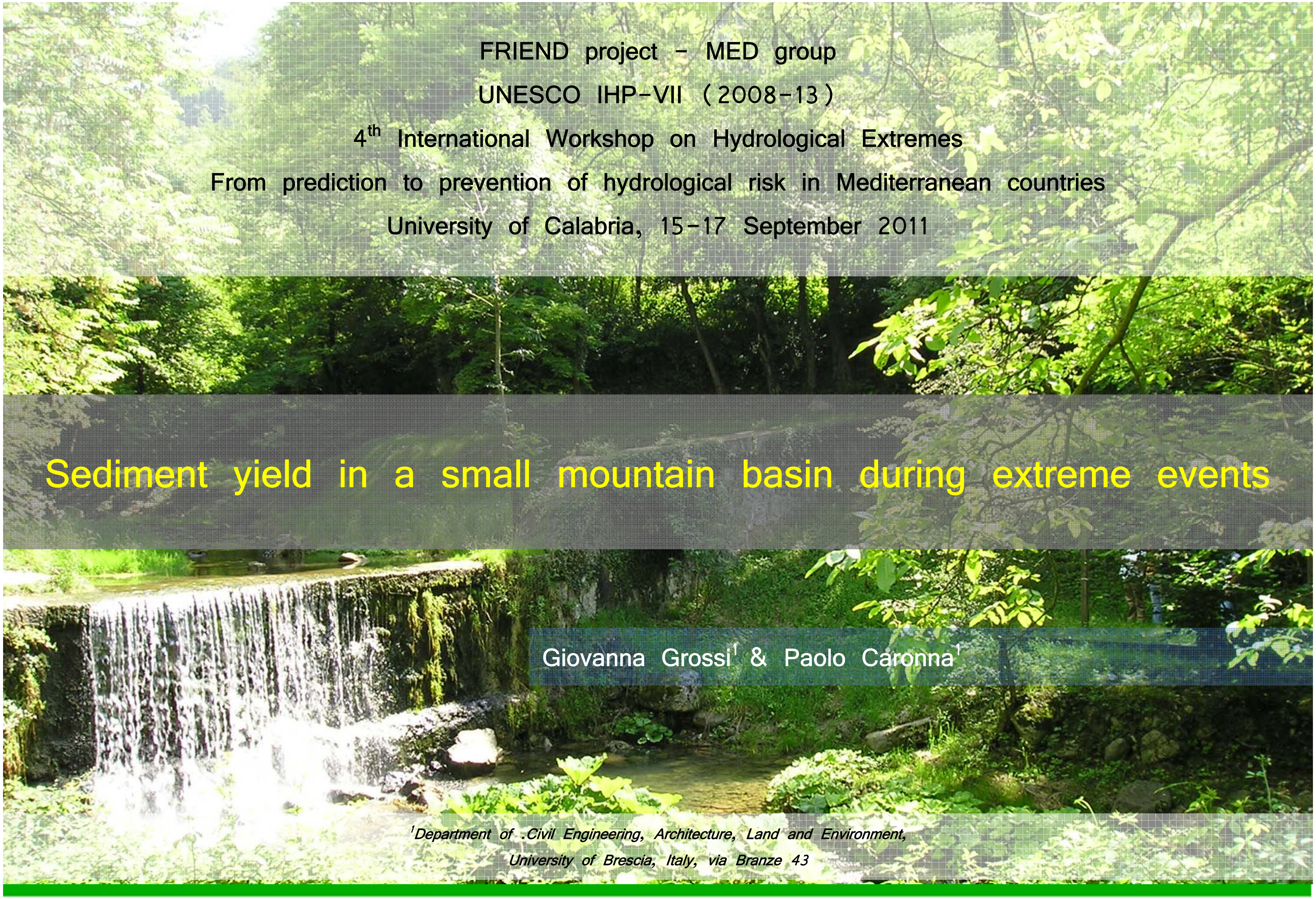

FRIEND project – MED group
UNESCO IHP-VII (2008-13)
4th International Workshop on Hydrological Extremes
From prediction to prevention of hydrological risk in Mediterranean countries
University of Calabria, 15-17 September 2011

Sediment yield in a small mountain basin during extreme events

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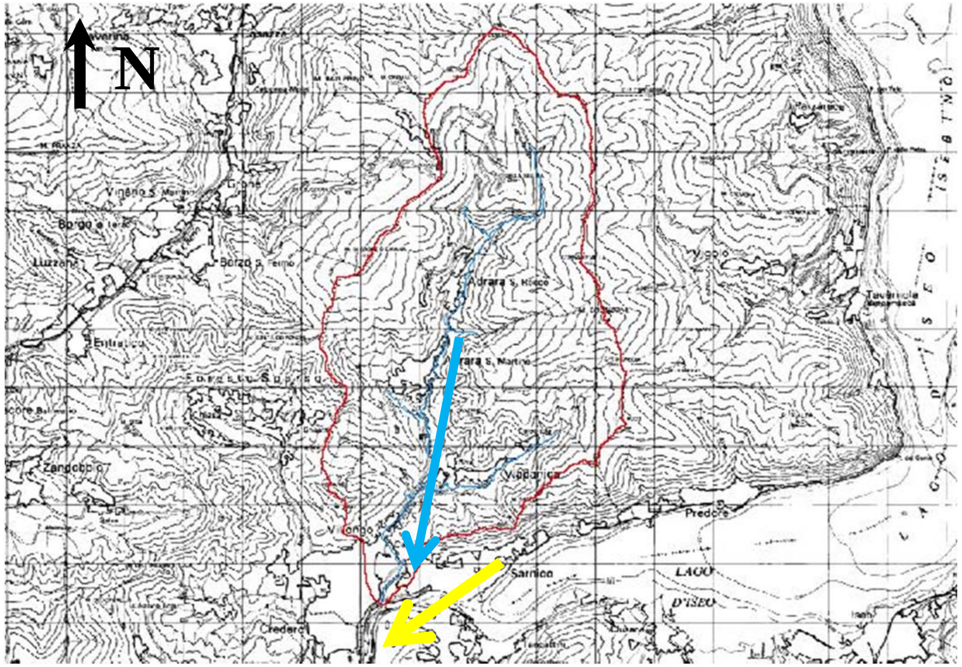
Objectives, methodologies, case study

