Unit 9:
Risk Assessment of Soil Erosion

H.P. Nachtnebel

IWHW-BOKU

Structure of presentation

- Objectives and background information
- Process analysis
- Analysis of loads
- Analysis of impacts
- Summary and conclusion

Objectives

- Objective: assessment of soil erosion risk
  - Estimate loads
  - Estimate impacts
  - Quantify erosion risk

Background

- Background
  - Types of water induced erosion

Gully erosion

Background

- Background
  - Types of water induced erosion

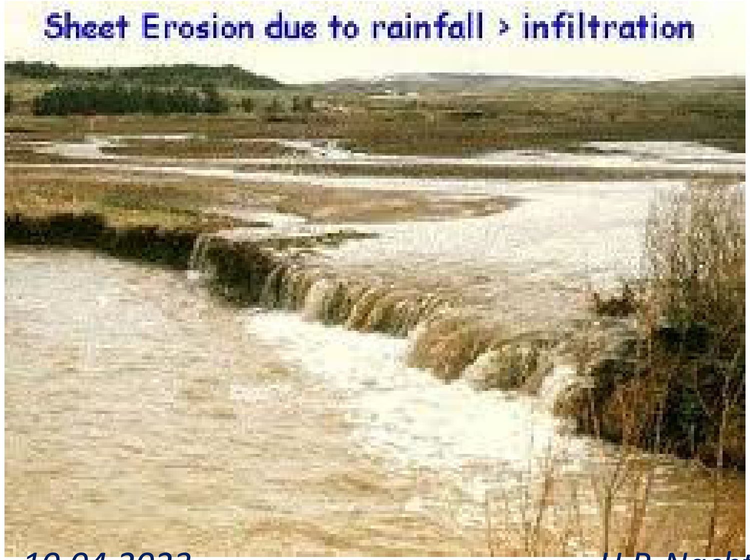
Gully erosion

Rill erosion

Background

- Background
  - Types of water induced erosion

Gully erosion
Rill erosion
Sheet erosion



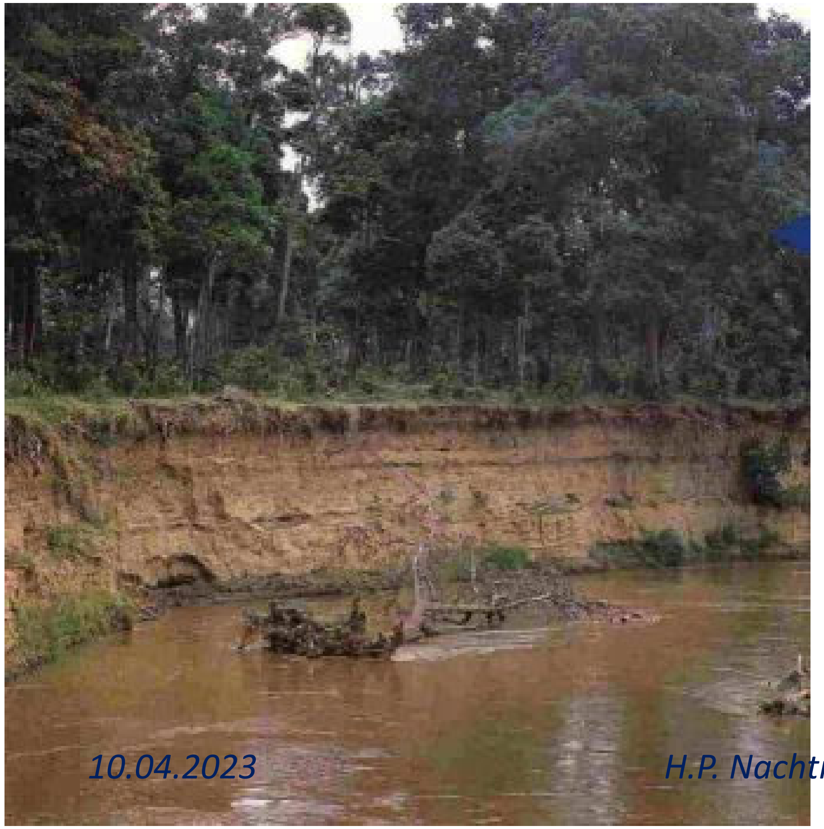
Background

- Background
  - Types of water induced erosion

Gully erosion
Rill erosion
Sheet erosion
Local slope erosion and mud flow

Objectives and background

- Objective: assessment of sol erosion risk
- Background
  - Types of water induced erosion



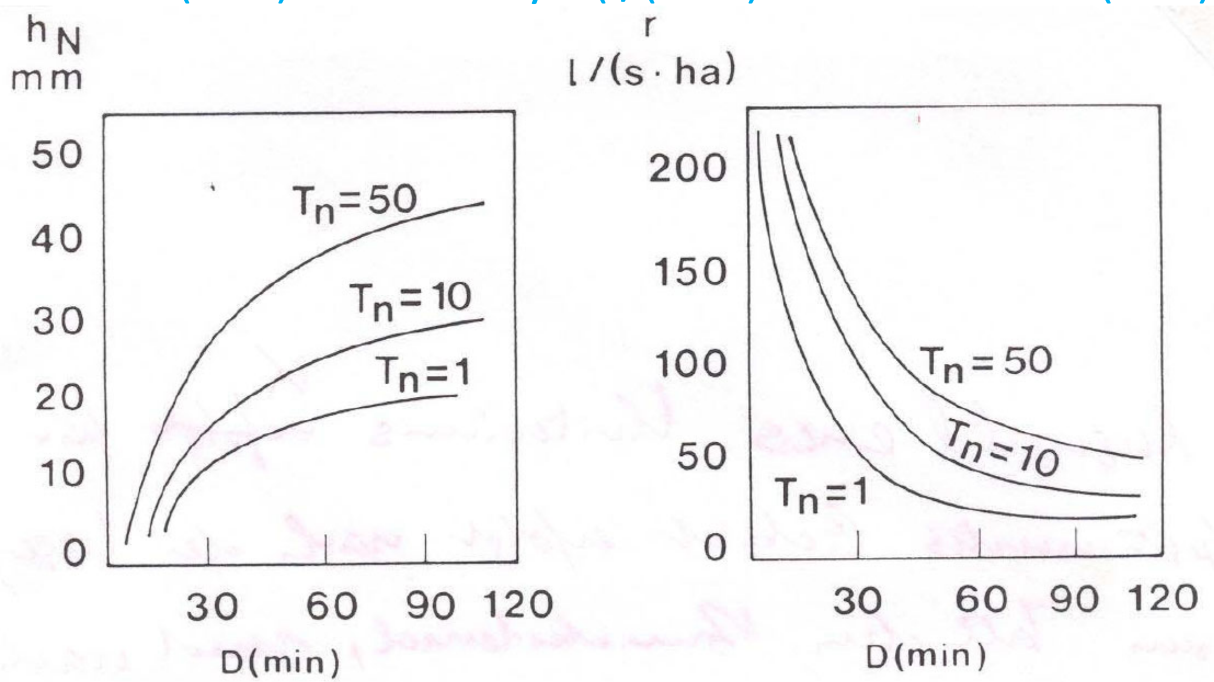
Gully erosion
Rill erosion
Sheet erosion
Local slope erosion
Bank erosion

