



Common borders. Common solutions.
Common borders. Common solutions.

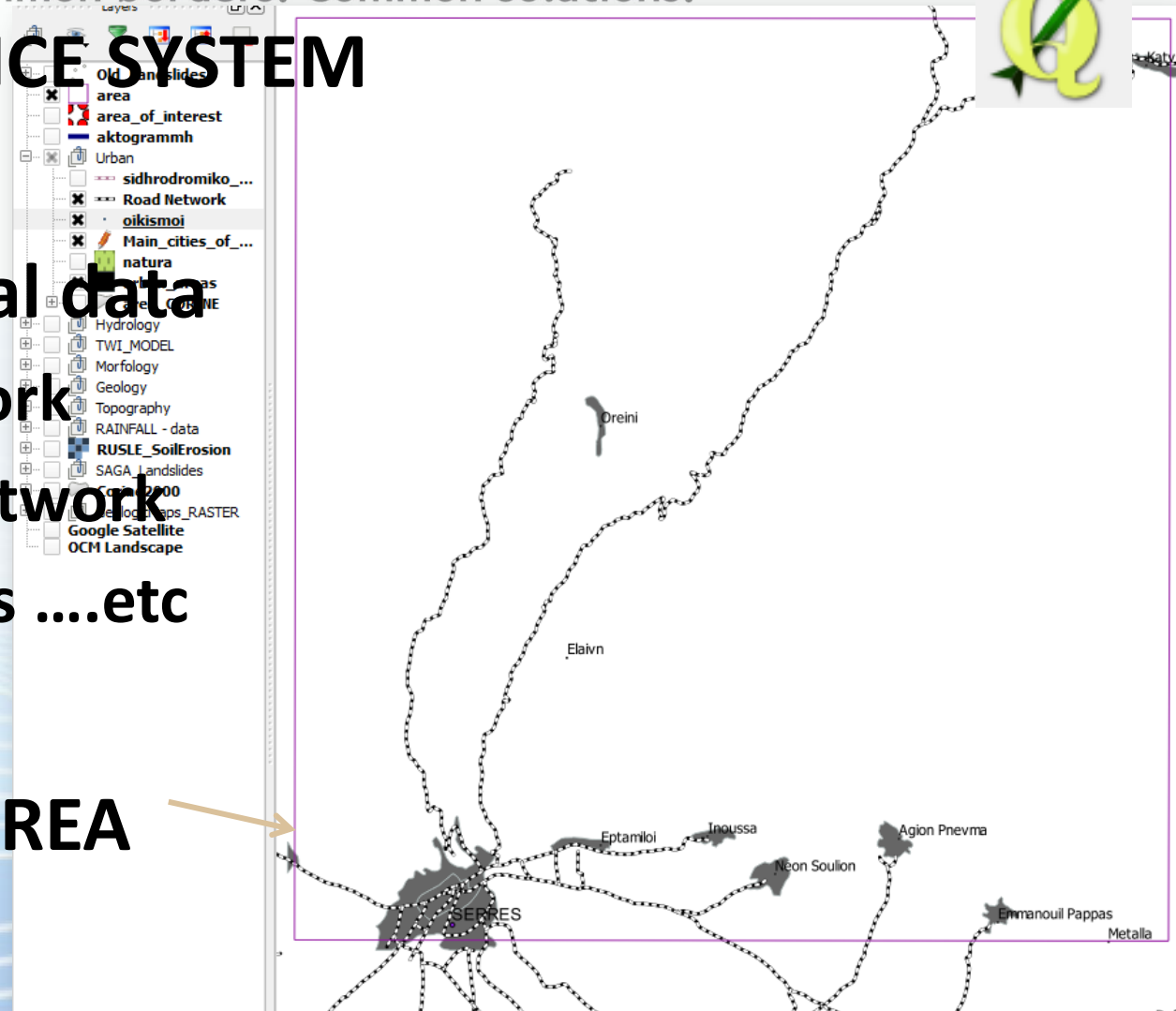
Landslide Hazard Assessment

**A brief presentation of the
SciNetNatHaz adopted approach**
Phase 1. Calculation of Factor of Safety

Konstantinos Papatheodorou, Nikolaos Klimis

Common borders. Common solutions.

- **Set REFERENCE SYSTEM**
- **Input General data**
 - Road network
 - Railroad network
 - Urban areasetc
- **Define the AREA**



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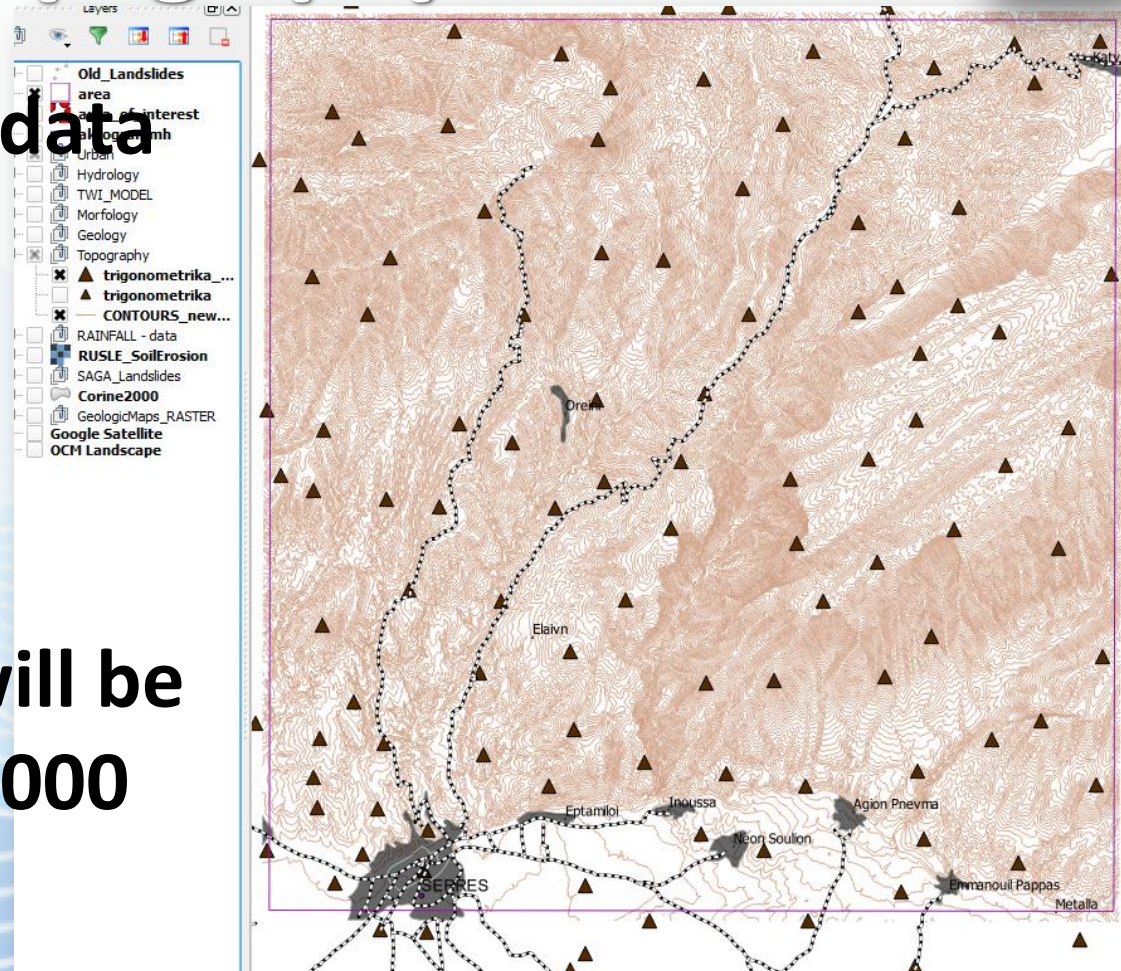
Topography