1) Water erosion on the hillslope → GIS implementation of the RUSLE equation

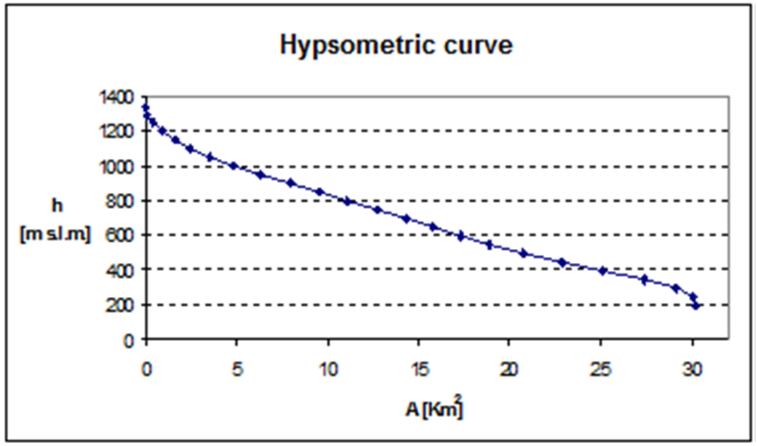
2) Sediment yield in the river network → Hec-Ras hydraulic model

3) Sediment transport → Application of a ‘lumped type’ sediment transport flow equation

Guerna watershed （BG – North Italy）

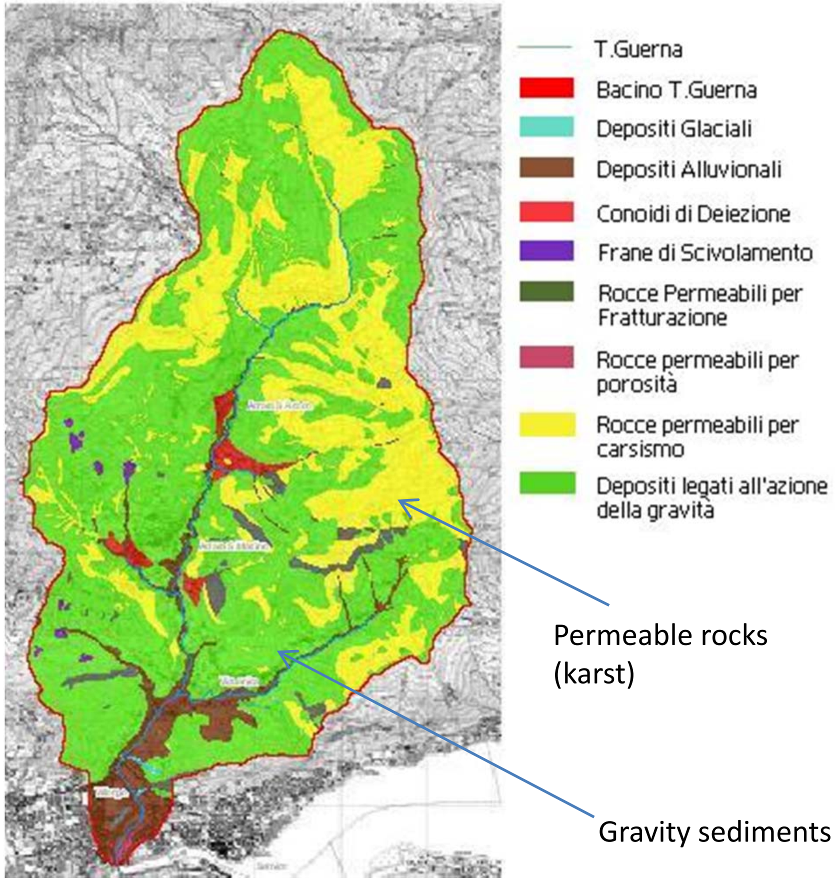


Area (A)	30.9 km^2
Contour (P)	33.3 km
Main stream length (L)	10.6 km
Minimum elevation (H_{min})	195 m s.l.m.
Maximum elevation (H_{max})	1131 m s.l.m.
Mean elevation (H_{media})	643 m s.l.m.
Max elevation range (ΔH_{max})	1136 m
Mean elevation range(ΔH_{medio})	448 m