Drivers of erosion

- Heavy rainfall events
- Inclined terrain
- Low resistance of plant layer

Analysis of loads

- Erosion is driven by precipitation (R) and /or runoff
- Statistics of erosive rainfall events (amount, duration, intensity, drop size)
  - High intensity rainfall events quaraterized by amount h(mm) and duration D(min) or intensity r (l/(s.ha) and duration D(min)



Consequences/Impacts

- Removal of fertile top soil
- Degradation of soil layers
- Losses in agricultural production
- Adverse impacts on surface water bodies due to high inputs of nutrients
- Some figures
  - 92,8 Mio ha suffer in Europe from loss of top soil (JRC, 2000)

Con

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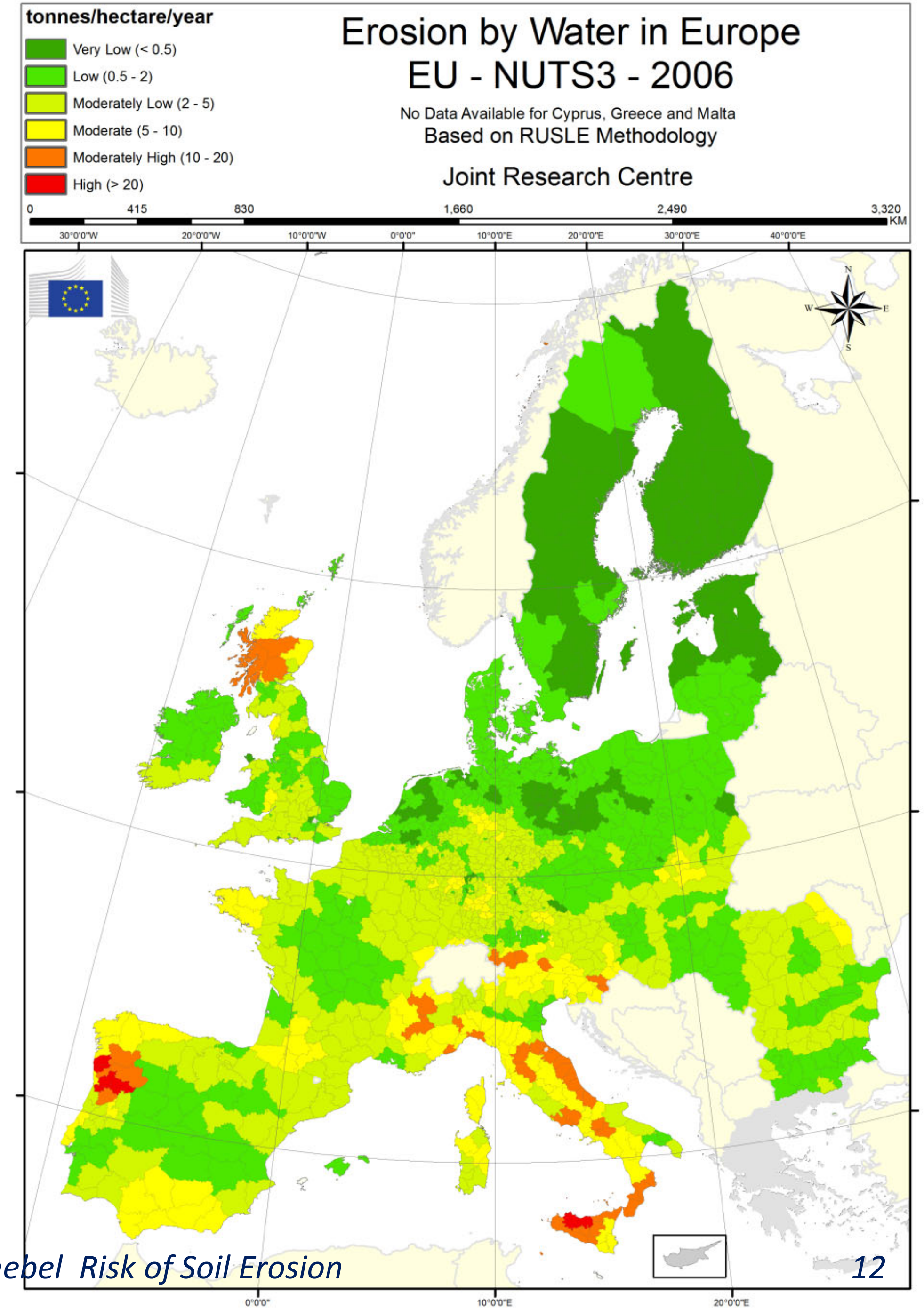

Estimation of soil losses

– **physically-based models**

AGNPS (Young et al., 1987),
ANSWERS (Beasley et al ., 1980)
WEPP (Nearing et al ., 1989).

– **empirical models**

Universal Soil Loss Equation (USLE) (Musgrave, 1947),

Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975),

Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1991)

Analysis of impacts (loss function)

- Exposition: slope factor L, slope length factor S
- Vulnerability: soil erodibility factor K, cover factor C
- Response functions
  different models are applied
  - USLE: A(mean annual soil loss)= R*K*L*S*C
    - A : Mean (annual) soil loss (t/ha*a)
    - R : Rainfall erosivity factor (MJ mm ha^{-1} hr^{-1})
    - K : Soil erodibility factor (t ha hr MJ^{-1} ha^{-1} mm^{-1})
    - L : Slope factor
    - S : Slope length factor
    - C : Cover management factor
  - RUSLE
  - MUSLE
  - Models (WEPP,...)

