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ESTIMATION OF SEDIMENT YIELD WITH MUSLE AND MONITORING. A CASE STUDY FOR TSIKNIAS DAM AT LESVOS ISLAND IN GREECE

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PROJECT

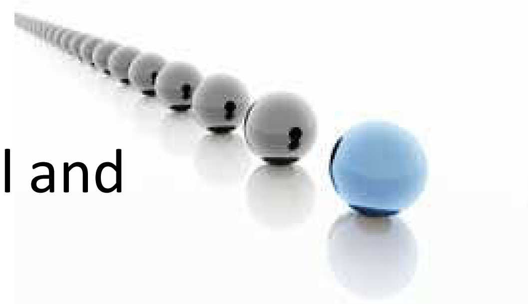
Tsiknias river sediment yield management plan is part of the project:

"Construction of water supply works at Lesvos island, Preliminary and Final design of hydraulic and other works "

Ministry of Infrastructure, Transport and Networks (Employer)

Main studies of this project:

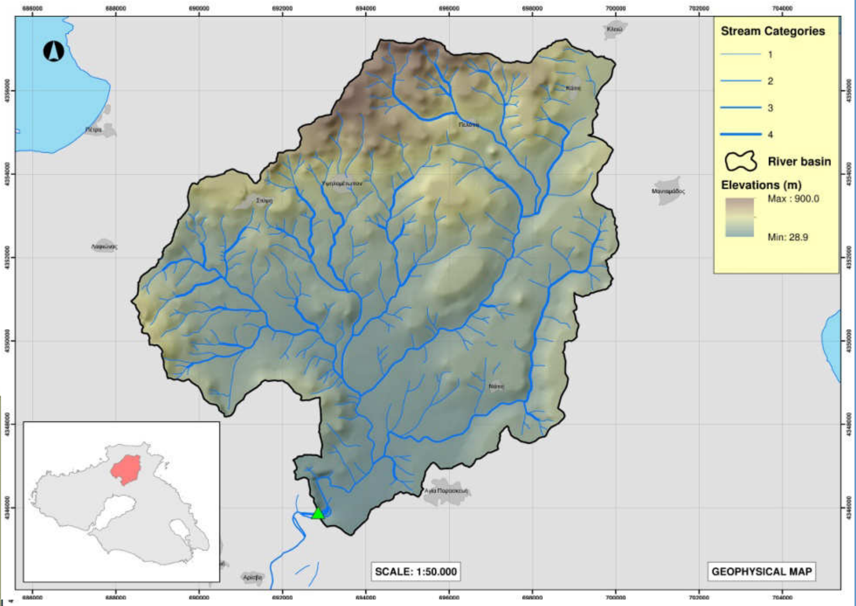
- Tsiknias dam final study
- Water supply networks design
- Surveying, Geological, Geotechnical, Structural and Environmental studies
- Fish fauna study
- Dam break analysis
- Tsiknias river sediment yield management plan

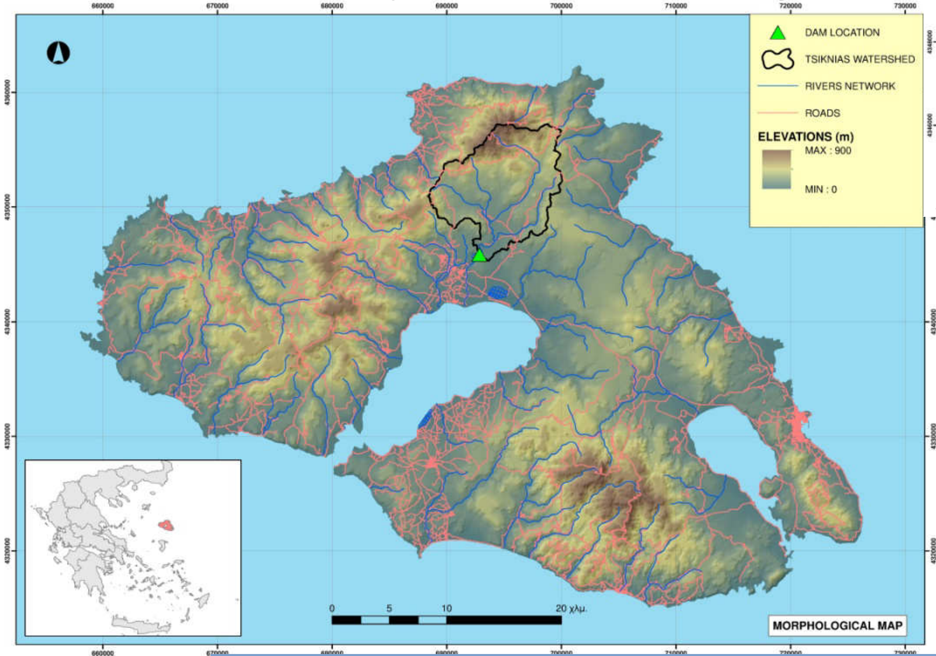


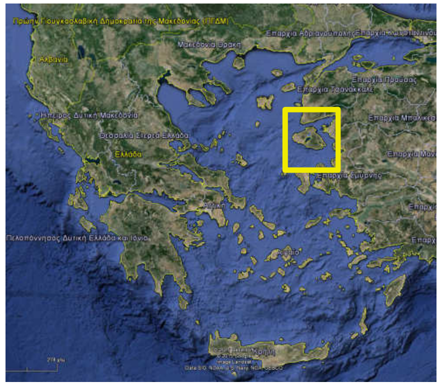
INTRODUCTION

LOCATION

- Lesvos, Northeastern Greece
- Tsiknias river
- Total river basin A=92km^2
- Total river length L=22.5km
- Dam is ~6km upstream Kalloni gulf



