State of the Art and Future Development of Erosion Modelling in Italy and Europe

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Synopsis

Part I - Importance of soil erosion models.. Why We need them

Part II - Soil erosion process and paradigms, in Italy and Europe

Part III – Current soil erosion models

Part IV – Possible Future Research Trends

Why We need of soil erosion models and…. modelling efforts?

Landscape evolution
And scenario analysis

Basic soil erosion processes

Intrinsic soil erodibility
And soil degradation processes

Evaluate the soil conservation techniques (existing ones and new design)

Impact on crop and food production

Impact , rate and contribution of high dynamics processes in the land degradation

Inland water quality

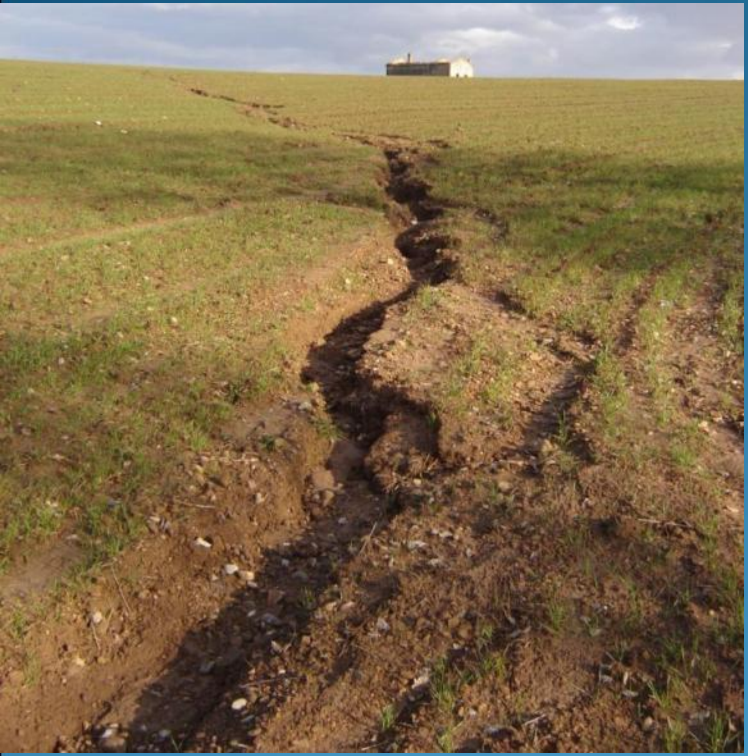
Part II - Soil erosion process and paradigms, in Italy and Europe

Soil wetting, slaking, sealing

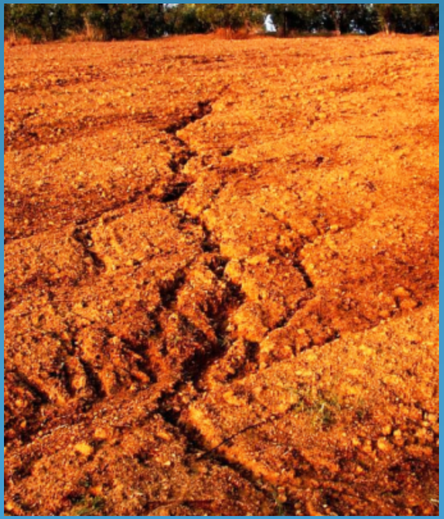
Sheet erosion

Runoff excess
can produce
Diffuse erosion
(and deposition)

Rill erosion

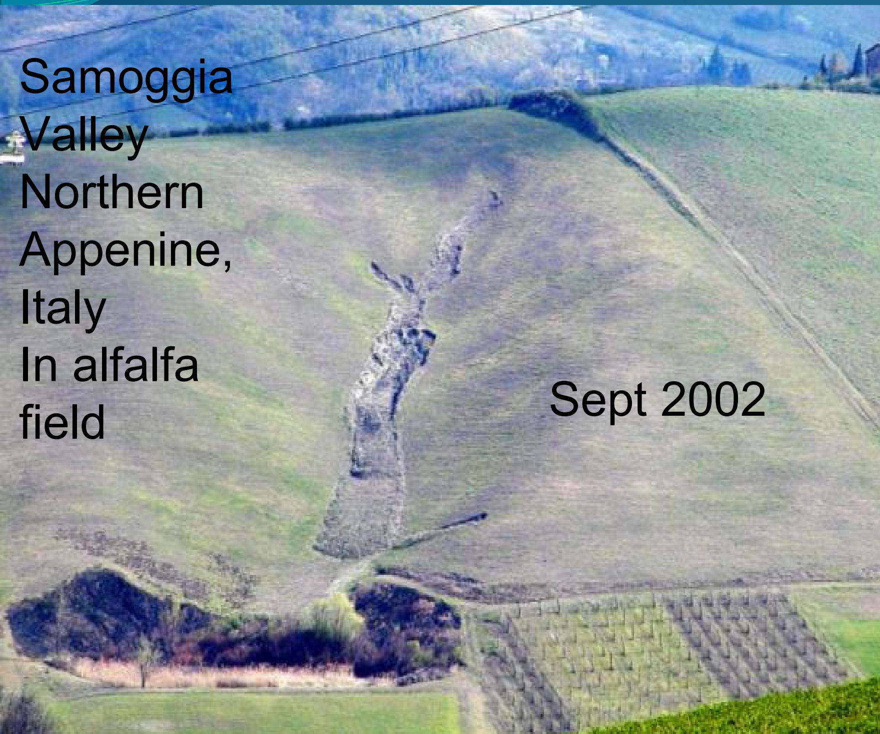


Concentrate water flow
Producing small ephemeral
Channels (rills)



Gully erosion

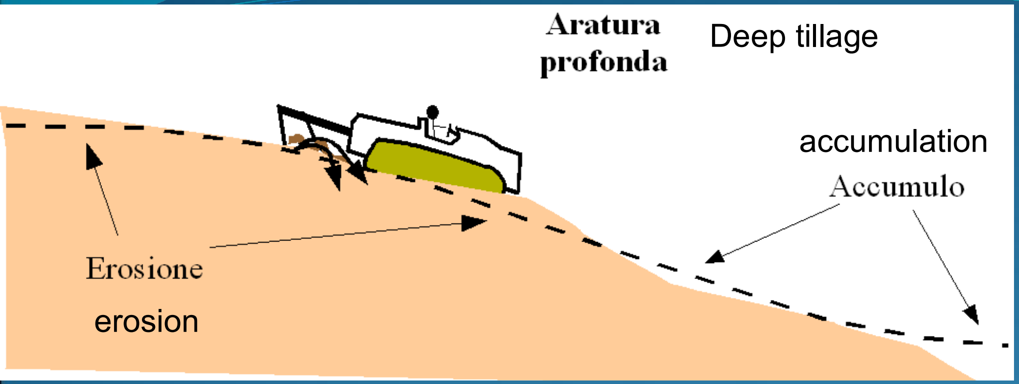
Shallow landslides

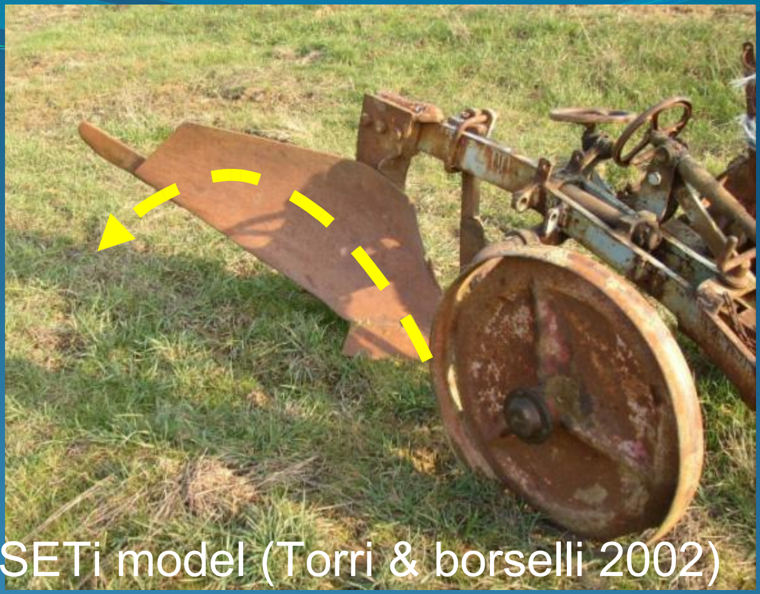


Shallow mass movements are important in water erosion because tay contribute to a direct soil loss and loss of crop production, and damages at the infrastructures

Mass movements may trigger gullies, rilling and piping.

Soil erosion by tillage

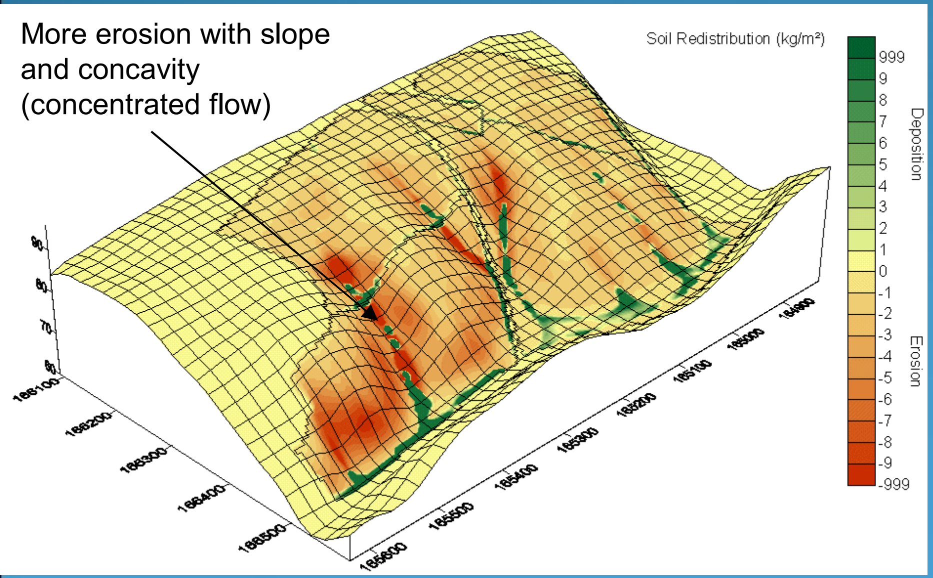




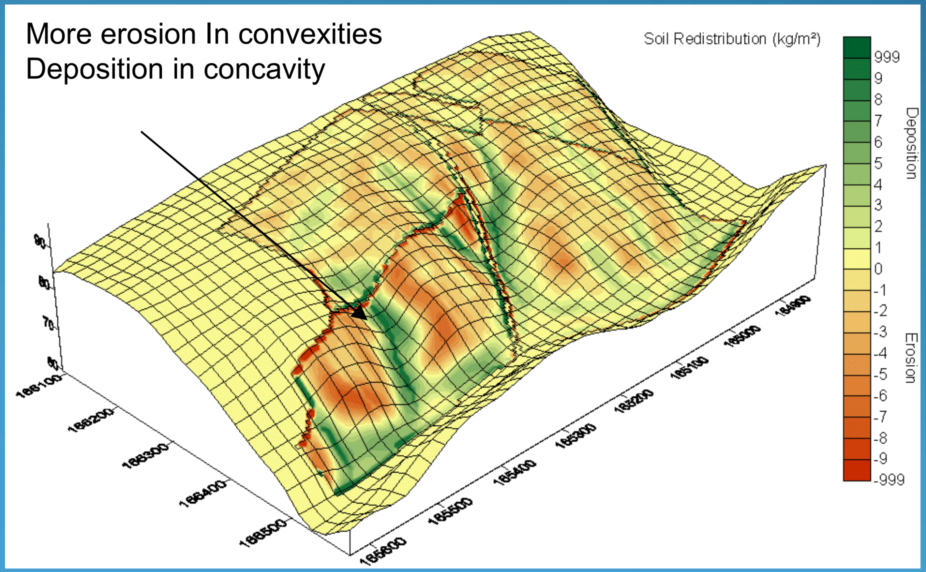
SETi model (Torri & borselli 2002)

Source : http://www.kuleuven.be/geography/frg/modelling/erosion/watemsedemhome/index.htm