- **Input topographic data**

- Contour Lines
- Elevation points

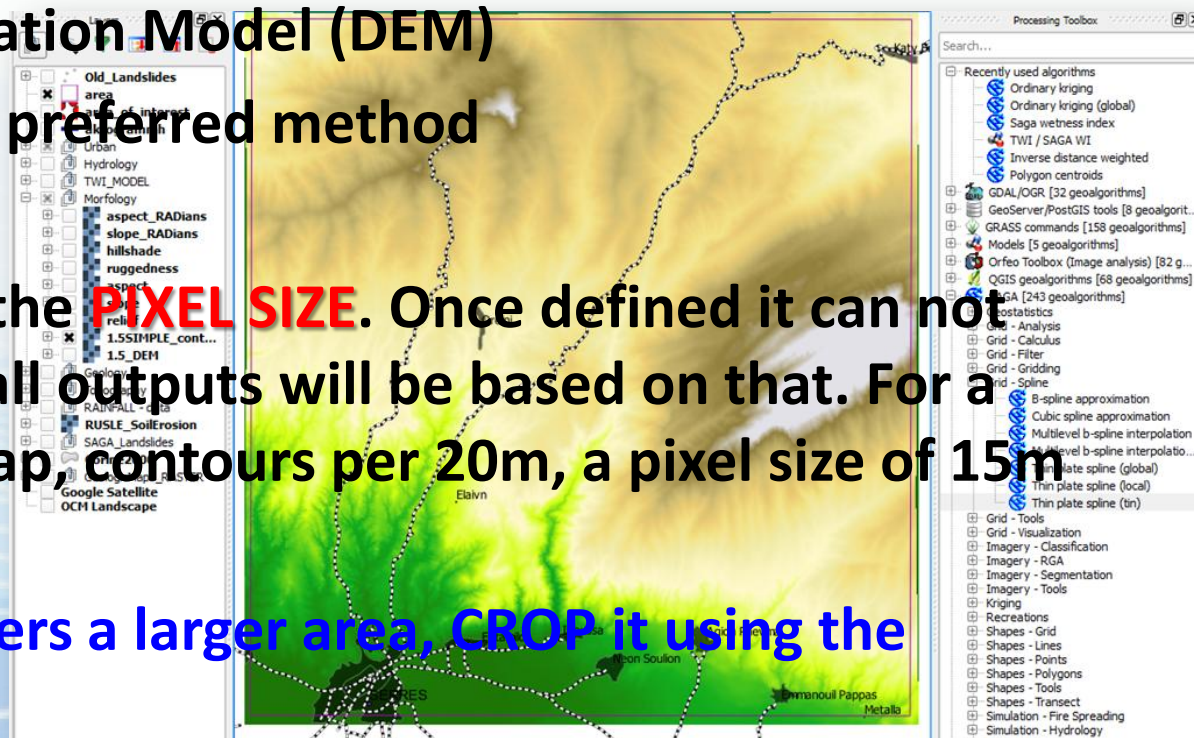
- **Please Note!** We will be working on a 1:50.000 (Regional) scale



Common borders. Common solutions.

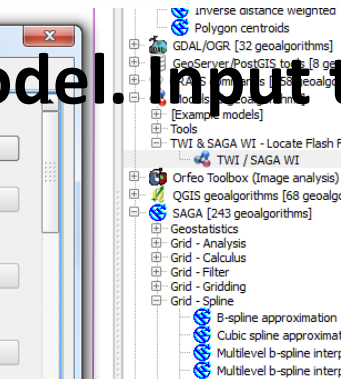
Digital Elevation Model

- 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.

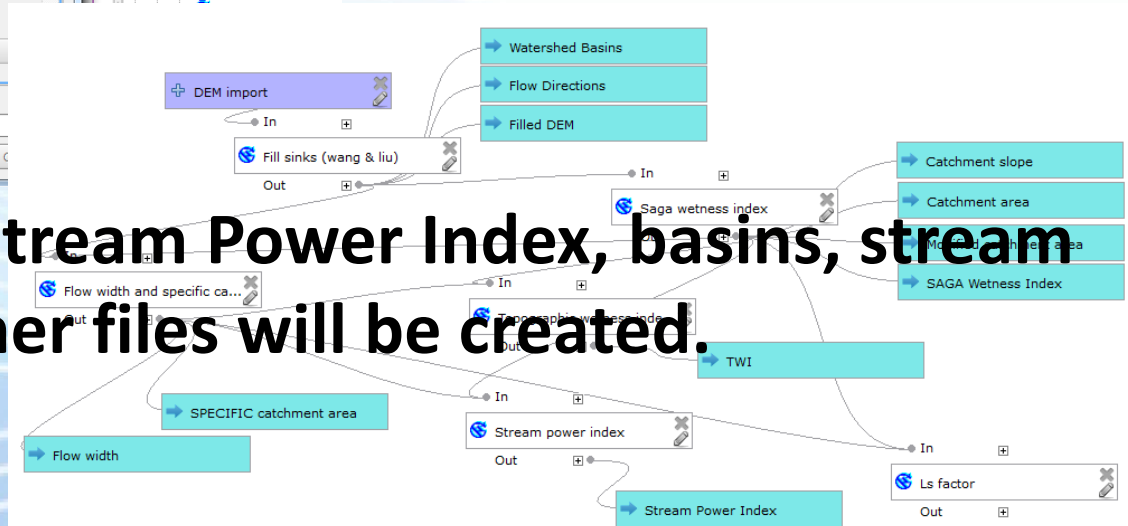


Hydrology- Assessment of Flood prone areas

RUN the TWI model. Input the DEM file



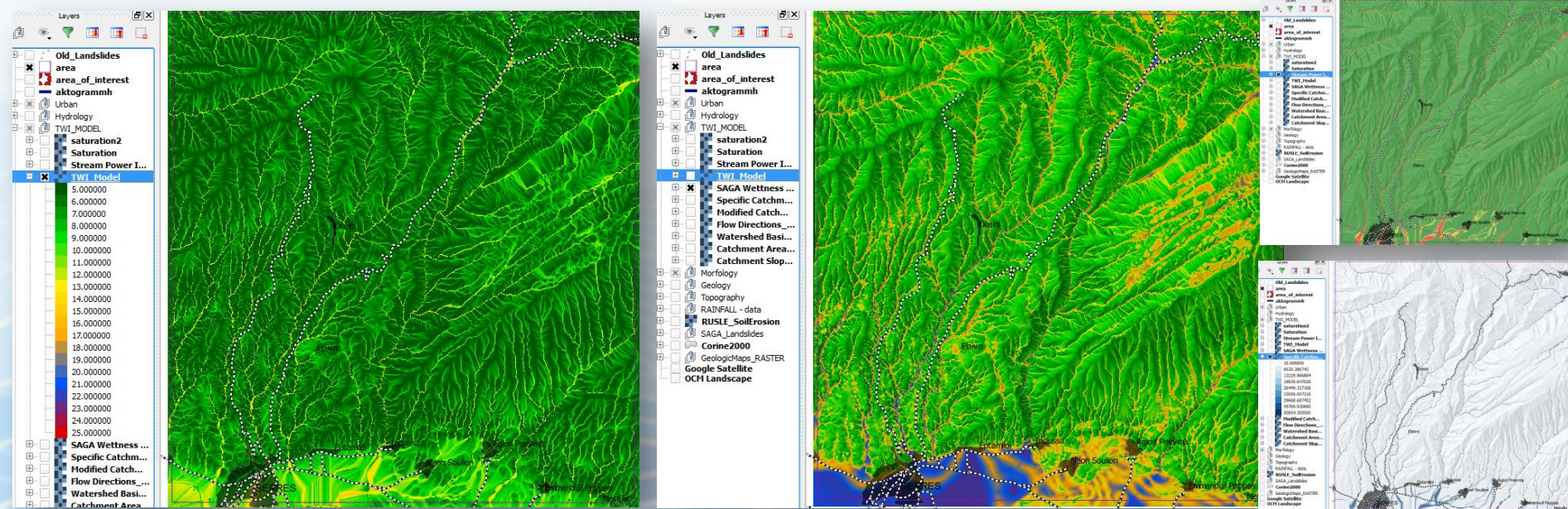
- **TWI, SAGA WI, Stream Power Index, basins, stream network and other files will be created.**



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Indices: TWI, SAGA WI etc

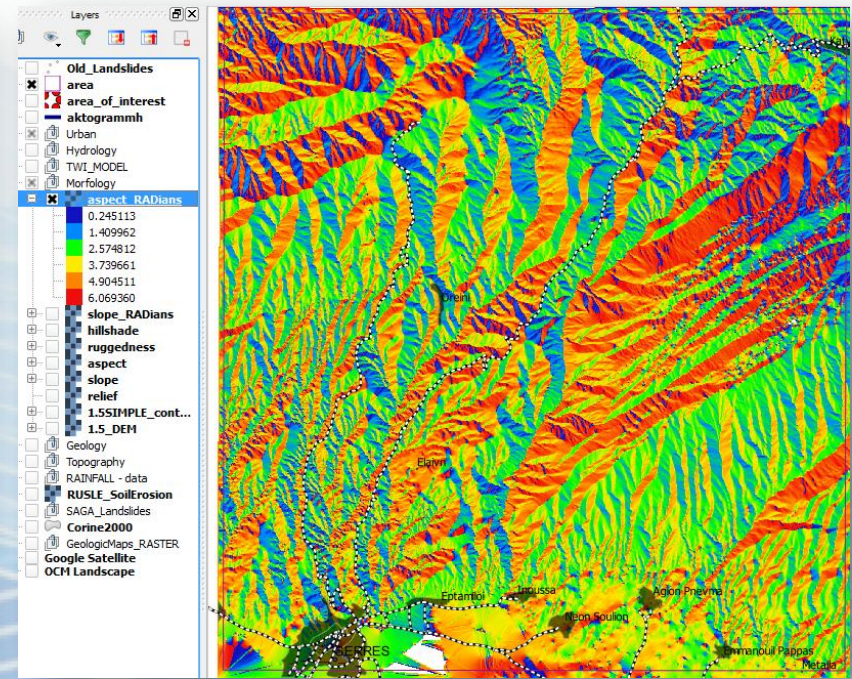
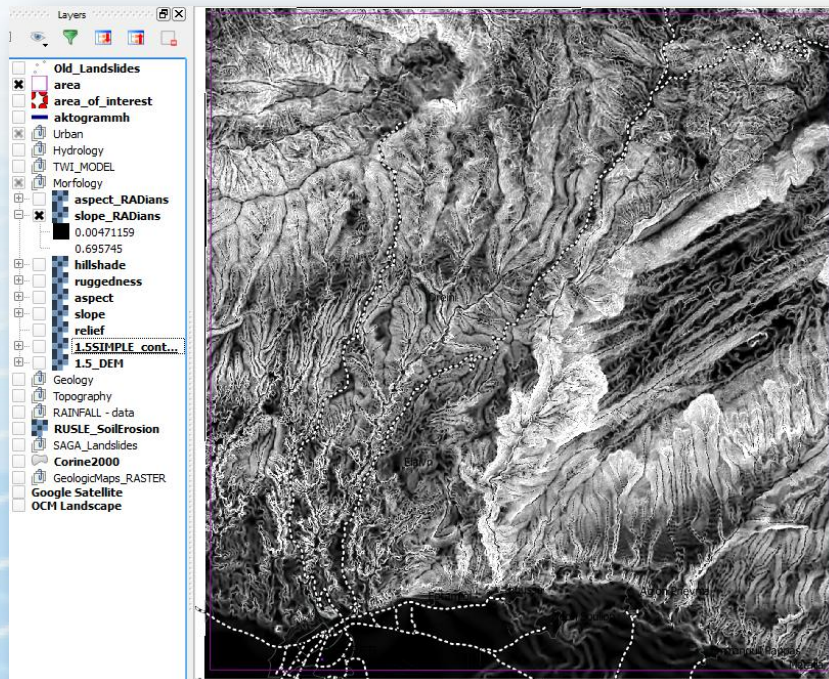
- TWI, SAGA WI, Stream Power Index, basins, stream network and other files created with the model



