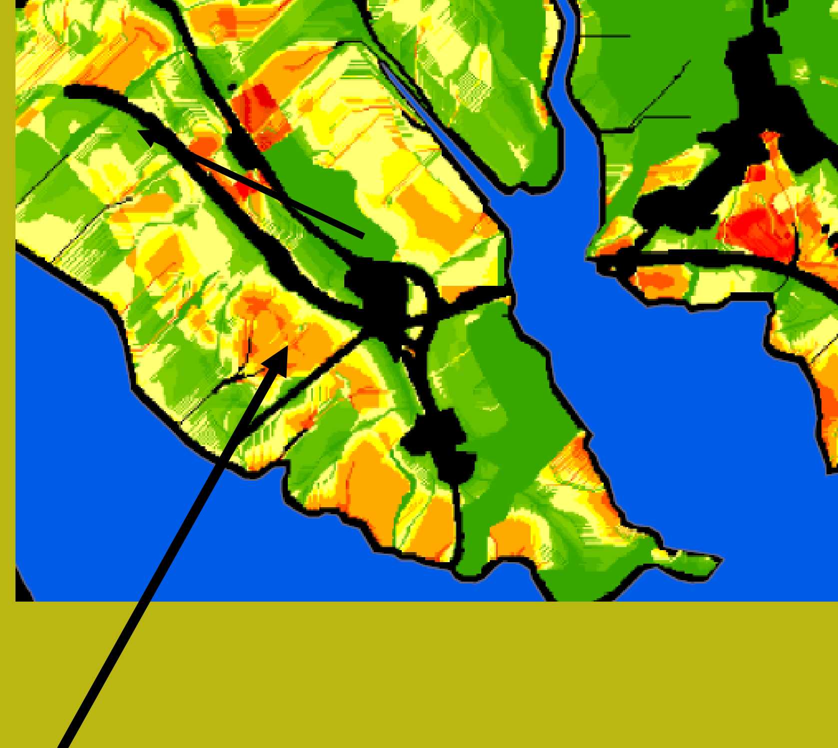
SDR map in a watershed for correction of average annual erosion rate (under USLE-type models)



Many authors have used the SDR to correct for distributed soil erosion model outputs (Ferro and Porto 2000; Lu et al., 2006)







Local average erosion rate...
Classic RUSLE 2D

In the Bilancino application
a new algorithm for the calculation
of erodibility (k) based on global dataset and
climatic classification was also used …
KUERY software 1.2.
See Borselli al. (2009,2012)
www.Lorenzo-borselli.eu/kuery

Average sediment yield contribution:
RUSLE2D corrected according to *IC* and SDR

Primary sources of sediment are in red (higher erosion rate)

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Proposals for extensive applications of IC (….and FIC) *in 2008*:

The proposed procedure for the IC model contained a large set of potential applications such as:

1) **hot spot identification of primary sediment sources to permanent drainage lines;**
2) **verification of effects of eco-compatible mitigation measures to reduce or favor connectivity (Hooke and Sandercock, 2007);**
3) **monitoring changes in the degree of connectivity in areas with high geomorphological evolution rates;**
4) **Performing scenario analysis to assess efficiency of conservation measures against soil erosion, sediment, and nutrients transport, and siltation (all strongly related to flux connectivity).**

A first Tool :

In the paper there is as sequence of commands for arcMap (ArcGIS 8.3) was provided to facilitate the calculation of IC

The procedure is not yet outdated….

even if now exists some other valid and more rapid alternatives (e.g. Connectivity Toolbox , Cavalli et al. 2014 see forward..)

Pseudocode fragment for IC calculation - Borselli et al. 2008

Appendix A. ArcGIS 8.3, ArcMap (spatial analyst extension)

Given data
grid: elevation, C
shapefile: road, urban area
Computation of input data

1. *Slope without null value*
   a. Enable Spatial Analyst
      under *View… Toolbars*, select *Spatial Analyst*
   b. Calculate Slope
      from the Spatial Analyst toolbar, select *Surface Analysis… Slope*
      name the new theme *Slope*
   c. Raster Calculator
      from the Spatial Analyst toolbar, select *Raster Calculator*
      build an expression *(([Slope]==0) *0.005)+[Slope]);*
      name the new theme *S*
2. *Road/urban mask*
   a. create a raster map of road and urban areas
      from the Spatial Analyst toolbar, select *Convert.. feature to raster*
      ….

Other applications of connectivity index IC were found in the international scientific literature, after 2008 …. Mainly after 2010….

Only publications in ISI journals area have been considered in following slides….

Geomorphology 138 (2012) 74–88

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Contents lists available at SciVerse ScienceDirect

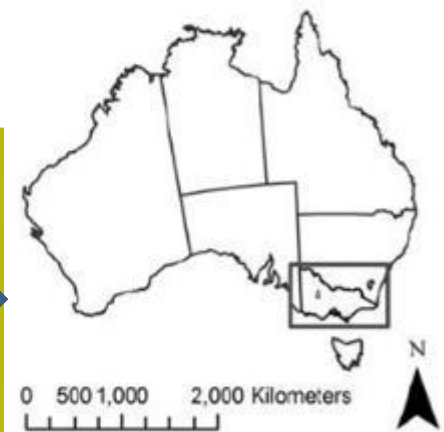
Geomorphology

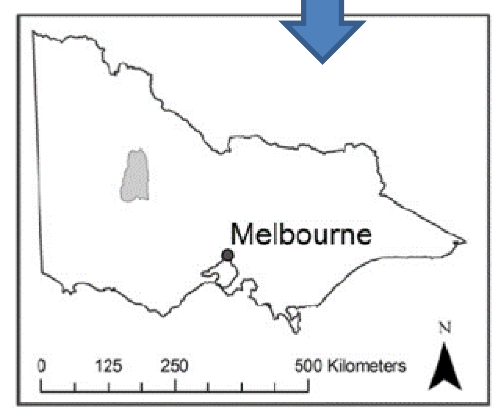
journal homepage: www.elsevier.com/locate/geomorph

Comparison of conceptual landscape metrics to define hillslope-scale sediment delivery ratio

O. Vigiak [a,*], L. Borselli [b], L.T.H. Newham [c], J. McInnes [a], A.M. Roberts [a]

Site : Avon-Richardson catchment (Victoria, Australia) 3300 km2 .. **DEM:** Raster DEM 20x20 m



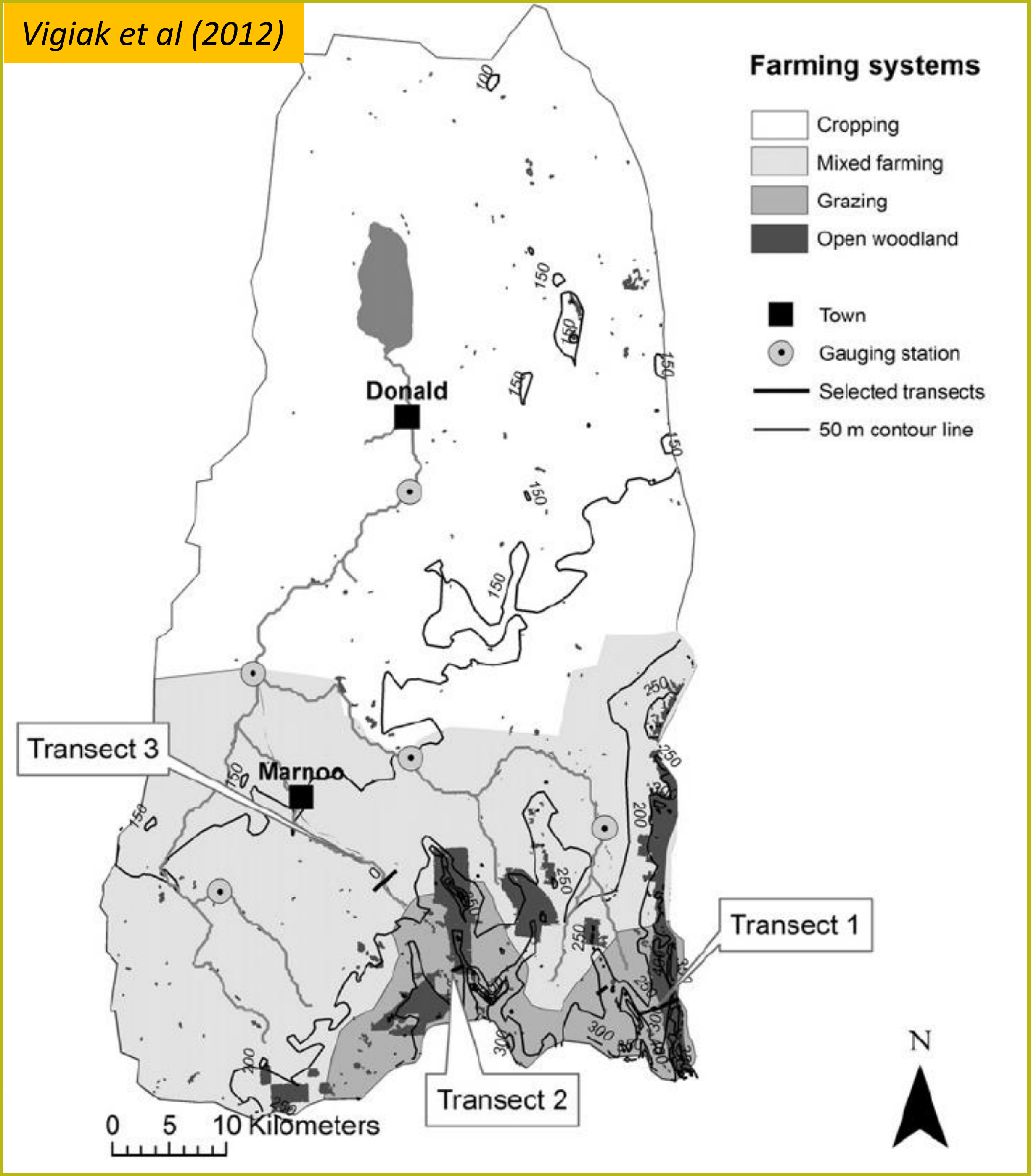


AIMS:

To calibrate and apply a point-to-catchment linked model (**HowLeaky + CatchMODS**) for daily soil loss estimation (developed by Olga Vigiak and collaborators)

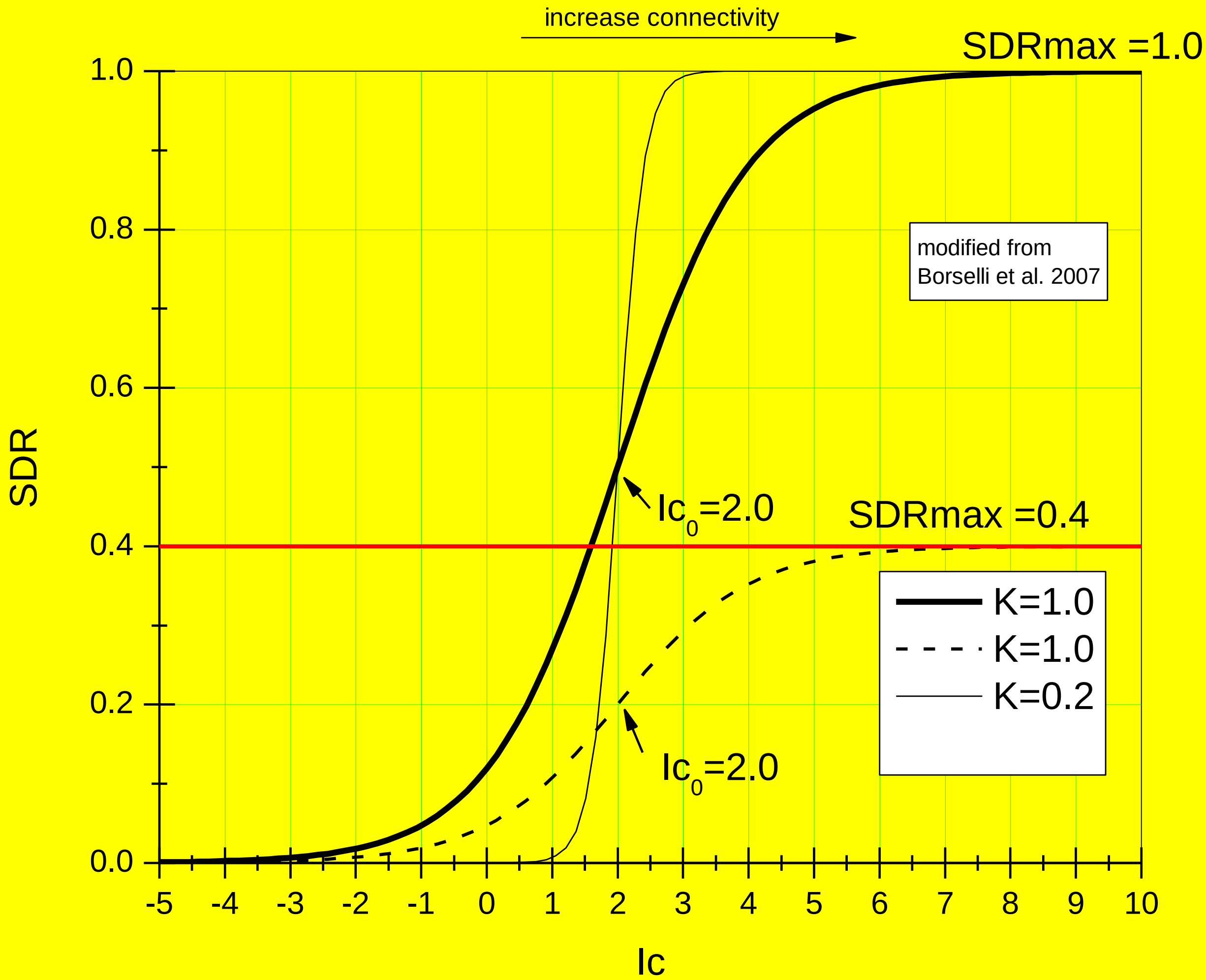
4 metrics for regionalization of SDR were compared in terms of pattern distributions and efficiency in matching sediment yields at 5 monitoring stations (4 indices of connectivity in total, including IC)

- **Avon-Richardson catchment (Victoria, Australia)**



Comparison of 4 connectivity metrics…

Metric	Main concepts
Travel Time (TT, Ferro and Minacapilli, 1995)	(time) distance to the stream
Stream Transport (ST, based on Rustomjii and Prosser, 2001)	Stream transport capacity (Upstream accumulation area and local slope)
Flux Connectivity Index (IC, Borselli et al., 2008) linked to SDR ⇨	**Potential for down routing of runoff vs potential for sinks to the stream**
Sediment Residence Time (RT, Lu et al., 2006)	Travel time vs effective storm duration, sediment settling properties



Implementation of *SDR = f (conn. Index)* For 4 types of connectivity indexes (including IC…) and optimization of parameters (Ic0 and k) by Observed SSY at a series of Gauging stations

$$SDR = \frac{SDR_{Max}}{1 + \exp\left(\frac{Ic_0 - Ic}{k}\right)}$$

Case of SDR by IC, and optimized IC0 and k
IC0=0.5 and k=2.0

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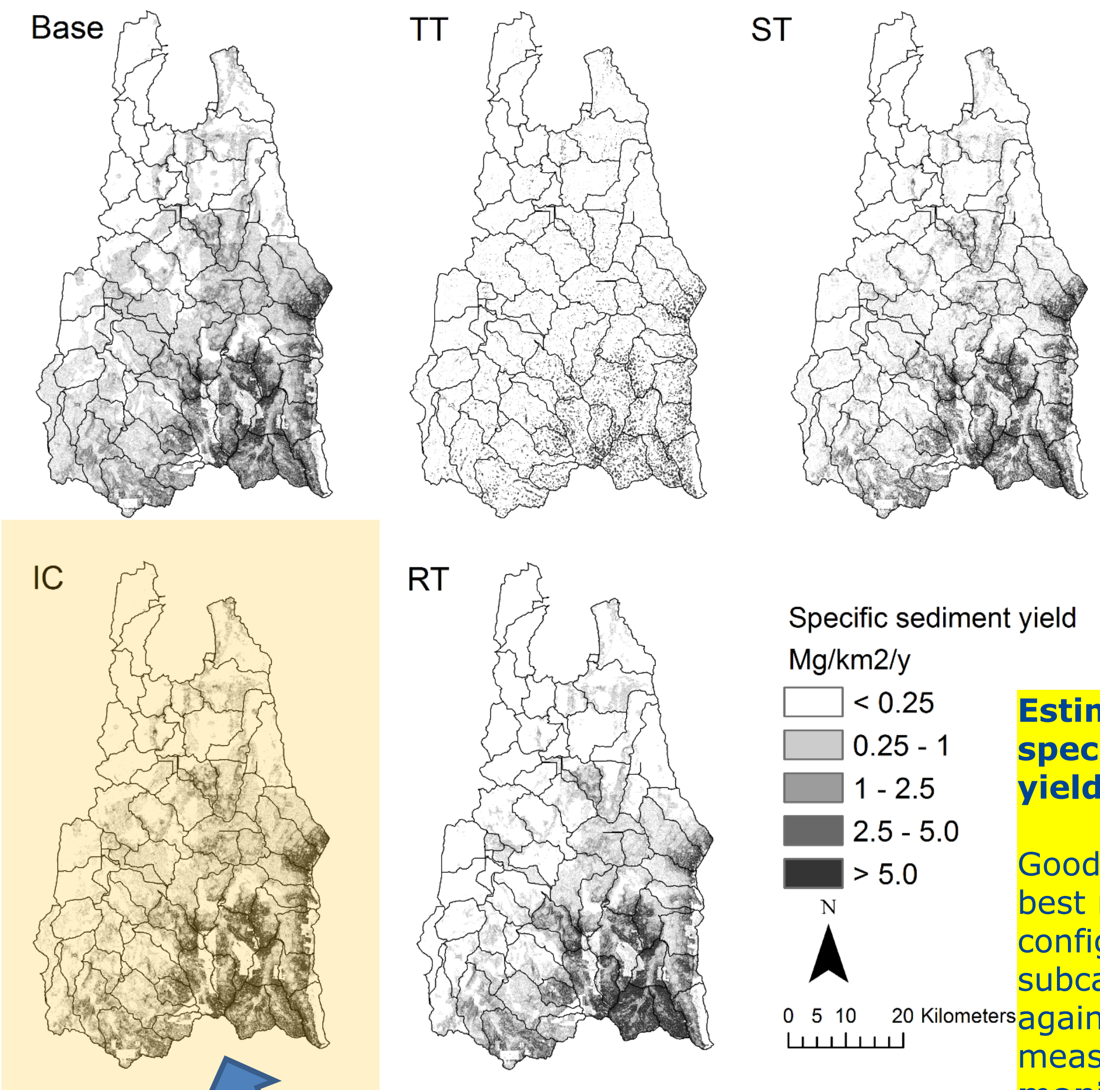
Hillslope erosion patterns (pixel)