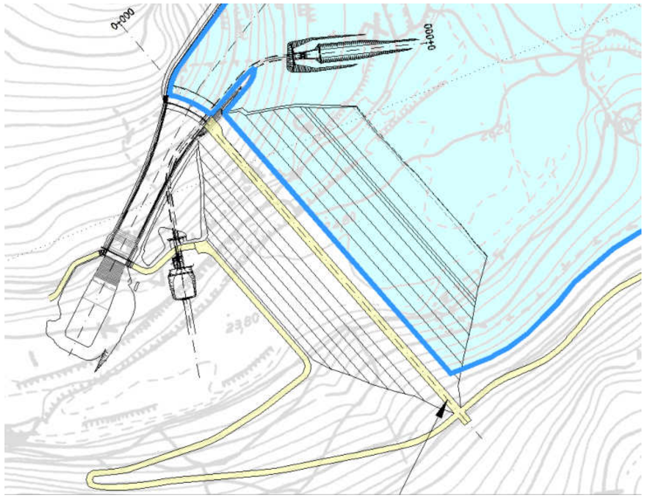


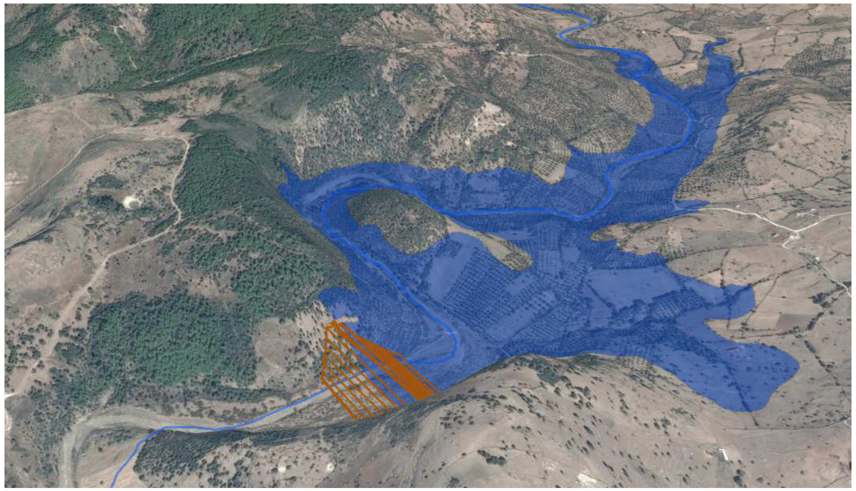


BASIN	AREA (km^2)	Mean Elevation (m)	Max. Elevation(m)	Mean Slope (%)	River Length (km)
R.TSIKNIAS AT DAM LOCATION	85.9	285.5	916.8	16.8	17.2

TSIKNIAS DAM

TSIKNIAS DAM TECHNICAL CHARACTERISTICS	
Dam type	Gravel with clay core
Dam height from the natural bed of the stream	38 m
Crest Elevation	+62 m
Maximum normal operating level	+56 m
Total volume of the embankment	1.114 x10^6 m^3
Functional reservoir volume	12,5x10^6 m^3
Reservoir area	120 ha
The area of the upstream basin of Tsiknias dam	84 km^2
Maximum water discharge at spillway entrance	1.310 m^3/s



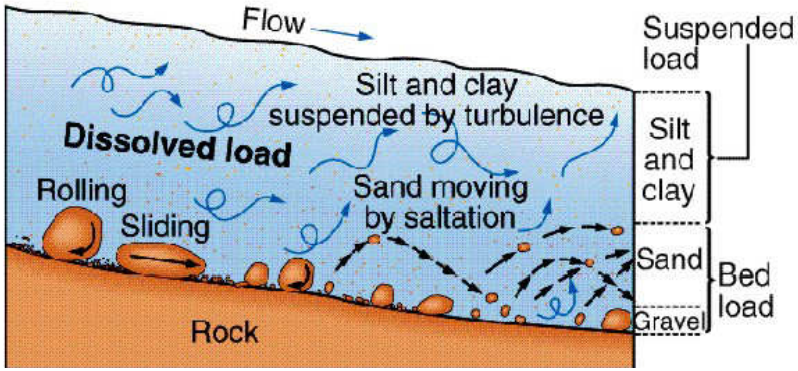


MODIFIED UNIVERSAL SOIL LOSS EQUATION (MUSLE)

Suspended and bedded sediment yield was calculated by a well known empirical model based on estimated and measured input data.

According to the MUSLE, the annual soil loss is given:

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



A:	Annual soil loss	(t/ha/year)
R:	Rainfall erosivity factor	(MJ mm/ha h year)
K:	Soil erodibility factor	(t ha h/ha MJ mm)
LS:	Topographic factor	(-)
C:	Cover management factor	(values from 0 to 1)
P:	Erosion control practice factor	(values from 0 to 1)

RAINFALL EROSIVITY FACTOR R

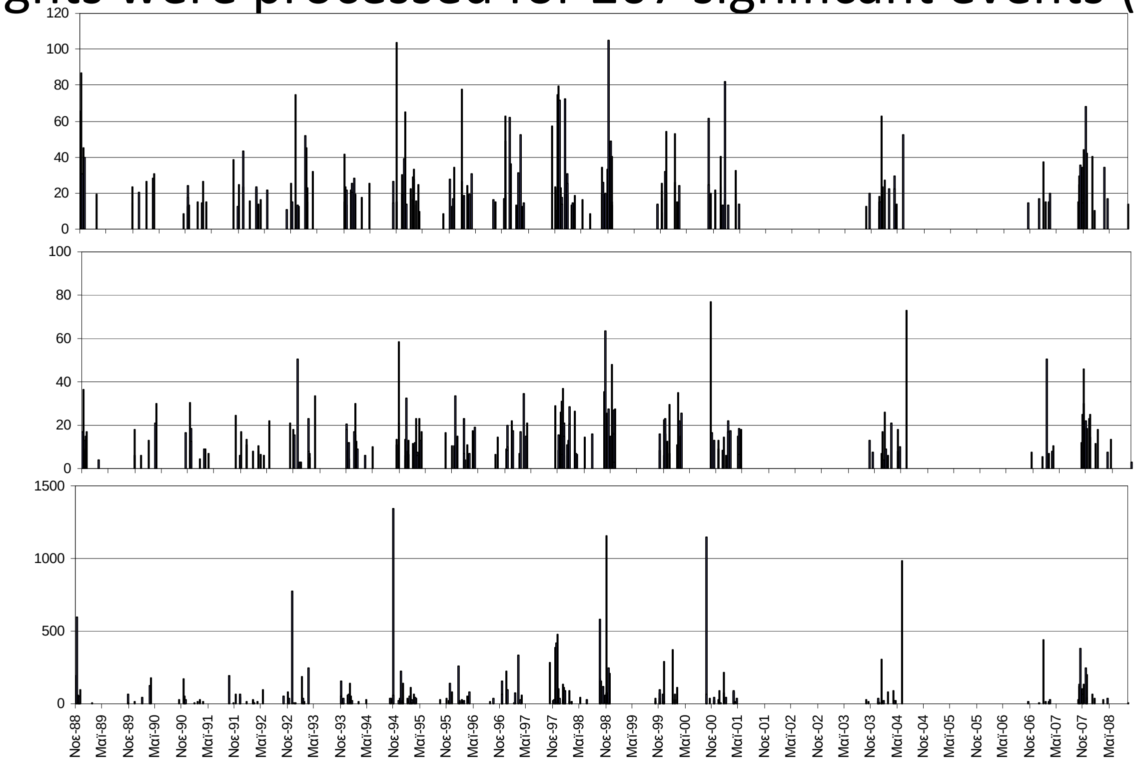
The R-factor describes the effect of rainfall events on soil erosion.