Water erosion

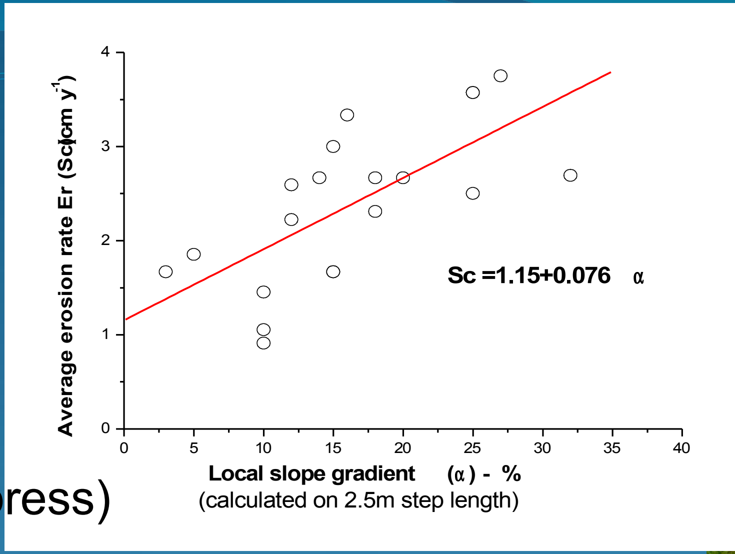


Tillage erosion

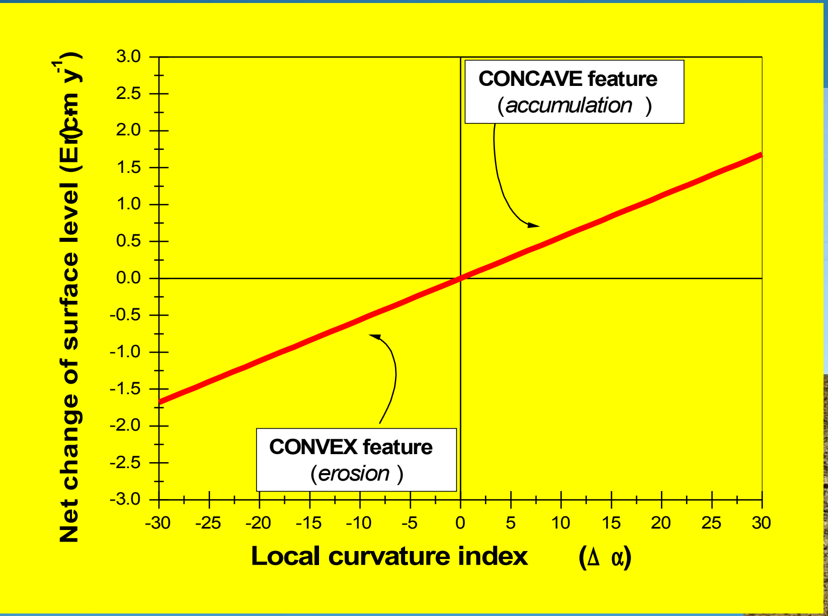


Soil erosion by tillage

Field evidences



De alba, borselii (in press)

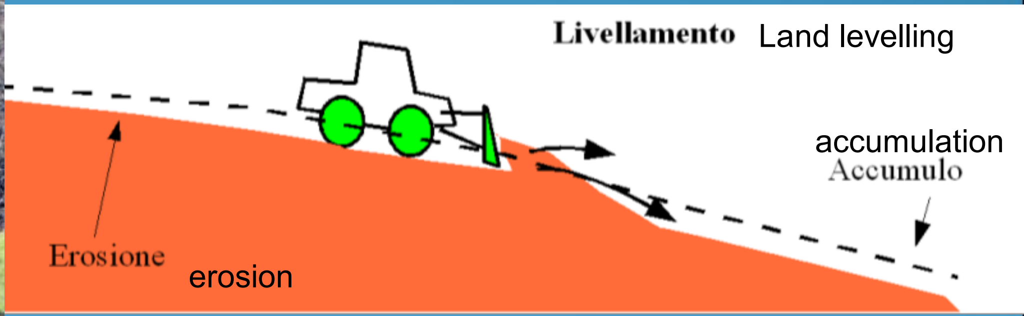


De Alba et al. 2006

Borselli et al. 2000

Foto Bazzoffi 2007

Land levelling
Operations for planting new vineyards
(central and south italy)



Land levelling
Mechanical erosion evidences – new vineyard on sandy soil on Pliocen lacustrine (chianti region, Tuscany, Italy)

Dispersion, piping
Tunnel erosion

Badland area
in val D'orcia, Tuscany, Italy

Soil with High ESP , CEC, Ph
May have dispersive
characteristics and it usually enhance
soil erodibility

Inland Water quality and siltation

Foto Bazzoffi 2007

OFF-SITE Impacts

Foto Bazzoffi 2007

Source (Franke et al. 2008)

Increased sediment load in streams.
Accelerated sedimentation in reservoirs
Ecological and landscape impacts

Desertification process and Desertification risk

Average rainfall
1100-600
mm/yr

Badland and arable land

North and central Italy

Levelled previous badland areas for winter wheat crops

Arcidiaconata (Basilicata, Italy) sept. 2007
rage rainfall 550 mm/yr

Desertification process and
Desertification risk

Tillage erosion

Water erosion

landslides

Land levelling

Burning residue

Study site
DESIRE
EU project
(2007-2012)

Rio Carcabo (Murcia , Spain) 2006
Average Rainfall 250 mm/yr

Desertification process and Desertification risk

Tillage erosion

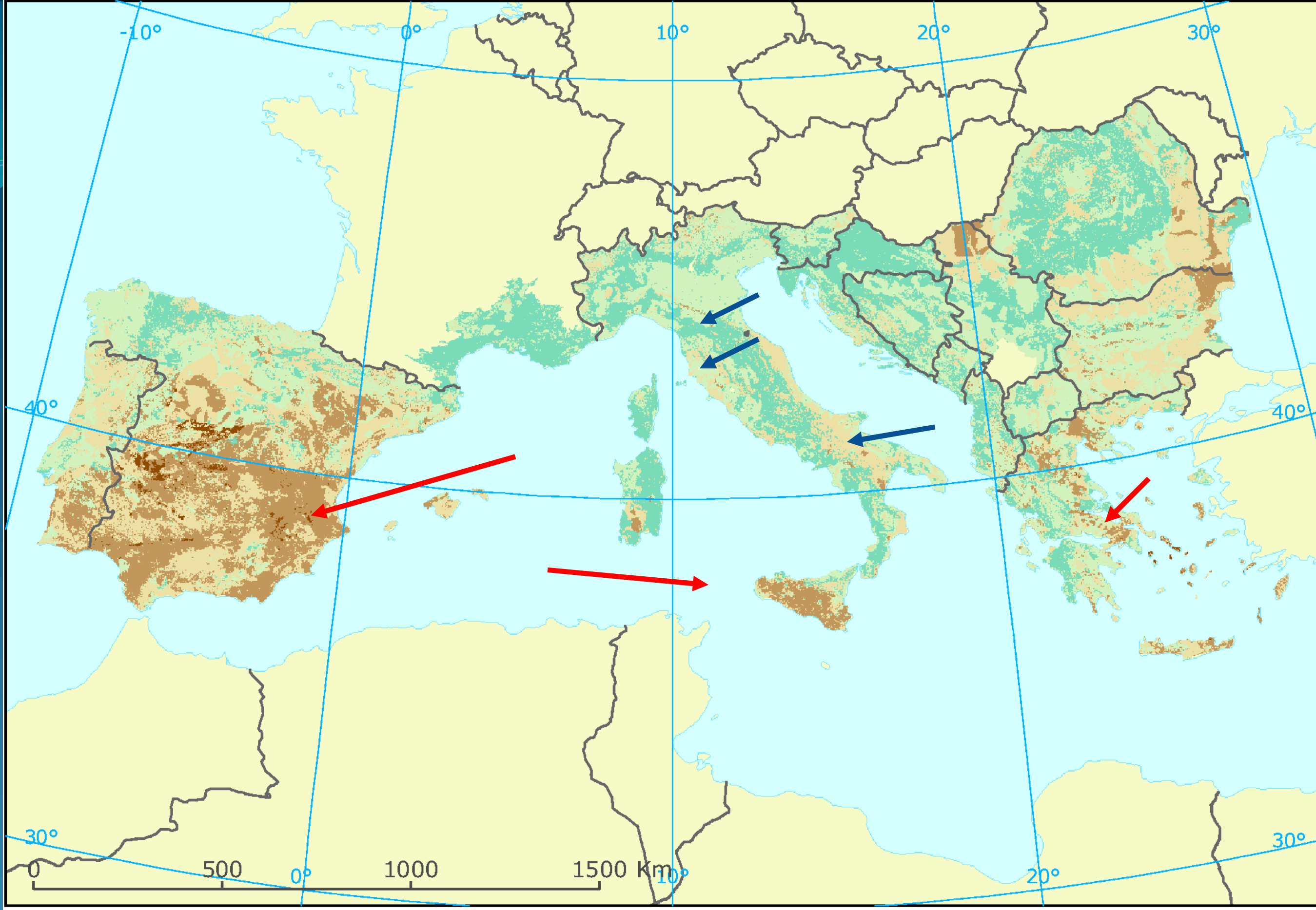
Water erosion

landslides

Land levelling

Dispersivity and piping

Study site RECONDES EU project (2004-2006)



Index of sensitivity to desertification (SDI), 2008

- < 1.2 Non affected areas or very low sensitive areas to desertification
- 1.2 - 1.3 Low sensitive areas to desertification
- 1.3 - 1.4 Medium sensitive areas to desertification
- 1.4 - 1.6 Sensitive areas to desertification
- > 1.6 Very sensitive areas to desertification

European Environment Agency (EEA) (2009)

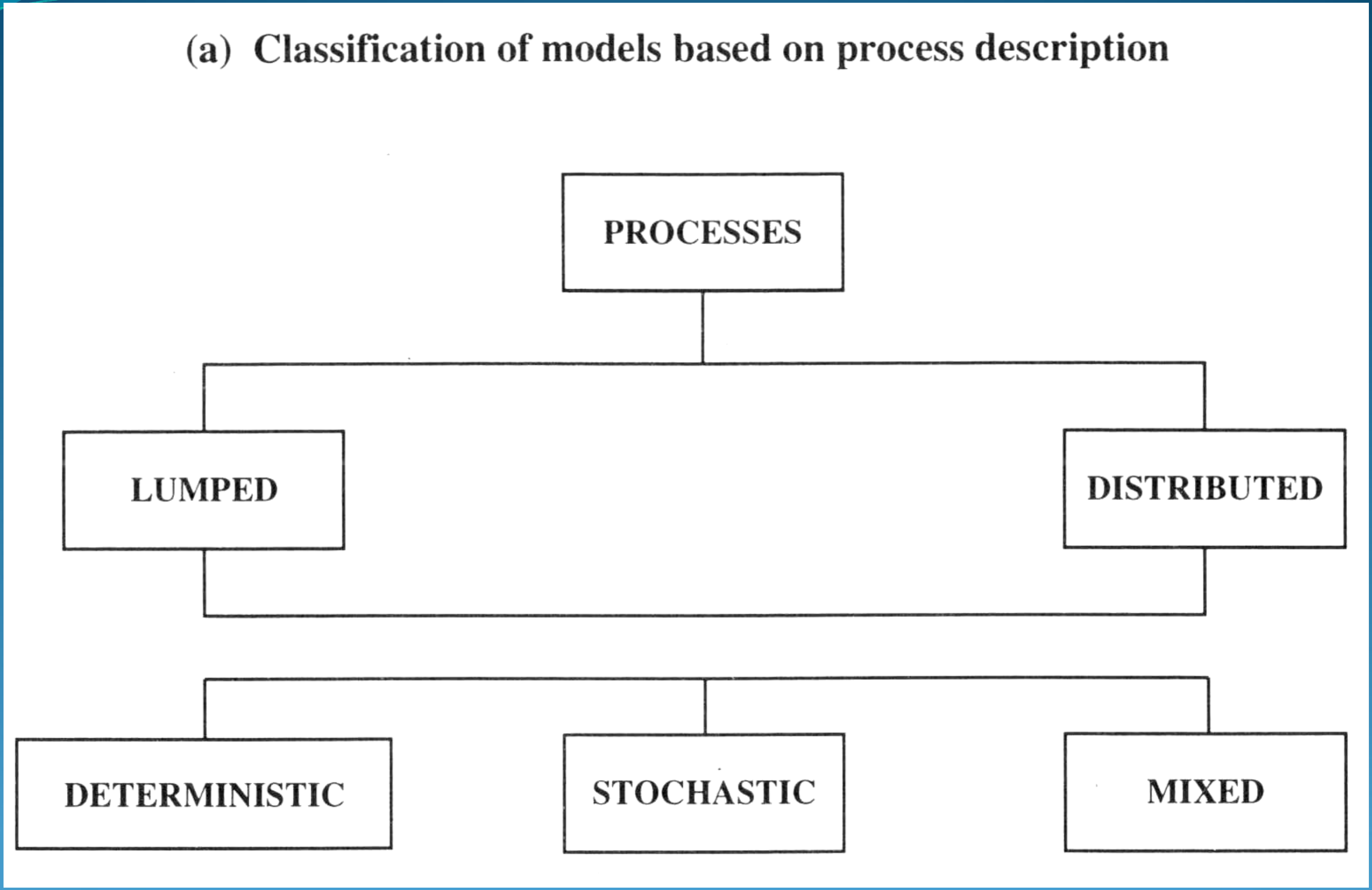
Sensitivity to Desertification

Based on Medalus methodology Kosmas et al. (1999) And Domingues & Fons –Esteve (2008)

