Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Hazard Assessment on Regional Scales: Pilot Implementation in Greece

Acknowledgments:
The SciNetNatHaz Project
is partially funded by the **EU** and National funds
within the context of the
Black Sea Basin Joint Operational Programme 2007-2013

K. Papatheodorou, TEI of Kentriki Makedonia, Hellas
Nikolaos Klimis, Democritus University of Thrace

SciNetNatHaz project Open Seminars, September-October 2015

Landslide Hazard Assessment in the Blaxi area. The….Gaps!

- **Usable Data are lacking**. Inventories of past landslides do not exist or are not accessible.
- **Metadata** are not supplied so it's very difficult to assess **reliability and accuracy** of available data (if found!).
- **Different LHA methodologies** are used even in the same country, **making comparison** of outputs, **impossible.**
- **Hazard identification & Risk assessment on regional and on local scales** (that could provide the essential information for planning typical preventive measures) has only been **sparsely implemented**.

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

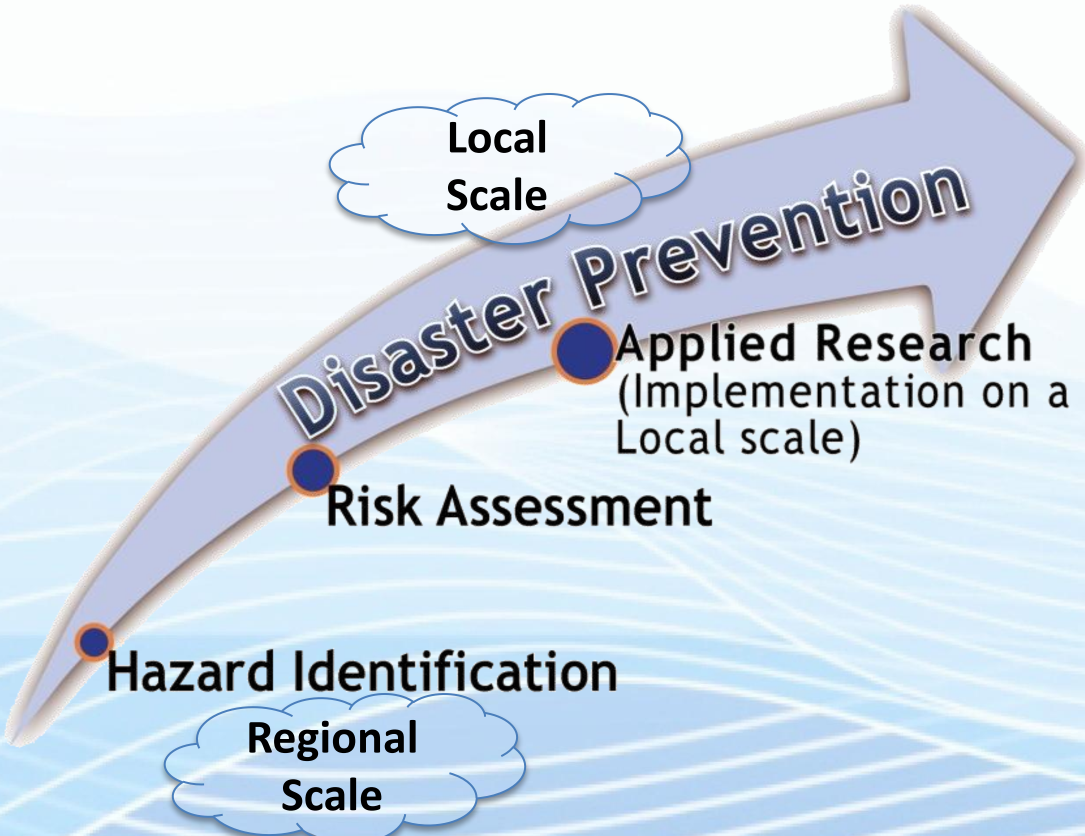
SciNetNatHaz Landslide Hazard Assessment (LHA) related actions

The SciNetNatHaz project actions taken include:

- Select **worldwide accepted methodologies**, **applicable** in the wider area of the Black Sea basin, given the restrictions regarding data availability
- **Adapt** to “local” conditions and **implement LHA on regional scales** and **in pilot implementation areas**
- **Compare** selected methodologies in terms of **feasibility to implement** and **accuracy & reliability** of outputs
- Provide **free access to data** produced and processed with **Metadata** according to the INSPIRE directive provisions
- Indicatively **assess the Risk on regional scale and implement analysis on a local scale** which could provide the essential information for **planning typical preventive measures**.

Common borders. Common solutions.

Regional and Local scale LH Assessment to promote Prevention



- Landslide Hazard Assessment on **Regional Scale** to **promote strategic planning & development**
- Stability analysis on a **local scale to assess typical preventive measures**

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Selected, Adapted to local conditions and Applied Methodologies

A. **Mora & Vahrson** methodology (Sergio Mora C., & Wilhelm-Gunther Vahrson (1994): Macrozonation Methodology for Landslide Hazard determination. Bulletin of the Association of Engineering Geologists, Vol. XXXI No.1, 1994, pp.49-58.

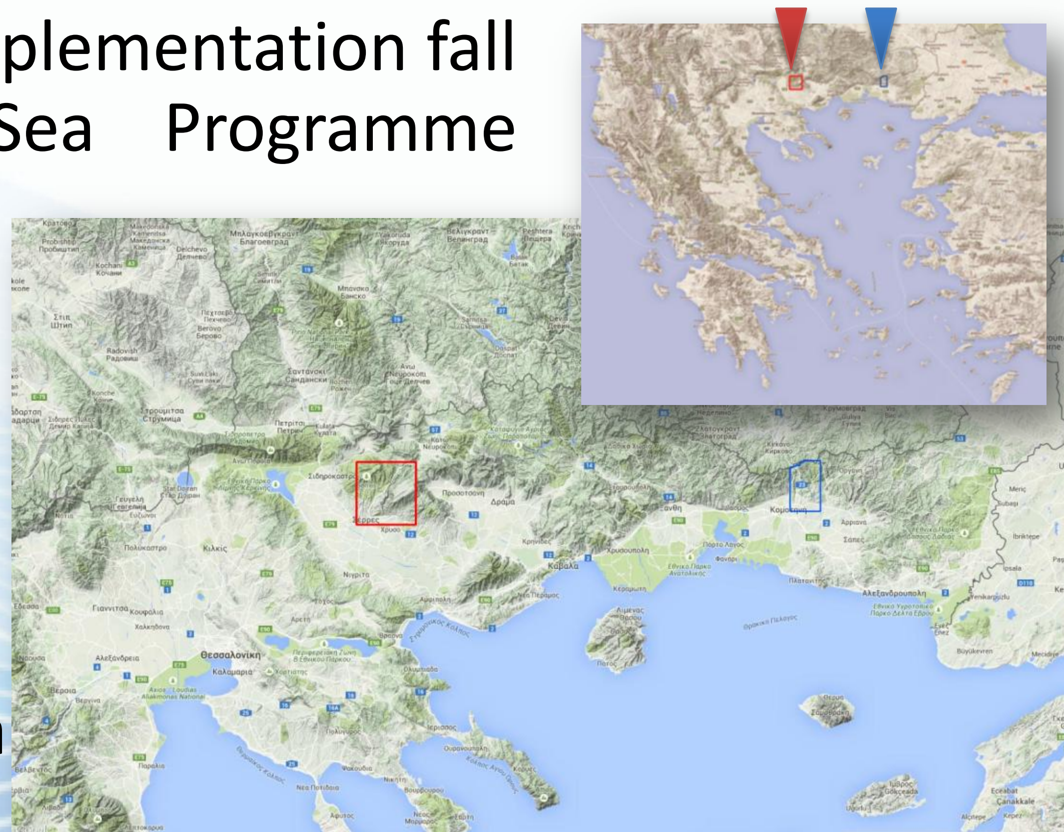
B. **F**ederal **E**mergency **M**anagement **A**gency (FEMA, USA) methodology – **HazUS** (https://www.fema.gov/hazus)

C. **Factor of Safety** calculation (Infinite Slope Model)

Common borders. Common solutions.

Implementation areas - Hellas

Both areas of pilot implementation fall inside the Black Sea Programme eligible area:



A. **S**erres

B. **K**omotini-Nymfaia

Project funded by the EUROPEAN UNION

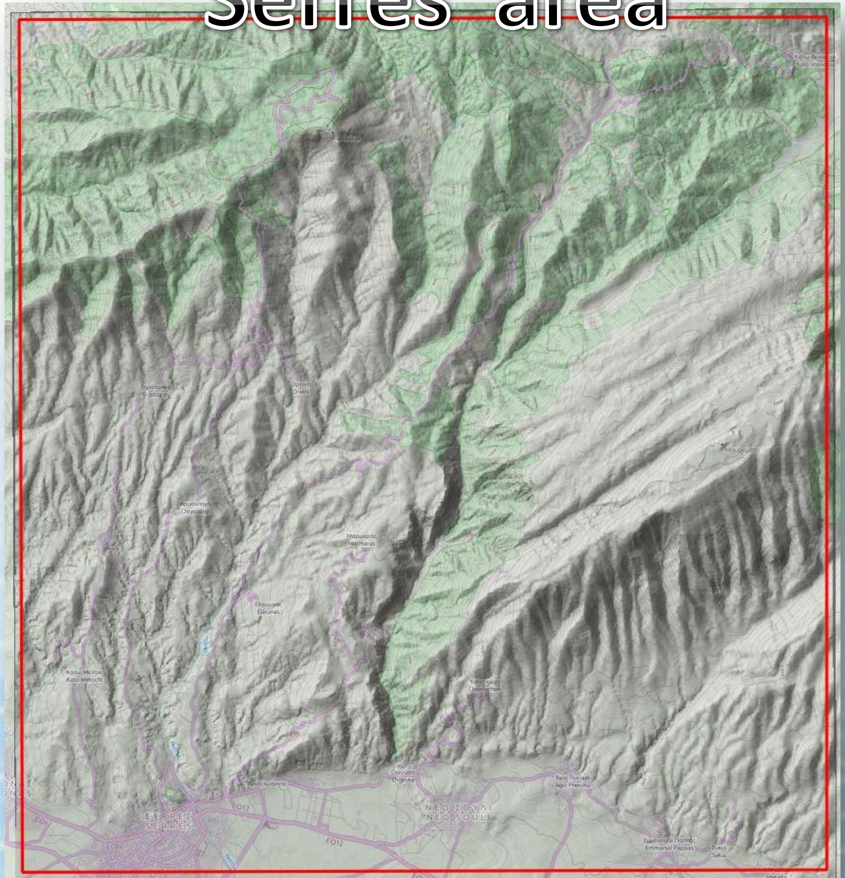
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

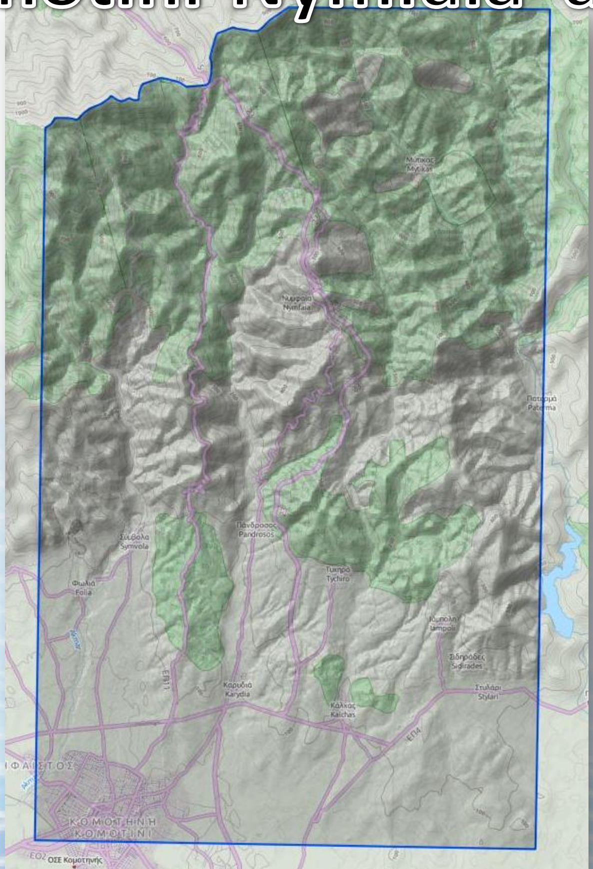
Common borders. Common solutions.

Implementation areas - Hellas

Serres area



Komotini-Nymfaia area

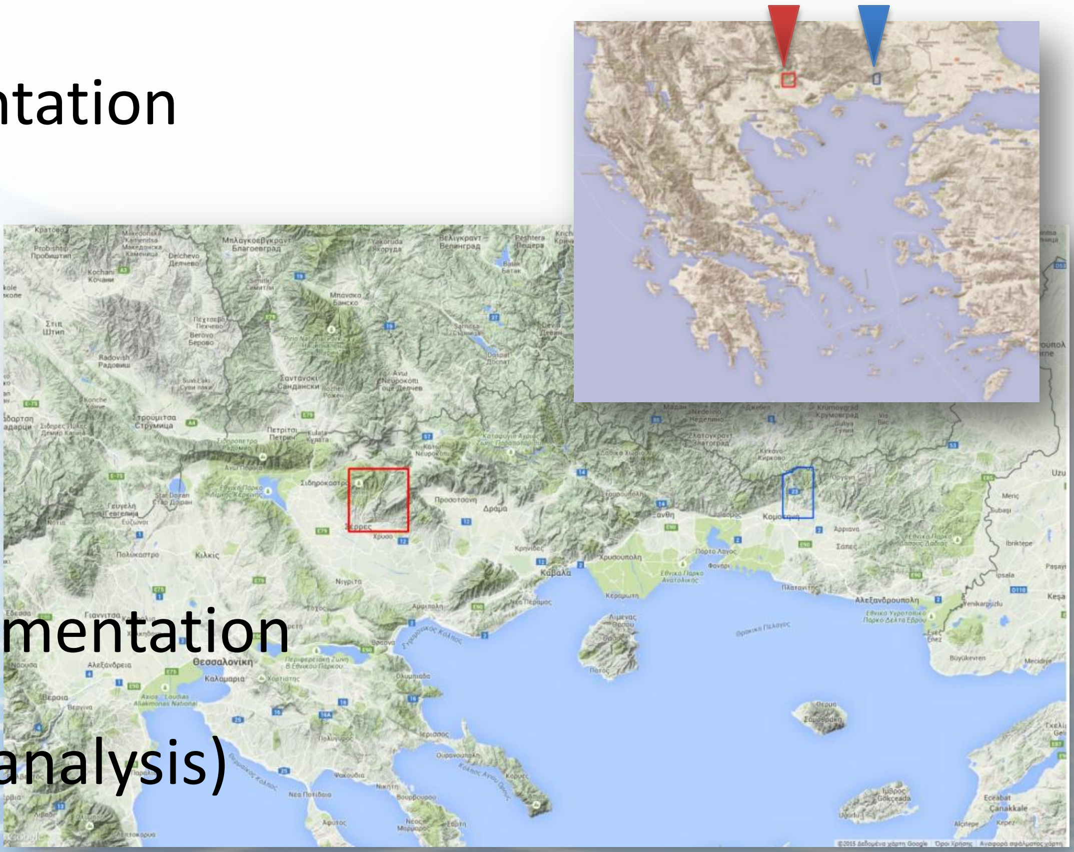


A. Mora & Vahrson Methodology

Areas of pilot implementation

A. **S**erres

B. **K**omotini-Nymfaia



Scale of Regional Implementation

1:50.000 (input data & analysis)

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

A. Mora & Vahrson Methodology

Calculates the "Intrinsic Landslide Susceptibility" (SUSC)
Taking into account the:
Slope Factor (**Sr)**
Lithology Factor (**Sl)**
Soil Humidity Conditions (**Sh**)

And the Triggering Factor (TRIG)
Deriver from the combination of
Seismic factor (**Ts**)
Precipitation factor (**Tp**)

HI = SUSC * TRIG=
= (Sr * Sl * Sh) * (Ts + Tp)

A. Mora & Vahrson Methodology

The landslide **Hazard indicator (HI)**

$$HI = SUSC * TRIG$$
$$= (Sr * Sl * Sh) * (Ts + Tp)$$

Where:

Sr : "Slope" factor
Sl : Geology factor
Sh: Humidity factor

Ts: (Earthquake) Seismic triggering factor
Tp: Precipitation triggering factor

A. M&V Methodology-Data requirements

- Scale of Implementation 1:50.000
- Topographic data (topographic Maps, elevation data, lattice points etc). In case topographic data at a 1:50000 scale are not available, ASTER DEMs can be used at the expense of accuracy.
- Geologic Maps
- Ground Motion data (PGA values)
- Mean Monthly Rainfall (mm) and MAX daily precipitations

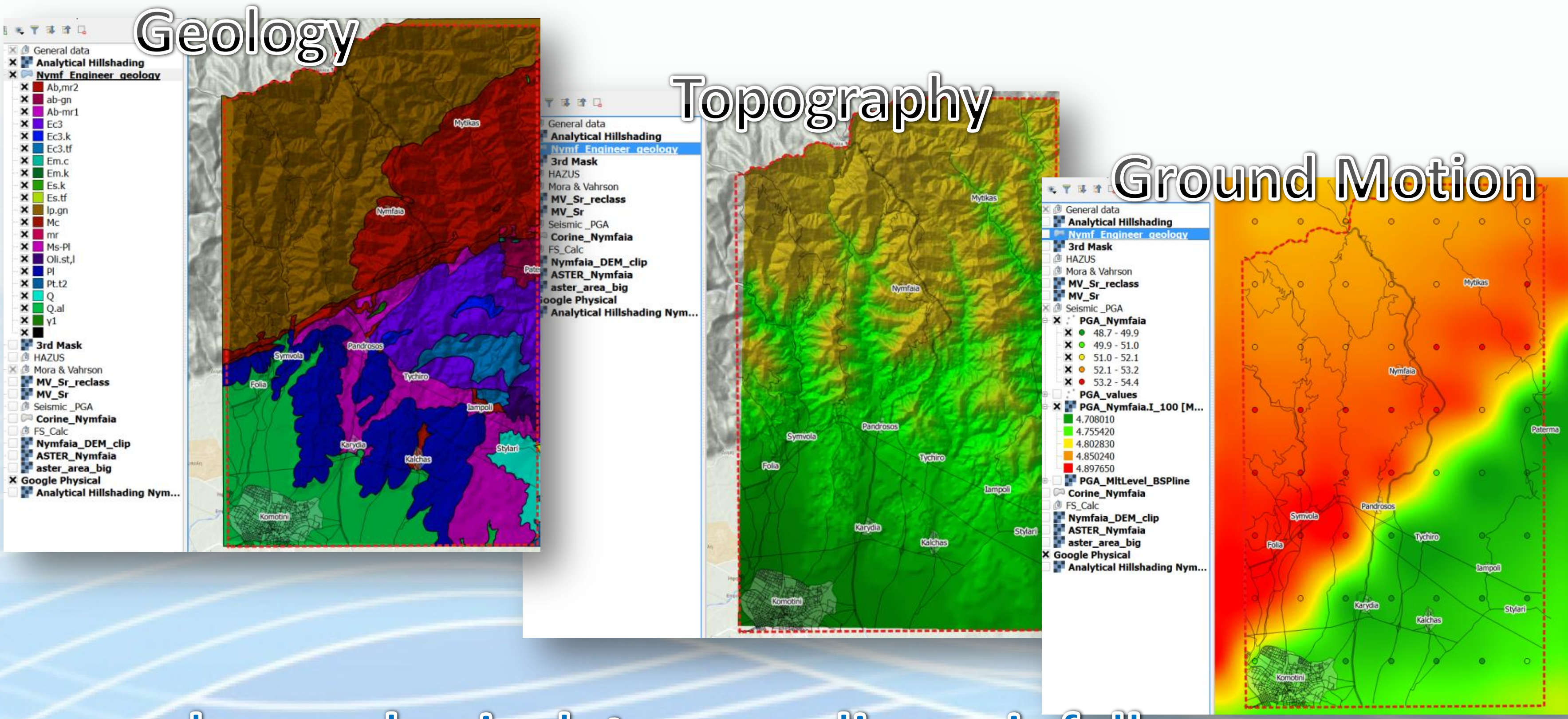
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

A. M&V Methodology-Data requirements



...and some basic data regarding rainfall

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC

HI = **SUSC** * TRIG = **(Sr * Sl * Sh)** * (Ts + Tp)

Includes the intrinsic properties of the landscape, the mechanical quality and its “passive” behavior. The parameters are the following:

- Slope Factor (**Sr**=Relative Relief),
- Lithology Factor (**Sl**),
- Soil Humidity Conditions (**Sh**)

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC – Slope Factor

HI = **SUSC** * TRIG = (**Sr** * Sl * Sh) * (Ts + Tp)

The Slope Factor is defined by the maximum difference in elevation per unit area **Rr = Relative Relief per grid unit (square km) Rr = (Hmax-Hmin)/km2**

Relative Relief Rr (m/km2)	Classification	Slope Factor Sr
0-75	Very Low	0
76-175	Low	1
176-300	Moderate	2
301-500	Medium	3
501-800	High	4
>800	Very High	5

Table 1. Slope factor classification

Project funded by the EUROPEAN UNION

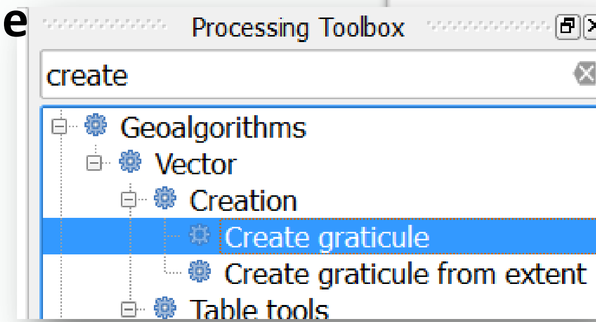
SciNet NatHaz Prevention

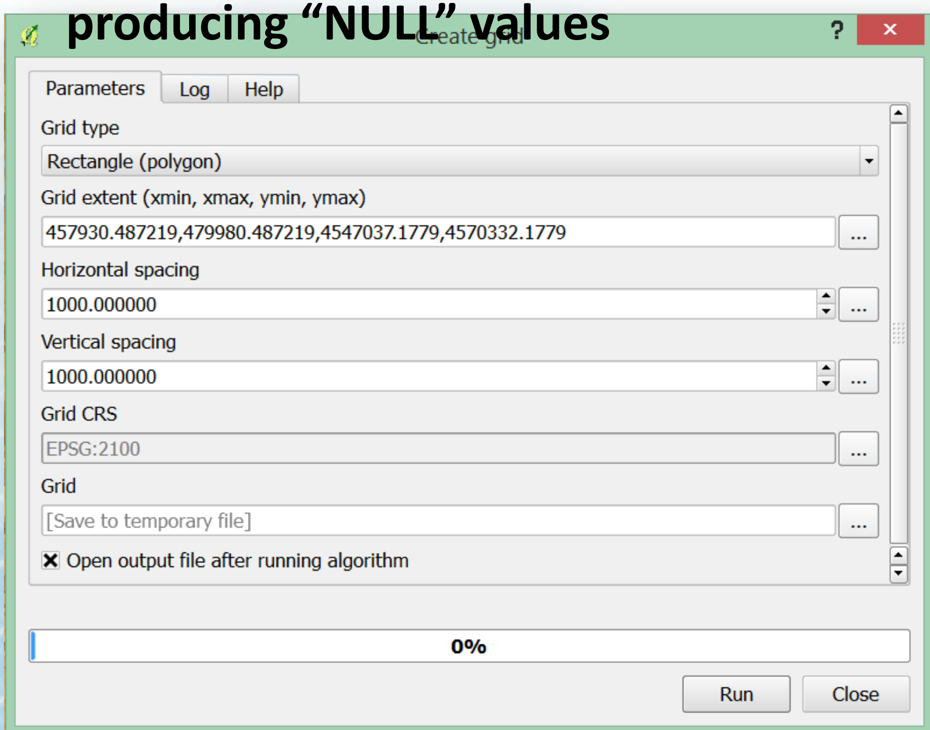
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Relative Slope Factor(Sr) Calculation step 1/3

- QGIS / Toolbox / Vector / Creation / Create graticule
- SET as GRID EXTENT the DEM file in order to avoid producing "NULL" values





- Grid Type: **polygon**
- Grid Extend: **Select a layer** which covers the implementation area (the DEM will be fine)
- Horizontal and Vertical spacing: **1000m**
- Grid CRS: Insert the **Geodetic Reference System** of your choice
- Grid: grid **name**

Project funded by the EUROPEAN UNION

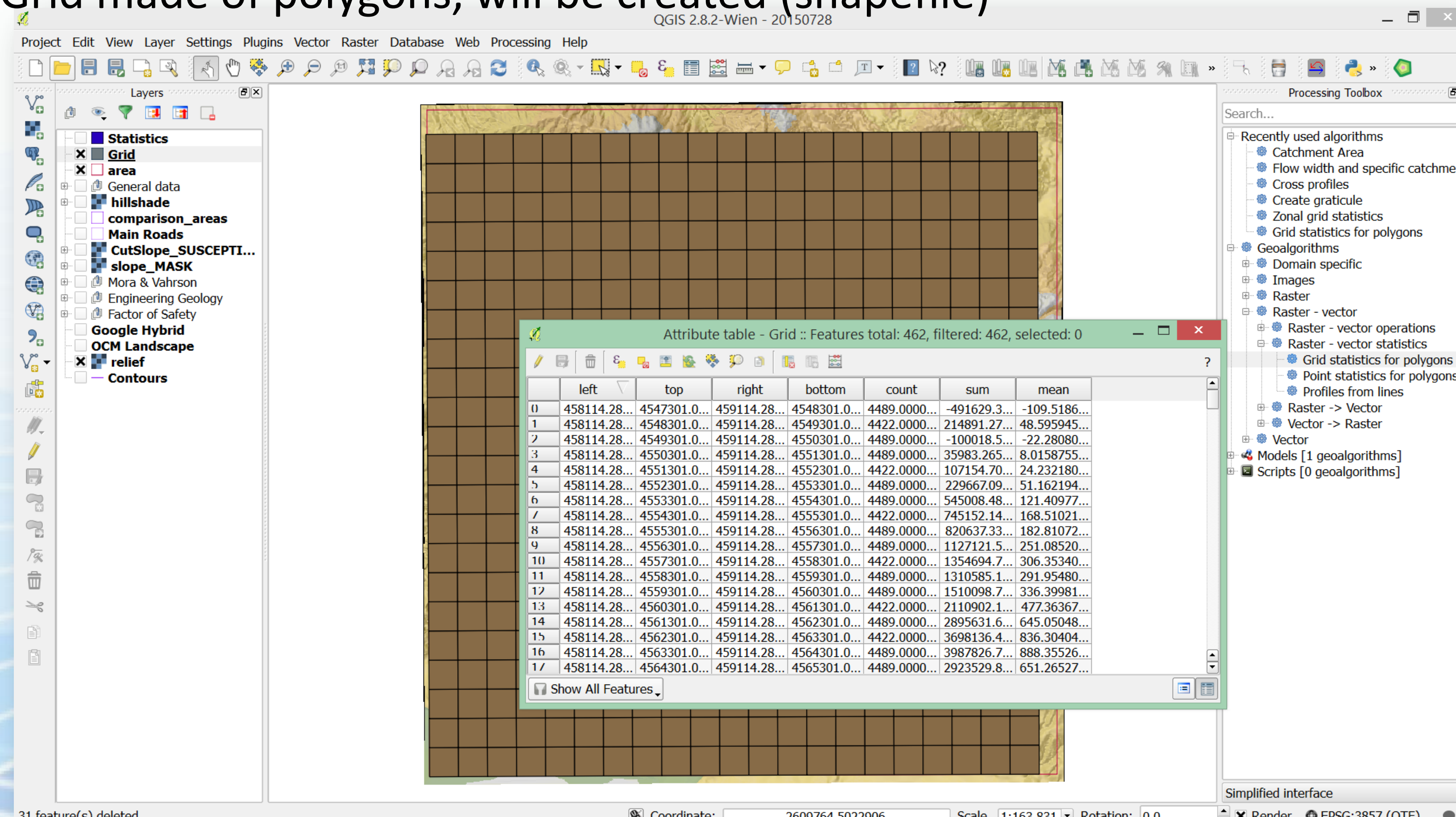
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Relative Slope Factor(Sr) Calculation step 1/3

- A Grid made of polygons, will be created (shapefile)



Project funded by the EUROPEAN UNION

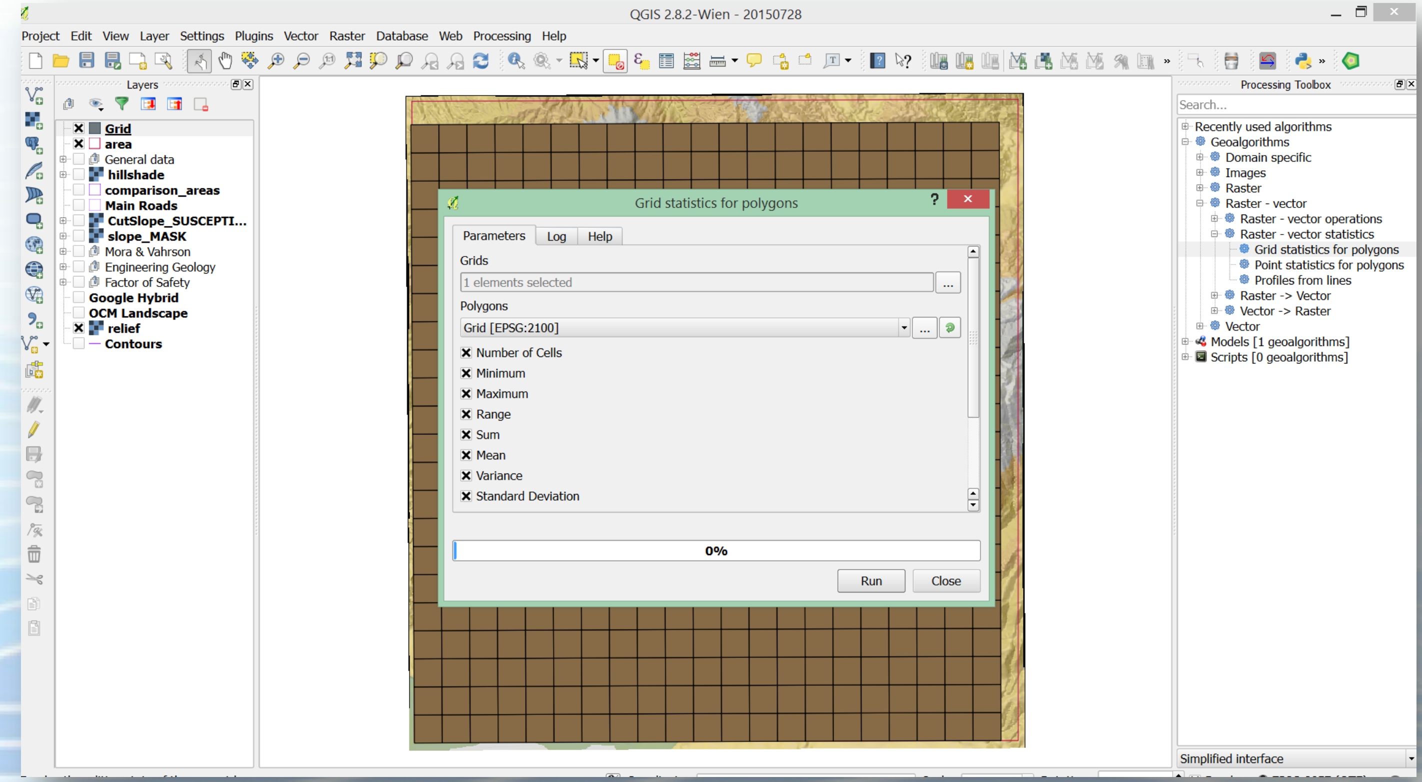
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Relative Slope Factor(Sr) Calculation step 2/3

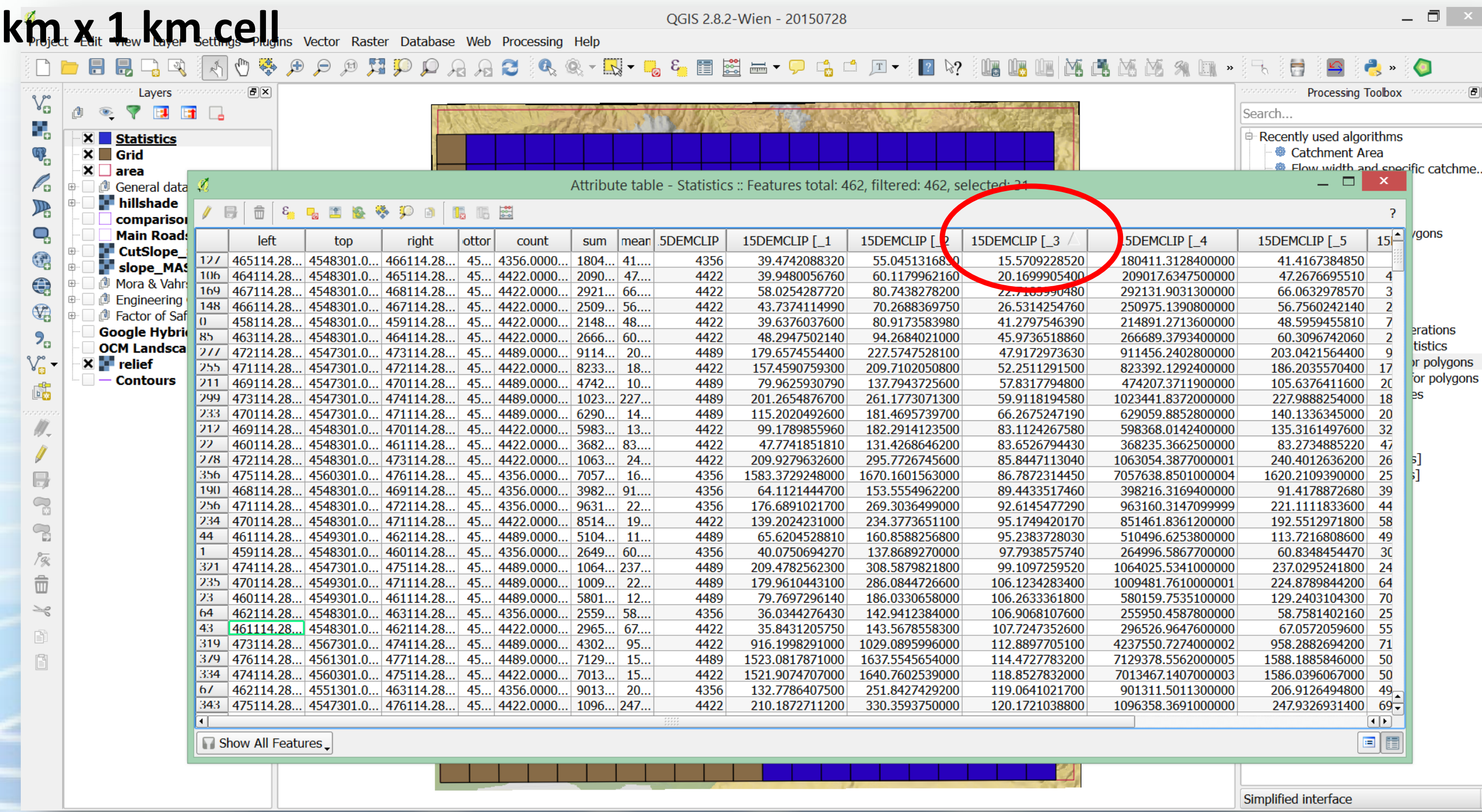
- Toolbox/ Raster-Vector / **Grid Statistics from polygons**
- Insert the requested statistical parameters (especially "RANGE") and…*Run*



Common borders. Common solutions.