- R was calculated based on a 5-minute rainfall time
- Data were available for a span of 20 hydrological years (1988-2008)
- Rainfall heights were processed for 207 significant events (>12mm)

(i)

(ii)

(iii)



Significant rainfall events:
i) 5-minute rainfall intensiy (mm),
ii) max rainfall intensity of 30min duration (mm/h),
iii) rainfall erosivity factor Re (MJ mm/ha h)

MUSLE

RAINFALL EROSIVITY FACTOR R - CALCULATION PROCEDURE

1. For each one of these significant rainfall events (>12mm), the following parameters were calculated:

- Precipitation height h_t (mm)
- Rainfall intensity i_t (mm)
- Specific kinetic rainfall energy e_t (MJ/ha mm):

$$e_t = 0.29 \cdot [1 - 0.72 \cdot \exp(-0.05 \cdot i_t)]$$

- Total kinetic rainfall energy E_t (MJ/ha): $E_t = h_t \cdot e_t$
- Summary of total kinetic rainfall energy E (MJ/ha): $E = \Sigma E_t$
- Maximum 30-minute rainfall intensity i_{30} (mm/h)
- Rainfall erosivity factor R_e (MJ mm/ha h) : $R_e = E \cdot i_{30}$

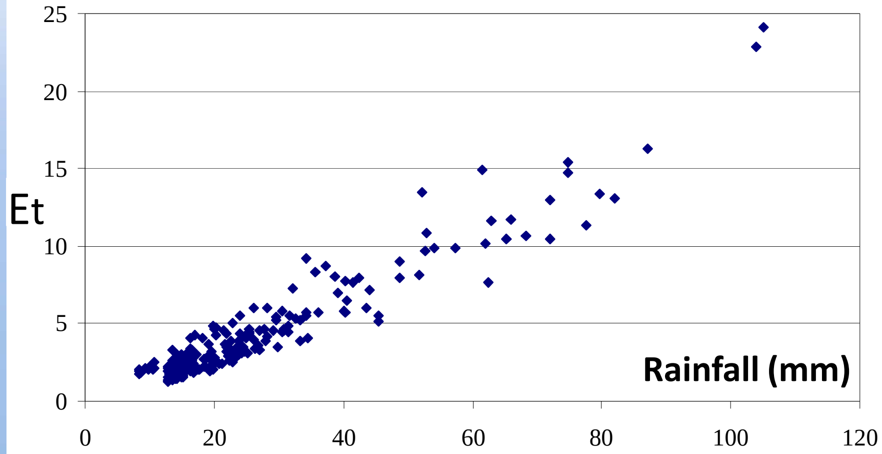
2. Monthly and annual R by summing up Re: $R = \Sigma R_e$

Mean annual value

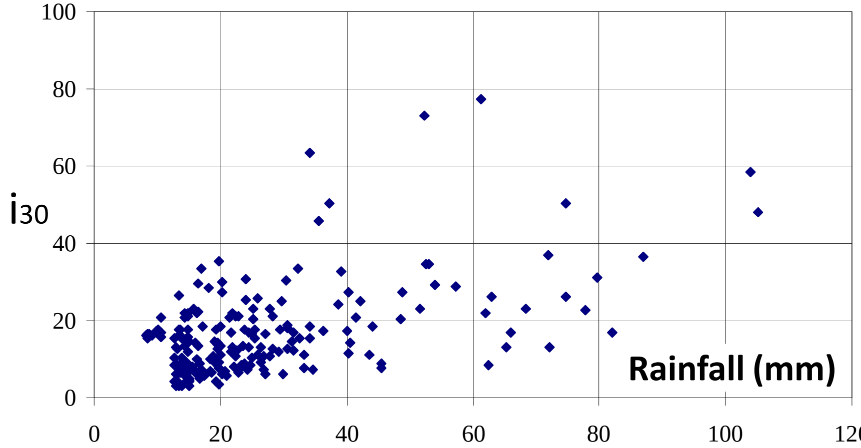
R=1428 MJ mm/ha·h

MUSLE

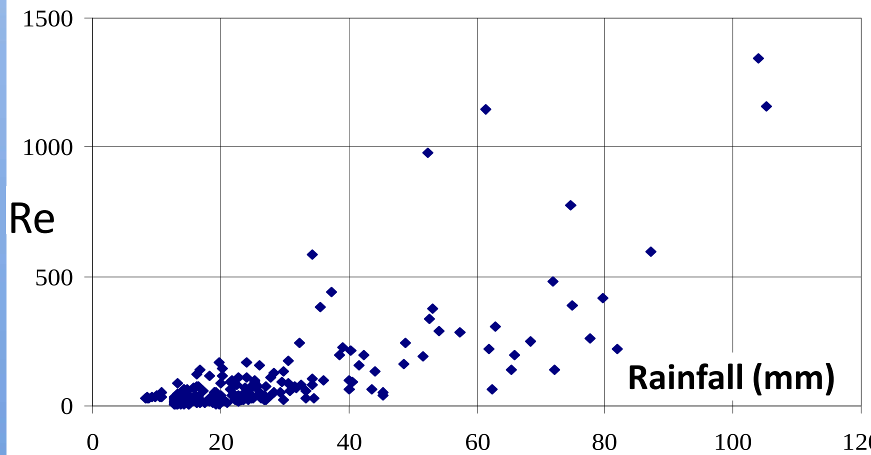
RAINFALL EROSIVITY FACTOR R - CORRELATIONS