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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



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Landslide Hazard Assessment

- **Basic Information comes from topographic data (DEM, Slope, Aspect)**
- **Essential Information comes from the Geologic map**
 - **Geologic formations**
 - **Dip and Dip Direction**
 - **c' (effective cohesion), ϕ' (effective friction angle), h (hydraulic conductivity), γ (unit weight) etc**

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Geology – Engineering Geology

- 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-y			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

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Geology – Engineering Geology

- Digitize the Geologic Map

- Assign additional attributes to geologic formation polygons

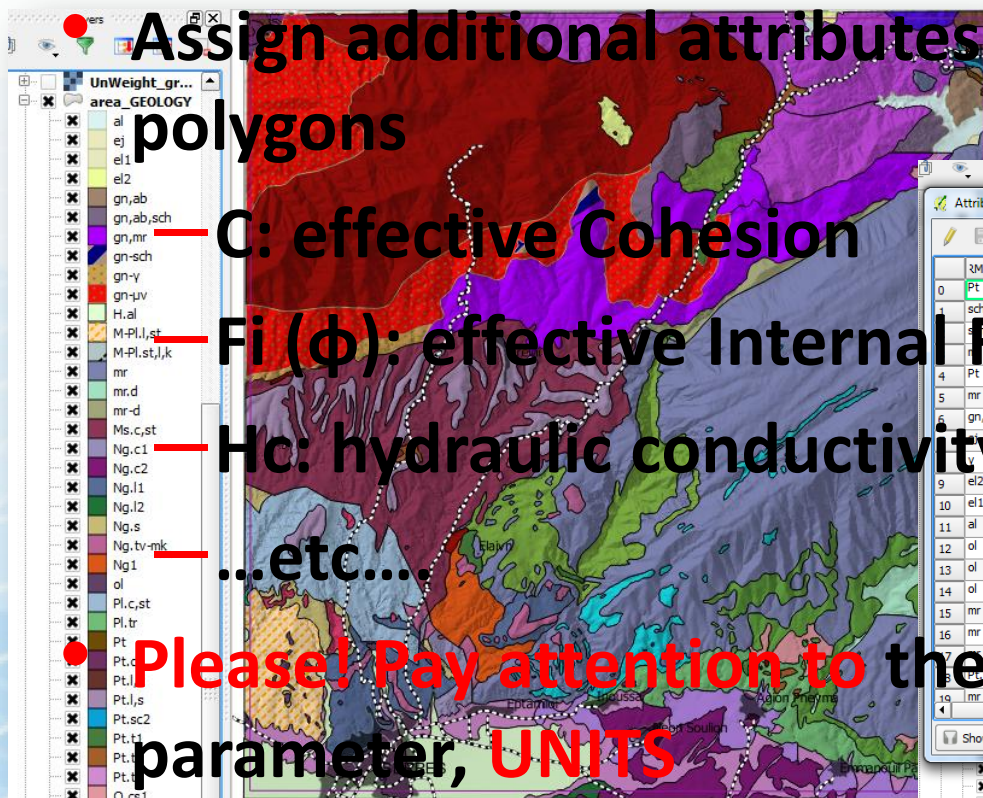
— C: effective Cohesion

— F_i (ϕ): effective Internal Friction angle

— H_c : hydraulic conductivity

— ...etc....

- Please! Pay attention to the respective to each parameter, **UNITS**



Attribute table - area_GEOLOGY :: Features total: 297, filtered: 297, selected: 0

	3M_CC	PERIMETER	AREA	IGME_NAME	DRO_CO	C	ϕ	y	g_kN_m3	Hyd_Conduc	C.N_m2	g.N_m3	fi_RAD	tan.fi_RA
0	Pt	17205.425	2618217.828	Káτω Neu...	121	8	25	1.800	17.658	2.50000	8000.0000	17658.000	0.4363	0.466
1	sch1.gn	281.469	4727.945	Káτω Neu...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	0.382
2	sch1.gn	281.469	4727.945	Káτω Neu...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	0.382
3	sch1.gn	281.469	4727.945	Káτω Neu...	413	30	21	2.700	26.487	1.50000	30000.0000	26487.000	0.3665	0.382
4	Pt	4470.918	250013.883	Káτω Neu...	31	8	25	1.800	17.658	2.50000	8000.0000	17658.000	0.4363	0.466
5	mr	466.214	9410.828	Káτω Neu...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
6	gn,ab	1183.697	73727.187	Káτω Neu...	413	59	35	2.700	26.487	2.50000	59000.0000	26487.000	0.6109	0.700
7	mr	1197.833	82850.883	Káτω Neu...	311	0	38	1.800	17.658	4.00000	0.0000	17658.000	0.6632	0.781
8	mr	20709.849	25583317.827	Axλαδοx...	222	53	34	2.650	25.997	3.00000	53000.0000	25997.000	0.5934	0.674
9	el1	8317.077	1707235.767	Axλαδοx...	42	5	38	1.800	17.658	4.00000	5000.0000	17658.000	0.6632	0.781
10	el1	2211.929	181100.154	Axλαδοx...	42	5	32	1.800	17.658	4.00000	5000.0000	17658.000	0.5585	0.624
11	al	5339.410	349796.514	Axλαδοx...	311	5	28	1.800	17.658	2.70000	5000.0000	17658.000	0.4887	0.531
12	ol	548.239	17449.036	Axλαδοx...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
13	ol	825.987	28115.140	Axλαδοx...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
14	ol	2333.586	146100.504	Axλαδοx...	321	32	19	2.300	22.563	1.50000	32000.0000	22563.000	0.3316	0.344
15	mr	2134.190	285691.607	Axλαδοx...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
16	mr	644.204	23543.455	Axλαδοx...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
17	mr	644.204	23543.455	Axλαδοx...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
18	mr	644.204	23543.455	Axλαδοx...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600
19	mr	455.823	11108.927	Axλαδοx...	323	94	31	2.700	26.487	4.00000	94000.0000	26487.000	0.5411	0.600

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Factor of Safety – Calculate Parameters

Ε40												
1	Εισαγωγή δεδομένων											
2												
3	gn,ab		gn,ab,sch		gn,mr		gn-sch		gn-y			
4	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m	H=5m	H=50m
5	sigci (Mpa)	100	100	100	100	100	100	100	100	100	120	120
6	GSI	30	30	31	31	30	30	29	29	31	31	31
7	mi	23	23	23	23	12	12	10	10	10	26	26
8	D	1	1	1	1	1	1	1	1	1	1	1
9	Ei	40000	40000	30000	30000	85000	85000	30000	30000	48000	48000	48000
10	MR	400	400	300	300	850	850	300	300	400	400	400
11	Hoek Brown Criterion											
12	mb	0.15497	0.15497	0.16645	0.16645	0.08086	0.08086	0.06273	0.06273	0.18816	0.18816	0.18816
13	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
14	a	0.52234	0.52234	0.52089	0.52089	0.52234	0.52234	0.52390	0.52390	0.52089	0.52089	0.52089
15	Failure Envelope Range											
16	Application	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes	Slopes
17	sig3max (Mpa)	0.12892	1.04787	0.12946	1.05227	0.12066	0.98074	0.12344	1.00331	0.13236	1.07000	1.07000
18	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
19	Slope Height (m)	5	50	5	50	5	50	5	50	5	50	50
20	Mohr-Coulomb Fit											
21	c (Mpa)	0.0587	0.2299	0.0616	0.2391	0.0530	0.1798	0.0500	0.1653	0.0685	0.2299	0.2299
22	phi (degrees)	51.6	35.1	52.3	35.9	46.3	29.9	43.6	27.4	54.4	38.1	38.1
23	Rock Mass Parameters											
24	sigt (Mpa)	-0.0055	-0.0055	-0.0061	-0.0061	-0.0106	-0.0106	-0.0116	-0.0116	-0.0065	-0.0065	-0.0065
25	sigc (Mpa)	0.2256	0.2256	0.2503	0.2503	0.2256	0.2256	0.2031	0.2031	0.3004	0.3004	0.3004
26	sigcm (Mpa)	4.5577	4.5577	4.7751	4.7751	3.2471	3.2471	2.8123	2.8123	6.1073	6.1073	6.1073
27	Erm (Mpa)	1128.98	1128.98	869.793	869.793	2399.08	2399.08	825.615	825.615	1391.67	1391.67	1391.67
28												
29												
30	Αποτελέσματα											
31	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)
32	5	51.61	58.71	5	52.30	61.65	5	46.31	52.98	5	54.40	58.71
33	50	35.14	229.90	50	35.88	239.11	50	29.90	179.85	50	38.10	229.90
34												
35	ΤΕΛΙΚΕΣ ΤΙΜΕΣ	φ	c (kPa)	φ	c (kPa)	φ	c (kPa)	φ	c (kPa)	φ	c (kPa)	φ
36		35	59	36	62	30	53	27	50	27	50	3
37												
38												

aktogrammi

Urban

Hydrology

TWI_MODEL

Morfology

Geology

springs

area_TECTONICS

Dir_IDW

DipDir_IDW

Dip_IDW_SAGA...