Relative Slope Factor(Sr) Calculation step 2/3

- A NEW shapefile will be created having as additional attributes the requested parameters including the “Range” which corresponds to the **elevation difference in each 1km x 1 km cell**



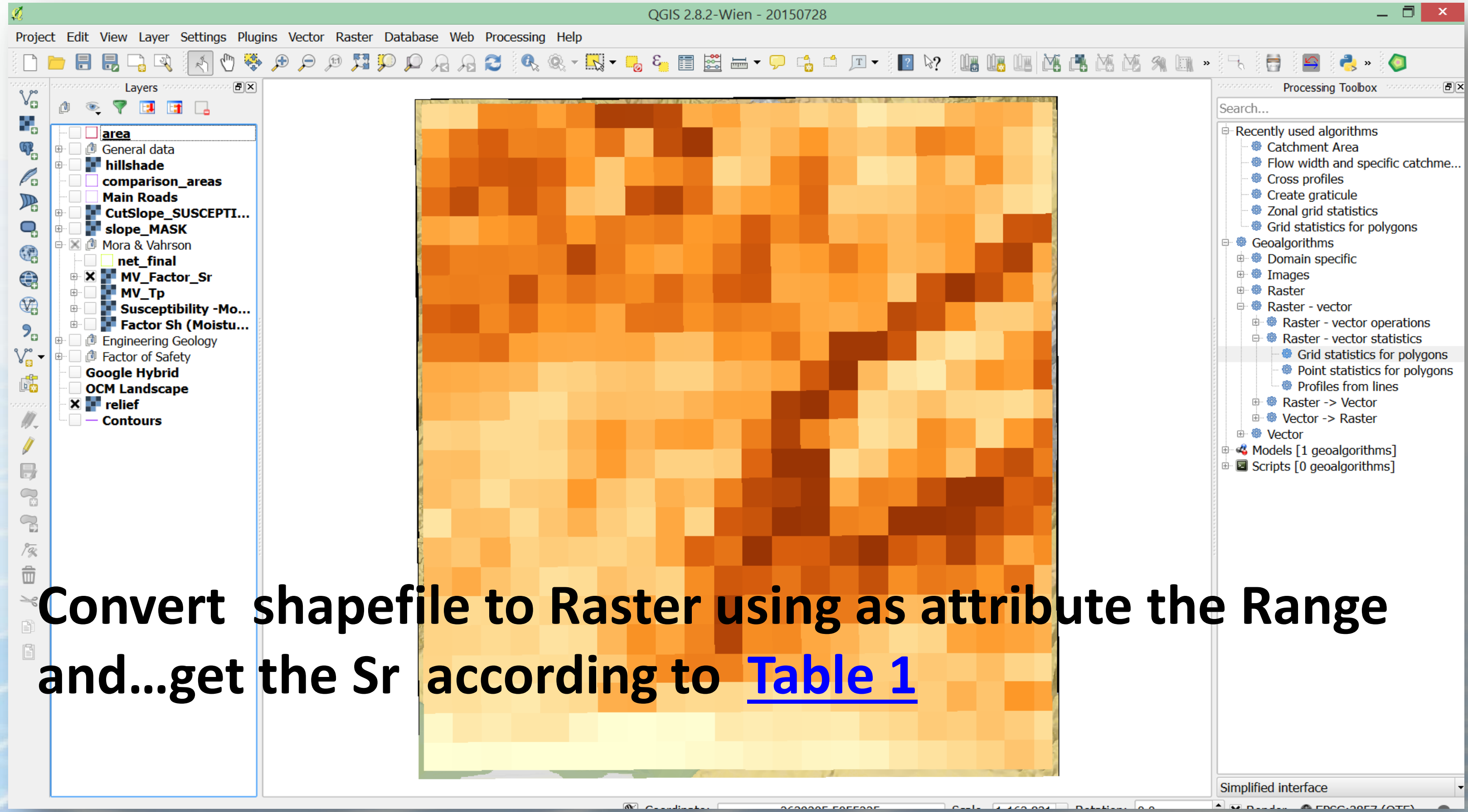
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

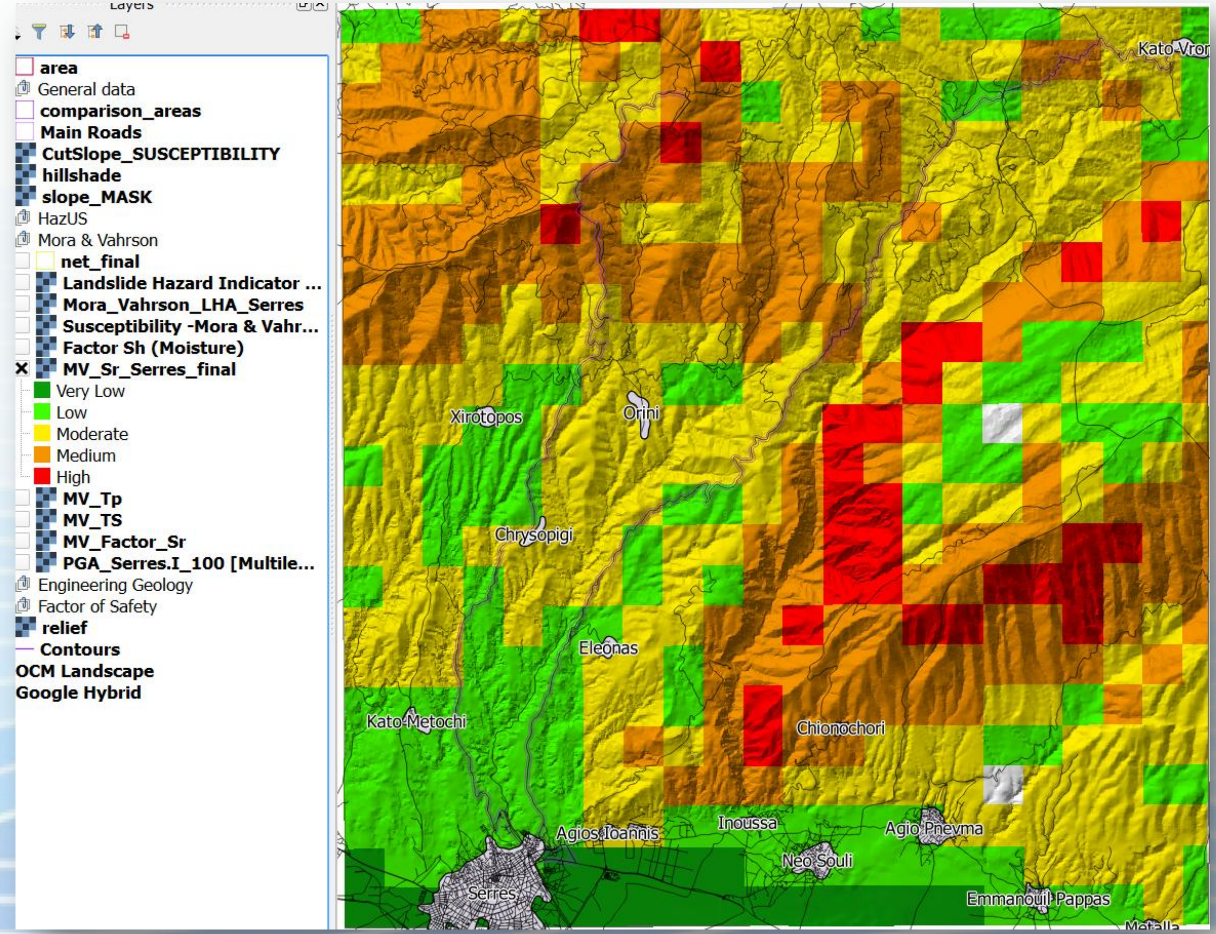
Relative Slope Factor(Sr) Calculation step 3/3



- **Convert shapefile to Raster using as attribute the Range and…get the Sr according to [Table 1](#)**

Common borders. Common solutions.

Relative Slope Factor(Sr) Calculation



Susceptibility Indicator SUSC – Lithology Factor 1/2

HI = **SUSC** * TRIG = (Sr * **Sl** * Sh) * (Ts + Tp)

Includes the intrinsic properties of the landscape, the mechanical quality and its “passive” behavior. The parameters are the following:

The Lithology Factor (**Sl),** is assessed from the **description of the geologic formations** and ideally, **geotechnical parameters** should be taken into account. There should be an, as close as possible to real conditions, estimation of the geotechnical behavior of the geologic formations.

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC – Lithology Factor 2/2

HI = **SUSC** * TRIG = (Sr * **Sl** * Sh) * (Ts + Tp)

Parameters to be considered: volumetric weight, shear strength, weathering, discontinuities and their spatial distribution and orientation, their relation to slope geometry, drainage and pore pressure conditions, water table etc

Lithology can be used to **evaluate susceptibility** as very low (0), low (1), moderate (2), medium (3), high (4) and very high (5) (the highest the number the highest the susceptibility)

Project funded by the EUROPEAN UNION

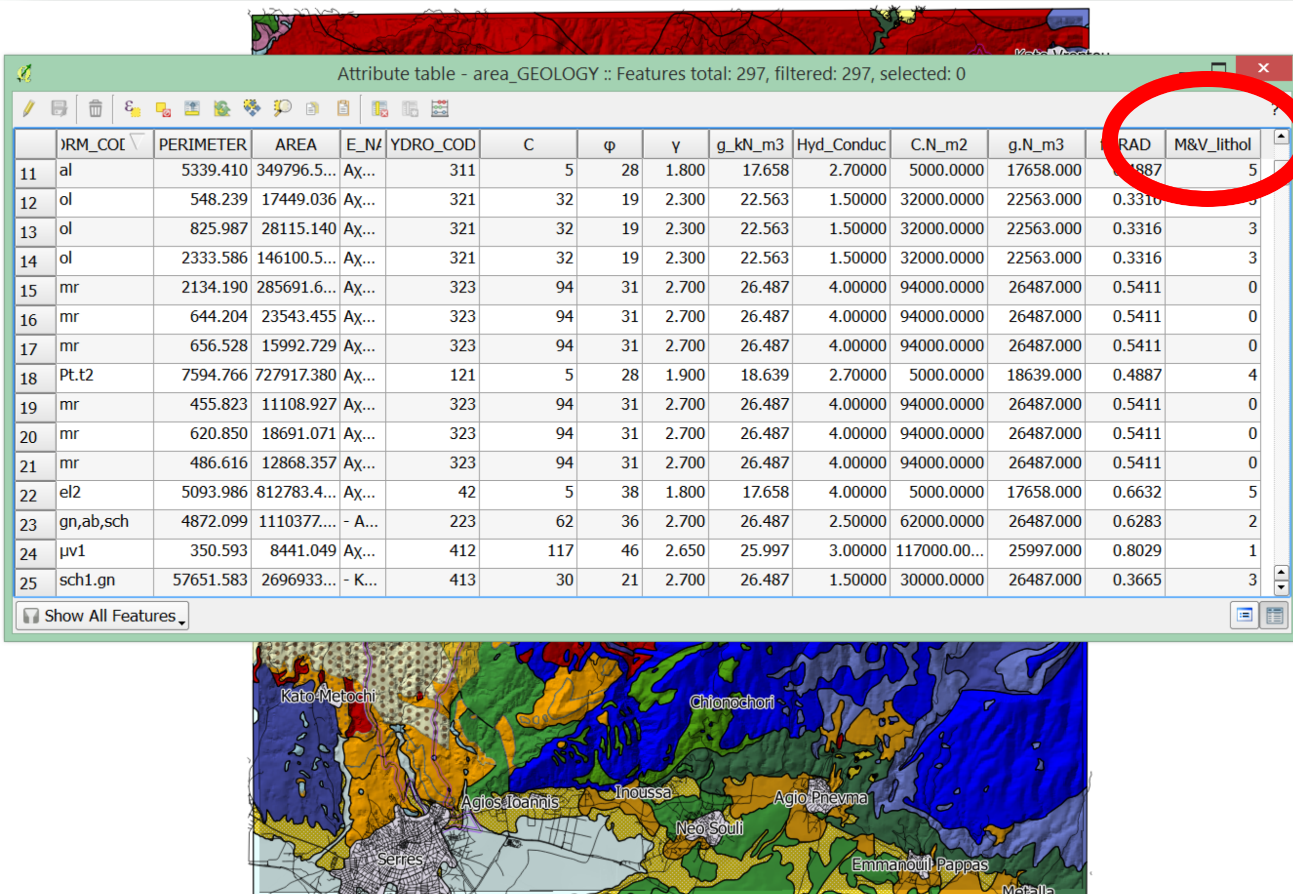
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC – Geology Factor 2/2

Lithology factor according to Parameters considered (volumetric weight, shear strength, weathering etc)



	)RM_COI	PERIMETER	AREA	E_N/	YDRO_COD	C	φ	γ	g_kN_m3	Hyd_Conduc	C.N_m2	g.N_m3	RAD	M&V_lithol
11	al	5339.410	349796.5...	Αχ...	311	5	28	1.800	17.658	2.70000	5000.0000	17658.000	…4887	5
12	ol	548.239	17449.036	Αχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.331…	[illegible]
13	ol	825.987	28115.140	Αχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	3
14	ol	2333.586	146100.5...	Αχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	3
15	mr	2134.190	285691.6...	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
16	mr	644.204	23543.455	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
17	mr	656.528	15992.729	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
18	Pt.t2	7594.766	727917.380	Αχ...	121	5	28	1.900	18.639	2.70000	5000.0000	18639.000	0.4887	4
19	mr	455.823	11108.927	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
20	mr	620.850	18691.071	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
21	mr	486.616	12868.357	Αχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0
22	el2	5093.986	812783.4...	Αχ...	42	5	38	1.800	17.658	4.00000	5000.0000	17658.000	0.6632	5
23	gn,ab,sch	4872.099	1110377....	- A...	223	62	36	2.700	26.487	2.50000	62000.0000	26487.000	0.6283	2
24	μv1	350.593	8441.049	Αχ...	412	117	46	2.650	25.997	3.00000	117000.00...	25997.000	0.8029	1
25	sch1.gn	57651.583	2696933...	- K...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	3

Project funded by the EUROPEAN UNION

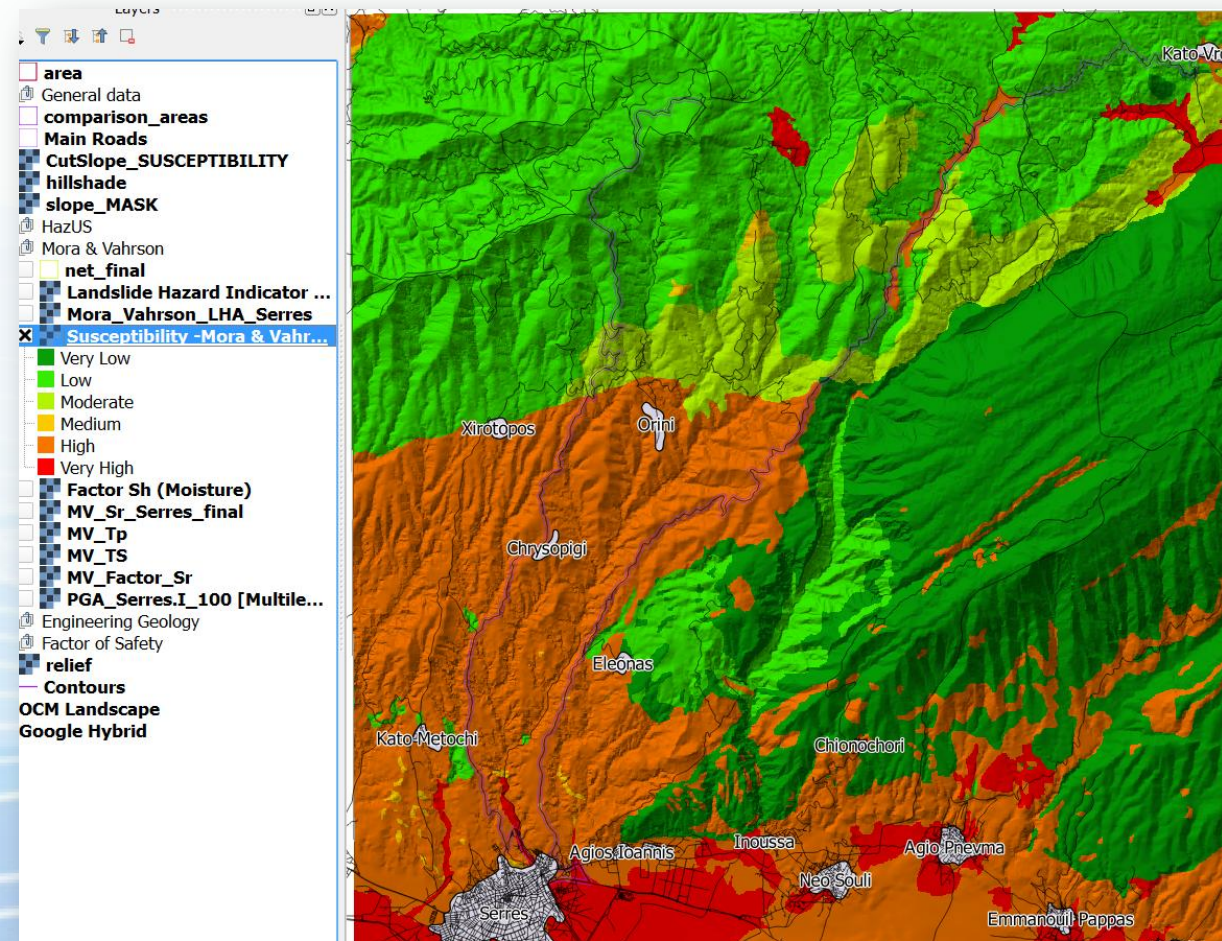
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC – Lithology Factor 2/2

Lithology factor according to Parameters considered (volumetric weight, shear strength, weathering etc)



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility Indicator SUSC – Soil Moisture

HI = **SUSC** * TRIG = (Sr * Sl * **Sh**) * (Ts + Tp)

Takes into account he average conditions of soil moisture. Quantifies the influence of **accumulated humidity throughout the year.**

Best measured in situ, but usually a simple methodology of soil-water balance can be used requiring only the average monthly precipitations.

Steps to follow:

1. Calculate the AVERAGE Monthly potential evapotranspiration (PET) for the implementation area
2. Each monthly average precipitation is assigned an index value according to **Table 3**
3. The TOTAL of all 12 month assigned values are calculated for each analyzed rain gage station. These values range from 0 to 24.
4. The total is classified into 5 groups according to **Table 4**

Project funded by the EUROPEAN UNION

Relative Soil Moisture

Average Monthly Precipitation AMP (mm/month)	Assigned Value
<125*	0
126-250	1
>250	2

Table 3. Average monthly rainfall values classification

* 125 is the proposed value for South America. We must use a value around the average monthly potential evapotranspiration…which may have been correlated to elevation.

Accumulated value of Precipitation Indices	Qualification	Factor Sh
0-4	Very Low	1
5-9	Low	2
10-14	Medium	3
15-19	High	4
20-24	Very High	5

Table 4. Moisture factor (Sh) from accumulated AMP values

Both Serres and Nymfaia areas present average monthly precipitations below 125mm, so they fall into the **"Very low"** category

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Triggering Indicator TRIG

HI = SUSC * **TRIG** = (Sr * Sl * Sh) * **(Ts + Tp)**

Represents the EXTERNAL driving forces which trigger the event.

Combines two factors:

i) the 100 year earthquake and

ii) The 100 year intense rainfall events

Triggering Indicator TRIG - Earthquakes

HI = SUSC * **TRIG** = (Sr * Sl * Sh) * (**Ts** + Tp)

Seismic intensity factor Ts is determined by analyzing landslides triggered by earthquakes to assess the influence of seismic intensities on the group of lithologic, climatic and morphologic conditions.

Intensities (MM) Tr=100yr	Qualification	Factor Ts
III	Slight	1
IV	Very Low	2
V	Low	3
VI	Moderate	4
VII	Medium	5
VIII	Considerable	6
IX	Important	7
X	Strong	8
XI	Very Strong	9
XII	Extremely Strong	10

Table 5. Seismic Intensity factor **BASED ON OBSERVATIONS in Costa Rica and Central America**

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

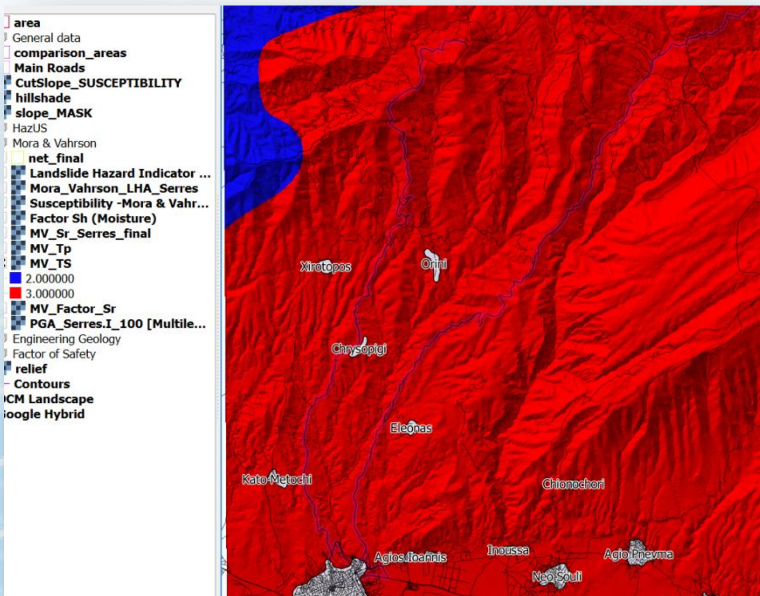
Common borders. Common solutions.

Triggering Indicator TRIG - Earthquakes

HI = SUSC * **TRIG** = (Sr * Sl * Sh) * (**Ts** + Tp)

The **Seismic Intensity for 100yrs return period** needs to be calculated

ln PGA = 0.55*Imm + 1.30 (R^2=0.88), PGA in cm/sec^2 (Koliopoulos et al., 1998, JEE)



Attribute table - PGA_Serres :: Features total: 42, filtered: 42, selected: 0

X	--------Y	TR-----10	--------25	--------50	------100	------200	------475	------950	-----1[illegible]0	I_100
00...	41.076099...	22.920000...	34.859999...	47.869999...	65.750000...	90.290000...	196.68999...	234.37999...	279.000[illegible]...	5.25
00...	41.076099...	22.149999...	34.359999...	47.890000...	66.739999...	93.030000...	216.12999...	291.57999...	294.00999...	5.27
00...	41.076099...	18.440000...	30.690000...	45.119999...	66.340000...	98.340000...	277.75000...	345.06000...	360.89999...	5.26
99...	41.076099...	15.630000...	27.840000...	43.079999...	66.670000...	105.53000...	291.33999...	346.99000...	360.93000...	5.27
00...	41.076099...	13.100000...	25.140000...	41.170000...	67.430000...	113.34999...	294.06999...	350.16000...	360.99000...	5.29
00...	41.076099...	11.039999...	22.859999...	39.659999...	68.790000...	120.48000...	296.56000...	351.87000...	361.01999...	5.33
00...	41.076099...	8.9700000...	20.399999...	37.979999...	70.689999...	127.68000...	298.00999...	346.62999...	360.87999...	5.38
00...	41.116100...	16.579999...	27.989999...	41.600000...	61.829999...	91.890000...	182.74000...	205.09999...	217.25000...	5.14
00...	41.116100...	15.029999...	26.660000...	41.140000...	63.479999...	98.620000...	203.68999...	244.47999...	290.72000...	5.18
00...	41.116100...	12.850000...	24.399999...	39.630000...	64.379999...	107.03000...	220.58000...	292.19999...	309.75999...	5.21
99...	41.116100...	11.050000...	22.500000...	38.520000...	65.930000...	116.07999...	231.28000...	295.94999...	318.00000...	5.25
00...	41.116100...	9.0700000...	20.140000...	36.829999...	67.370000...	127.64000...	243.52000...	302.80000...	332.01999...	5.29
00...	41.116100...	6.8600000...	17.320000...	34.890000...	70.280000...	141.90000...	256.91000...	310.43000...	345.18000...	5.37
00...	41.116100...	5.4700000...	15.380000...	33.609999...	73.480000...	155.31000...	268.85000...	316.86000...	354.77999...	5.45

Show All Features

Precipitation Intensity factor Tp

Triggering Indicator TRIG - Precipitation

HI = SUSC * **TRIG** = (Sr * Sl * Sh) * (Ts + **Tp**)

Maximum Rainfall n>10yrs, Tr = 100yrs	Rainfall n<10yrs; Average	Qualification	Tp Factor
<100mm	<50mm	Very Low	1
101-200mm	51-90mm	Low	2
201-300mm	91-130mm	Medium	3
301-400mm	131-175mm	High	4
>400mm	>175mm	Very High	5

Table 6. Precipitation factor (Tp) originating from the classification of maximum daily precipitations over a return period if 100yrs. An auxillary classification based on the average yearly maximum values per day is given in column 2.

*Both Serres and Nymfaia areas present average maximum DAILY precipitations in the range of 51-90mm, so they fall into the **"Low"** category (Tp=2)*

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Classification of Landslide Hazard Indicator (HI)

HI = SUSC * TRIG = (Sr * Sl * Sh) * (Ts + Tp)

HI values range from 0 to 1250 or more

These values are indicative of the landslide hazard according to Table 7

Value of HI	Class	Classification of Hazard of Landslide Potential
<6	I	Negligible
7-32	II	Low
33-162	III	Moderate
163-512	IV	Medium
513-1250	V	High
>1250	VI	Very High

Table 7. Classification of the Landslide Hazard HI parametric values.

Project funded by the EUROPEAN UNION

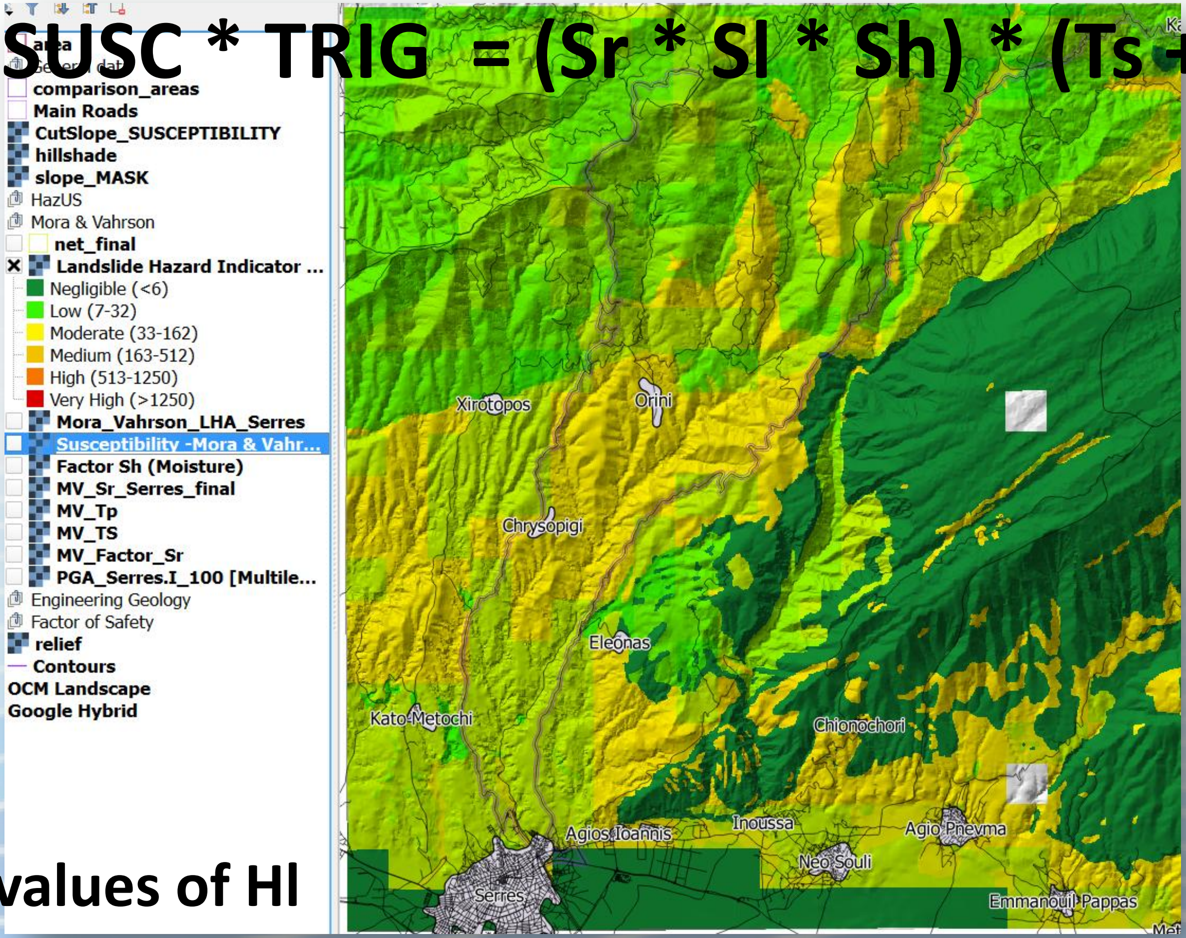
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Classification of Landslide Hazard Indicator (HI)

HI = SUSC * TRIG = (Sr * Sl * Sh) * (Ts + Tp)



Classified values of HI

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

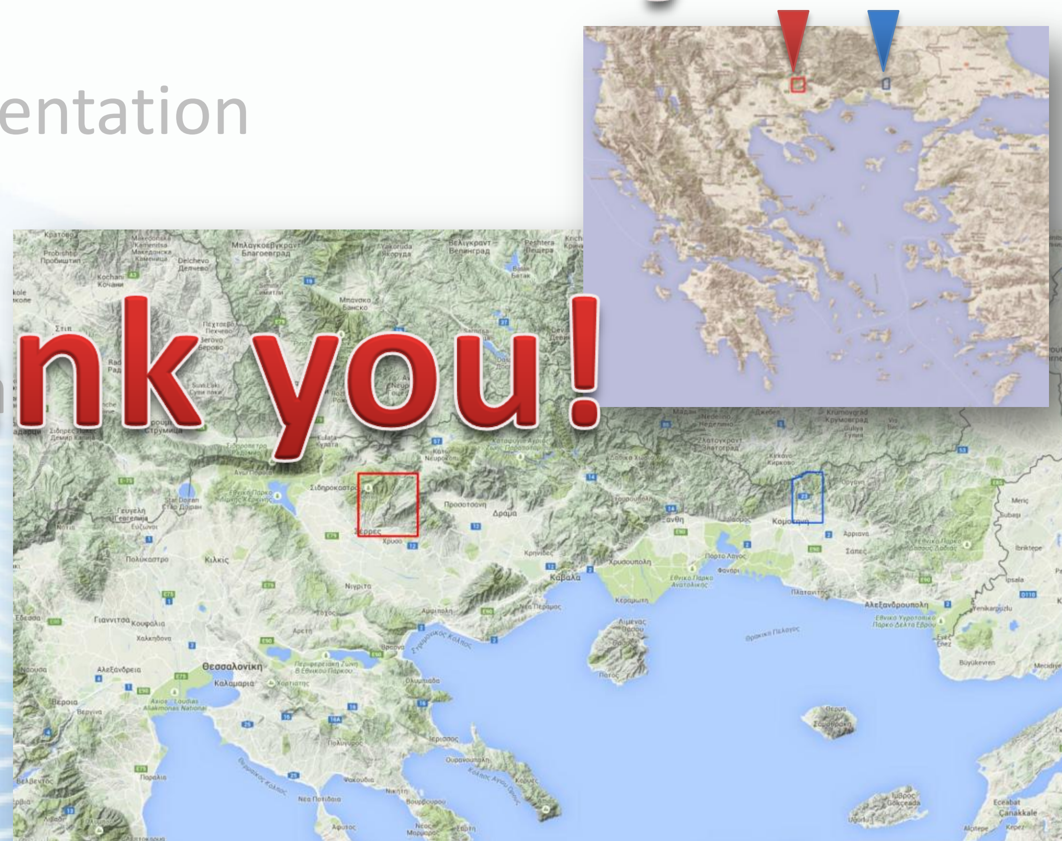
Common borders. Common solutions.