IC

By Vigiak et al (2012)

Base = spatially-constant SDR

TT = travel time (Ferro and Minacapilli 1995)

ST = sediment transport (Rustomjii and Prosser, 2001)

IC = flux connectivity index (Borselli et al. 2008)

RT = residence time (Lu et al 2006)

Estimation of specific sediment yields

Goodness of fit of best model configurations at subcatchment scale against measurements at **monitoring gauging stations (sample size=7)**

	Nash-Sutcliffe Model Efficiency	AICc
Base	0.48	-52
TT	-0.25	-46
ST	0.55	-50
IC	**0.66**	**-52**
RT	0.61	-54

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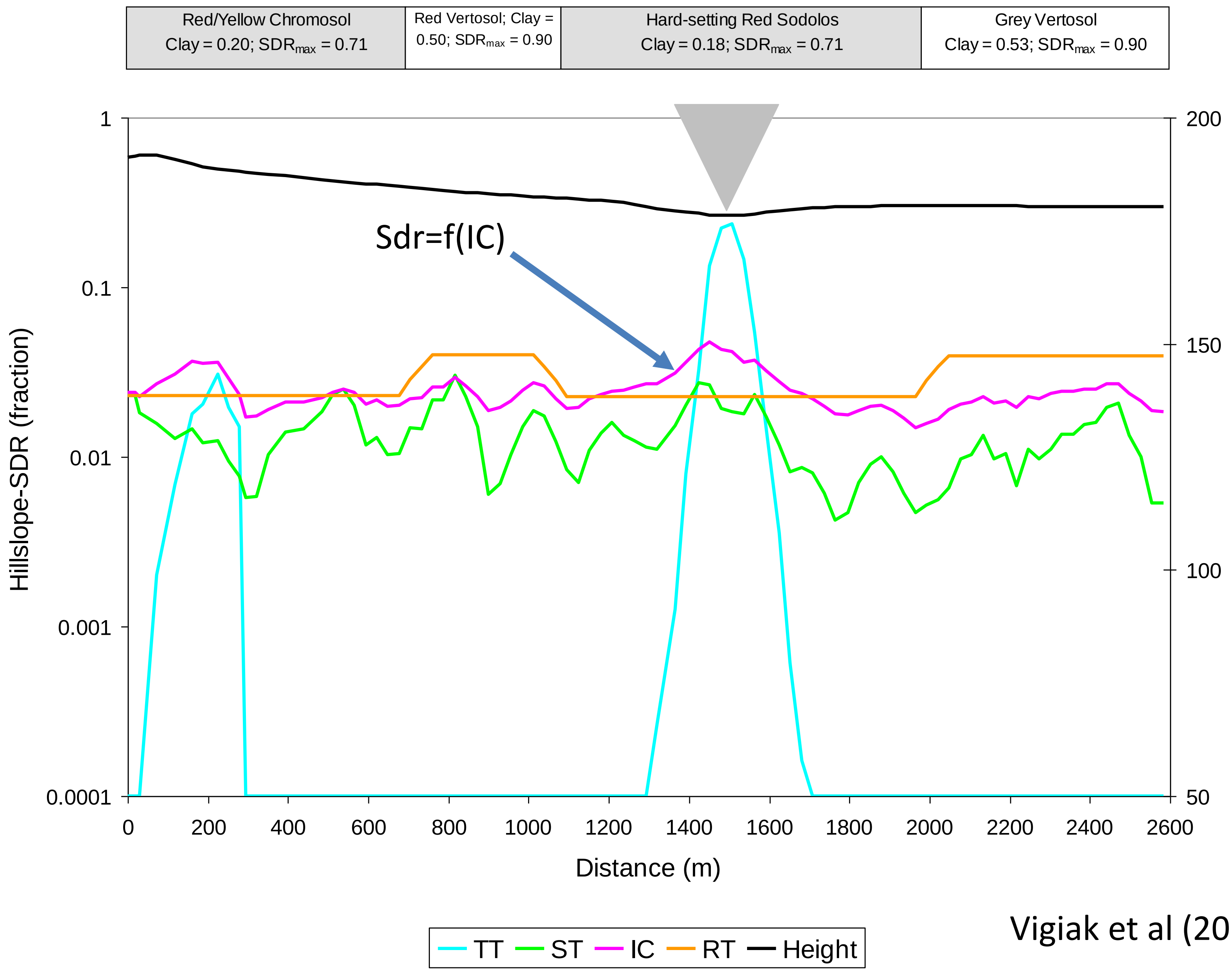
SDR pattern along a transect



Vigiak et al (2012)

Conclusions (Vigiak et al. 2012)

Regionalisation of hillslope SDR improved the estimation of specific sediment yields at subcatchment scale (less so at pixel scale)

The introduction of all metrics (except RT) did not increase data requirements

The 4 metrics differ in data requirements, dominance of landscape factors, and conceptualization of sedimentological connectivity

IC metric can be recommended in small-medium catchments (homogeneous climatic conditions)

RT metric can be recommended on large catchments (e.g. continental scale; important climatic gradient)

Catena 84 (2011) 1–11

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Year 2011

Review

Low erosion rates measured for steep, sparsely vegetated catchments in southeast Spain

N. Sougnez *, B. van Wesemael, V. Vanacker

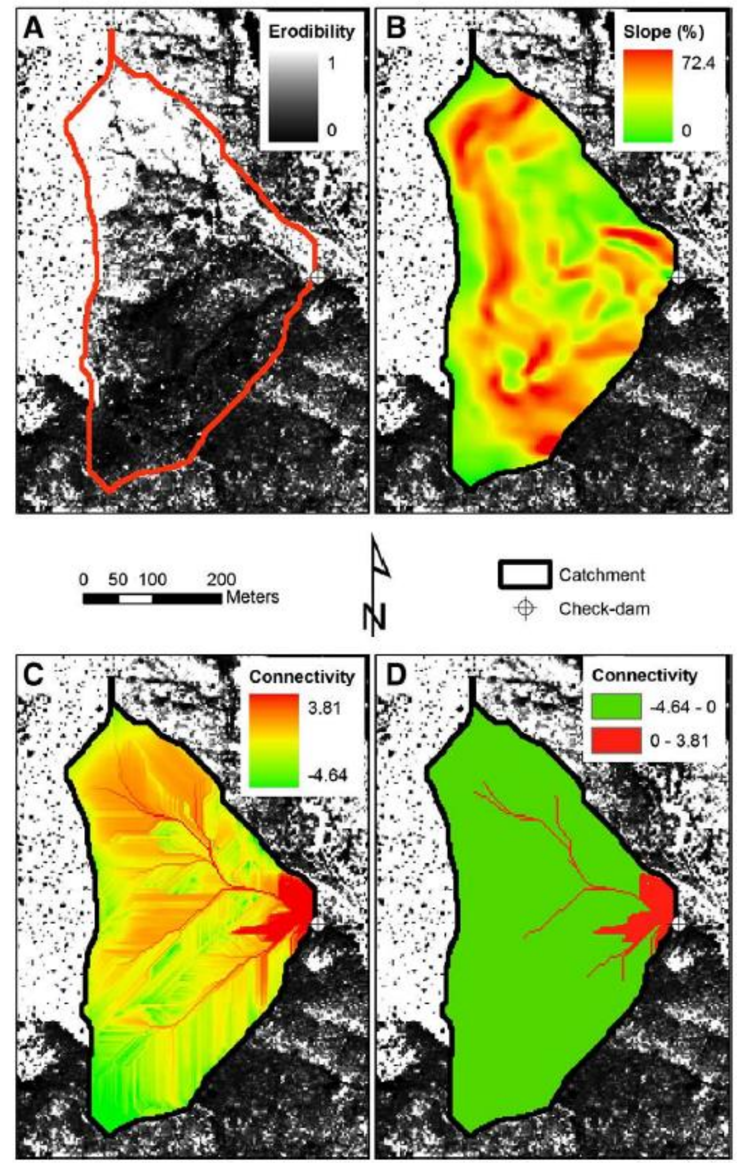
George Lemaître Centre for Earth and Climate Research (TECLIM), Earth and Life Institute (ELI), Université Catholique de Louvain, B-1348 Louvain-la-Neuve, B

Site: Sierra de la Torrecilla and the Sierra de Carrascoy (Murcia, South Spain) – several small catchments of 1-20 ha each.

DTM: 3x3 m from contour lines, topographic Map 1:25.000

aims: to provide an **accurate estimation of catchment-wide erosion rates for a semi-arid mountainous region**. A variety of methods combined to measure and analyze spatial **patterns in vegetation cover; and to evaluate their effect on water and sediment connectivity**

N. Sougnez et al. / Catena 84 (2011) 1–11



Catena 102 (2013) 62–73

Contents lists available at SciVerse ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Year 2013

Predicting runoff and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees

M. López-Vicente [a,*], J. Poesen [a], A. Navas [b], L. Gaspar [b]

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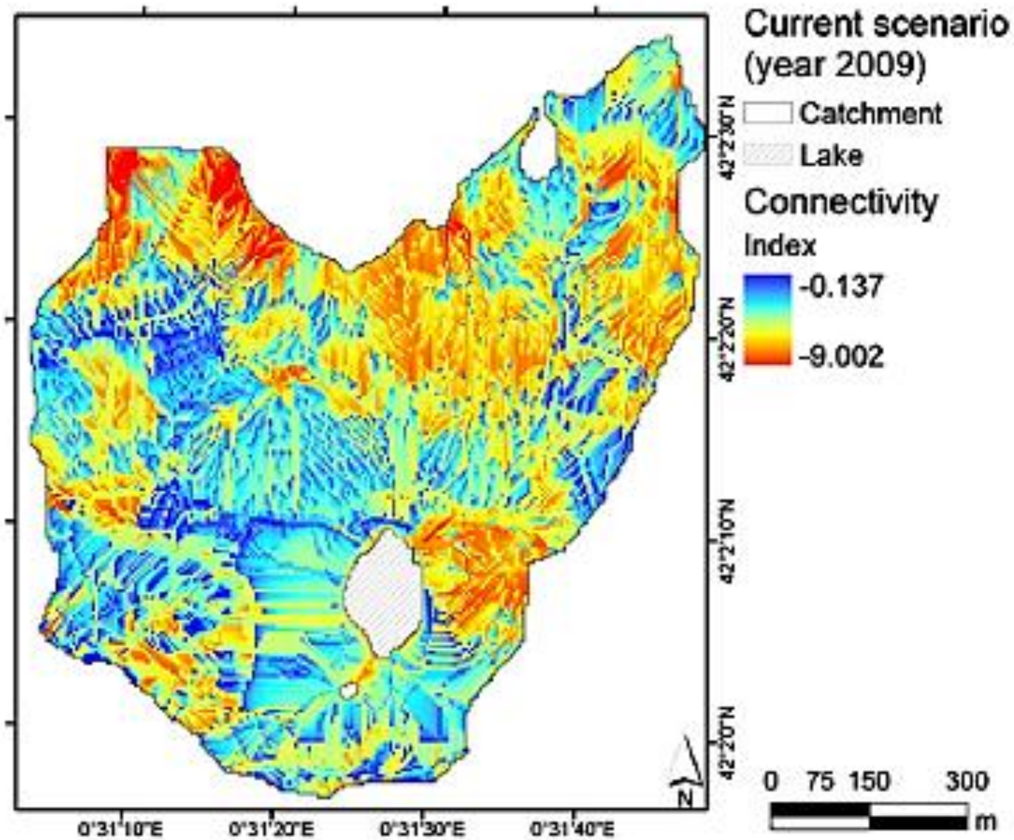
[b] Dept. of Soil and Water, Experimental Station of Aula Dei, CSIC, Postal Box 202, 50080, Zaragoza, Spain

Site: Spanish Central Pre-Pyrenees. 0.74 km2 catchment

DTM: not provided (probably 5x5m)

aims: the study seeks **to assess the effect of agricultural terraces, irrigation channels, trails, sinks, scarps, and land abandonment on the hydrological connectivity** of a small catchment and its **consequences on predicting rates of soil erosion under four different scenarios of land uses**.



Geomorphology 188 (2013) 31–41

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments

Marco Cavalli [a,*], Sebastiano Trevisani [b], Francesco Comiti [c], Lorenzo Marchi [a]

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[b] University IUAV of Venice, Faculty of Architecture, Venezia, Italy
[c] Free University of Bozen-Bolzano, Faculty of Science and Technology, Bolzano, Italy

Lithology: mica-schist, gneiss, and phyllite.

Land use: coniferous forest, mountain grassland, bare rock and debris.

Annual rainfall: around 500 mm in the valley floor, strong increase with elevation.

Gadria catchment : area 6.36 km^2, average slope 79.1%, range in elevation: 1394 – 2945 m.

Strimm catchment : area 8.5 km^2, average slope 61.8%, range in elevation 1394 – 3197 m.

Sites: Gadria and Strimm catchments (Eastern Italian Alps) - 14.4 km2

DTM: 2.5x2.5 m (high resolution)

aims: development and **adaption of IC index to model sediment pathways dealing with debris flows and channelized sediment transport**, based on the one proposed by Borselli et al. (2008) with *ad hoc* modifications aimed at better exploitation of HR-DTMs

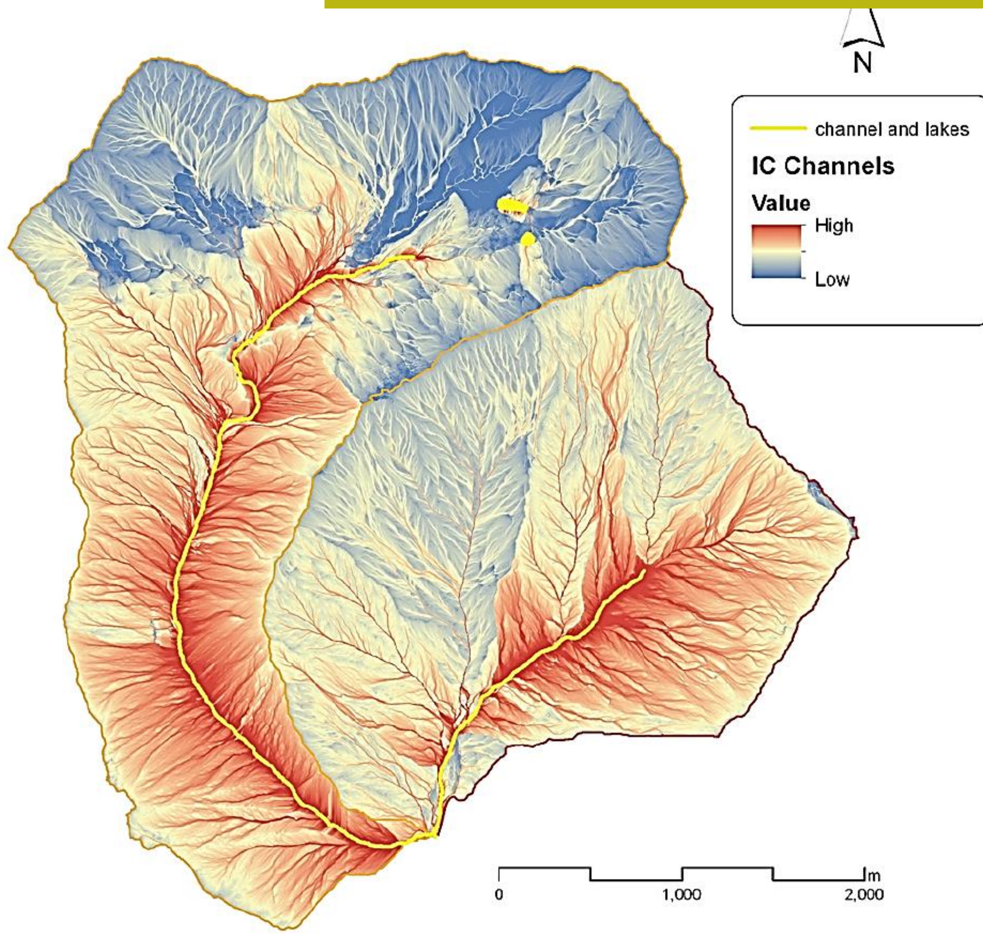
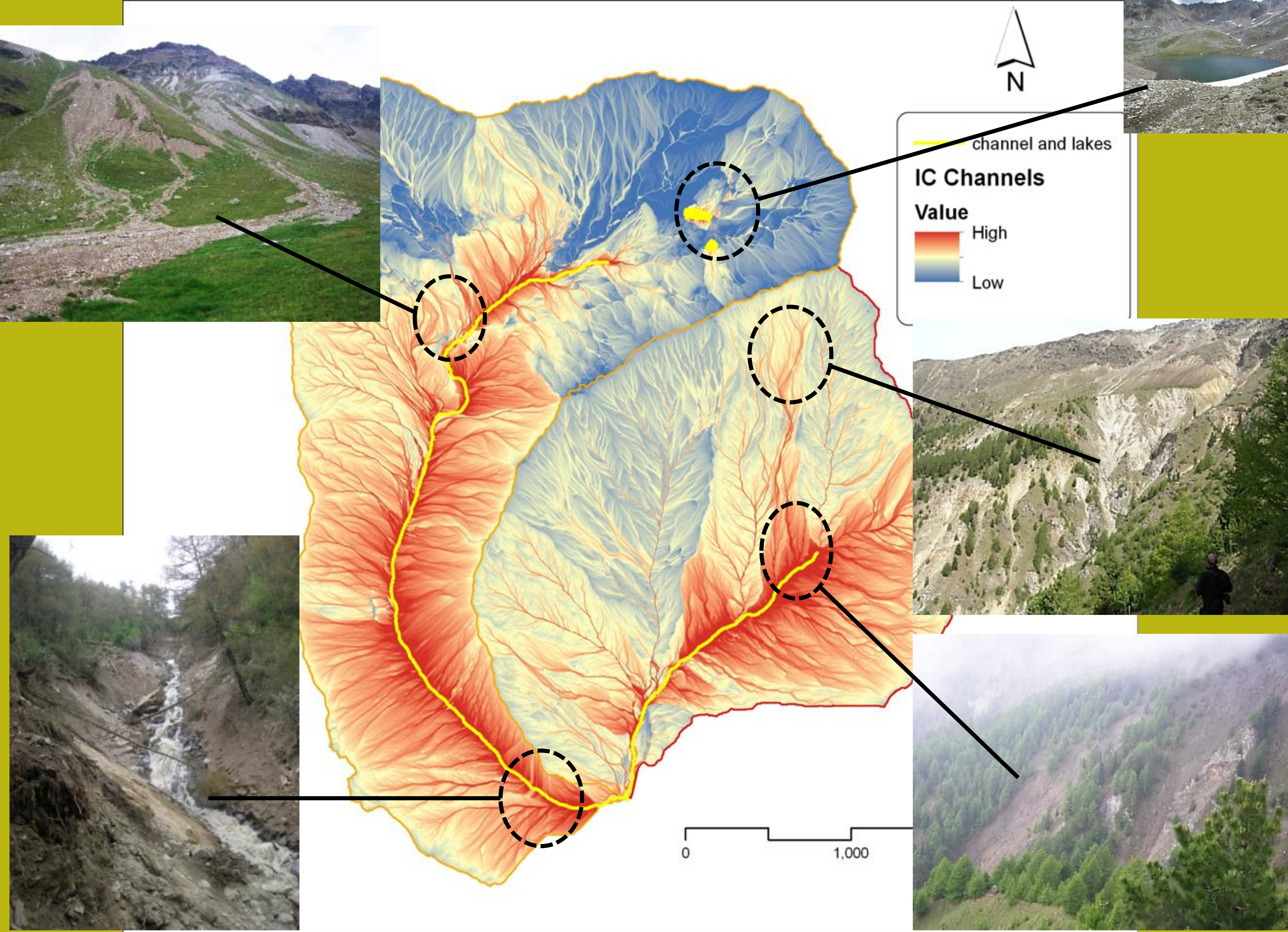