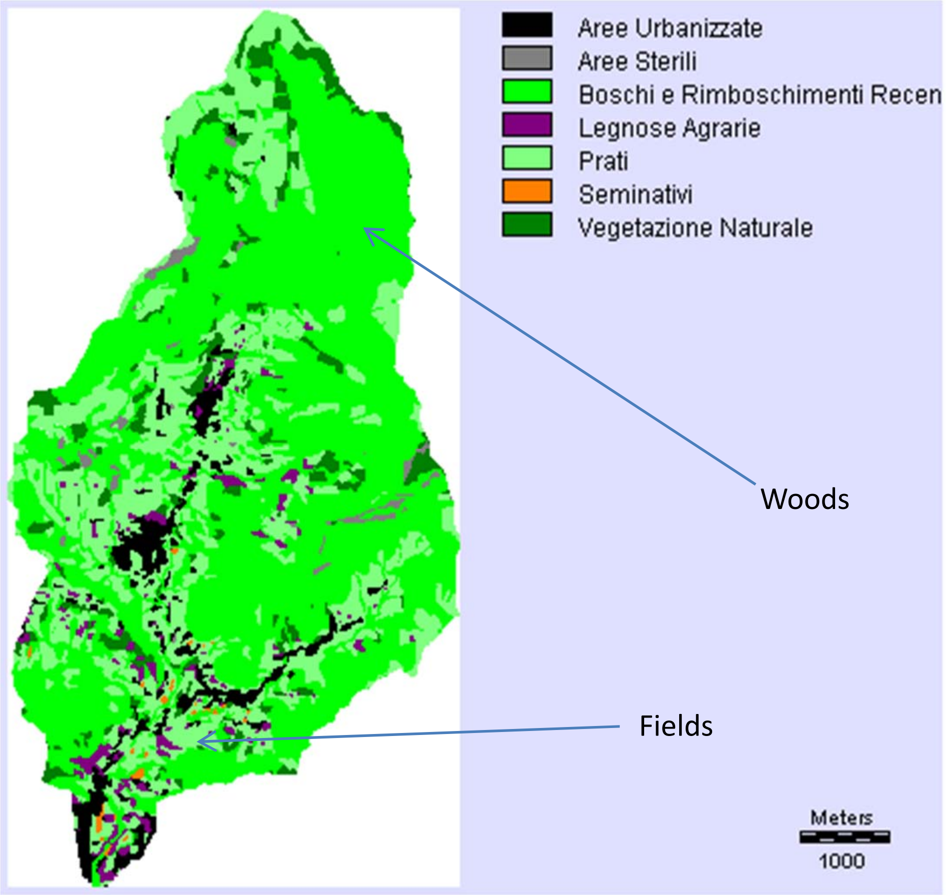
Lithology & Land use

Lithology and land use – maps were used for the GIS application



Permeable rocks (karst)

Gravity sediments



Woods

Fields

Erosion: Revised Universal Soil Loss Equation （RUSLE）（Renard et al.1991）

- Revised version of USLE: *Universal Soil Loss Equation* (Wischmeier e Smith, 1978)

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

A	annual soil loss from sheet and rill erosion	$\left[\frac{t}{ha \cdot y}\right]$
R	rainfall erosivity factor	$\left[\frac{MJ \cdot mm}{ha \cdot h \cdot y}\right]$
K	soil erodibility factor	$\left[\frac{t \cdot ha \cdot h}{ha \cdot MJ \cdot mm}\right]$
L	slope length factor	[–]
S	steepness factor	[–]
C	cover and management factor	[–]
P	support practice factor	[–]

Erosion estimate: R and K factors

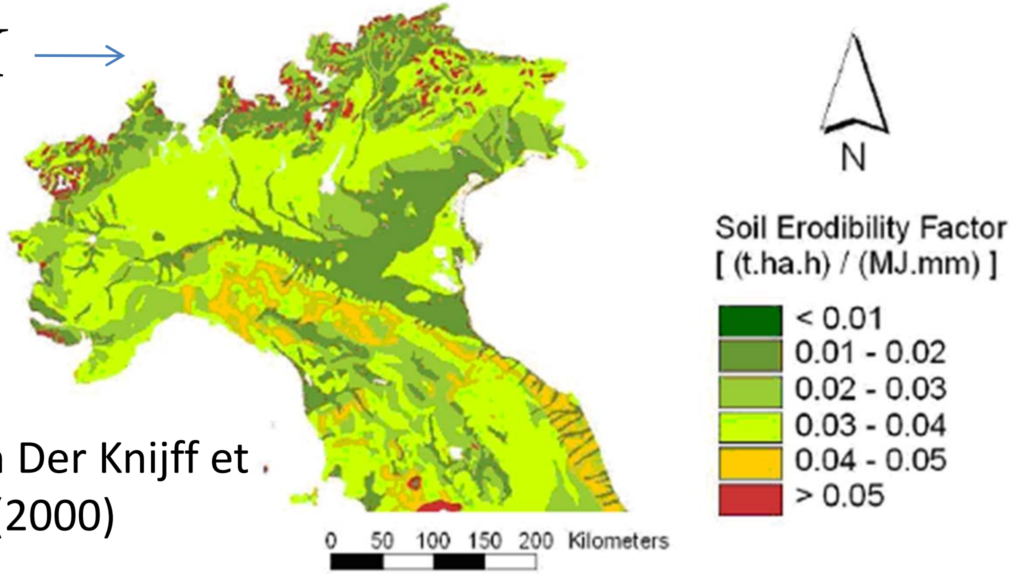
$$R = 38.46 + 3.48 \cdot P_{year}$$

(*"Actual Erosion in the Alpine Space"* , European Soil Bureau)

$$P_{year} = 1260mm$$

$$\boxed{R = 4423.26 \; \frac{MJ \cdot mm}{ha \cdot h \cdot y}}$$

$K \rightarrow$



Van Der Knijff et al. (2000)

$$\boxed{K = 0.035 \; \frac{t \cdot ha \cdot h}{ha \cdot MJ \cdot mm}}$$

Erosion estimate: L and S factors

Being:

β the slope

$$f = \frac{\sin\beta}{0.0869} \cdot \frac{1}{\left(3\sin^{0.8}\beta + 0.56\right)}$$

$$m = \frac{f}{1+f}$$

Renard et al. (1991) write:

$$LS = \left(\frac{\lambda}{22.13}\right)^{m} \left(10.8\sin\beta + 0.03\right)$$ if $\tan\beta < 0.09$

$$LS = \left(\frac{\lambda}{22.13}\right)^{m} \left(16.8\sin\beta - 0.05\right)$$ if $\tan\beta \geq 0.09$

