Early Warning Systems for Landslides in the urban area of Rome (Italy): an integrated approach

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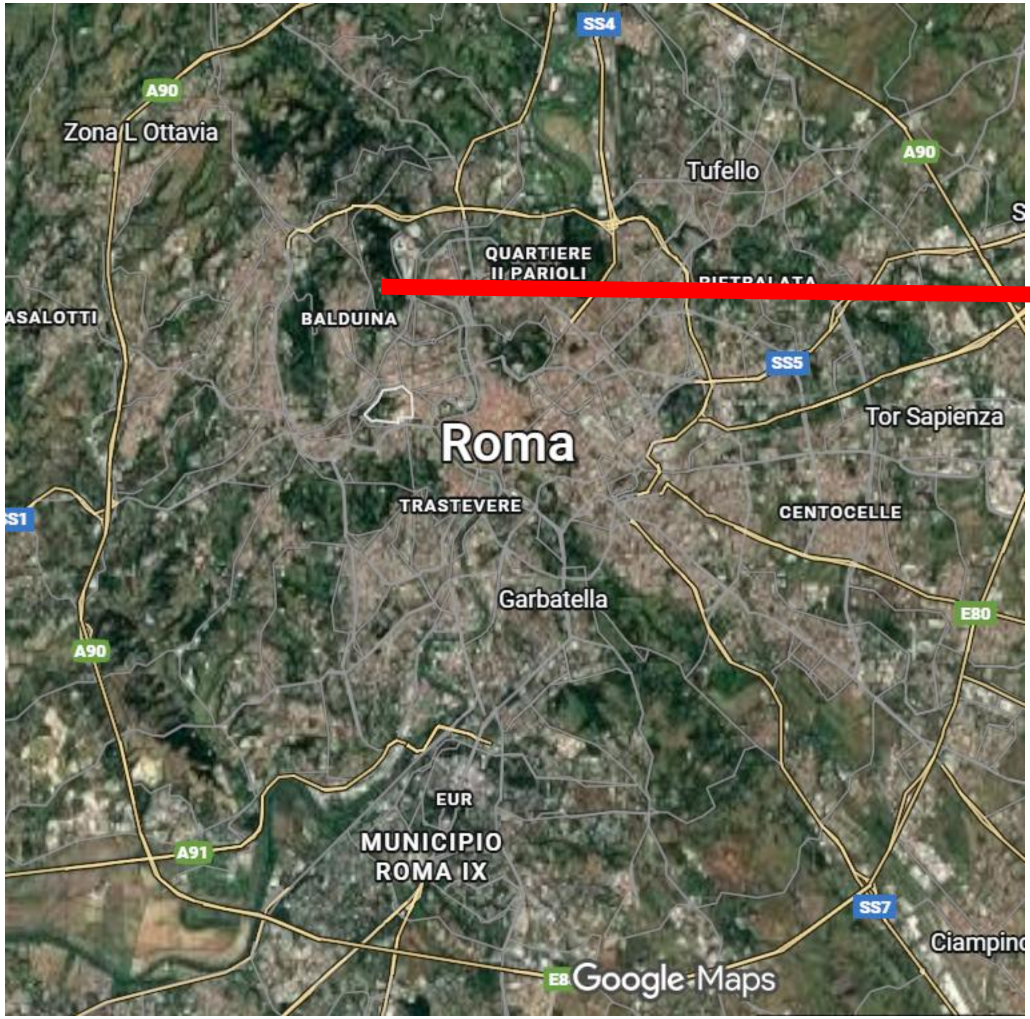
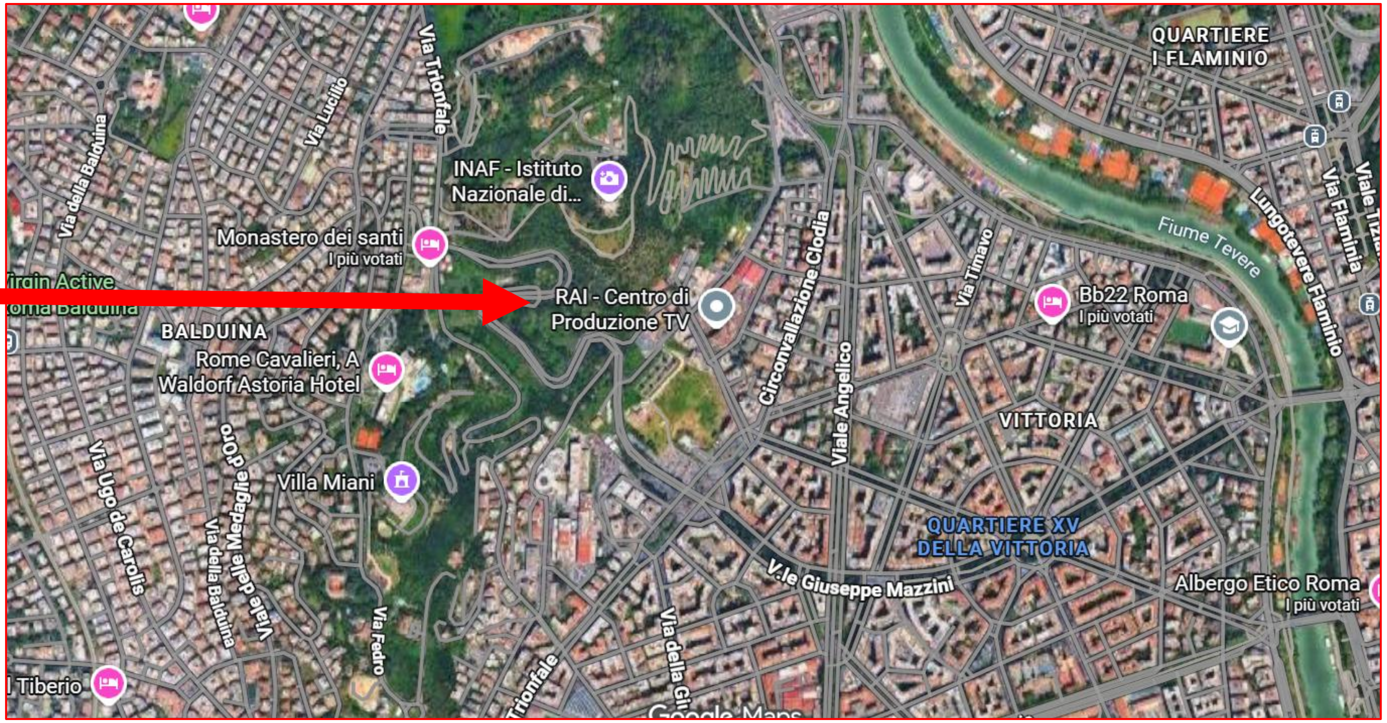
ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