Hyd_Cond

hydr_conductivity

tan.fi_RAD

c_coh_MPa

q.N_m3

C_H_m2

0.000000

23376.600000

46753.200000

70129.800000

93506.400000

116883.000000

F_internal_Frict...

Cohesion_MPa

UnitWeight_gr...

UnitWeight_kN...

c_cohesion_geo...

FS_5m

11111_test_arit...

11111_test_par...

UnWeight_gr_cm...

area_GEOLOGY

DipDir_Dip_ALL...

tectonic_Data_F...

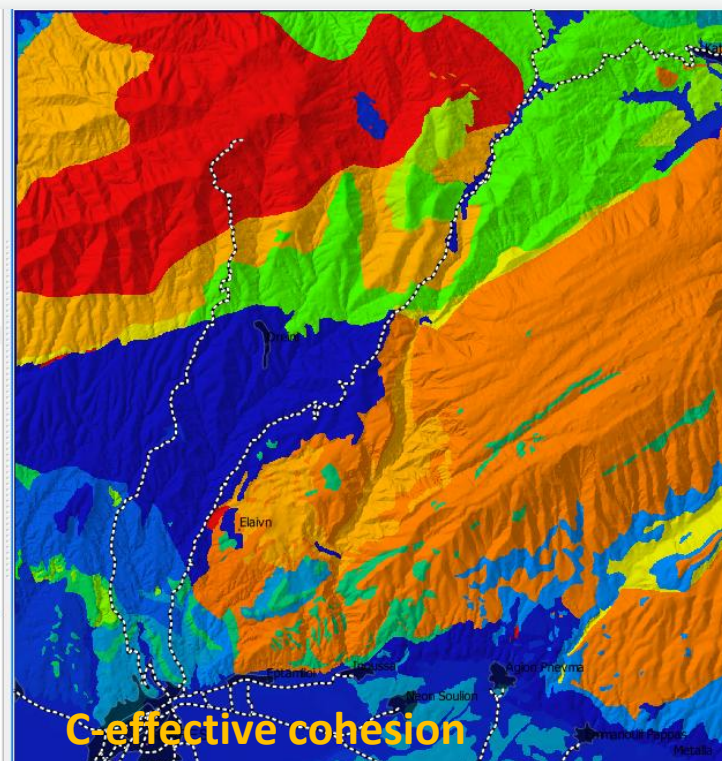
makedonia_geo...

Topography

RAINFALL - data

RUSLE_SoilErosion

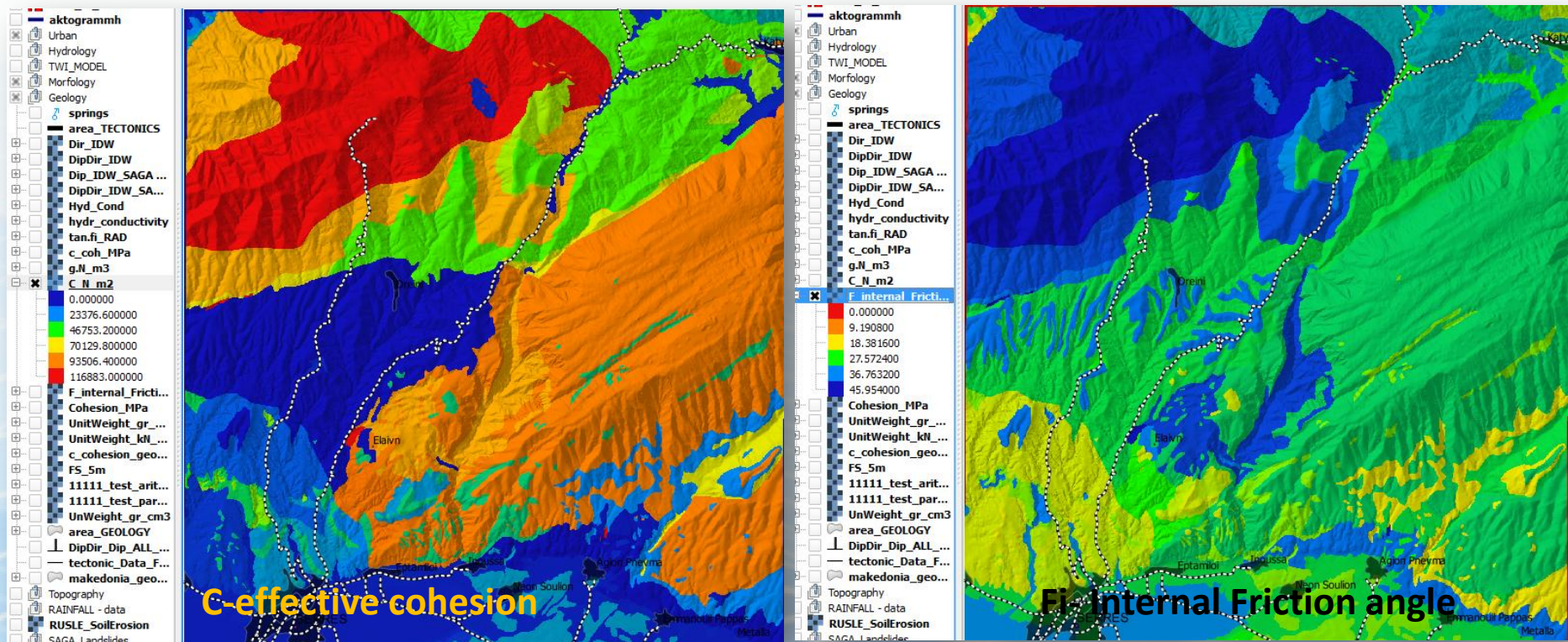
SAGA_Landslides



- c' & ϕ' calculation (left)
- Effective cohesion map (right)

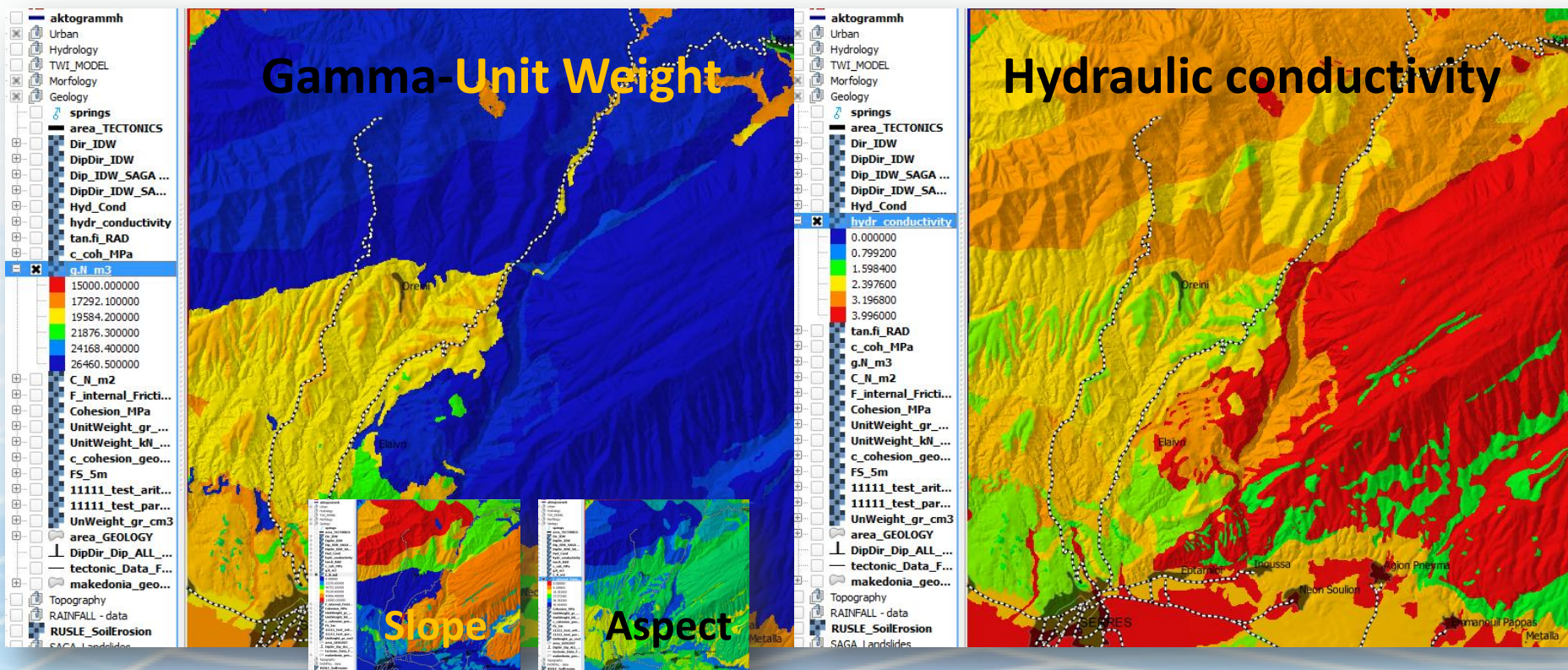


Geology – Engineering Geology



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Geology – Engineering Geology



