Sustainable mountain soil use and erosion control

Eleonora Bonifacio
University of Torino – DISAFA
Eleonora.bonifacio@unito.it

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SOIL EROSION: GENERAL CONCEPTS

Soil erosion refers to all processes that act on the soil surface and lead to losses of soil material by particle detachment and transport. The eroded material is at least partially deposited in other areas.

Soil erosion is a natural process, occurring over geological time. With respect to soil degradation, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by human activity.

The processes of soil erosion involve detachment of material and transport either by saltation through the air or by overland water flow. Runoff is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity.

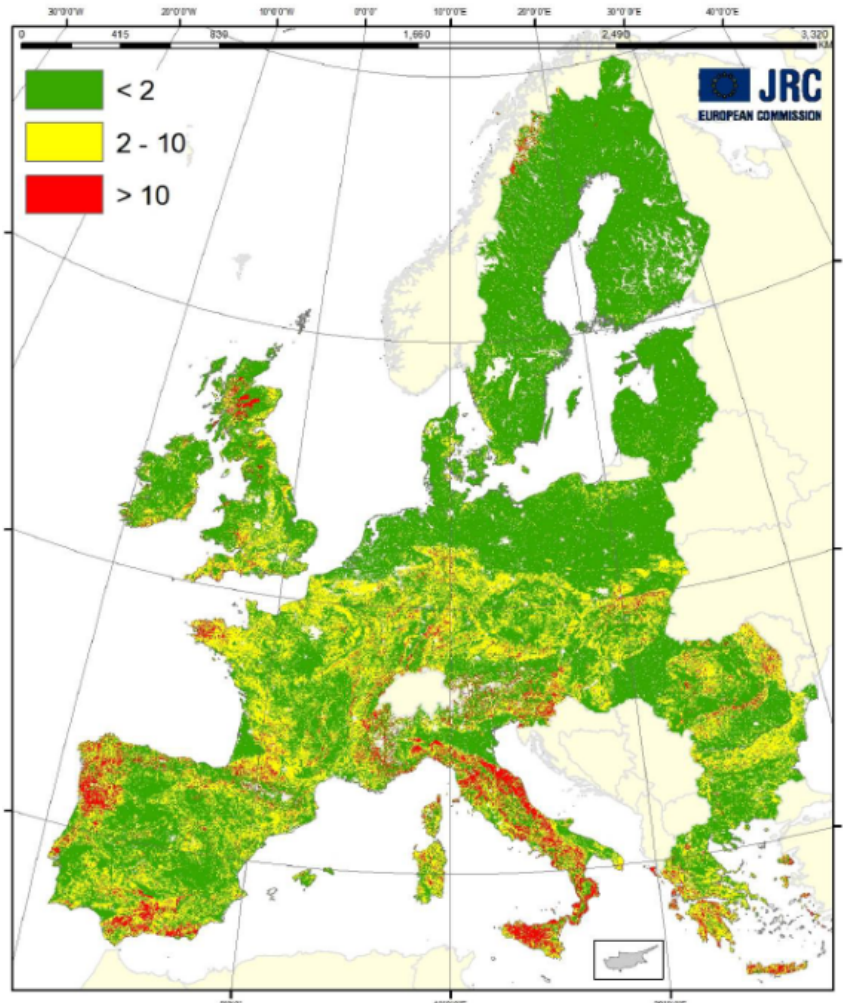



By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of this the resource. The soil removed by runoff accumulates below the eroded areas, in severe cases blocking roadways or drainage channels and inundating buildings.

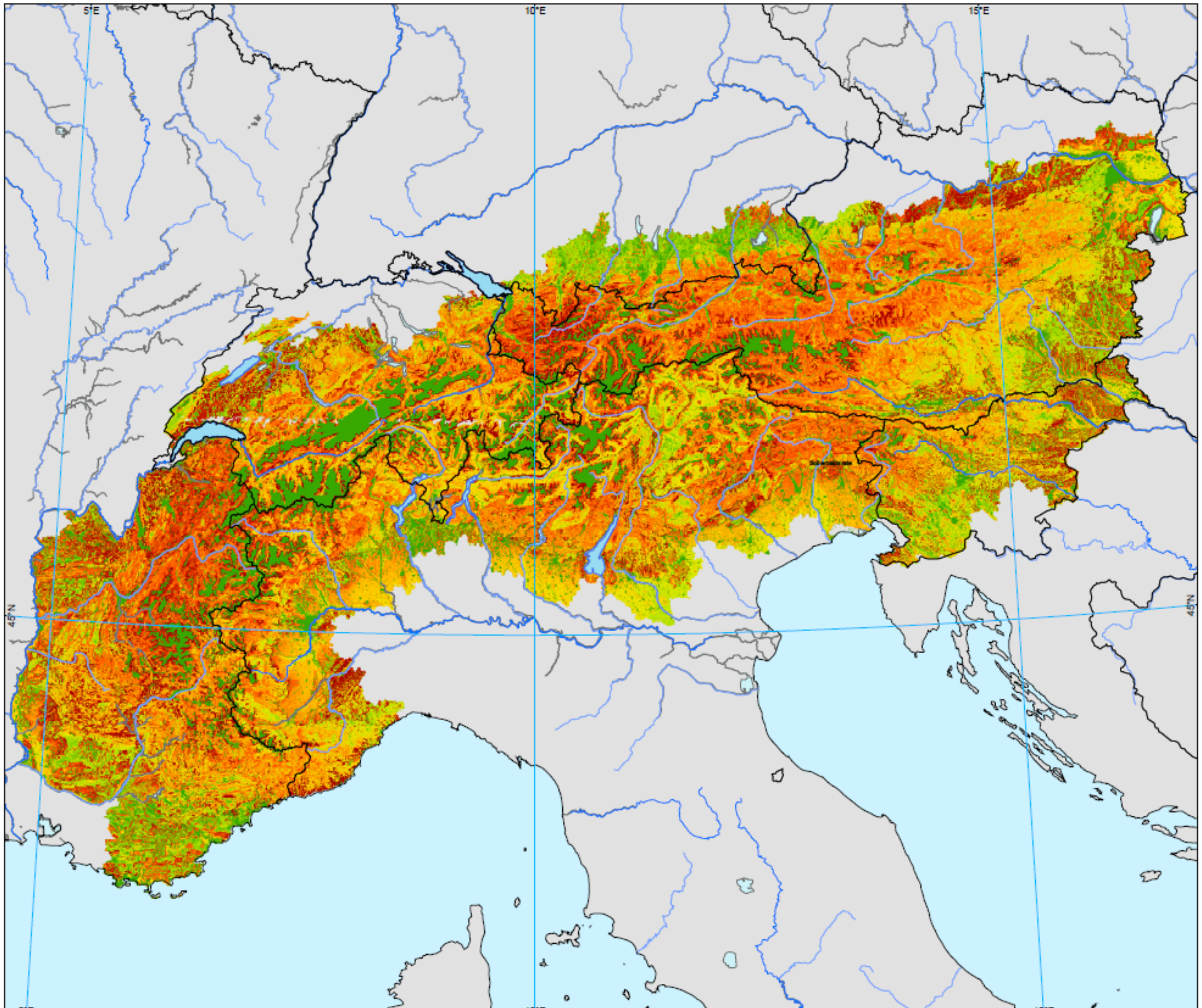
With a very slow rate of soil formation, any soil loss of more than 1 t $ha^{-1}yr^{-1}$ can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t ha^{-1}in extreme events.

The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, forest fires and construction activities.

Figura 3: Erosione del suolo per azione dell'acqua nell'UE (t/ha/anno).



Soil Erosion in the Alps



Erosion Rate in the Alps

Soil Erosion (t / ha yr)

- 0 - 0.5
- 0.5 - 1
- 1 - 3
- 3 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- > 50
- Country boundary
- Rivers (large)
- Rivers (medium)
- Lake (large)
- Major water

N

This map shows the rate of soil erosion by water in the alpine territory.
This map is derived from the RUSLE model which calculates the actual sediment loss by soil erosion.
The index values indicate the intensity of the change in the soil erosion rate.

MAP INFORMATION

Spatial coverage : Alps as defined by Convention for Alps protection
Pixel size: 100 m
Projection: Lambert Azimuthal Equal Area

<u>Input data - source</u>
Climatic data - The rainfall measurement data have been provided by the International Centre for Theoretical Physics (ICTP) of Trieste. These data are the output of a prevision model of the climatic change (RegCM, Regional Climate Model), that provides the daily rainfall values for the years 1960 – 1990.

Soil data - European Soil Database

Land use - CORINE Land Cover 1990 and 2000

Topography - DEM SRTM (Shuttle Radar Topography Mission) has been used.
The accuracy of the DEM is 90 m.