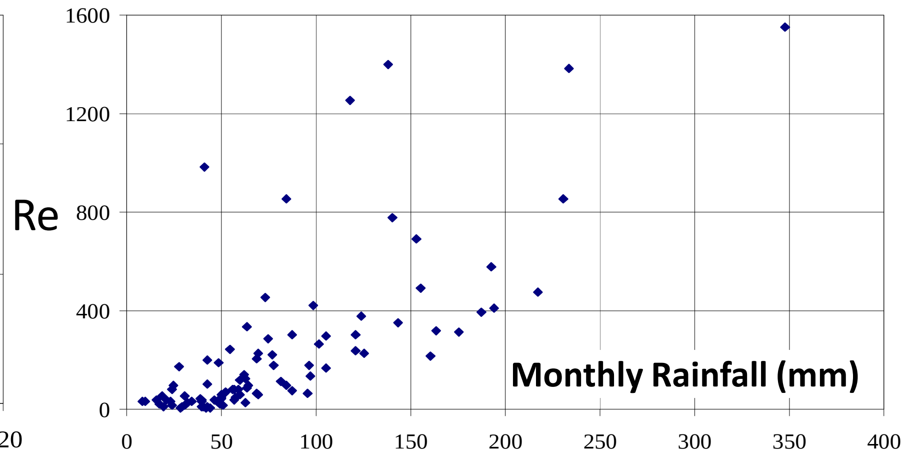
Correlation between rainfall height (mm) and total kinetic rainfall energy Et (MJ/ha)



Correlation between rainfall height (mm) and maximum 30-minute rainfall intensity i30 (mm/hr)



Correlation between rainfall height (mm) and rainfall erosivity factor Re (MJ mm/ha h)



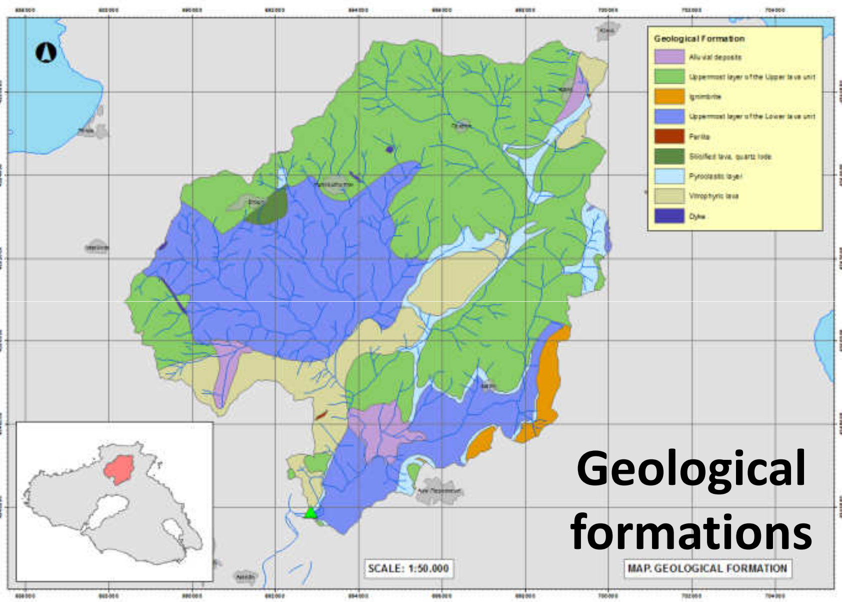
Correlation between monthly rainfall height (mm) and rainfall erosivity factor Re (MJ mm/ha h)

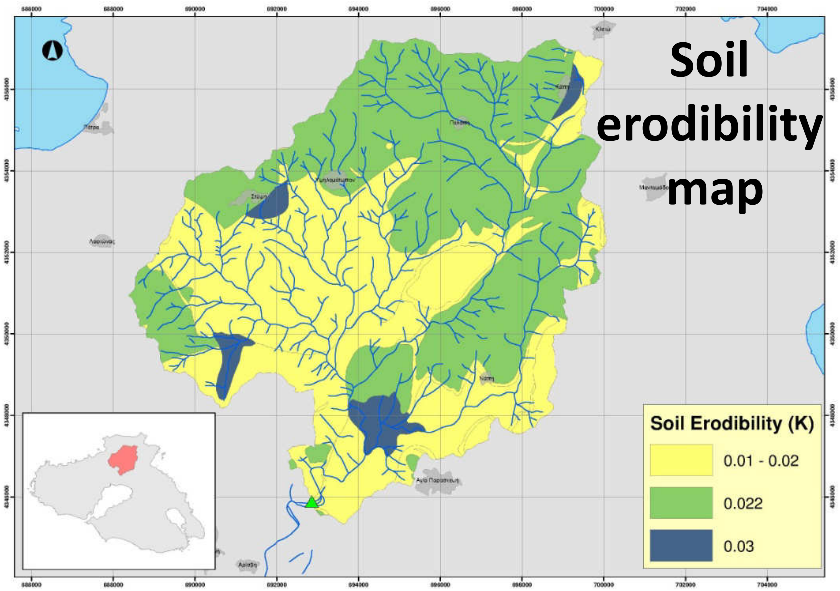
MUSLE

SOIL ERODIBILITY FACTOR K

Soil erodibility factor K represents the influence of geology at soil erosion. K values were assigned for every geological formation according to literature and IGME maps