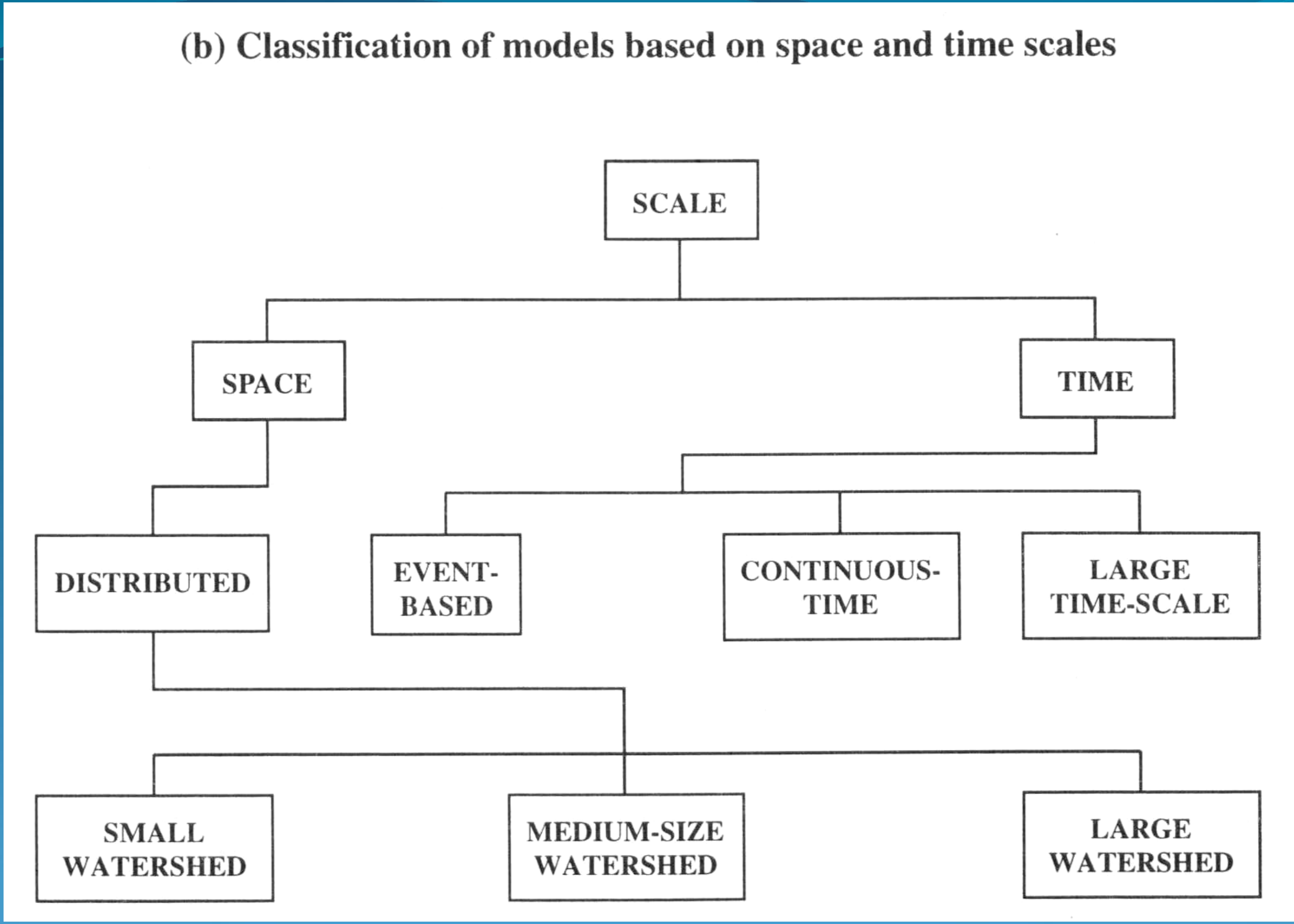
Web ref:

http://www.eea.europa.eu/

Part III – Current soil erosion models



From SINGH (1995)



From SINGH (1995)

Lumped MODELS

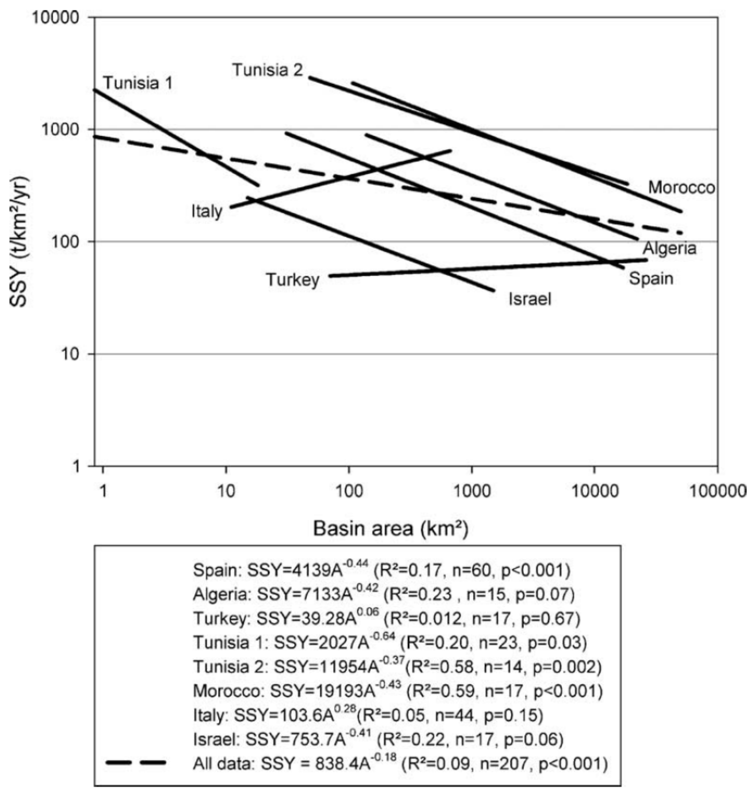


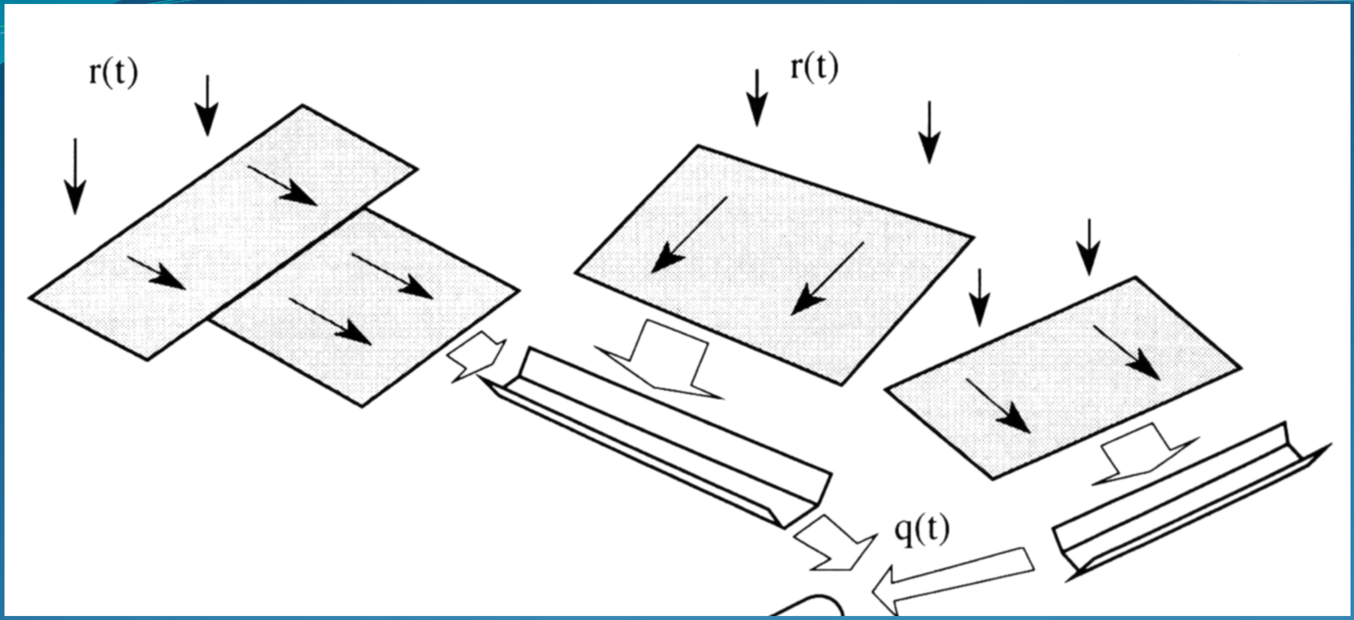
Fig. 3. Relation between area-specific sediment yield (SSY) and basin area for various Mediterranean basins. Source of data: Spain: (Avendaño Salas et al., 1997); Algeria: (Tidjani et al., 1998); Turkey: (Gögüs and Yener, 1997); Tunisia 1: (Albergel et al., 2000); Tunisia 2: (Lahlou, 1996); Morocco: (Lahlou, 1996; Fox et al., 1997); Italy: (Tamburino et al., 1990; Van Rompaey et al., 2003a; Van Rompaey et al., 2005); Israel: (Inbar, 1992).

Developed to assess
The specific Sediment yield (SSY) ,Usually expressed in Mg/km2,
given a set of lumped Watershed Parameters as:

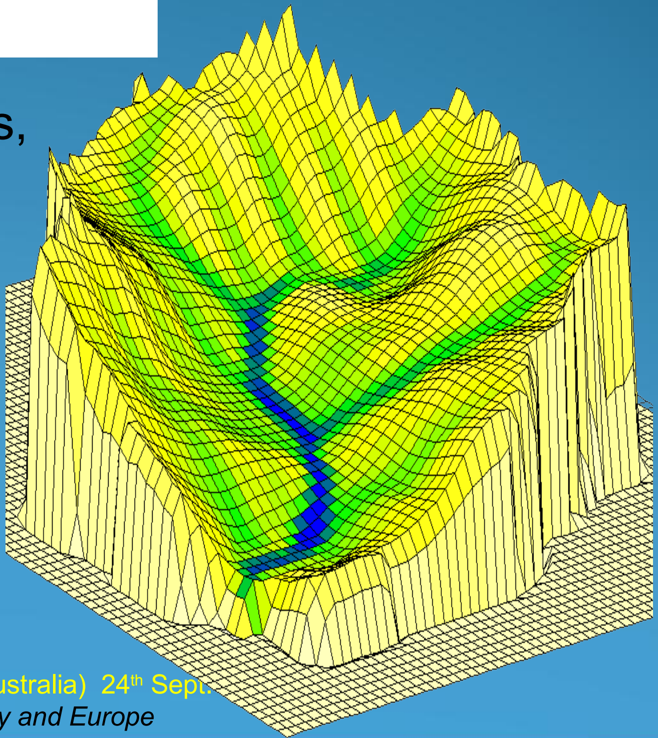
- Area (the most simple)
- Mean slope
- Drainage network length
- Type of soil
- Substratum
- Climate
- Anthropic activity
- Presence of specific
- Erosion processes
- ……

Geometrical representation on terrain in EUROSEM

DISTRIBUTED MODELS



Conceptual representation - through a cascade of planes, and channels



Raster representation

Description of the scores for factors used with semi-quantitative analysis of SSY in Northern Ethiopian catchments (after modifying Verstraeten et al., 2003)

Factor	Score	Description
Topography[a]	1	Gentle slopes near the reservoir and main rivers; elevation differences <300 m within 5 km.
	2	Moderate slopes near the reservoir and main rivers; elevation difference between 300 and 750 m within 5 km.
	3	Very steep slopes near reservoir; elevation difference >750 m within 5 km.
Gullies (G)[a]	1	Gullies are rare or channel banks and beds have low erodibility (or stabilized) and poor connectivity between gullies.
	2	A few active gullies with medium connectivity.
	3	Many active gullies with lots of bank collapse and high connectivity.
Surface cover (V)[a]	1	Vegetation and/or stone cover of the soil is very good (>75% of the soil is protected).
	2	Moderate vegetation and/or stone cover (25–75% of the soil is protected).
	3	Little contact cover (<25% of the soil surface is protected).
Lithology (L)[a]	1	High percentage of rock outcrops.
	2	Coarse colluvium (e.g. gravels).
	3	Strongly weathered (loose) material and marls.
Catchment shape (S)[b]	1	Elongated catchment shape with one main channel draining to the reservoir.
	2	Catchment shape in between elongated shape and semi-circular catchment shape.
	3	Semi circular catchment shape with many rivers draining into the reservoir and/or with much direct runoff from hill slopes to the reservoir.
Conservation practice (P)[c]	1	High density of soil conservation structures (>70% of the contributing area has been treated).
	2	Medium density (30% to 70%) of conservation structures.
	3	Low density (<30% of the contributing area).
Climate (C)[c]	1	Arid climate with low annual rainfall (Fournier index <75).
	2	Semi-arid climate with storms of moderate duration and intensity, (Fournier index between 75 and 150).
	3	Wet climate with relatively high annual rainfall, concentrated in a few months (Fournier index >150).