Model used : RUSLE (Revised Universal Soil Loss Equation)

BIBLIOGRAPHIC INFORMATION

Author(s) : Claudio Bosco, Ezio Rusco, Luca Montanarella, Stefano Oliveri & Panos Panagos
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For more information:

Dr. Luca Montanarella, European Commission, Joint Research Centre, Institute of Environment and Sustainability, Land Management & Natural Hazards Unit, Ispra, Italy.
Email: Luca.Montanarella@jrc.it

Maps can be downloaded from http://eusoils.jrc.ec.europa.eu/

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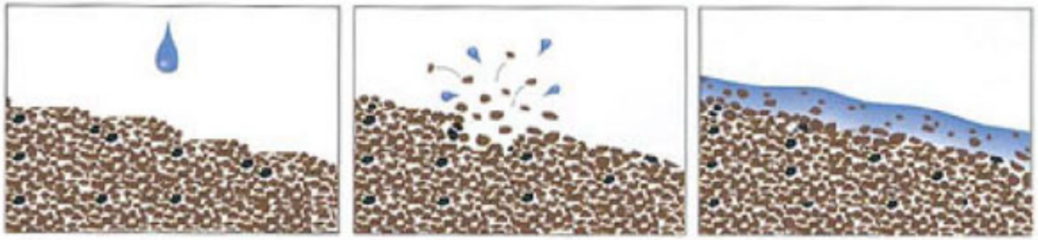
Erosion rate is very sensitive to **topography**, **climate** and **land use**.

Regions having long dry periods followed by heavy bursts of erosive rain are particularly prone to erosion. In other areas soil erosion is less because rain is evenly distributed throughout the year.

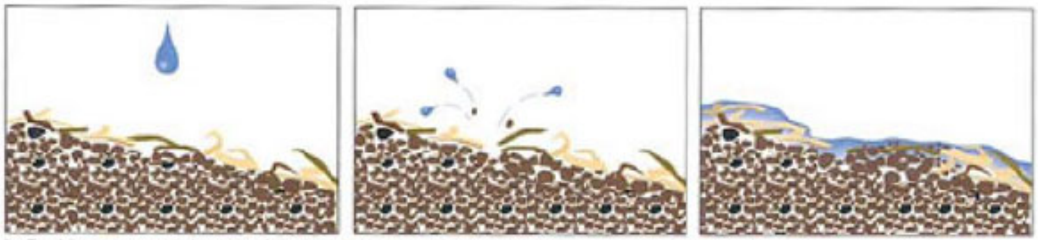
If the rainfall event provides more water than the amount that can enter the soil, the excess is accumulated on the soil surface and, depending on the slope gradient, runoff originates.

Runoff is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity.

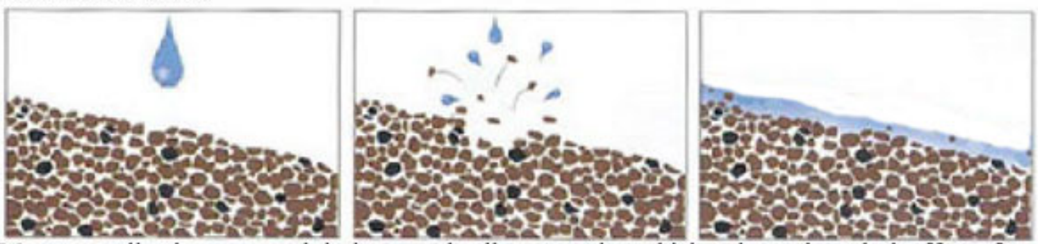
Runoff is mitigated by vegetation growing on the soil and by agricultural practices (e.g. mulching). Bare soils do not have any protection from runoff. Timing of agricultural and forestry practices is extremely important



With no protective cover, raindrops can splash soil particles up to 3' away. Soil particles and aggregates that have been detached are then transported down the slope by runoff water.



Residue cover cushions the fall of raindrops and reduces or eliminates splash erosion. Small natural dams are formed that cause ponding of runoff. Sediment is deposited in these ponds and remains in the field.



Manure application can result in improved soil aggregation which reduces the splash effect of raindrops and increases infiltration with reduced runoff.

Plant & Soil Sciences eLibrary^PRO
http://passel.unl.edu/pages/index.php?category=top0

Splash erosion or rain drop impact represents the first stage in the erosion process.

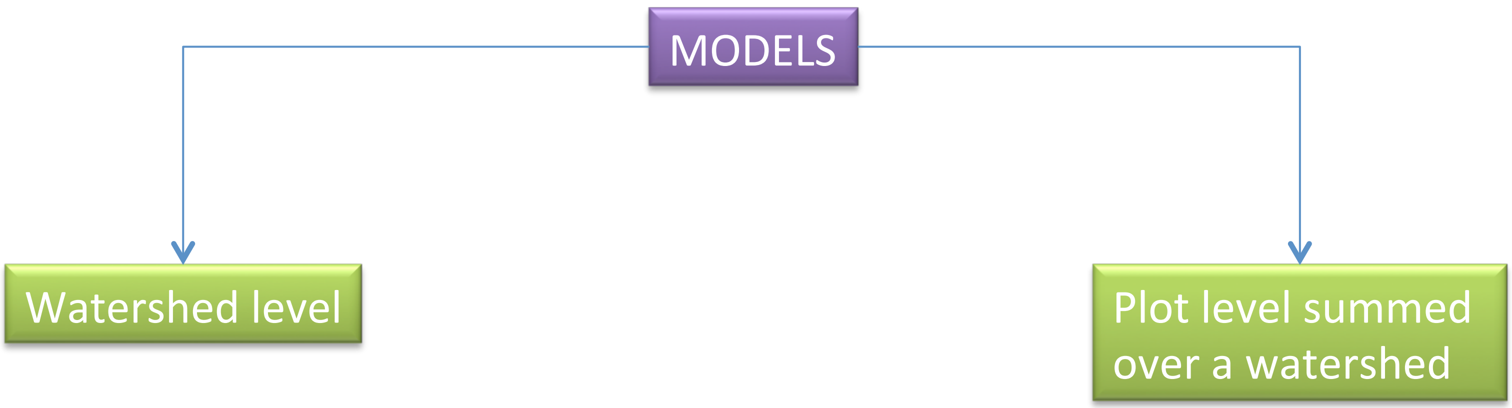
Sheet erosion: Detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a *sheet* instead of in definite channels or rills.

Rill erosion: process by which numerous sub-parallel and randomly occurring small channels are formed on slopes by running water.

Gully erosion occurs when running water erodes soil to form channels deeper than 30 cm.

How to evaluate soil erosion?

Direct measurements are complicated (sediment traps, isotopes....) thus very often modelling is used. We do not have evaluation we have estimates.



- PSIAC (Pacific Southwest Inter Agency Committee, 1968)
- Gavrilovich (1971)

- USLE (Pacific Southwest Inter Agency Committee, 1968)
- Gavrilovich (1971)

Other models have been developed which are more physically based, but they often require so many parameters that their application is complicated and, often, unprecise. An example is EUROSEM http://www.eurosem-soil-erosion.org/

Pacific Southwest

INTER-AGENCY COMMITTEE

Report of the Water Management Subcommittee

Rating of determining factors at the watershed level then conversion to sediment yield

Factor	Rating classes
Surface Geology	10-5-0
Soils	10-5-0
Climate	10-5-0
Runoff	10-5-0
Topography	20-10-0
Ground cover	10-0-(-10)
Land use	10-0-(-10)
Upland erosion	25-10-0
Channel erosion and sediment transport	25-10-0

______ Watershed ______ State ______ Condition

______ Subwatershed Name ______

______ Acres **PSIAC – 1968** Date ______

SEDIMENT YIELD FACTOR RATING

SURFACE GEOLOGY (a)	SOILS (b)	CLIMATE (c)	RUNOFF (d)	TOPOGRAPHY (e)
(10) a. Marine shales and related mudstones and siltstones	(10) a. Fine textured; easily dispersed; saline-alkaline; high shrink-swell characteristics b. Single grain silts and fine sands	(10) a. Storms of several days' duration with short periods of intense rainfall b. Frequent intense convective storms c. Freeze-thaw occurrence	(10) a. High peak flows per unit area b. Large volume of flow per unit area	(20) a. Steep upland slopes (in excess of 30%) b. High relief; little or no floodplain development
(5) a. Rocks of medium hardness b. Moderately weathered c. Moderately fractured	(5) a. Medium textured soil b. Occasional rock fragments c. Caliche layers	(5) a. Storms of moderate duration and intensity b. Infrequent convective storms	(5) a. Moderate peak flows per unit area b. Moderate volume of flow per unit area	(10) a. Moderate upland slopes (less than 20%) b. Moderate fan or floodplain development
(0) a. Massive, hard formations	(0) a. High percentage of rock fragments b. Aggregated clays c. High in organic matter	(0) a. Humid climate with rainfall of low intensity b. Precipitation in form of snow c. Arid climate, low intensity storms d. Arid climate; rare convective storms	(0) a. Low peak flows per unit area b. Low volume of runoff per unit area c. Rare runoff events	(0) a. Gentle upland slopes (less than 5%) b. Extensive alluvial plains
Factor value				