END of the 1st cycle

Areas of pilot implementation

A. Serres

B. Komotini-Nymf



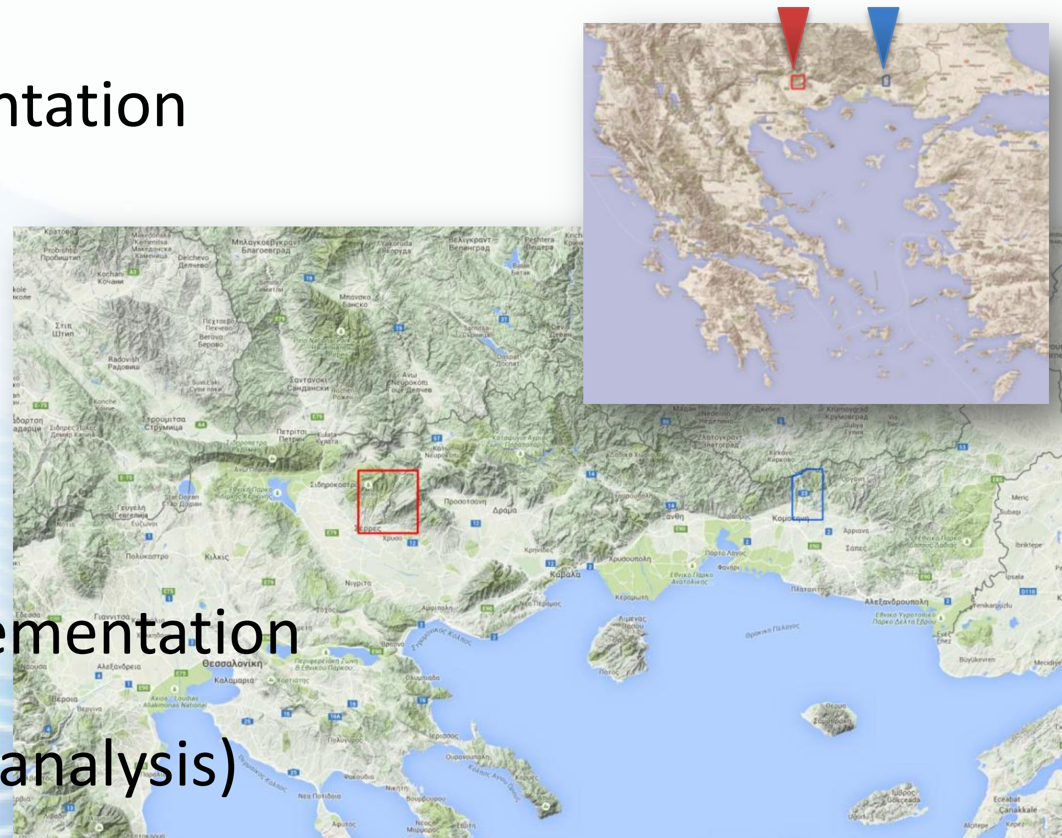
Thank you!

B. FEMA methodology (Hazard US)

Areas of pilot implementation

A. **S**erres

B. **K**omotini-Nymfaia



Scale of Regional Implementation

1:50.000 (input data & analysis)

Landslide Hazard Assessment (FEMA)

1. **A**ssess Landslide **Susceptibility** (under static conditions)
2. **A**ssess the **Critical Acceleration** (Ac)
3. **C**ompare (**Ac/PGA**) the Critical Acceleration (Ac) with the actual Peak Ground Acceleration (PGA)

All the above parameters are calculated for two different moisture/ groundwater conditions: “DRY” and “WET” whereas **“DRY”** corresponds to groundwater level **BELOW** surface of failure and **“WET”** corresponds to groundwater **ON** ground surface.

1. Landslide Susceptibility under static conditions

Step 1: Geology (need to classify the formations in one of the 3 categories in Table 1)

Step 2: Slope angle (need to classify the formations in one of the six categories in Table 1)

Step 3: Underground Water Table (need to distinguish between "DRY" (when ground water below of level of sliding) and "WET" (when ground water at ground surface).

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility under static conditions

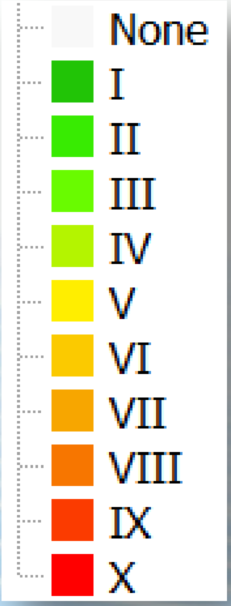
Table 8. Landslide susceptibility under static conditions

(HazUS MH, Chapter 4 – PESH)

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\phi' = 35^{o}$)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c' = 0$, $\phi' = 35^{o}$)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$ $\phi' = 20^{o}$)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\phi' = 35^{o}$)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c' = 0$, $\phi' = 35^{o}$)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$ $\phi' = 20^{o}$)	VII	IX	X	X	X	X

scale I: less susceptible

scale X: most susceptible



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

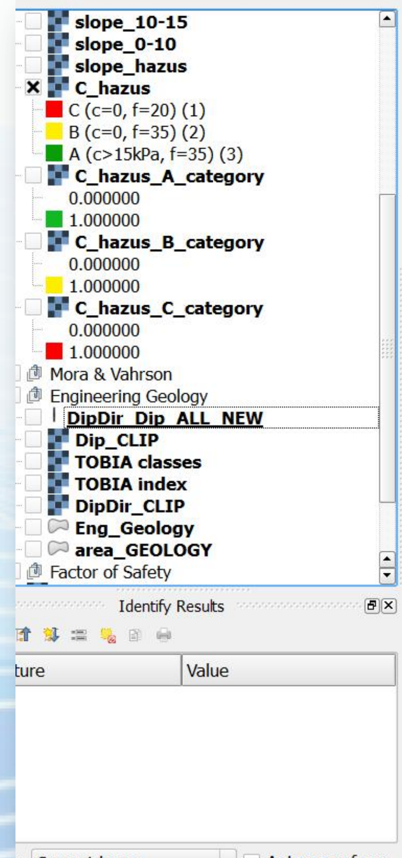
Black Sea CROSS BORDER COOPERATION

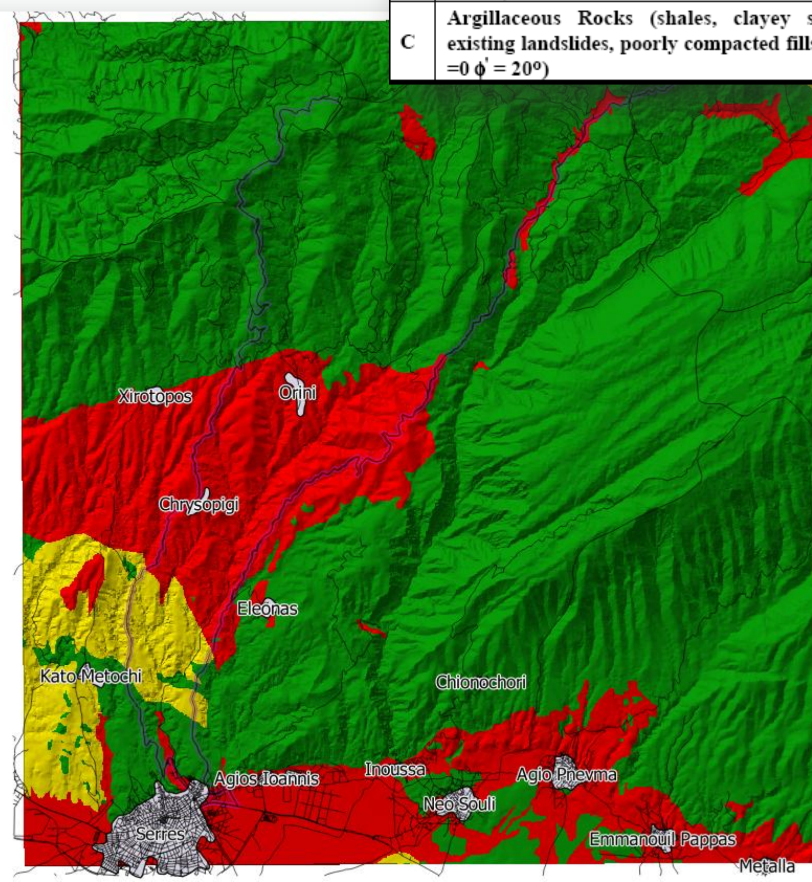
How to...1/4

Common borders. Common solutions.

Geologic Group	
	(a) DRY (groundwate
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)

1. Create a NEW column in "geology.shp" and classify the geologic formations according to ***Table 8*** in **A , B & C Categories**
2. Create a NEW raster with all three categories (as the C_Hazus shown)
3. Create for **EACH** category, a **SEPARATE file to be used as MASK** (C_Hazus_A_category etc)
4. The classes made will cover the entire area as shown on the map





Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

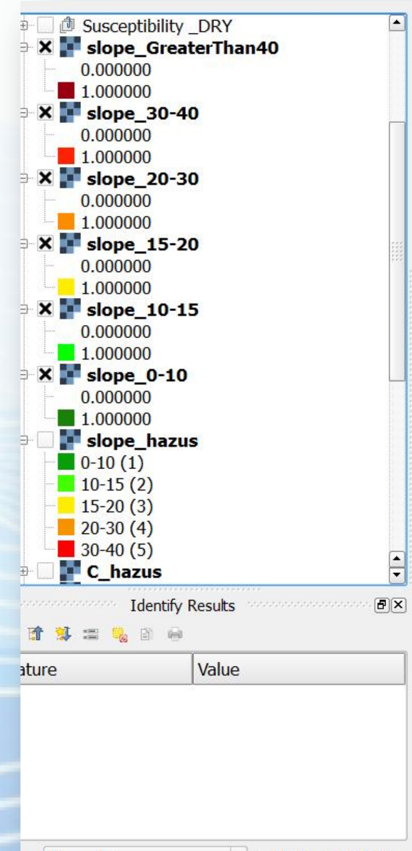
Black Sea CROSS BORDER COOPERATION

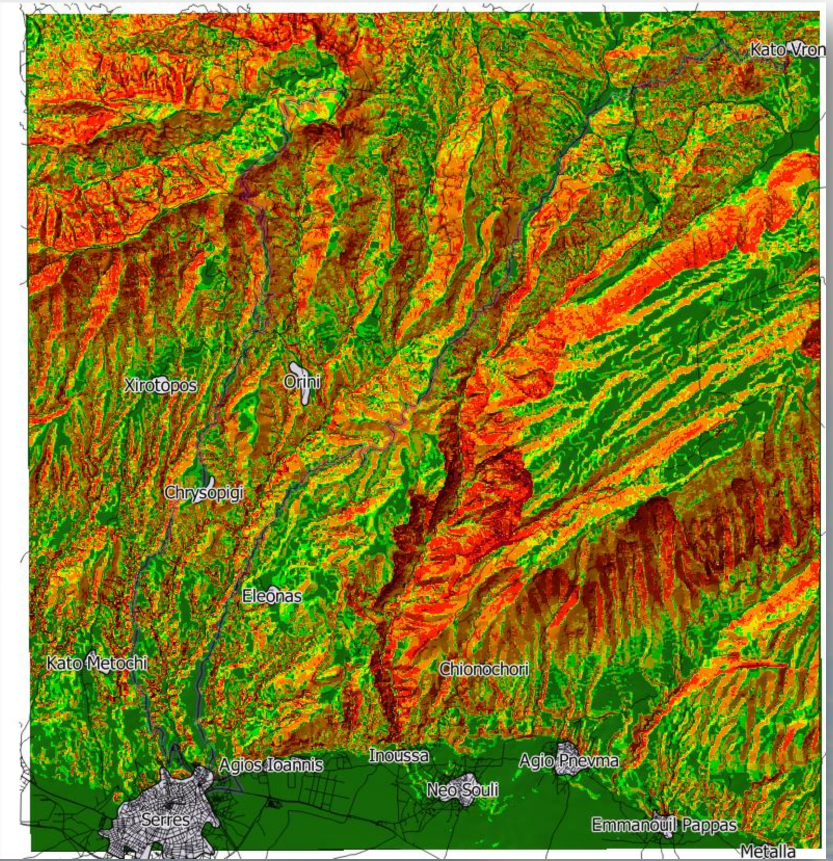
How to...2/4

Common borders. Common solutions.

Slope Angle, degrees					
0-10	10-15	15-20	20-30	30-40	>40

1. Reclassify “**slope**” into the slope categories shown in ***Table 8***
2. Create a NEW raster with all six categories (as the slope_hazus shown)
3. Create for **EACH** category, a **SEPARATE file** to be used as **MASK** (slope_0-10 etc)
4. The classes made will cover the entire area as shown on the map





Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

How to…3/4

Common borders. Common solutions.

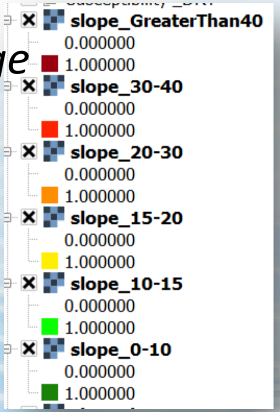
1. Calculate the respective **susceptibility category for each Geologic Group Class** and then **for each moisture condition** (DRY or WET)

2. i.e. For calculating the Geologic Group "**A**" susceptibility under **WET conditions,** the formula used was:

*"C_hazus_A_category@1" * (0 * "slope_0-10@1" + 3 * "slope_10-15@1" + 6 * "slope_15-20@1" + 7 * "slope_20-30@1" + 8 * "slope_30-40@1" + 8 * "slope_GreaterThan40@1")* *See the layer names in the next image*

Table 8

	Geologic Group	Slope Angle, degrees 0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	VII	IX	X	X	X	X



Where:

- "C_Hazus_A_category" is the mask to erase values outside this specific category area (is "1" where valid and "0" outside the specific category area)
- Slope_*@1 are the "slope" classes and
- the multiplication factors correspond to the susceptibility values shown in the table

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

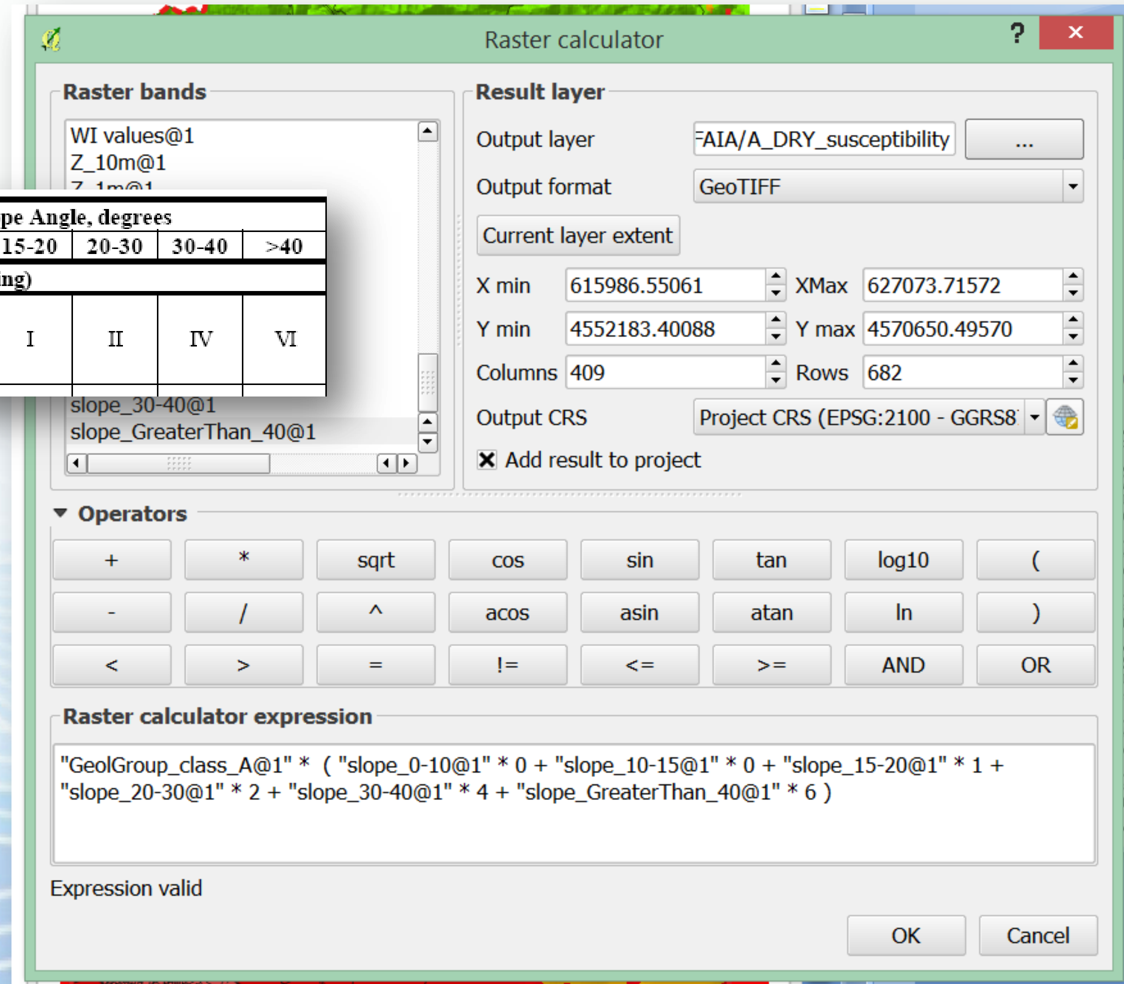
Black Sea CROSS BORDER COOPERATION

How to…4/4

Common borders. Common solutions.

Susceptibility under different moisture conditions

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	None	I	II	IV	VI



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

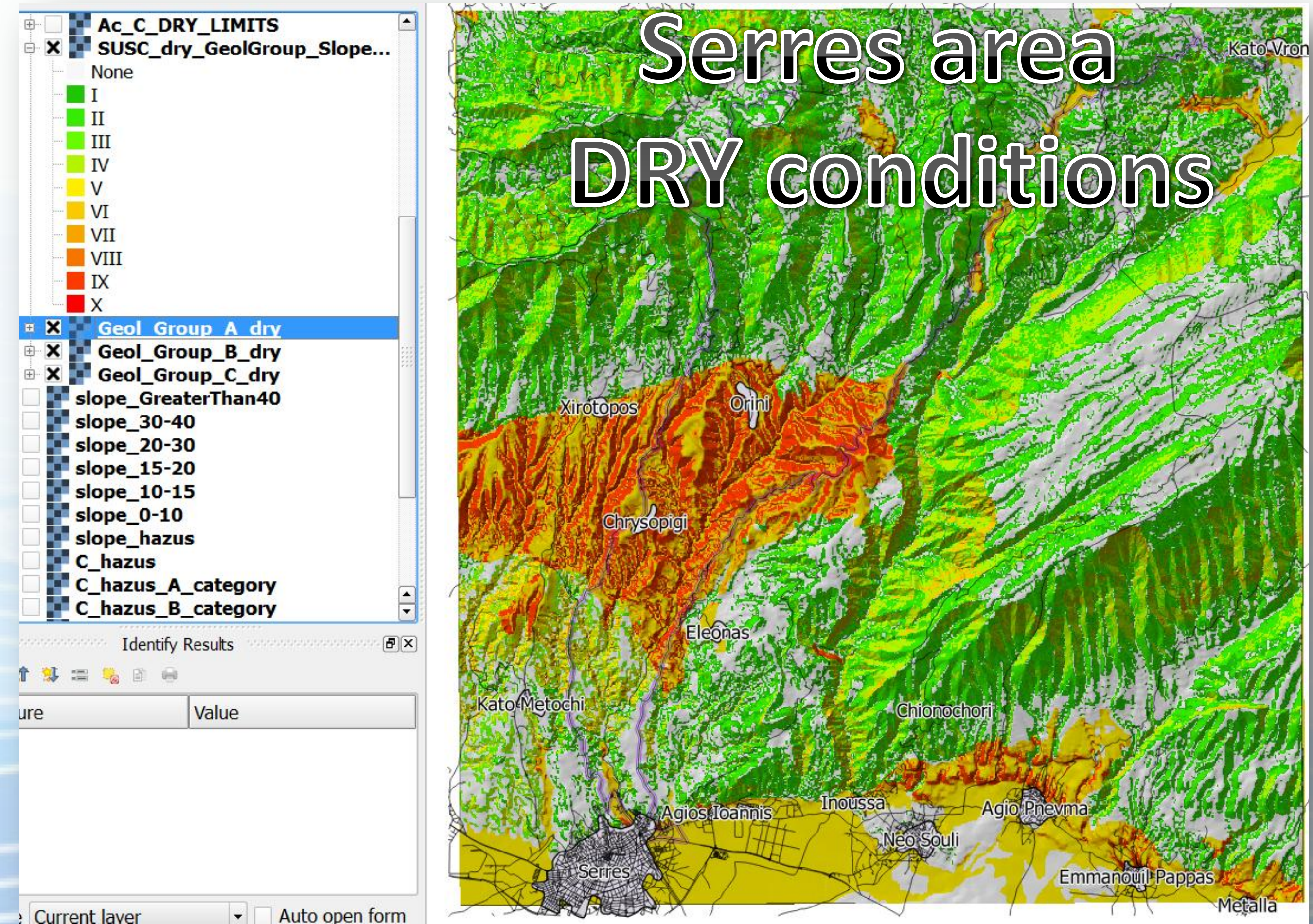
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility under static conditions

Susceptibility under different moisture conditions

is calculated by adding the individual Susceptibilities Per Geologic Group



Project funded by the EUROPEAN UNION

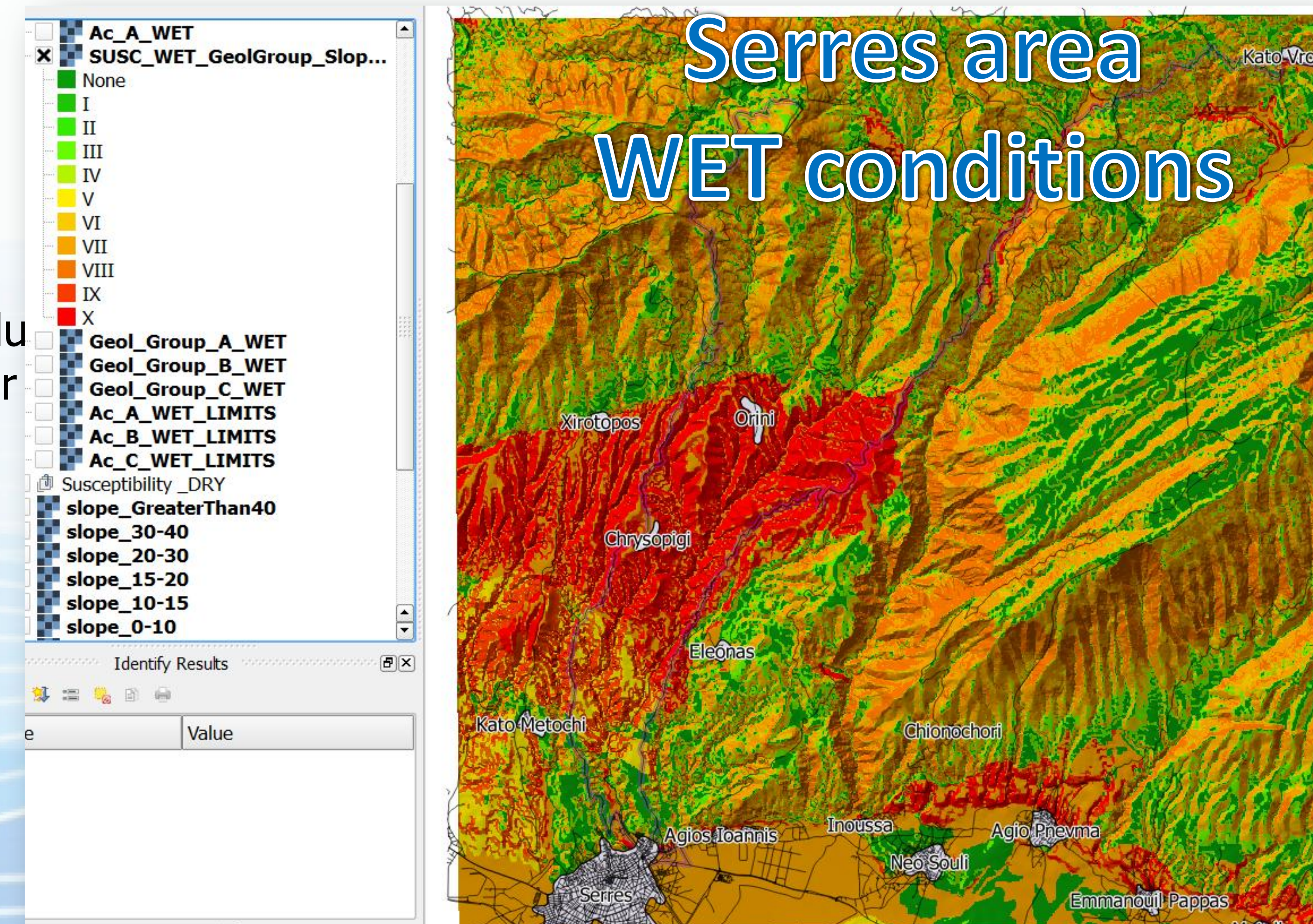
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Susceptibility under different moisture conditions

is calculated by adding the individu Susceptibilities Per Geologic Group



Project funded by the EUROPEAN UNION

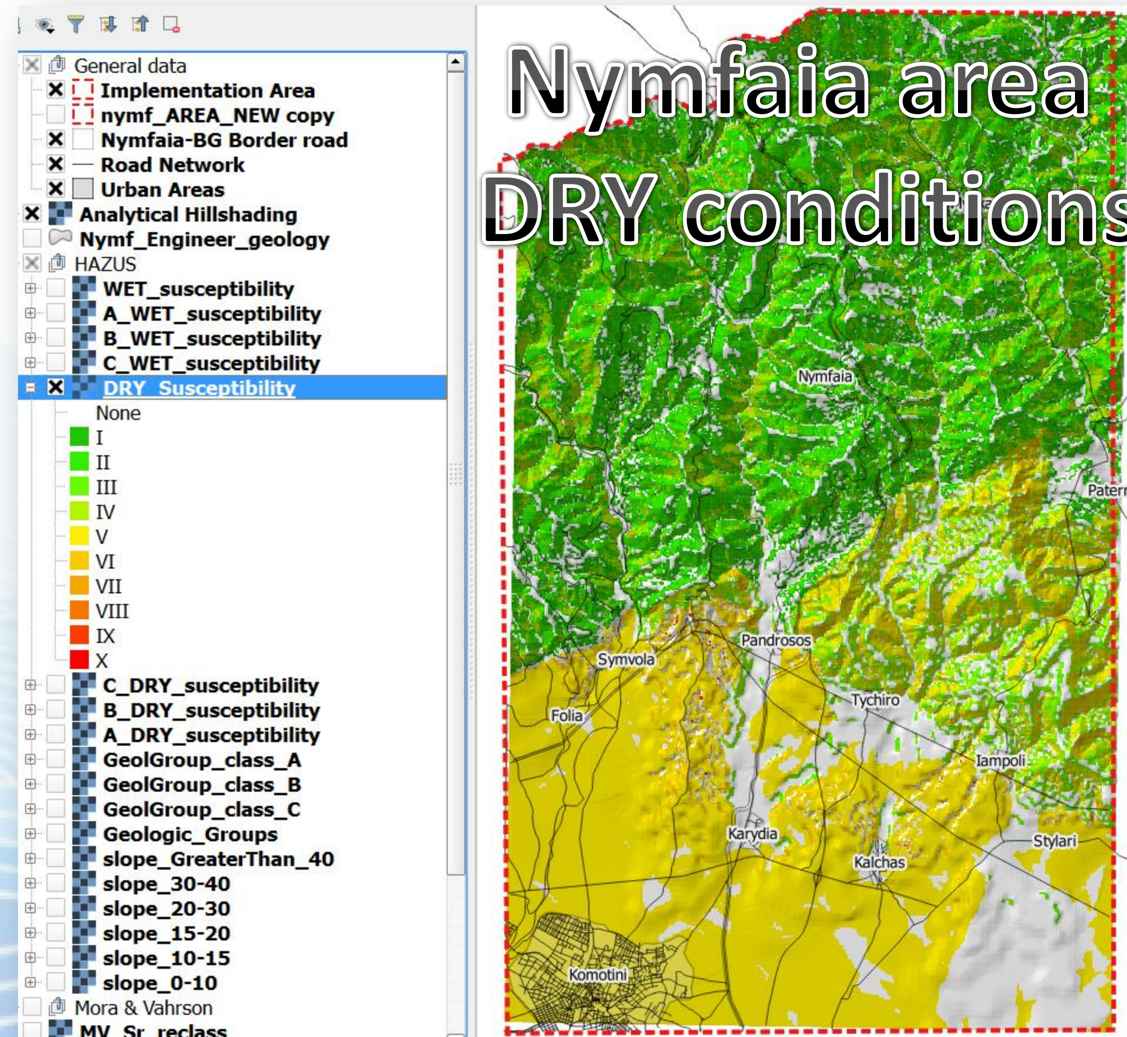
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

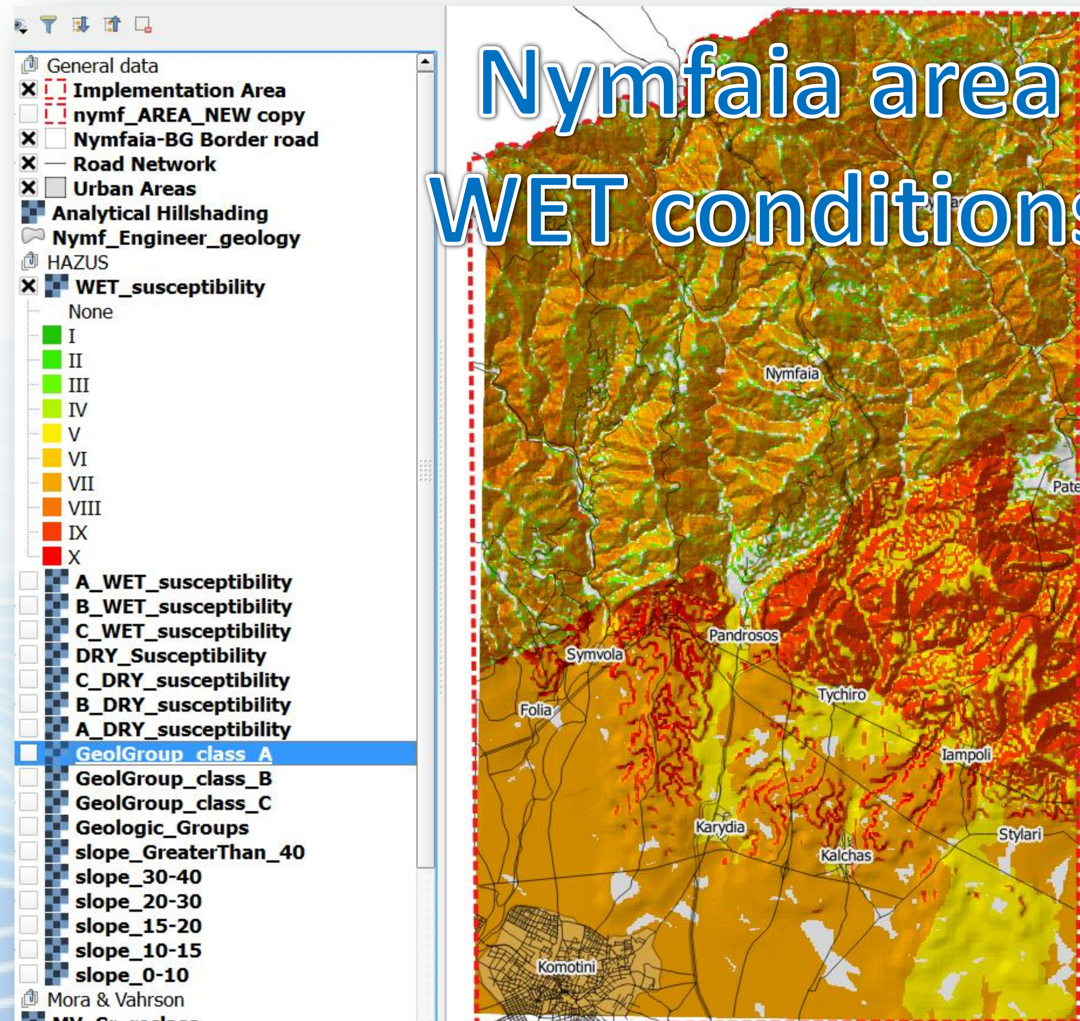
Susceptibility under different moisture conditions

is calculated by adding the individual Susceptibilities Per Geologic Group



Susceptibility under different moisture conditions

is calculated by adding the individual Susceptibilities Per Geologic Group



2. Landslide Susceptibility under seismic conditions

Limit Equilibrium Method principle: an earthquake is considered as a horizontal force (seismic coefficient * weight of the potentially sliding mass of a slope)

Critical Acceleration (A_c) is defined as the **horizontal acceleration that produces a F_S = 1.0**

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

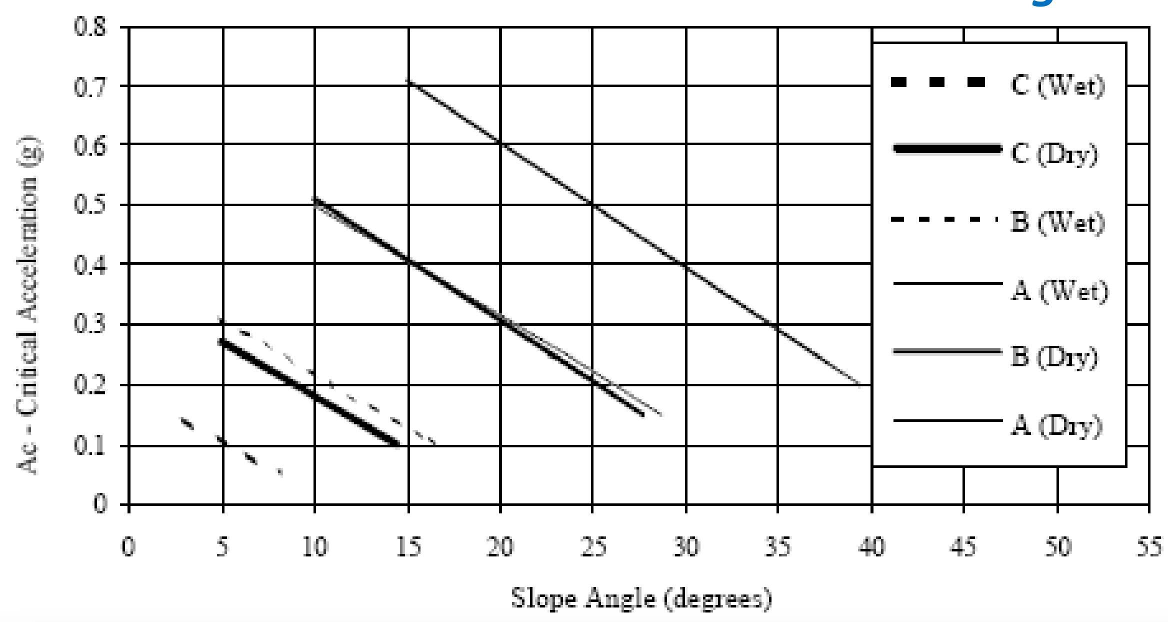
Common borders. Common solutions.