[a] Modified factors.
[b] Factors removed.
[c] Newly incorporated factors.

PSIAC – Type (lumped model)

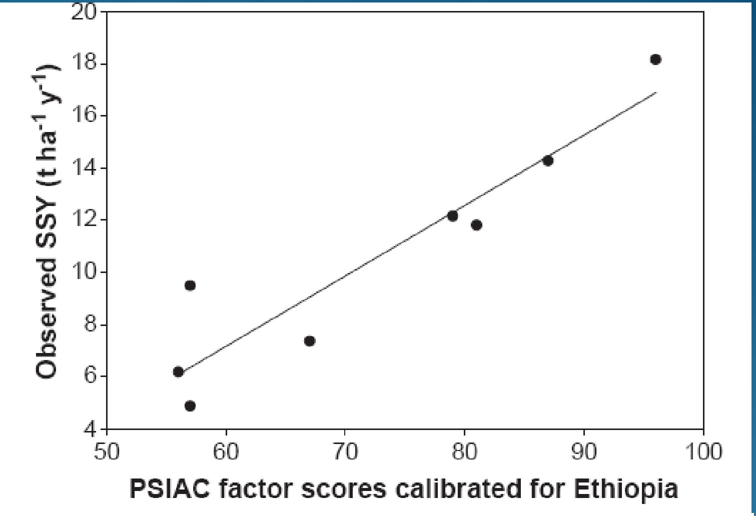
From N Haregeweyna et al 2005

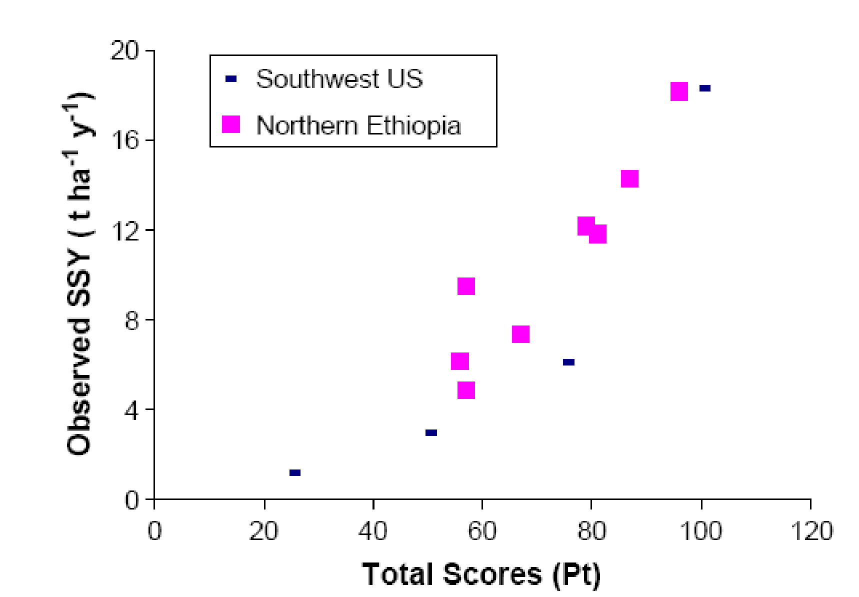
Assessment of Specific sediment yield Mg/km²/yr

$$SSY = 0.27Pt - 9 \quad (r^2 = 0.87)$$

For Ethiopia

Where
Pt = sum of multiple scores





(PSIAC, 1968)

USLE –TYPE
many variant with respect the USLE model (Wishmeier 1978)

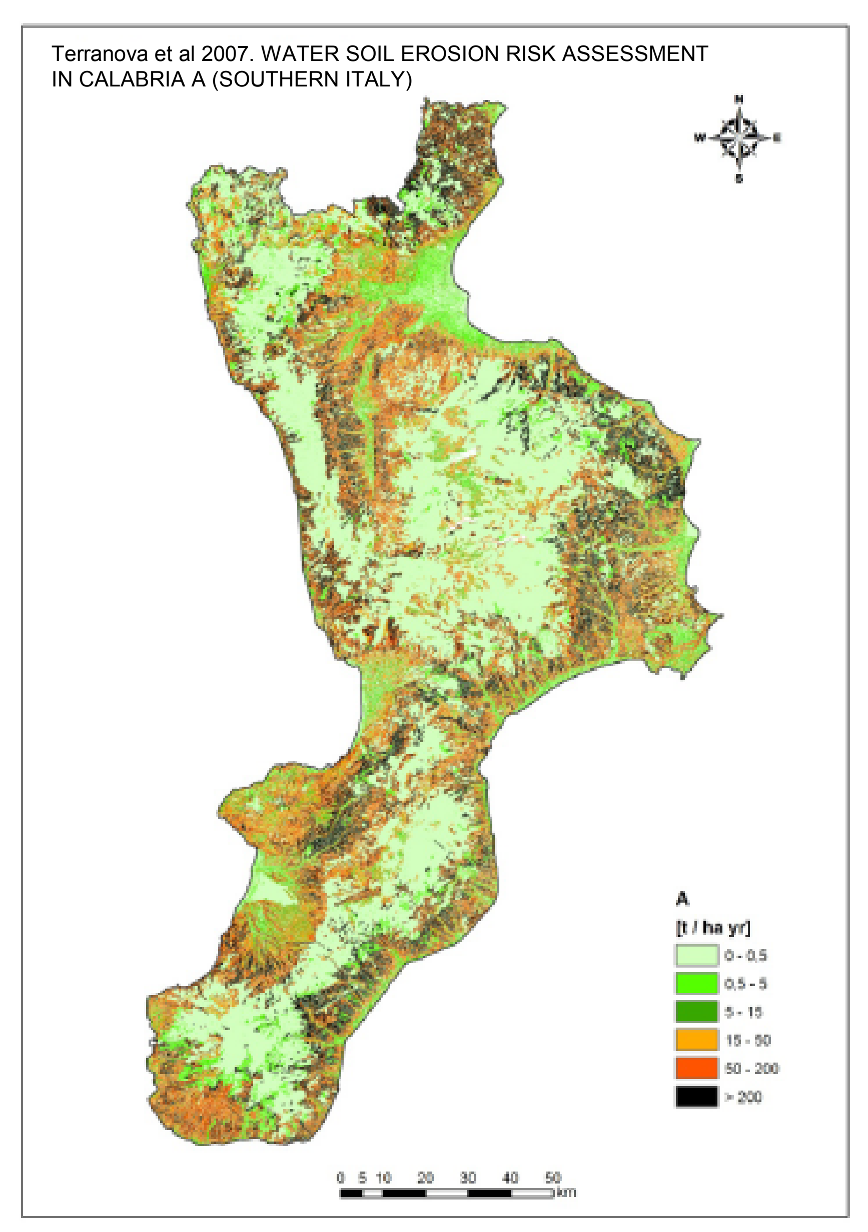
e.g. RUSLE model (Moore & Burch, 1986):

A = R •K •L •S •C •P

Where:
A [t ha-1yr-1]: the estimated average soil loss;
R [MJ mm ha-1h-1yr-1]: the rainfall–runoffer osivity factor;
[t h MJ-1mm-1]: the soil erodibility factor;
L [ ]: the slope length factor;
S [ ]: the slope steepness factor;
C [ ]: the cover-management factor;
P [ ]: the support practice factor..

MUSLE , USPED, WATEM-SEDEM…
And many others…

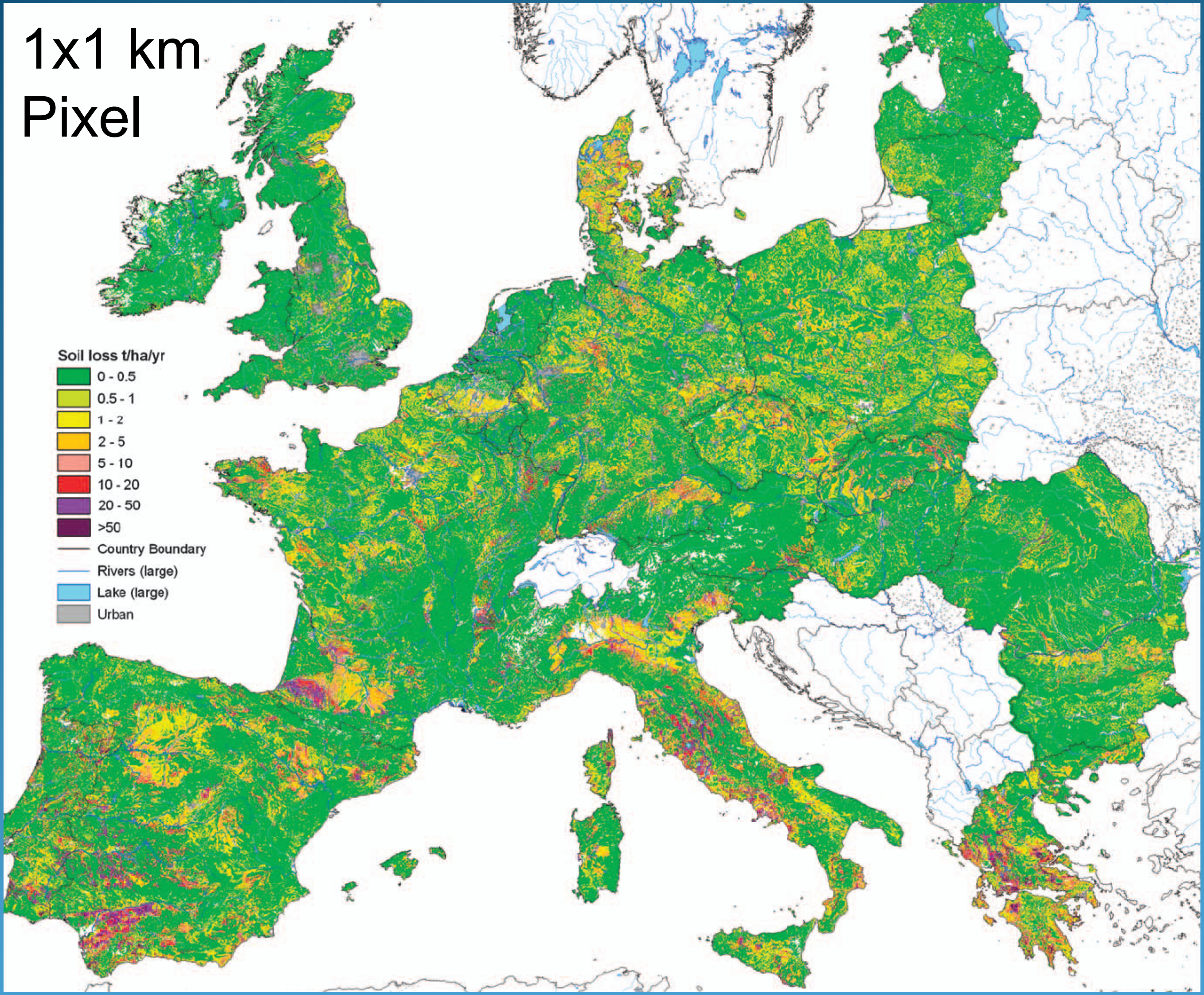
Product of erosion factors.
In origin developed for field base approach
Now used extensively in RASTER – GIS



Pesera - Type

Pan European Soil Erosion risk assessment (rill and interrill erosion)
Kirkby et al 2000,2008

1x1 km
Pixel



E=k Δ Ώ

E= Erosion rate [Mg/ha/yr]

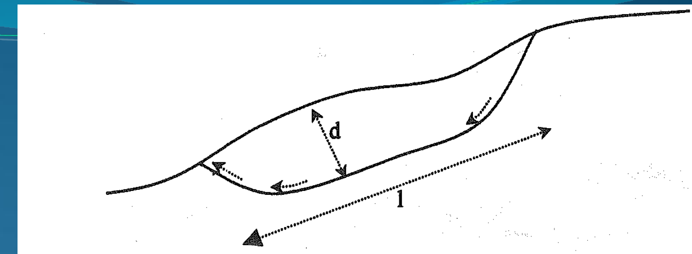
K depends from Erodibility based on land use soil and Vegetation

Δ = topographic potential (use of DTM)

Ώ=runoff generation Capability based on Climate,vegetation soil water balance..