GROUND COVER (f)	LAND USE (g)	UPLAND EROSION (h)	CHANNEL EROSION AND SEDIMENT TRANSPORT (i)
(10) Ground cover does not exceed 20% a. Vegetation sparse; little or no litter b. No rock in surface soil	(10) a. More than 50% cultivated b. Almost all of area intensively grazed c. All of area recently burned	(25) a. More than 50% of the area characterized by rill and gully or landslide erosion	(25) a. Eroding banks continuously or at frequent intervals with large depths and long flow duration b. Active headcuts and degradation in tributary channels
(0) Cover not exceeding 40% a. Noticeable litter b. If trees present understory not well developed	(0) a. Less than 25% cultivated b. 50% or less recently logged c. Less than 50% intensively grazed d. Ordinary road and other construction	(10) a. About 25% of the area characterized by rill and gully or landslide erosion b. Wind erosion with deposition in stream channels	(10) a. Moderate flow depths, medium flow duration with occasionally eroding banks or bed
(−10) a. Area completely protected by vegetation, rock fragments, litter b. Little opportunity for rainfall to reach erodible material	(−10) a. No cultivation b. No recent logging c. Low intensity grazing	(0) a. No apparent signs of erosion	(0) a. Wide shallow channels with flat gradients and short flow duration b. Channels in massive rock, large boulders, or well vegetated c. Artificially controlled channels
Factor value			

Subtotal (a) – (g)	Subtotal (h) – (i)	TOTAL RATING = = ac.ft./sq. mi./yr.

(Instructions on reverse)

SHEET ______ OF ______

GENERAL INSTRUCTIONS

District Office prepares one copy for District file.

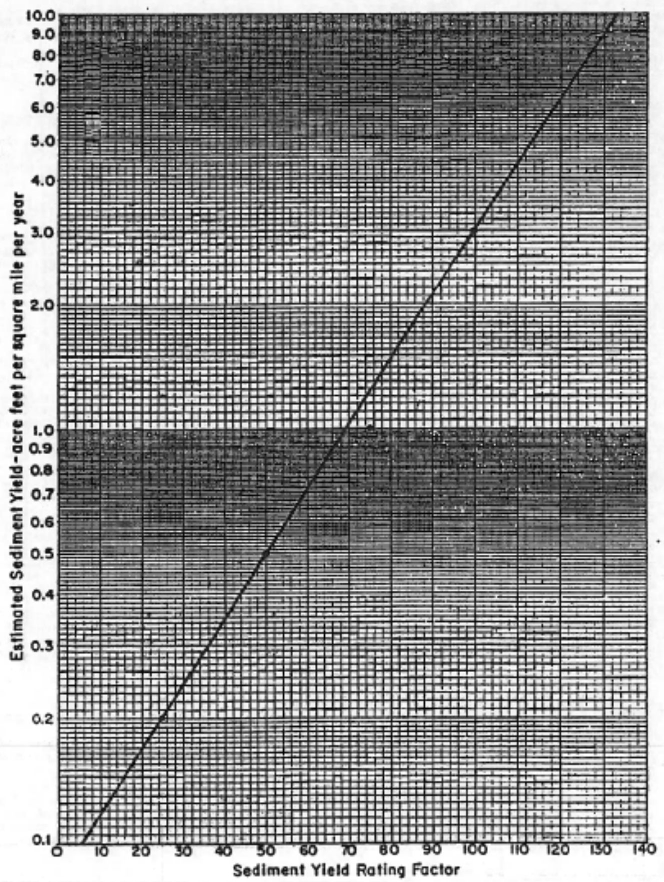
SPECIFIC INSTRUCTIONS

(Items not listed are self-explanatory)

Numbers indicate values assigned appropriate characteristics. Letters a, b, c, and d refer to independent characteristics to which full value may be assigned.

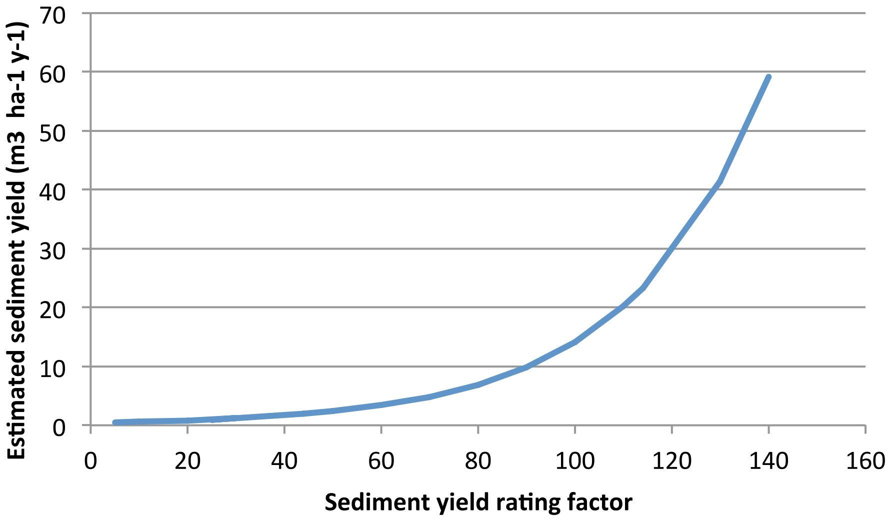
Interpolation between the sediment yield levels may be made. High values for columns (a) through (g) should correspond to high values for (h) and (i). If they do not, factors (a) through (g) should be reevaluated. If they do not correspond, then a special erosion condition exists.

Convert *Total Rating* to sediment yield by use of graph.



$Y = 0.0816\, e^{0.0353X}$

GPO 836-319



$$Y = 0.3939\, e \uparrow 0.0358\, x$$

Rating Factor	Erosion Class	Sediment yield ($m^3 ha^{-1} y^{-1}$)
> 100	1	>14.29
75-100	2	4.76-14.29
50-75	3	2.38-4.76
25-50	4	0.95-2.38
0-25	5	<2.38

1 $m^3 ha^{-1} y^{-1}$ correspond to a loss of 0.1 mm of soil

Assuming a bulk density of 1.3 T m^{-3} a loss of 1 m^3 ha^{-1} y^{-1} correspond to 1.3 T ha^{-1} y^{-1}

Gavrilovich developed a method that was applied to southern and south-eastern watersheds of Jugoslavia
The basic principles are similar to those of the PSIAC model, but a lower degree of expert judgement is required, as many ratings are found from their relationships with quantitative variables.

$$W = T \times h \times \pi \times \sqrt{Z^3} \times F$$

W = sediment yield (m^3)
T = temperature coefficient (from average mean annual temperature)
H = annual rainfall (mm)
Z = geologic-pedologic and topographic factor (obtained from tables)
F= watershed surface (Km^2)

It's an empirical model, it needs to be tested before being applied to other environments

The U.S.L.E Model

(Universal Soil Loss Equation)

$$A = R \times K \times LS \times C \times P$$

A = annual soil loss [$t\ ha^{-1}\ y^{-1}$]

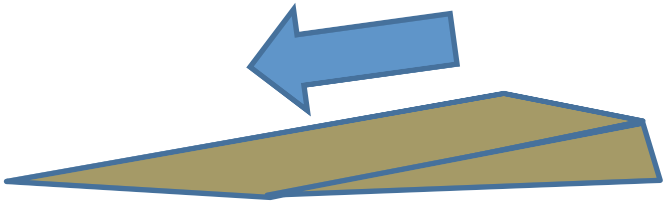
R = rainfall erosivity [$MJ\ mm\ h^{-1}\ ha^{-1}\ y^{-1}$]

K = soil erodibility [$t\ ha\ h\ MJ^{-1}\ mm^{-1}$]

LS = topographic factor

C = protection factor (land cover)

P = erosion control factor



It's an empirical equation that was originally formulated based on more than 10000 data on erosion plots in 46 areas of the Great Plains .

Since its original development (Wischmeier & Smith, 1960, 1978) it has been revised (RUSLE, 1985) to allow its application in different environments. Moreover it may be used on GIS (imprtant for topographic factors in a watershed or in a non-agricultural lanscape)

$$A = R \times K \times LS \times C \times P$$

R is the rainfall erosivity index, it takes into account both the kinetic energy of rain drops and rainfall intensity

If all other parameters are held constant, soil losses during a rainfall event are linearly related to a kinetic Energy-Intensity factor (EI). For multiple events EI values are additive.