Geological formations	IGME CODE	K
Perlite	Ng.pl	0.020
Dyke	Ng.d	0.020
Silicified lava, quartz lode	Ng.q	0.030
Ignimbrite	Ng.ig	0.010
Alluvial deposits	Q.al	0.030
Pyroclastic layer	Ng.pc	0.020
Vitrophyric lava	Ng.vl	0.016
Uppermost layer of the Lower lava unit	Ng.li1	0.020
Uppermost layer of the Upper lava unit	Ng.ul	0.022



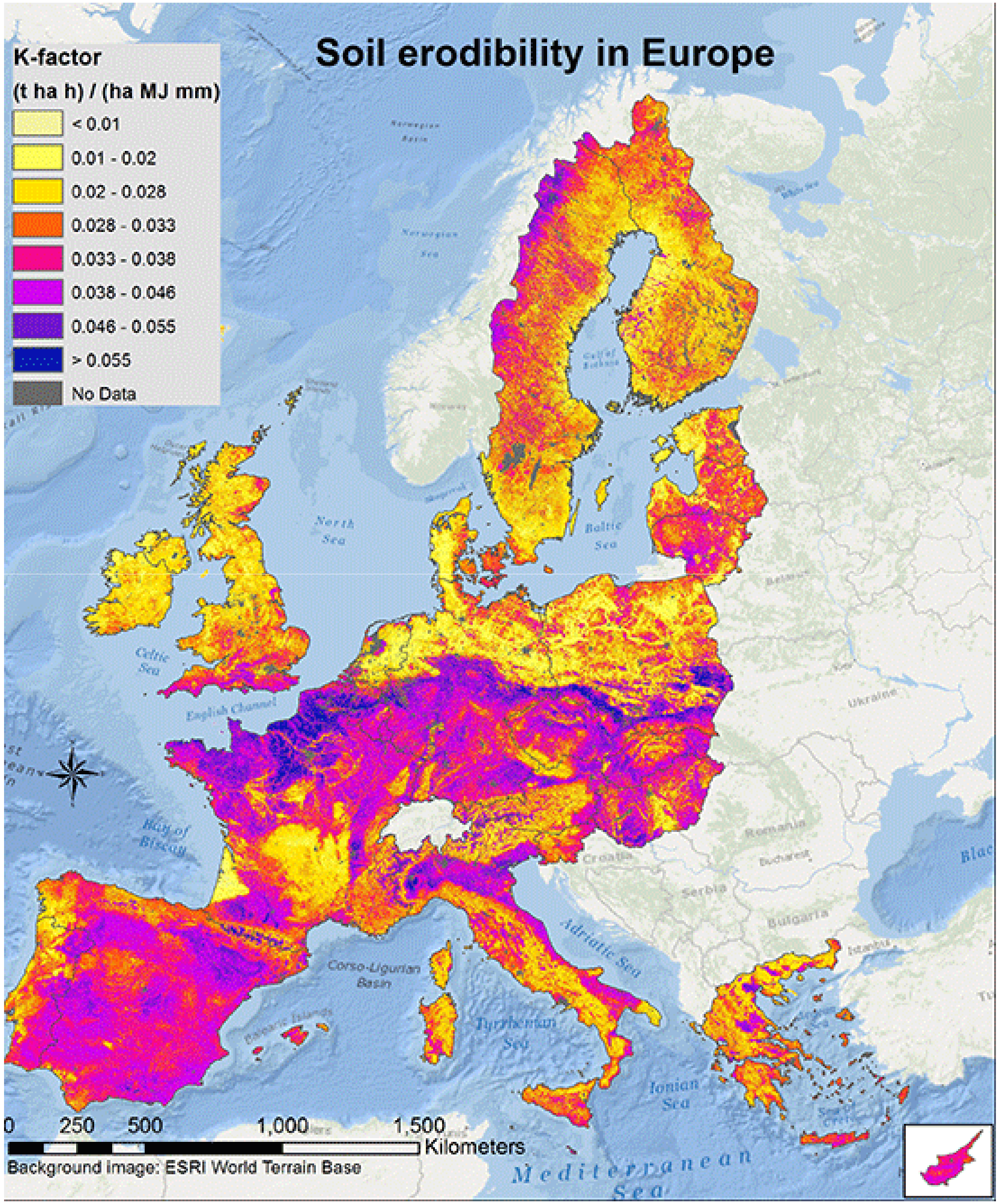


The weighted areal mean value of K at Tsiknias watershed

K=0.021 t ha h/ha MJ mm

MUSLE

SOIL ERODIBILITY FACTOR K



<u>EUROPEAN BUREAU MAP OF SOIL ERODIBILITY</u>

(Joint research center, European Soil Portal – Soil Data and Information Systems)