Shallow - landslides

Many variants models:
SINMAP (Tarboton et al. 1998)
Shalstab (Montgomery and Dietrich 1994)
And interaction with rainfall and infiltration
(Iverson 2000)



Shallow mass movement: definition of the d and l parameters

Shallow landslide if d/L < 0.05

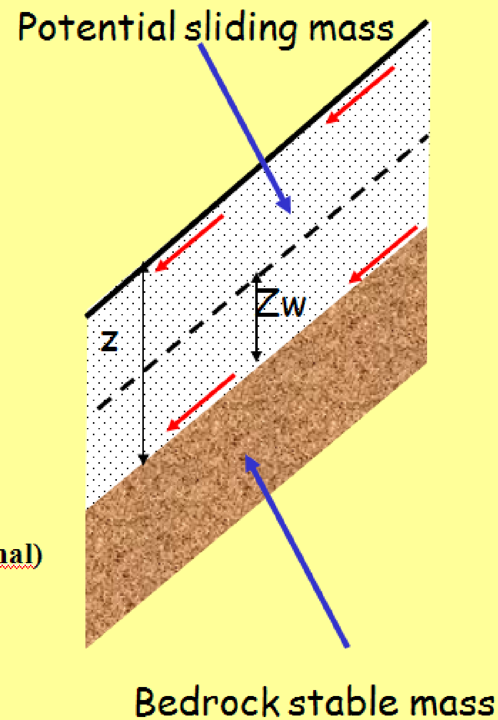
Limit equilibrium – Infinite slope model

$$Fs = \frac{\left(\frac{c'}{\gamma z} + (\cos^2\beta - r_u)\tan\phi'\right)}{\sin\beta\cos\beta}$$

where:

- β= slope gradient (degrees)
- ϕ'= internal friction angle(degrees)
- c'= soil cohesion+ roots strength (kPa)
- γ=soil unit weight (kN/m³)
- Z= depth of sliding surface (in m)
- Zw = depth of water saturated horizon
- r_u = coefficient of interstitial pressure (adimensional)

$$r_u = \frac{9.81 * z_w}{\gamma z}$$



If Fs < 1.0 = unstable condition

If Fs < 1.3 = stable condition

3D – type

LISEM
Basic processes incorporated in the model are rainfall, interception, surface storage in micro-depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow (in man-made ditches), detachment by rainfall and throughfall, transport capacity and detachment by overland flow ….

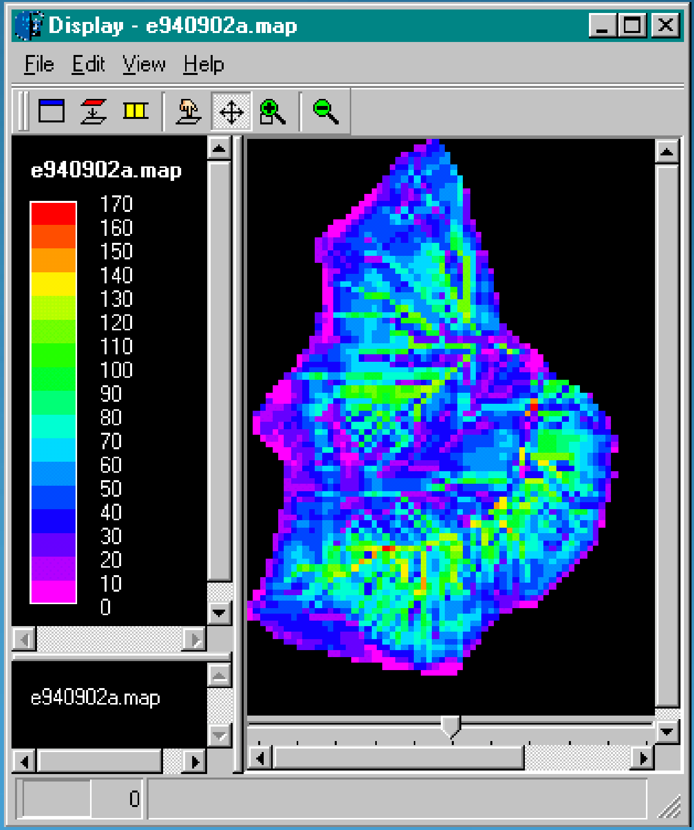
LISEM
(Jetten 2000)
http://www.itc.nl/lisem/

Single event
Small watershed
Pixel 5x5m
Samoggia valley, north Italy

Other similar model
.. but less complete
Is the **Erosion 3D**
Smidth (2007)

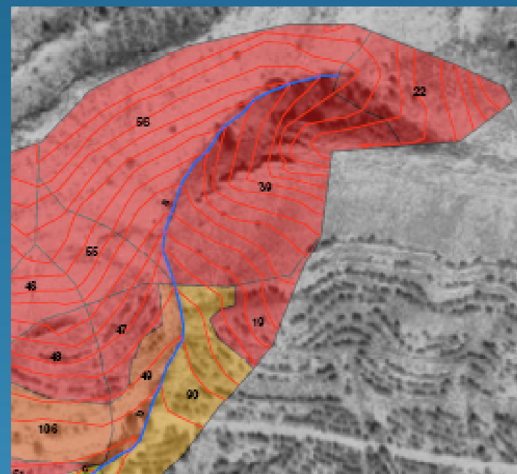
LISEM – rainfall event 2.9.1994

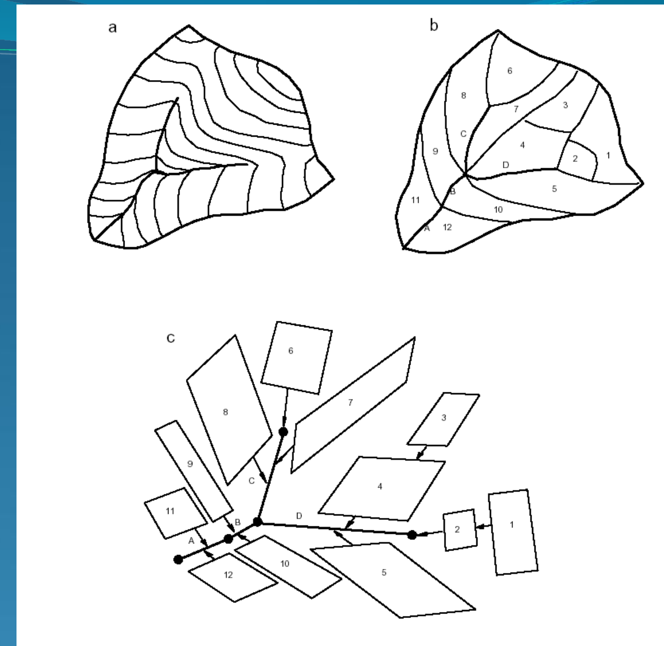
Catchment area	(ha):	**33.41**
Total rainfall	(mm):	**122.00**
Total discharge	(mm):	**21.30**
Total interception	(mm):	0.17
Total infiltration	(mm):	**100.51**
Average surface storage	(mm):	0.0
Water in runoff	(mm):	0.0
Mass balance error (water)	(%):	0.00007
Total discharge	(m3):	7119.49
Peak discharge	(m3/s):	**2.13**
Peak time	(min):	1499.69
Discharge/Rainfall	(%):	17.4
Splash detachment	(ton):	44.88
Flow detachment (land)	(ton):	**1634.63**
Deposition (land)	(ton):	**-215.28**
Erosion channel/wheeltr.	(ton):	0.0
Deposition channel/wht.	(ton):	0.0
Total soil loss	**(ton):**	**1464.23**
Average soil loss	(ton/ha):	**43.82**



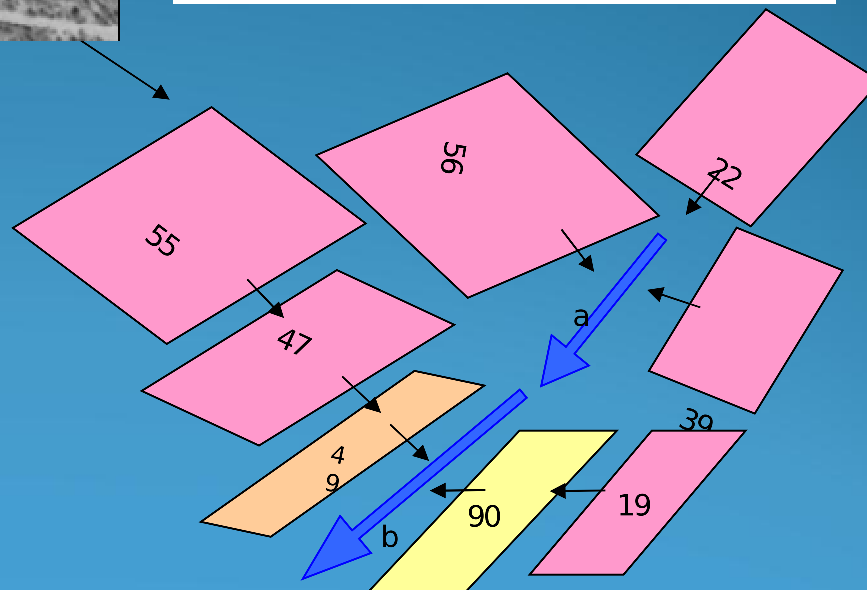
Eurosem - Type

EUROSEM
Conceptual - distributed
Physically based.
Same basic erosion
Ah hydrological process
as in LISEM model