EI indicates how particle detachment is combined with transport capacity.

$$EI = 0.119 + 0.0873 \log_{10} I$$

EI in MJ ha^{-1} mm^{-1}

$$R = EI \times I_{30}$$

I_{30} is the maximum rainfall intensity during an event of at least 30'

Practically, because of lack of rainfall data, a number of estimates have been developed

$R =$ (4.17 X MFI – 152) X 17.02 (Arnoldus, 1980)

Monthly rainfall

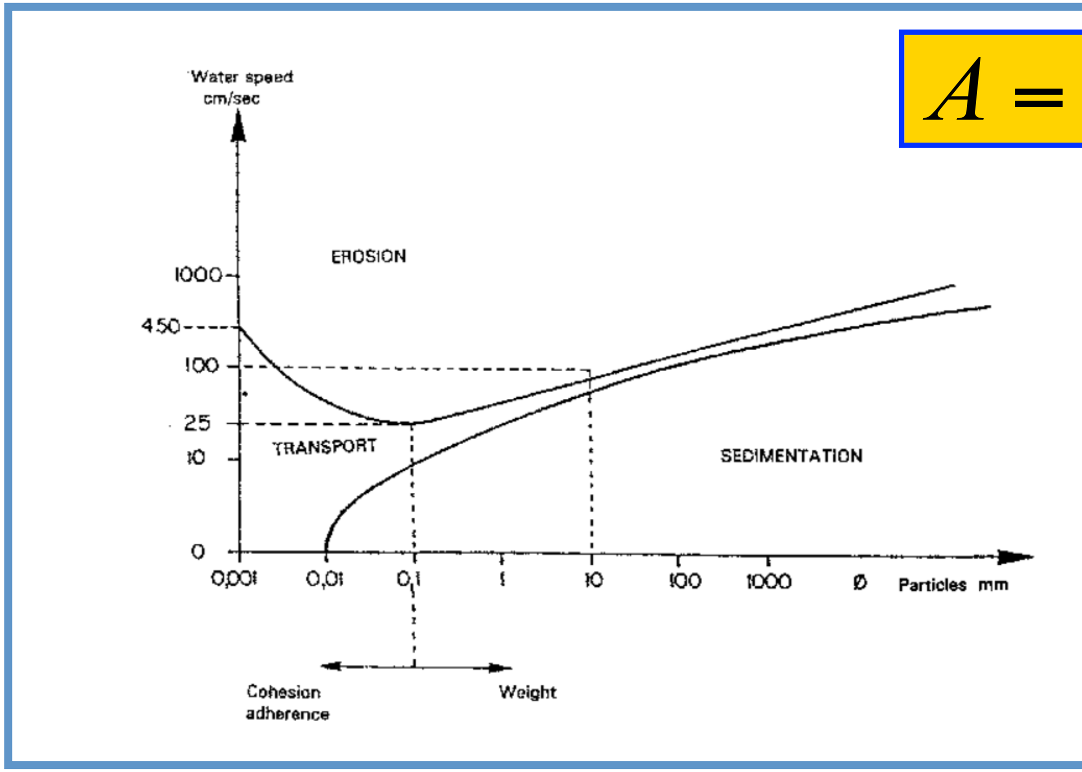
$$MFI = \sum p_i^2 / P$$

Where MFI is the *Modified Fournier Index*

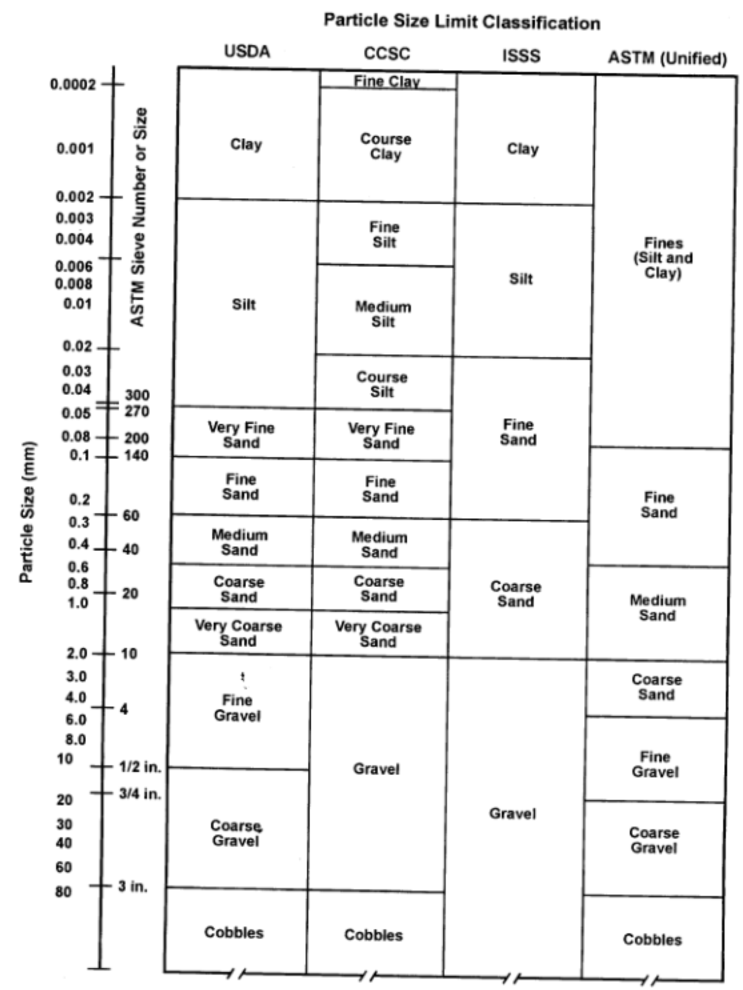
Annual rainfall

And the coefficients allow the transformation from mmm to MJ mm ha^{-1} y^{-1}

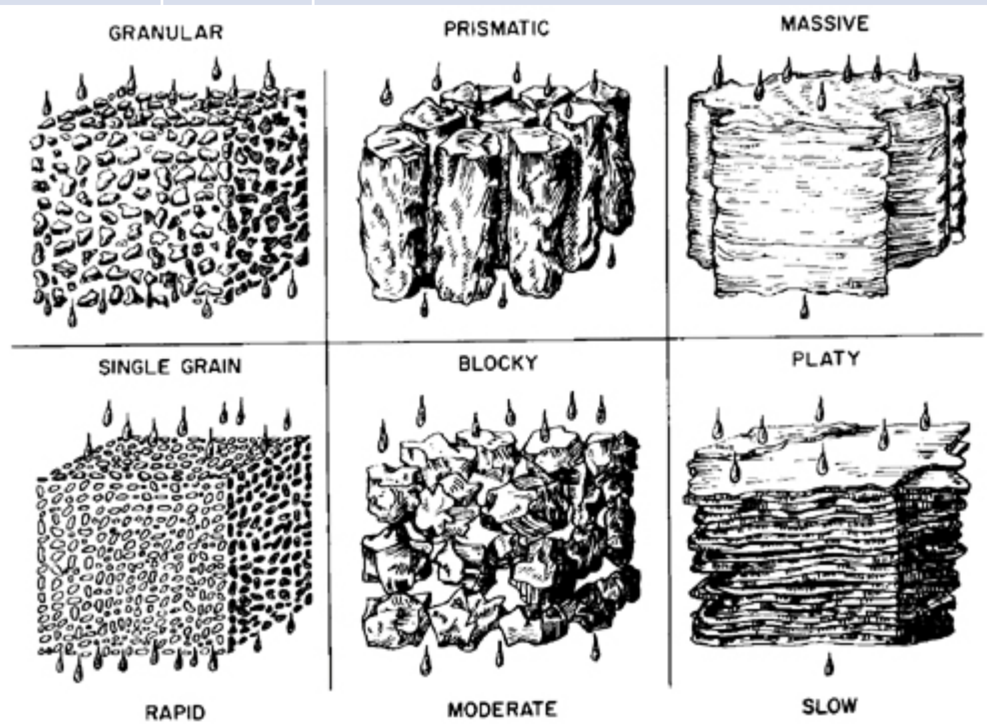
$$A = R \times K \times LS \times C \times P$$



- Very fine sand (0.1-0.05 mm) is the most sensitive to erosion particle size class. Silt (0.05-0.002 mm) is also easily eroded. In addition soil texture affects soil permeability.
- Aggregation contrasts splash erosion and organic matter is the most important aggregating agent in many soils.
- Aggregation is visible in the field through soil structure. Structure also affects permeability



Soil pemeability (P)		Soil structure (S)	
1	Fast (> 12.7 cm h^{-1})	1	Very fine granular
2	From moderate to fast (6.4-12.7 cm h^{-1})	2	Fine granular
3	Moderate (2.0-6.4 cm h^{-1})	3	Medium granular
4	From slow to moderate (0.5-2.0 cm h^{-1})	4	Blocky, platy or massive
5	Slow (0.1-0.5 cm h^{-1})		
6	Very slow (<0.1 cm h^{-1})		



P and S are highly interrelated!