Calculating the Critical Acceleration A_c

Critical Acceleration (A_C) is a complex function of **slope**, **geology**, **steepness**, **groundwater table**, **type of landsliding** & **history of previous slope performance**.

There are certain limits (bounds) for these relations (as shown in the graph)

Fig. 1

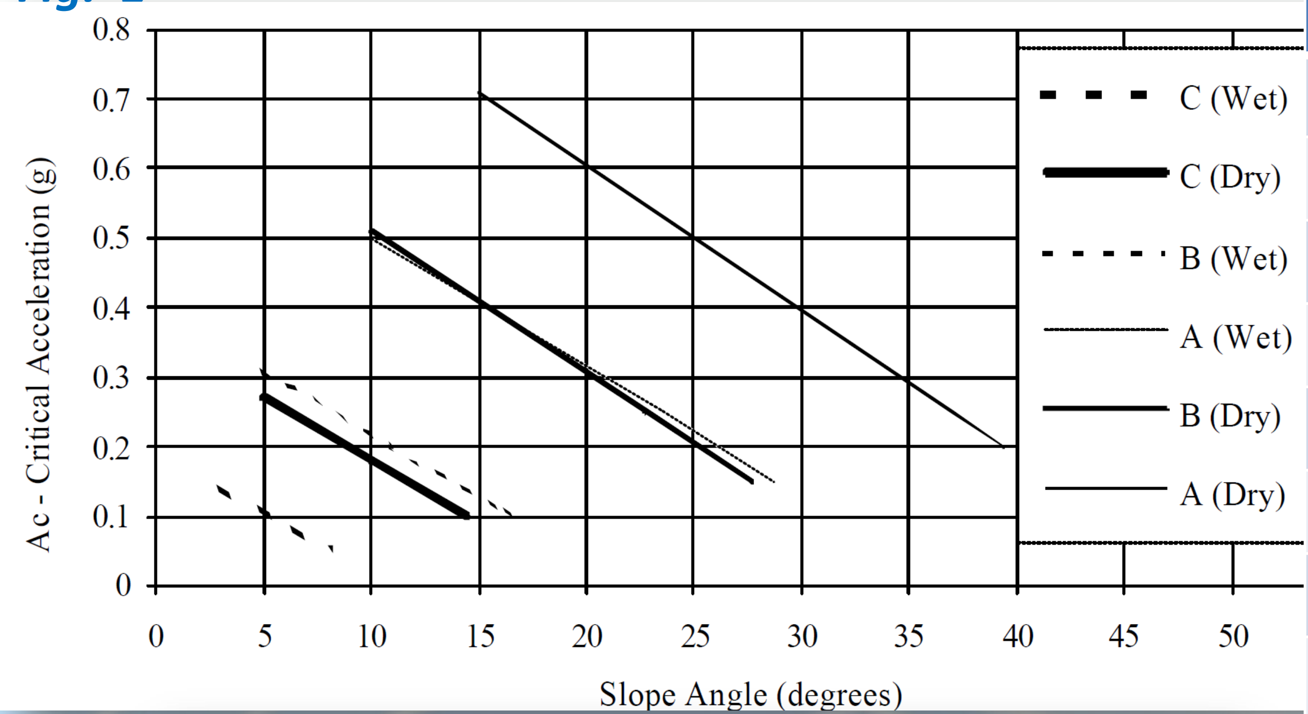


Critical Acceleration as a Function of Geologic Group and Slope Angle (Wilson and Keefer, 1985).

Common borders. Common solutions.

Slope limits for a valid Ac

Fig. 1



Critical Acceleration as a Function of Geologic Group and Slope Angle (Wilson and Keefer, 1985).

	Slope Limits	
Geology	**LOWER**	**HIGHER**
A_dry	15	39
B_dry	10	27.80
C_dry	5	14.5
A_wet	10	28.75
B_wet	5	17
C_wet	3	8

Table 9. Upper and lower bounds of **Ac** calculated values

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Limits of slope angles and Critical Accelerations

Table 10

Group	Slope Angle, degrees		Critical Acceleration (g)	
	Dry Conditions	Wet Conditions	Dry Conditions	Wet Conditions
A	15	10	0.20	0.15
B	10	5	0.15	0.10
C	5	3	0.10	0.05

Table 11 Critical Accelerations (a_c) for Susceptibility Categories

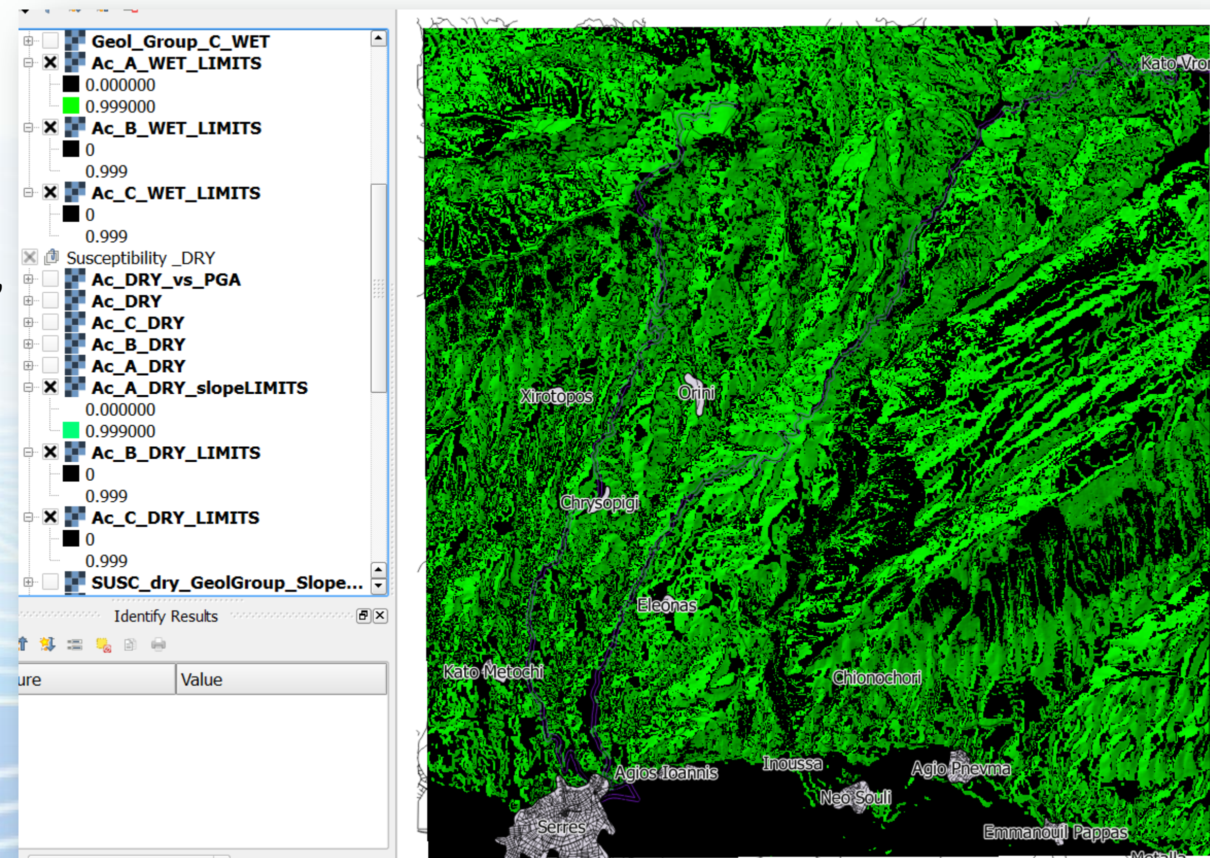
Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Critical Accelerations (g)	None	0.60	0.50	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05

Definition of Slope lower bounds for calculating a valid value of Ac (how to…)

To calculate the Ac calculation **slope based limits** (Table 2: 10-28 degrees) for the **Geologic Group "A" - WET conditions,** in QGIS Raster Calculator insert:

"slope_CLIP@1" >= 10 AND "slope_CLIP@1" <= 28

Where: "slope_CLIP" is the slope map of the area in degrees



Project funded by the EUROPEAN UNION

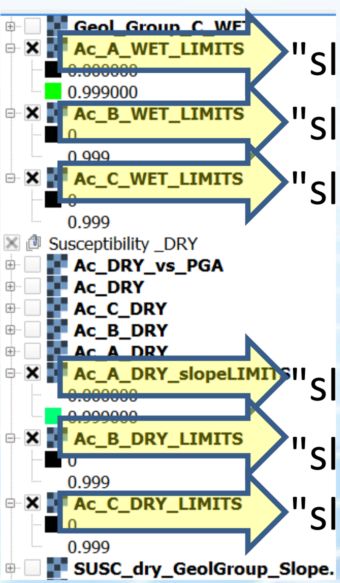
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Definition of Slope lower bounds for calculating a valid value of Ac (equations)

ie. To calculate the Ac calculation **slope based limits** (Table 2) for each **Geologic Group and WET conditions,** in QGIS Raster Calculator insert:



"slope_CLIP@1" >= 10 AND "slope_CLIP@1" <= 28.75

"slope_CLIP@1" >= 5 AND "slope_CLIP@1" <= 17

"slope_CLIP@1" >= 3 AND "slope_CLIP@1" <= 8

"slope_CLIP@1" >= 15 AND "slope_CLIP@1" <= 39

"slope_CLIP@1" >= 10 AND "slope_CLIP@1" <= 27.8

"slope_CLIP@1" >= 5 AND "slope_CLIP@1" <= 14.5

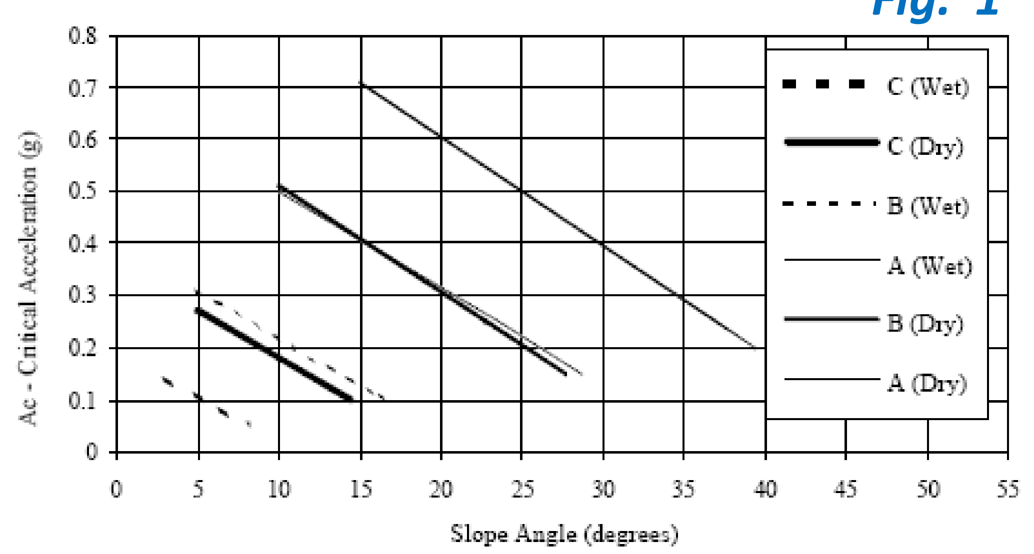
	Slope Limits	
GeolGr	**LOWER**	**HIGHER**
A_wet	10	28.75
B_wet	5	17
C_wet	3	8
A_dry	15	39
B_dry	10	27.80
C_dry	5	14.5

Project funded by the EUROPEAN UNION
SciNet NatHaz Prevention
Black Sea CROSS BORDER COOPERATION
Common borders. Common solutions.

Calculate the Ac for EACH geologic Group and moisture condition

To that end, we need the **equations for calculating Ac** as a function of "Slope Angle", as shown in Wilson & Keefer diagramm

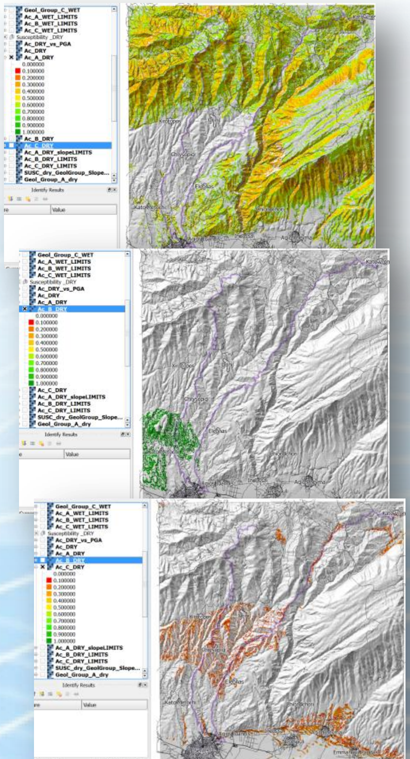
Fig. 1



	A dry	A wet	Bdry	Bwet	Cdry	Cwet
Slope	-0.02094	-0.0186	-0.20469	-0.01794	-0.01815	-0.01676
Interception	1.025017	0.68664	7.169656	0.397308	0.362313	0.187761
R	-0.99999	-0.9999	-0.99998	-0.99974	-0.99997	-0.99903

Ac calculation for EACH geologic Group and moisture condition

Equations in RasterCalc : ”Slope Based Upper and Lower Bounds” * “Geologic Group Category” * [equation for calculating Ac as a function of SLOPE]



"Ac_A_DRY_slopeLIMITS@1" * "C_hazus_A_category@1" * (1.025017 - 0.02094 * "slope_CLIP@1")

"Ac_B_DRY_LIMITS@1" * "C_hazus_B_category@1" * (7.169656 - 0.20469 * "slope_CLIP@1")

"Ac_C_DRY_LIMITS@1" * "C_hazus_C_category@1" * (0.362313 - 0.01815 * "slope_CLIP@1")

Respective equations are used for calculating the Ac limits for WET conditions

PGA values

PGA values are calculated according to the seismic hazard assessment for the examined region (i.e. for 475 years or 1000years or 2000years) with the use of:

- either the relevant **Ground Motion Prediction Equations** (**GMPE**) suitable for the examined region and soil type

- or the relevant GMPEs suitable for the examined region and for rock conditions, which we will be multiplied with an amplification factor ($PGA_i = PGA_R * F_{Ai}$)

Example

Local GMPEs (Skarlatoudis et al., 2003) for the case of Greece

$$\log PGA = 1.07 + 0.45M - 1.35 \times \ln(R + 6) + 0.09F + 0.06S \pm 0.286$$

$$\log PGA = 0.86 + 0.45M - 1.27 \times \ln(R^2 + h^2)^{\frac{1}{2}} + 0.10F + 0.06S \pm 0.286$$

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Calculating PGA values

$$PGA_i = PGA * F_{Ai}$$

PGA_i is peak ground acceleration for site class i (in units of g)

PGA is peak ground acceleration for site class B (in units of g)

F_{Ai} is the short period amplification factor for site class i, as specified for spectral acceleration $S_{AS}(g)$

Site Class B Spectral Acceleration	Site Class				
	A	B	C	D	E
Short-Period, S_{AS} (g)	Short-Period Amplification Factor, F_A				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8*

Soil amplification factors (Hazus 99-SR2 Technical Manual, Chapter 4-PESH)

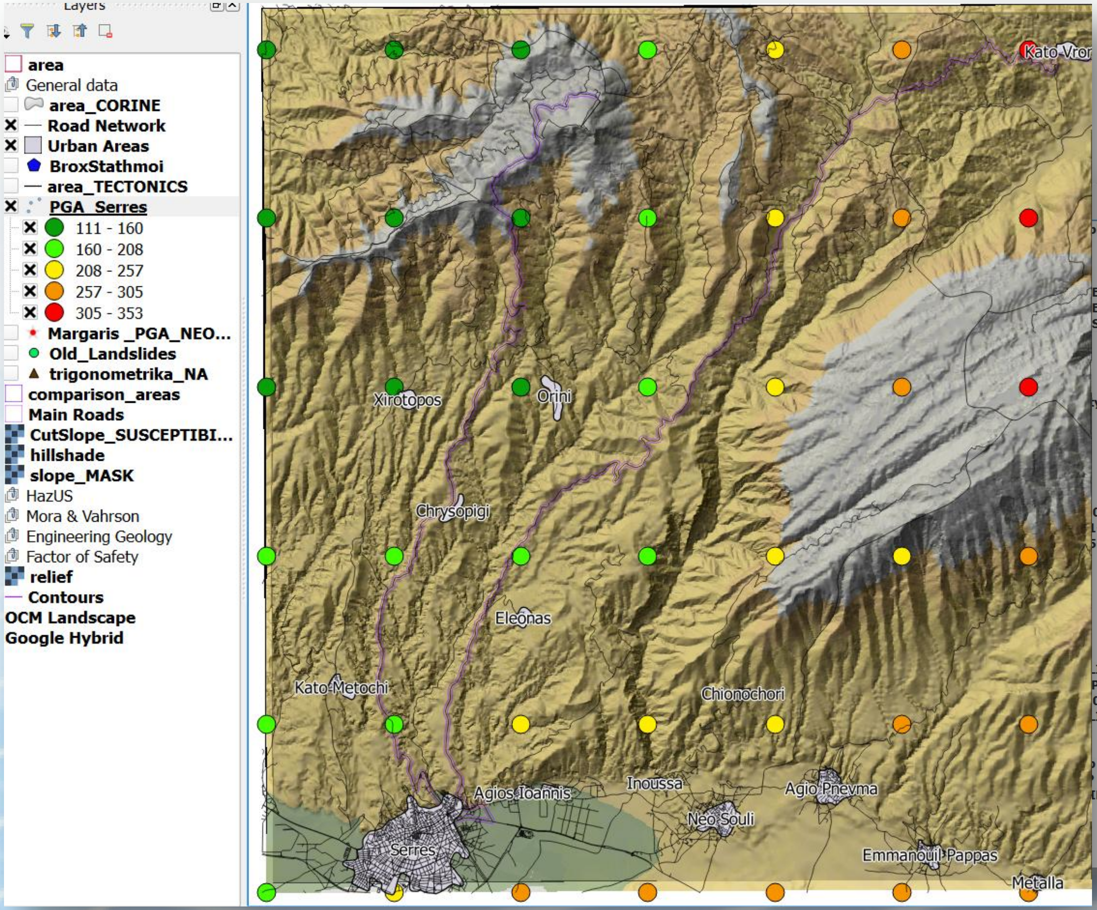
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

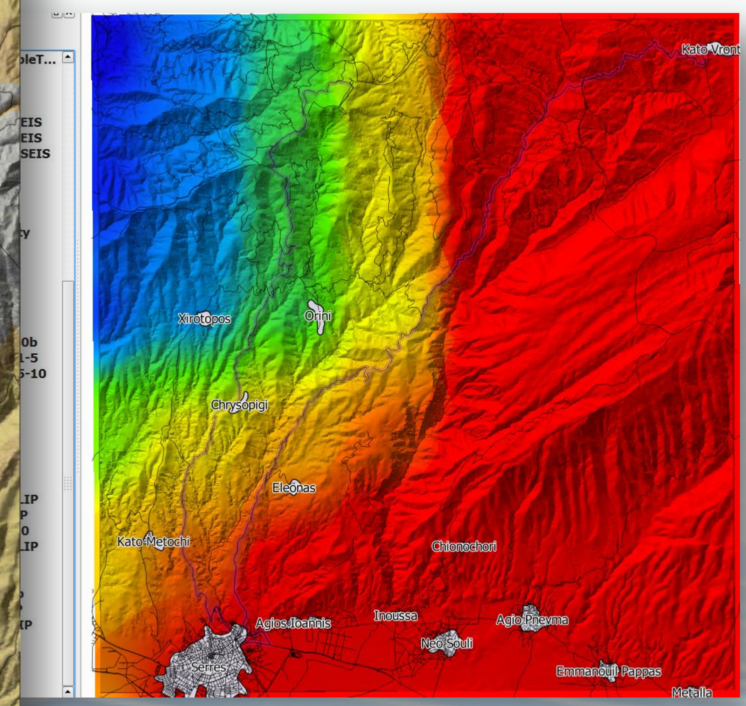
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

PGA values for Serres pilot implementation area



PGA values



Project funded by the EUROPEAN UNION

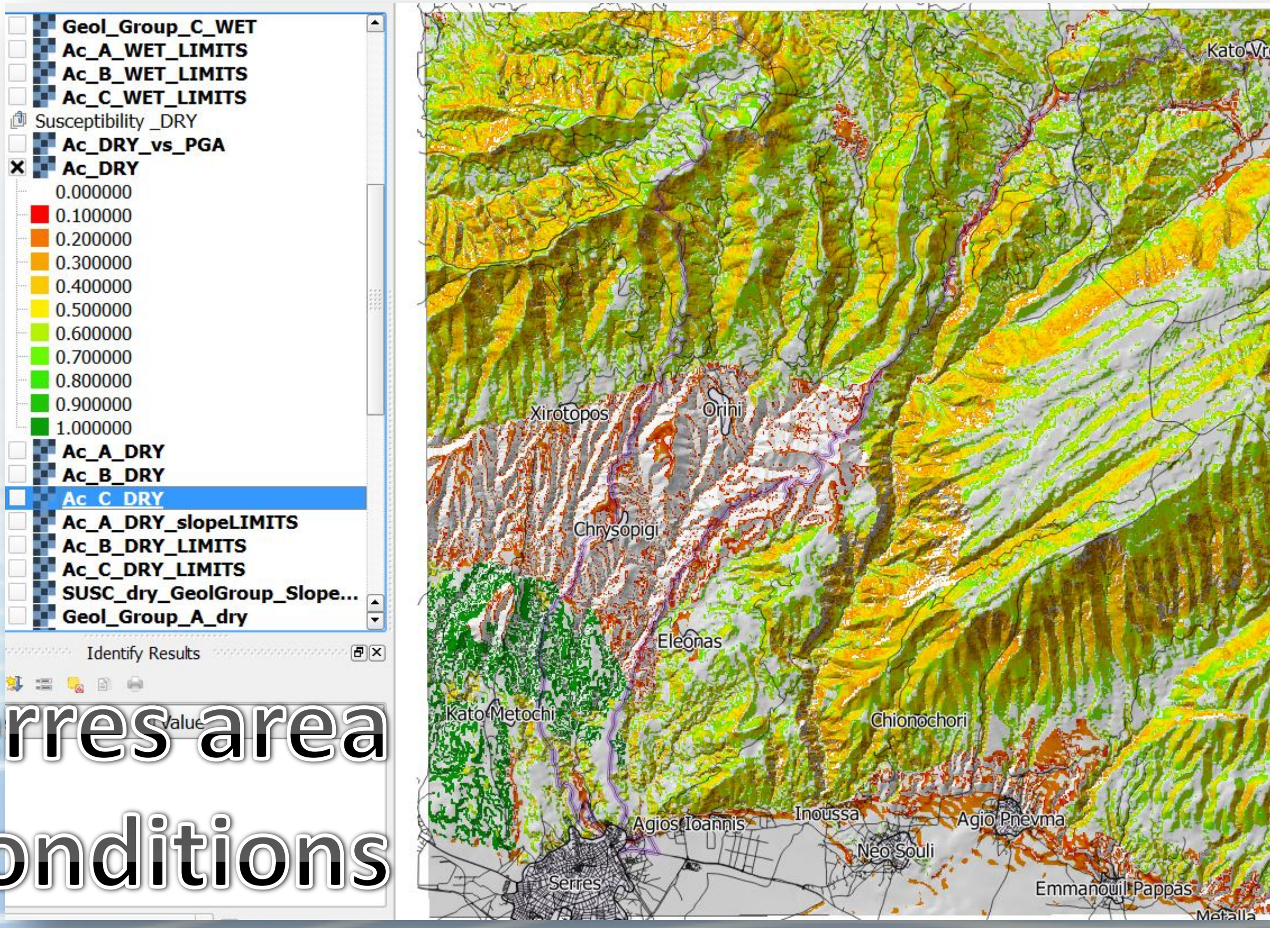
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Ac calculation for EACH geologic Group and moisture condition

ADD the Ac_A_DRY + Ac_B_DRY + Ac_C_DRY to get the **Ac_DRY of the entire area**



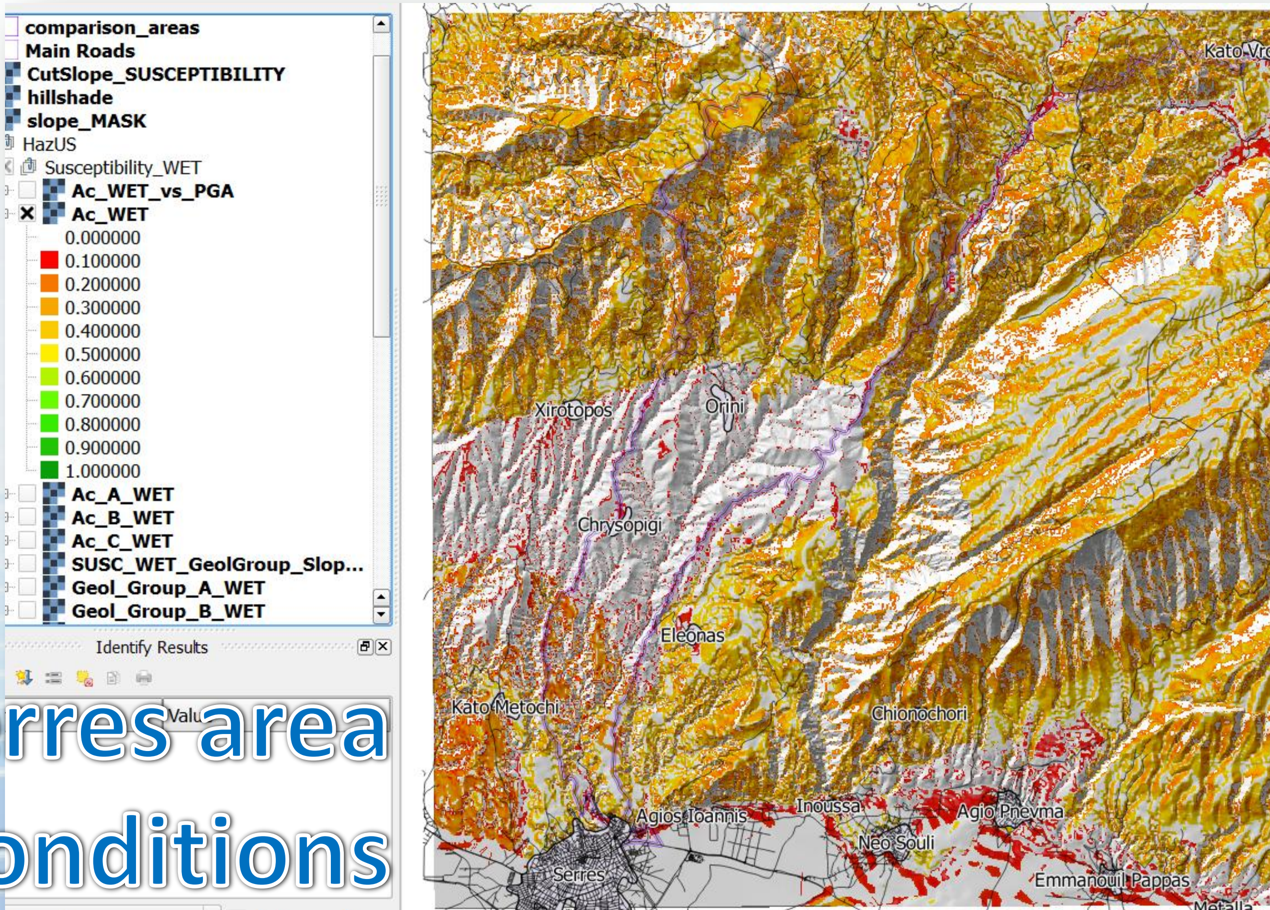
Serres area

DRY conditions

Ac calculation for EACH geologic Group and moisture condition

The same procedure with the respective files to calculate the Ac_WET for the entire area

Note: High Ac values are missing because of the slope based bounds applied



Serres area WET conditions

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

"Shallow" landslide Susceptibility under seismic conditions

Critical Acceleration (A_c) is defined as the **horizontal acceleration that produces a F_S = 1.0**

Criterion:

Index A_C/PGA and a "subjective" categorization

- **Very high: < 0.3**
- **High: 0.3 – 0.6**
- **Moderate: 0.6 – 0.8**
- **Low: 0.8 – 1.0**
- **Very Low: 1.0 – 3.0**
- **None: > 3.0**

"Shallow" landslide susceptibility to earthquake-induced displacements, as specified by the **index Ac/PGA**

Project funded by the EUROPEAN UNION

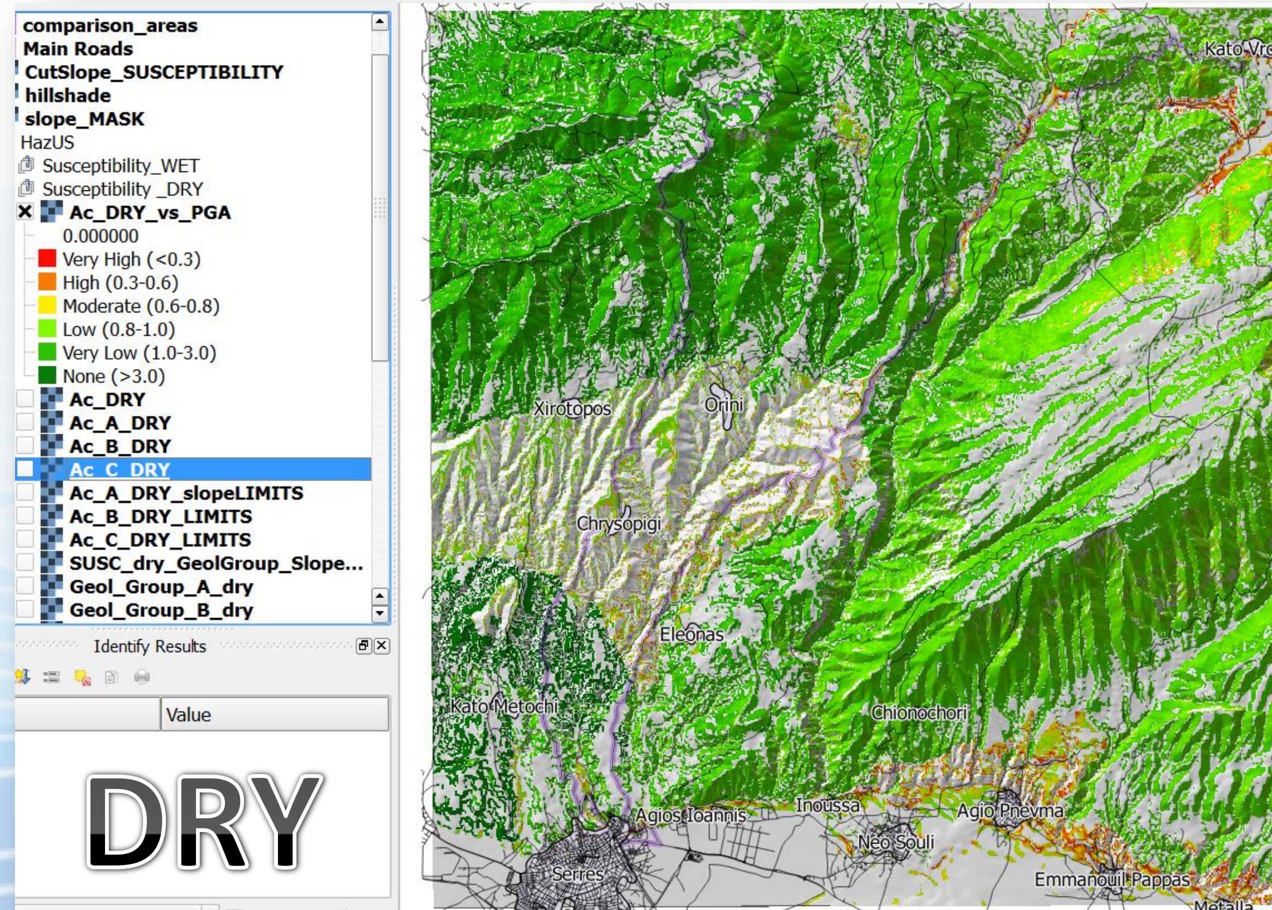
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