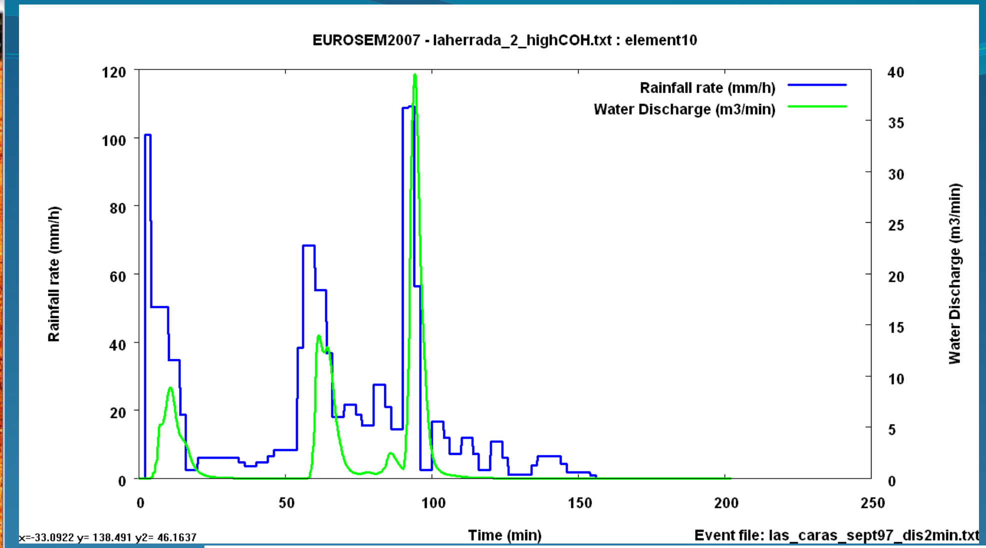


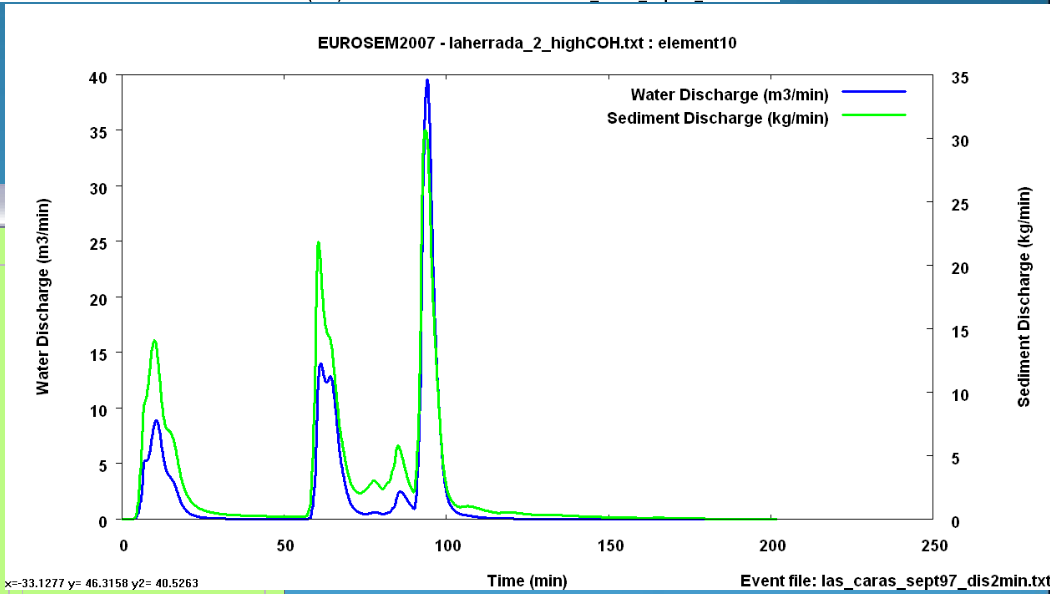


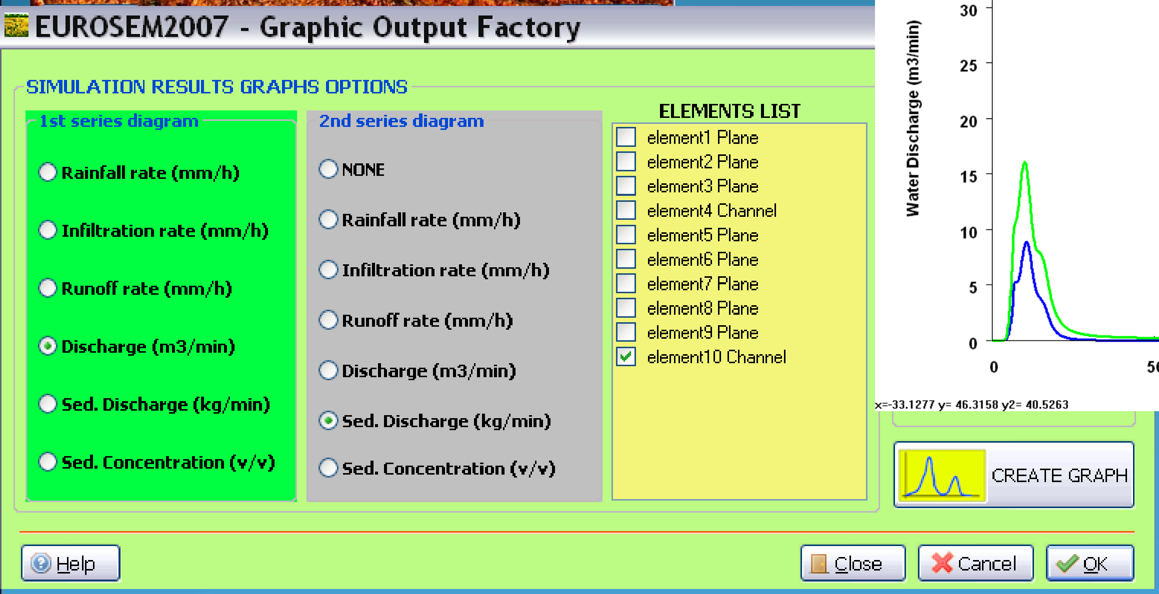
EUROSEM (Morgan et al 1998) describes catchments by decomposition into elements which are either **planes or channels**. The method is taken from the KINEROS, and more details and examples can be found in the KINEROS manual (Woolhiser et al, 1990)



Similar model, but more complete
is the WEPP model



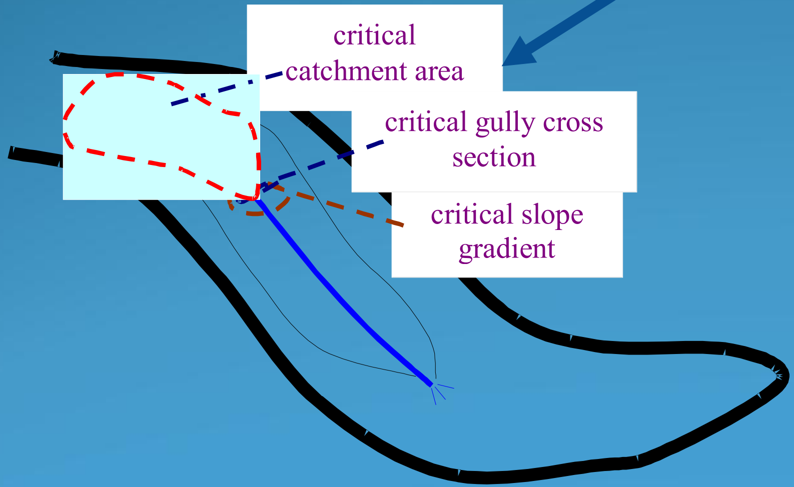




EUROSEM2008
CNR-IRPI

Single erosion process models – implemented and integrated in many physically based models (as LISEM, Erosion 3D , Eurosem ..)

e.g.
Splash erosion
Critical stream power, shear stress for soil particle detachment
Sediment transport capacity
Settling velocity
Erosion by overland flow
Rill –gully erosion and their evolution
Detachment-transport-sedimentation balance
Topographic Ephemeral Gully threshold



Field evidences of threshold condition defined by relationships :

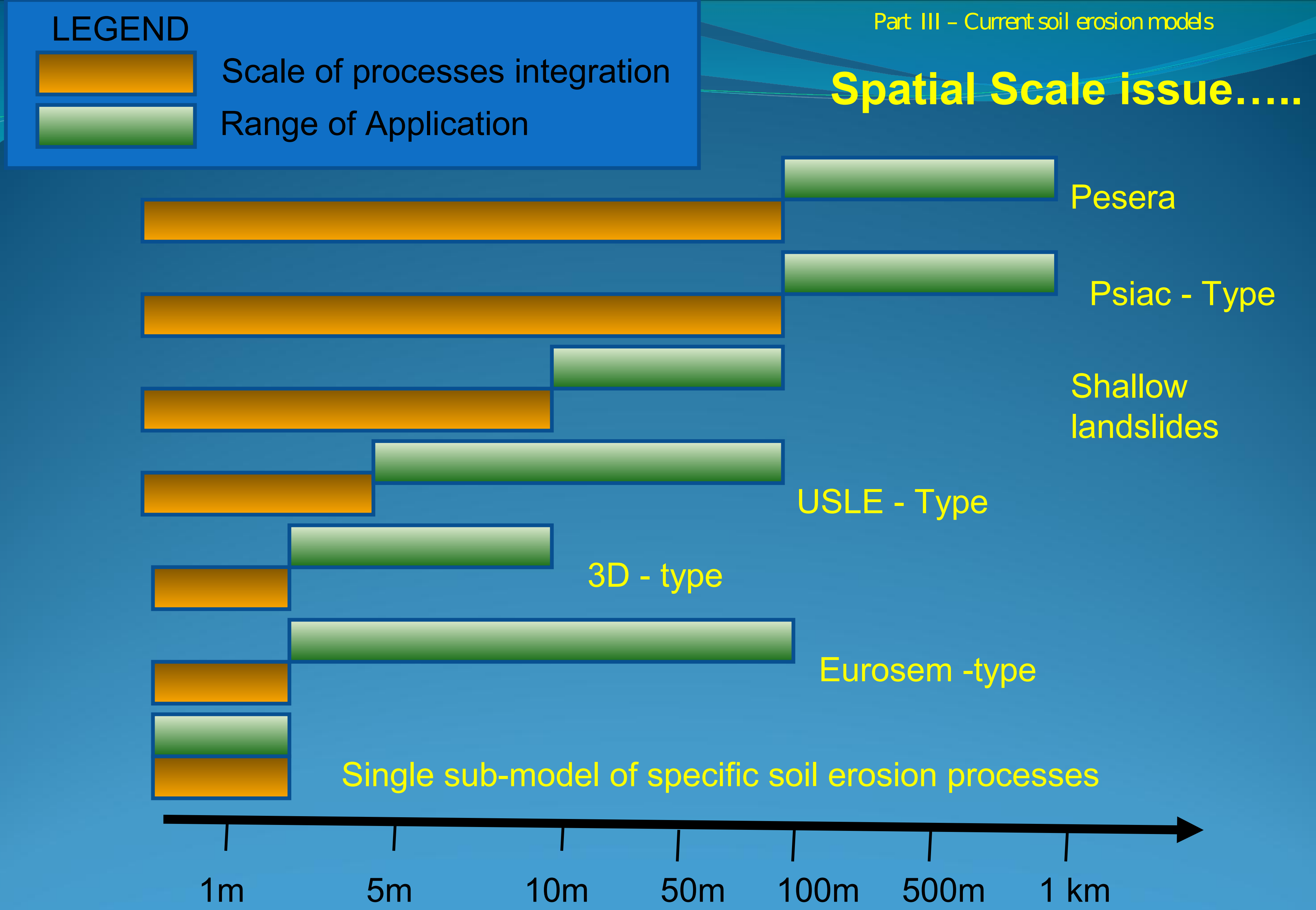
$$slope = aA^{-b}$$

After:
Vandekerckhove et al. (2000)
Bennet et al. (2000)
Nachtergaele et al. (2001)

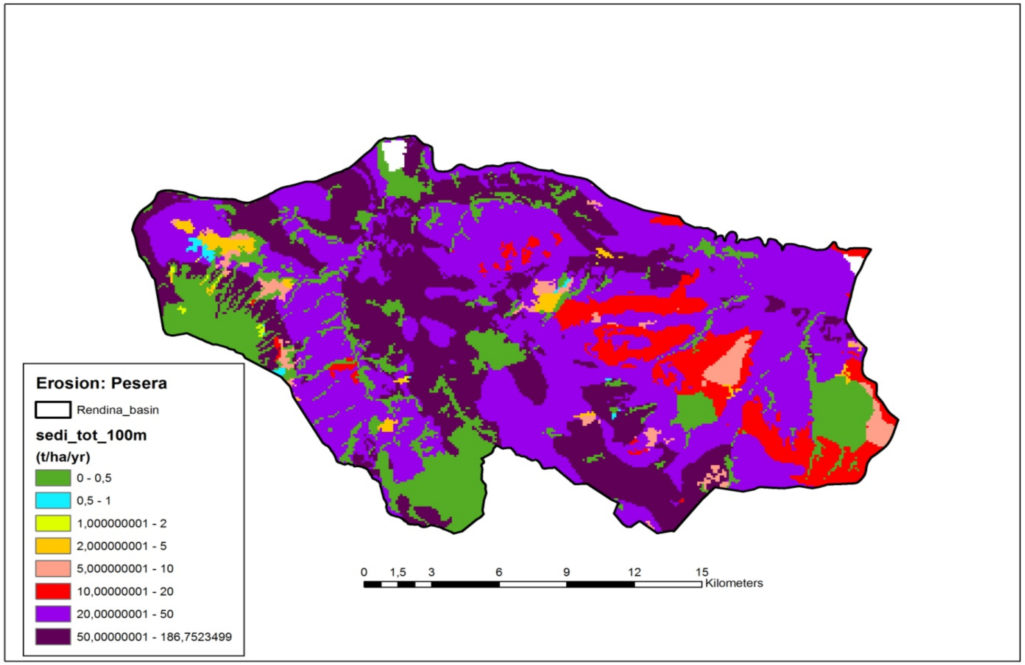
Some general considerations on soil erosion models

Spatial Scale issue
Temporal scale issue
Data availability
Modeled erosion and hydrological Processes
Complexity to use
Reliability , calibration and validation

Spatial Scale issue…..