USLE & RUSLE

- The Universal Soil Loss Equation **(USLE)** predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion.
- **RUSLE** has the same formula as USLE, but has several improvements in determining factors. These include some new and revised iso-erodential maps; a time-varying approach for soil erodibility factor; a subfactor approach for evaluating the cover-management factor; a new equation to reflect slope length and steepness; and new conservation-practice values (Renard, et al., 1997).
- Agriculture Handbook (No. 703; 1997) by the U.S. Department of Agriculture

Discussion of factors: driver

R: Rainfall erosivity factor

- R = 10 (-1.48 + 1.48 *NS) Bavaria (Rogler&Schwertmann)
  NS (mm rainfall May-Oct)
- R = α*Pa
  Pa annual rainfall in mm Tuscany (Zanchi)
  $\alpha = $ 1.1-1.5

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R: Rai

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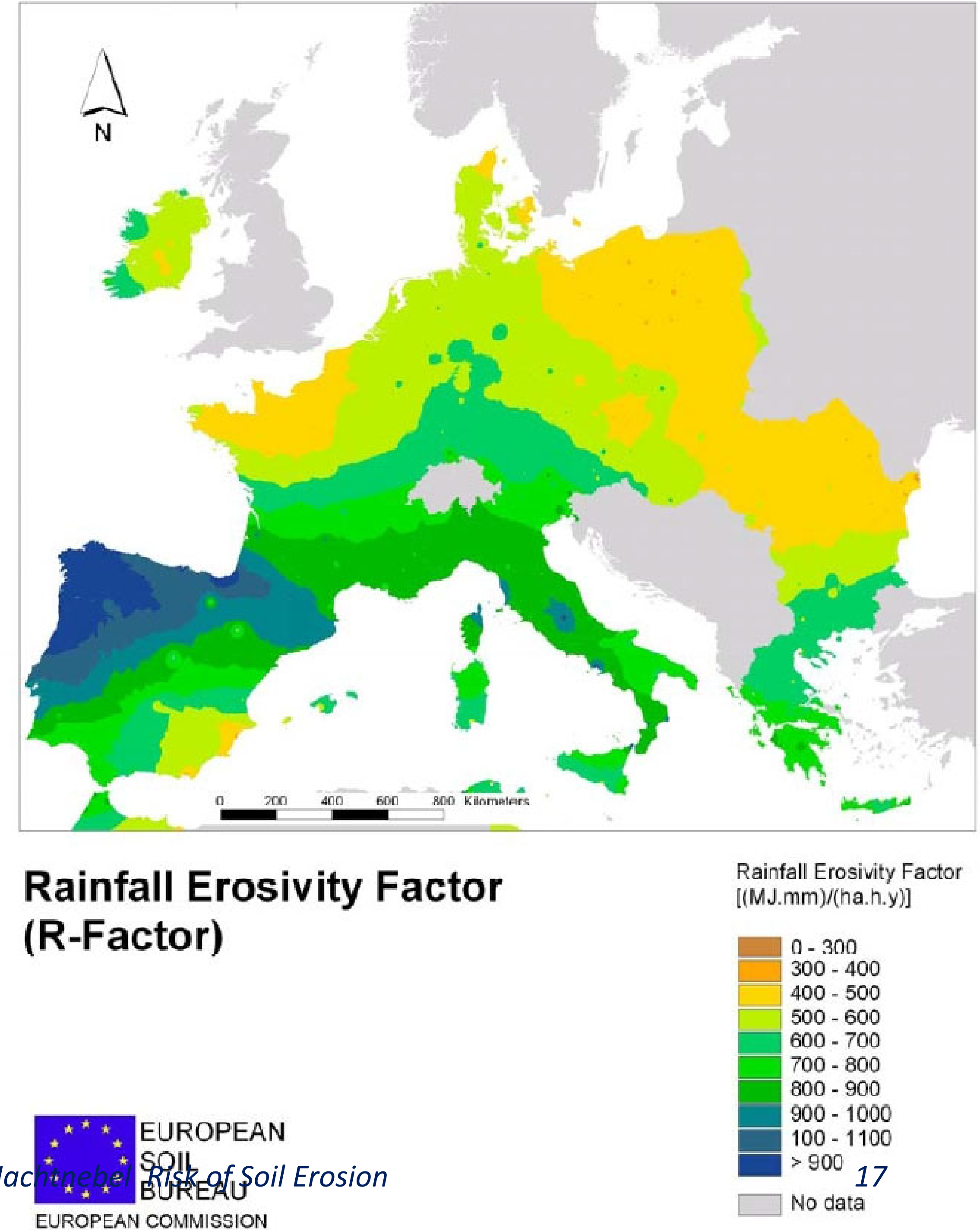

Soil erodibility factor

- The K-factor, which expresses the susceptibility of a soil to erode, is related to soil properties such as organic matter content, soil texture, soil structure and permeability.
- The K-factor is a lumped parameter that represents an integrated annual value of the soil profile reaction to the process of soil detachment and transport by raindrops and surface flow (Renard et al., 1997).
- Since 2009 a pan-European high resolution soil dataset (500 m) is available for the first time, consisting of around 20,000 points across 25 Member States of the European Union.
- See LUCAS (Land Use/Cover Area frame Survey).

Discussion of factors: Resistance

K: soil erodibility factor

- The *K* factor is defined as the rate of soil loss per unit of *R* as measured on a unit plot (‘Wischmeier plot’). It accounts for the influence of soil properties on soil loss during storm events (Renard *et al.*, 1997).
- Römkens et. al. (1986) based on regression analysis (revised in Renard *et al.*, 1997):

$$K = 0.0034 + 0.0405 \cdot \exp[-0.5(\frac{\log D_g + 1.659}{0.7101})^2]$$

K : Soil erodibility factor

Dg : Geometric mean weight diameter of the primary soil particles (mm)

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Discussion of factors: Resistance

K: soil erodibility factor

- $K = [(2.1 \times 10^{-4} M^{1.14} (12 – OM) +3.25 (s -2) + 2.5 (p - 3)) / 100] * 0.1317$
- K [(t ha h)/(ha MJ mm)]
- M : the textural factor with $M = (m_{silt} + m_{vfs}) * (100 - m_c)$;
- m_c [%]: clay fraction content (<0.002 mm);
- m_{silt} [%]: silt fraction content (0.002 – 0.05 mm);
- m_{vfs} [%]: very fine sand fraction content (0.05 – 0.1 mm);
- OM [%]: the organic matter content;
- s: the soil structure class (s=1: very fine granular, s=2: fine granular, s=3, medium or coarse granular, s=4: blocky, platy or massive);
- p: the permeability class (p=1: very rapid, …, p=6: very slow).