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Saturation percentage

The screenshot displays the SAGA GIS software interface. The 'Tool Libraries' pane on the left shows the 'Slope Stability' category selected. The 'Properties: WETNESS' dialog box is open, showing the tool's name, ID, author, and a detailed description. The 'Description' text explains that the module calculates a topographic wetness index (TWI) following Montgomery & Dietrich (1994). The 'References' section lists the source of the algorithm. The 'Data Objects' pane shows the 'Grid system' with various input and output grids. The 'Options' pane shows the 'Min global material depth (m)' set to 5. The 'Map' window on the right shows a map of the study area with a color-coded saturation percentage (SP) overlay.

References:

Montgomery, D.R., Dietrich, W.E. (1994) A physically based model for the topographic control on shallow landsliding. *Water Resources Research*, 30, 1153-1171.

Input Data:

Name	Type	Identifier	Description	Constraints
DEM	Grid (input)	DEM	A DEM	
Min hydraulic conductivity grid (m/hr)	Grid (optional input)	Cmin	A grid representing minimum material hydraulic conductivity (m/hr)	
Max hydraulic conductivity grid (m/hr)	Grid (optional input)	Cmax	A grid representing maximum material hydraulic conductivity (m/hr)	

Output Data:

Name	Type	Identifier	Description	Constraints
24. WI values	Grid	24. WI values	Topographic Wetness Index (TWI) values	

Options:

- Min global material conductivity (m/hr): 2.7000000000000002
- Max global material conductivity (m/hr): 2.7000000000000002
- Min global groundwater recharge (m/hr): 0.001
- Max global groundwater recharge (m/hr): 0.001
- Min global material depth (m): 5
- Max global material depth (m): 10

Map: The map shows the study area with a color-coded saturation percentage (SP) overlay. The color scale ranges from 0 (blue) to 100 (red). The map is titled '24. WI values'.

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

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Saturation percentage parameters

Parameters taken into consideration

- Upslope Contribution (flow accumulation)
- Slope
- Hydraulic conductivity
- A combination of Rainfall and effective infiltration (GW recharge)
- Sliding mass thickness

WETNESS

☐ Data Objects

☐ Grids

☐ Grid system

>> DEM	14.997417; 1446x 1524y; 458121.783135x 454729.
> Min hydraulic conductivity grid (m/h)	16. 1-5_DEM_CLIP
> Max hydraulic conductivity grid (m/h)	21. Hyd_Cond_CLIP
> Min groundwater recharge grid (m/hr)	<not set>
> Max groundwater recharge grid (m/hr)	<not set>
> Min material depth grid (m)	<not set>
> Max material depth grid (m)	<not set>
<< WI values	<create>
< WI classes	<not set>

☐ Options

Min global material conductivity (m/hr)	2.7000000000000002
Max global material conductivity (m/hr)	2.7000000000000002
Min global groundwater recharge (m/hr)	0.001
Max global groundwater recharge (m/hr)	0.001
Min global material depth (m)	5
Max global material depth (m)	10
Parameter sampling runs	1
Catchment Area Calculation	Multiple Flow Direction
Preprocessing	<input type="checkbox"/>

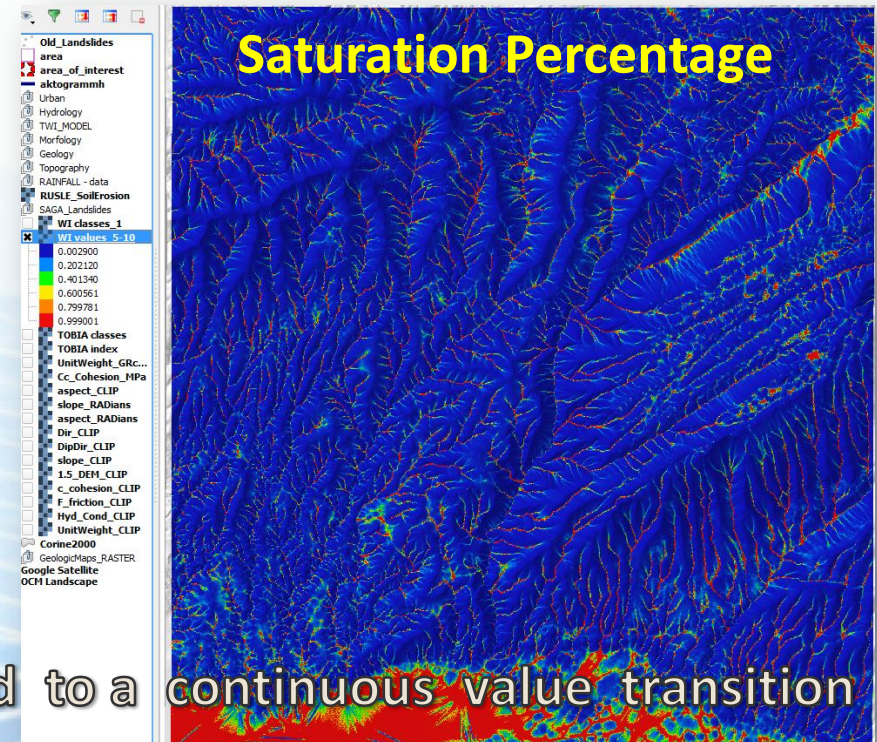
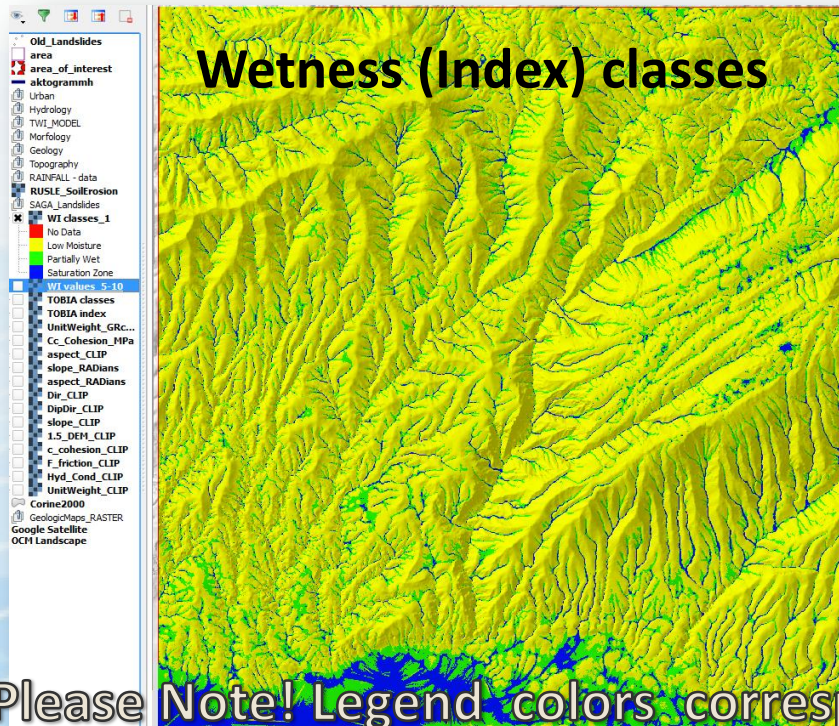


Project funded by the
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Saturation percentage



Please Note! Legend colors correspond to a continuous value transition

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Landslide HA – Susceptibility mapping