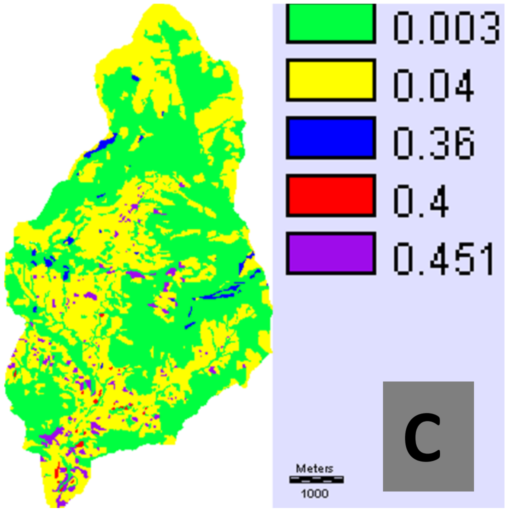
Topographic factors **L** and **S** were computed on the basis of a 20 m resolution digital elevation model.

Erosion estimate: C and P factors

The coltural factor C is computed as the ratio between the soil loss under actual conditions to losses experienced uder the reference conditions.

Tables depending on crops and crops rotation

Description	C factor
Urban area	0.003
Unproductive soil	0.36
Old and new forest	0.003
Woodland	0.451
Lawn	0.04
Sown ground	0.4
Wild vegetation	0.003



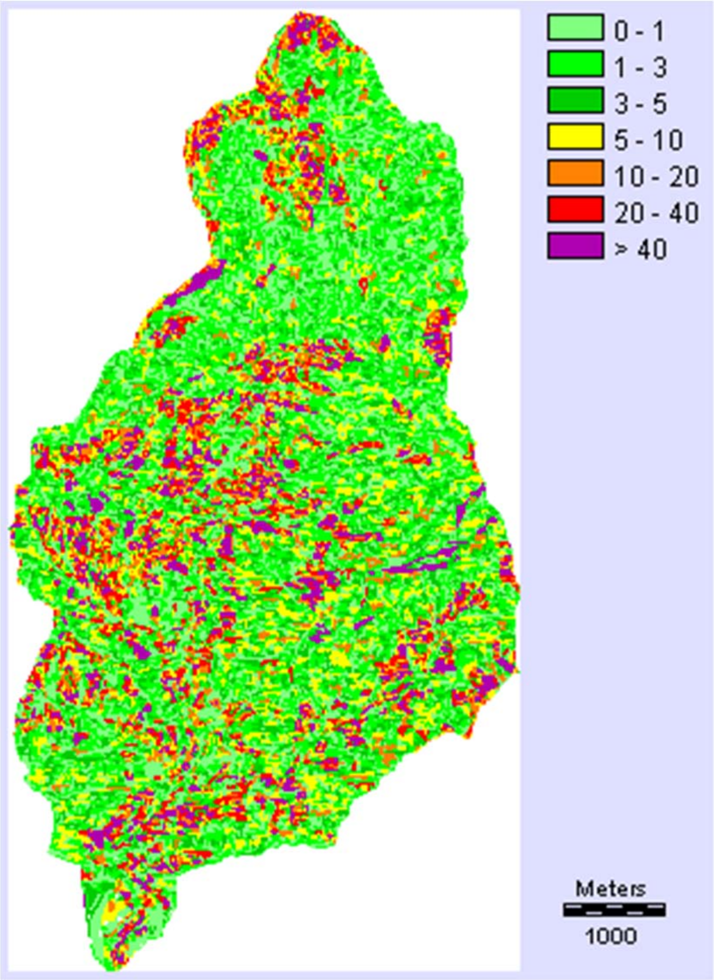
The *P* factor is defined as the ratio between the soil loss with contouring and/or stripcropping to that with straight row farming up-and-down slope.

P=1 ; **P=0.34 (woodland)**

,

Erosion estimate: obtained results

Average soil loss map for the Guerna watershed:



Category [t/y]	Area [Km^2]
0 - 1	7.66
1 – 3	8.40
3 – 5	3.82
5 - 10	3.83
10 – 20	2.62
20 - 40	2.17
> 40	2.30

Parcel soil loss, averaged over the basin area: 13 t/y

Total soil loss: 225 000 t/y
(Vol. 86 790 m^3/y)

Specific loss: 2.8 mm/y.

Sediment transport in the river network: HEC-RAS

Hydrologic Engineering Centers River Analysis System **(HEC- RAS)**

US Army Corps
of Engineers ®

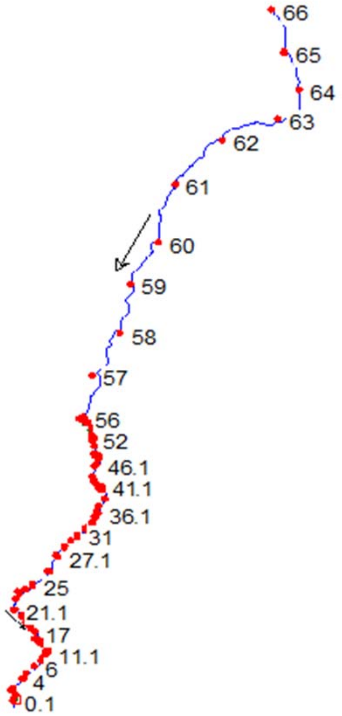
Sediment flow equation → ***Meyer-Peter-Muller***
Fall velocity→ ***Ruby***

Requested data for the definition of the hydraulic model of the creek:

A) Reaches and cross sections geometry
B) Grain classes
C) Quasi-unsteady flow computational scheme (definition of the upstream inflow event)