- Conclusion:
- K is low when M is low (high clay fraction)
- K is low when OM is high (high organic matter)
- K is low when when p is low (high permeability)

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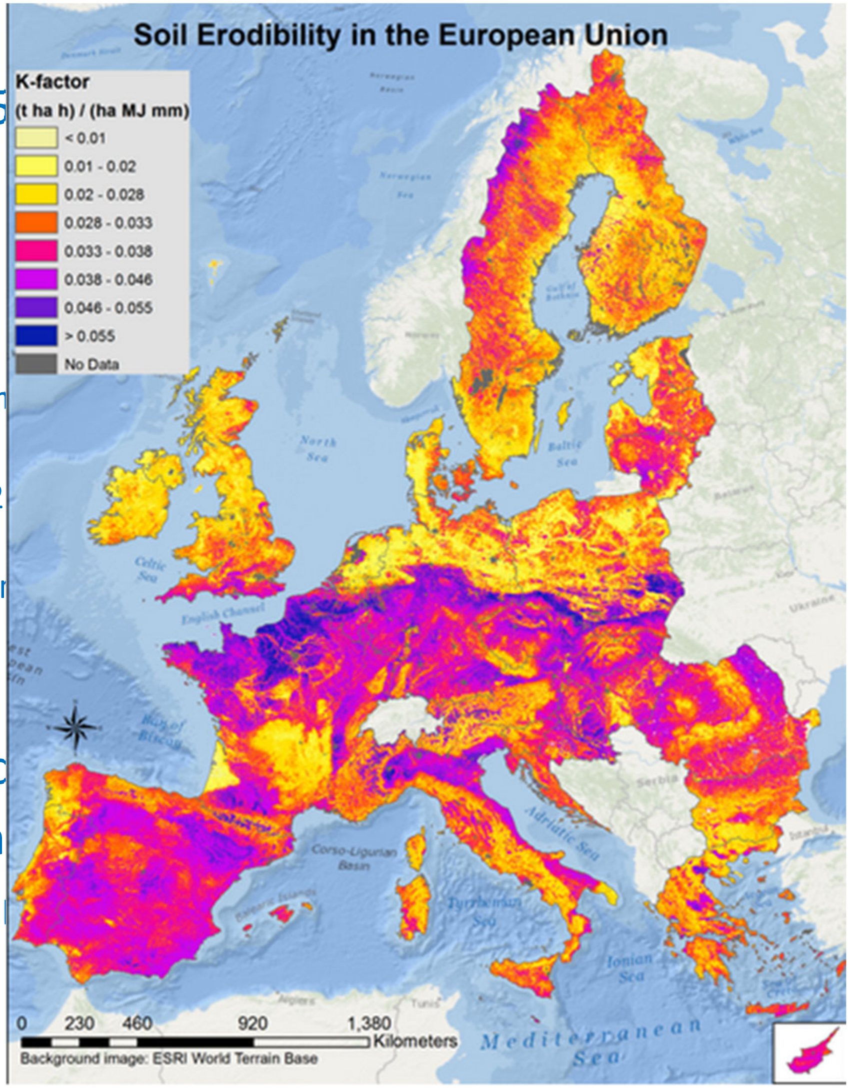

Discussion of factors: Vulnerability

S and L: slope factors

- The slope- and slope length factors (*S* and *L*, respectively) account for the effect of topography on soil erosion.

Discussion of factors: Vulnerability

L: slope factor

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$$L = 1.4\left(\frac{A_s}{22.13}\right)^{0.4}$$

$$S = \left(\frac{\sin\beta}{0.0896}\right)^{1.3}$$

As : Specific contributing area (m^2/m)

β : Slope angle (degrees)

- Slope was estimated using a 1-km resolution digital elevation model (DEM) of Europe. A_s was set to a constant value of 50 metres because the 1-km DEM is simply too coarse for assessing this variable

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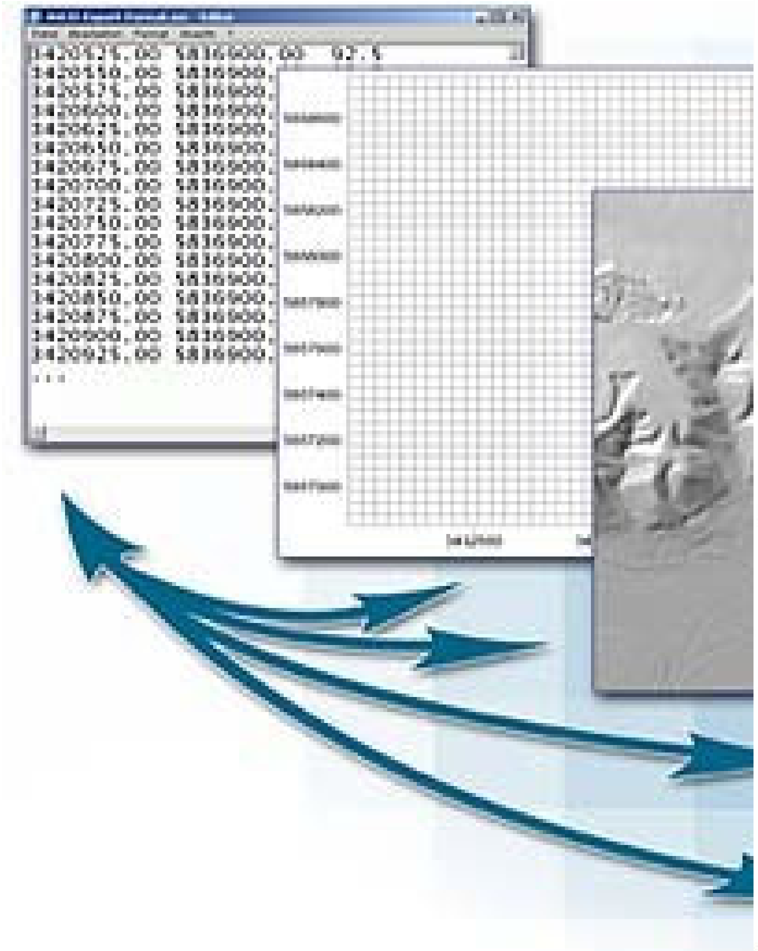
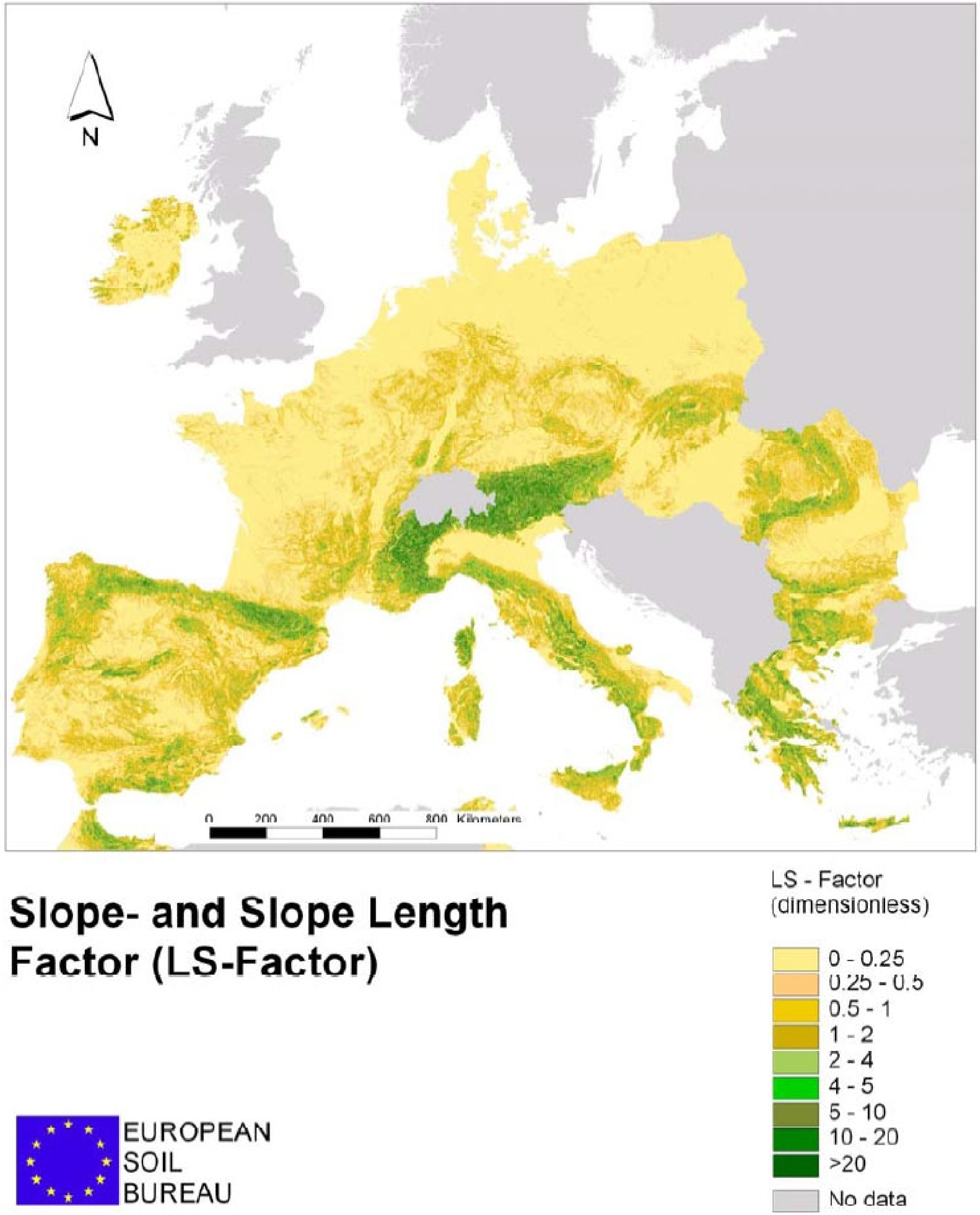
- The slope- and slope l
  account for the effect