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

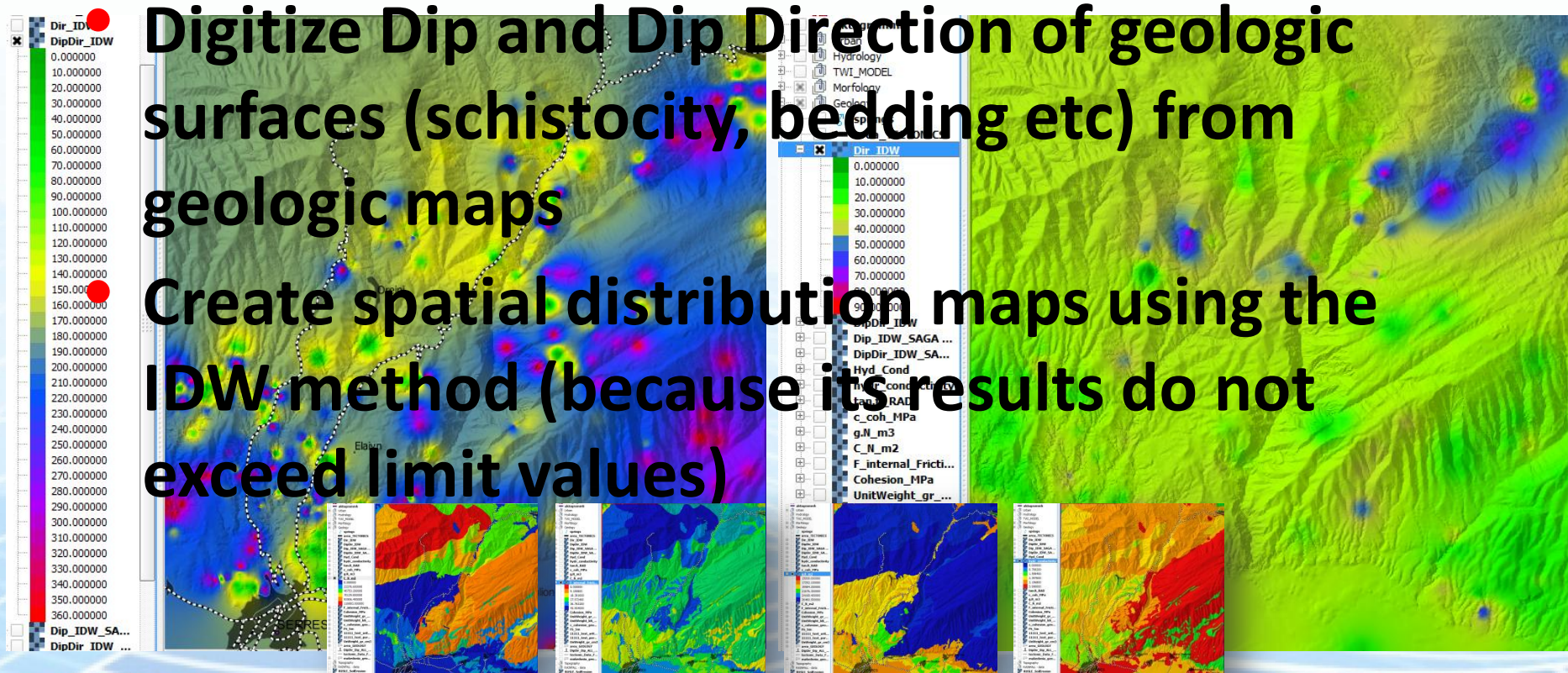
Meentemeyer R. K., Moody A. (2000). Automated mapping of conformity between topographic and geological surfaces. Computers & Geosciences, 26, 815 - 829.

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Dip and Dip Direction of geologic surfaces

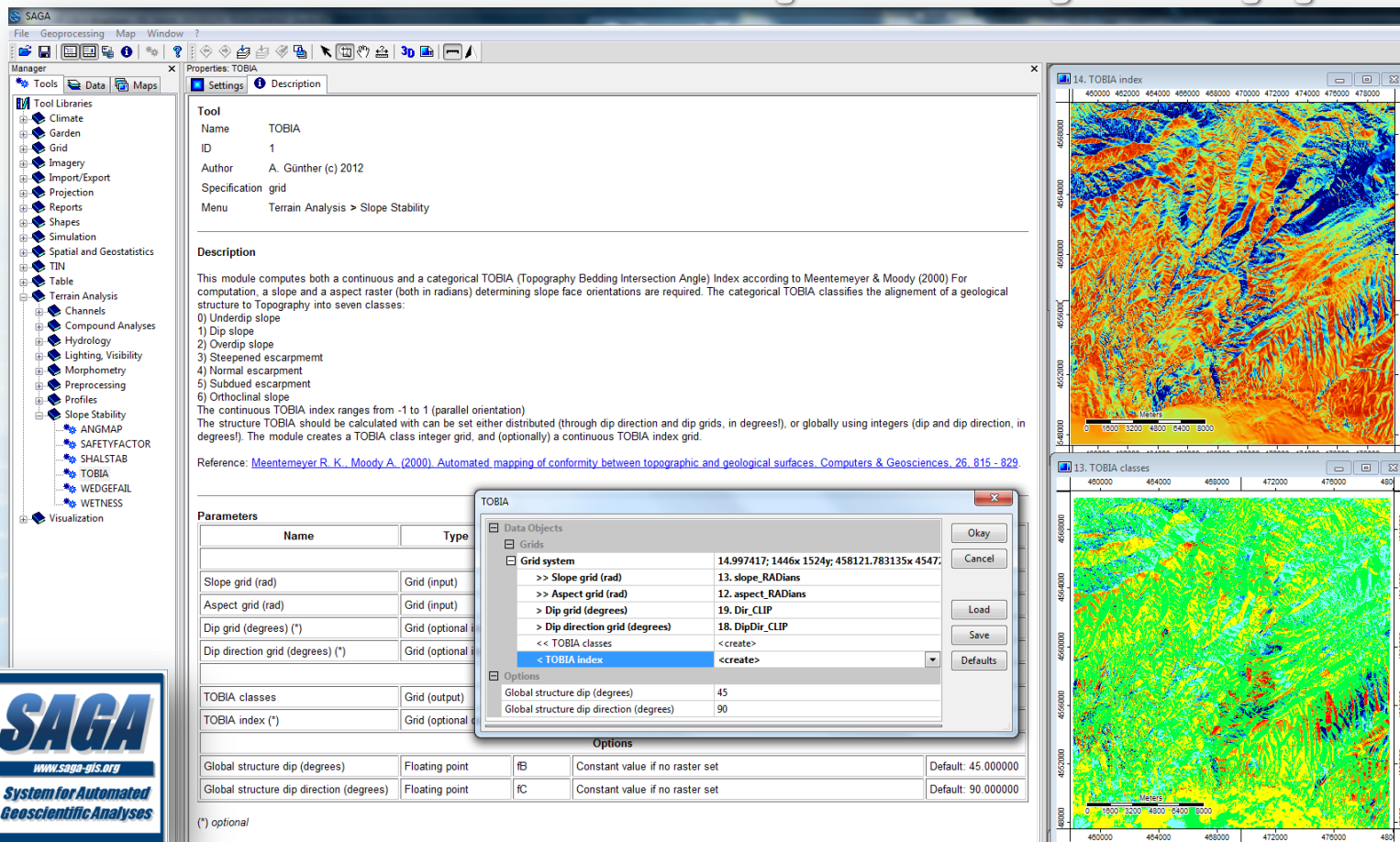
Digitize Dip and Dip Direction of geologic surfaces (schistosity, bedding etc) from geologic maps

Create spatial distribution maps using the IDW method (because its results do not exceed limit values)



Common borders. Common solutions.

Landslide HA - Susceptibility mapping



The screenshot displays the SAGA GIS software interface. The main window shows the 'Properties: TOBIA' dialog box, which includes a 'Settings' tab and a 'Description' tab. The 'Settings' tab is active, showing the 'TOBIA' tool configuration. The 'Description' tab provides a detailed explanation of the TOBIA (Topography Bedding Intersection Angle) Index, including its purpose, calculation methods, and reference to Meentemeyer & Moody (2000).

The 'Parameters' section of the 'Settings' tab lists the following inputs and outputs:

Name	Type
Slope grid (rad)	Grid (input)
Aspect grid (rad)	Grid (input)
Dip grid (degrees) (*)	Grid (optional)
Dip direction grid (degrees) (*)	Grid (optional)
TOBIA classes	Grid (output)
TOBIA index (*)	Grid (optional)

The 'TOBIA' dialog box also includes a 'Data Objects' section with a list of grids and a 'Grid system' section with a list of grid systems. The 'Options' section at the bottom of the dialog box includes the following settings:

Options	Value	Default
Global structure dip (degrees)	45	45.000000
Global structure dip direction (degrees)	90	90.000000

On the right side of the interface, two maps are displayed. The top map, titled '14. TOBIA index', shows a color-coded map of the TOBIA index values. The bottom map, titled '13. TOBIA classes', shows a color-coded map of the TOBIA classes. Both maps include a scale bar and a coordinate system.