P depends on soil texture and soil structure.
S in turns depends on texture, organic matter and other factors such as biotic activity (e.g earthworms) and man

$$A = R \times K \times LS \times C \times P$$

K (soil erodibility) in T h MJ^{-1} mm^{-1}

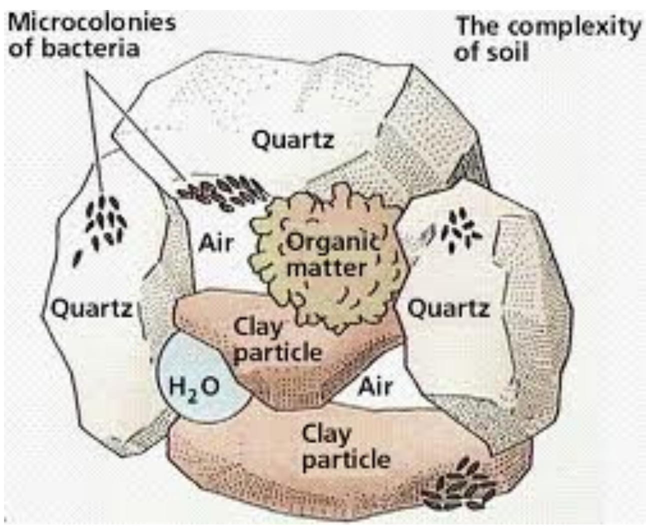
$$K = 2.1\times10^{-4}\times(12-OM)\times M^{1.14}+3.25\times(S-2)+2.5\times(P-3)/7.59\times100$$

Where OM is soil organic matter

M is (silt + very fine sand) x (100 – clay)

P ranges from 1 to 6 increasing with decreasing soil permeability
S ranges from 1 to 4 depending on soil structure

Wang et al., 2001

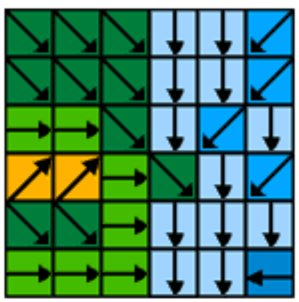


$$A = R \times K \times LS \times C \times P$$

Erosion increases with increasing lenghth and slope. LS is a dimensionless topographic factor, it takes into account the length and the slope of the plot

It is now computed using GIS that allow the calculation of the additional parameters related to erosion.

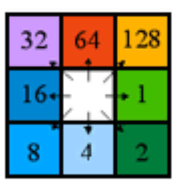
Flow accumulation (F) represents the n of cells contributing flow to a specific cell



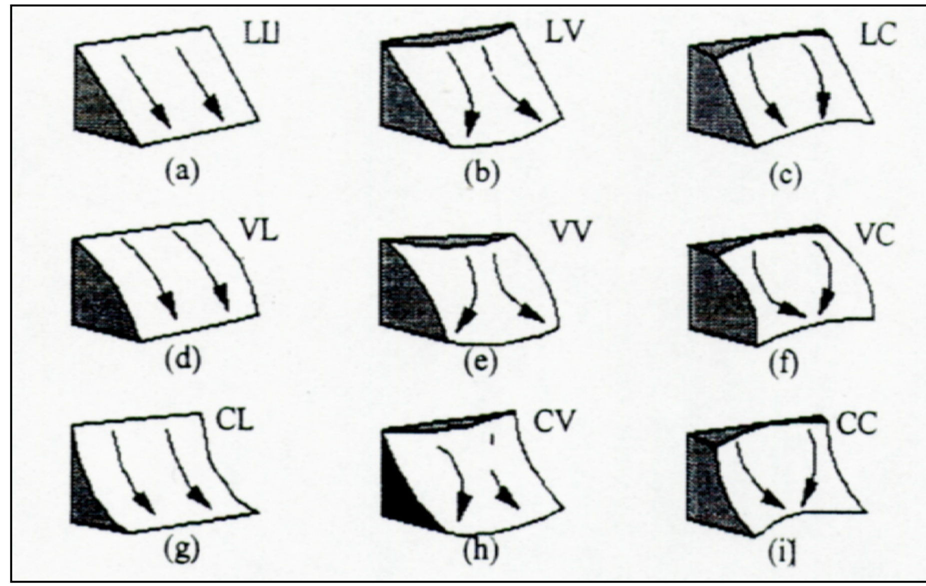
Flow direction

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Flow accumulation



Direction coding



$$LS=(F\times C/22.13)^{0.4}\times(\sin S/0.09)^{1.3}$$

C length of cell side

S slope

$$A = R \times K \times LS \times C \times P$$

The C factor takes into account soil cover and the protection offered towards erosion. Practically it's the ratio between soil losses under a specific land use and the losses from a bare soil surface.

Forest land use	C	
Shrubs	0.05	Stone & Hilborn, 2000
Mixed forests, 75-100% canopy cover, 90-100 % ground cover by litter	0.002	Wischmeier & Smith, 1978
Mixed forests, 45-70% canopy cover, 75-85 % ground cover by litter	0.003	Wischmeier & Smith, 1978
Mixed forests, 20-40% canopy cover, 40-70 % ground cover by litter	0.007	Wischmeier & Smith, 1978
Grasslands and pastures	0.02	Stone & Hilborn, 2000
Sparse vegetation and areas with frequent wildfires	0.3	Stone & Hilborn, 2000

$$A = R \times K \times LS \times C \times P$$

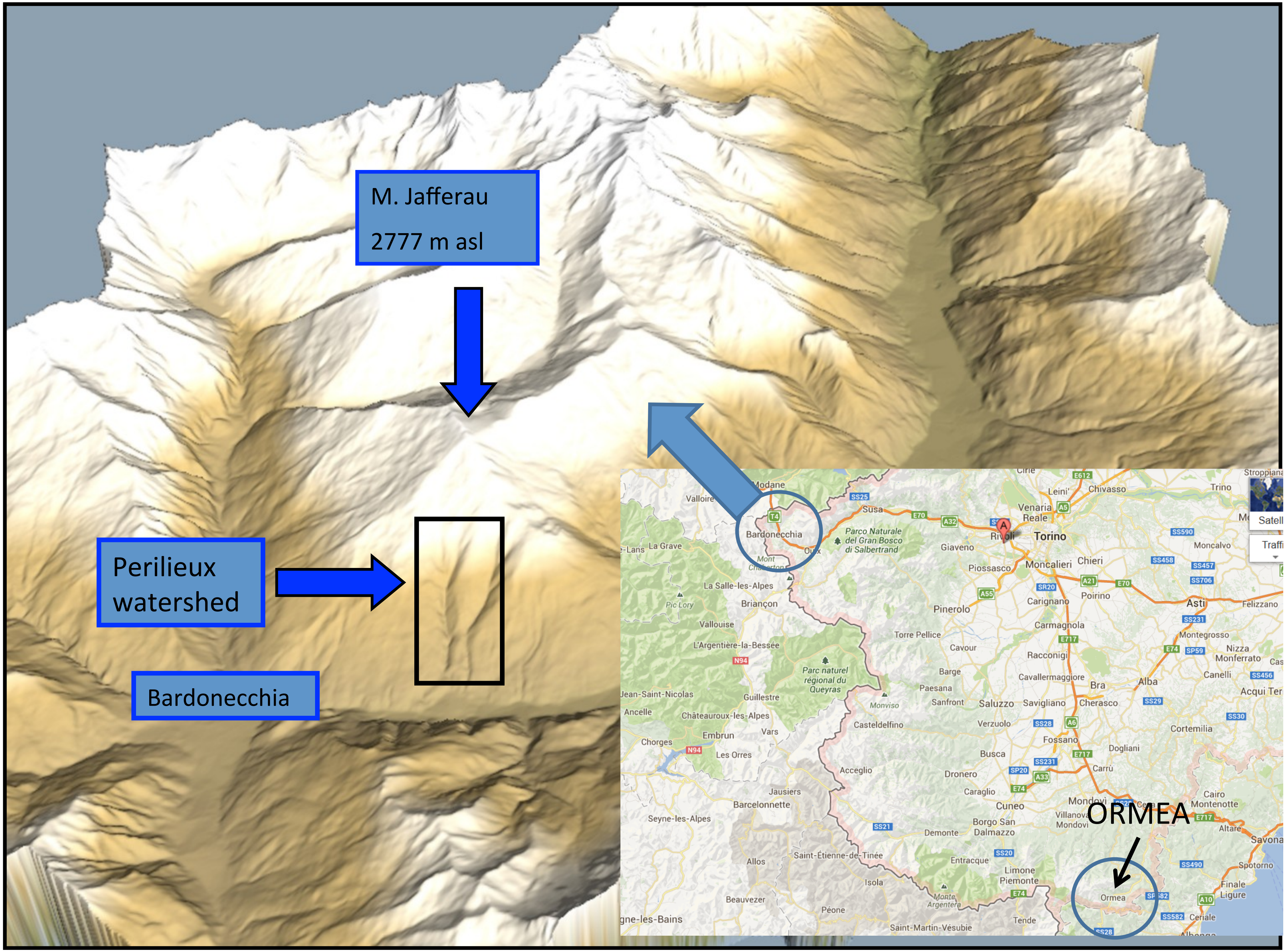
How to apply the USLE equation to a watershed? → Land Mapping Units