Discussion of factors: Resistance

C: cover management factor

- Vegetation cover is – after topography – the second most important factor that controls soil erosion risk.
- The C-factor is defined as the ratio of soil loss from land with a specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier & Smith, 1978). Its value depends on vegetation cover and management practices.

Discussion of factors: Resistance

C: cover management factor

Continuous urban fabric
Discontinuous urban fabric
Industrial or commercial units
Road and rail networks and associated land
Port areas
Airports
Mineral extraction sites
Dump sites
Construction sites
Green urban areas
Sport and leisure facilities
Non-irrigated arable land
Permanently irrigated land
Rice fields
Vineyards
Fruit trees and berry plantations
Olive groves
Pastures
Annual crops associated with permanent crops
Complex cultivation patterns
Land principally occupied by agriculture with significant areas
Agro-forestry areas
Broad-leaved forest
Coniferous forest
Mixed forest
Natural grasslands
Moors and heathland
Sclerophyllous vegetation
Transitional woodland-shrub
Beaches - dunes - sands
Bare rocks
Sparsely vegetated areas
Burnt areas
Glaciers and perpetual snow
Inland marshes
Peat bogs
Salt marshes
Salines
Intertidal flats

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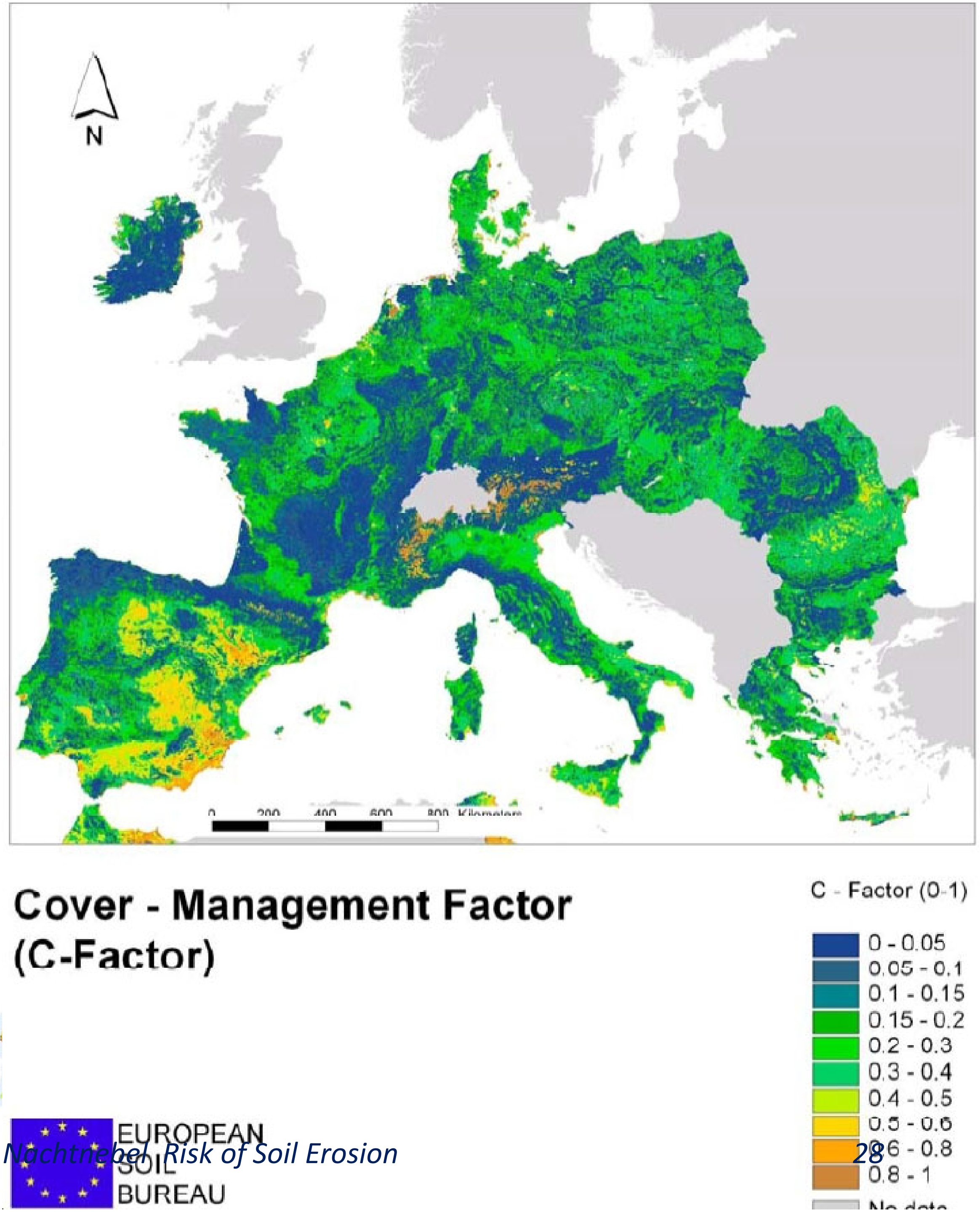