The site





Rome Municipality:

2.8 Millions inhabitants (end of 2023)

2133 inhabitants / km^2 : average population density

9000 inhabitants / km^2 peak population density in the most populated neighbourhoods

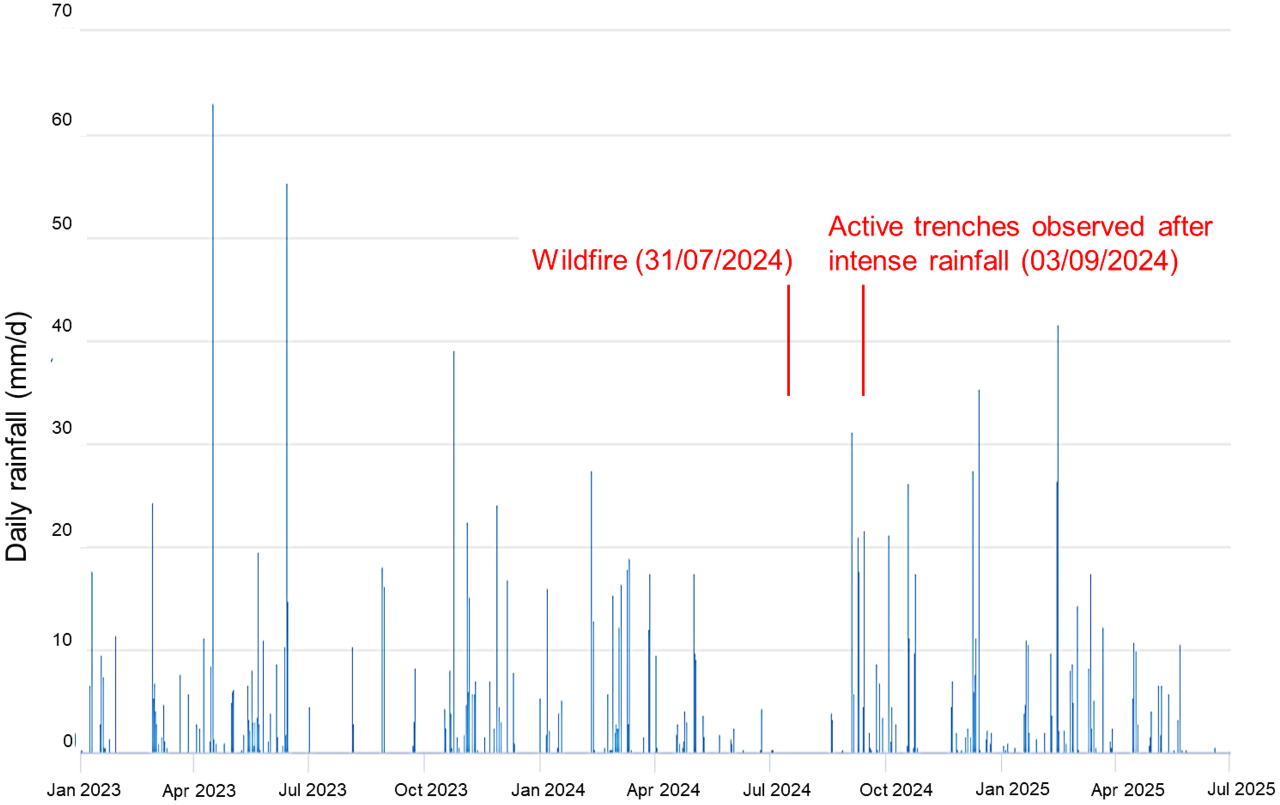
The site

La Repubblica

Redazione Confinelive

- Severe and persistent **wildfire** (on July 31st, 2024), covering an area of about **12 hectares.**
- **Mt. Mario Regional Protected Urban Park affected.**
- **Burnt vegetation species:** *Holm Oak (tree), Cork Oak (tree) and Cistus (shrub).*