Fig. 5. *IC channels* map: index of connectivity *IC* computed with reference to main channels and lakes.



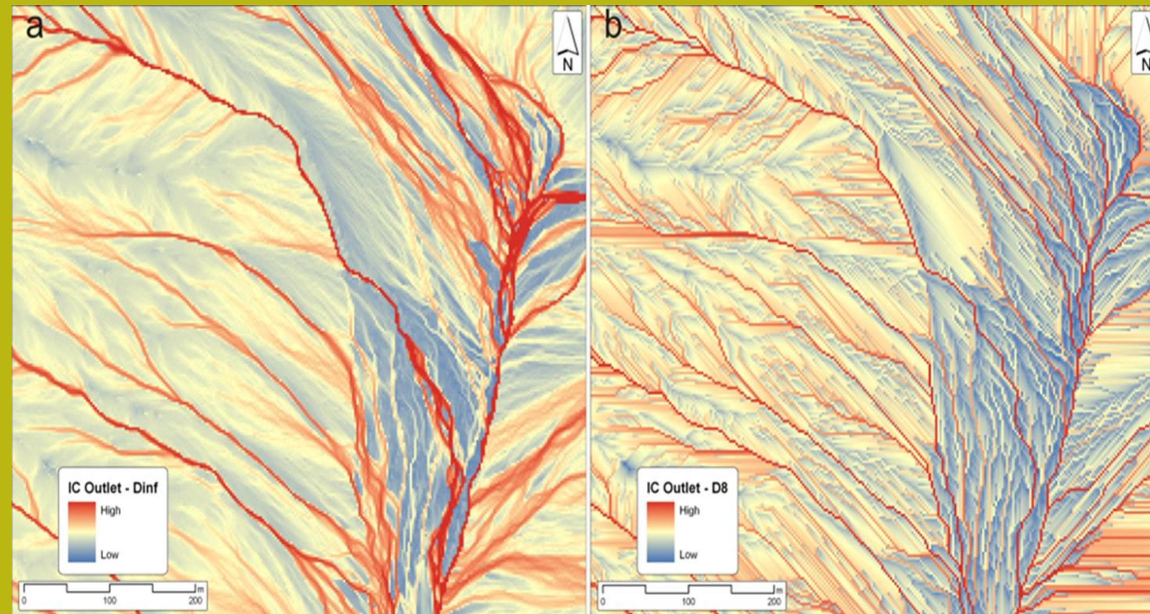
Borselli and al. (2014)- *Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306*

Adaptation of the IC to mountain catchments and its use with HR-DTMs (Cavalli et al., 2013)

BEWARE !!!
High resolution DTM is required….

<u>Flow direction</u>

D ∞ method (Tarboton, 1997)



<u>Slope *S* (m/m)</u>

S > 1 -> *S* = 1

<u>Weighting factor *W*</u>

- Related to the impedance to water and sediment fluxes;
- *C* factor of USLE – RUSLE in the original model;
- Replaced by a roughness index (Cavalli et al., 2008).

$$W = 1 - \left(\frac{RI}{MAX(RI)} \right)$$

High *W* : Low roughness and low impedance to fluxes
Low *W* : High roughness and high impedance to fluxes

W (m/m) ranges from 0 to 1; minimum value set to 0.01

Application to debris flow and Surface landslide process .. But not only

standard dev of local residual Cavalli (2008)

$$RI = \sqrt{\frac{\sum_{i=1}^{25} (x_i - x_m)^2}{25}}$$

Borselli and al. (2014)- *Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306*

Geomorphology 197 (2013) 64–75

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

A sediment fingerprinting approach to understand the geomorphic coupling in an eastern Mediterranean mountainous river catchment

Koen D'Haen, Bert Dusar, Gert Verstraeten *, Patrick Degryse, Hanne De Brue

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Centre for Archaeological Science, KU Leuven, Celestijnenlaan 200E box 2408, B-3001 Leuven, Belgium

Site: Büğdüz River catchment in SW Turkey (262 km2)
DTM: Detailed information not provided.
aims: to elucidate the **spatial variability of sediment sources and geomorphic coupling between hillslope and floodplains**

Cavalli's approach was also used by Authors

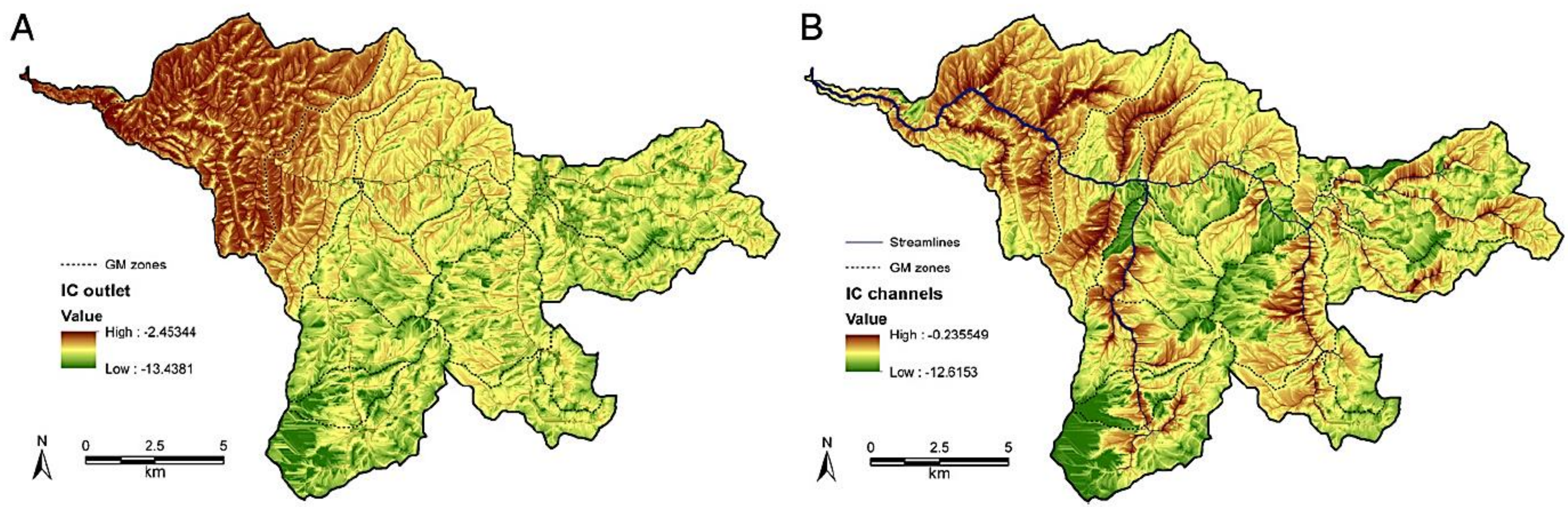

Fig. 4. (A) Connectivity index of Büğdüz catchment with respect to catchment outlet (IC outlet). (B) Connectivity index of Büğdüz catchment with respect to catchment outlet (IC channels).

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **38**, 1496–1512 (2013)

Published online 11 February 2013 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.3384

Initial hydro-geomorphic development and rill network evolution in an artificial catchment

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†Current affiliation: 2 Brandenburg University of Technology (BTU) - Chair of Geopedology and Landscape Development, Cottbus, Germany

Site: open-cast lignite mine Cottbus, 150 km south of Berlin (Germany)
Approx 0.04 km2

DTM: 1x1 m survey in several phases of erosion evolution (during 5 years)

aims: to **characterize and to identify characteristic phases of rill network development in the artificially-created catchment** as an example for initial hydrogeomorphic landform development in temperate climate

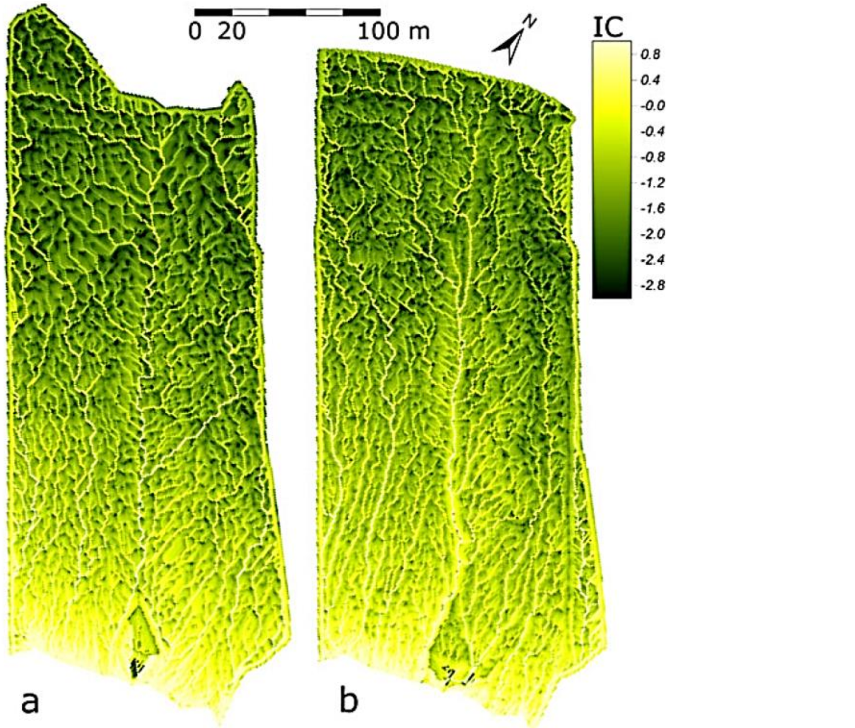


Figure 13. Spatial distribution of DEM cell values of the IC in the erosion-dominated area (as defined in Figure 3b), based on DEMs for (a) November 2005, and (b) March 2010. Grid cell size is 1 m by 1 m. Modification of the surface catchment area in autumn 2009 results in lower IC values in b).

Site: **Fukushima Prefecture** (Japan) Approx 600 km2

DTM: 10x10 m

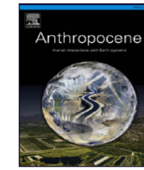
aims: In post-accidental context, the paper aims to provide alternative **methods to estimate the early dispersion of contaminated sediment during the 20 months that followed the nuclear accident in the mountainous catchments exposed to a succession of erosive rainfall, snowfall and snowmelt events.**

Anthropocene 1 (2013) 23–34

Contents lists available at ScienceDirect

Anthropocene

journal homepage: www.elsevier.com/locate/ancene



Tracking the early dispersion of contaminated sediment along rivers draining the Fukushima radioactive pollution plume

Caroline Chartin [a], Olivier Evrard [a,*], Yuichi Onda [**,b], Jeremy Patin [b], Irène Lefèvre [a], Catherine Ottlé [a], Sophie Ayrault [a], Hugo Lepage [a], Philippe Bonté [a]

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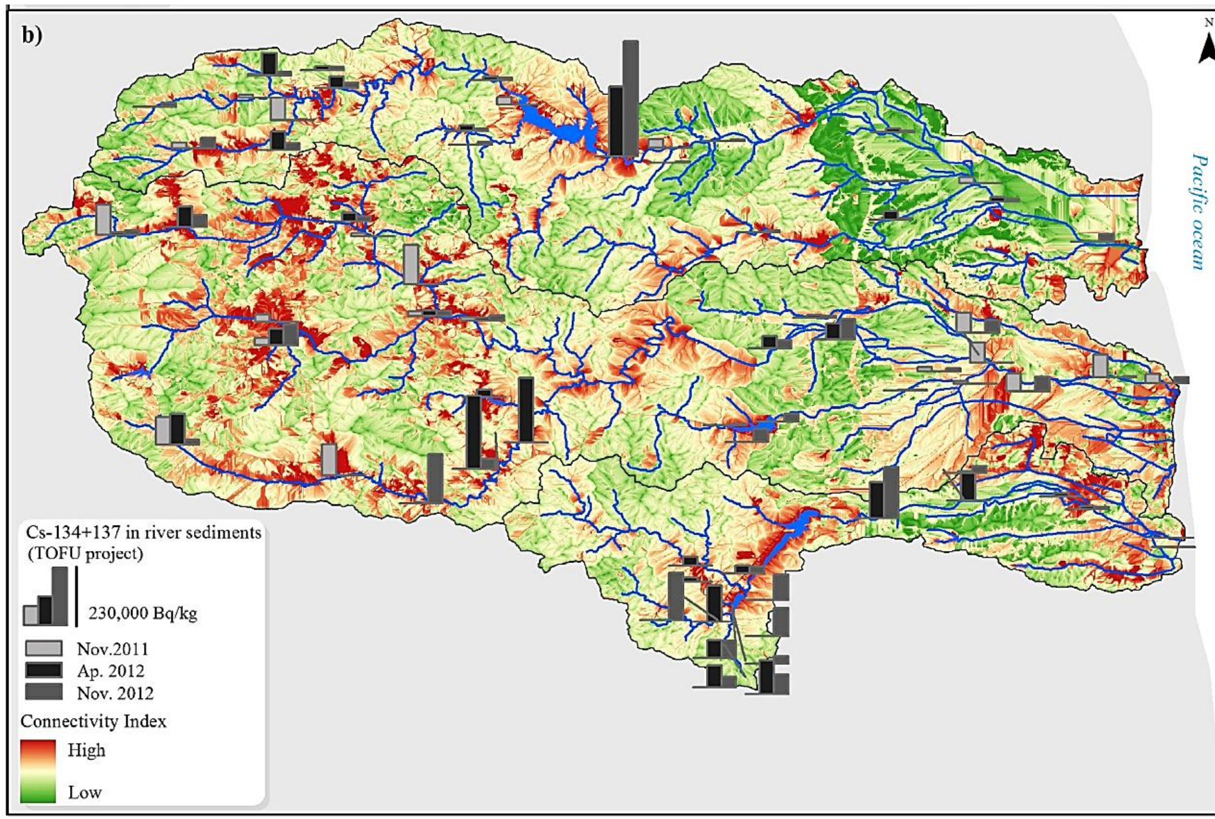

Fig. 6. Dominant land uses in the coastal catchments derived from analysis of satellite images (a) and associated hillslope-to-sinks hydro-sedimentary connectivity index compared to river sediment radiocaesium activities (b). ((M) Mano catchment); (N) Nitta catchment); (O) Ota catchment).

Borselli and al. (2014)- *Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306*

Site: in Swiss National Park (SNP), Engadine region in Switzerland - study area 6.4km2

DTM: LiDAR-based 2x2m

aims: 1) **to evaluate the morphometric GIS modelling results against the field based geomorphic map**, 2) to decipher **key controls on the present-day sediment flux in a small, de-glaciated mountain valley,** and 3) to address the question of whether traditional geomorphic field maps have become indispensable today when studying mountain cascading systems.