Application

- The published factors dependend on the units (US, SI)

Dimensions of universal soil loss equation (USLE) factors

Factor	Symbol	Dimensions		Typical U.S. customary units
Rainfall intensity	i or I	[1] $\frac{length}{time}$	$\frac{L}{T}$	$\frac{inch}{hour}$
Rainfall energy per unit of rainfall	e	$\frac{length \cdot force}{area \cdot length}$	$\frac{LF}{L^2 L}$	[2] $\frac{foot \cdot tonf}{acre \cdot inch}$
Storm erosivity	EI	$\frac{length \cdot force \cdot length}{area \cdot time}$	$\frac{LFL}{L^2 T}$	[3] $\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour}$
Soil loss	A	$\frac{mass}{area \cdot time}$	$\frac{M}{L^2 T}$	$\frac{ton}{acre \cdot year}$
Annual erosivity	R	$\frac{length \cdot force \cdot length}{area \cdot time \cdot time}$	$\frac{LFL}{L^2 TT}$	$\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour \cdot year}$
Soil erodibility	K	$\frac{mass \cdot area \cdot time}{area \cdot length \cdot force \cdot length}$	$\frac{ML^2 T}{L^2 LFL}$	$\frac{ton \cdot acre \cdot hour}{hundreds\ of\ acre \cdot foot \cdot tonf \cdot inch}$

Application

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Slope length	L	$\left(\frac{length}{length}\right)^m$	$\left(\frac{L}{L}\right)^m$
Slope steepness	S	Dimensionless	
Cover-management	C	Dimensionless	
Supporting practices	P	Dimensionless	

[1]F=forces, L=length, M=mass, T=time, m=exponent that varies from 0.2 to 0.5
[2]Tonf indicates ton force. Ton without a subscript indicates ton.
[3]This notation, "hundreds of," means that the numerical value of the factor is 0.01 times its true value. That is, if R=125, its true value is 12,500 ft· tonf· in $(acre \cdot h \cdot yr)^{-1}$. The converse is true for "hundreds of" in the denominator of a fraction.

Source: Foster et al., 1981.

Results

- By combining all these factors an „Actual Soil Erosion Estimate“ (longterm mean annual erosion rate) is obtained