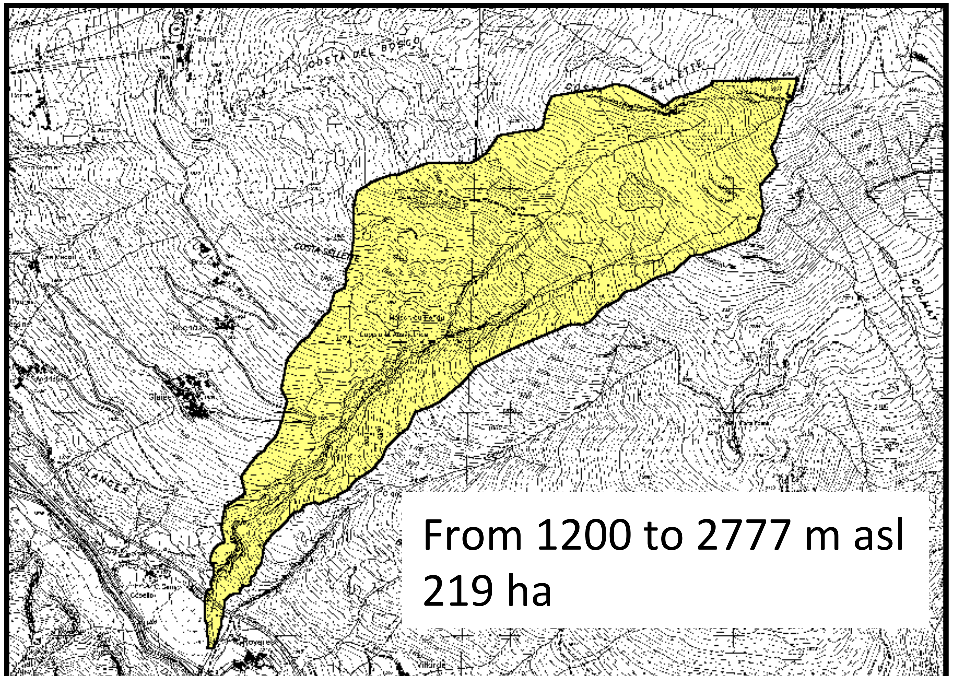
A LMU is a portion of the earth surface that is homogeneous for all properties under consideration

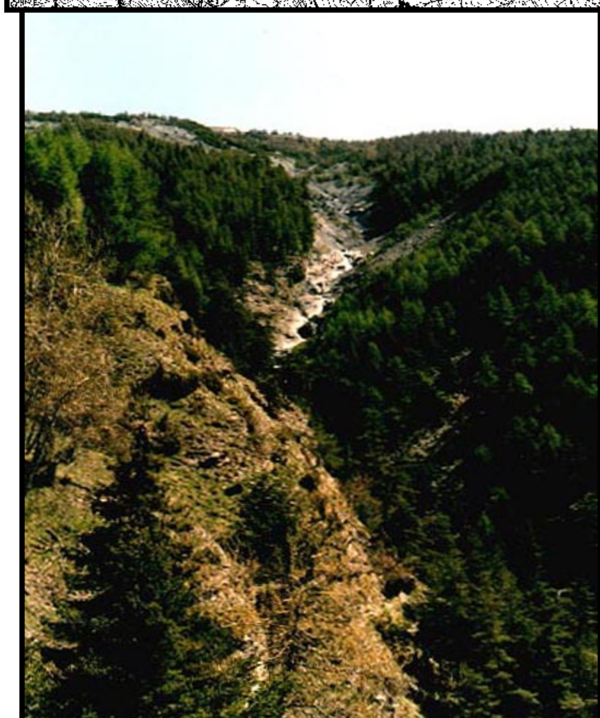
K: Soil particle size distribution and organic matter