Cavalli et al (2013) variant for W factor

Geomorphology 221 (2014) 215–229

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Sediment connectivity in the high-alpine valley of Val Müschauns, Swiss National Park — linking geomorphic field mapping with geomorphometric modelling

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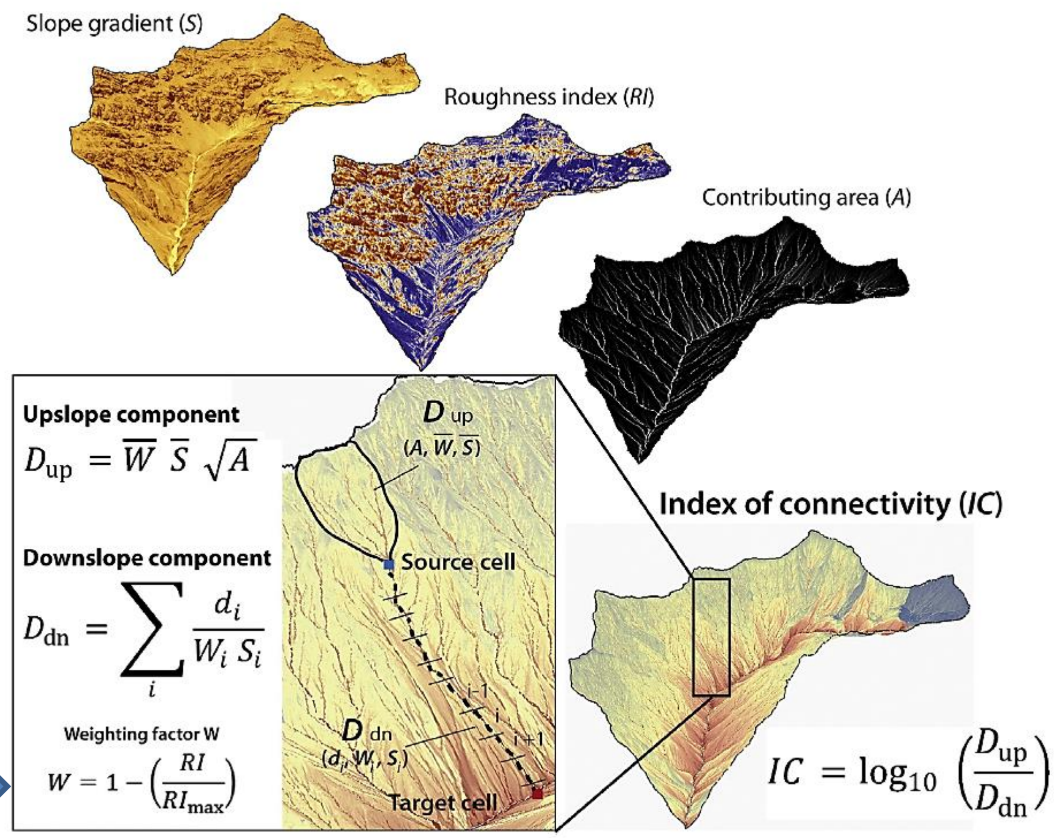

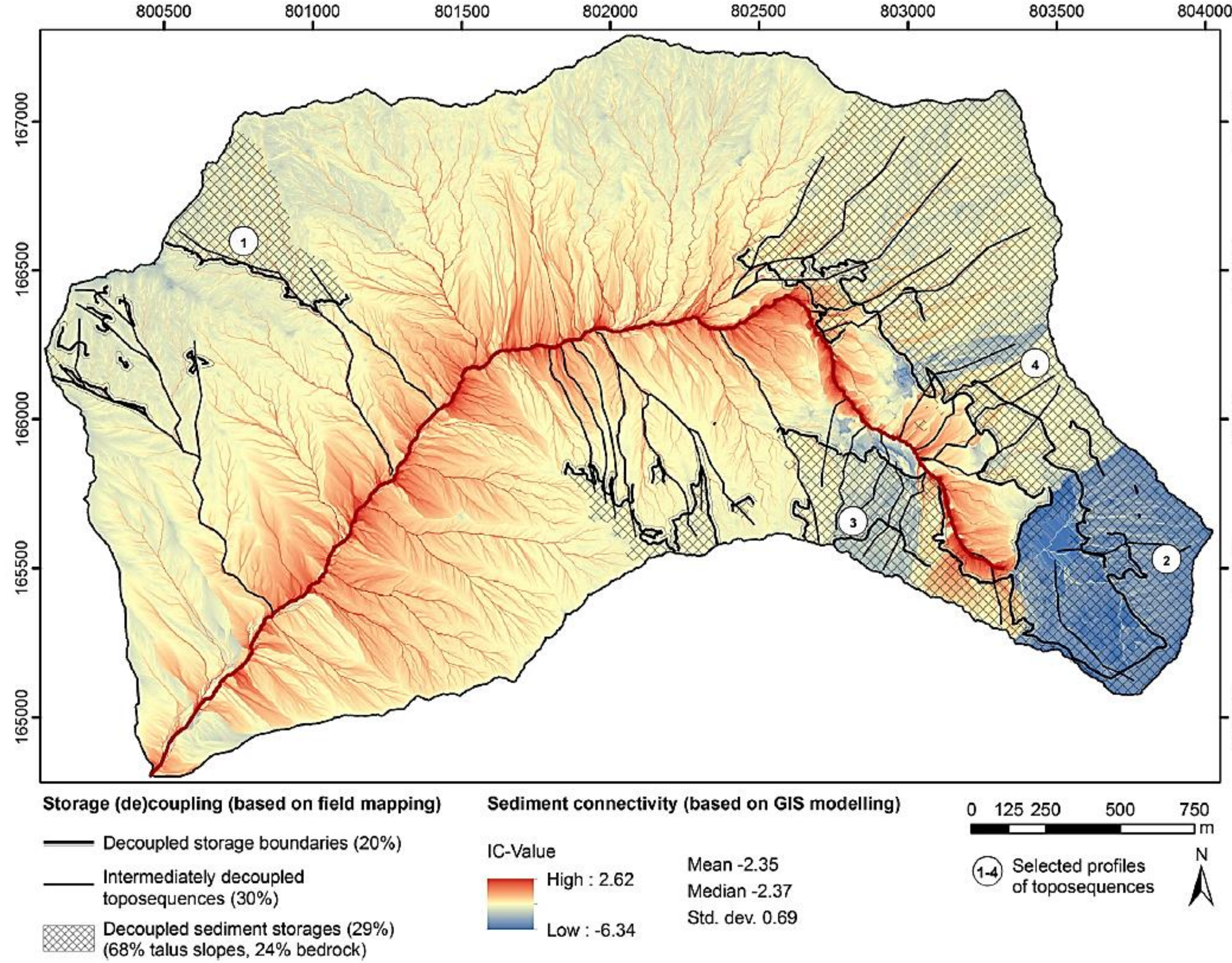

Fig. 9. Storage (de)coupling, according to the field-based analysis of toposequences, and index of connectivity (*IC*), calculated by the GIS modelling approach (2-m DTM, © SwissTopo, in 2013). Thick double lines show storage boundaries qualitatively defined as decoupled due to lacking sediment transfer between adjacent landforms caused by inactivity of geomorphic processes or the occurrence of buffers. As a consequence, around 29% of the basin surface has no connectivity to the fluvial system (crosshatched area). Among them, 68% of the talus slopes and 24% of the bedrock-coverage are affected by this disconnectivity.

IC related to different geomorphological units and processes depending on sediment storage types

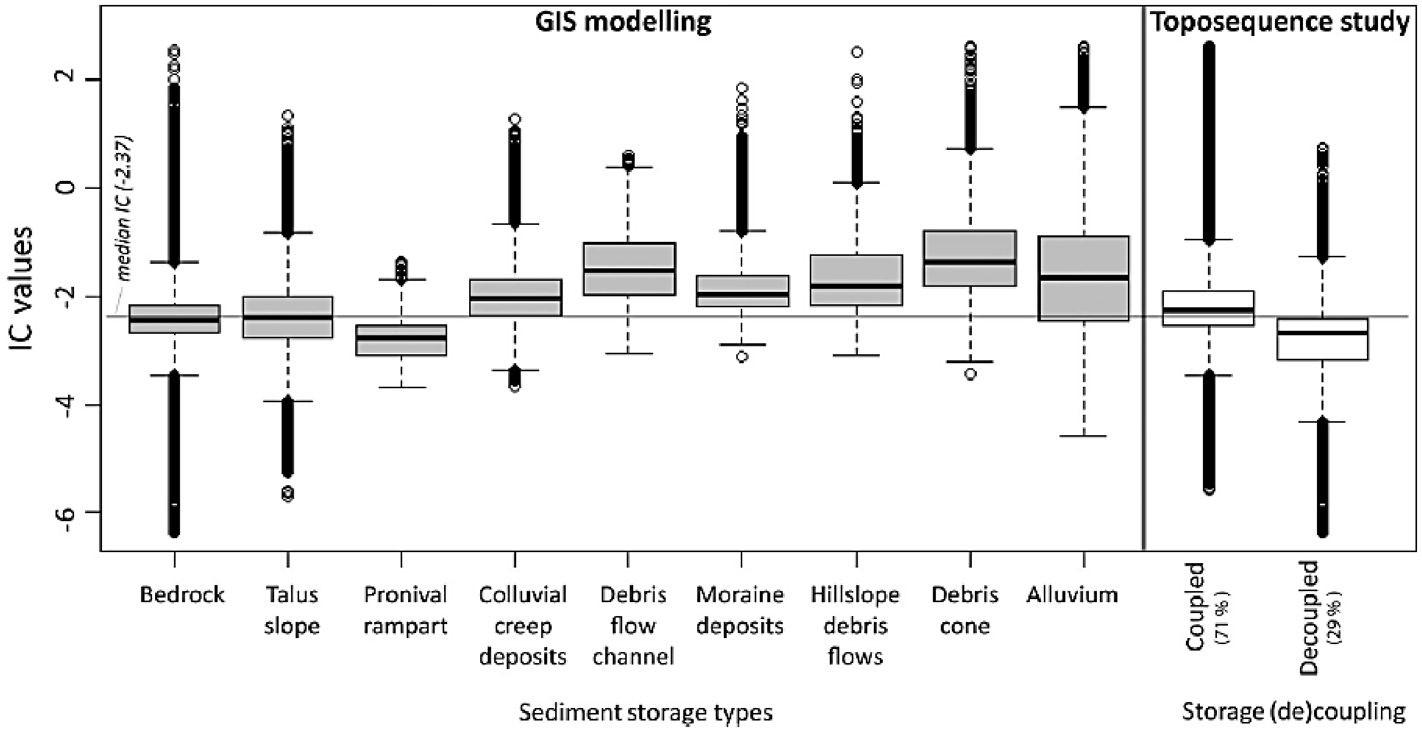

Fig. 10. *IC* values of sediment storage types in Val Müschauns and comparison between the modelling results (grey boxplots, left-hand side) and the field-based mapping results of the toposequence study (white boxplots right-hand side). Around 35% of the basin surface, which has been qualitatively classified as being decoupled, is related to *IC* values higher than the basin's median *IC*.

Site: Kangaroo River State forest, northern NSW, Australia
21.7 km2.

DTM:10x10 m

aims: to apply a **distributed hillslope erosion-SDR approach** in raster data layers **to assess the impacts of vegetation removal** (single tree selection logging) on the **spatial distribution of estimated sediment yields**

HYDROLOGICAL PROCESSES
Hydrol. Process. **28**, 2671–2684 (2014)
Published online 24 April 2013 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.9805

Distributed empirical algorithms to estimate catchment scale sediment connectivity and yield in a subtropical region

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[2] *Forestry Corporation of NSW, PO Box 4019, Coffs Harbour Jetty, NSW, 2450, Australia*
[3] *Australian Centre for Agriculture and Law, University of New England, NSW, 2351, Australia*

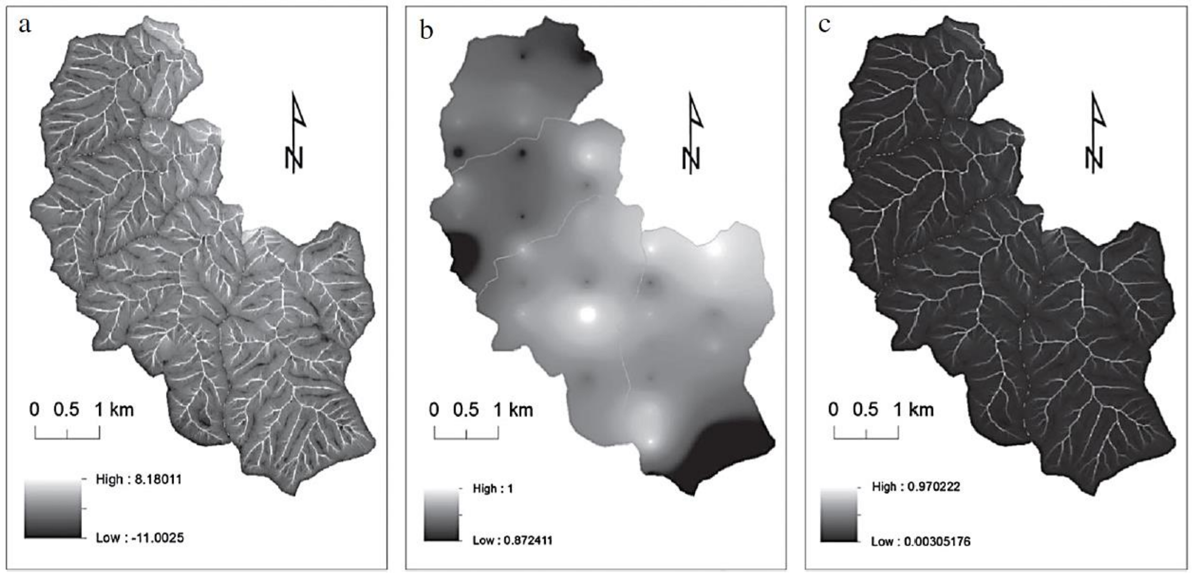

Figure 2. The predicted maps of (a) index of connectivity IC, (b) the maximum theoretical SDR coefficient SDR_{max} and (c) SDR variability within the study area. The IC and SDR maps in this figure were selected for spatial variability in 2007. Catchment boundaries are depicted in Figure 1

$$SDR = \frac{SDR_{Max}}{1 + \exp\left(\frac{Ic_0 - Ic}{k}\right)}$$

Use of SDR by IC, and optimized IC_0 and k, by Vigiak et al. 2012
IC_0=0.5 and k=2.0

ARTICLE IN PRESS
GEOMOR-04764; No of Pages 14
Geomorphology xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Geomorphology
journal homepage: www.elsevier.com/locate/geomorph

Connectivity structure of the Kosi megafan and role of rail-road transport network

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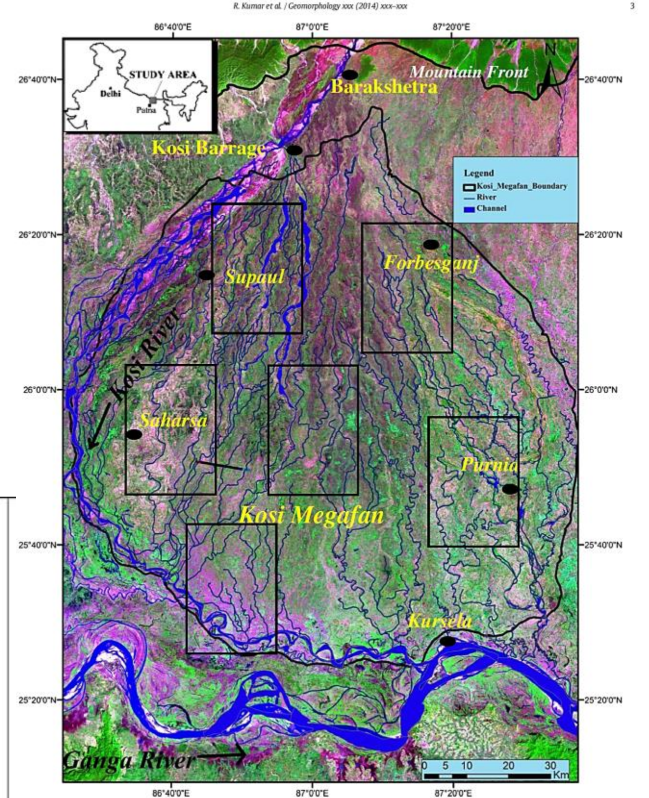
[b] Discipline of Earth Sciences, Indian Institute of Technology Gandhinagar, Ahmedabad, Gujarat 382424, India
[c] UNDP, Disaster Management Unit, 55 Lodi Estate, New Delhi 110003, India
[d] Department of Earth Sciences, Indian Institute of Technology Kanpur, Kanpur 208 01

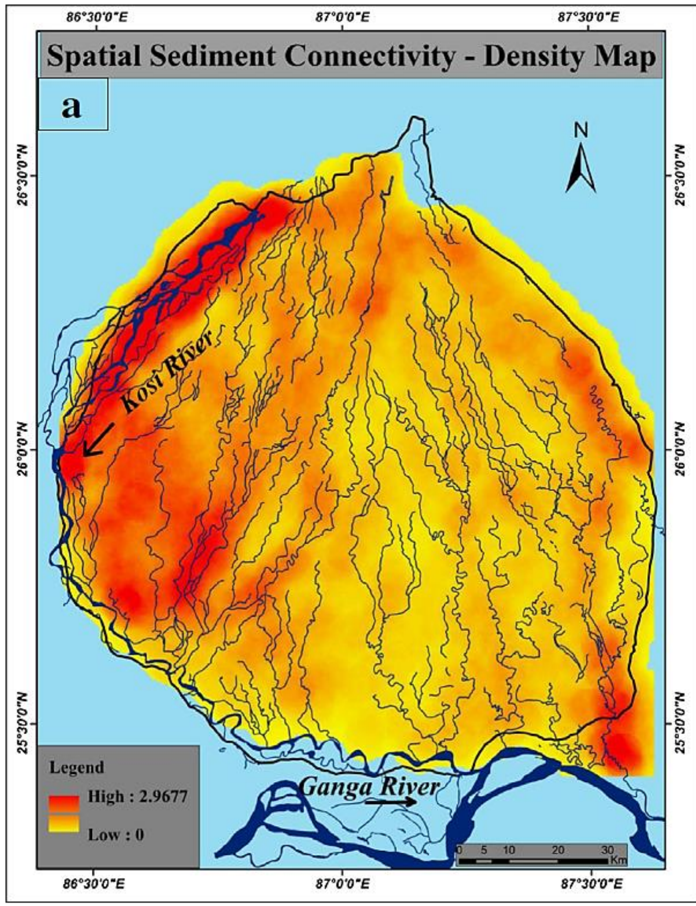


. 1. Study area showing the Kosi River in the North Bihar, India. The megafan surface has numerous small paleochannels most of which are activated during the monsoon period. The
si River debouches into the plains at Barakshetra and joins the Ganga River system at Kursela. Windows for field-based classification of the intersection points have been marked.