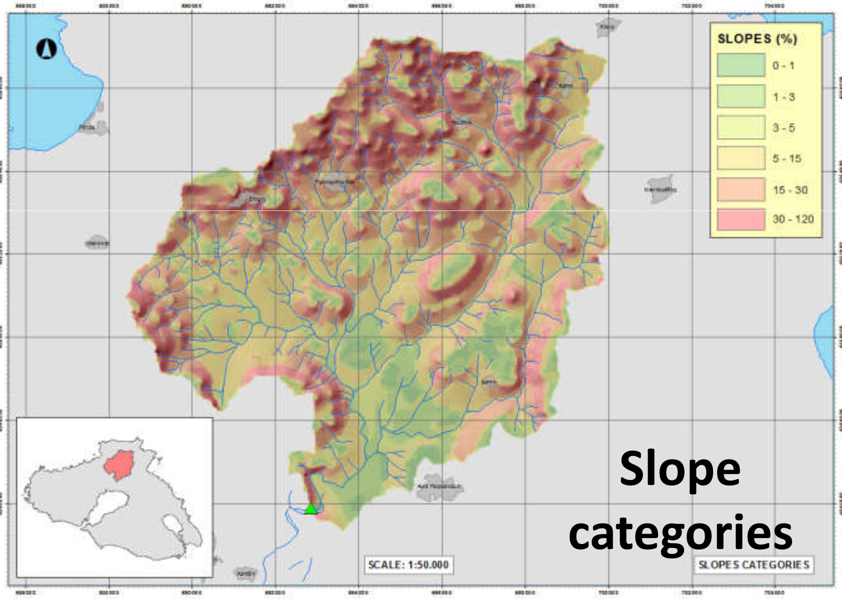
MUSLE

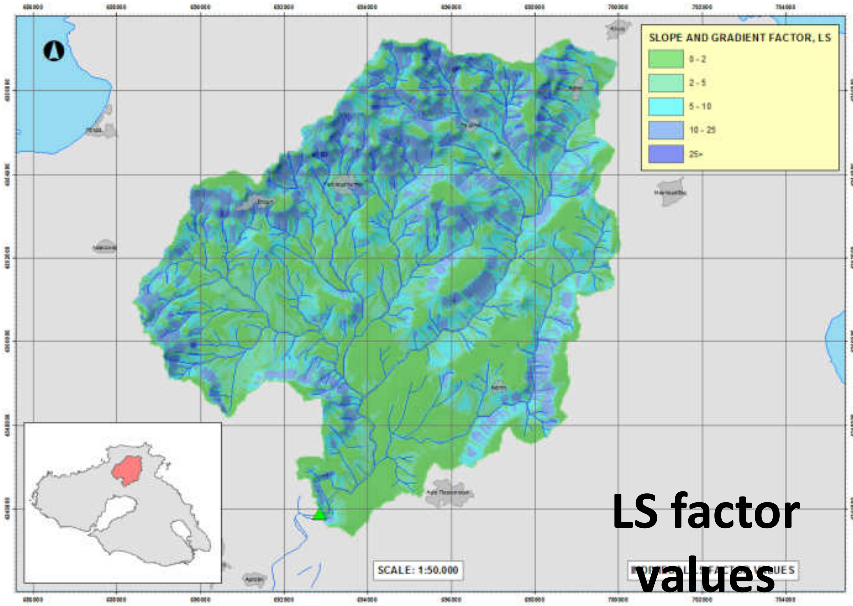
TOPOGRAPHIC FACTOR LS

LS is the topographic factor which represents the effect of slope length and slope gradient on soil erosion.

L: represents the effect of slope length and

S: represents the influence of slope gradient on soil erosion.





The calculation of LS can be optimally carried out using spatial analysis tools and GIS.

TOPOGRAPHIC FACTOR LS

At the present study, Mitasova and Mitas methodology was used to compute the LS factor by the following equation:

$$LS = (m+1) \cdot (As/22.13)^{m} \cdot (\sin\beta/0.09)^{n}$$

m=0.40, n=1.1

As: The specific catchment area which represents the runoff upstream contributing area per unit width. It was calculated by applying the following raster function (using ArcGIS) :

As=Flow accumulation x squared cell size / cell size

β: Slope angle, calculated by applying the raster ArcGIS function

β = Atan [(slope β)/100] in degrees

Based on the above formula and applying spatial analysis techniques, the mean Tsiknias catchment value for LS was calculated at **LS=6.465** using a 25m x 25m DTM grid

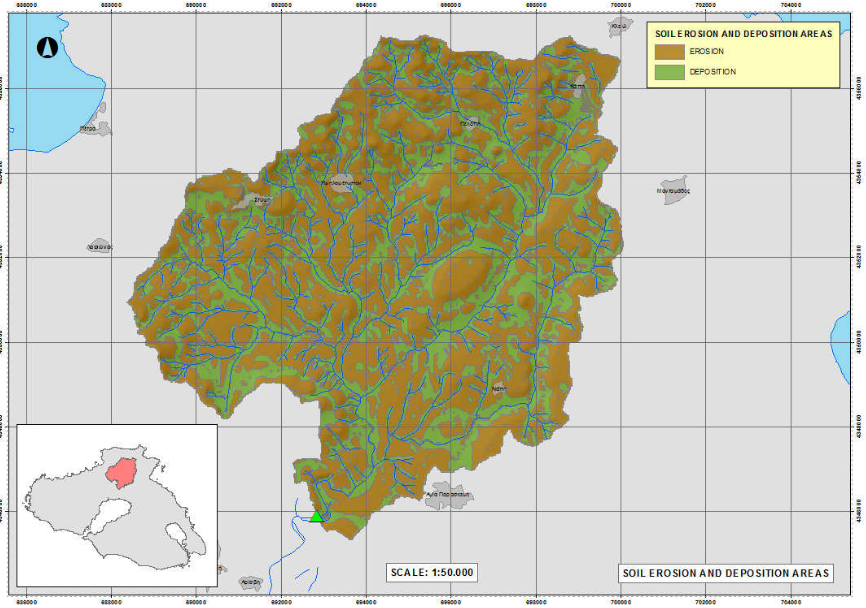
TOPOGRAPHIC FACTOR LS

MUSLE equation must be applied only at soil erosion areas.

Curvature=2nd derivative of surface or the 1st derivative of slope

The slope affects the overall rate of movement downstream.

The curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition.



Erosion and deposition areas

Soil erosion areas (positive curvature): 49.2 km^2 (57%)