A1) Reaches

Main stream legnth: 10.6 Km
- Upstream reach: 6.2 Km
- Downstream reach: 4.4 Km (i = 0.006)



Basic data requirements (I)

A2) cross section geometry

Upstream reach: 10 rectangular cross sections

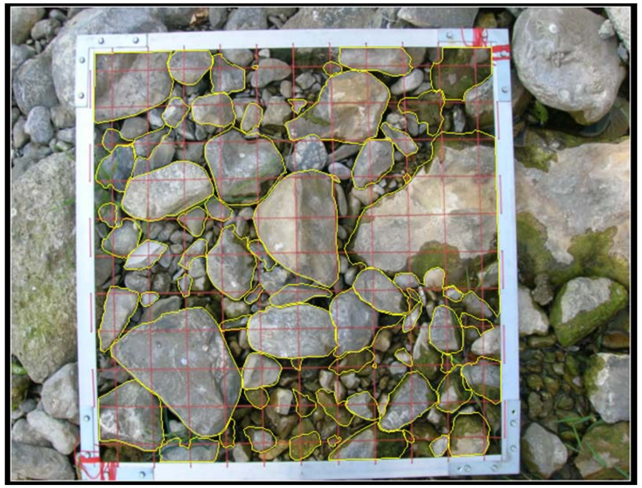
width [m]	height [m]
2	0.4

Downstream reach: topographic survey

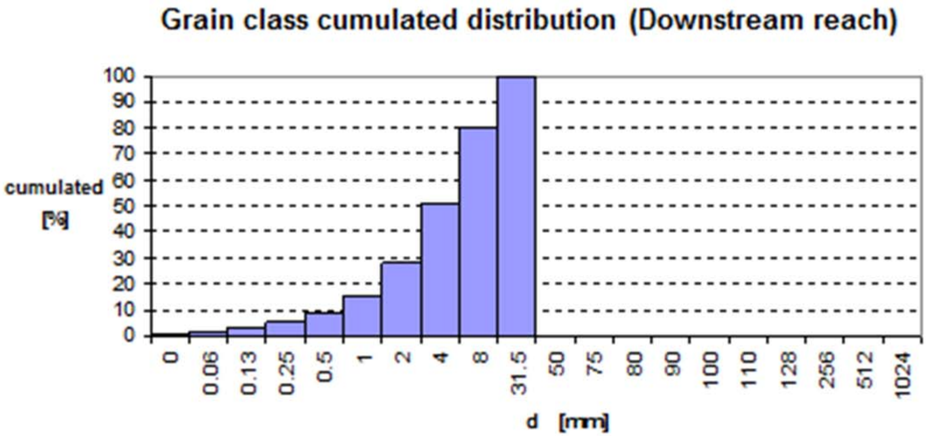
B) Roughness *of the banks and of the s*tream bed

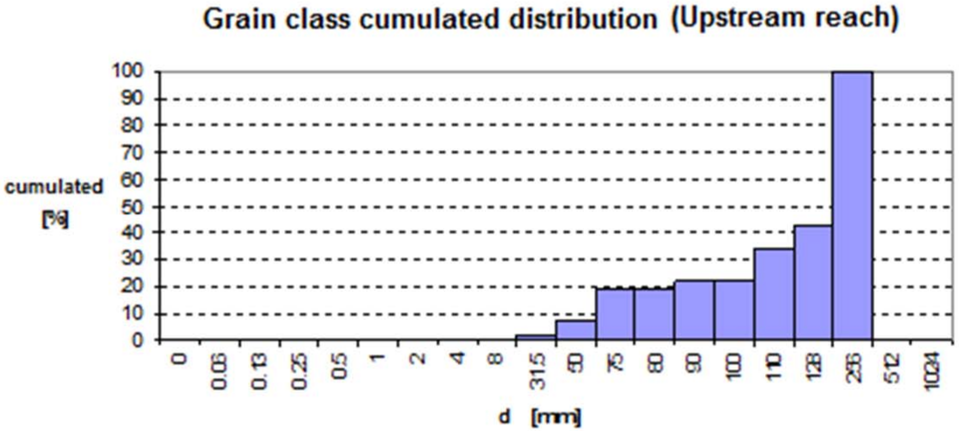
Manning coefficient (0.02 0.07 s/m$^{1/3}$)

C) Grain classes



Basic data requirements （II）


Grain class cumulated distribution (Downstream reach)


Grain class cumulated distribution (Upstream reach)

C) Quasi-unsteady flow computational scheme (precipitation event)

The peak discharge for a fixed return period was computed on the basis of the results of a regionalisation study by Bacchi et al. (1999)

$$Q_{c,T} = X_T \cdot m(Q_c)$$

with: $m(Q_c) = 3.24 \cdot A^{0.73} \quad 1 \leq A \leq 40 \text{ km}^2$

$$X_T = 1 + 0.53 \cdot \frac{(\exp(0.0521 \cdot (-\ln(-\ln((T-1)/T))) - 1.033}{0.072}$$