Parent material
Topography (slope class)
Vegetation
Climate
Time

C: land cover/land use

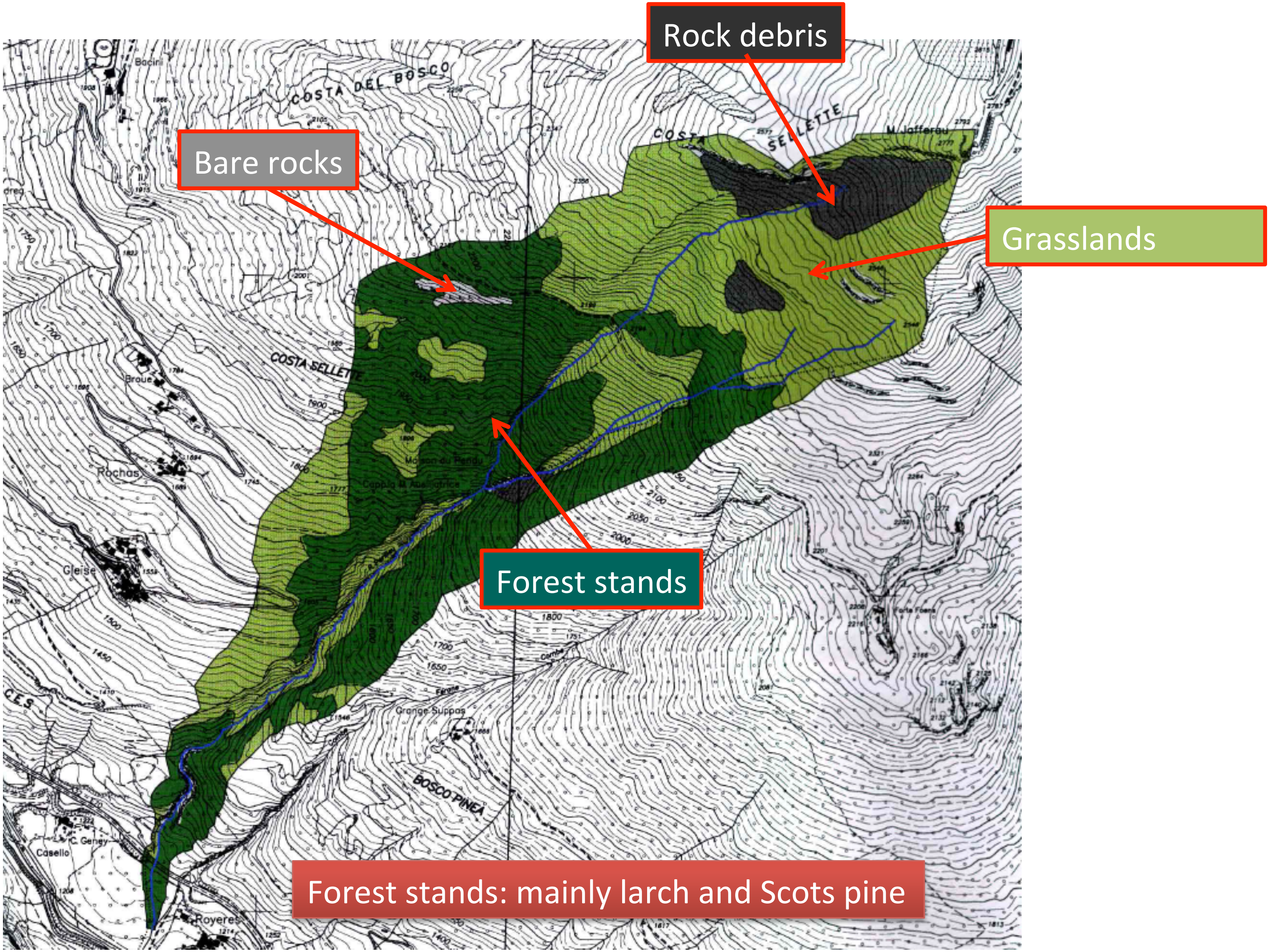

M. Jafferau
2777 m asl
Perilieux watershed
Bardonecchia
ORMEA
Bardonecchia
Torino
Ormea

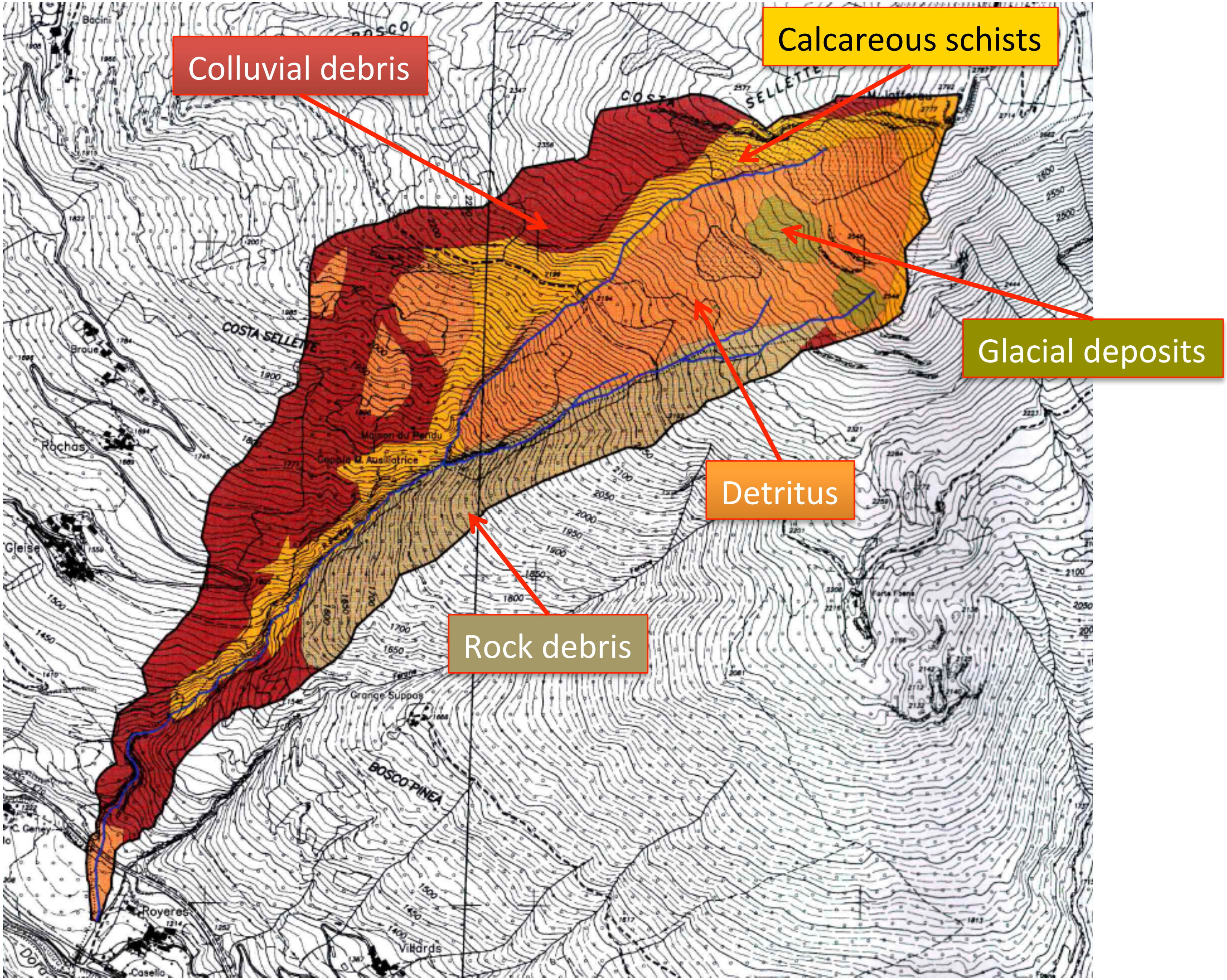




Climatic data, Bardonecchia (30 years)

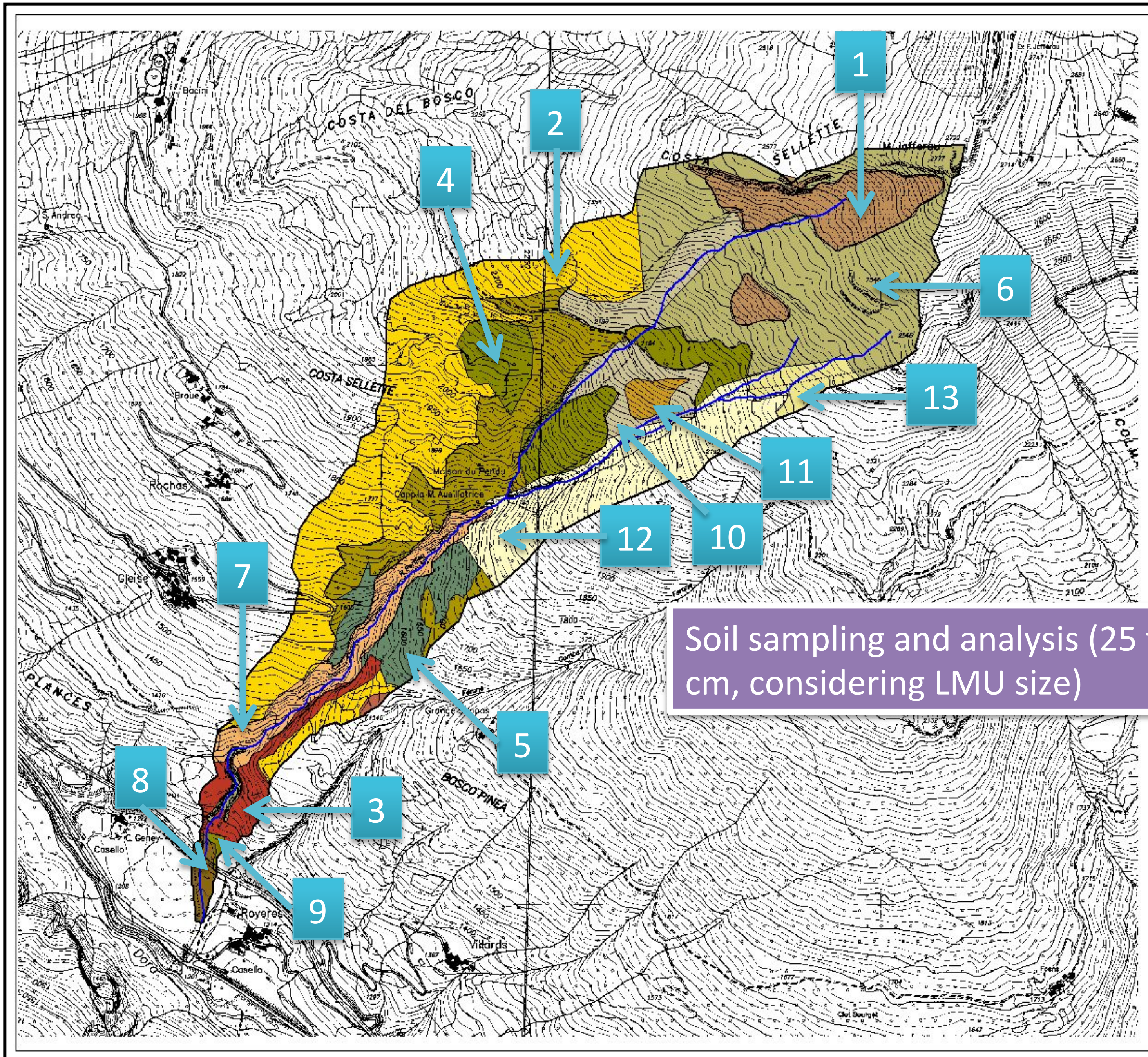
Month	Rainfall (mm)	Average Temp. (°C)
January	51	3.1
Febraury	53	3.4
March	54	5.4
April	64	8.7
May	76	12.2
June	65	15.5
July	40	18.6
August	50	17.7
September	63	15.2
October	81	12.4
November	73	6.3
December	54	4.0


Rock debris
Bare rocks
Grasslands
Forest stands
COSTA DEL BOSCO
COSTA SELLETTE
COSTA SELLETTE
M. Jafferau
Broue
Rochas
Gleise
Caselle
Royeres
Grange Suppas
BOSCO PINEA
Forest stands: mainly larch and Scots pine