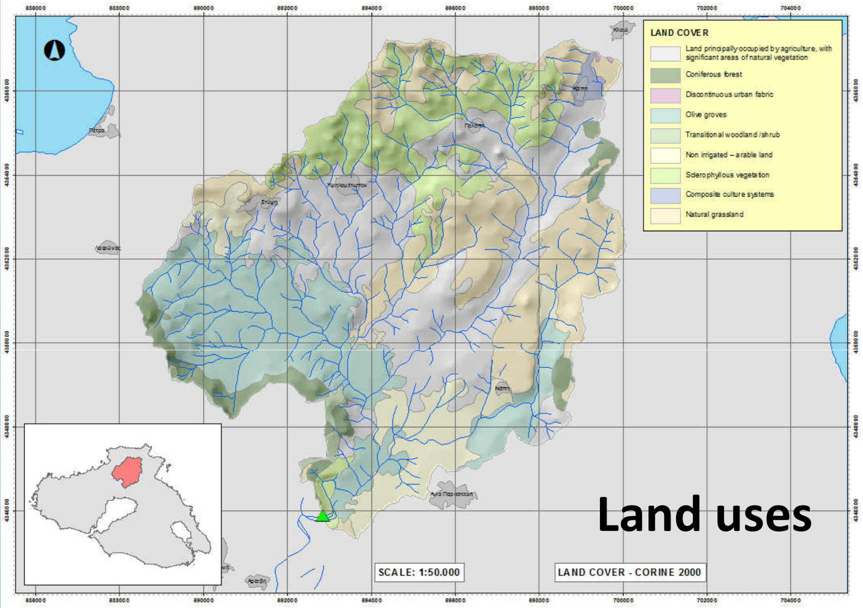
Deposition areas (negative curvature): 36.7 km^2 (43%)

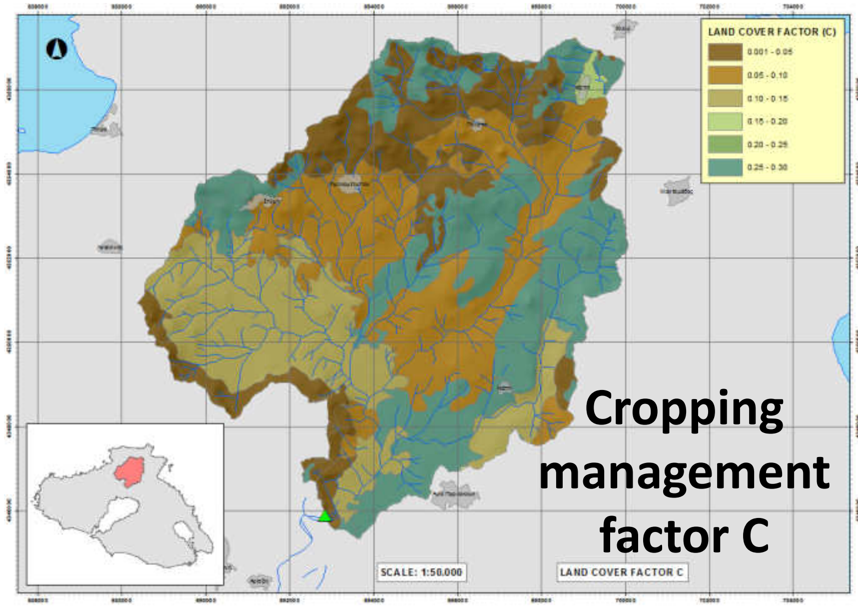
Final LS value reduced to **LS=4.670**

CROPPING MANAGEMENT FACTOR C

C factor is related to land uses (Corine 2000). It is a reduction factor to soil erosion vulnerability and represents the conditions that can be changed to reduce soil erosion

Land cover	C
Discontinuous urban fabric	0.001
Composite culture systems	0.180
Transitional woodland /shrub	0.020
Coniferous forest	0.001
Non irrigated – arable land	0.300
Sclerophyllous vegetation	0.025
Natural grassland	0.300
Olive groves	0.100
Land principally occupied by agriculture, with significant areas of natural vegetation	0.070





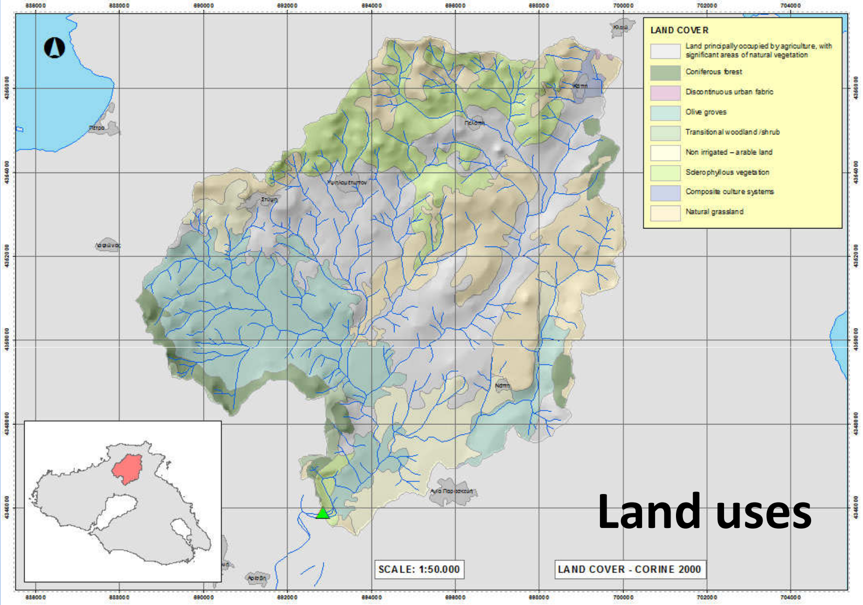
The weighted areal mean value of C at Tsiknias watershed

C=0.136

EROSION CONTROL PRACTICE FACTOR P

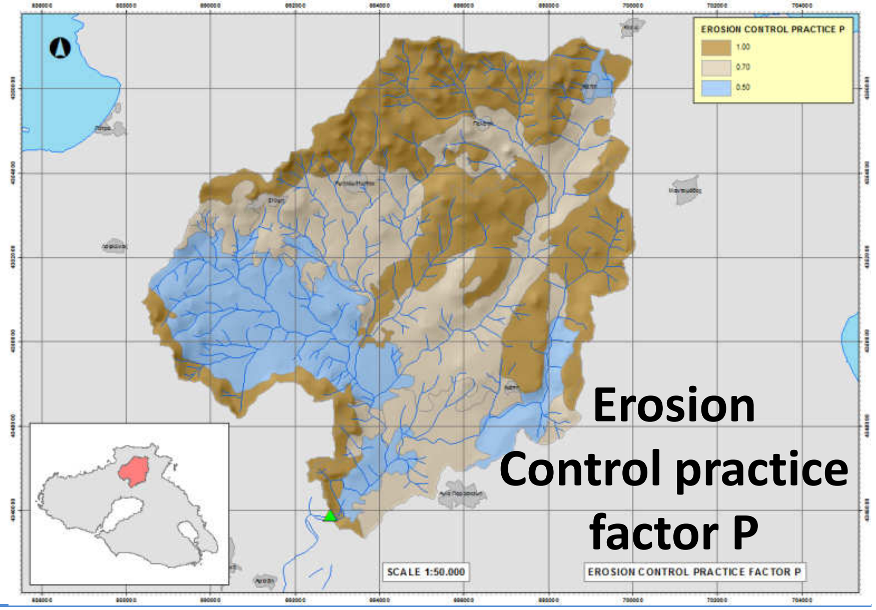
P factor applies only to arable land describing the effects of practices such as contouring, strip cropping, silt fences etc. If none of the above protection practices is applied, P=1.0