Site: Kosi megafan, India Hymalayan region. approx. 7000 km2

DTM: SRTM DEM data of February 2002. http://www.cgiar-csi.org (*resolution not provided*)

Aims: The paper presents the **two-dimensional dis(connectivity) structure** of the Kosi megafan, India, including the lateral and longitudinal dimensions (continued …)

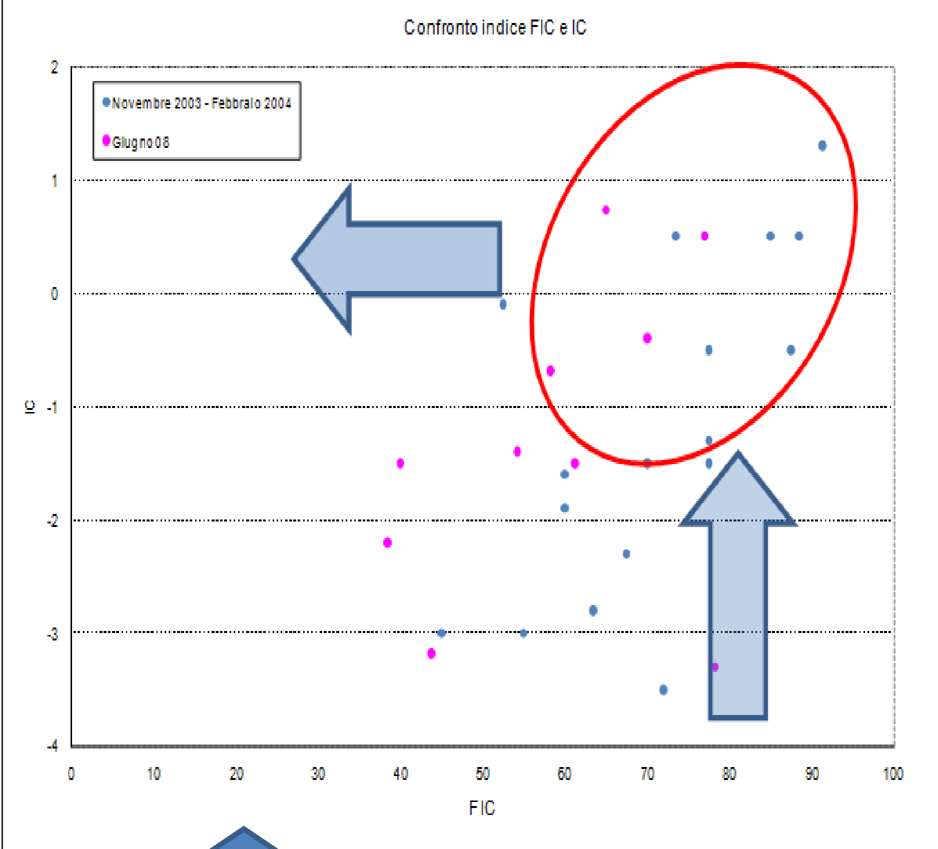


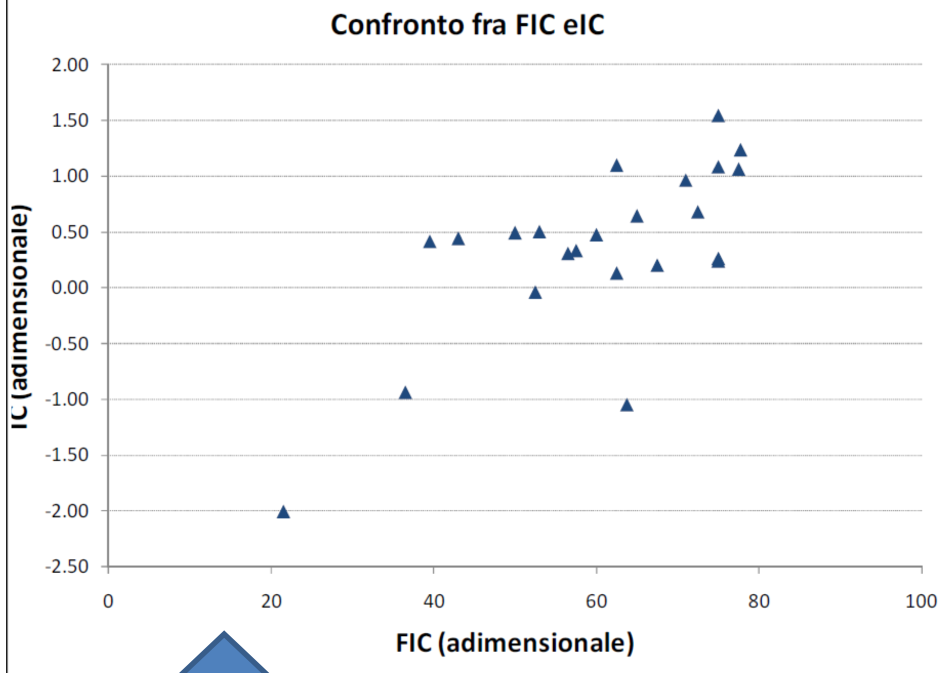
(continued …) of geomorphic connectivity. The quantitatively defined and the **'anthropogenic' impacts on the connectivity structure due to railroad transport network** were also estimated.

IC computations and variants

Some main tested variants:

- Areas from 0.04 km2 to 7000km2
- DEM resolution: from 1x1 m to 50X50m
- Use (or not) of river mask as local sink
- Variable Minimum contributing area to generate permanent drainage lines (river mask) from 0.5 ha to 20 ha, or more…
- Use (or not) of roads and urban areas as SINK (like river mask do)
- W factor (classical is W=C(USLE TYPE)) or W=RI(Cavalli 2013) or W=ER (Sougnez et al. 2011)
- Different countries, environments, landscapes , climates and anthropogenic impacts
- At moment has been published 11 applications

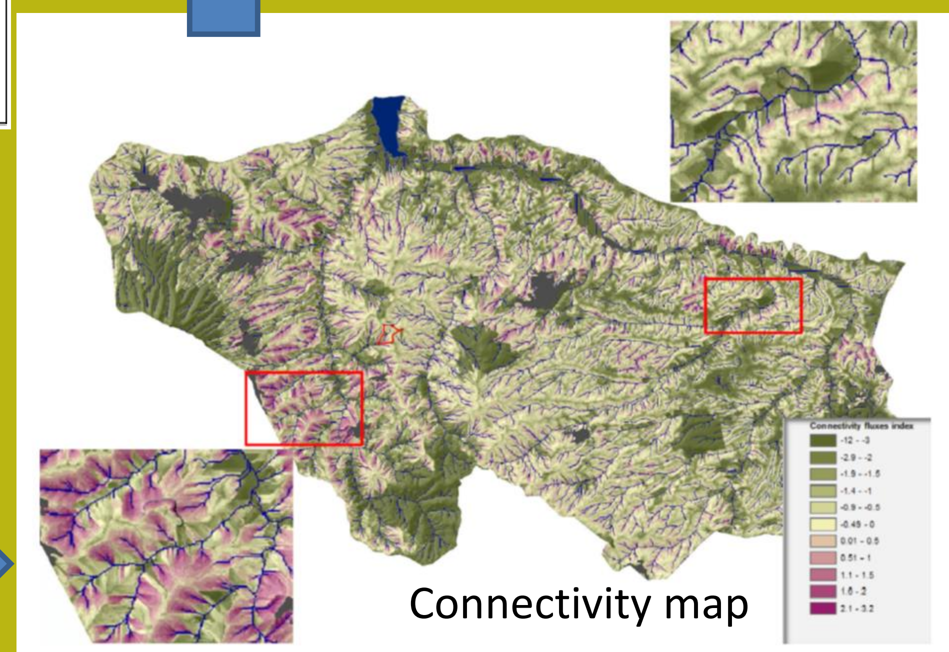




Extended dataset IC versus FIC
(Bilancino watershed; Cassi, 2010)

In both cases
we observe high
connectivity for
IC>0.0

Rendina watershed,
South Italy (240 km2)
DTM 20x20
Project DESIRE



Borselli and al. (2014)- *Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306*

W factor: an evolution for IC2 model

The second version of IC accounts of : *hydrologic soil properties , magnitude of rainfall event, surface roughness*

$$C_r = 1 - \frac{I_{dt} + S}{P_{dt}}$$

Step 1: computation event runoff coefficent (C_r) (adimensional) , by total infiltration volume (I_{dt}), surface water storage (S) and rainfall volumes (P_{dt}) (all in mm) Infiltration can be calculated locally by model e.g. model di Morel-Seytuox (1978) for each land units,
S was computed with relationship by Borselli and Torri (2010, Journal of Hydrology), as a function of surface roughness and local slope gradient

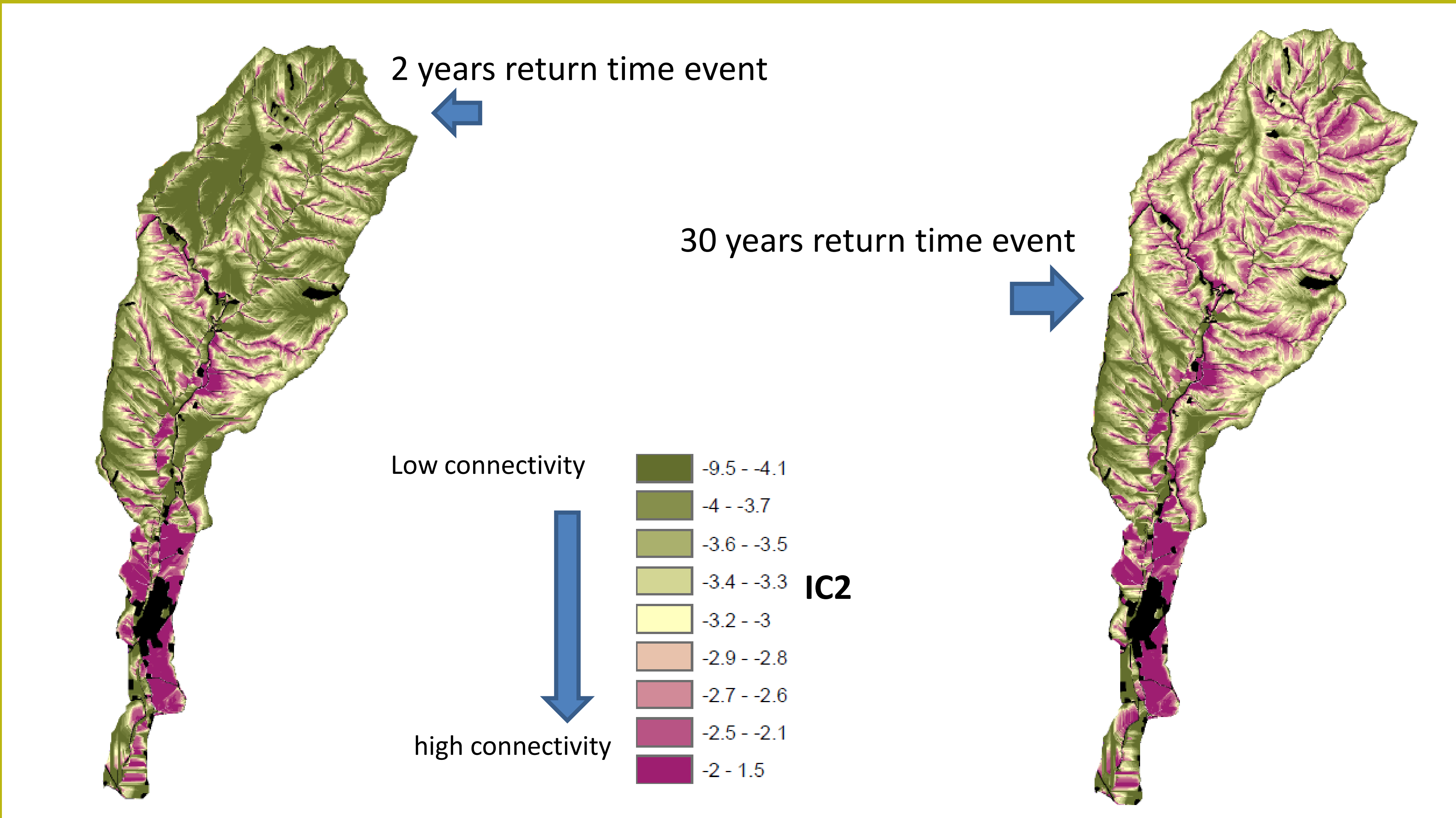
$$\frac{1}{f}$$

Step 2 Hydraulic roughness due land use and soil surface characteristics (including vegetation) by Darcy Weisbach (f) friction factor (adimensional)

$$W = C_r * \frac{1}{f}$$

Step 3: Final W calculation
(please note W is still adimensional)

Cassi, 2010 (PhD thesis)



Average Intensity 15.7 mm/h
Duration 2.5 h
Amount 39.2 mm

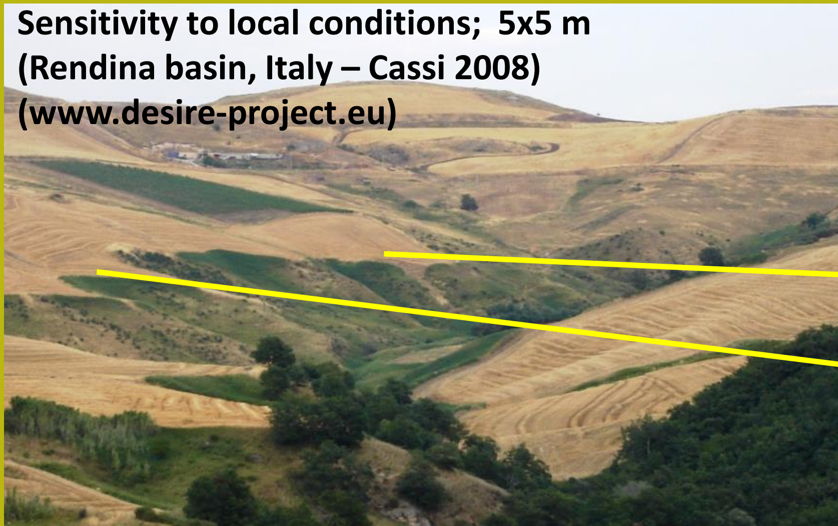
First application of IC2
Portion of Bilancino watershed

Average Intensity 37.9 mm/h
Duration 1 h
Amount 37.9 mm

Cassi, 2010 (PhD thesis)

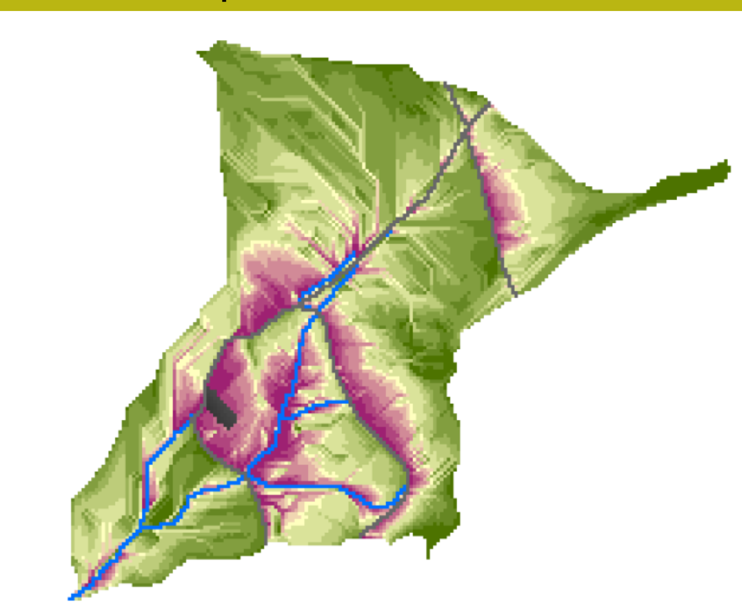
Scenario analysis of connenctivity evolution due to land management practice

Prevailing land use of the watershed is wheat crop. The connectivity index is evaluated before and after harvesting (June) when the borders of the fields are ploughed for 5 meters wide.