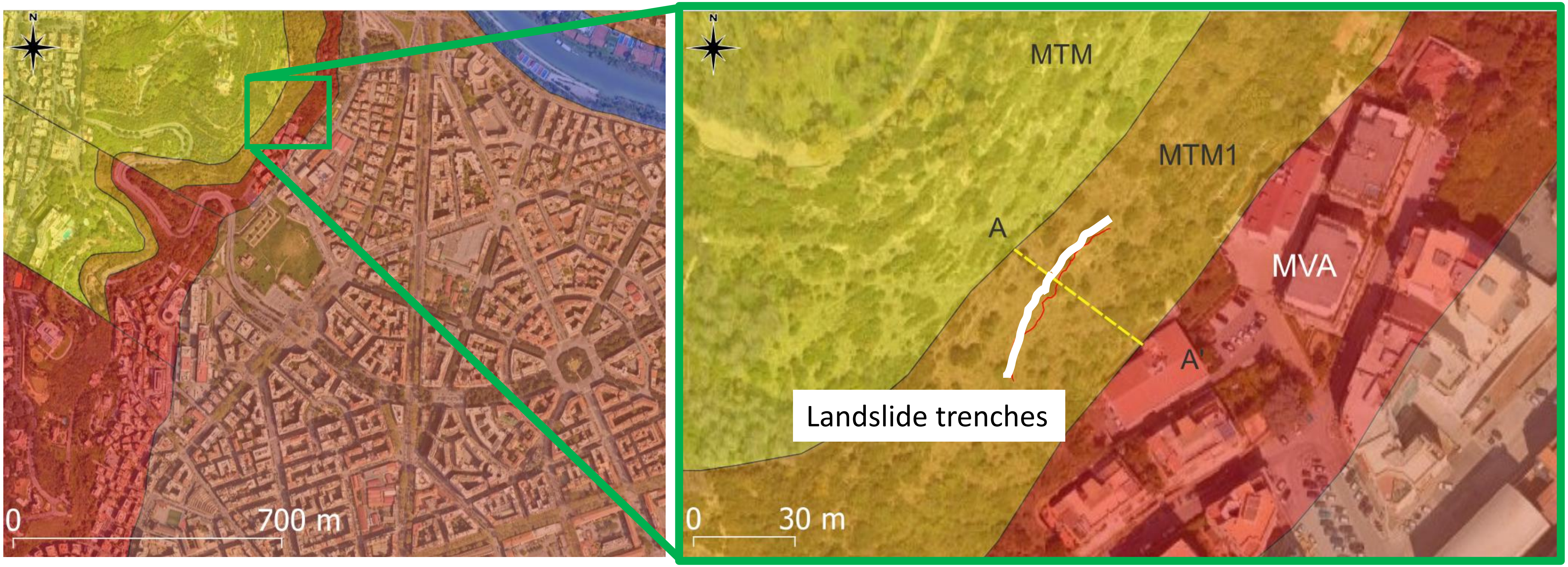
The site



- Following the **fire event** and **intense rainfall events**, on September 03rd, 2024, **landslide trenches and scarps** were observed on the slope
- An agreement between ISPRA and the Civil Protection Department of Rome Municipality has been set to carry out a geotechnical characterization of the site and monitoring for **Early Warning** purposes

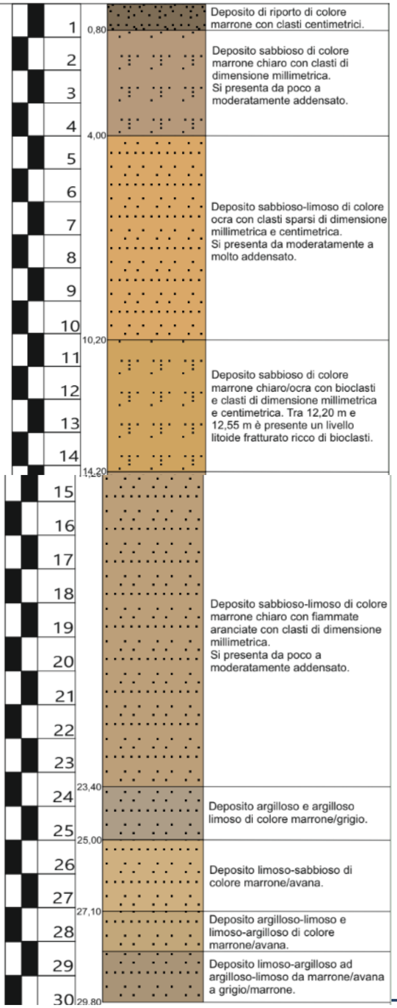
The geology

Foglio 374 – “Roma” – Geological map 1:50000, ISPRA



- MVA, at the base of the slope, stands for Monte Vaticano formation (layered marly clays).
- MTM1 is the Monte Mario formation – Farneto member (sandy silt). **Landslide trenches and scarps observed in this formation**
- On the top of the slope, MTM is reported (Monte Mario formation, silty sands).

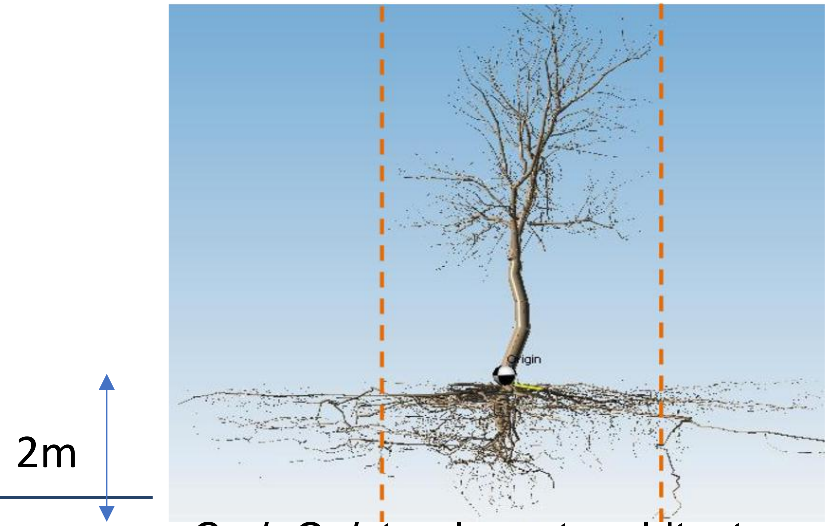
Preliminary geotechnical characterization – ISPRA's soil and rock mechanics laboratory



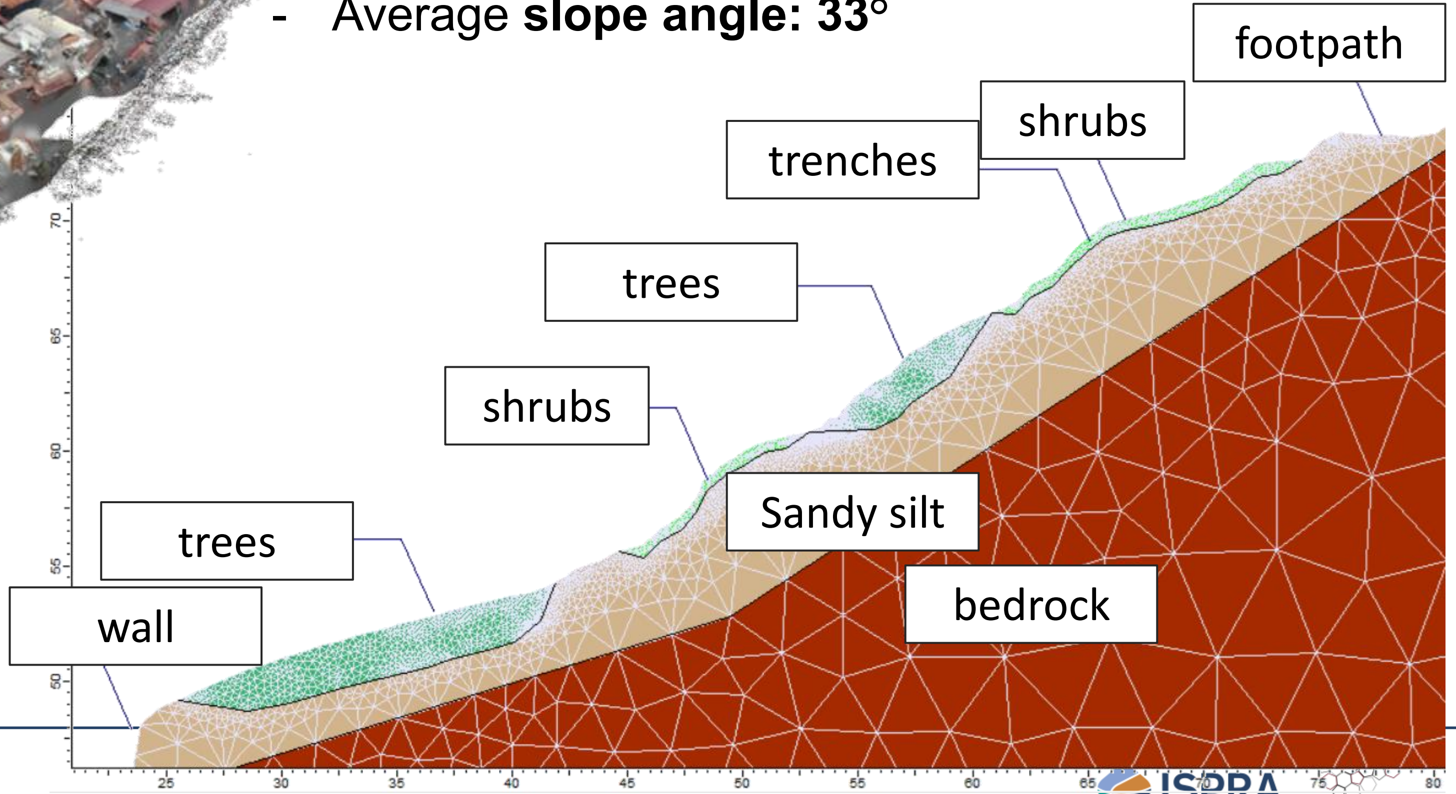
ID	c' kPa	ϕ' °	γ_d kN/m³	k_w m/s
Sandy silt	0	23	16	3.4×10^{-7}