Basic data requirements （III）

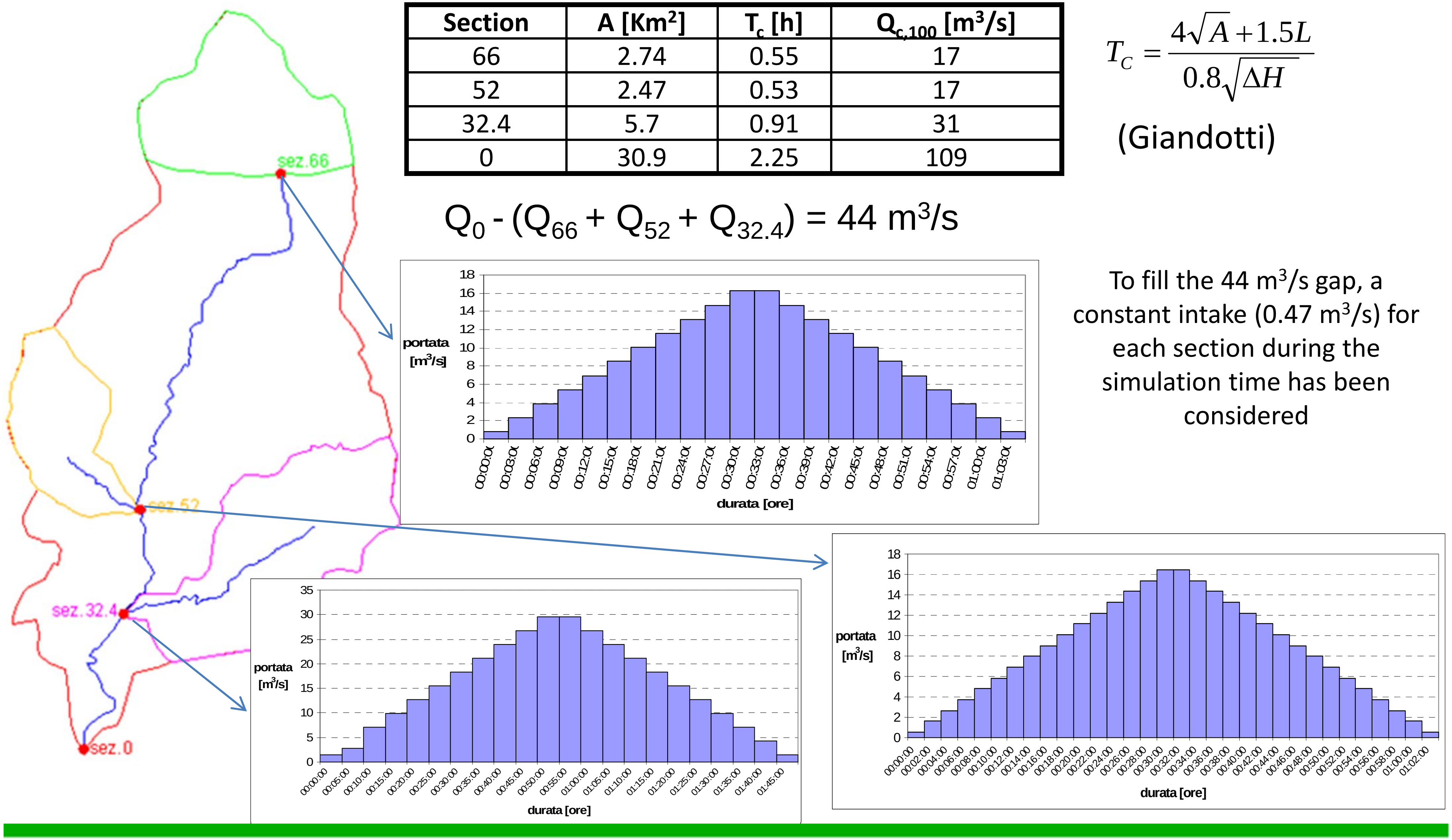
Section	A [Km^2]	T_c [h]	$Q_{c,100}$ [m^3/s]
66	2.74	0.55	17
52	2.47	0.53	17
32.4	5.7	0.91	31
0	30.9	2.25	109

$$T_C = \frac{4\sqrt{A} + 1.5L}{0.8\sqrt{\Delta H}}$$

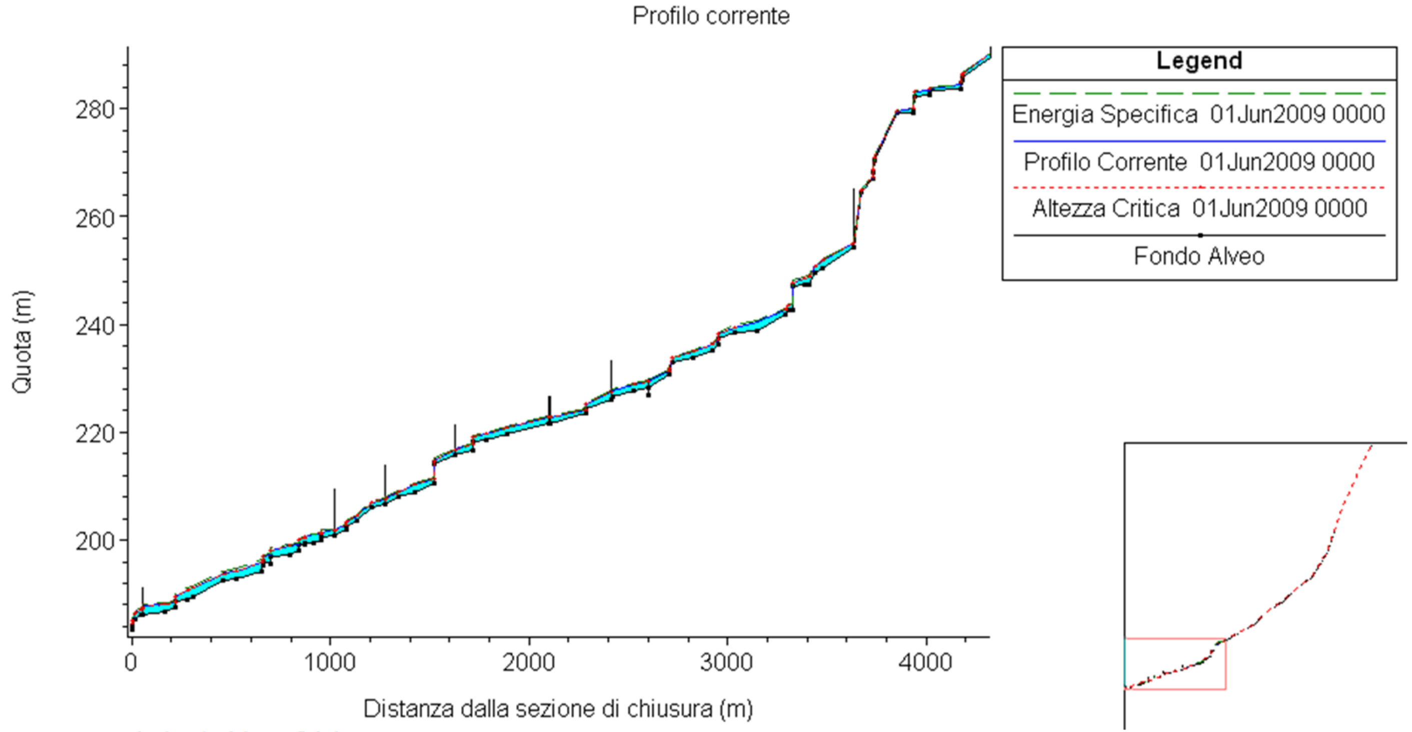
(Giandotti)