Ploughed field border with erosion evidences

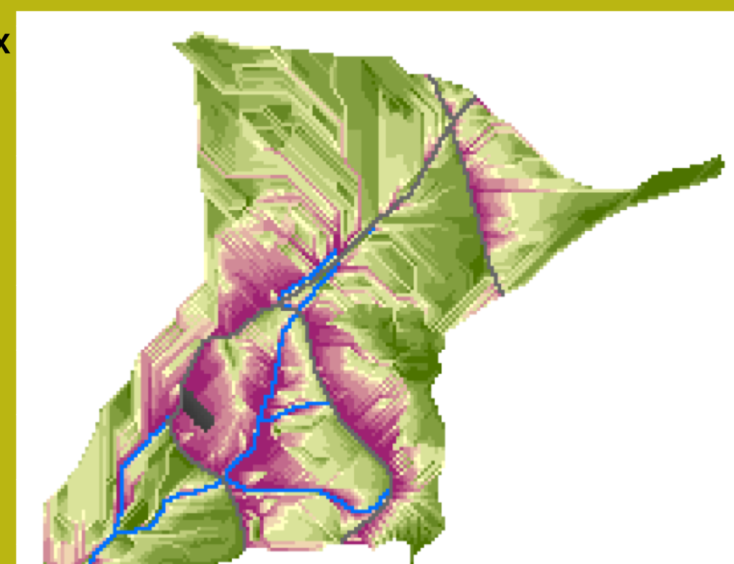
Without strip of bared soil on field border



Connectivity fluxes index

- -4.1 - -2
- -1.9 - -1.5
- -1.4 - -1
- -0.9 - -0.8
- -0.79 - -0.5
- -0.49 - -0.1
- -0.09 - 0
- 0.01 - 0.1
- 0.11 - 0.25
- 0.26 - 0.5
- 0.51 - 0.66
- 0.67 - 1
- 1.1 - 1.5

With strip of bared soil on field border



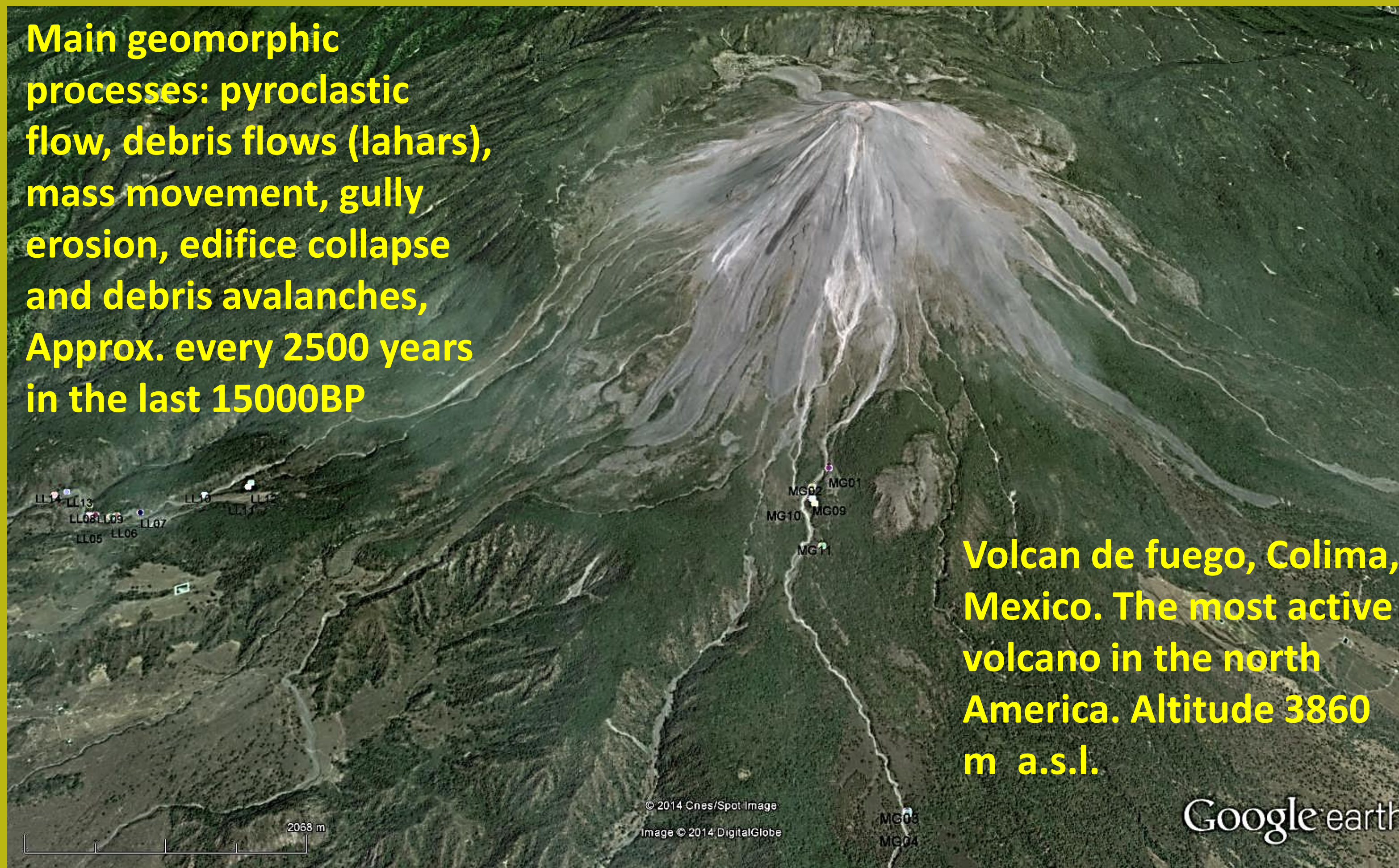
Cassi, 2010 (PhD thesis)

IC

Now …..Connectivity in Mexico…

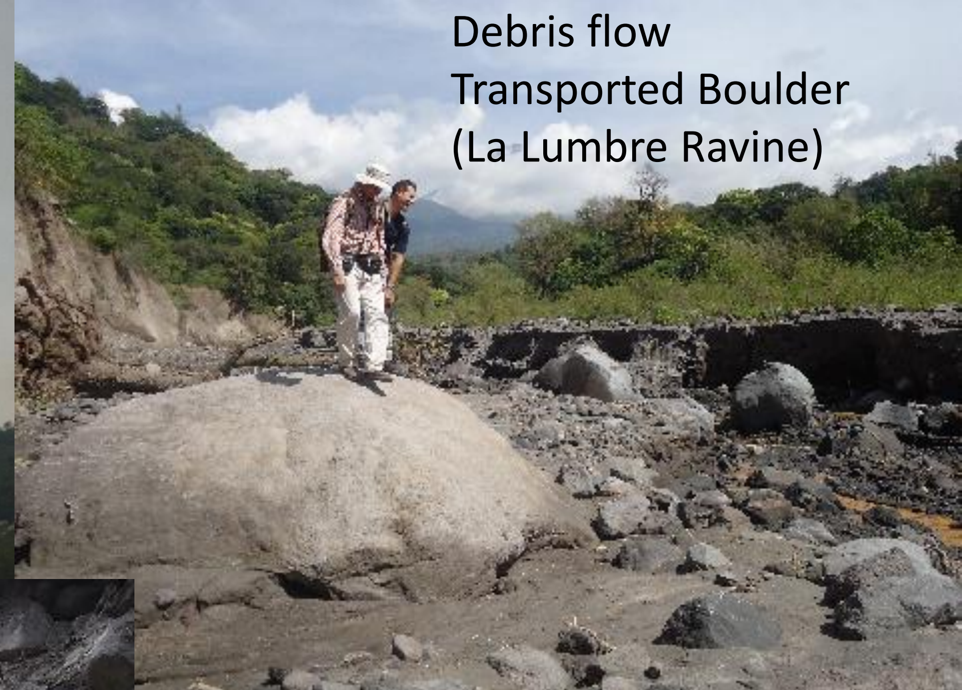
Project MOPRI (2013-2015)

"Modelado de procesos hidrológico, dinámica de hidrofobicidad e infiltración, para su aplicación en la evaluaciones del riesgo debido a inundaciones y lahares: aplicación en la ciudad de San Luis Potosì y en el Volcán De Colima" (2013-2015)(CONACYT-Ciencia Basica-2012-01 -184060)



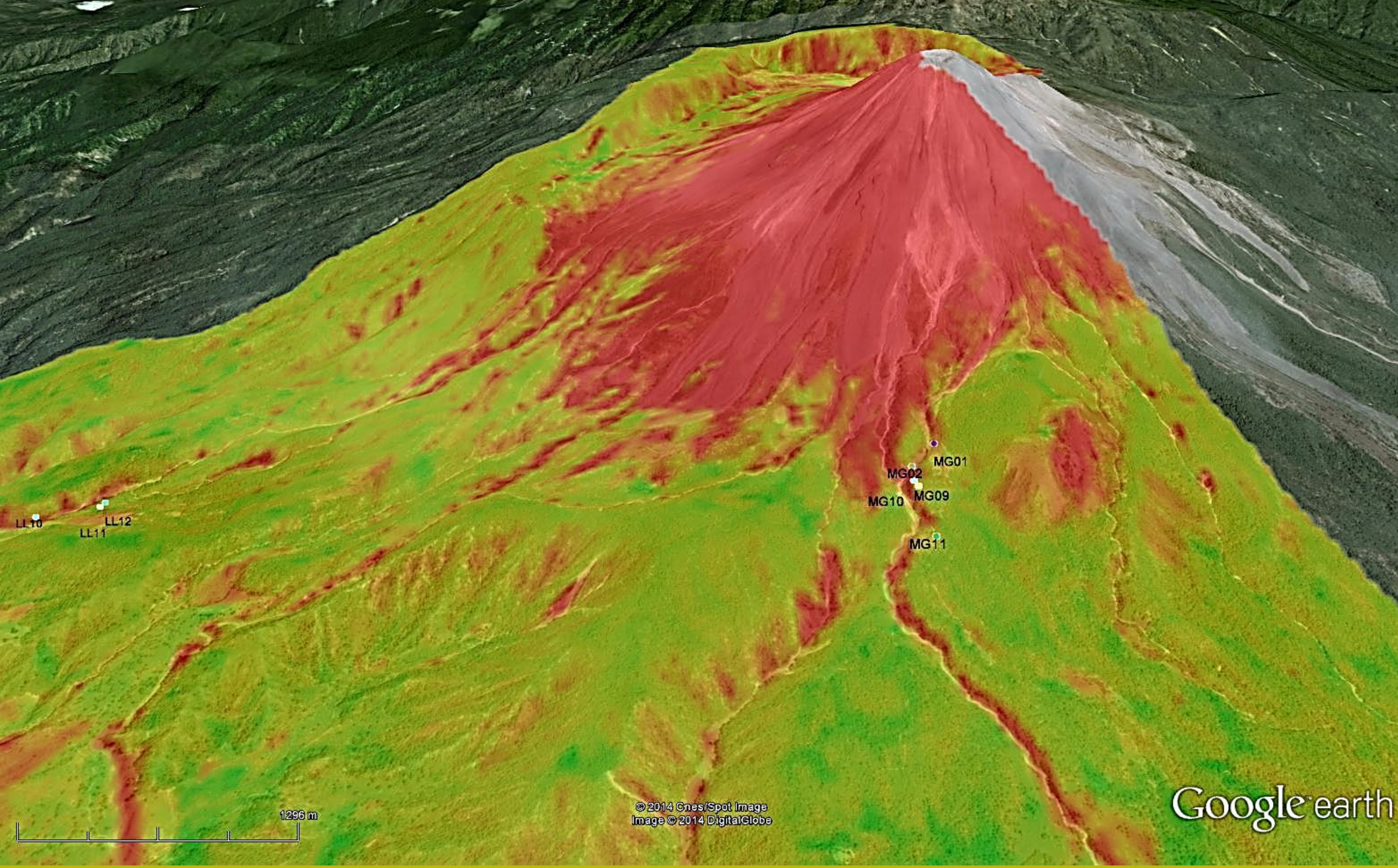
Borselli and al. (2014)- ***Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306***


Colima,
Volcan de
Fuego


Debris flow
Transported Boulder
(La Lumbre Ravine)


Debris flow
Transported Boulders
(Montegrande ravine)

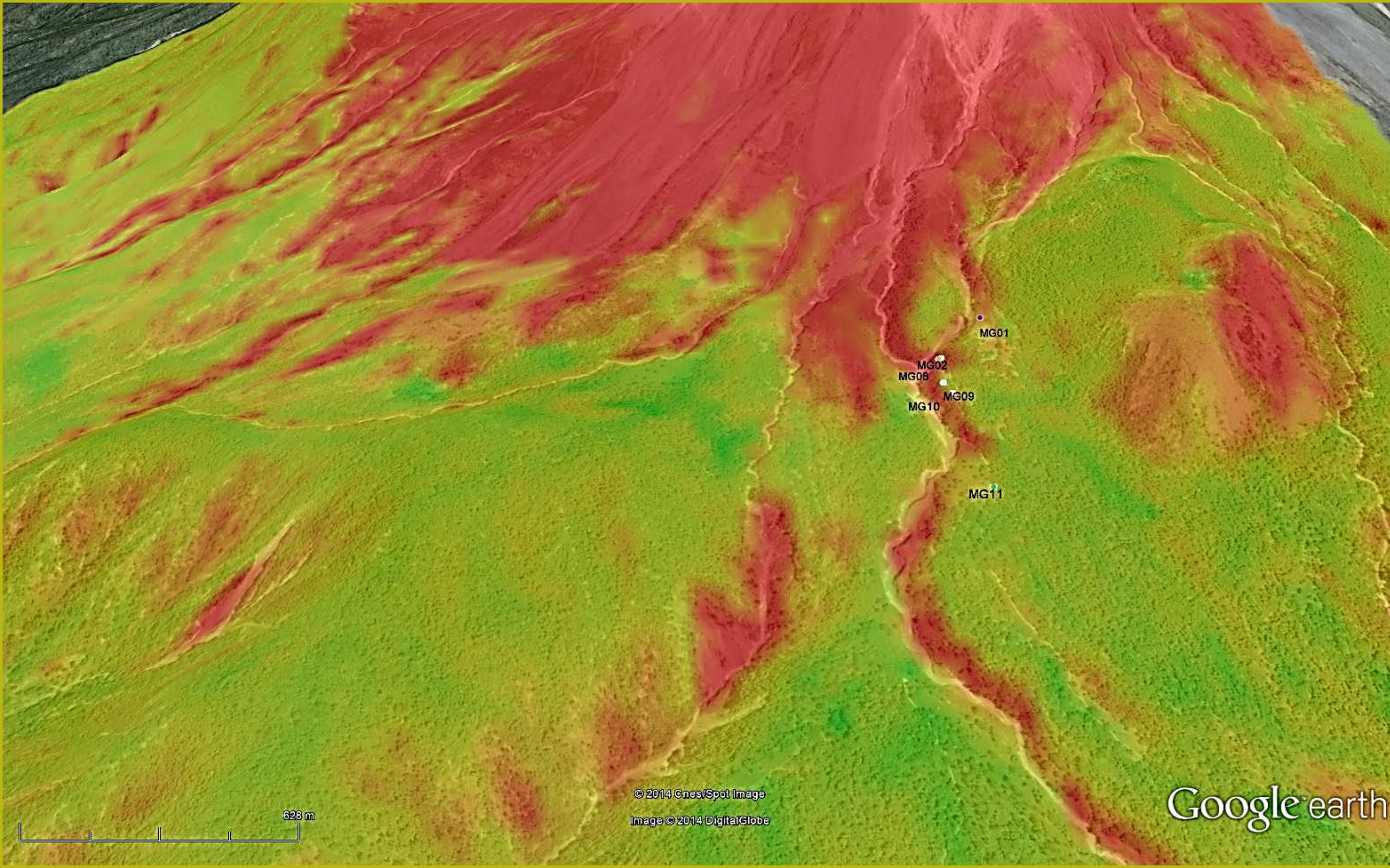

Infiltration Test
(Montegrande Ravine)



Connectivity map (IC) DEM 5x5m (transparent overlay on Google Earth image 2014)

Portion of Colima volcano South flank with several barrancas and main source areas of lahars (above 2500 m a.s.l.); local remobilization, mass movements, and instability of older deposits are in evidence.

Borselli and al. (2014)- ***Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306***



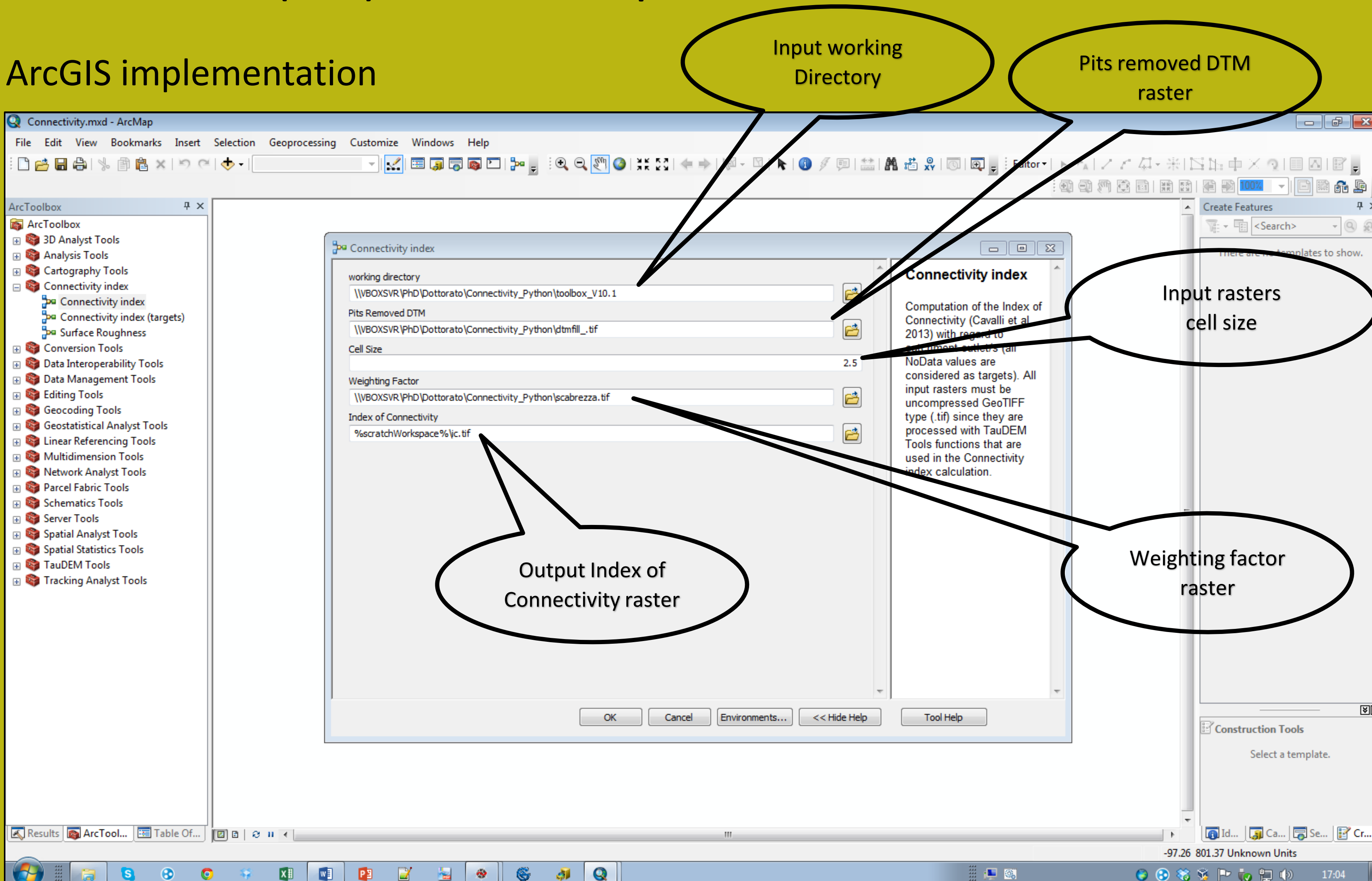
Connectivity may help understanding the dynamic of lateral hydrologic contributions that trigger or remobilize the lahars at the beginning of the rain season, when the soil is hydrophobic (Capra , Borselli et al. 2010).