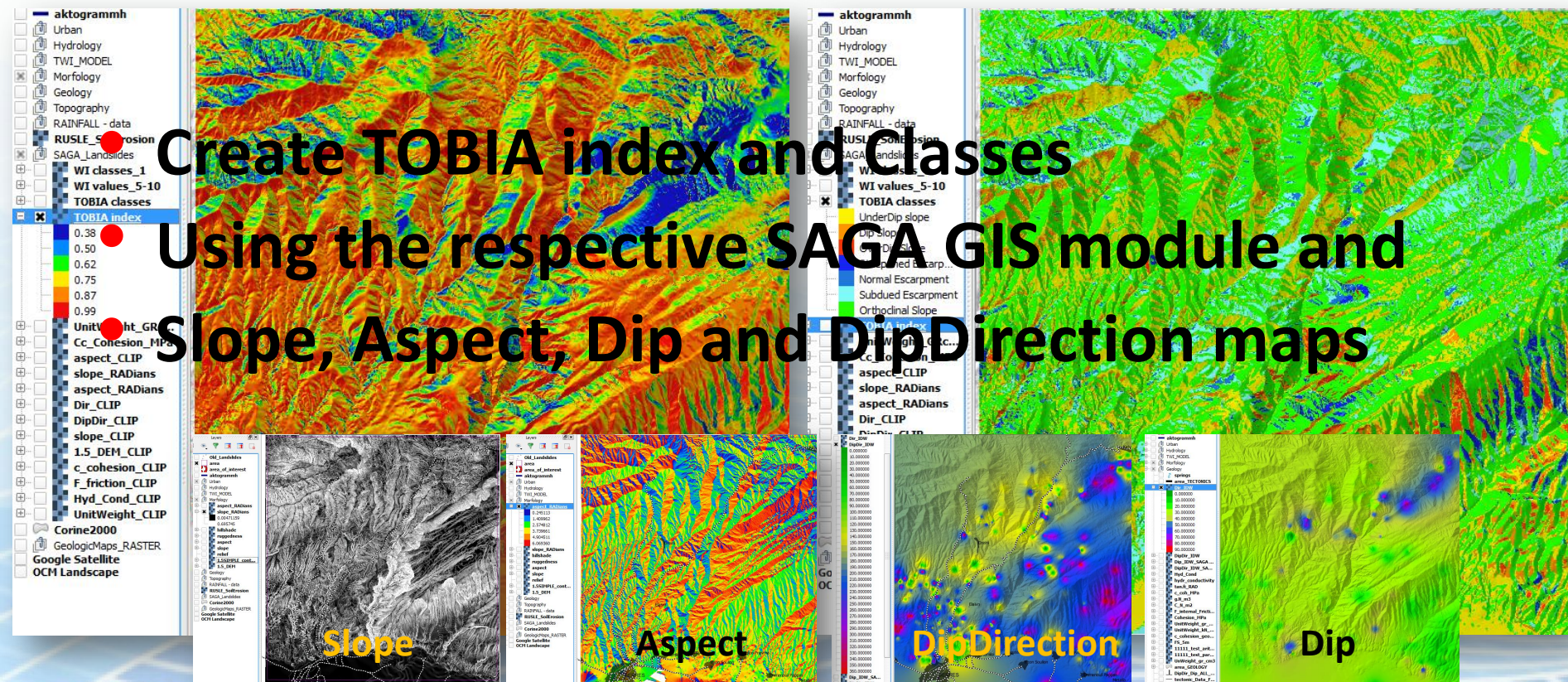
Common borders. Common solutions.

Landslide Susceptibility

Create TOBIA index and Classes

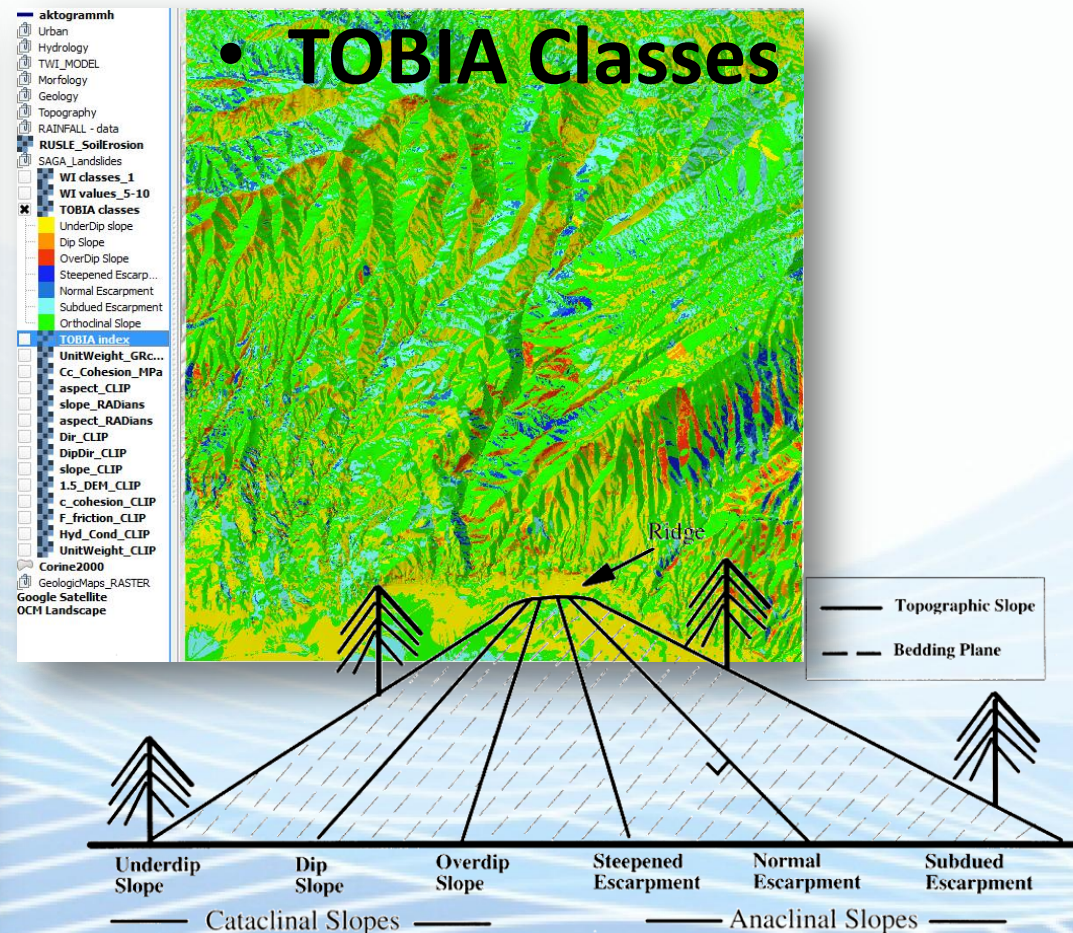
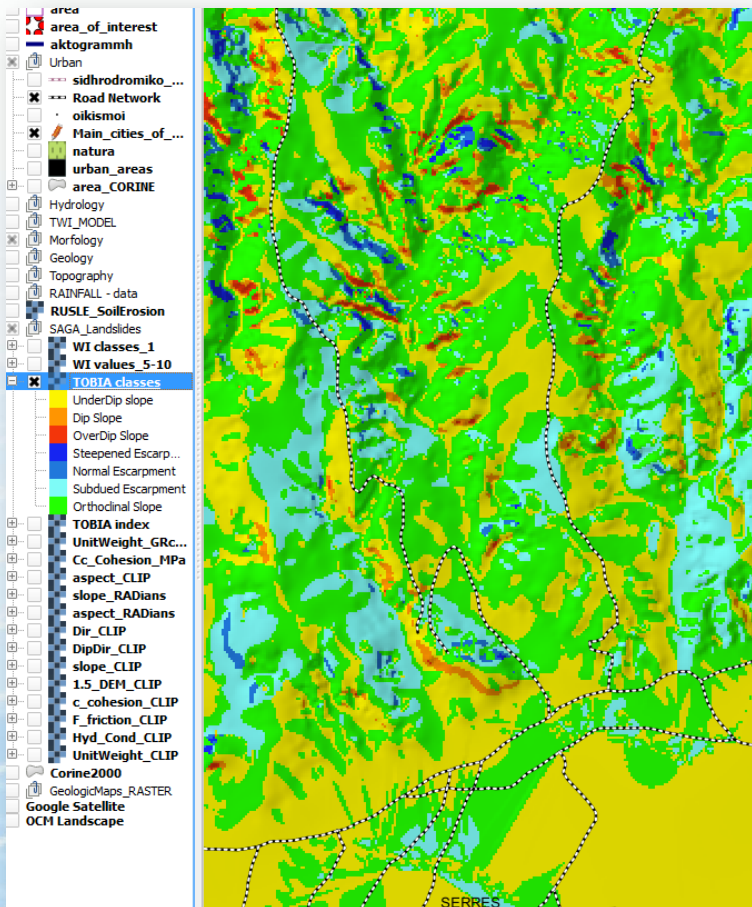
Using the respective SAGA GIS module and

Slope, Aspect, Dip and Dip Direction maps



Common borders. Common solutions.

Landslide Susceptibility – TOBIA classes



Common borders. Common solutions.