“Shallow” landslide susceptibility under seismic conditions

Ac/PGA



Project funded by the EUROPEAN UNION

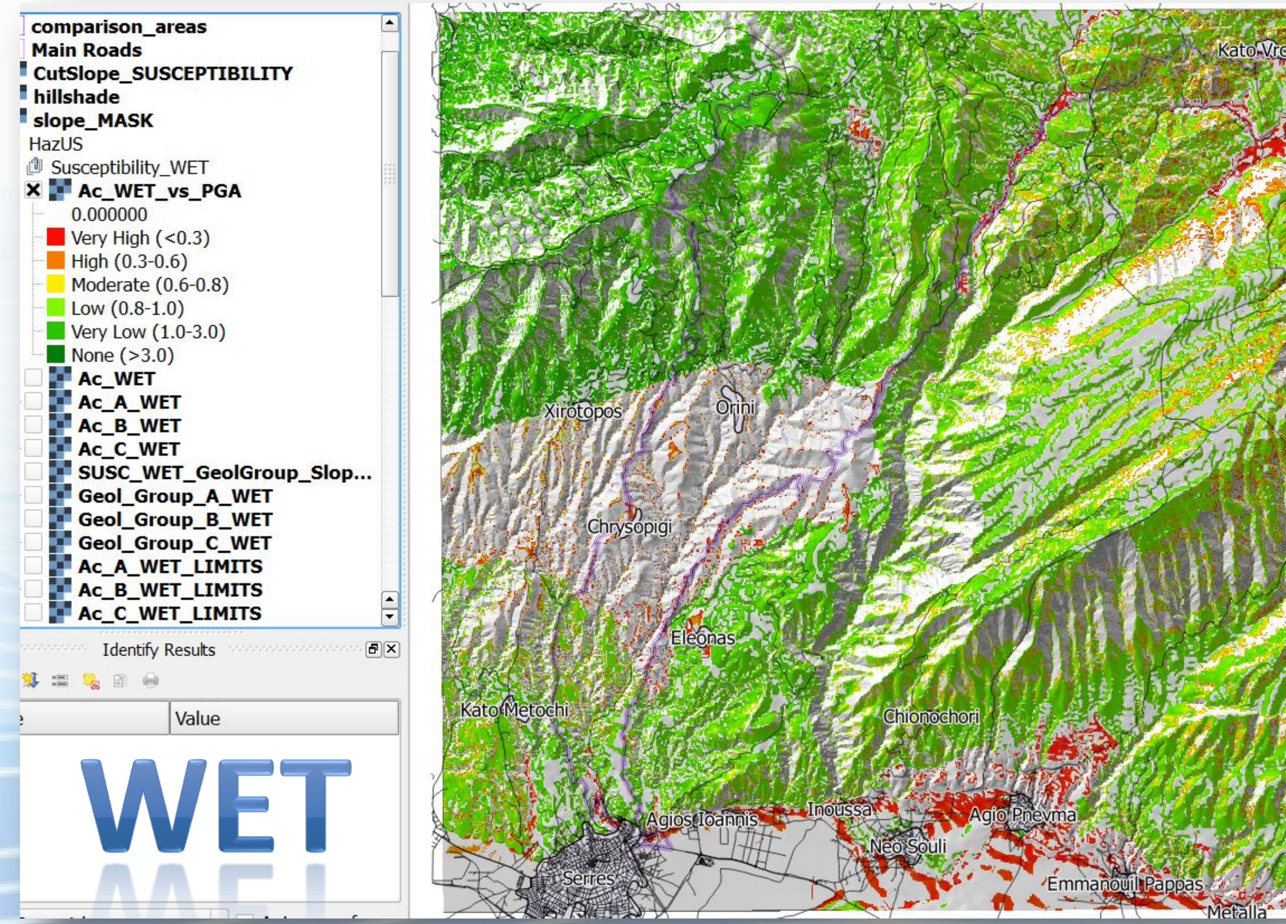
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

"Shallow" landslide susceptibility under seismic conditions

Ac/PGA



Project funded by the EUROPEAN UNION

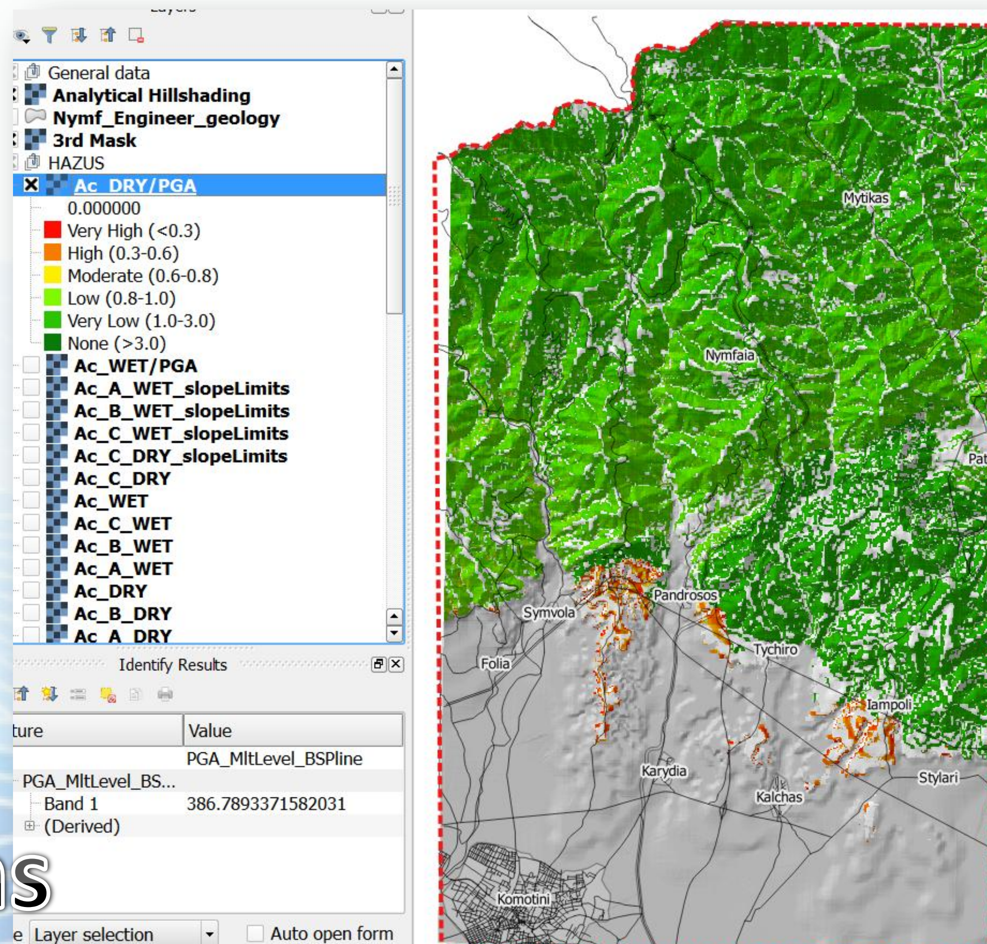
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

"Shallow" landslide susceptibility under seismic conditions

Ac/PGA



Nymfaia area DRY conditions

Project funded by the EUROPEAN UNION

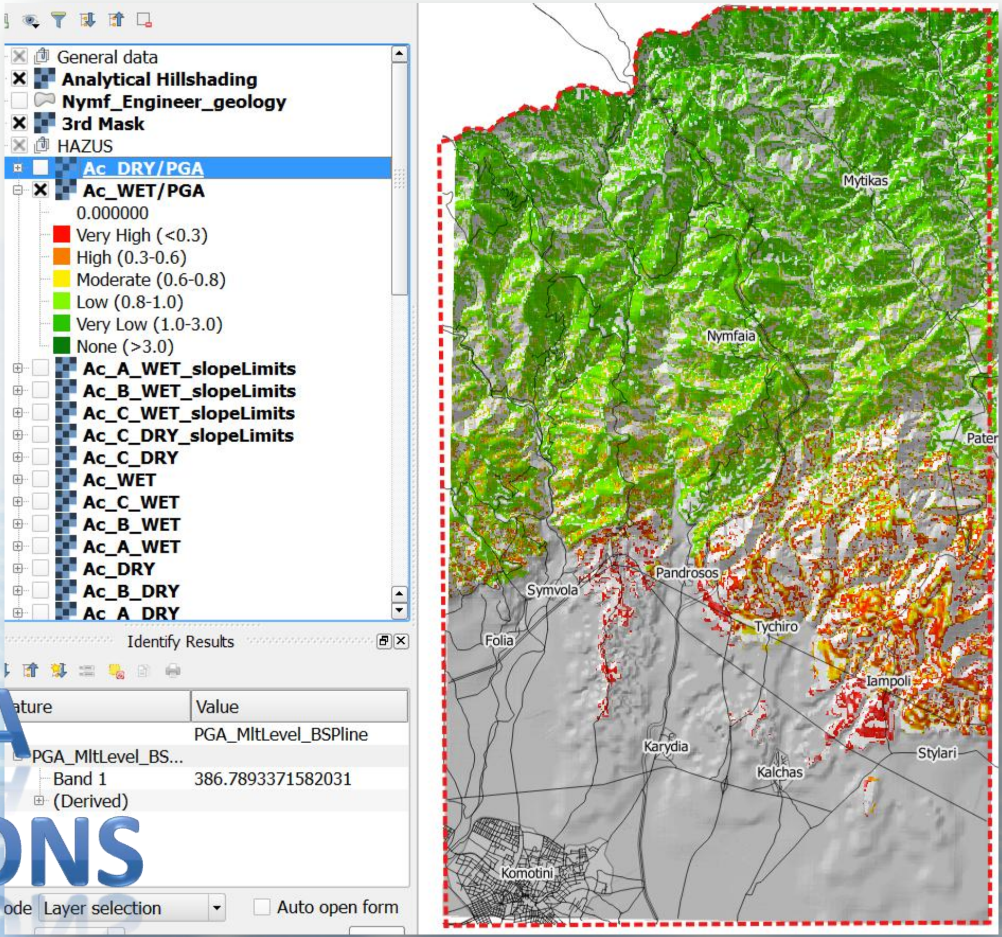
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

“Shallow” landslide susceptibility under seismic conditions

Ac/PGA



NYMFAIA AREA WET CONDITIONS

3. Landslide Hazard under seismic conditions

- Based on FEMA method.
- Hazard is assessed over the calculation of Permanent Ground Displacements
- The methodology is applicable to Hazard assessment of “shallow” landslides

Data Requirements

- Data produced during the previous implementation stages

Permanent Ground Displacements (PGD) assessment

- The FEMA method is based on the assessment of **PGD (Permanent Ground Displacements) for landslides**;
- it is valid for "shallow" landslides, i.e with a depth of the failure surface not exceeding 7 to 10m max from the surface.

Requirements:

A_c: critical acceleration (g); has already been analyzed and calculated in previous stages

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Permanent Ground Displacements (PGD) assessment

- The FEMA method is based on the assessment of **PGD (Permanent Ground Displacements) for landslides** (Goodman and Seed, 1966)

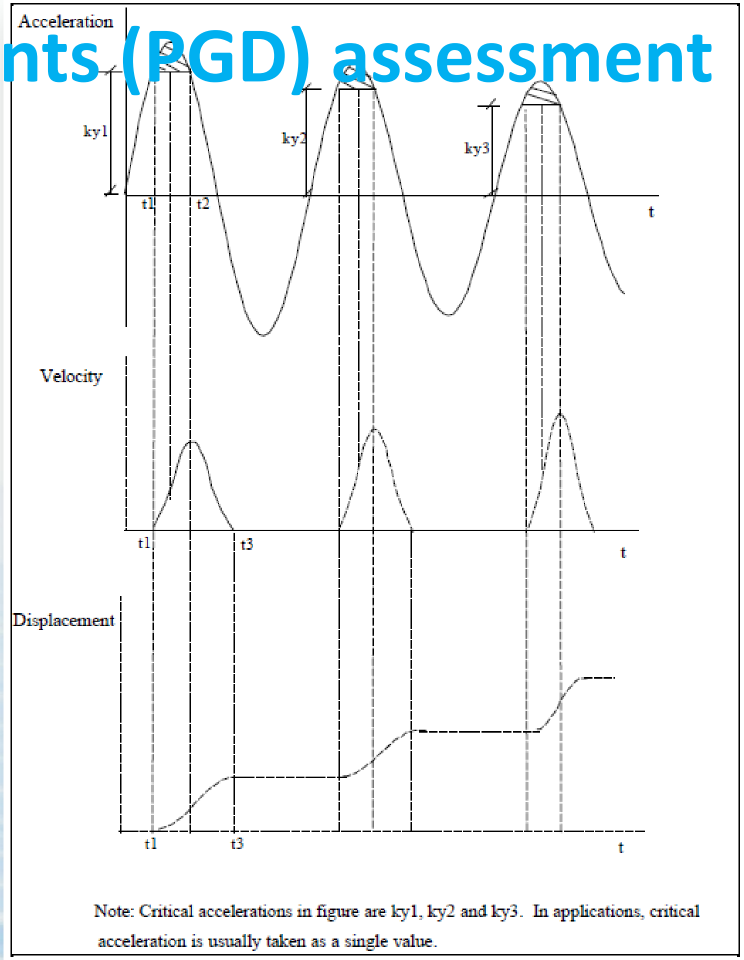


Figure 4.11 Integration of Accelerograms to Determine Downslope Displacements (Goodman and Seed, 1966).

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Permanent Ground Displacements (PGD) assessment

$$E[PGD] = E[d/A_{is}]*A_{is}*n$$

A_{is}: induced acceleration (g) – A_{is} = PGA

A_{is} = PGA : for shallow landslides

A_{is} = 2/3*PGA: for massive, deep and large landslides

n: number of cycles (function of earthquake magnitude M_w)

$E[d/A_{is}]$: expected displacement factor for each cycle

n: Number of Cycles (moment Magnitude)

Fig. 3

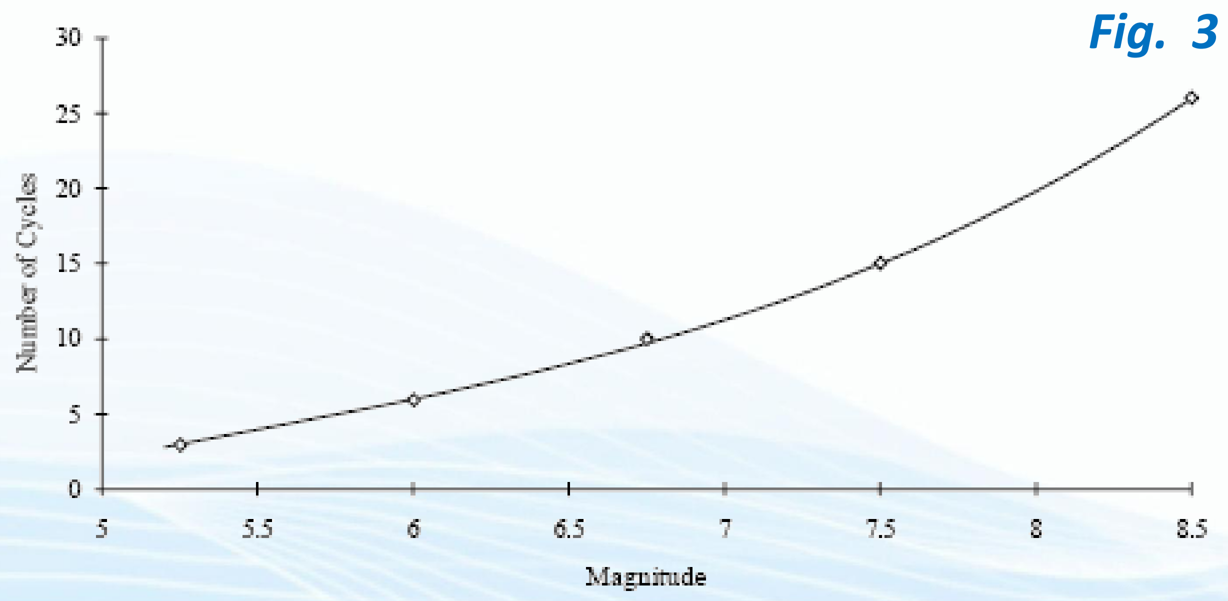


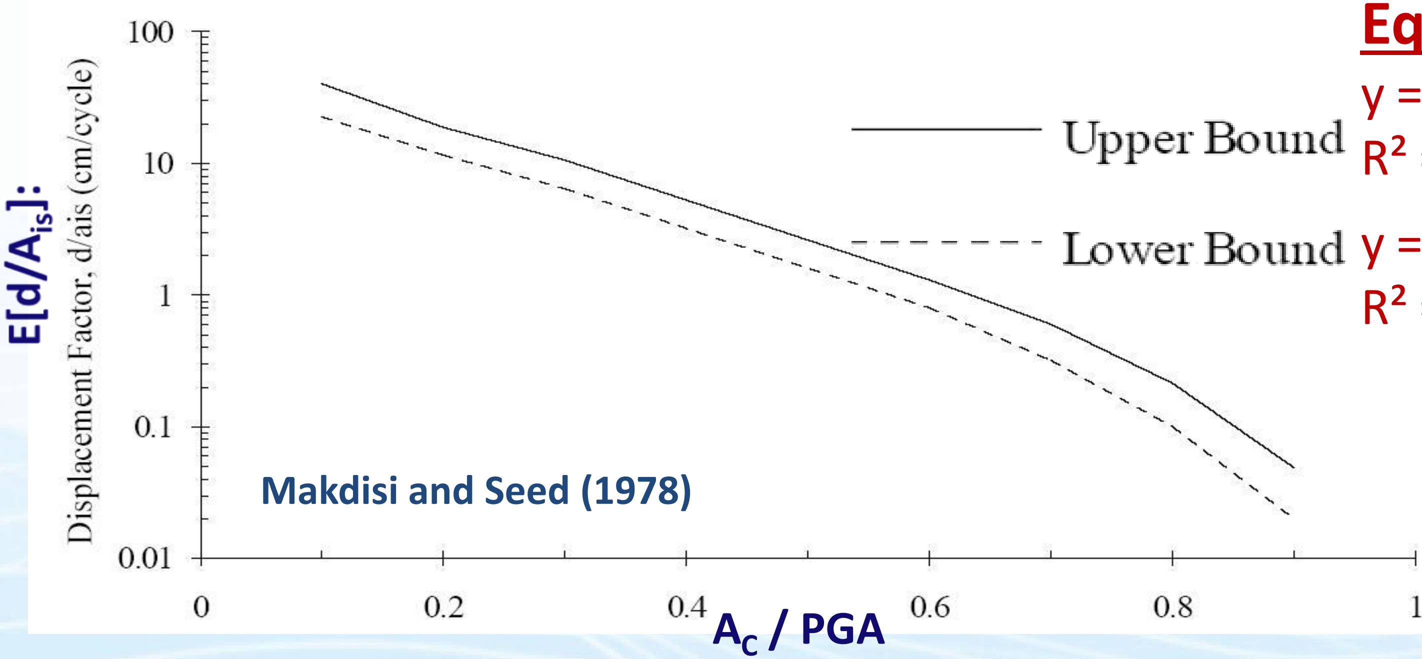
Figure 4.15 Relationship between Earthquake Moment Magnitude and Number of Cycles.

$$n = 0.3419M_w^3 - 5.5214M_w^2 + 33.6154M_w - 70.7692$$

(Seed and Idriss, 1982)

Common borders. Common solutions.

Permanent Ground Displacements (PGD) assessment



Equations

$y = 103.68e^{-7.784x}$

$R^2 = 0.9865$

$y = 69.806e^{-7.953x}$

$R^2 = 0.9818$

Fig.2. Relationship between Displacement Factor and ratio Critical Acceleration (Ac) to Induced Acceleration (PGA)

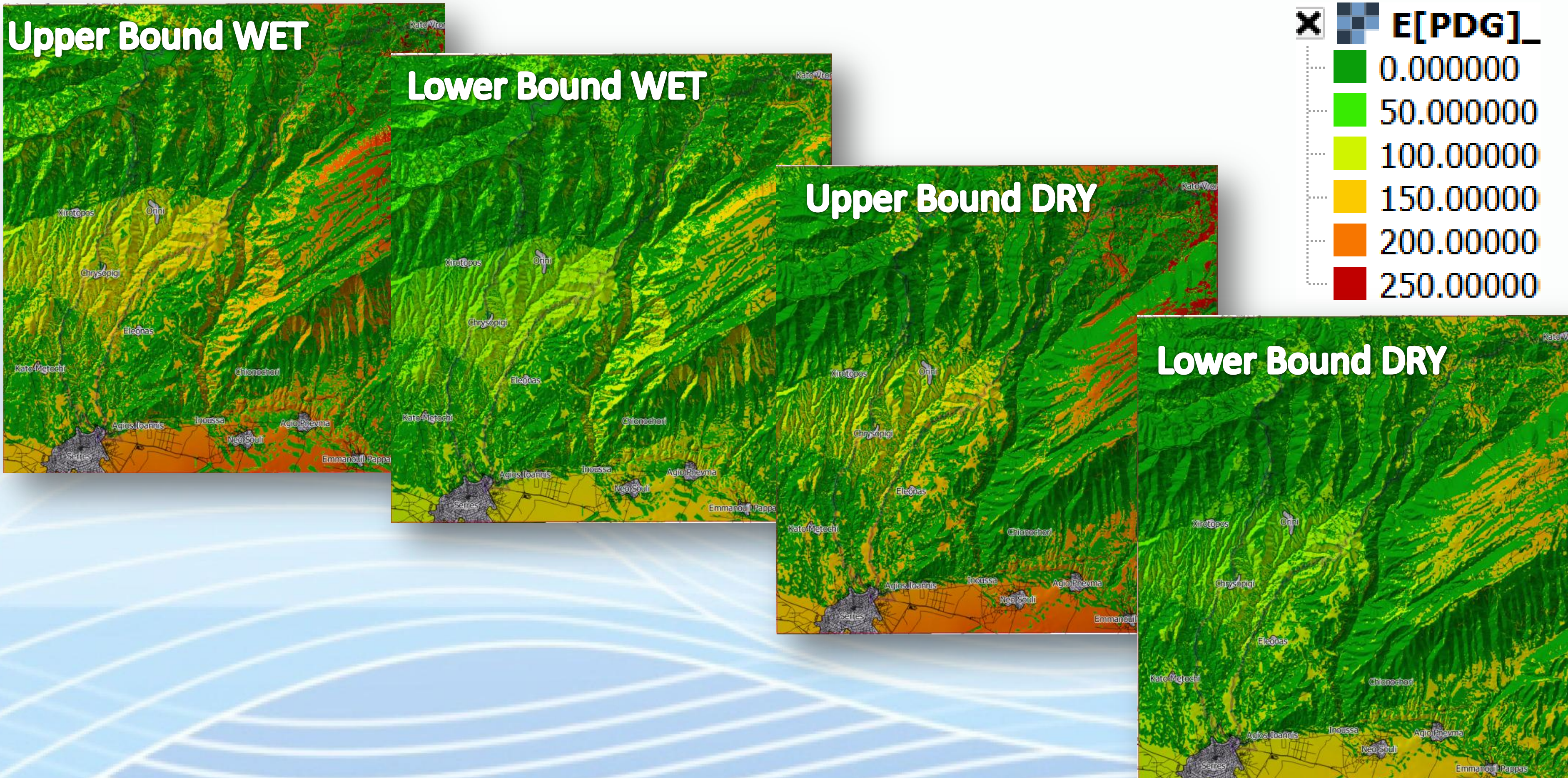
Calculation of the expected displacement factor in cm/cycle. Two (2) equations are given for the lower and upper bound for the earthquake induced permanent displacements

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Common borders. Common solutions.

Permanent Ground Displacements (PGD) assessment



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

B. FEMA methodology (Hazard US)

Areas of pilot implementation

A. Serres

B. **K**omotini-Nymfaia

Scale of Regional implementation

1:50.000 (input data & analysis)

END of the 2nd cycle

Thank you!

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

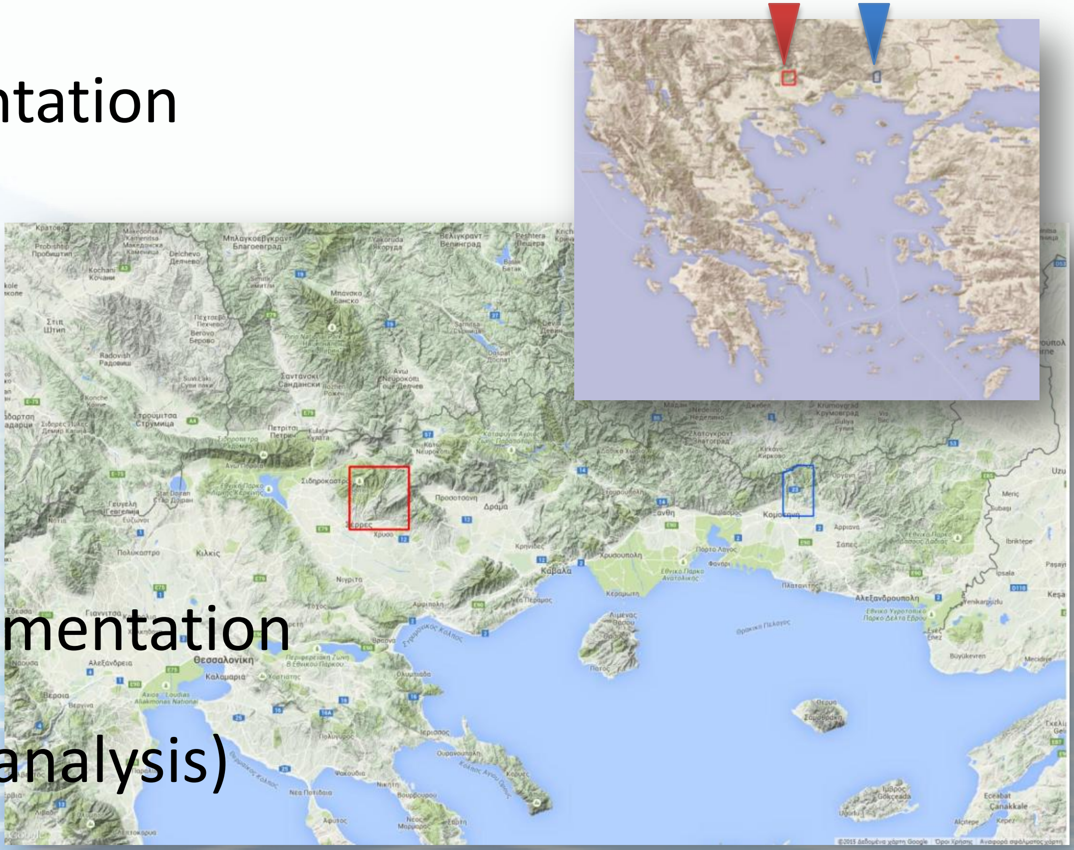
Common borders. Common solutions.

C. Landslide Hazard Assessment - FS

Areas of pilot implementation

A. **S**erres

B. **K**omotini-Nymfaia



Scale of Regional Implementation

1:50.000 (input data & analysis)

Landslide Hazard Assessment - FS

- Physically based landslide hazard assessment methods are based on *modeling of slope failure processes*
- Applicable over large areas if geological & geomorphological conditions are fairly homogeneous and landslide types relatively simple
- Applicable to areas with incomplete or even non - existing landslide inventories
- Most of them apply the infinite slope model, therefore they are applicable in the case of shallow landslides
- Also, a deterministic model for plane or circular landslides can be applied
- They account for different triggering parameters: rainfall and transcient groundwater response or to the effects of earthquake excitation

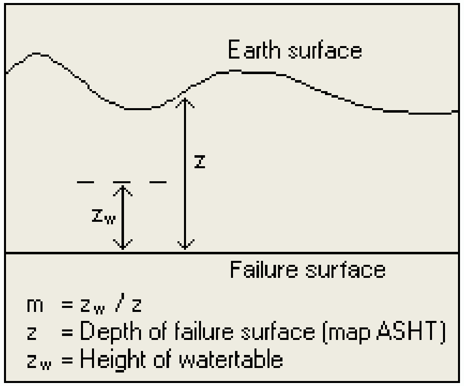
Landslide Hazard Assessment - FS

- Physically based landslide hazard assessment methods are based on *modeling of slope failure processes*
- the factor of safety F_S computation method **(triggering factors: rainfall & earthquake)**

Landslide Hazard– Static conditions / Precipitation

Infinite Slope Model (Factor of Safety)

$$F_S = \frac{c' + (\gamma_{app} - m * \gamma_w) * z * \cos^2 \beta * \tan\varphi'}{\gamma_{app} * z * \sin \beta * \cos\beta}$$



$$\gamma_{app} = \gamma * (1 - m) + \gamma_{sat} * m$$

If totally dry slope, then $\gamma_{app} = \gamma$ (m=0%)

If totally saturated slope, then $\gamma_{app} = \gamma_{sat}$ (m=100%)

- φ': **effective angle of friction** of geomaterial (^{0})
- c': **effective cohesion** of geomaterial (kPa),
- γ: **specific weight** (kN/m^3),
- β: **slope angle** (Deg),
- γ_w: **specific weight** of the water (kN/m^3),
- **z: normal thickness** of the failure slab (m)
- m: **percentage** of the water **saturated** failure slab (%)

C. LHA Factor of Safety -Data requirements

- Scale of Implementation 1:50.000
- Topographic data (topographic Maps, elevation data, lattice points etc). In case topographic data at a 1:50.000 scale are not available, ASTER DEMs can be used at the expense of accuracy.
- Geologic Maps
- Engineering geologic/geotechnical parameters (Cohesion, Friction angle, unit weight)
- Ground Motion data (PGA values)
- Mean Monthly Rainfall (mm) and MAX daily precipitations

Project funded by the EUROPEAN UNION

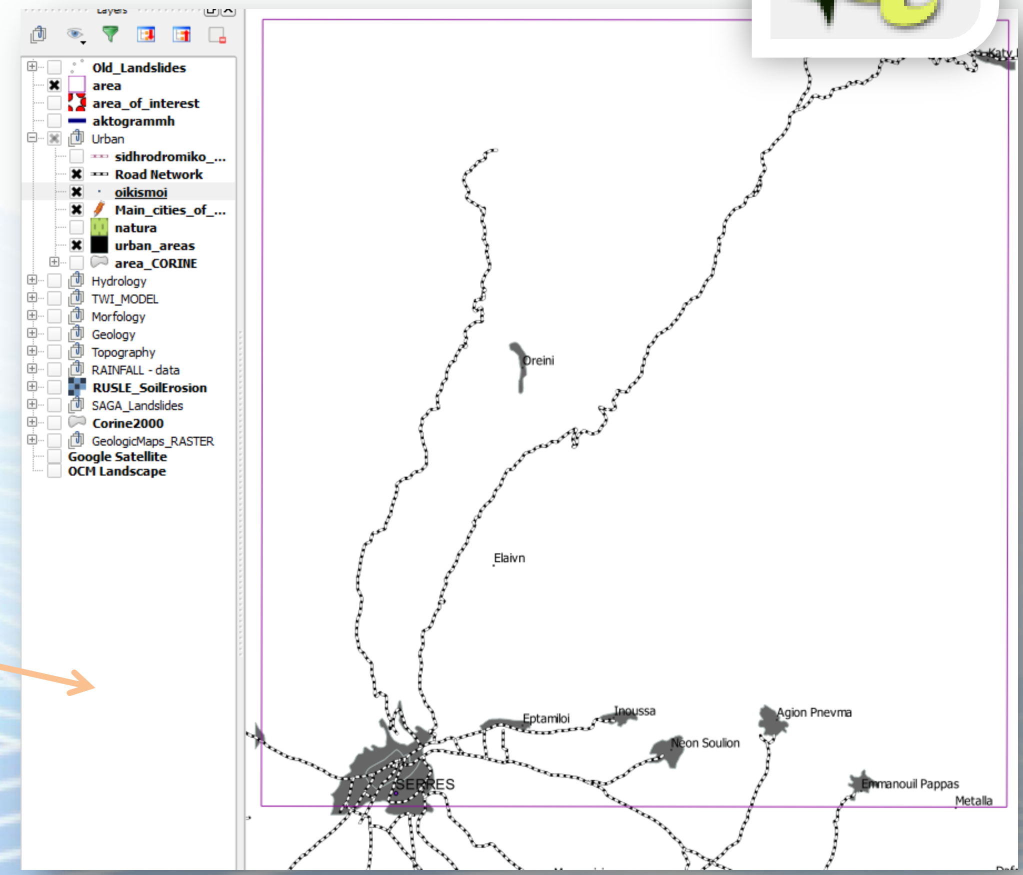
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Basic Info – Starting a Project in

- Set REFERENCE SYSTEM
- Input General data
  - Road network
  - Railroad network
  - Urban areas ….etc
- Define the AREA



Project funded by the EUROPEAN UNION

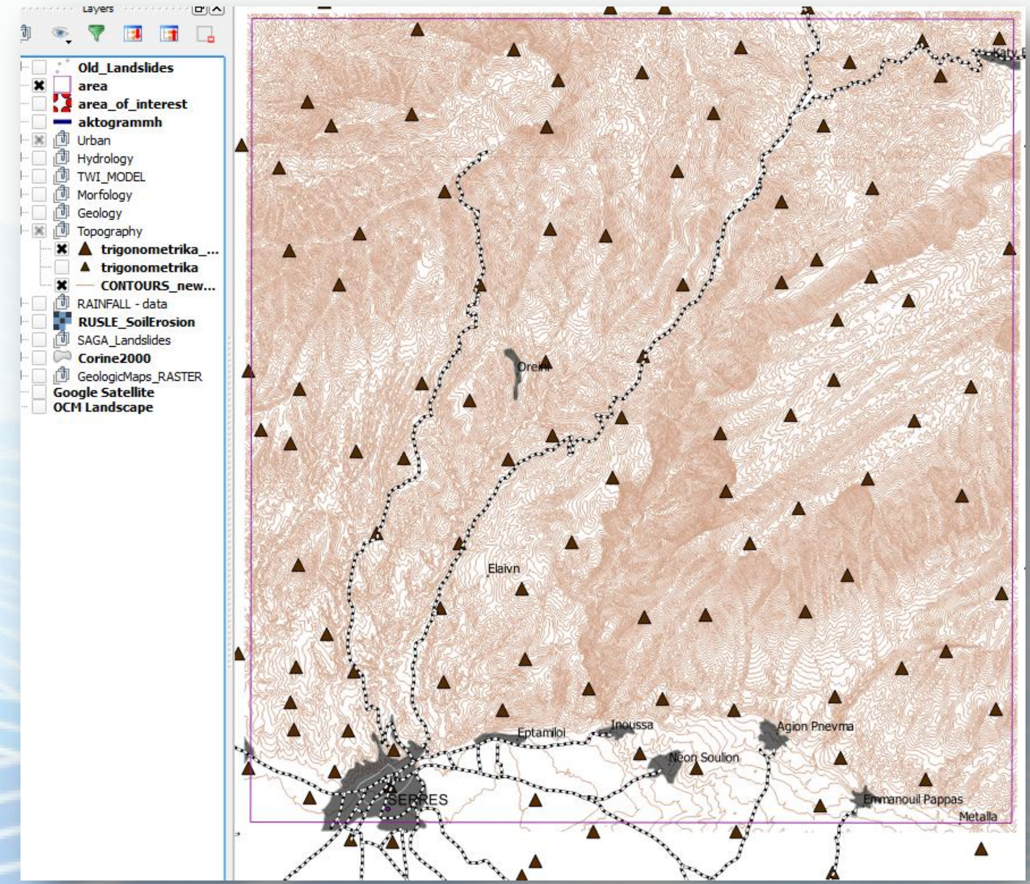
SciNet NatHaz Prevention

Common borders. Common solutions.