$$Q_0 - (Q_{66} + Q_{52} + Q_{32.4}) = 44\ m^3/s$$

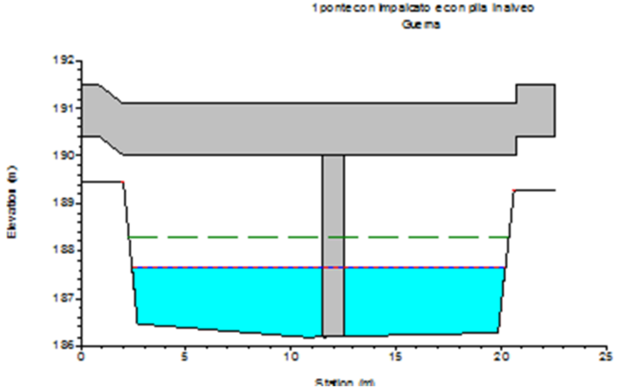
To fill the 44 m^3/s gap, a constant intake (0.47 m^3/s) for each section during the simulation time has been considered

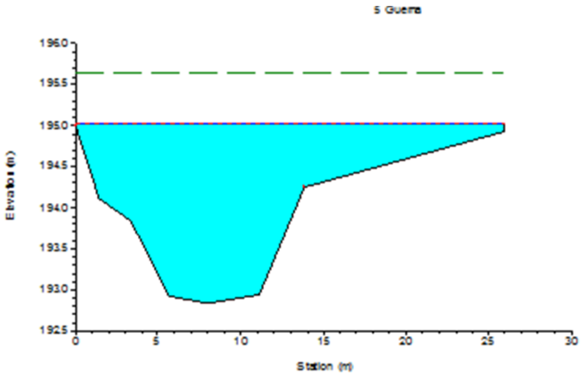


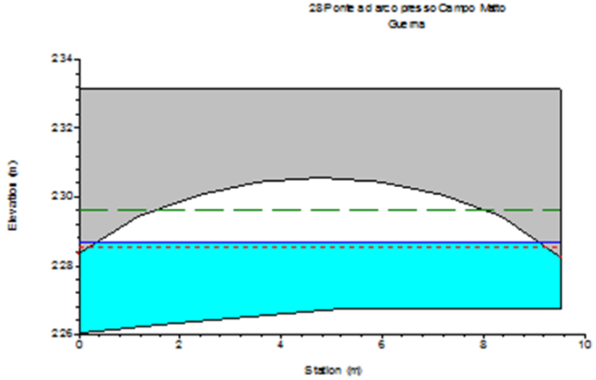
Sediment yield：modeling results （I）



Water levels And profiles

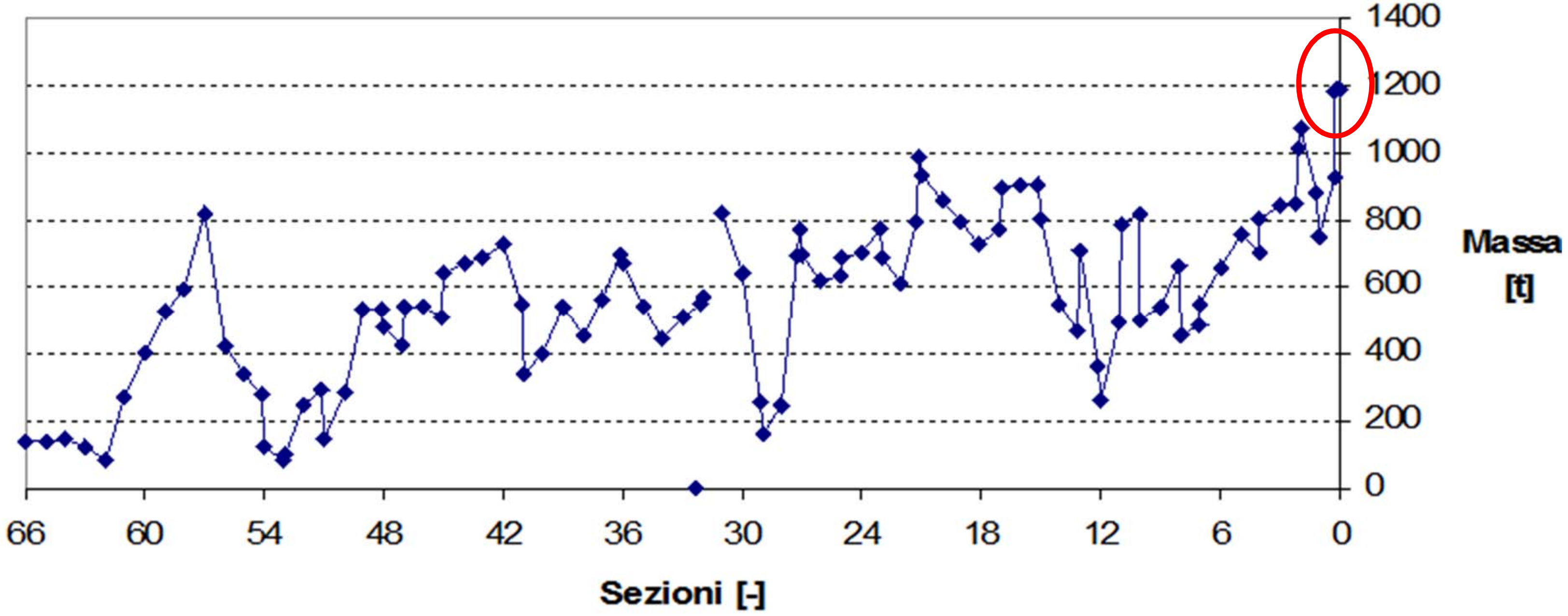






Sediment yield: modeling results （II）

Obtained results: Sediment yield at the end of the simulation period



At the outlet in the Oglio river (section 0) sediment yield is **1192 t** (γ_s=2600 kg/m^3 → **V_s~460 m^3**)

Estimate of sediment transport: Meyer−Peter Müller equation

The sediment transport rate $\boldsymbol{q_s}$ is the sediment volume discharge per section width unit.

The index Φ, is the non dimensional form for q_s :

$$\Phi = 13.3 \cdot (\phi - \phi_c)^{1.5} = \frac{q_s}{\sqrt{{d_{50}}^3 \cdot g \cdot \Delta}}$$ (Meyer-Peter Müller, 1948)

$$\Delta = \frac{\rho_S - \rho}{\rho} \;;\; \phi_C = 0.047 \;;\; \phi = \frac{R \cdot i}{\left(\frac{\rho_S}{\rho} - 1\right) \cdot d_{50}} \cdot \left(\frac{k_S}{k'_S}\right)^{3/2} \;;\; k'_S = 26 \cdot d_{90}^{-1/6}$$

ρ : water unit mass

ρ_s : sediment unit mass

ϕ_C : Shields number

R : hydraulic radius