Borselli and al. (2014)- *Using connectivity to assess soil erosion and mass movement processes in the landscape: applications and discussion of a new paradigm –key note lecture – CONNECTEUR –COST Action ES1306*

Connectivity: toolbox, software and extensions

Cavalli's TOOLBOX (2014) for IC index computation

ArcGIS implementation



- Running under ArcGIS version 10.1 (with SP1!) and 10.2
- It requires the installation of TauDEM 5.1

http://hydrology.usu.edu/taudem/taudem5/downloads.html

Marco Cavalli 2014
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Stand-alone application (SedInConnect 1.0)

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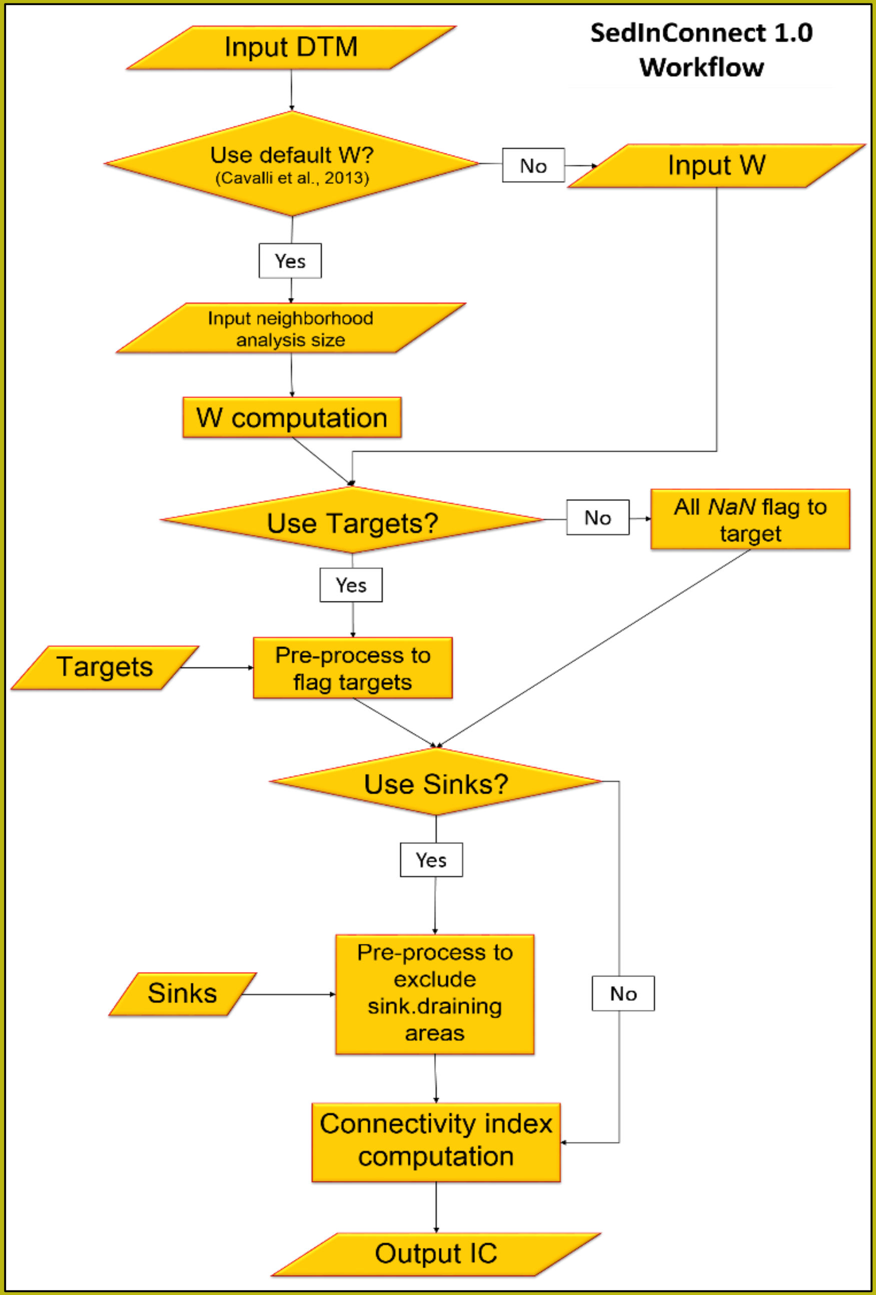
- **Free application and open source code** -> thus encouraging its usage and receiving improvements from the scientific community.
- **Development based on the Python Experience** -> exploiting available libraries for efficient analysis of geographic datasets and guaranteeing cross-platform portability (Windows/Linux/MacOS), thus enhancing the potential users' community.
- **Stand-alone application** -> independent from any GIS software and more accessible to management authorities less involved in research issues but very close to management issues and priorities.



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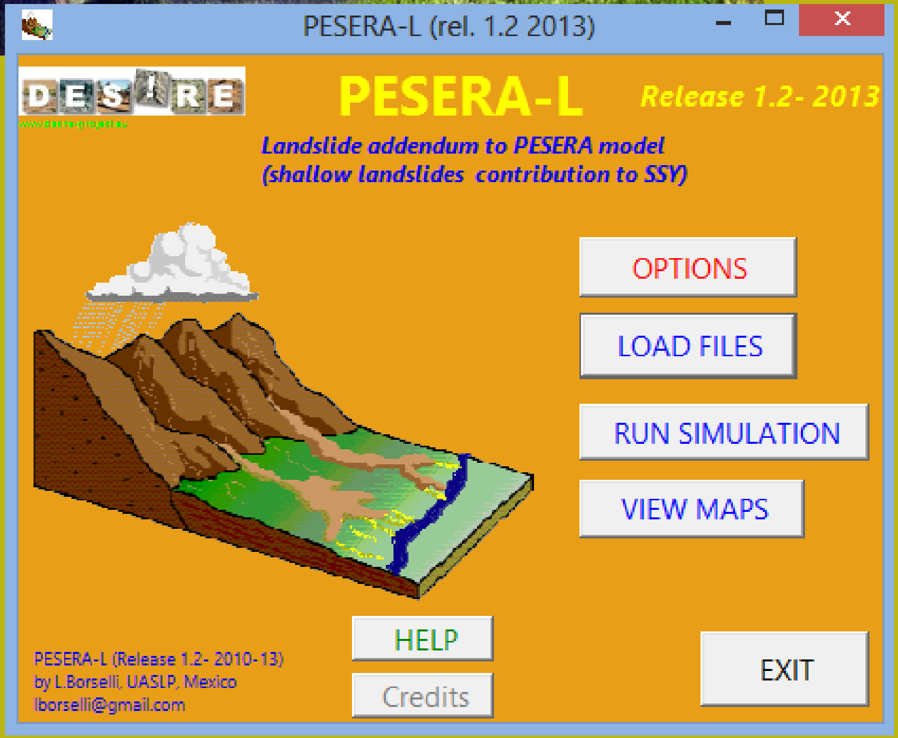
DES!RE
A global initiative to combat desertification

Consiglio Nazionale delle Ricerche

PESERA-L, the shallow landslides contribution to specific sediment yield (SSY), as extensions of the PESERA soil erosion model

See www.Lorenzo-borselli.eu/peseral
For software download and documentation



The Sediment delivery ratio for landslides SDRL
And how to obtain SSY (under Pesera-L)

$$V = 10^6 A\ D\ \Psi\ SDR_L$$

$$SSY = \frac{V\gamma_s}{100 A \Delta_t} \qquad [Mg\ ha^{-1} yr^{-1}]$$

Where

***V*= net eroded Volume (m3)**

***A*= area of HLU (km2)**

***D*= average depth of landslides (m)**

Ψ= fraction of area potentially unstable (-)

SDR_L= sediment delivery ratio from landslides (-)

γ_s= soil unit weight (Mg/m3)

Δ_t = annual frequency (yr)

SSY= specific sediment yield from hillslope [Mg/ha/yr]

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Exponential distribution model for sediment delivery

Derived by *Miller and Burnett (2008*) and modified by implementation of a portion of IC

Where:

L_R = landslide average runout (m)

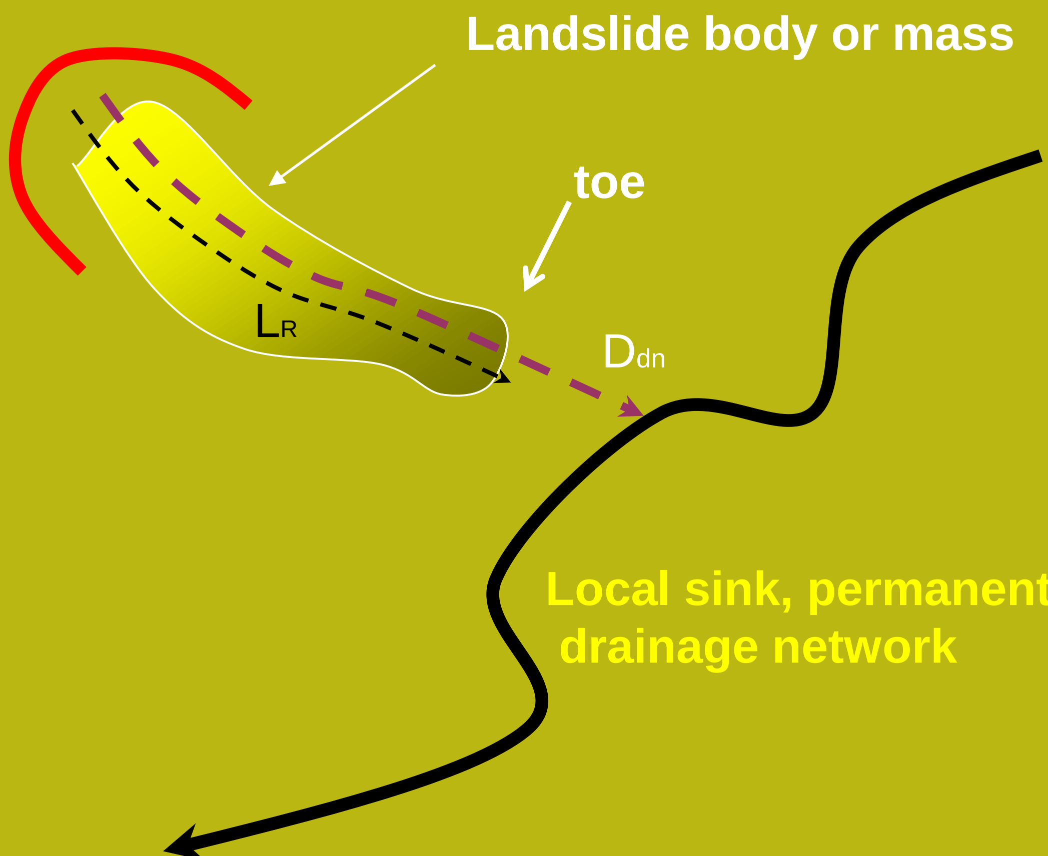
D_{dn}= Downslope routing weigthed distance (m)

(downslope component IC model Borselli et al. 2008)

$$SDR_L = e^{-\lambda D_{dn}}$$

$$\lambda = \frac{1}{\overline{L_R}}$$

$$SDR_L = e^{-\frac{D_{dn}}{\overline{L_R}}}$$



Mobility parameter that depends on average observed runout L_R and local D_{dn}

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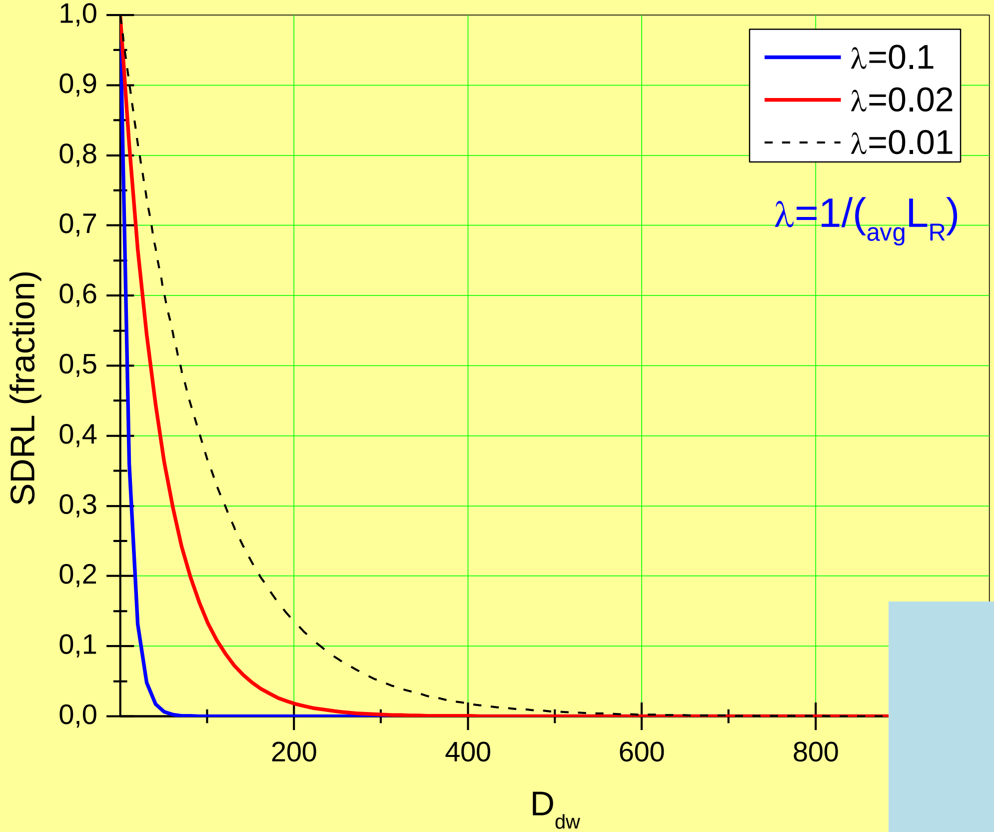
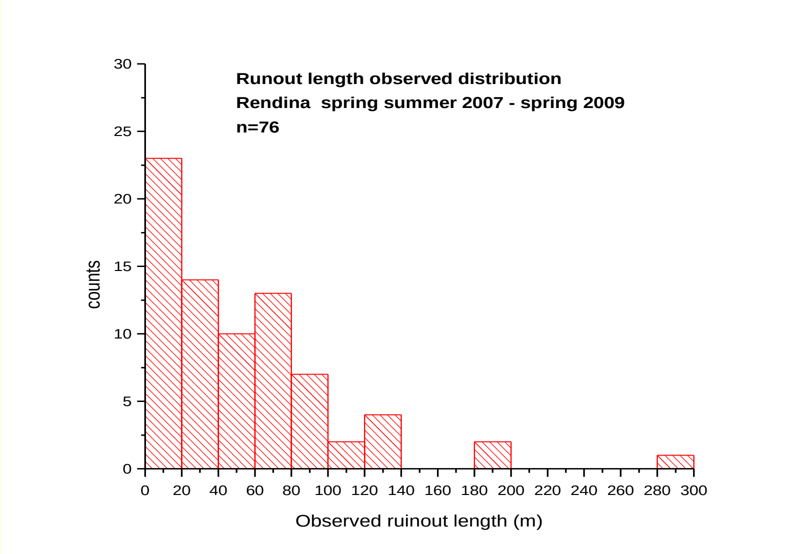
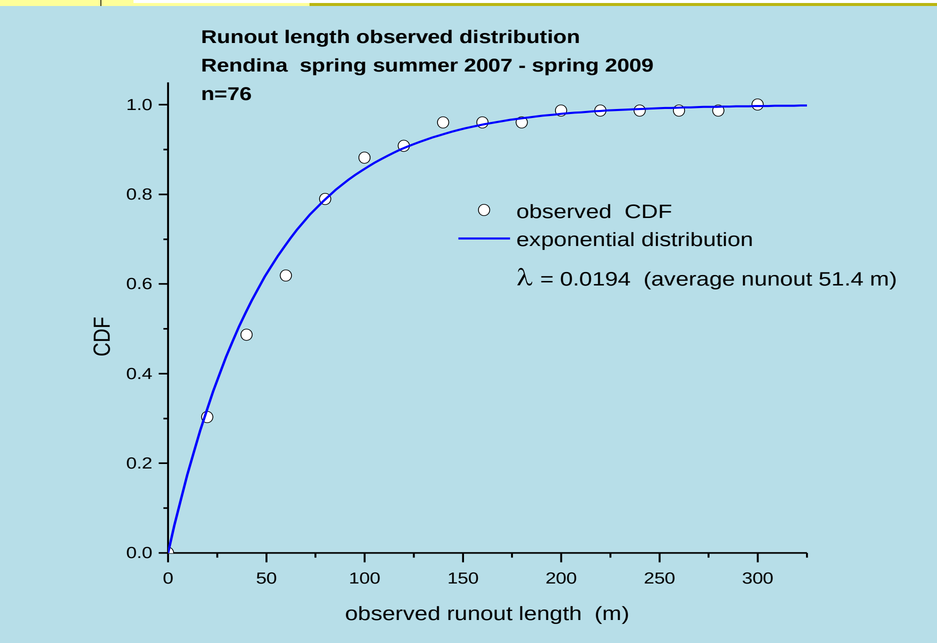
probabilistic model of landslides and debris flow delivery to stream channels