The geological – geotechnical model (FEM)

- A DSM with 5cm resolution (UAS laser scanner) was available for the study site.
- visual observations on the site allowed to individuate trees and shrubs partitions on the slope
- Roots depth given from literature data on vegetation found on the slope (2 m for trees, 0.5 m for shrubs)
- Average **slope angle: 33°**

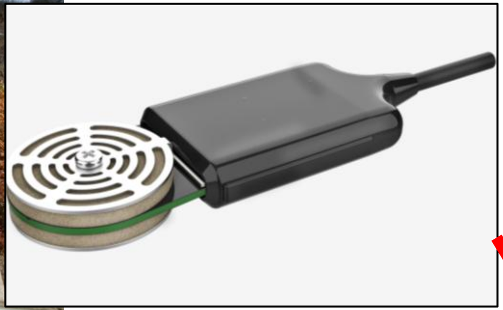


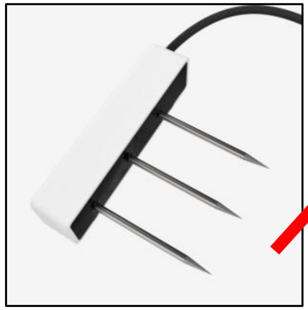
Cork Oak tree's root architecture (Dinis, 2014)



Early Warning monitoring system (installed – first 4 months of data)

Provide rainfall thresholds of instability and safety factors evaluated on physically based models





Weather station:

Wind direction and velocity
Rainfall intensity – duration
Air temperature and relative humidity
Data logger and remote transmission
Optical camera

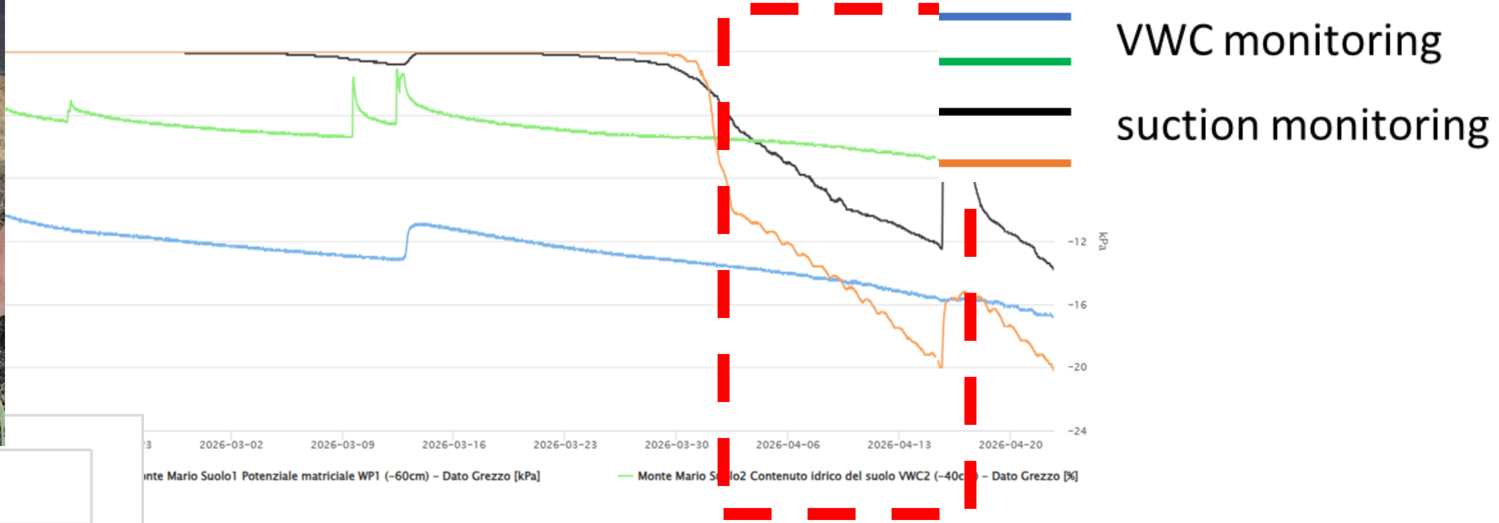
TDR - Time domain reflectometry sensors:

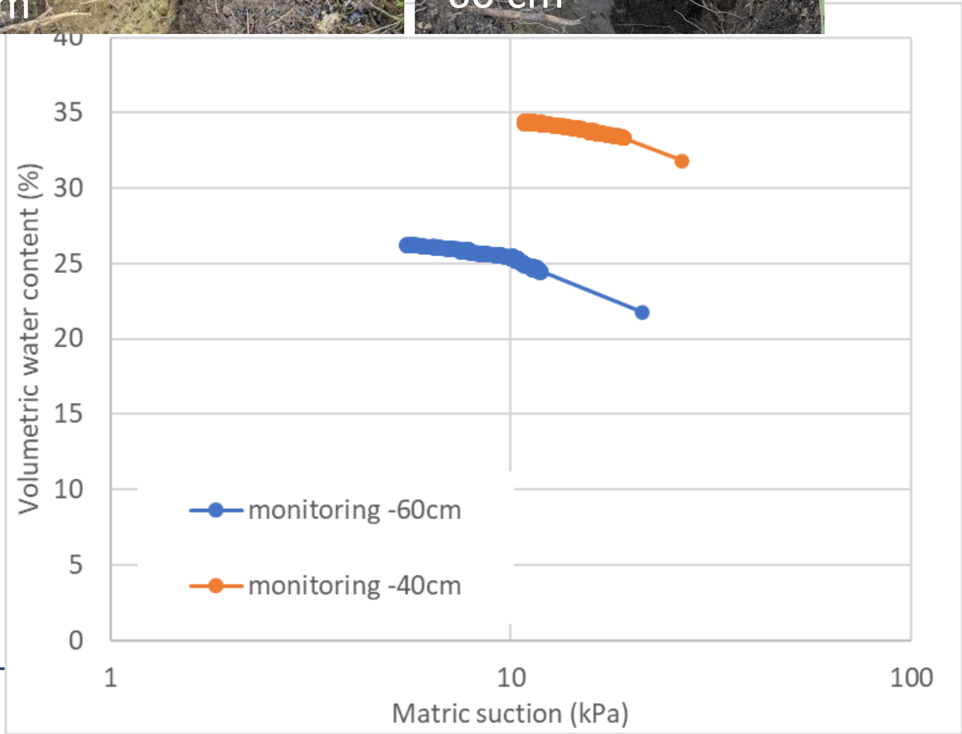
Soil matric suction and volumetric water content (at – 40cm and -60 cm below g.l.)

2D Clinometers:

Shallow soil displacements (installed on a screw within 1 m below g.l.)

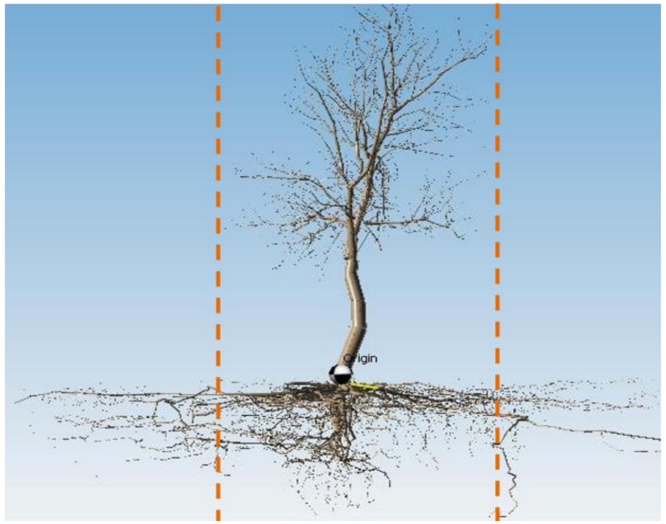
Early Warning monitoring system (installed – first 4 months of data)





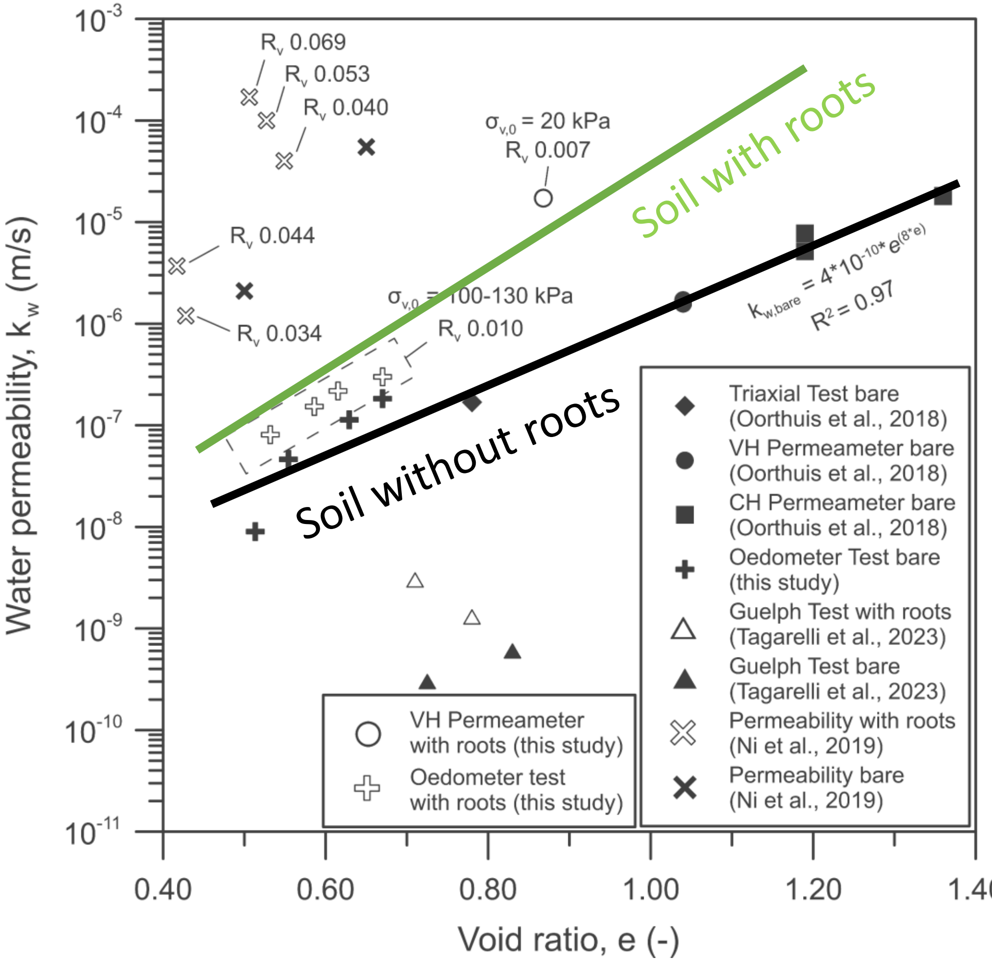
- From monitoring data, days without rainfalls were selected to plot jointly VWC and suction correspondent points to obtain a "main drying" SWRC for in-situ soil (to be enhanced in the future, with more data)
- Laboratory SWRC in progress (soil retrieved close to the sensors)
- A SWRC consistent with the nature of the silty soil was adopted in the numerical model (to be enhanced with more data)