Land cover	P
Discontinuous urban fabric	1.00
Composite culture systems	0.50
Transitional woodland /shrub	1.00
Coniferous forest	1.00
Non irrigated – arable land	0.70
Sclerophyllous vegetation	1.00
Natural grassland	1.00
Olive groves	0.50
Land principally occupied by agriculture, with significant areas of natural vegetation	0.70



The weighted areal mean value of P at Tsiknias watershed

P=0.776



MUSLE

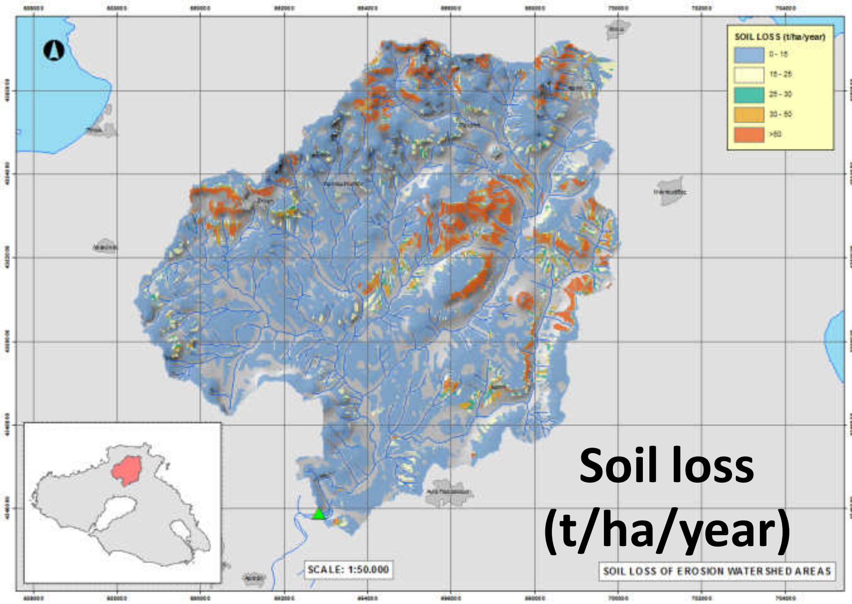
SEDIMENT YIELD ASSESSMENT AT THE DAM LOCATION

Density of sediment material is estimated 1.65 t/m^3

Results	Units	Musle	Gavrilovic	Koutsogianni & Tarla*
Final annual soil loss mass per km^2	$t/km^2/year$	352	319	117
Final annual soil loss volume per km^2	$m^3/km^2/year$	213	193	71
Final annual soil loss volume	$m^3/year$	**18,332**	16,629	6,117
Sediment yield volume at dam location at the 50 years period	m^3	**916,606**	831,444	305,827

**only for suspended sediment transport*

As far as the spatial distribution of soil loss is concerned, the regions with the greater soil loss are located at the central and eastern areas of Tsiknias watershed (red color)



MONITORING PROGRAM

The use of empirical and deterministic approach without measurements, introduces uncertainties in sediment yield estimation. Therefore, a program of field measurements is in progress since 10/2014 to enhance the above results. This program of measurements includes:

1. Hydrometeorological data measurements. A new weather station has already been installed (3/2015) at Agia Paraskevi high school
2. Water level measurements. A radar level sensor has been installed since 7/2014 at Prini bridge
3. Flow velocity and water dicharge measurements have been carried out since 5/2014 at different locations of Tsiknias river
4. Suspended sediment concentration was analysed at the Minicipal Water and Sewerage Company laboratory of Lesvos.
5. Bedded sediment yield measurements. Bedded sediment traps (6.0 x 6.0 x 1.5m) were constructed at two locations, downstream of the dam (11/12/2014).
6. Aggregate grading analysis of the two sediment traps.


SEDIMENT TRAP No1
SEDIMENT TRAP No2
KREMASTI BRIDGE
PRINIS BRIDGE
DESIGN WATER SURFACE+56.00m
POINT EAST OF KREMASTI BRIDGE
AGIA PARASKEUI
METEO STATION

CONCLUSIONS

1. Sediment yield estimation is very crucial not only for the inactive storage determination but also for the finalization of the abstraction works design
2. MUSLE implementation provides a sediment yield estimation along with:

- ✓ small timescale (5-minute) rainfall data
- ✓ GIS models
- ✓ Spatial analysis

3. MUSLE results are equivalent to Gavrilovic methodology. Koutsogianni and Tarla equation gives unfavourable results comparing to MUSLE
4. In order to minimize the uncertainties introduced by such an empirical model, results will be enhanced by a program of significant field measurements that is currently in progress
5. A sustainable sedimentation management plan will be proposed after the end of monitoring program

MONITORING PROGRAM INITIAL RESULTS

1. The first sediment trap (at a straight river segment) filled by 92% 4 months after its excavation
2. The second sediment trap (at a river curve) was fully covered one month after its excavation
3. A third sediment trap (dimensioned 6.0 x 6.0 x 1.2m) was created near the second trap location. It was also fully covered 20 days after its excavation.
4. Low suspended yield (~10%) volume was measured comparing to the bedded sediment yield

Thank you for your attention!

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