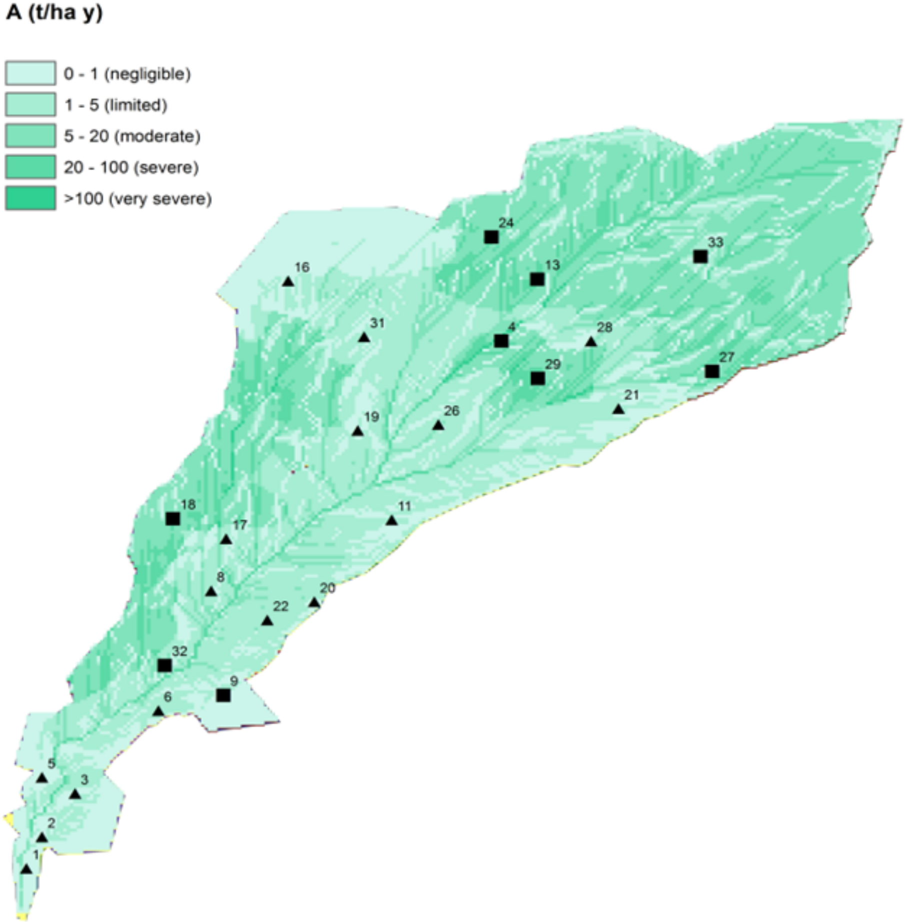

Colluvial debris
Calcareous schists
Glacial deposits
Detritus
Rock debris
COSTA SELLETTE
Rochas
Gleise
Broue
BOSCO PINEA
Grange Suppos
Royeres
Villards

	Forest stands			Grassland			Bare Rocks
Slope	*0-16*	*16-32*	*32-48*	*0-16*	*16-32*	*32-48*	
Colluvial debris	1	2	3				
Calcareous schists		4	5	6	7		
Glacial deposits							
Detritus	8	9			10	11	
Rock debris	12				13		

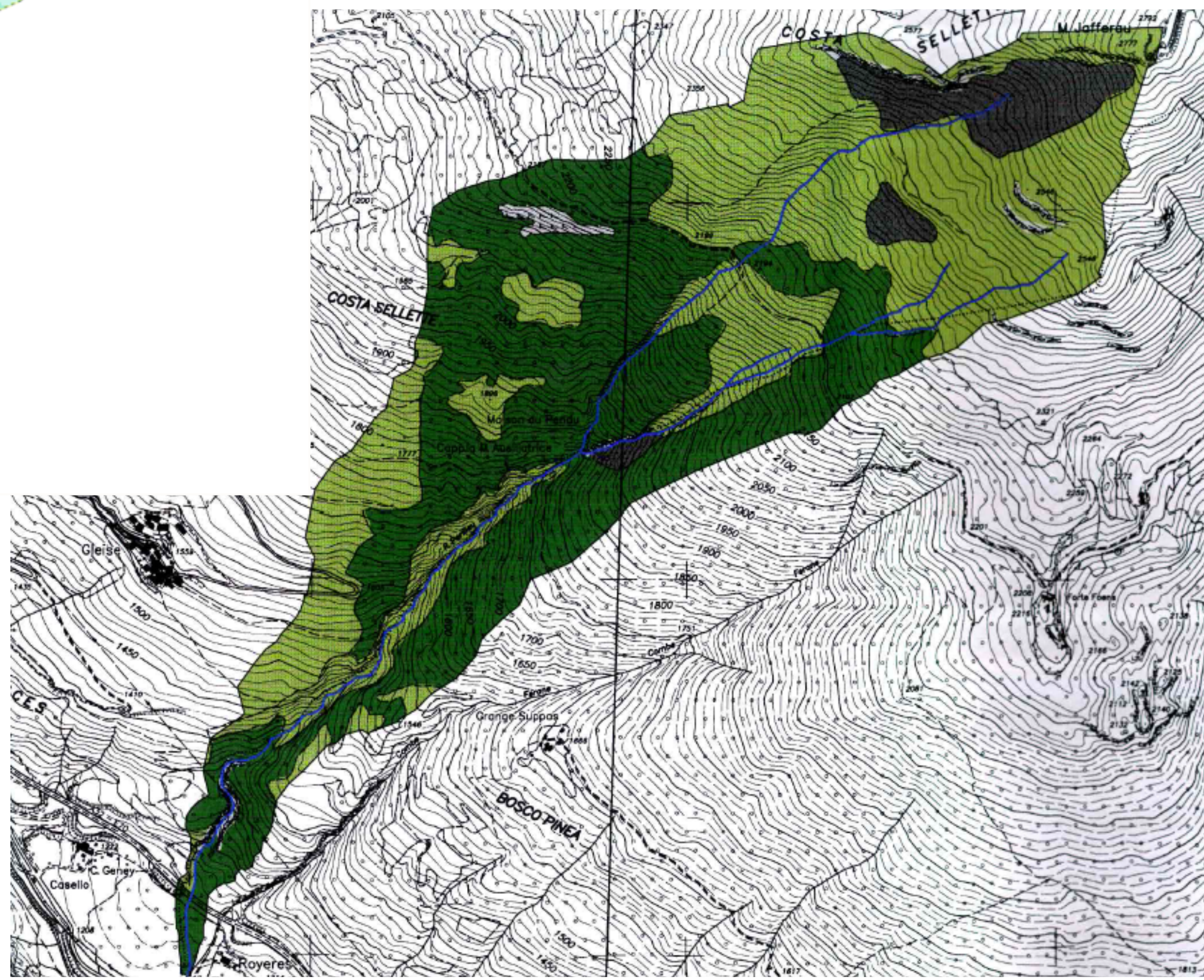
13 Land Mapping Units where soils are expected to have similar characteristics and protection by land cover towards erosion is expected to be the same



Soil sampling and analysis (25 topsoils 0-10 cm, considering LMU size)

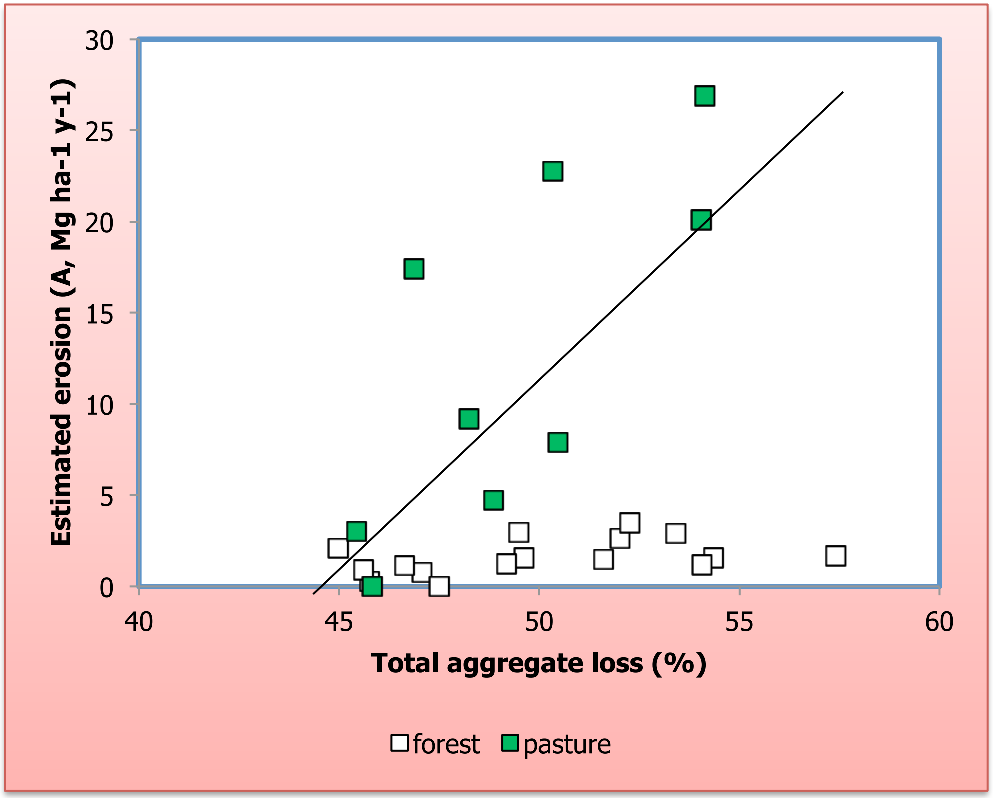


Which land use is the most senitive to erosion?



Aggregates can build up and become stable only if erosion does not impede their development

Aggregate stability should not only reflect erodibility but also be a proxy for soil erosion



Only in pastures, not in forest soils!

Possible effect of organic layers thickness and quality (humus forms) in protecting mineral topsoils from erosion

But RUSLE poorly takes this into account....