The effect of vegetation and wildfires on soil



Cork Oak tree's root architecture (Dinis, 2014)

Ash on the slope after the wildfire



ID	c' kPa	ϕ' °	γ_d kN/m³	k_w m/s
Sandy silt	0	23	16	3.4×10^{-7}
soil+living shrubs	15[d]	23	16	3.4×10^{-6}
soil+living trees	19[c]	23	16	3.4×10^{-6}
soil+burnt vegetation	0	23	16	3.4×10^{-6}

- Increase in soil cohesion and permeability (negligible effects on friction angle)
- Ashes reduce rainfall water infiltration (void clogging by fines)

[c] Masi et al. (2023); [d] average value for shrubs from De Baets et al. (2008)

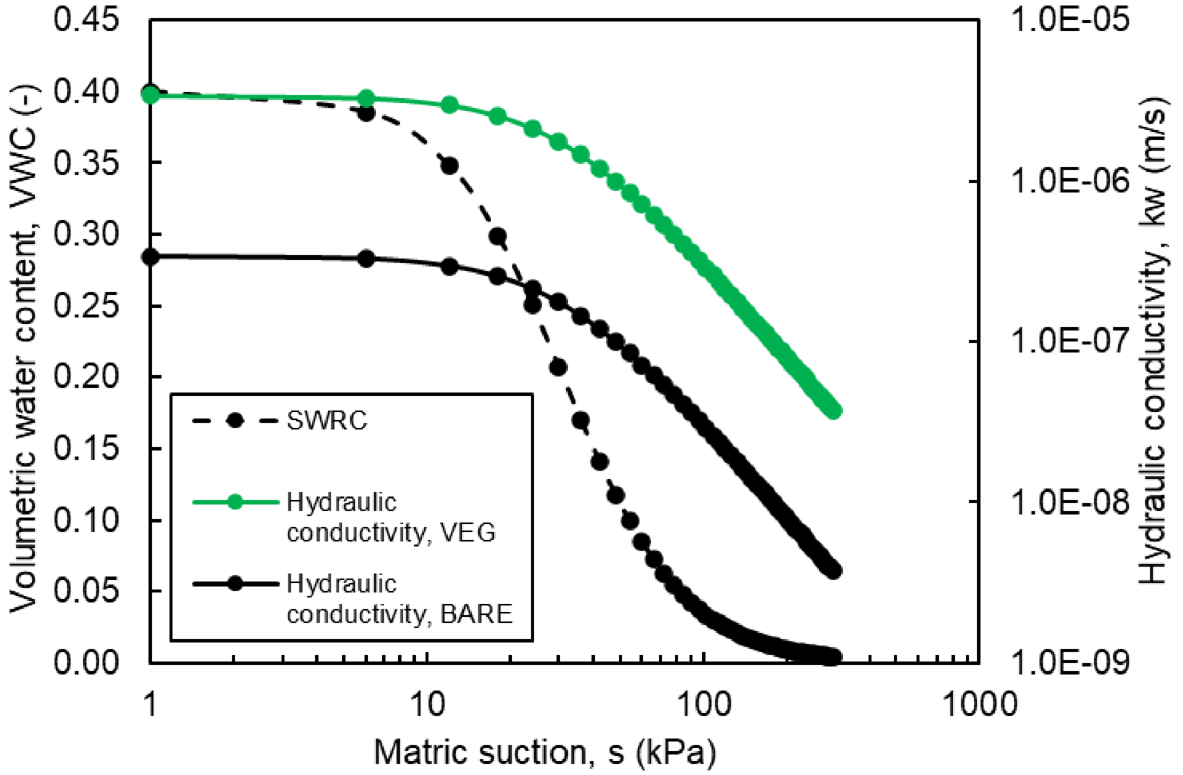
The effect partially saturation on soil permeability and shear strength (necessary in rainfall-induced landslides)

- Soil water content is controlled by soil matric suction (negative pore pressures) and soil physical properties (grain size, porosity, ..)
- Soil permeability decreases as soil gets drier (controlled by matric suction, s)
- Vegetation generates an increase in permeability (with respect to bare soil)

$$k_w = k_{w,s}\left(\frac{1}{1 + a\left(\frac{s}{\gamma_w}\right)^n}\right);$$

$$\mathrm{a} = 0.1\ m^{-1}, \mathrm{n} = 2$$

van Genuchten (1980); Gardner and Hsieh (1956)



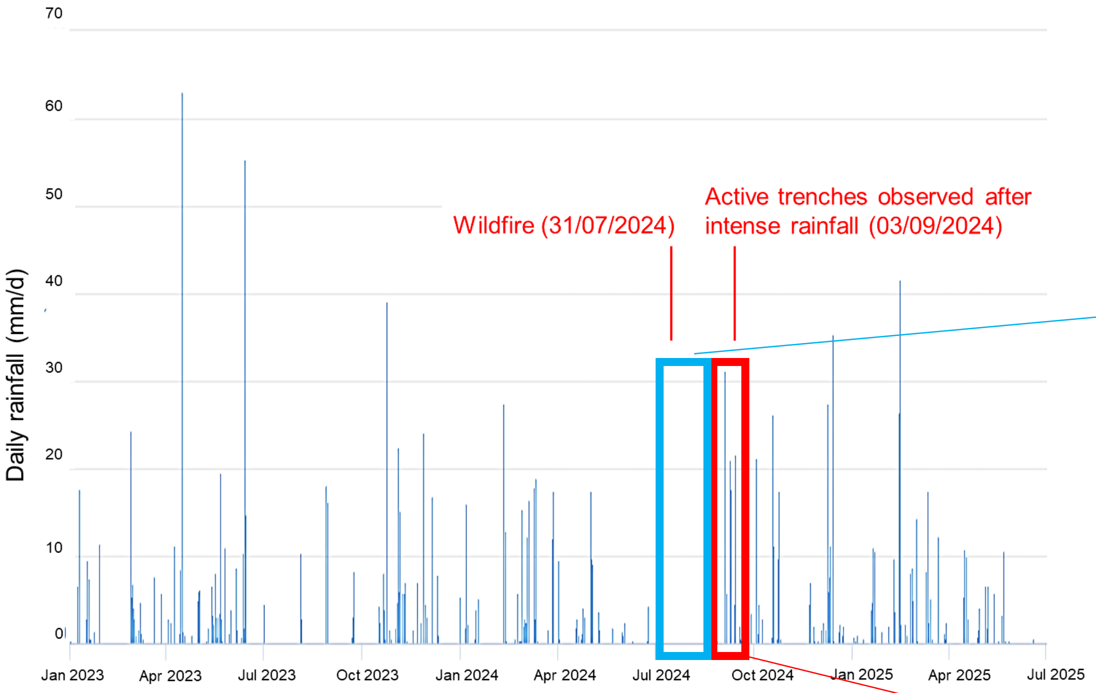
- Soil shear strength increases as soil gets drier (controlled by matric suction, s)