Topographic Data

- **Input topographic data**
  - **Contour Lines**
  - **Elevation points**

- **Please Note! We will be working on a 1:50.000 (Regional) scale**



Project funded by the EUROPEAN UNION

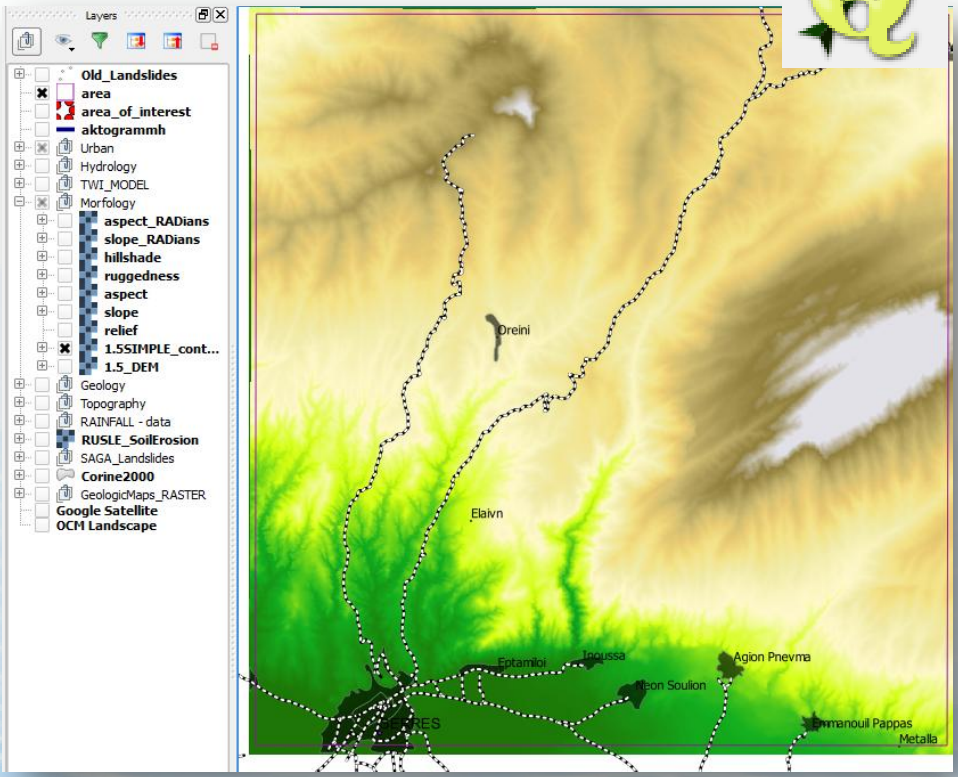
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Digital Elevation Model

- Create a Digital Elevation Model (DEM)
  – You can use your preferred method
  – ....BUT....
  – Pay attention to the **PIXEL SIZE**. Once defined it can not be changed and all outputs will be based on that. For a 1:50.000 scale map, contours per 20m, a pixel size of 15m is fine!
- **In case the DEM covers a larger area, CROP it using the "AREA" polygon.**



Project funded by the EUROPEAN UNION

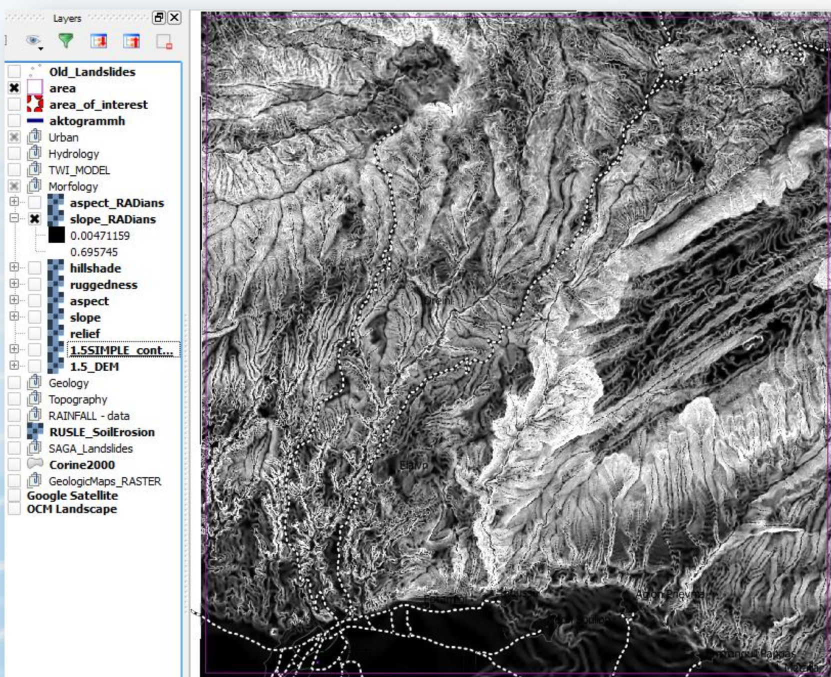
SciNet NatHaz Prevention

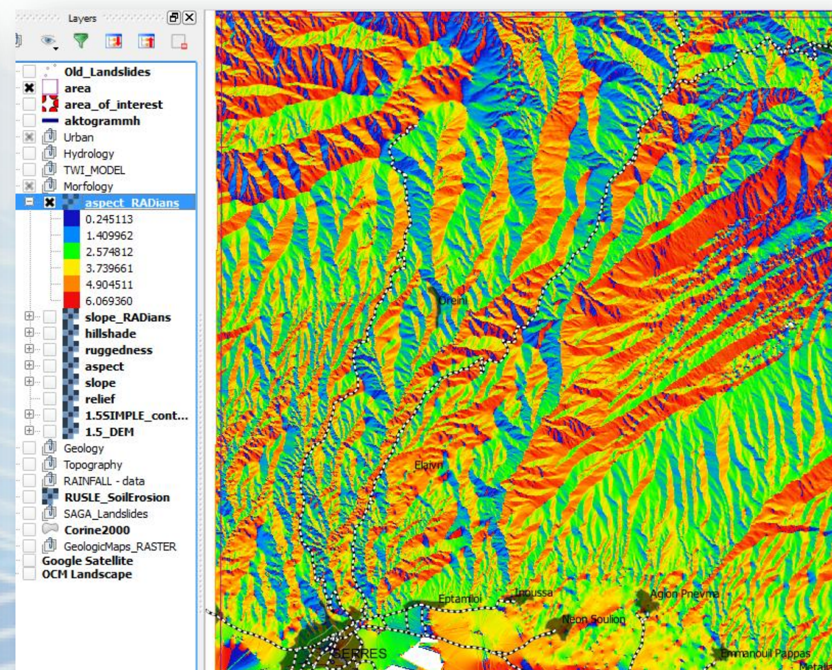
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Slope and Aspect maps

- **Create SLOPE and ASPECT maps**
  - **Please Note! QGIS uses/calculates angles in RADIANS.** Conversions in DEGREES may be needed in the process





Calculating effective Cohesion (c’) and friction angle (φ’)

- IF the geological formation is a **ROCKMASS**, then **Hoek and Brown failure criterion** is used in order to establish two pairs of (φ’ & c’) for low and high normal stress (small slope and high slope).
- **GSI (Geological Strength Index) and Uniaxial Compressive Strength** must be estimated according to rockmass lithology and the condition of the rockmass.

rocscience software tools for rock and soil

Geotechnical parameters (c’, φ’, γ)

- **IF the geological formation is a SOIL**, then according to the geological description (see geological maps) values of φ’, c’ and γ can be attributed according to international bibliography and your experience.

No matter if **SOIL** or **ROCKMASS** is encountered, geotechnical parameters should be estimated or calculated in a conservative way.

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Analysis of Rock Strength using RocLab

H=5m

Analysis of Rock Strength using RocLab

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 25 MPa
GSI = 32 mi = 8 Disturbance factor (D) = 1
intact modulus (Ei) = 16875 MPa
modulus ratio (MR) = 675

Hoek-Brown Criterion
mb = 0.062 s = 1.2e-5 a = 0.520

Mohr-Coulomb Fit
cohesion = 0.027 MPa friction angle = 34.17 deg

Rock Mass Parameters
tensile strength = -0.005 MPa
uniaxial compressive strength = 0.069 MPa
global strength = 0.723 MPa
deformation modulus = 503.42 MPa

c' = 27kPa

ϕ' = 22^0

H=50m

Analysis of Rock Strength using RocLab

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 25 MPa
GSI = 32 mi = 8 Disturbance factor (D) = 1
intact modulus (Ei) = 16875 MPa
modulus ratio (MR) = 675

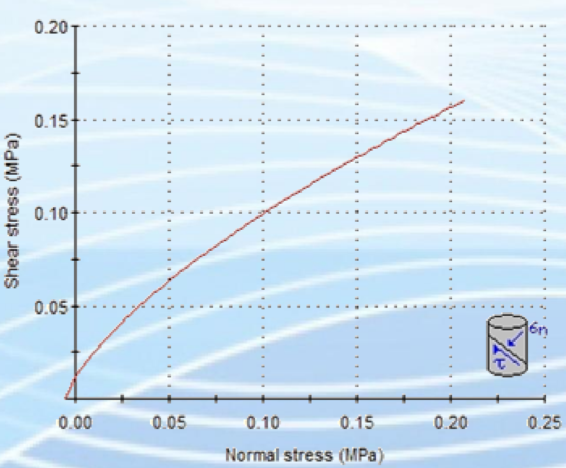
Hoek-Brown Criterion
mb = 0.062 s = 1.2e-5 a = 0.520

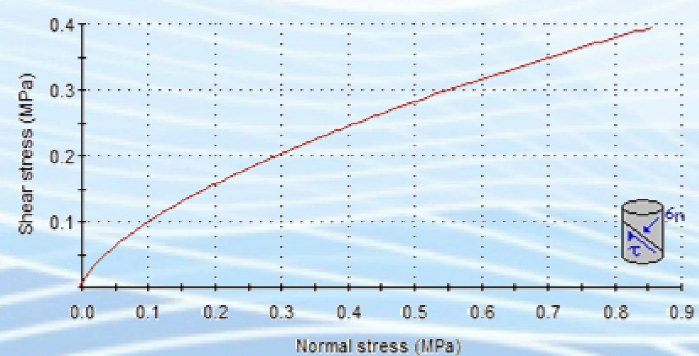
Mohr-Coulomb Fit
cohesion = 0.072 MPa friction angle = 21.91 deg

Rock Mass Parameters
tensile strength = -0.005 MPa
uniaxial compressive strength = 0.069 MPa
global strength = 0.723 MPa
deformation modulus = 503.42 MPa

http://www.rocscience.com

http://roclab.software.informer.com/1.0/





Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Calculating effective Cohesion (c') and friction angle (φ')

- **Calculate i) Cohesion (c'); ii) angle of Internal Friction (φ); iii) Unit Weight and iv) Hydraulic Conductivity for each of the geologic formations of the area**

	gn,ab		gn,ab,sch		gn,mr		gn-sch		gn-γ		gn-μv		gn1	
Hoek Brown Classification	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m
sigci (Mpa)	100	100	100	100	100	100	100	100	120	120	175	175	100	100
GSI	30	30	31	31	30	30	29	29	31	31	31	31	33	33
mi	23	23	23	23	12	12	10	10	26	26	26	26	25	25
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ei	40000	40000	30000	30000	85000	85000	30000	30000	48000	48000	70000	70000	30000	30000
MR	400	400	300	300	850	850	300	300	400	400	400	400	300	300
Hoek Brown Criterion														
mb	0.15497	0.15497	0.16645	0.16645	0.08086	0.08086	0.06273	0.06273	0.18816	0.18816	0.18816	0.18816	0.20870	0.20870
s	8.57E-06	8.57E-06	1.01E-05	1.01E-05	8.57E-06	8.57E-06	7.26E-06	7.26E-06	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.41E-05	1.41E-05
a	0.52234	0.52234	0.52089	0.52089	0.52234	0.52234	0.52390	0.52390	0.52089	0.52089	0.52089	0.52089	0.51826	0.51826
Failure Envelope Range														
Application	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes
sig3max (Mpa)	0.12892	1.04787	0.12946	1.05227	0.12066	0.98074	0.12344	1.00331	0.13236	1.07584	0.13693	1.11300	0.13103	1.06504
Unit Weight (MN/m3)	0.026	0.026	0.026	0.026	0.025	0.025	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
Slope Height (m)	5	50	5	50	5	50	5	50	5	50	5	50	5	50
Mohr-Coulomb Fit														
c (Mpa)	0.0587	0.2299	0.0616	0.2391	0.0530	0.1798	0.0500	0.1653	0.0685	0.2671	0.0827	0.3084	0.0688	0.2651
phi (degrees)	51.6	35.1	52.3	35.9	46.3	29.9	43.6	27.4	54.4	38.3	56.7	41.1	54.3	38.0
Rock Mass Parameters														
sigt (Mpa)	-0.0055	-0.0055	-0.0061	-0.0061	-0.0106	-0.0106	-0.0116	-0.0116	-0.0065	-0.0065	-0.0094	-0.0094	-0.0068	-0.0068
sigc (Mpa)	0.2256	0.2256	0.2503	0.2503	0.2256	0.2256	0.2031	0.2031	0.3004	0.3004	0.4380	0.4380	0.3067	0.3067
sigcm (Mpa)	4.5577	4.5577	4.7751	4.7751	3.2471	3.2471	2.8123	2.8123	6.1073	6.1073	8.9065	8.9065	5.4597	5.4597
Erm (Mpa)	1128.98	1128.98	869.793	869.793	2399.08	2399.08	825.615	825.615	1391.67	1391.67	2029.52	2029.52	922.432	922.432

Results																					
	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)
	5	51.61	58.71	5	52.30	61.65	5	46.31	52.98	5	43.63	50.02	5	54.43	68.54	5	56.70	82.66	5	54.27	68.77
	50	35.14	229.90	50	35.88	239.11	50	29.90	179.85	50	27.39	165.30	50	38.29	267.10	50	41.10	308.41	50	38.04	265.11
Final Values		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)
		35	59		36	62		30	53		27	50		38	69		41	83		38	69

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Geotechnical Parameters Spatial Distribution

- Digitize the **Geologic Map**
- **Assign additional attributes** to geologic formation polygons
  - C: effective Cohesion
  - Fi (ϕ): effective Internal Friction angle
  - Hc: hydraulic conductivity
  - …etc….
- Please! Pay attention to the respective to each parameter, UNITS

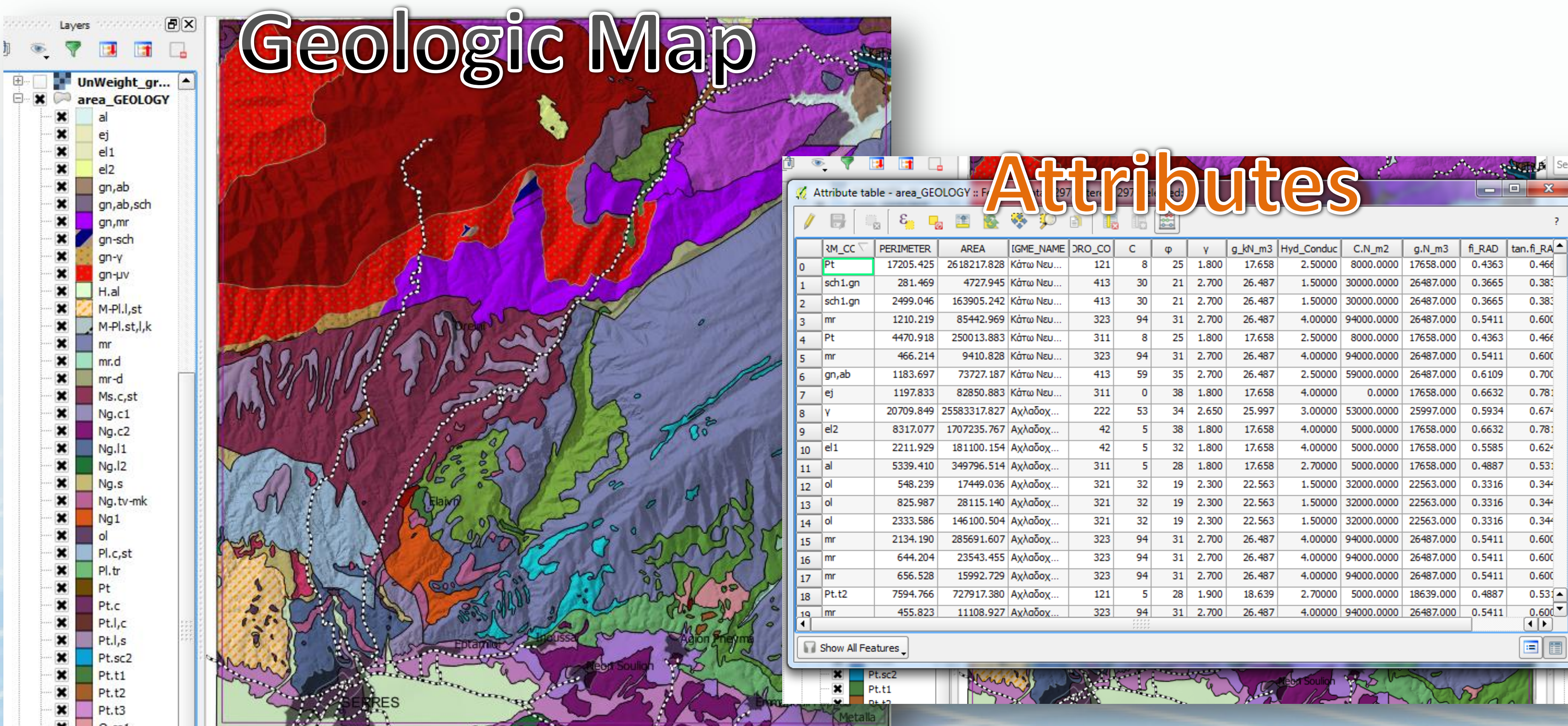
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Geotechnical Parameters Spatial Distribution



	RM_CC	PERIMETER	AREA	IGME_NAME	DRO_CO	C	φ	γ	g_kN_m3	Hyd_Conduc	C.N_m2	g.N_m3	fi_RAD	tan.fi_RA
0	Pt	17205.425	2618217.828	Κάτω Νευ...	121	8	25	1.800	17.658	2.50000	8000.0000	17658.000	0.4363	0.466
1	sch1.gn	281.469	4727.945	Κάτω Νευ...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	0.383
2	sch1.gn	2499.046	163905.242	Κάτω Νευ...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	0.383
3	mr	1210.219	85442.969	Κάτω Νευ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
4	Pt	4470.918	250013.883	Κάτω Νευ...	311	8	25	1.800	17.658	2.50000	8000.0000	17658.000	0.4363	0.466
5	mr	466.214	9410.828	Κάτω Νευ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
6	gn,ab	1183.697	73727.187	Κάτω Νευ...	413	59	35	2.700	26.487	2.50000	59000.0000	26487.000	0.6109	0.700
7	ej	1197.833	82850.883	Κάτω Νευ...	311	0	38	1.800	17.658	4.00000	0.0000	17658.000	0.6632	0.781
8	γ	20709.849	25583317.827	Αχλαδοχ...	222	53	34	2.650	25.997	3.00000	53000.0000	25997.000	0.5934	0.674
9	el2	8317.077	1707235.767	Αχλαδοχ...	42	5	38	1.800	17.658	4.00000	5000.0000	17658.000	0.6632	0.781
10	el1	2211.929	181100.154	Αχλαδοχ...	42	5	32	1.800	17.658	4.00000	5000.0000	17658.000	0.5585	0.624
11	al	5339.410	349796.514	Αχλαδοχ...	311	5	28	1.800	17.658	2.70000	5000.0000	17658.000	0.4887	0.531
12	ol	548.239	17449.036	Αχλαδοχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
13	ol	825.987	28115.140	Αχλαδοχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
14	ol	2333.586	146100.504	Αχλαδοχ...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
15	mr	2134.190	285691.607	Αχλαδοχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
16	mr	644.204	23543.455	Αχλαδοχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
17	mr	656.528	15992.729	Αχλαδοχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
18	Pt.t2	7594.766	727917.380	Αχλαδοχ...	121	5	28	1.900	18.639	2.70000	5000.0000	18639.000	0.4887	0.531
19	mr	455.823	11108.927	Αχλαδοχ...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600

Project funded by the EUROPEAN UNION

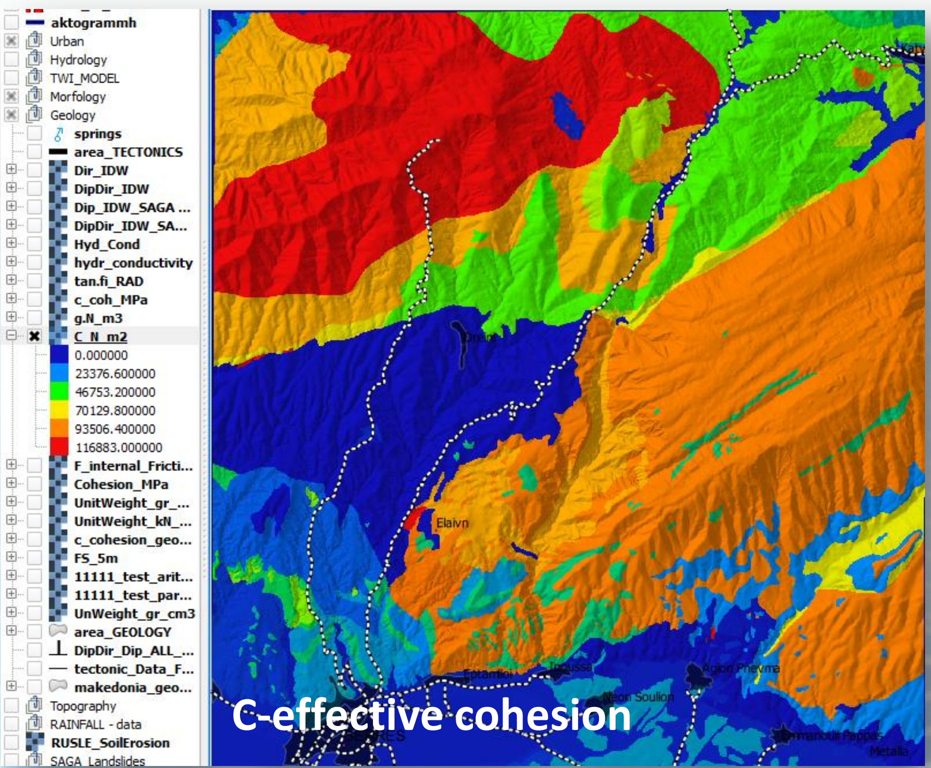
SciNet NatHaz Prevention

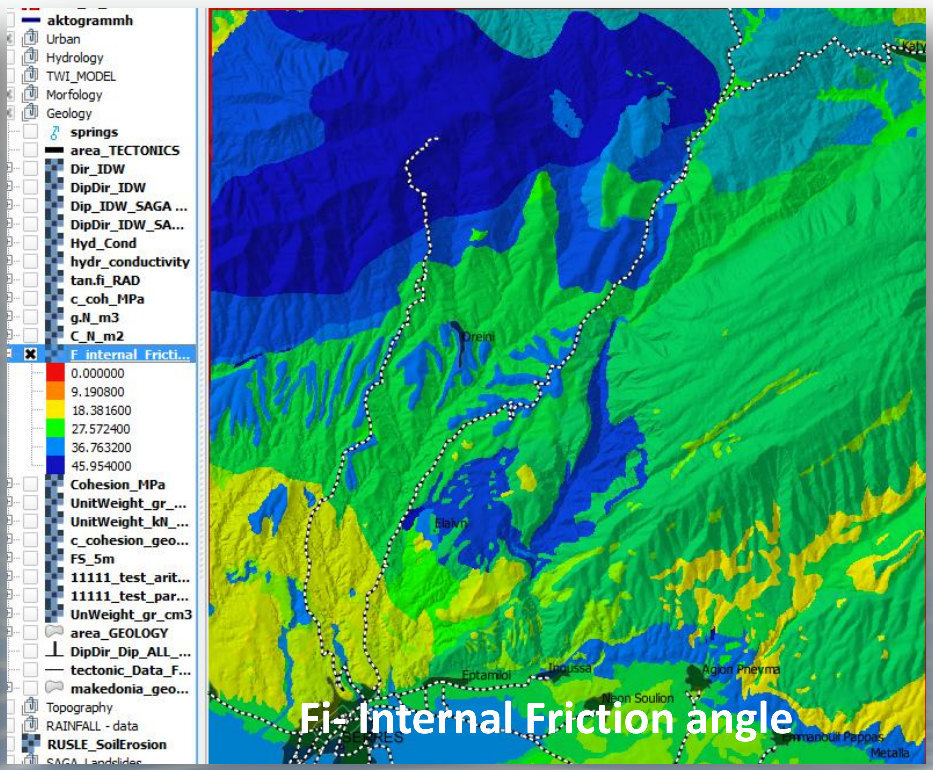
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Calculating effective Cohesion (c’) and friction angle (ϕ’)

- Preparing the parameters for the calculation of Factor of Safety (convert vector to Raster); c’ – effective cohesion and ϕ’-Internal Friction angle





Project funded by the EUROPEAN UNION

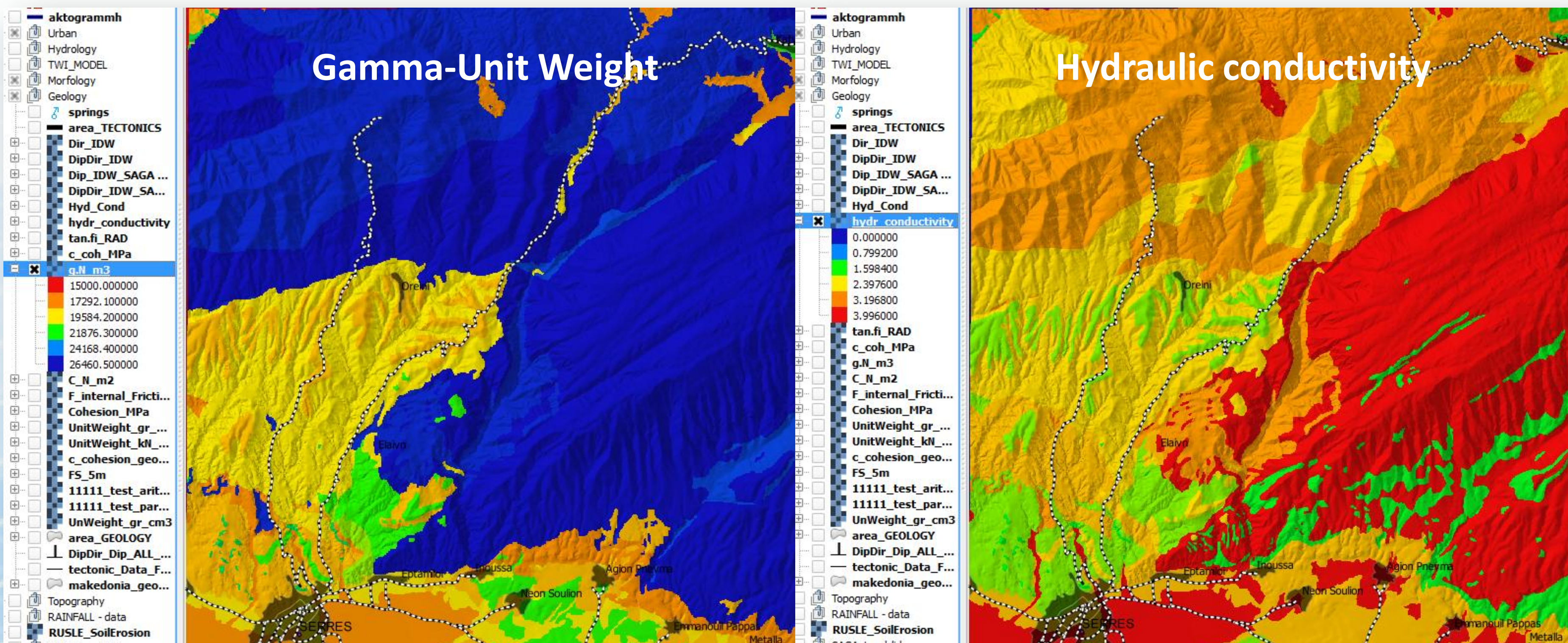
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Unit Weight & Hydraulic Conductivity Spatial Distribution

- Preparing the parameters for the calculation of Factor of Safety: Unit Weight and Hydraulic Conductivity (needed to calculate Saturation in SAGA GIS



Thickness and saturation of sliding slab

The Most difficult parameters to estimate for the infinite slope model !

z: normal thickness of the failure slab (m)

m: percentage of saturation of the failure slab (%)

- **Normal thickness of failure slab (z)** is to be determined as a function of slope angle (β), in order to calculate the factor of safety
- **Percentage of saturation (m %)** needs to be correlated with rainfall (mm) and a mean return period for the rainfall event (if such data exist for the examined region)

Thickness and saturation of sliding slab

- **The Normal thickness of failure slab (z)** can be defined parametrically (i.e. 1m, 5m, 10m) and taken into account as such or physically based models can be used to link it to soil (and regolith) development natural parameters related to weathering, erosion and deposition (morphometric: slope, curvature, position on slope, etc; hydrologic, geologic etc)

Indicative Relative Research: Dietrich and Reiss, 1995; Catani et.al, 2010; Shafique et.al, 2011.

Potentially useful info:

- Pan-European Soil Databases fpr Landslide Mapping (JRC)
- ESDAC Data Inventory
- EU Soils

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Saturation percentage of sliding slab

- **Percentage of saturation (m %)** needs to be correlated with rainfall (mm) and a mean return period for the rainfall event (if such data exist for the examined region)

- Create the Saturation Percentage (SP) using the WETNESS module in SAGA GIS
- Please note! The **SP** is **calculated** for a **respective sliding mass thickness**
- References and help are given within SAGA GIS (shown below).

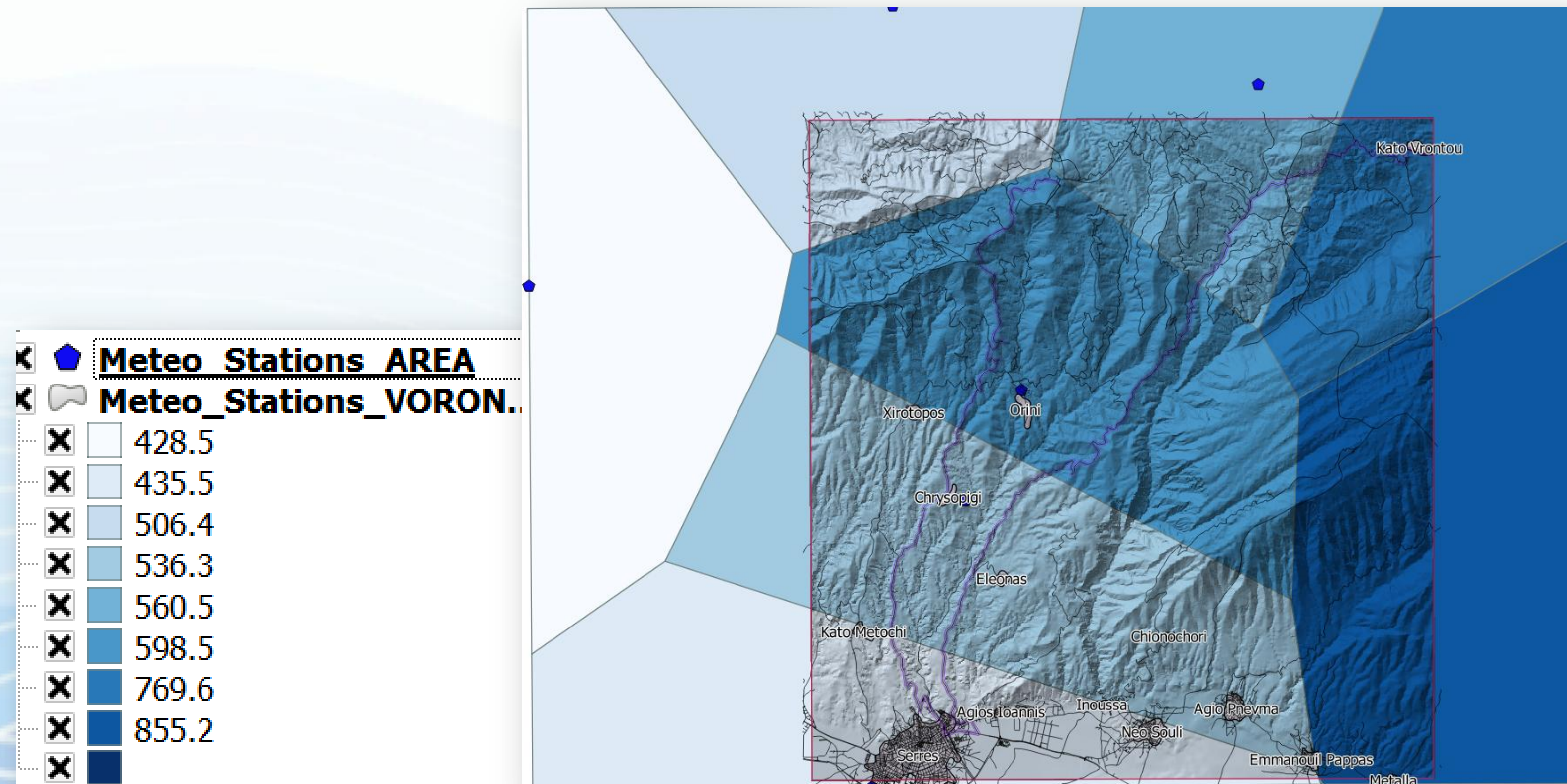
References:

- Beven, K.J., Kirkby, M.J. (1979) A physically-based variable contributing area model of basin hydrology. Hydrology Science Bulletin, 24, 43-69..
- Montgomery D. R., Dietrich, W. E. (1994) A physically based model for the topographic control on shallow landsliding. Water Resources Research, 30, 1153-1171.