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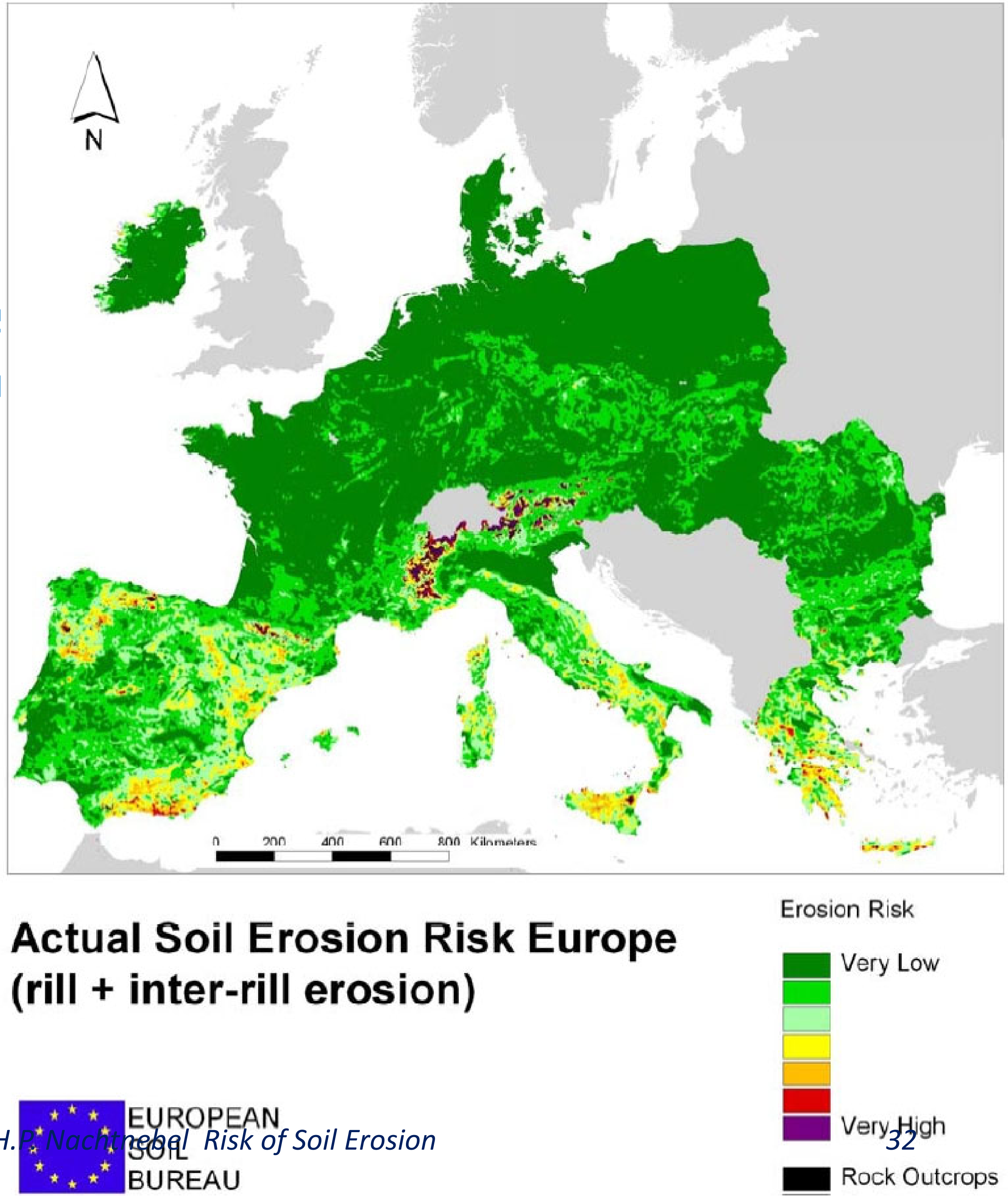
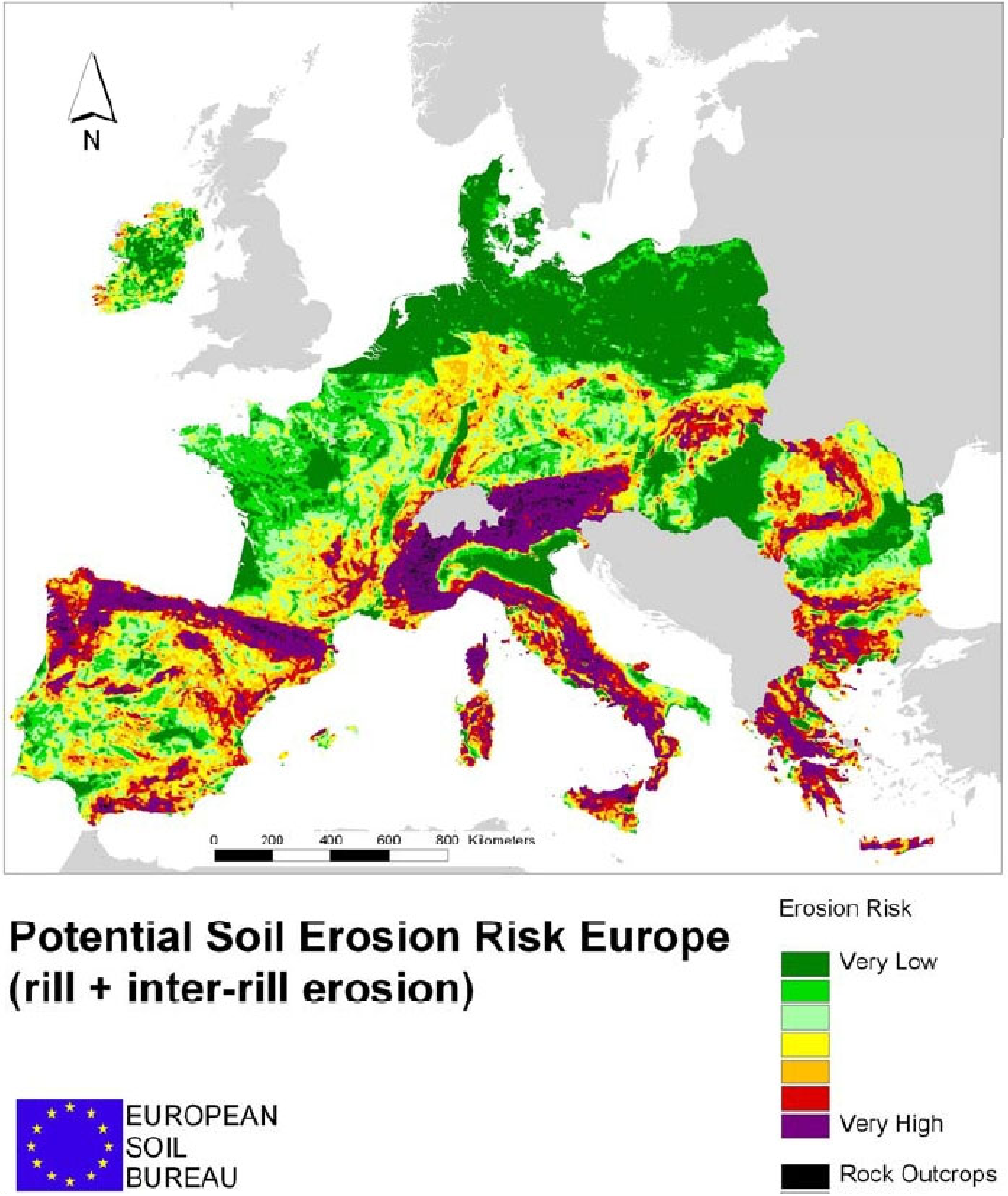
Estimate“ (longterm



Actual Soil Erosion Risk Europe (rill + inter-rill erosion)

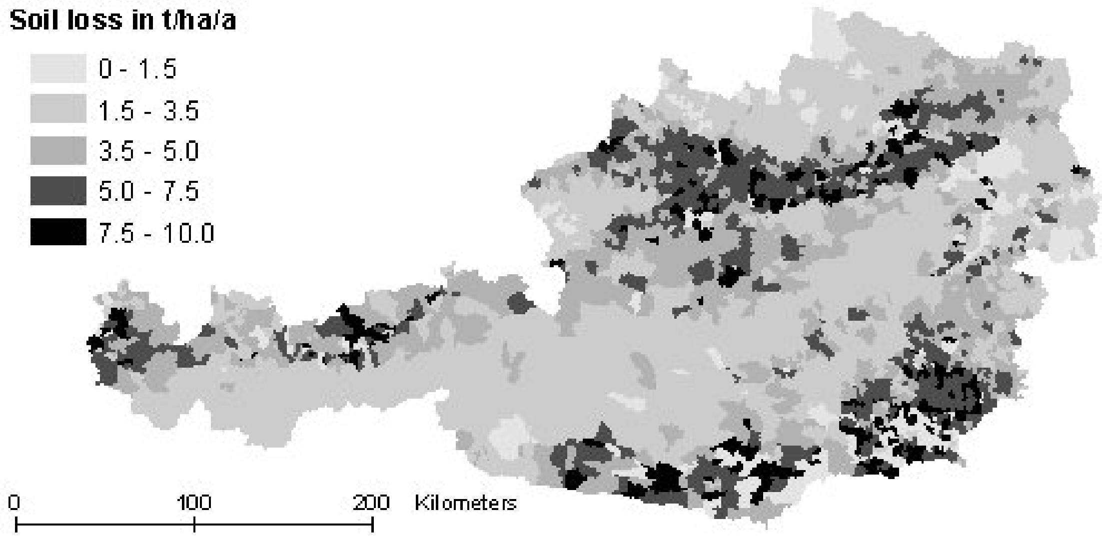

N
0 200 400 600 800 Kilometers
Potential Soil Erosion Risk Europe
(rill + inter-rill erosion)
Erosion Risk
Very Low
Very High
Rock Outcrops
EUROPEAN
SOIL
BUREAU

Consequences of soil erosion

- Decrease of top soil layer
- Reduced water holding capacity
- Reduced fertility
- Reduced productivity
- Economic consequences can be estimated
  - by the costs of counter measures (modification of land use, terracing, increase in fertilizer application, irrigation,…)
  - By the direct economic losses (losses in harvesting (onsite) and downstream due to deposition)
  - By social consequences (starvation, health problems, migration, ..)
  - Environmental consequences (environmental degradation, biodiversity, carbon sink,…)

- The dark coloured upper layer of soil, rich in humus (termed A1-horizon), in temperate climates has favourable properties for plant growth. Topsoil removal leads to a decline in soil productivity. This is an irreversible process, as topsoil forms very slowly.