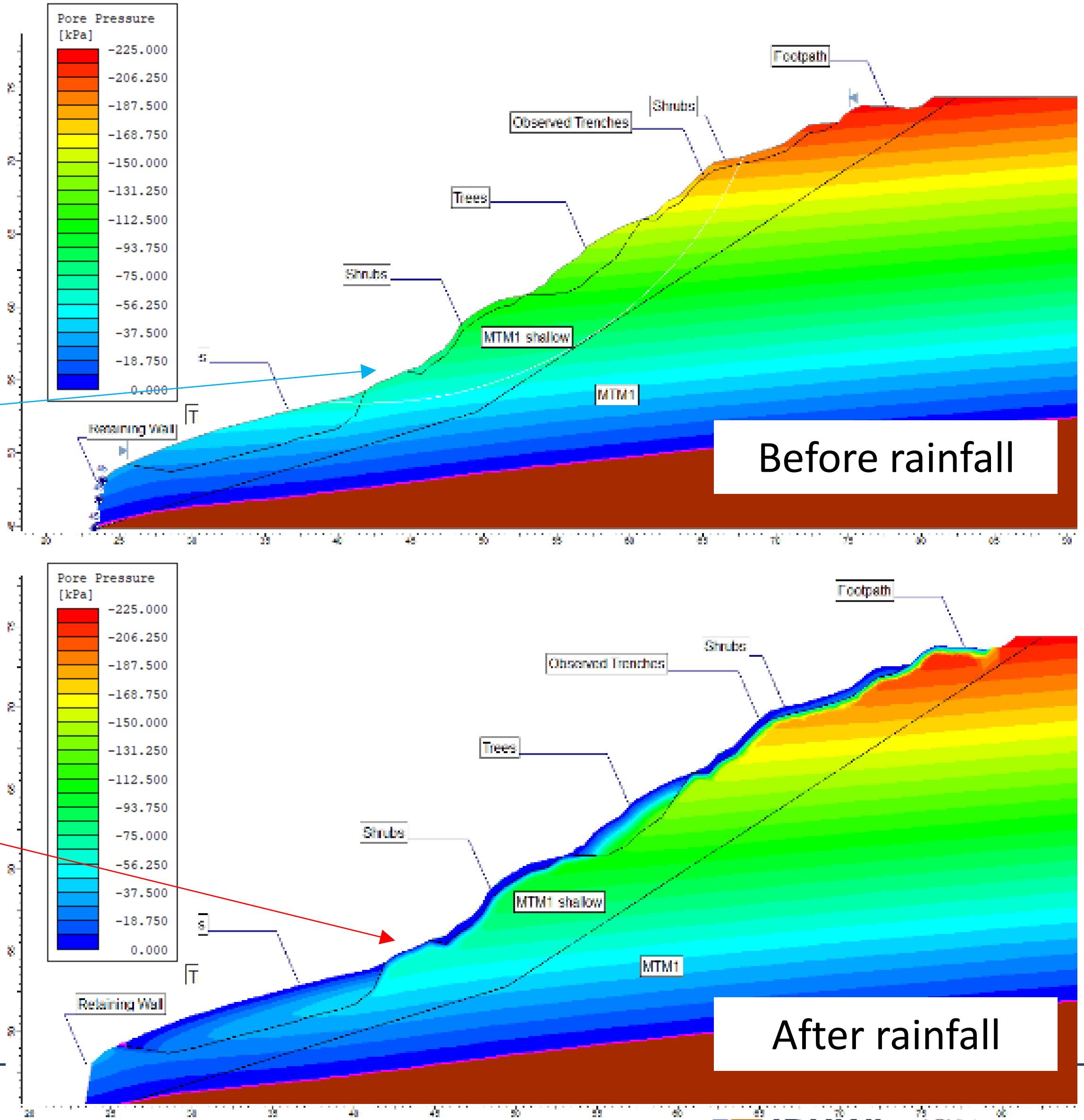
$$\tau_f = c' + (\sigma - u_a)tan\varphi' + S_r s * tan\varphi';$$

Vanapalli et al 1996

Numerical modelling in FEM + LEM

- **Steady state and transient hydraulic analyses** (heavy rainfalls) were carried out through a Finite Element solver