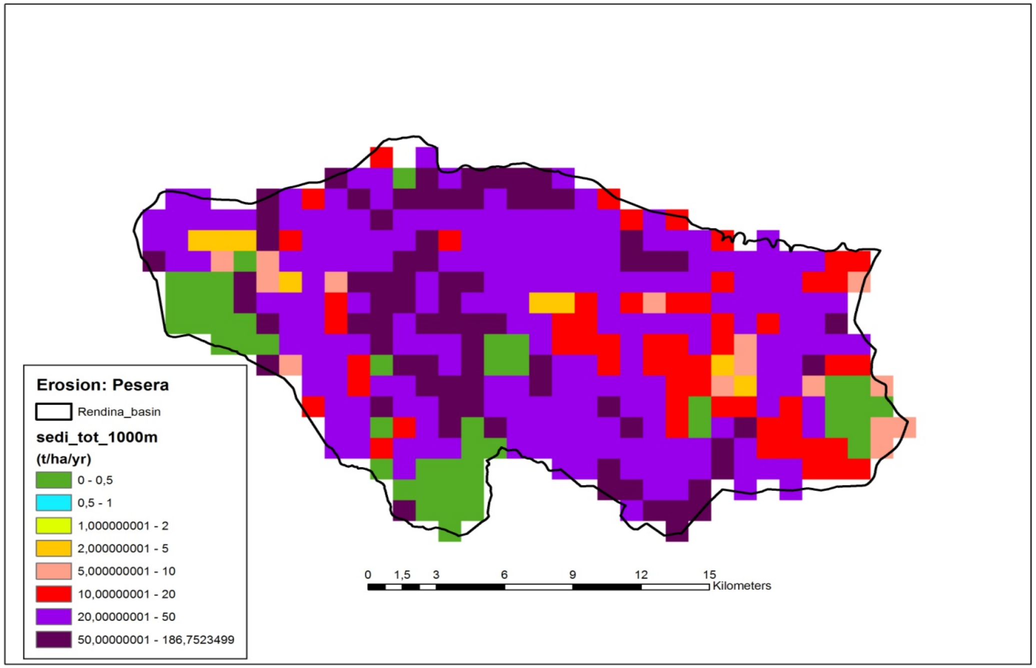


Part IV – Possible Future Research Trends



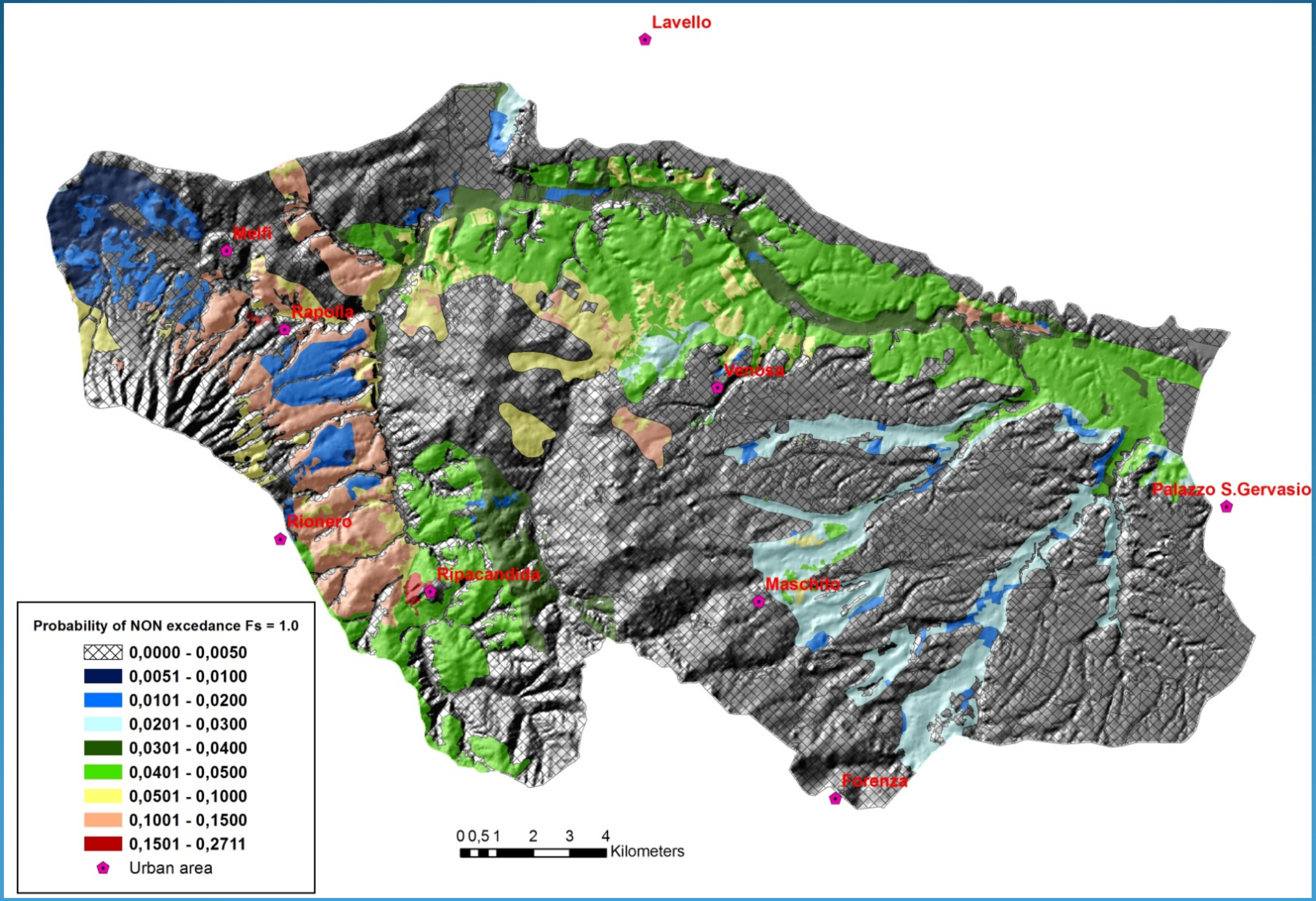
Pesera model

Application at study site
Rendina , Italy
Project DESIRE
Also at 100X100 m pixel



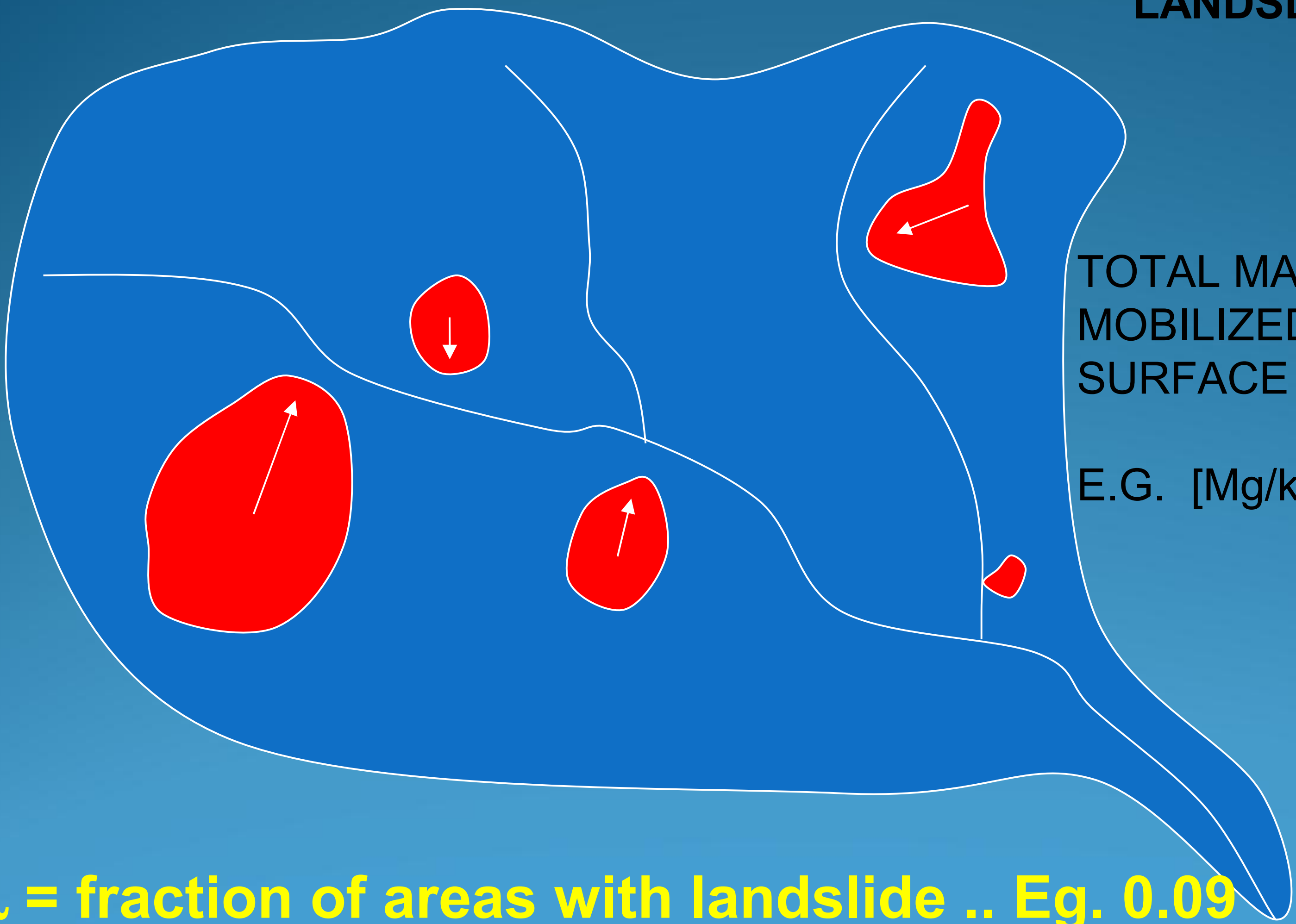
Present work at CNR-IRPI
Is the Extension with shallow
Landslide process contribution to
Gross erosion rate

Shallow landslides extension to PESERA It is One of the CNR-IRPI Activities within DESIRE project



Total LANDSLIDE VOLUME from area, given an average lanslide depth

It APPLIES AT SHALLOW LANDSLIDE ONLY..



TOTAL MASS THAT CAN BE MOBILIZED FOR SPECIFIC SURFACE IN A WATERSHED

E.G. [Mg/km2]

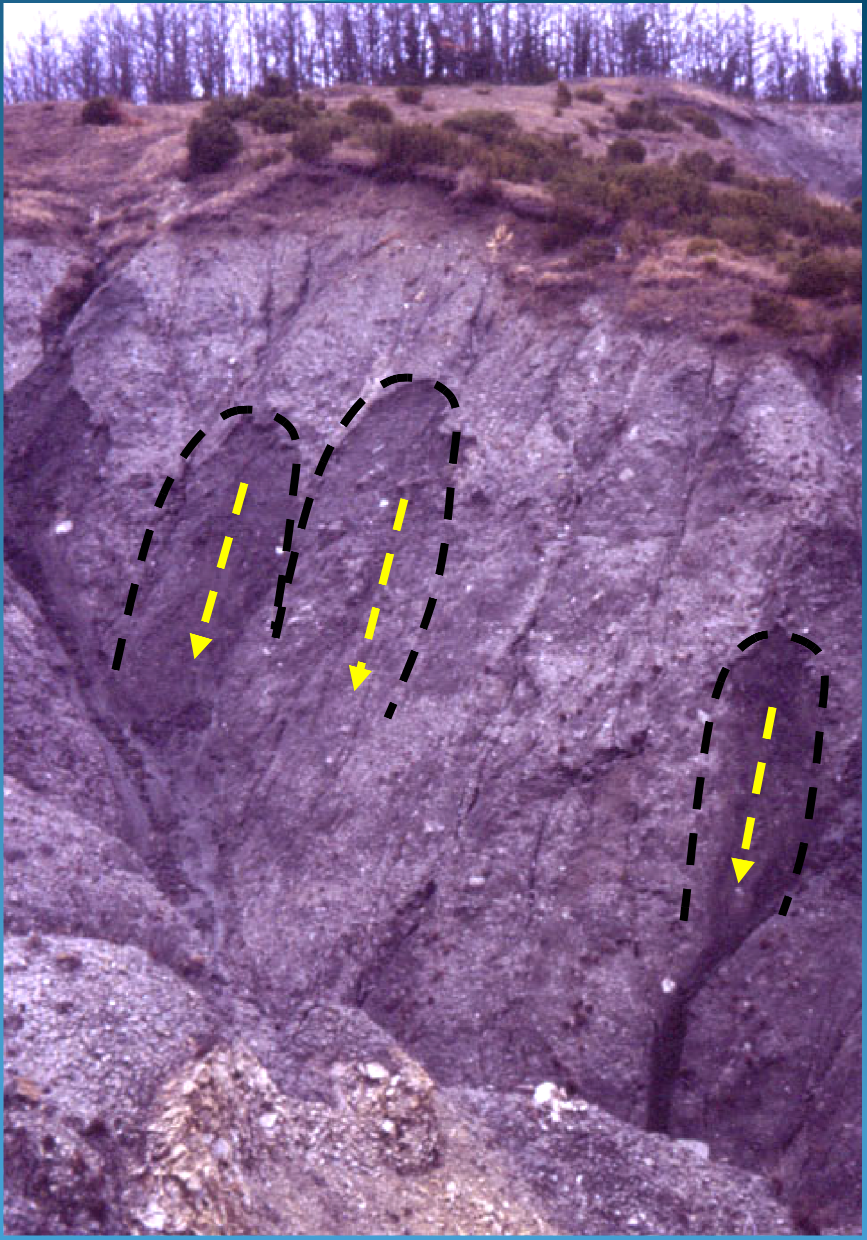
λ = fraction of areas with landslide .. Eg. 0.09

Badaland area where the main Erosion process is shallow landsliding

Translational landslides of wheatered rind formed from clay shales parent material

Temporary accumulation at the valley bottom and subsequent mudflow

(computed average depth erosion rate:
0.2-0.05 m/y)




sliding of weathered
rind (20-30cm) from all
the watershed at the
same time, during the
snowmelt phase

Specific Sediment yield due to landslide only

Two examples of computation

area (km^2)	λ	D(m)	SDRL	γ (Mg/m^3)	Δ T (years)	volume(m^3)	A equiv (Mg/ha/yr)	SSY (Mg/km^2/yr)
0.5	0.7	0.1	0.8000	1.5	1	28000.00	840.00	84000.0
0.5	0.04	1	0.0100	1.5	1	200.00	6.00	600.0

- λ: Fraction of surface affected by landslide
- D(m): Aveage depth of landslide
- SDRL: Average Sediment delivery ratio from landslide bodies (SDRL)
- γ: Density of soil mass
- Δ T: Annual frequency
  1 .. each year
  2 … each 2 years
  0.5 two time each year
- A equiv: Net erosion volume
- SSY: Specific sediment yield

The first row represents the situation in badland site SSY = 840 Mg/ha/yr

The second row represent an area affected of relevant fraction of shallow landslides less connected to drainage system SSY 6 Mg/ha/yr
Typical in study site of DESIRE Project