Landslide HA – Factor of Safety

- Calculate Factor of Safety (FS) – water – 5m thick sliding mass*

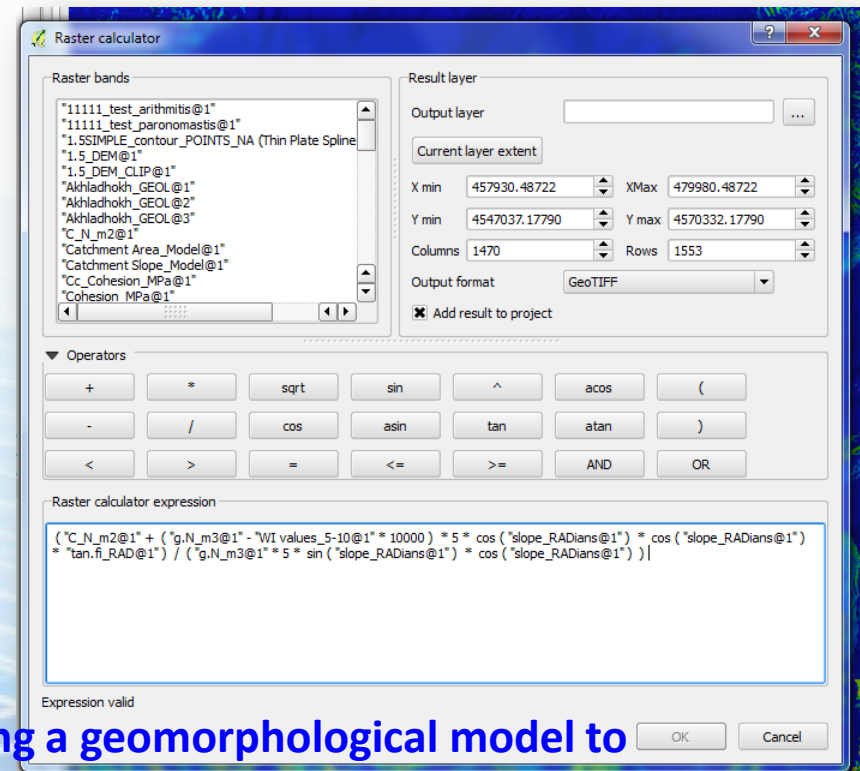
$$F = \frac{c' + (\gamma - m\gamma_w) z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$

in which:

- c' = effective cohesion (Pa= N/m²).
- γ = unit weight of soil (N/m³).
- m = z_w/z (dimensionless).
- γ_w = unit weight of water (N/m³).
- 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



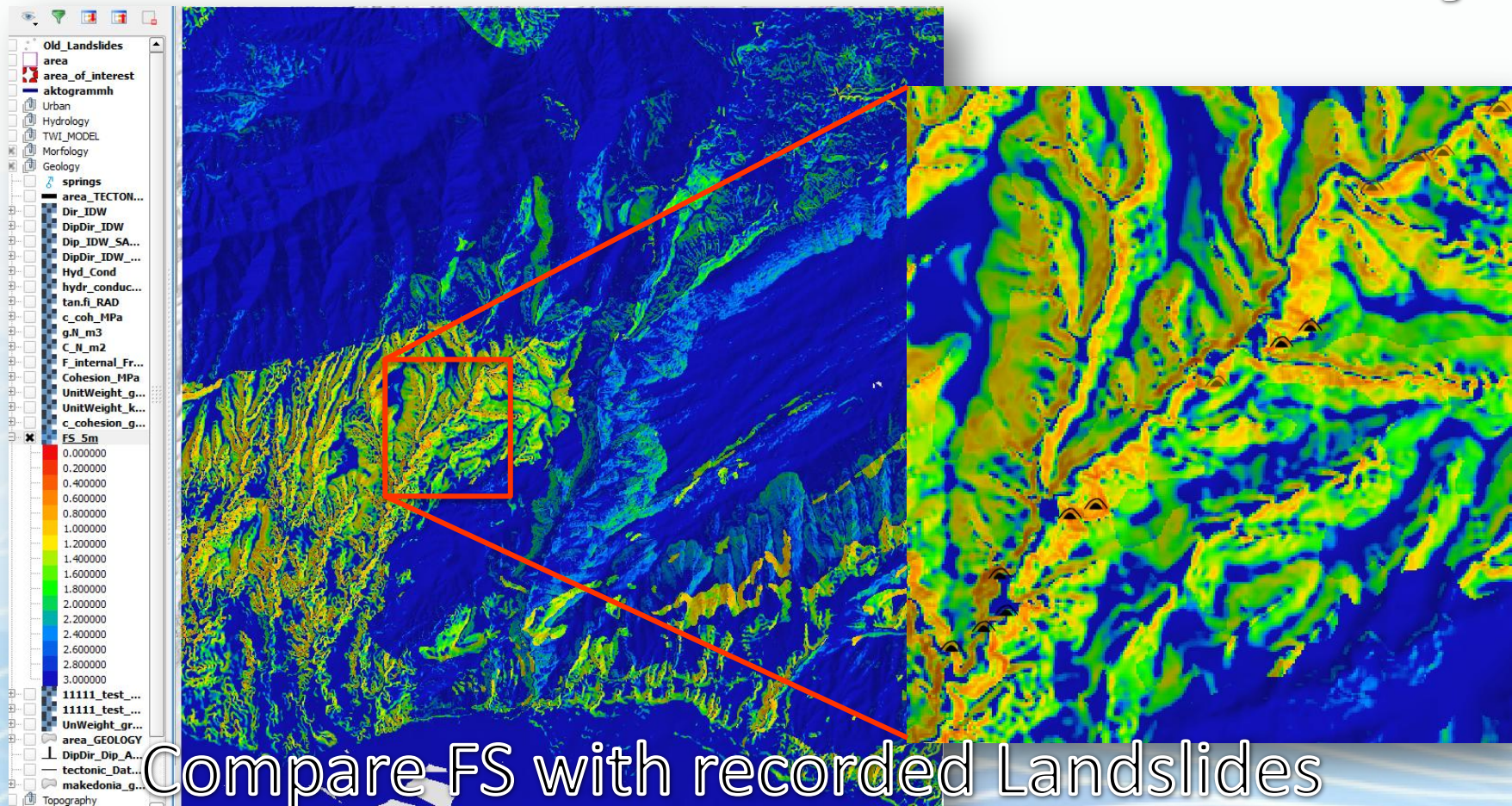


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Landslide HA – Factor of Safety



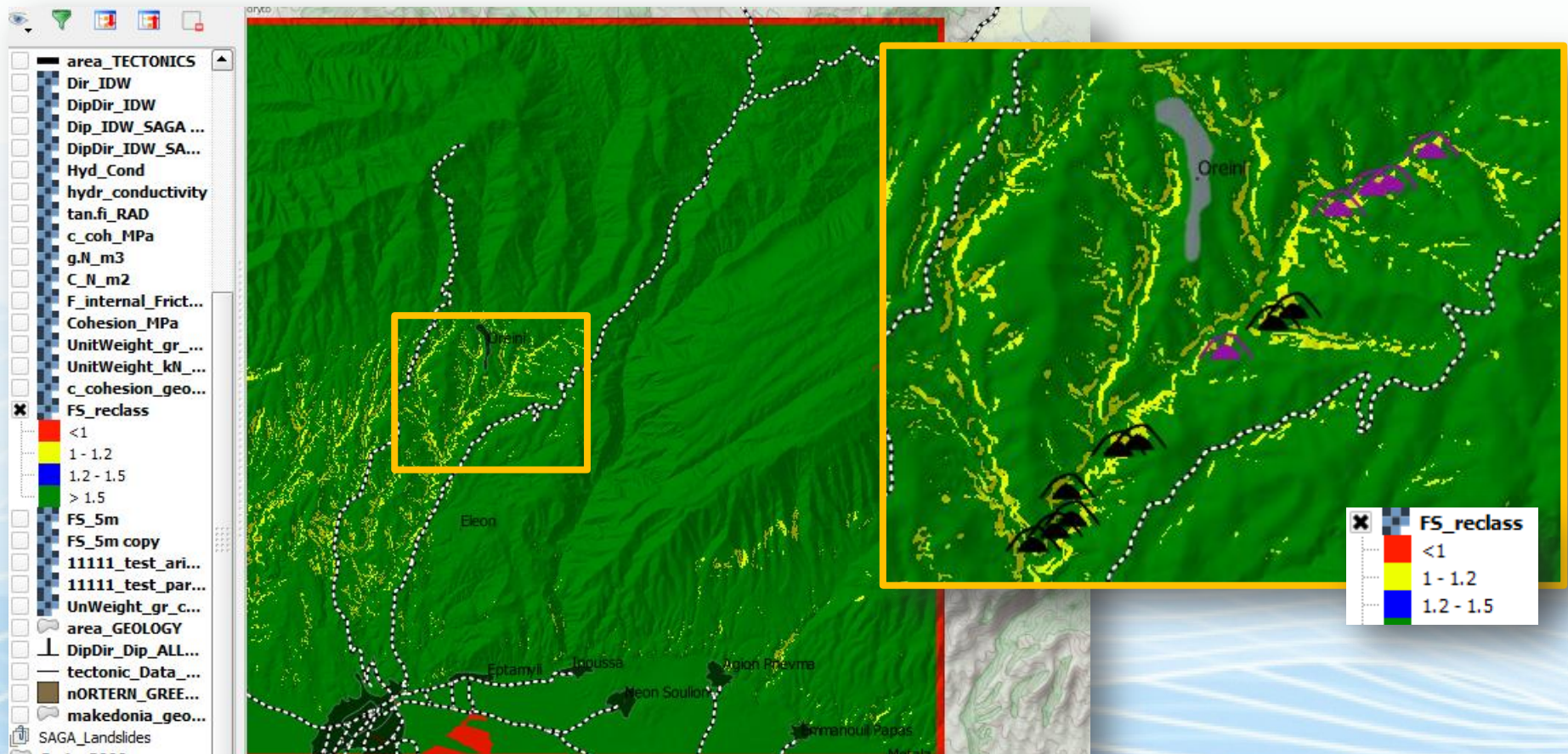


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Landslide Hazard ...FS on Regional Scales





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Landslide HA – Factor of Safety





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