Common borders. Common solutions.

Mean annual Rainfall (mm)

- Location of the Meteorological stations around the pilot implementation area



Project funded by the EUROPEAN UNION

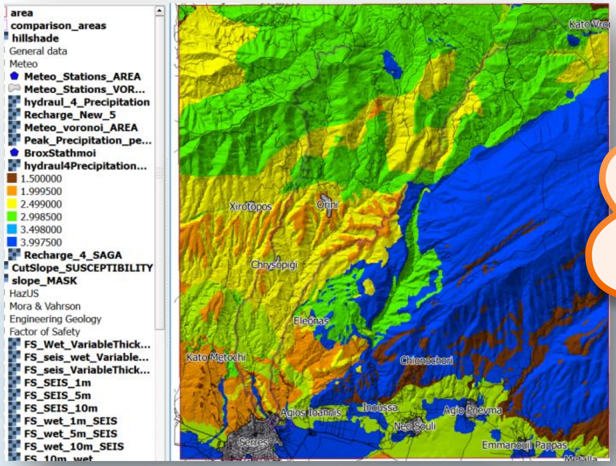
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

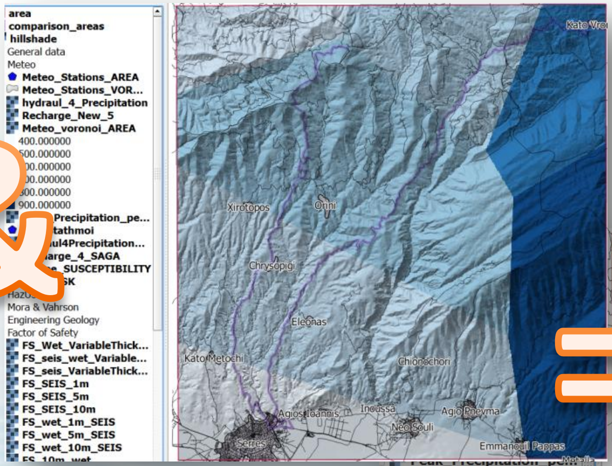
SAGA "Recharge" (m/hour)

- Effective **INFILTRATION**



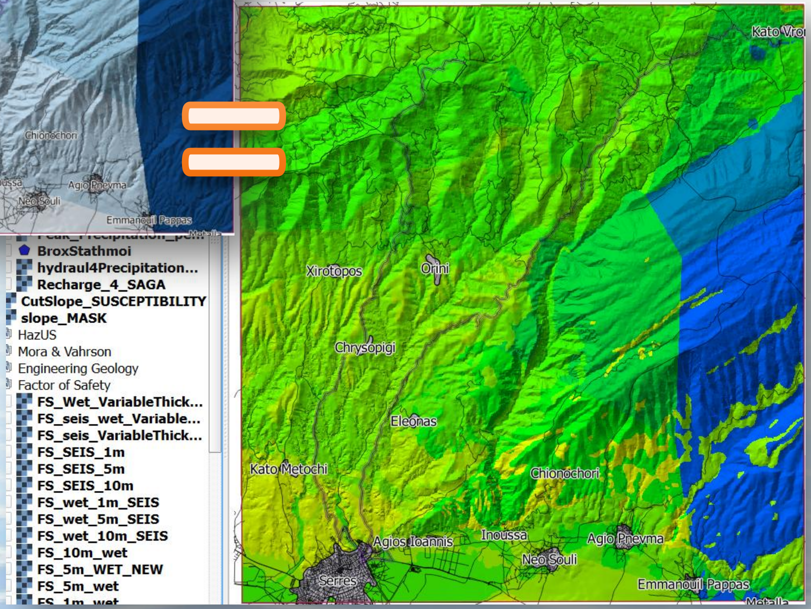
&

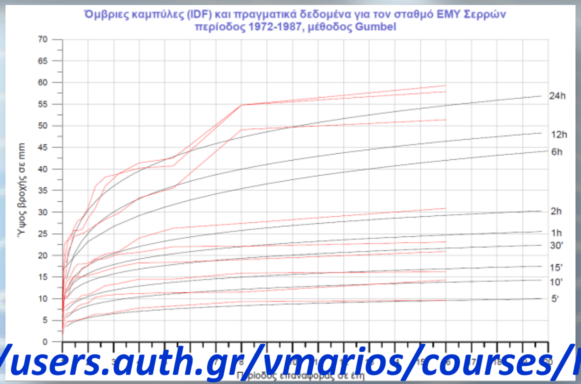
- **PEAK Rainfall** (m/hour)



=

- **Recharge** (m/hour)





- *http://users.auth.gr/vmarios/courses/IDF.pdf*

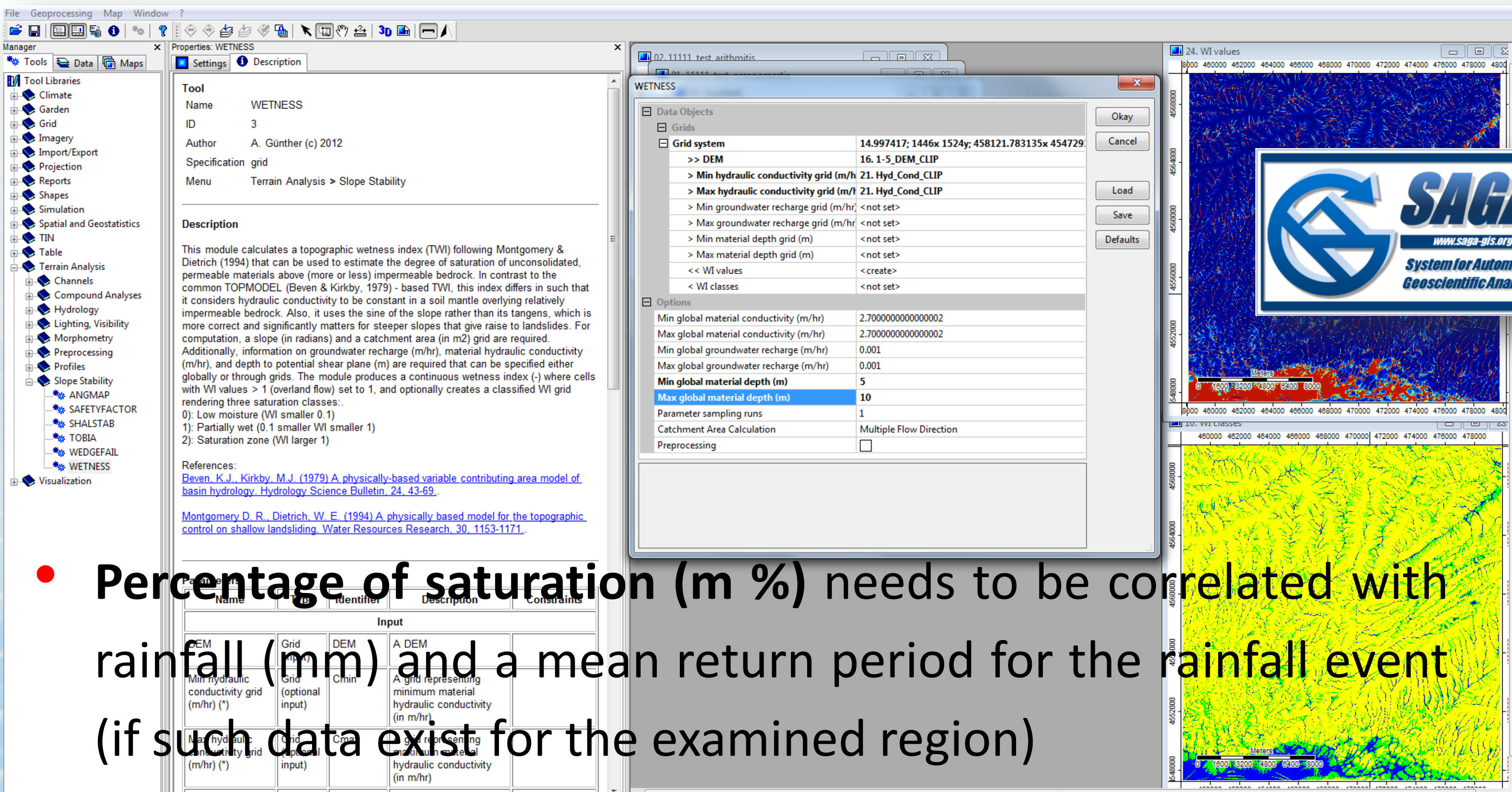
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Saturation percentage of sliding slab

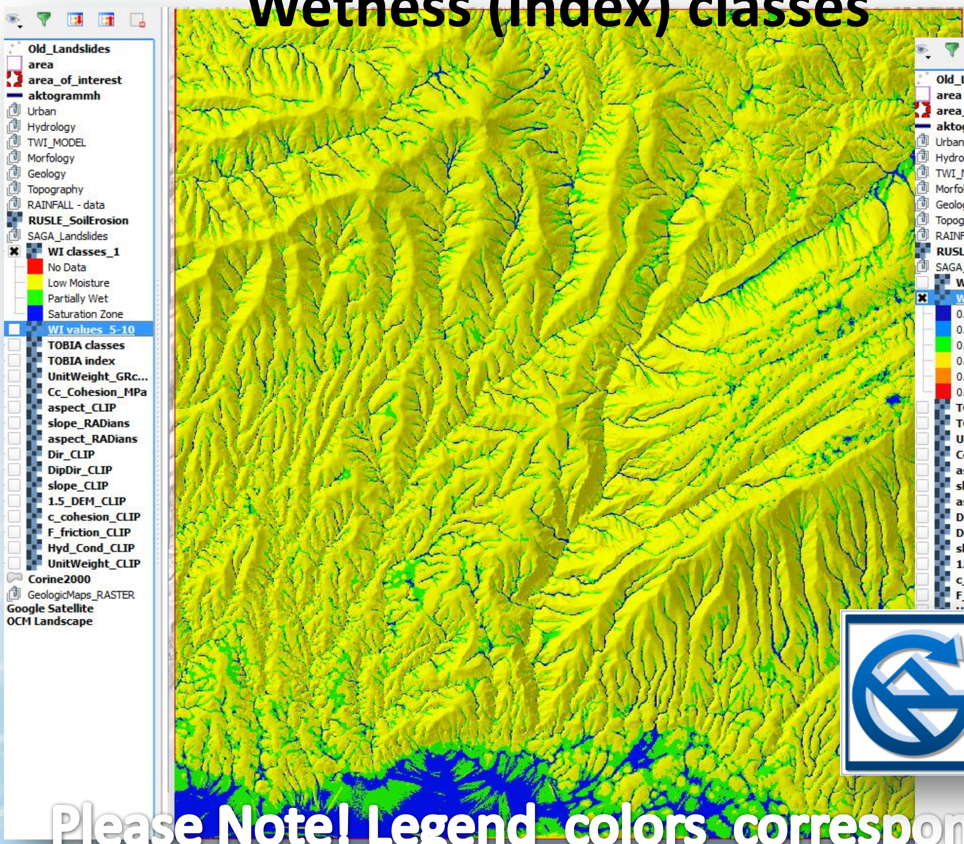


- **Percentage of saturation (m %)** needs to be correlated with rainfall (mm) and a mean return period for the rainfall event (if such data exist for the examined region)

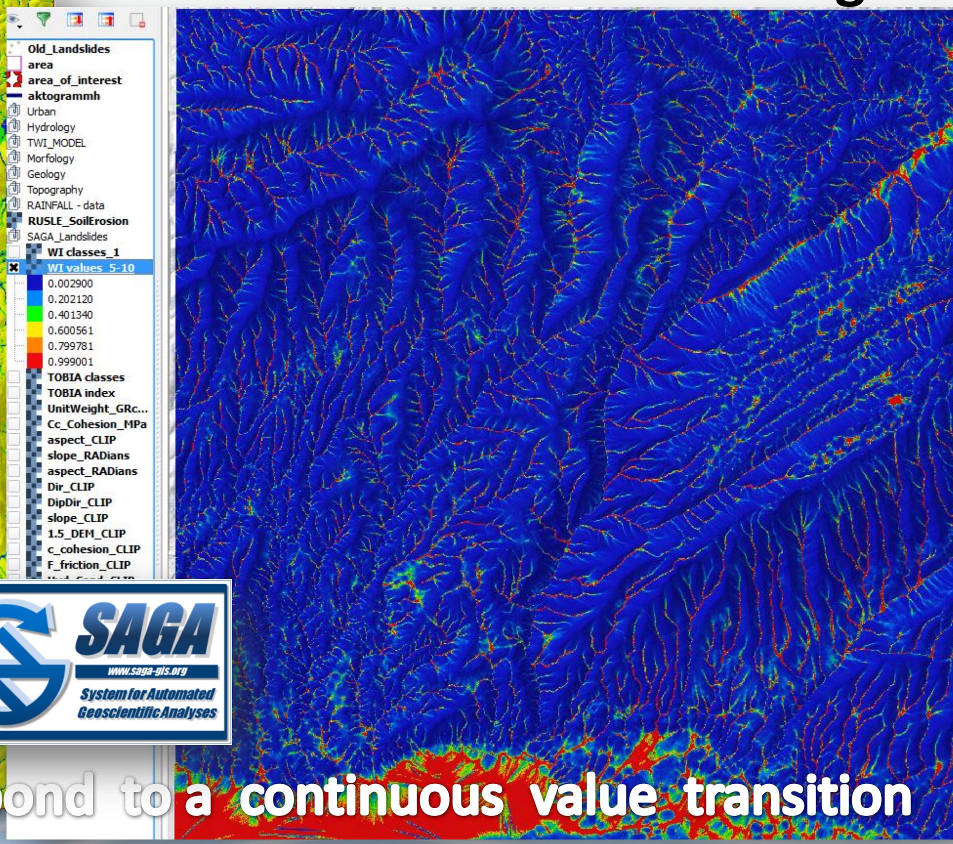
Common borders. Common solutions.

Saturation percentage of sliding slab

Wetness (Index) classes



Saturation Percentage



Please Note! Legend colors correspond to a continuous value transition

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

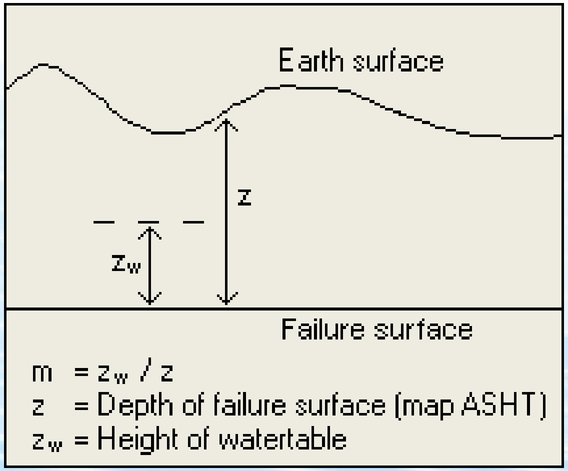
Common borders. Common solutions.

Landslide Hazard – Seismic/Wet conditions

Infinite Slope Model (Factor of Safety for a Wet slope)

$$F = \frac{c' + (z\gamma\cos^2\beta - z\rho\alpha\cos\beta\sin\beta - \gamma_w z_w \cos^2\beta)\tan\phi'}{z\gamma\sin\beta\cos\beta + z\rho\alpha\cos^2\beta}$$

ϕ': effective angle of friction of geomaterial (^{0})
c’: effective cohesion of geomaterial (kPa),
β: slope angle (Deg),
ρ: bulk density (Kg/m^3)
γ: specific weight (kN/m^3),
γ_w: specific weight of the water (kN/m^3),
a : earthquake acceleration (m/sec^2)
z: normal thickness of the failure slab (m)
$m = z_w/z$ % of the water saturated failure slab



Landslide Hazard – Seismic/Wet conditions

Landslide Hazard is assessed for the following conditions

- **DRY:** Thickness of failure slab 1, 5 and 10m (three cases)
- **WET:** Thickness of failure slab 1, 5 and 10m (three cases)

Seismic conditions

- **DRY:** Thickness of failure slab 1, 5 and 10m (three cases)
- **WET:** Thickness of failure slab 1, 5 and 10m (three cases)

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

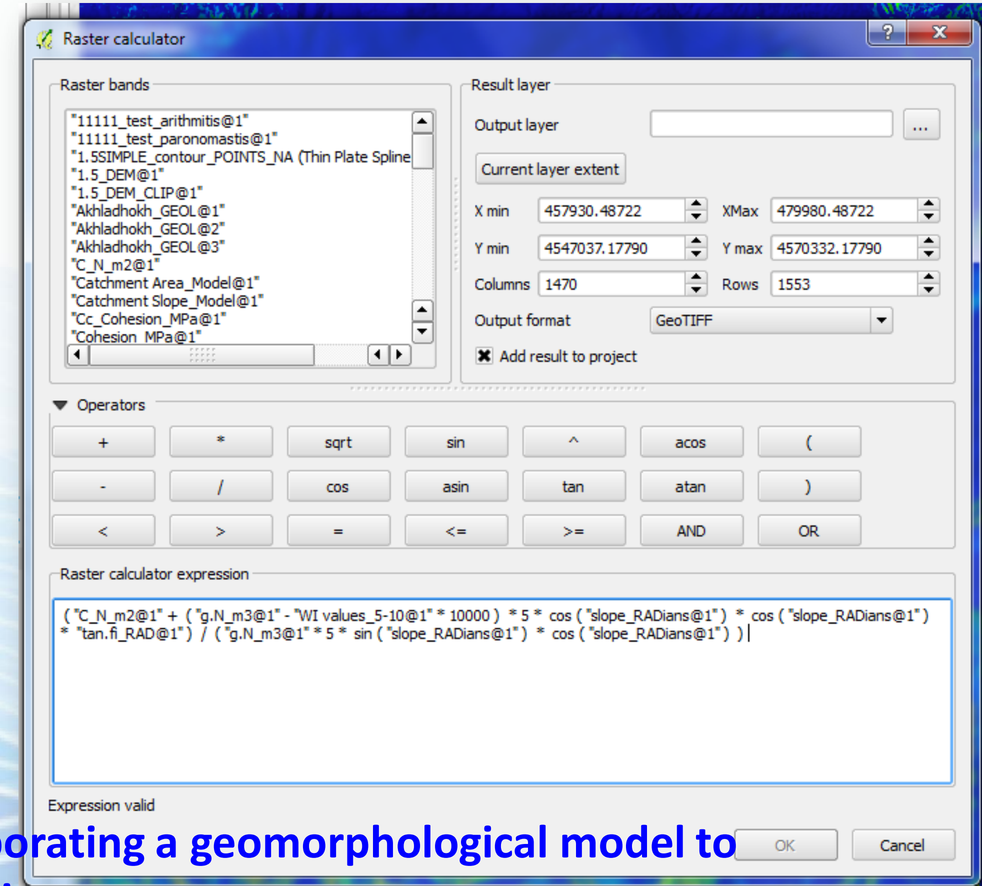
Calculate Factor of Safety– wet–5m thick sliding mass*

$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$

in which:

c'	= effective cohesion (Pa= N/m^2).
γ	= unit weight of soil (N/m^3).
m	= z_w/z (dimensionless).
γ_w	= unit weight of water (N/m^3).
z	= depth of failure surface below the surface (m).
z_w	= height of watertable above failure surface (m).
β	= slope surface inclination (°).
ϕ'	= effective angle of shearing resistance (°).

…using the information layers created previously and the RASTER CALCULATOR module in QGIS



* We are currently working into incorporating a geomorphological model to calculate the soil thickness in the entire area

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

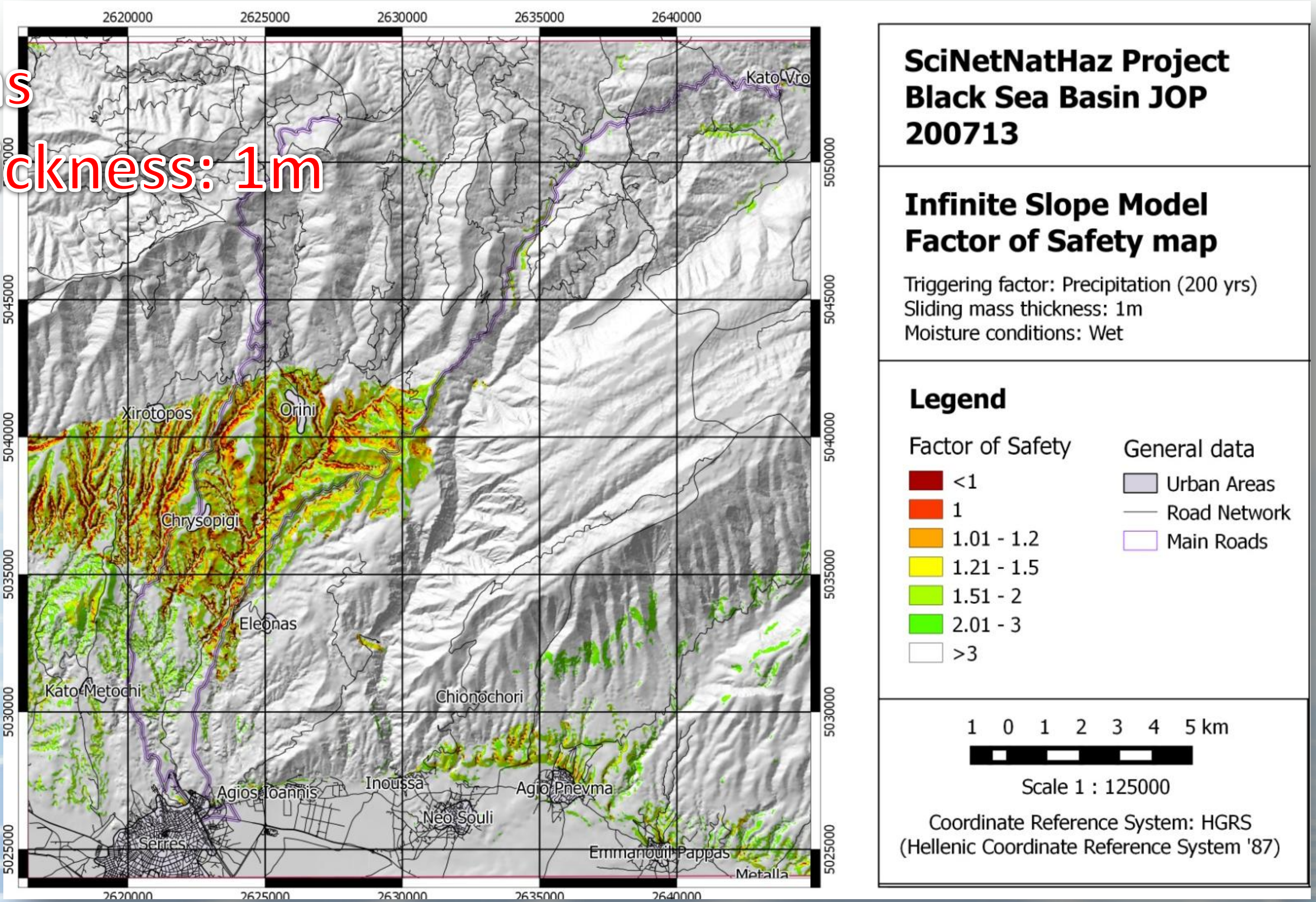
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Factor of Safety – Serres Pilot Implementation Area

WET conditions

Sliding slab thickness: 1m



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

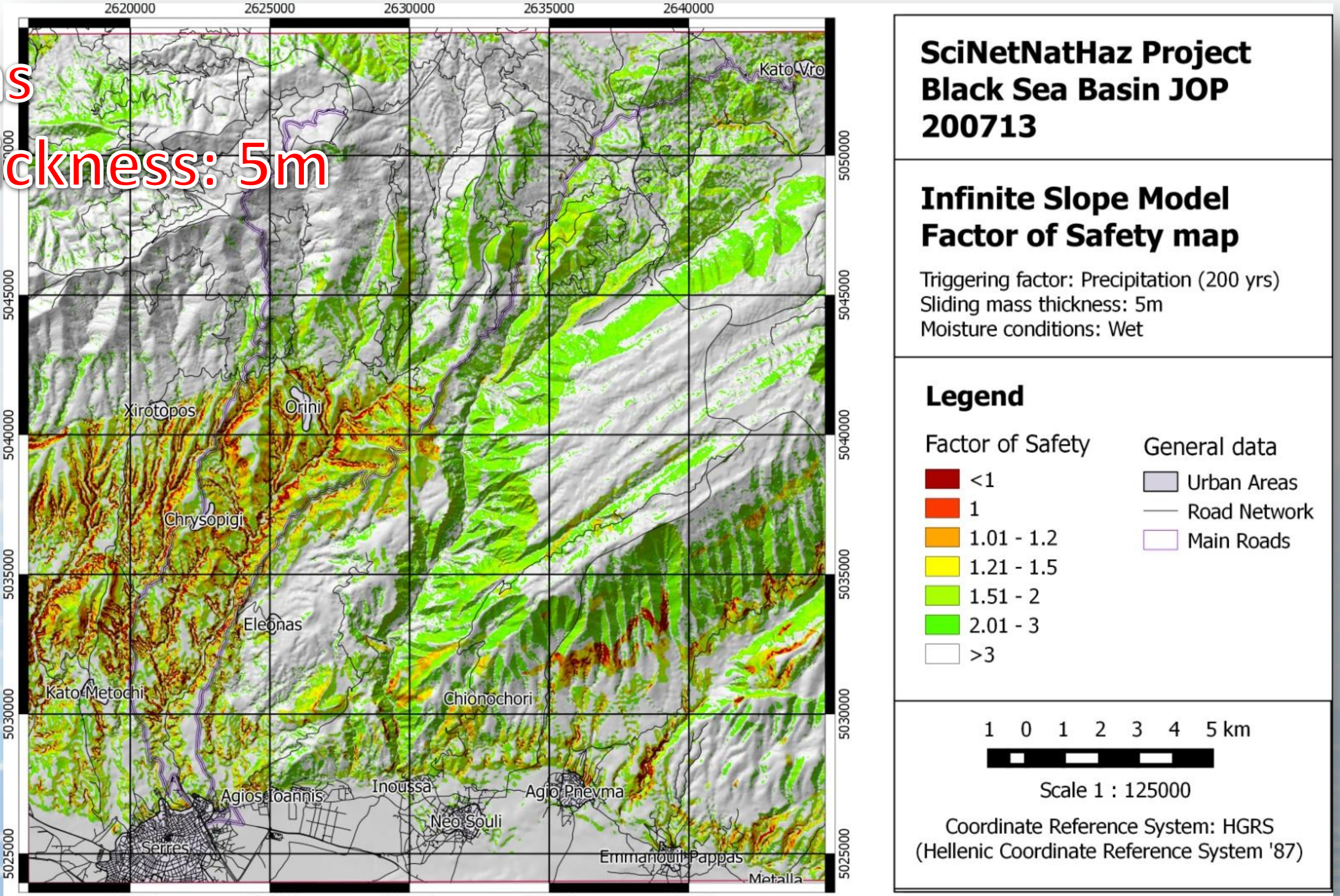
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Factor of Safety – Serres Pilot Implementation Area

WET conditions

Sliding slab thickness: 5m

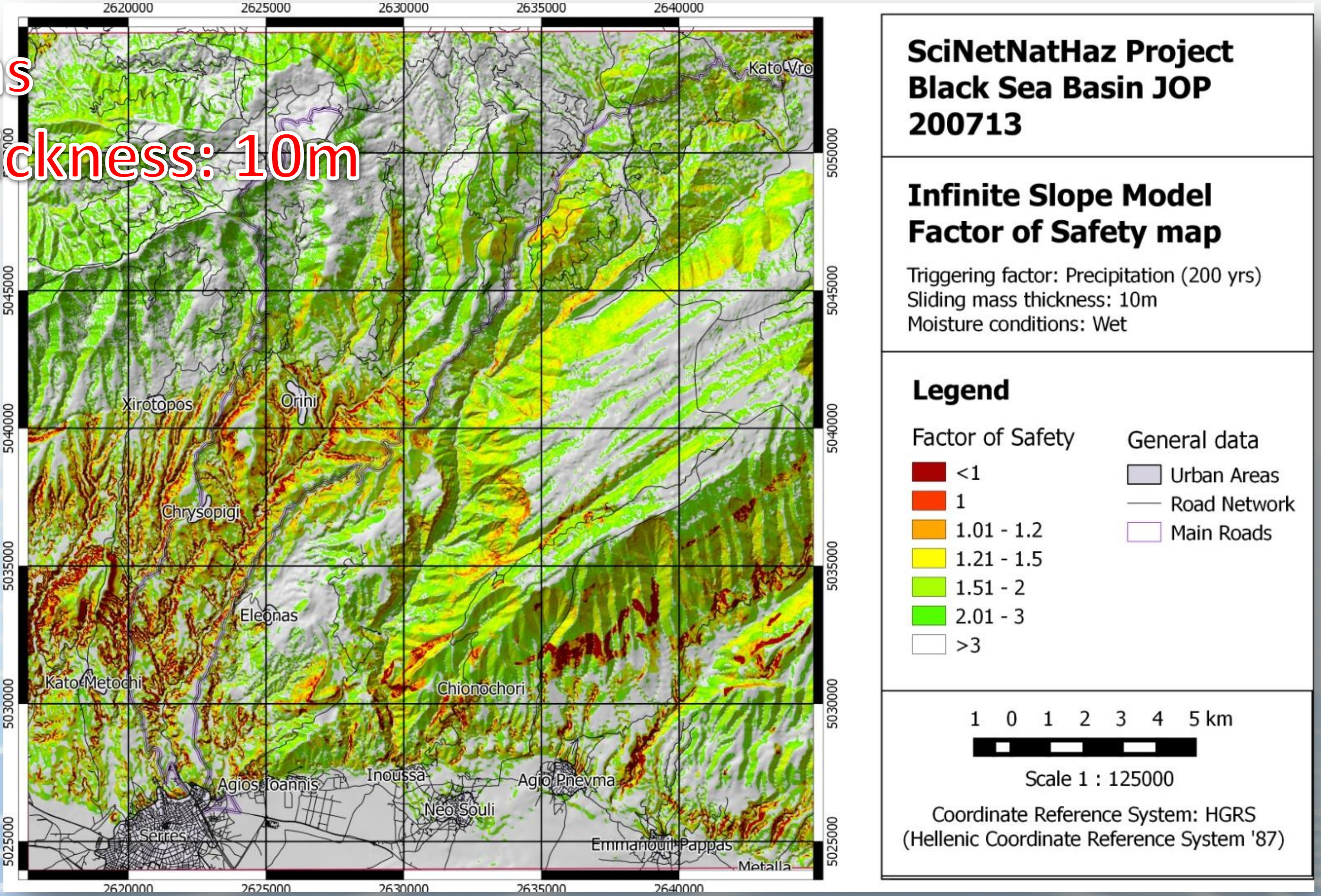


Common borders. Common solutions.