Connectivity issue

Local sinks at field scale positioned at bottom of a eroded fiedls

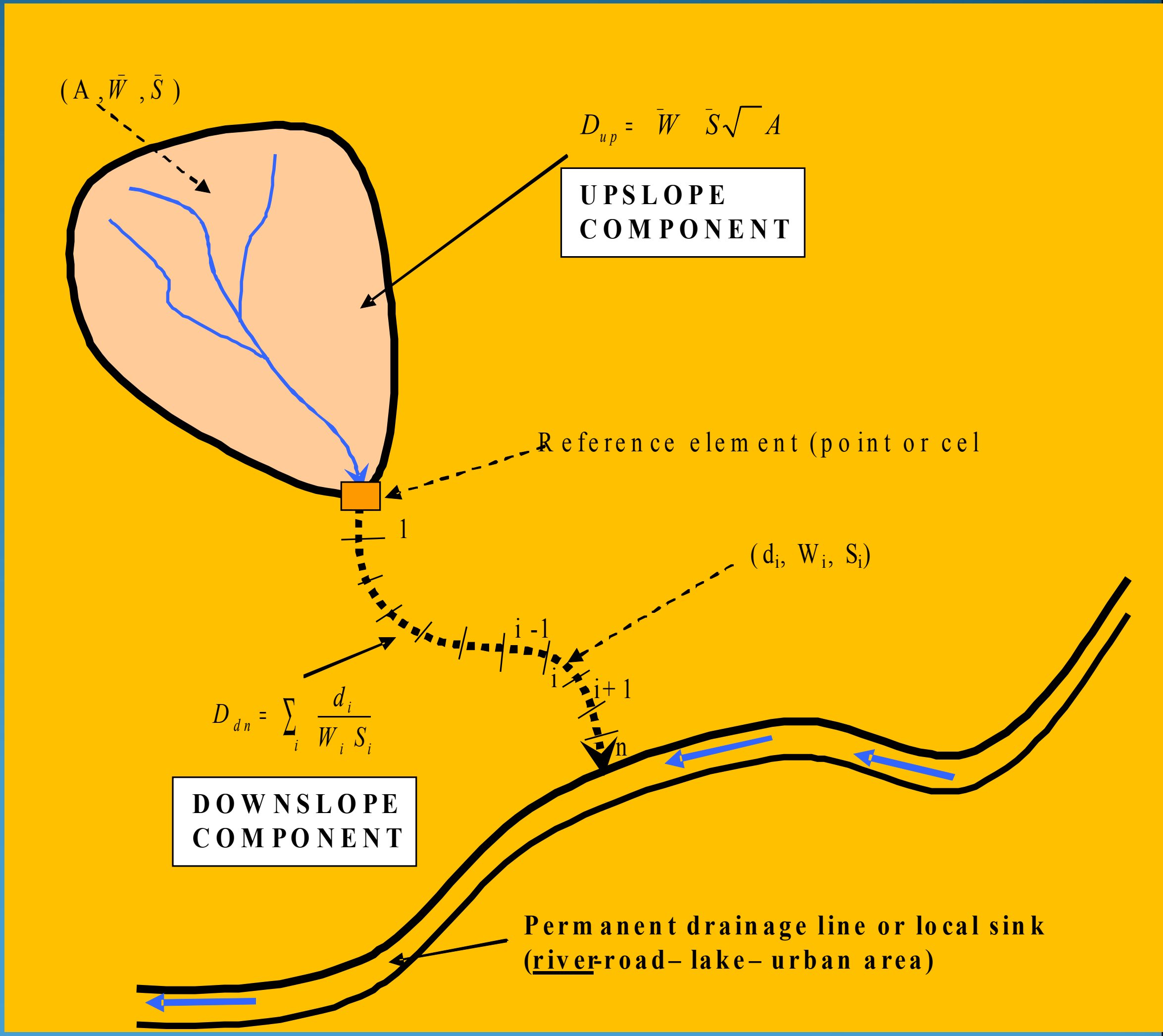
Connectivity index model - IC

Borselli et al. (2008). Prolegomena to Sediment and flows connectivity in the landscape: a GIS and field numerical assessment . CATENA(elsevier)

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

- **Downslope component**: is the sinking potential due to the path length, land use and slope along the downslope route.
- **Upslope component**: is the potential for down routing due to upslope catchment's areas, mean upslope and land use.

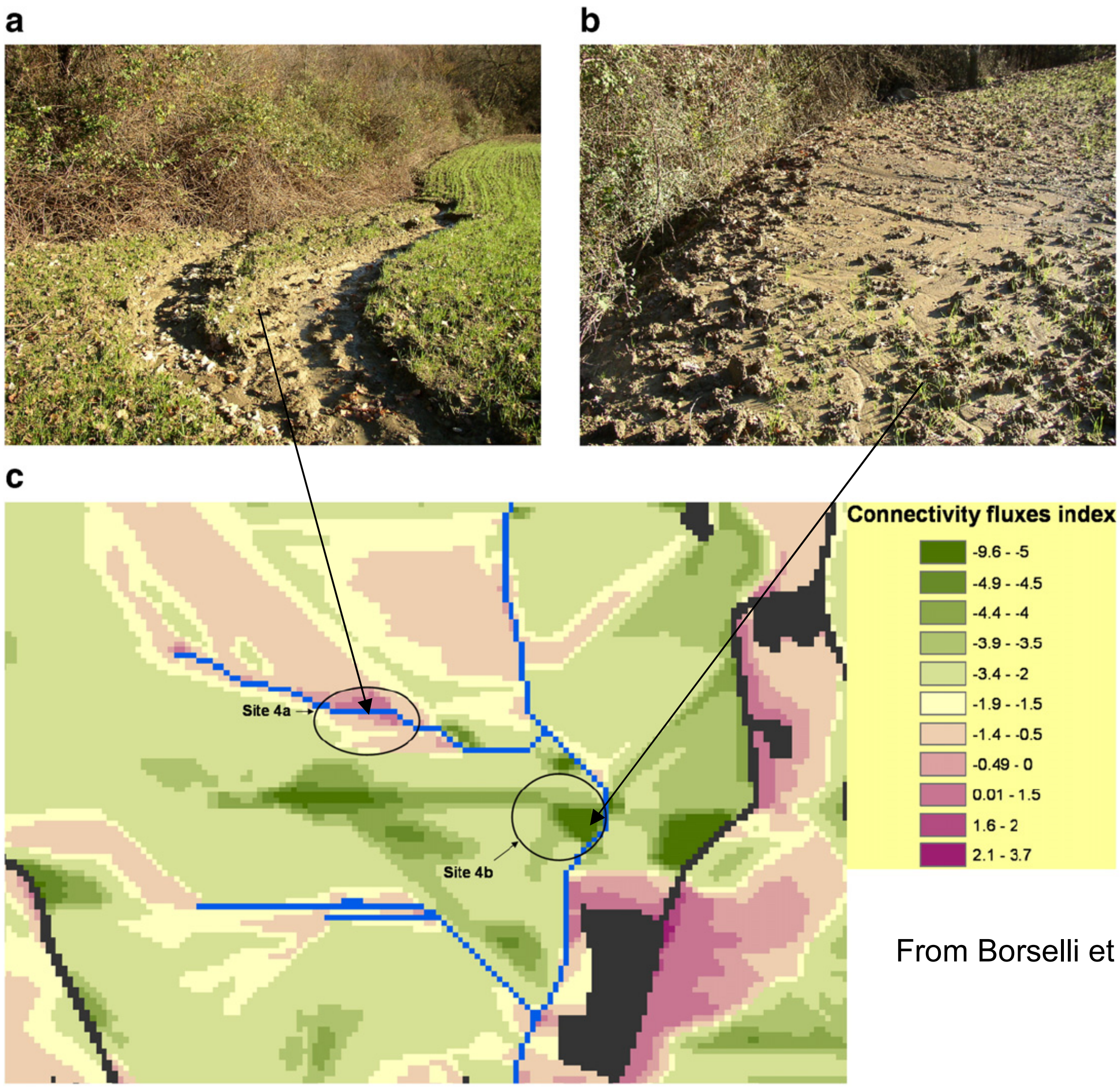
Connectivity issue



Main Objectives:

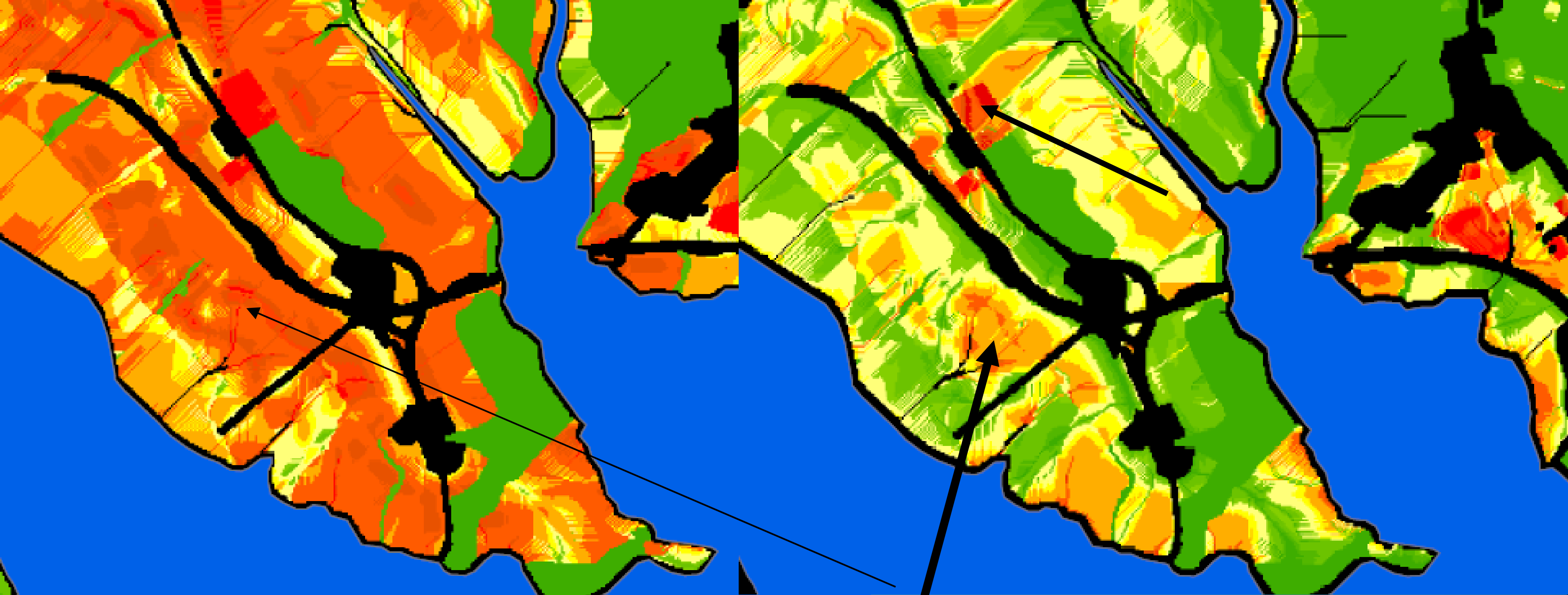
SDR (sediment delivery ratio) assessment

Integration with Distributed models



From Borselli et al. 2008

Fig. 4. a: Site 1—Area close to a local sink at the bottom of a field: direct connection of rill system without detectable sedimentation. b: Site 1—Area close to a local sink at the bottom of a field: direct connection of rill system and intense sedimentation. c: IC map of Site 1—deposition and connection areas are evidenced inside the circular areas.



Local Average erosion rate... Classic RUSLE3D

Average sediment yield Contribution: RUSLE3D corrected according to *lc* and SDR

SDR =SSY / A

Where: *SSY is average annual sediment yield per unit area, and A is average annual erosion over the same area*.

$$SDR = \frac{\text{Net erosion (SSY)}}{\text{Gross erosion (A)}}$$

where SDR [0.0 - 1.0]

Future trends….

Lumped models: further extension of use.

Pesera: possible important improvement (non only in the landslide integration)

USLE-type: still actives but improvement it is needed (mass conservation issue)

Physical based models :3D and Eurosem Type: are useful tools for research and some application in new design of soil conservation methods
Also they are the best playground to test the integration of the single soil erosion processes sub-model. Mass conservation Issue in some models
.
Single soil erosion processes models: basic research is still needed because the within storm soil dynamics should be improved, and because rivers Hydraulics laws can't be more used for rills and overland flow…
(e.g. manning equation)

Model's role and future trends in soil erosion studies.

Great relevance:
Computational capacity
Visualization
Analysis tools (statistics)
Scenario analysis .

Model methodologies constraints
Fundamental constraints (mass (and energy) conservation):
in some the checking is insufficient;
validation method it is not always reliable.

To be improved more !:
Basic research and knowledge …

Many thanks for your attention!