i : bed slope

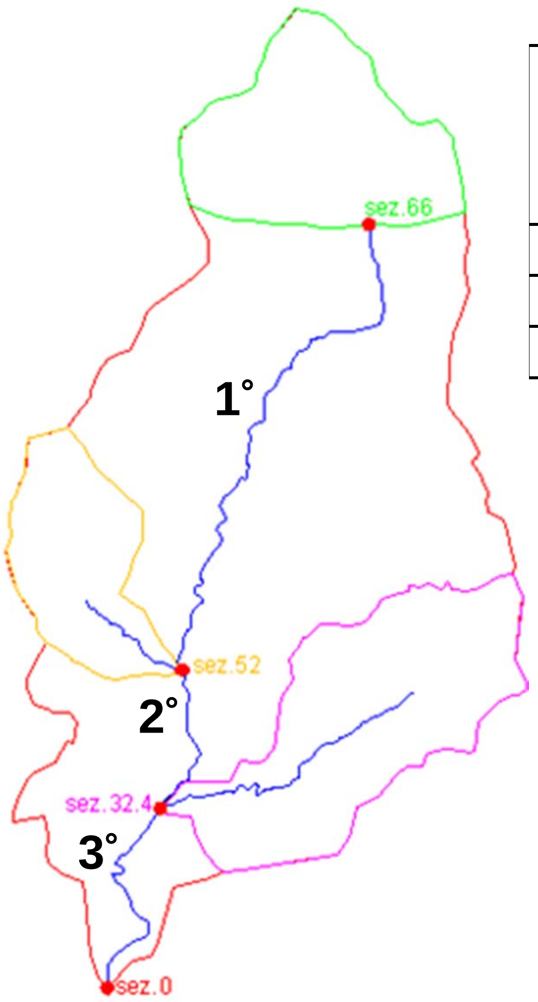
k_s : Strickler roughness due to bed grain and shape

k'_s : Strickler roughness due only to grains

d_{50} : 50% of sediment weight is lower in size

d_{90}: 90% of sediment weight is lower in size

Sediment transport: Meyer-Peter equation



	d_{50} [m]	d_{90} [m]	Slope i [%]	Water discharge Q [m^3/s]	Meyer-Peter Müller Q_S [m^3/s]
I reach	0.8	1.5	9.1	48	0.298
II reach	0.4	0.8	2.8	80	0.008
III reach	0.1	0.3	0.6	109	0.051

On the basis of Meyer-Peter Müller equation alone, sediment transport rates would be very low and their distribution would be much different from those obtained through the detailed hydraulic model.

Conclusions

The GIS implementation of RUSLE has provided an estimate of the annual sediment yield on the hillslopes of the watershed

225000 t/y (~ 86790 m^3/y)

Sediment Transport analysis was performed using Hec-Ras modeling framework, providing the sediment yield for a 100- year return period event

1192 t (~ 460 m^3)

Results are in agreement with literature values

Future research :

- Geometry of the upstream reach
- Improvement of the sediment gradation through additional field and laboratory analysis
- Link of the Gis- RUSLE and Hec-RAS frameworks

Thank you for your attention