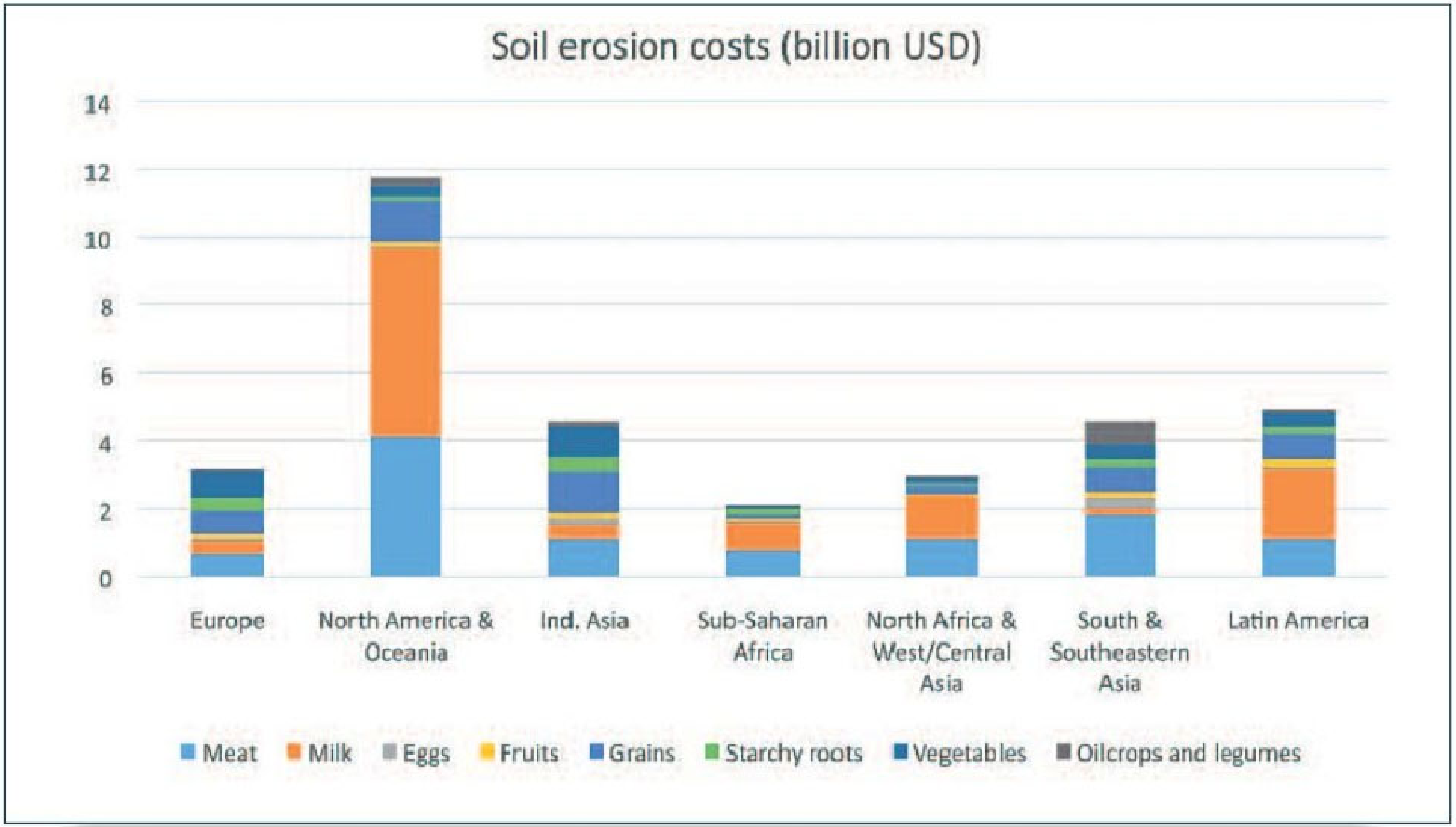
Mean annual soil erosion in Austria (USLE)



Slope information was collected from a DEM with a grid resolution of 250 m. Information on land use was obtained by merging the CORINE data set with exact land use data on a community level.Soil information was obtained from the Austrian mapping system in the scale of 1:50,000. Rainfall was obtained from mean annual rainfall data on community level using a transfer function to erosivity (Strauss *et al.*, 1994).

Economic losses due to soil loss (on-site)

Costs of soil erosion by water worldwide (from: [FAO, 2014. Food Wastage Footprint, p. 76](#)).



Economic losses (England) on and off-site (or direct and indirect losses)

- Comparison of some present day on- and off-farm costs of erosion in England and Wales.
  Source: based on Evans, 1994 and 1995, 1994 reference refers to 'Report to Friends of the Earth', London, pp.145; published in 1996

On-farm	£ million per year
Long-term	
Loss in agricultural production	700.0
Loss in value of land	0.04
Short-term	
Loss of agricultural inputs and outputs	4.8
Land value of eroded floodplain	3.8
Off-farm	
Short-term	
Roads and property	3.4
Footpaths	0.98
Stream channels	7.0
Water pollution*	260.0

Discussion:

- Universal Soil Loss Equation gives a very rough estimate of long-term expected soil loss.
- It considers rill- and interrill erosion: gully erosion is not taken into account. Deposition is not included, only gross erosion is predicted.
- The effect of stones and rock fragments in the soil is not included. Römkens (1985) suggests that the effect of stones is best considered in the C-factor of the USLE
- Effect of management practice, such as of contouring, strip cropping, terracing and subsurface drainage, is not directly included in the model

Discussion

- Load: rainfall intensity, better rainfall energy
- Resistance: land cover and second soil type
- Vulnerability: slopes, soil parameters

References: J.M. van der Knijff, R.J.A. Jones, L. Montanarella (2000) Soil Erosion Risk Assessment in Europe. JRC, European Soil Bureau
M. Grimm, R. Jones & L. Montanarella (2002) Soil Erosion Risk in Europe. JRC, European Soil Bureau
M. Janecek, E. Kubatova & M. Tippl (2006) Revised Determination of the Rainfall-runoff Erosivity Factor R for Application of USLE in the Czech Republic. Soil & Water Res., 1, 2, 65–71
R. J. A. Jones , Y. Le Bissonnais, J. S. Diaz, O. Düwel, L. Øygarden, P. Bazzoffi, V. Prasuhn, Y. Yordanov, P. Strauss, B. Rydell, J. Berenyi Uveges, G. Loj, M. Lane & L. Vandekerckhove (2003) Technical Working Group on Erosion: Nature and extent of soil erosion in Europe

Thank you for your attention !!!