Factor of Safety – Serres Pilot Implementation Area

WET conditions

Sliding slab thickness: 10m



Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

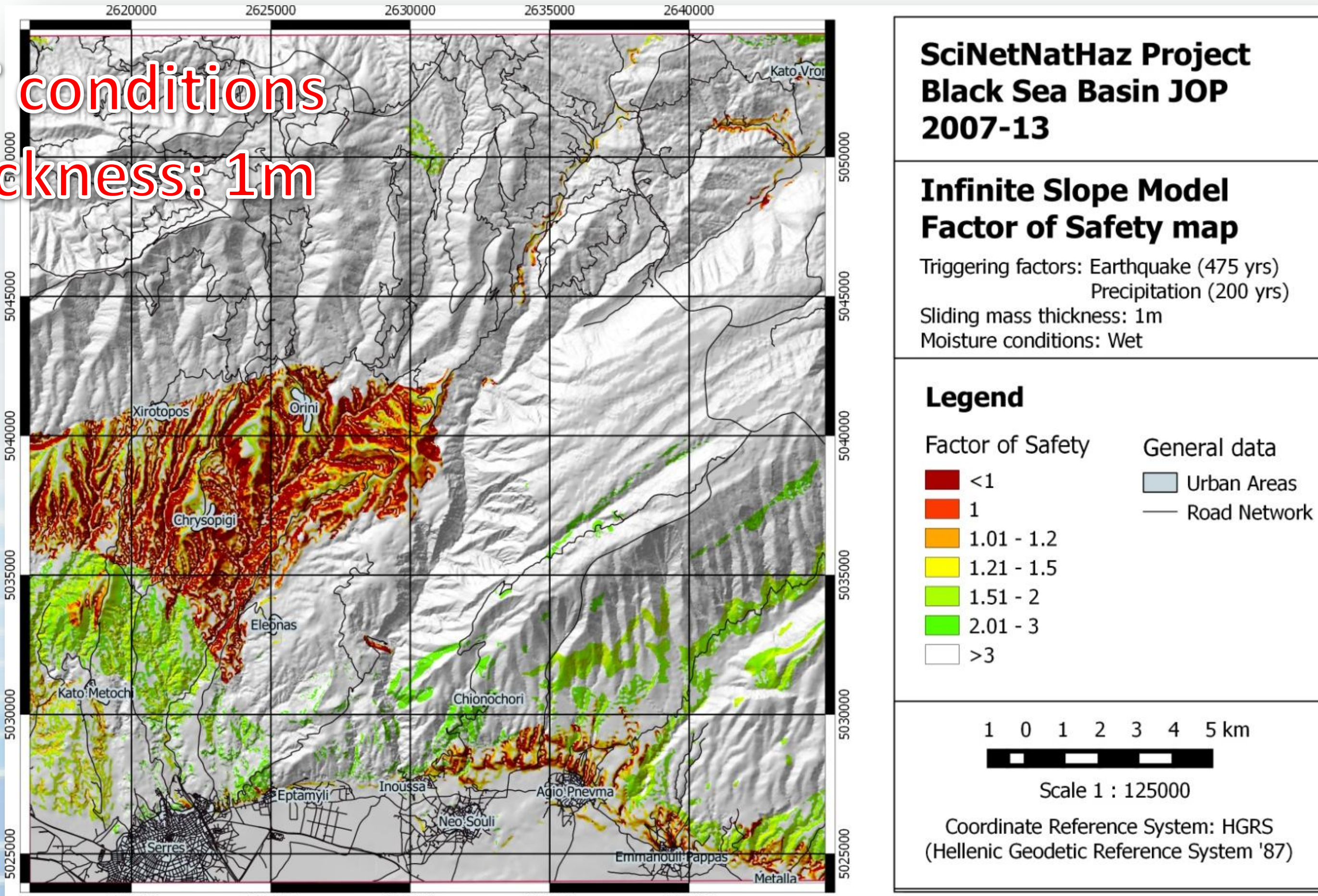
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Factor of Safety – Serres Pilot Implementation Area

Seismic & WET conditions

Sliding slab thickness: 1m



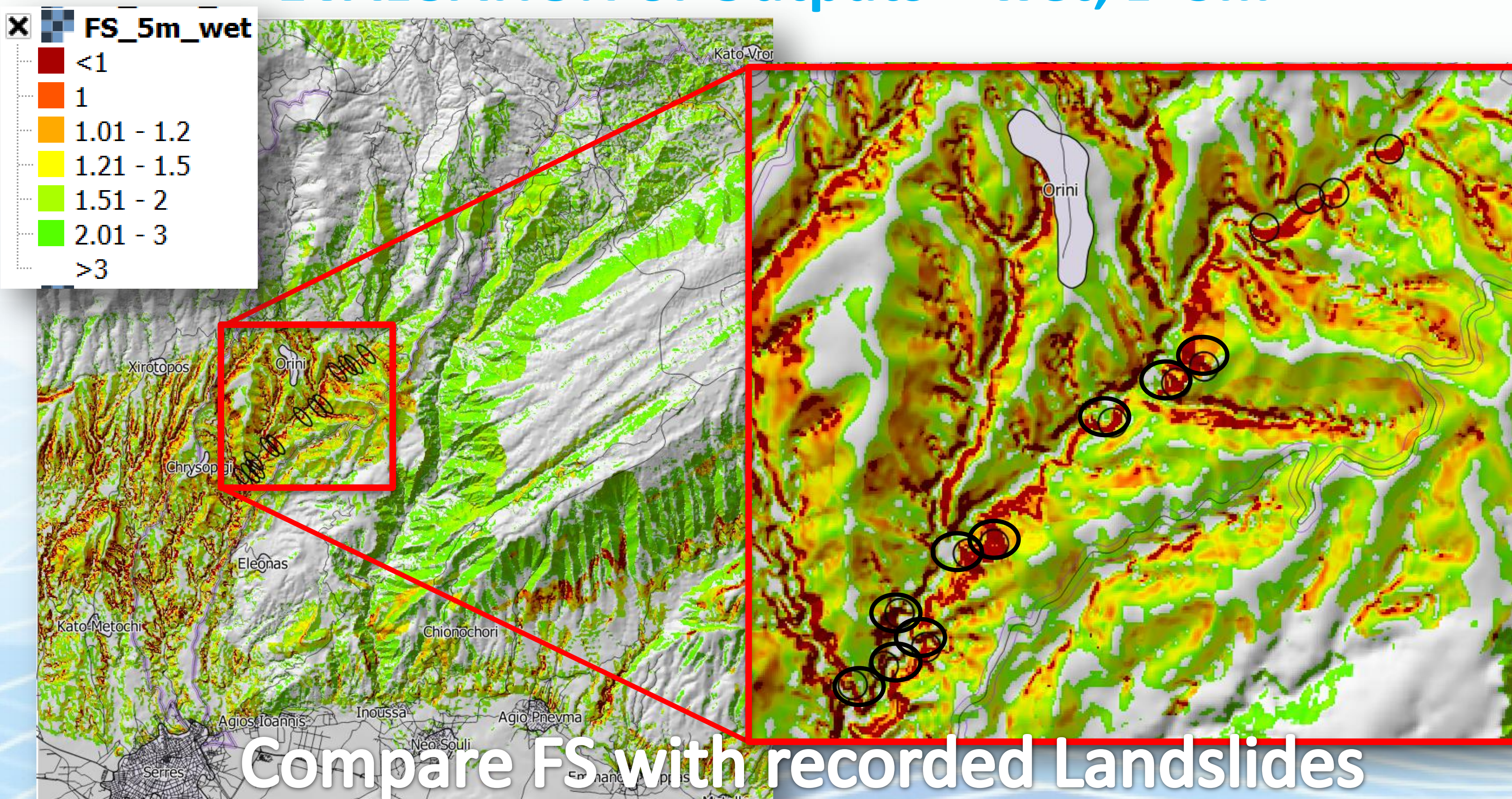
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

EVALUATION of Outputs – wet; z=5m



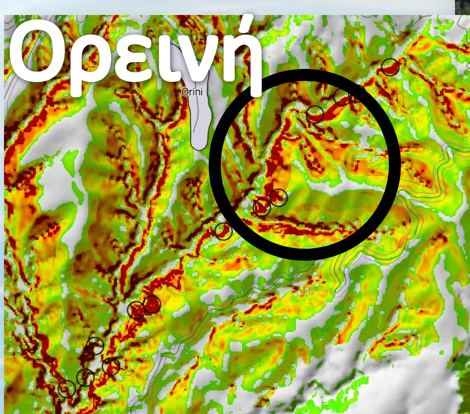
Project funded by the EUROPEAN UNION

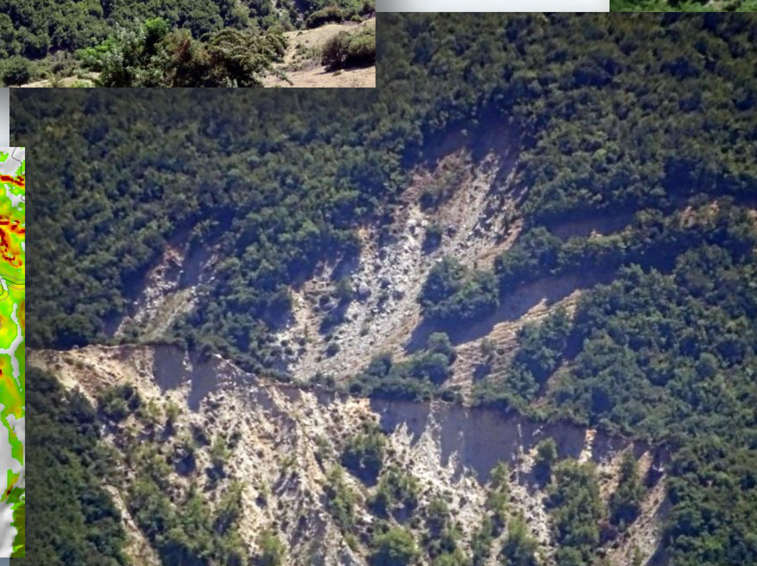
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

EVALUATION of Outputs – Recorded Landslides





Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

General Conclusions (1/3)

Landslide Susceptibility Assessment, Regional Scale 1:250,000 to 1:25,000 *(static & seismic conditions)*

- FEMA method (for **static conditions**: geologic maps + topography maps + hydraulic conditions) needs improvements (introduction of structure of soils/rocks: dip & dip direction of bedding, schistosity, interface of weathered zone and rockmass or soil over rockmass)
- FEMA method (for **seismic conditions**: geologic maps + topography maps + hydraulic conditions) + Critical Acceleration Index [A_C/PGA] seems to work fine with local GMPEs and "shallow" landslides

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

General Conclusions (2/3)

Landslide Hazard Assessment, Regional Scale 1:250,000 to 1:25,000 (static & seismic conditions)

- **Factor of Safety** method (for **static & seismic conditions**: geologic maps + topography maps + hydraulic conditions (% of sliding slab saturation) + geotechnical parameters (φ', c') + sliding slab normal thickness). For seismic conditions bulk density (ρ) + earthquake acceleration (a) are needed. The methodology **works fine for "shallow" landslides** BUT needs some improvement regarding the assessment of sliding slab thickness.

- FEMA method (for **seismic conditions**: geologic maps + topography maps + hydraulic conditions) + Critical Acceleration Index [A_C/PGA] resulting in the assessment of Permanent Ground Displacements, seems to work fine with local GMPEs and for "shallow type" landslides.

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Hazard Assessment on Regional Scales: Pilot Implementation in Greece

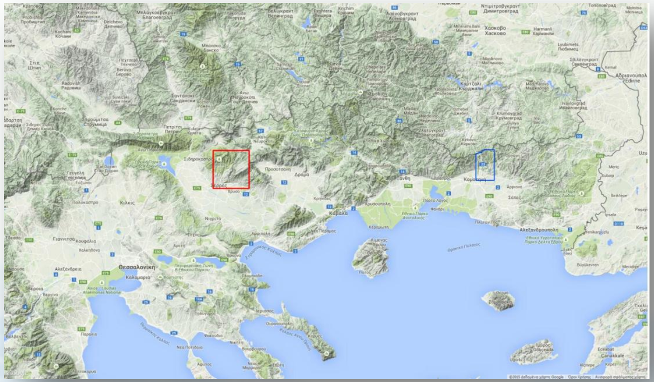
Thank You All for your Attention!

Acknowledgments:
The SciNetNatHaz Project
is partially funded by the EU and Hellenic National funds
within the context of the
Black Sea Basin Joint Operational Programme 2007-2013

K. Papatheodorou, TEI of Kentriki Makedonia, Hellas
Nikolaos Klimis, Democritus University of Thrace

Landslide Susceptibility -Some additional Info

Landslide susceptibility is closely related to low shear strength surfaces as :



- Bedding
- Schistocity
- Joints

Recording of the later (joints), requires field work thus…local scale implementation (costs in time and money)

Information regarding the other two parameters, can be digitized from geologic maps (minimal cost)

Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility Mapping

- Create TOBIA index and Classes..
- ..Using the respective SAGA GIS module and..
- …Slope, Aspect, Dip and DipDirection maps

SAGA www.saga-gis.org System for Automated Geoscientific Analyses

Meentemeyer R. K., Moody A. (2000). Automated mapping of conformity between topographic and geological surfaces. Computers & Geosciences, 26, 815 - 829.

Project funded by the EUROPEAN UNION

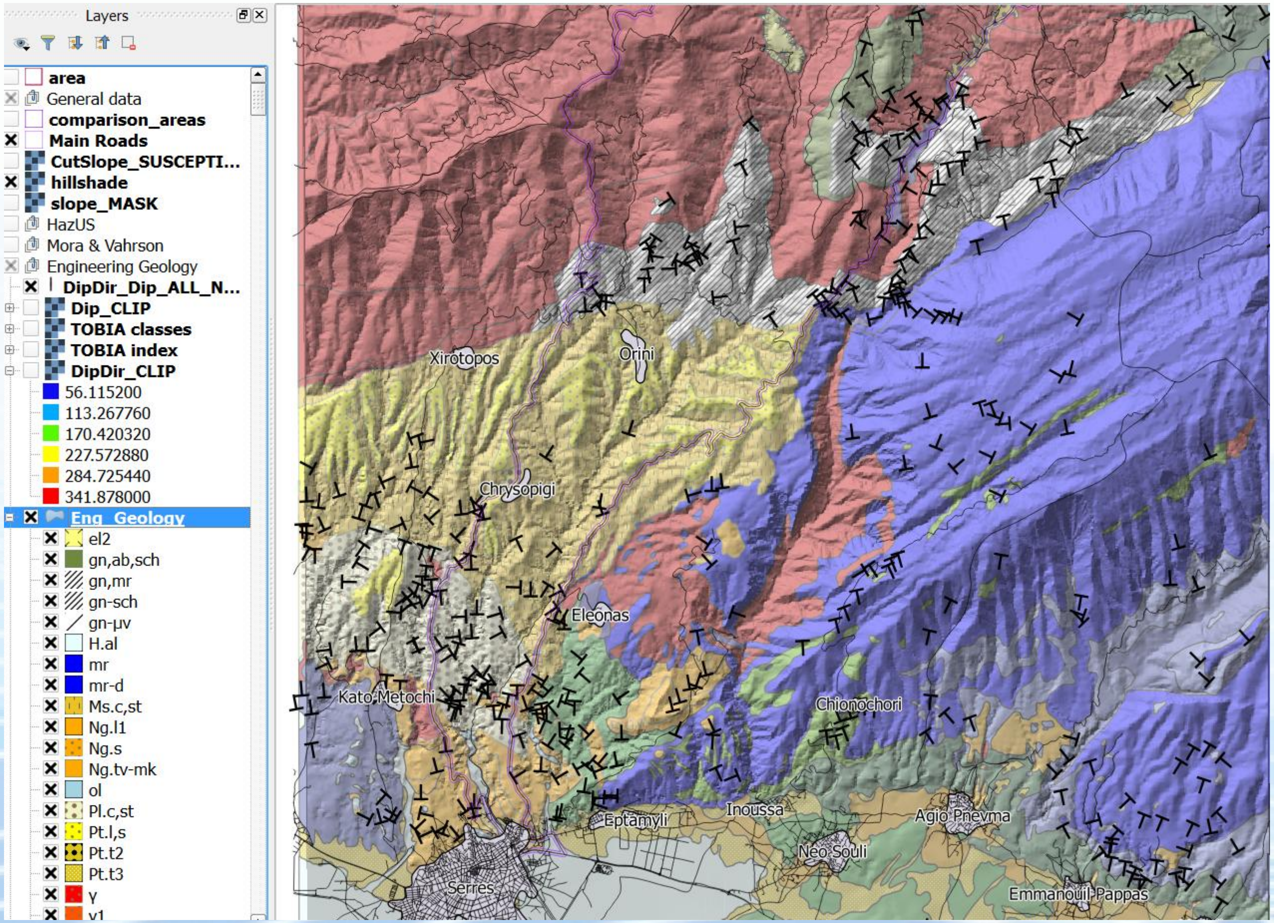
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility Mapping

- Digitize **Bedding** and **Schistocity** orientation (Dip & Dip Direction) from geologic maps



Project funded by the EUROPEAN UNION

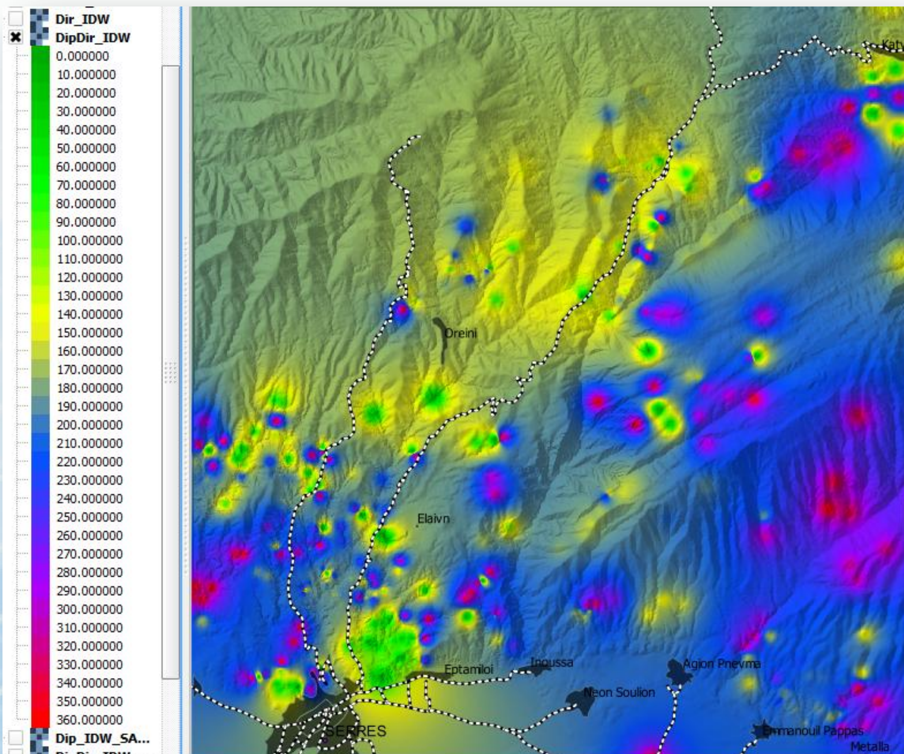
SciNet NatHaz Prevention

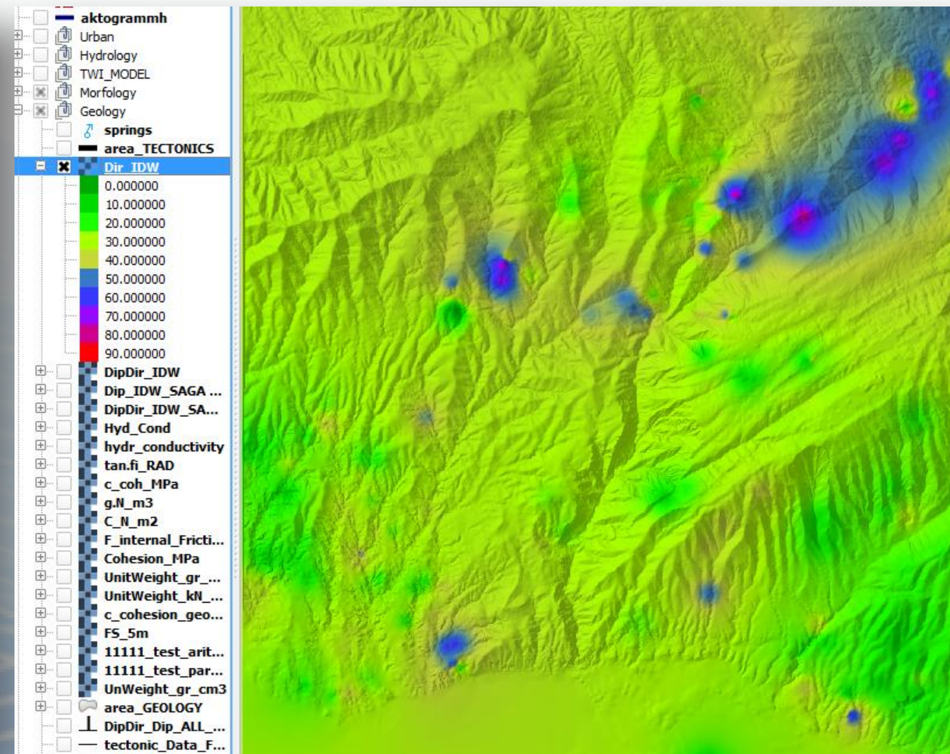
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Susceptibility Mapping

- **Create spatial distribution maps of each parameter** using the IDW method (does not exceed minimum-maximum value limits)





Project funded by the EUROPEAN UNION

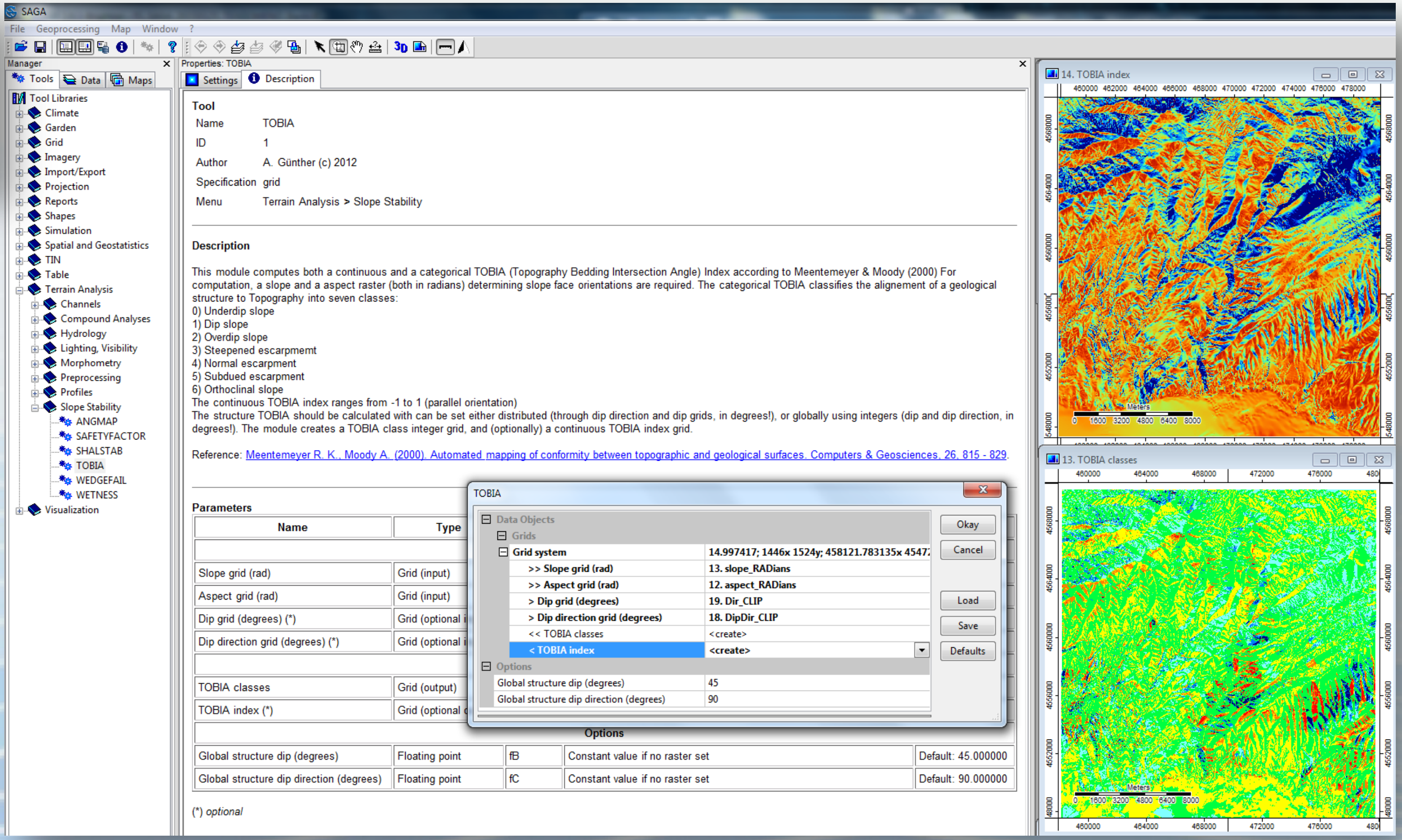
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Use SAGA “TOBIA” module to ….

SAGA www.saga-gis.org System for Automated Geoscientific Analyses



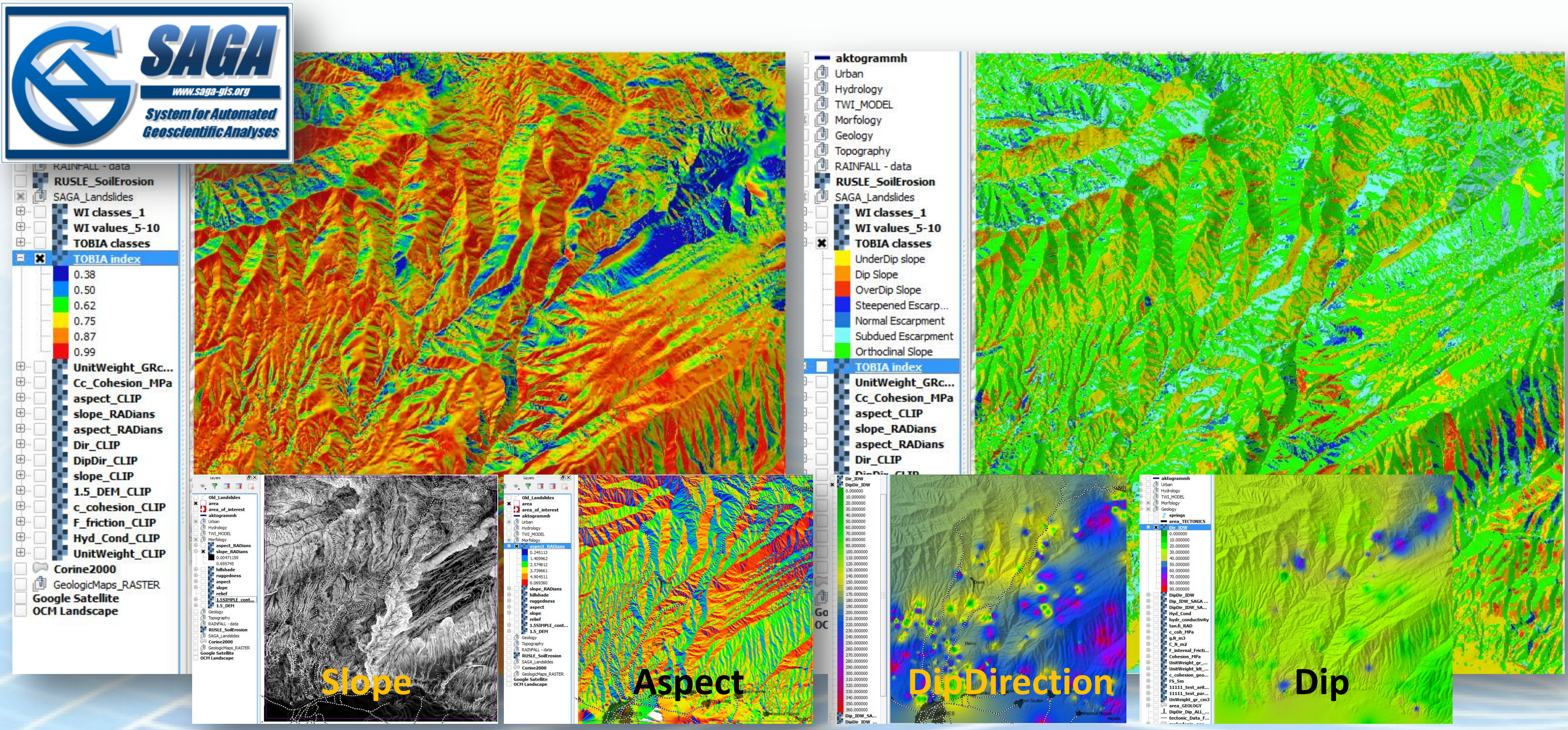
Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

..compare Slope with Dip and Aspect with DipDirection..



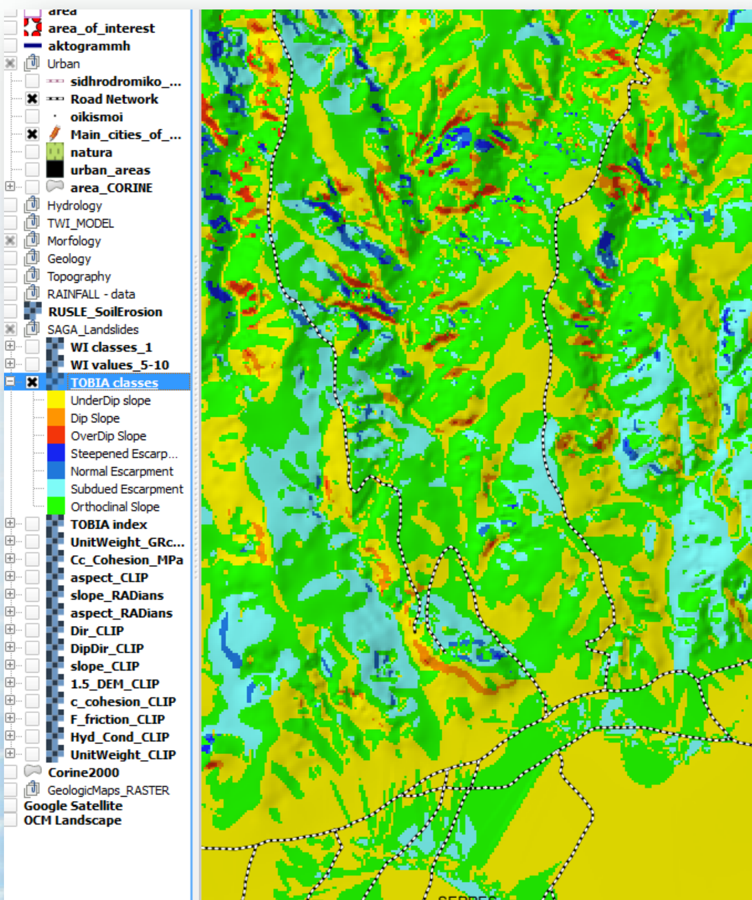
Project funded by the EUROPEAN UNION

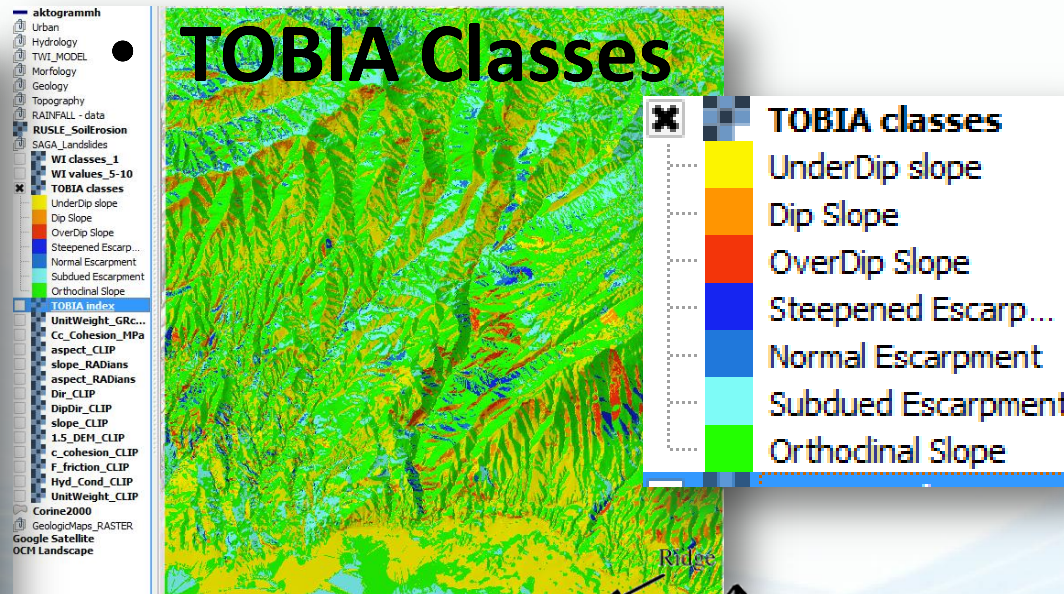
SciNet NatHaz Prevention

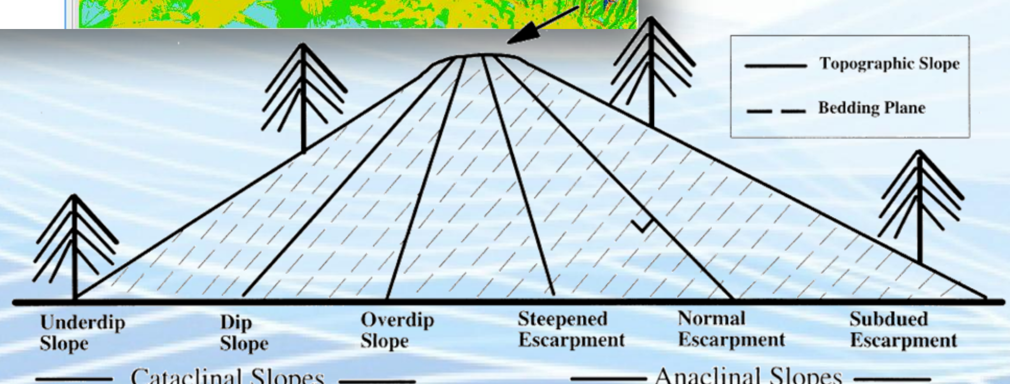
Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

..and create TOBIA Index classes..







Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Hazard Assessment on Regional Scales: Pilot Implementation in Greece

Thank You All for your Attention!

Acknowledgments:
The SciNetNatHaz Project
is partially funded by the EU and Hellenic National funds
within the context of the
Black Sea Basin Joint Operational Programme 2007-2013

K. Papatheodorou, TEI of Kentriki Makedonia, Hellas
Nikolaos Klimis, Democritus University of Thrace