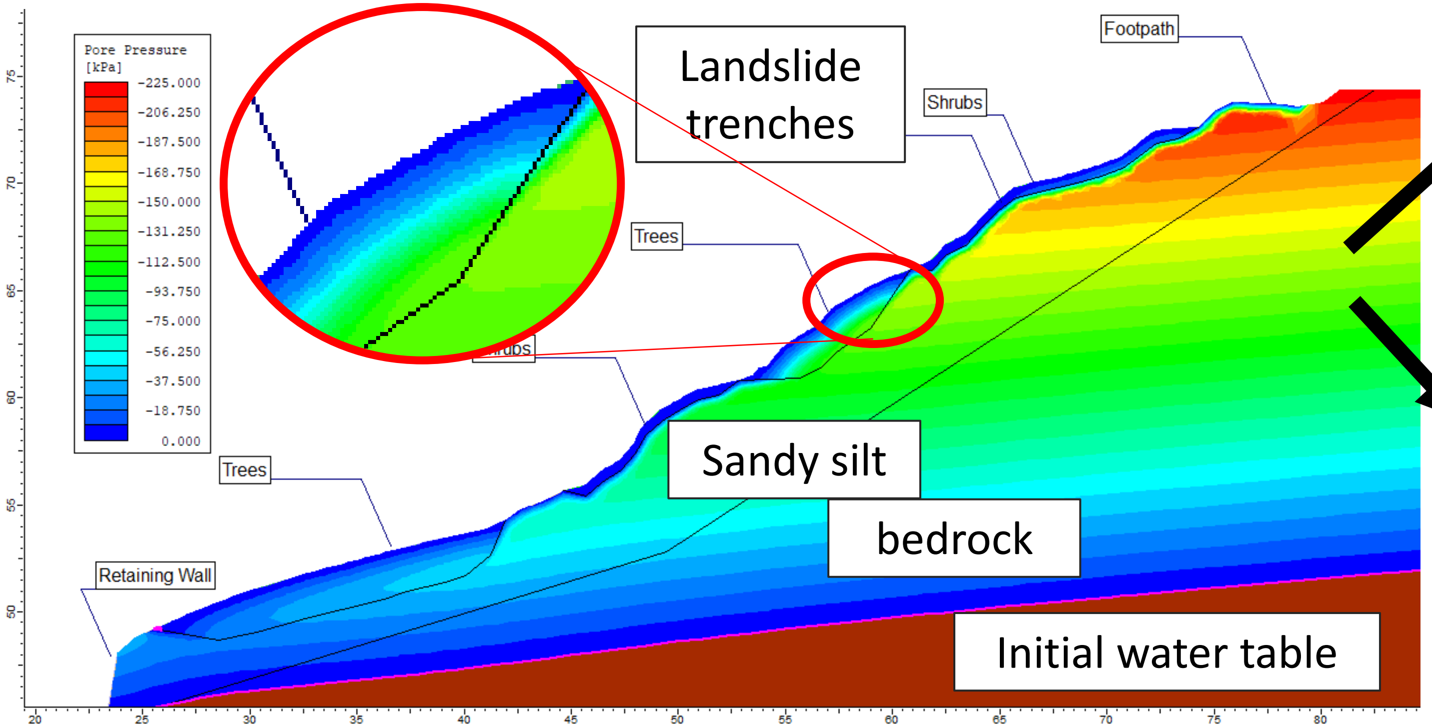


Simulating the effect of **heavy rainfall** (September 3rd, 2024), occurred after the **wildfire,** on slope stability with (hypothetically) living and burnt vegetation

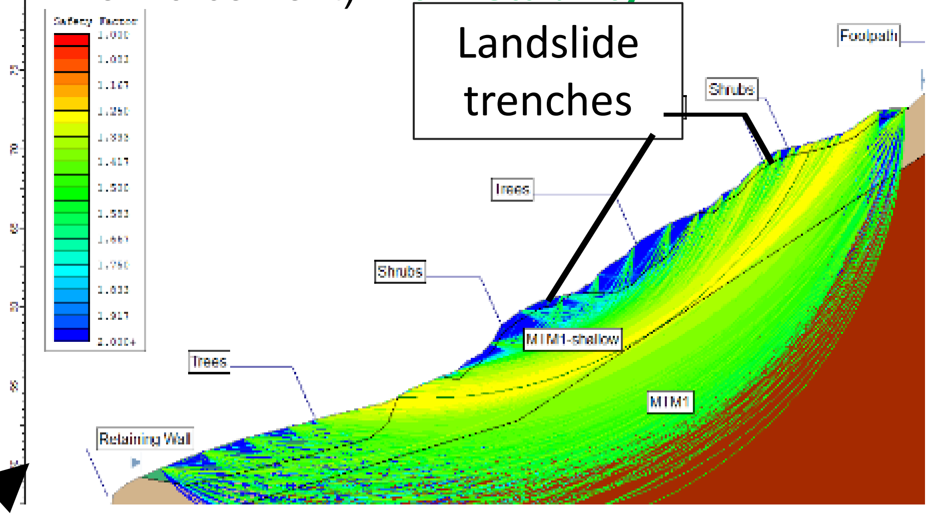
Numerical modelling in FEM + LEM

- **Safety factors** of the slope were evaluated by Limit Equilibrium (Morgenstern and Price, 1965)

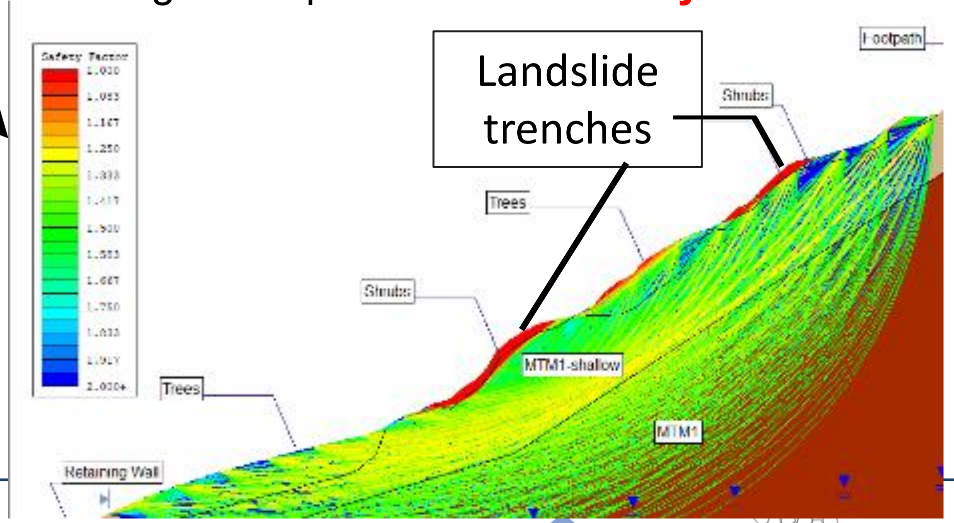
saturation fronts down 0.50 m from the ground surface



Simulation 2: slope including **LIVING** vegetated partitions (root reinforcement): **no instability**



Simulation 3: slope including **BURNT** vegetated partitions: **instability**



Conclusions

- The reduction of root reinforcement on soil induced by the persistent and severe wildfire is considered a major factor in triggering surface landslides on Mt. Mario Case. The preliminary numerical results reflect in-situ observations.
- Future laboratory results and in-situ monitoring (water content, suction, shallow displacements) will provide deeper understanding of the behaviour of the slope under saturated and unsaturated conditions and will improve the numerical predictions too, in view of developing **digital twins for Early Warning Systems**.
- Re-vegetation of the slope is in progress (**importance of nature-based solutions in urban environments**)

Thank you for your attention