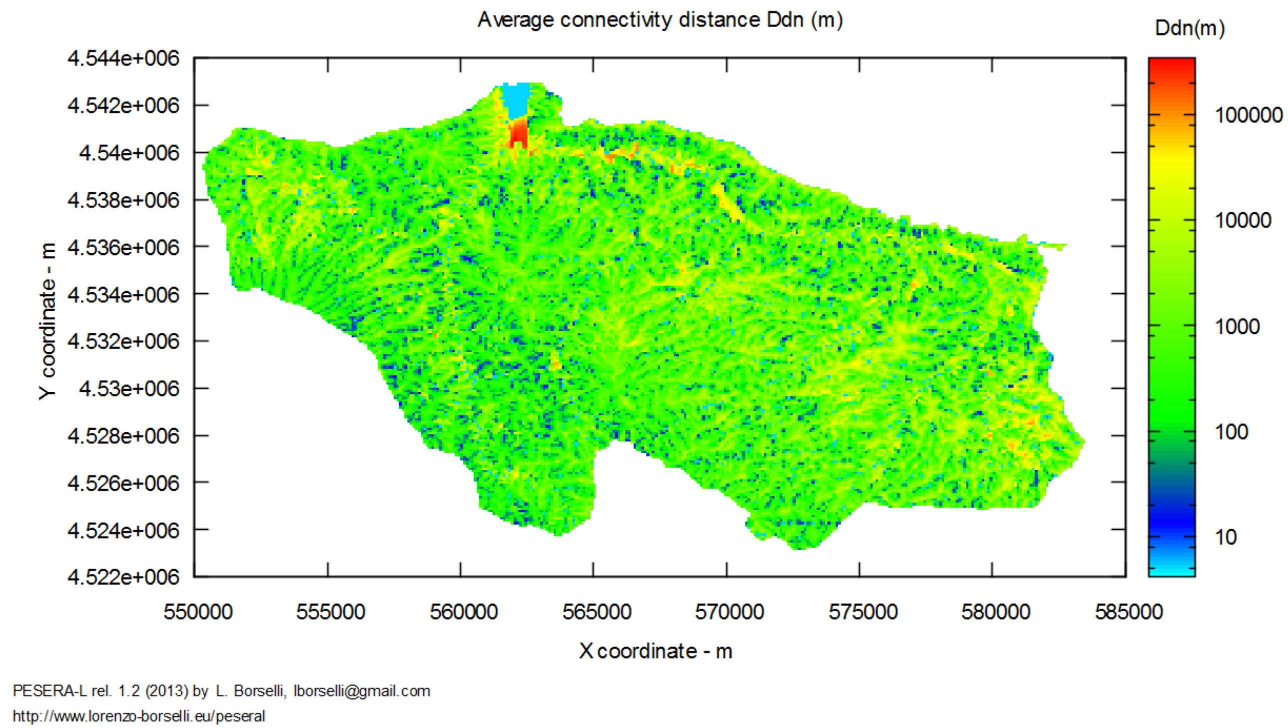
(Miller & Burnett, 2008)







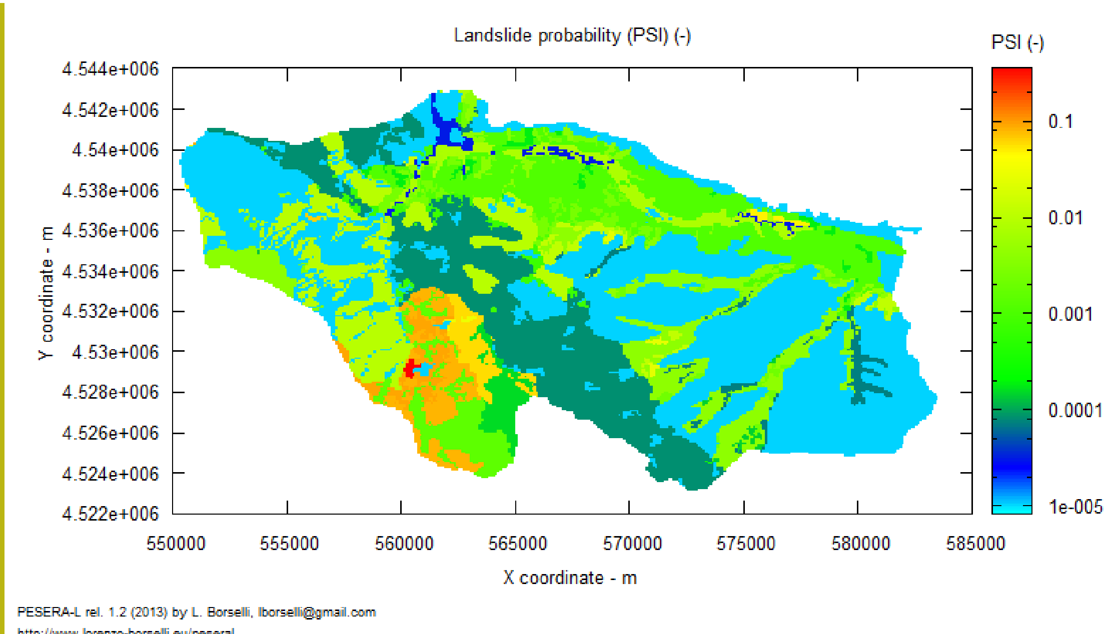
Exponential probability distribution function
depends from the average runout length Lr (measured)
and the local site D_{dn} distance to a sink



Application to Rendina watershed
Project DESIRE

Connectivity average downlospe distance

Landslide probability



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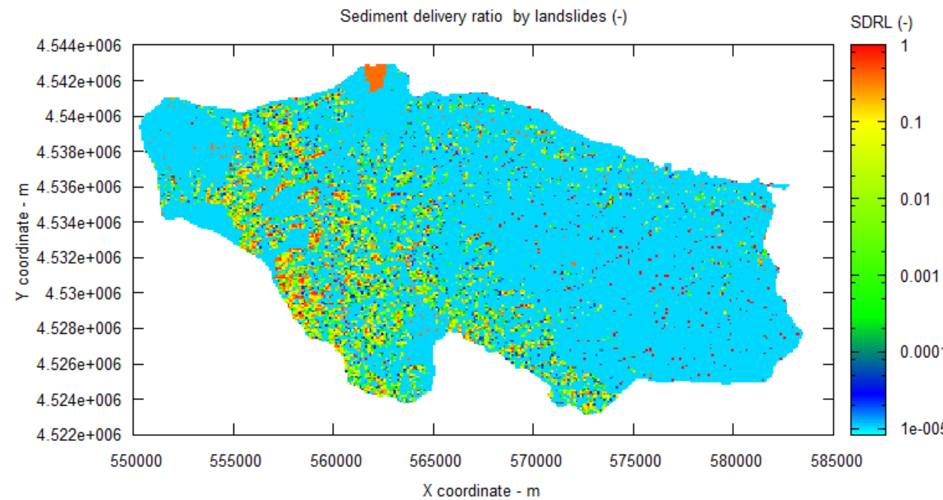
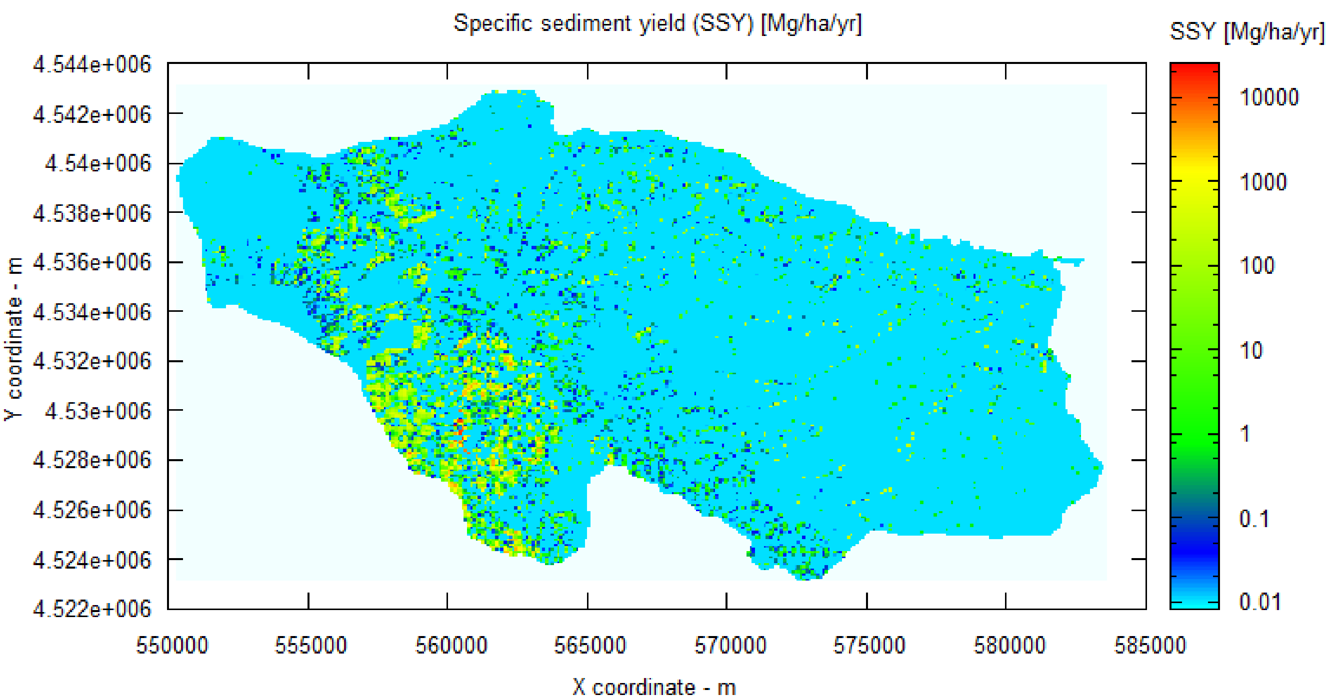
SDRL
Sediment delivery by
Shallow landslides



PESERA-L rel. 1.2 (2013) by L. Borselli, lborselli@gmail.com
http://www.lorenzo-borselli.eu/peseral



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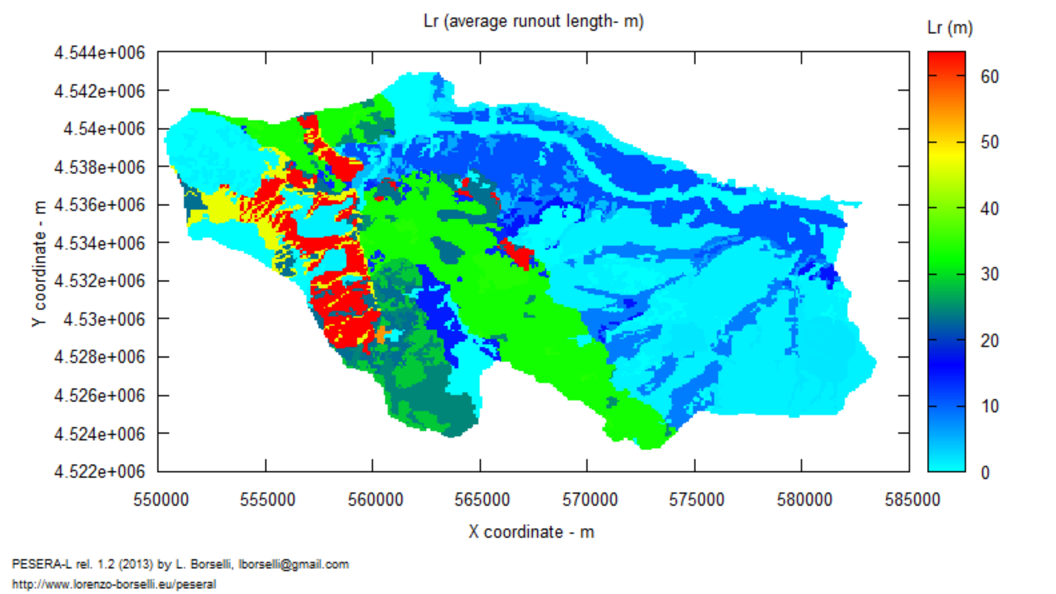
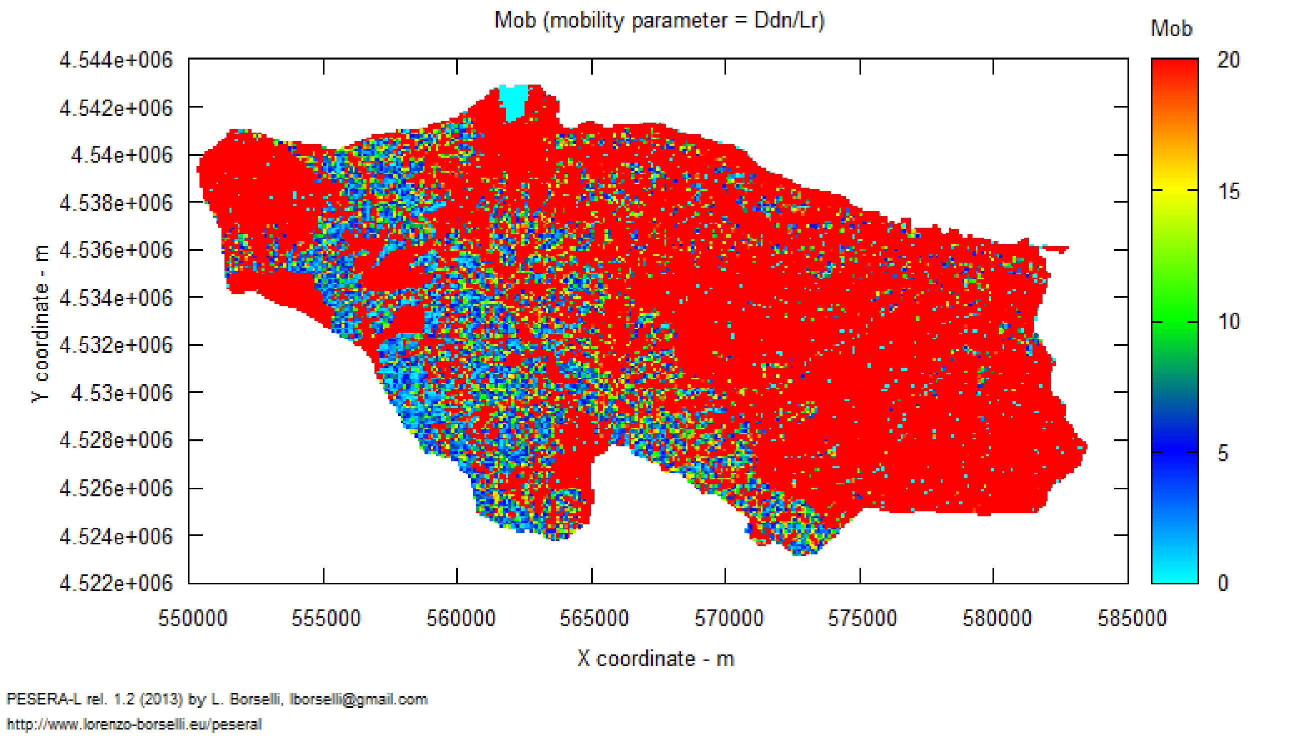
SSY by landlsides



Average run-out length of shallow landslides for each LUS (land unit system) obtained from field survey and multi-temporal aerial photos

Mobily parameter of landslides

$$\frac{\overline{D}_{dn}}{\overline{L}_R}$$



Mass movement type

Flow slide mudflow

Shallow Translational

Shallow Rotational

creeping

$$\frac{\overline{D}_{dn}}{\overline{L}_R}$$

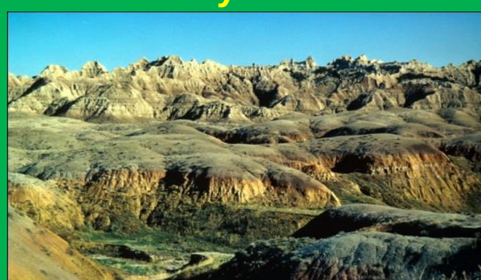
0.1 — **1.0** — **2.0** — **5** — **10**

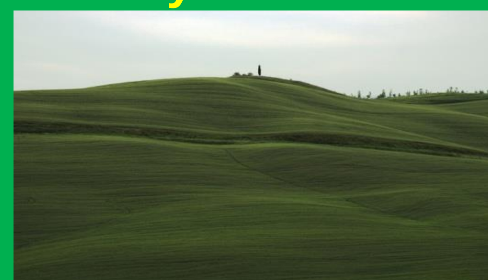
Land unit landforms

Badlands
Clay shale
Deposits
High drainage density

rolling topography
Medium steepness and medium drainage density

Rolling to flat topography





Landslide mobility parameter

And the possible dependence from processes and landforms

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Highlights and speculations - 1

The Connectivity index IC and FCA **provide an estimate of the potential connection index between the sediment eroded from hillslopes and the stream system or other local sinks**;

FCA can put in relation the IC index and SDR. SDR can be used then to correct the USLE-TYPE models (*transport capacity unlimited*) generally used for large catchments modelling and obtain a Sediment yield assessment .

The use of SDRmax limited values (Borselli et al. 2009 and Vigiak el a. 2012) can correct for inconsistencies indicated by some researchers (Kinnell 2004, Parson et al. 2006) in SDR assessment.

Highlights and speculations - 2

The IC model have a large set of potential applications such as hot spot identification of primary sediment sources to permanent drainage lines and **verification of impacts of eco-compatible mitigation measures to reduce or increase connectivity**. (without more complex Soil erosion models) (e.g. indications of Boardman, 2006)

IC can be easily transformed in a more physical based index (e.g. variants by Cavalli 2013 and Cassi 2010)

Potential application of IC to define **SDRL** can help to assessment of Sediment yield contribution due to Landslides and debris flow (PESERA-L model).

This presentation can be downloaded at

www.lorenzo-borselli.eu