Post-wildfire monitoring for hazard mitigation in Alpine area

Monica Corti[1], Laura Corti[1], Andrea Abbate[2], Monica Papini[1], Laura Longoni[1]

[1]Dipartimento di Ingegneria Civile e Ambientale, Politecnico di Milano
[2]Ricerca sul Sistema Energetico – RSE S.p.A, Milano, Italy

SEMINAR CS³ ENVIRONMENTAL, NATURAL AND ANTHROPIC RISKS FROM MODELLING TO ETHICAL DECISIONS

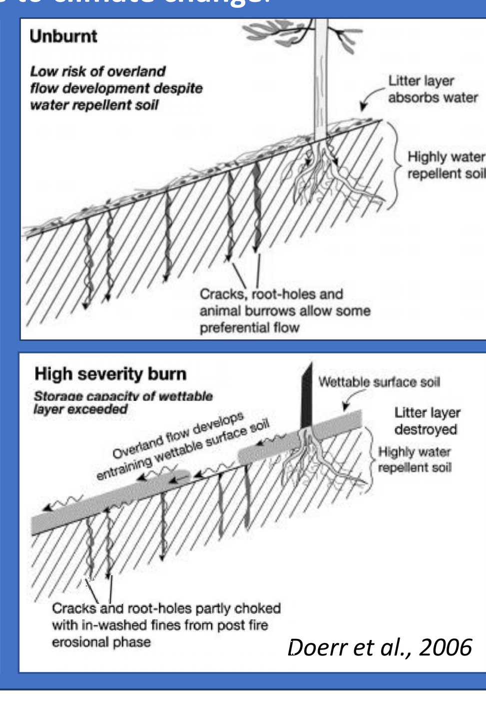
3 November 2022

POLITECNICO MILANO 1863

1. PROBLEMS RELATED WITH WILDFIRES

Wildfire events can be very harmful to the hydrological system of a mountain slope, changing the local **hydrogeological conditions** and frequently affecting **slope stability**. **Recovery** to pre-fire conditions often takes several years, depending on fire severity, vegetation type and meteorological conditions after fire. Even though these events are common in the Alps, the largest part of the studies comes from USA, Australia, Spain and Portugal.
Based on the raise of global temperature, wildfire hazard is expected to increase due to **climate change**.

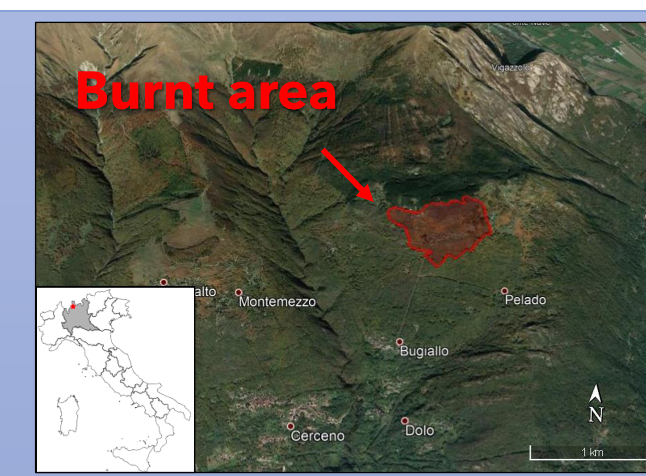
WILDFIRE:
Vegetation removal + soil burning
Reduction of canopy interception + litter layer disruption and enhancement of soil water repellency in the subsurface
Increased overland flow, runoff and erosion
Higher debris flow hazard



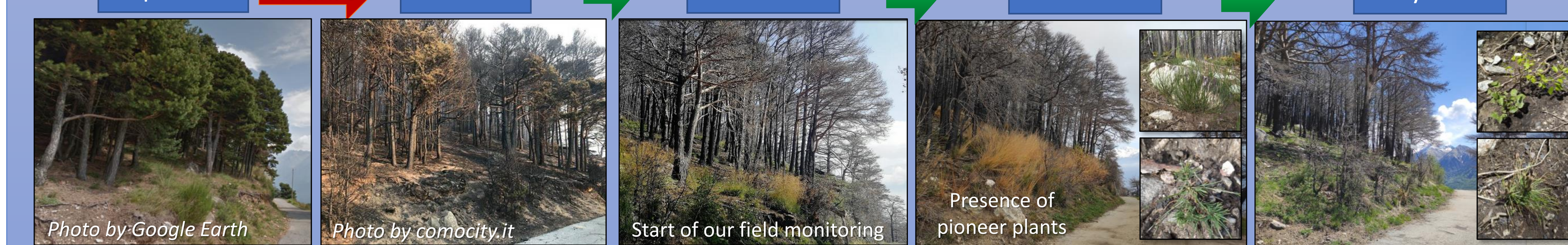
Doerr et al., 2006

2. CASE STUDY: SORICO (CO) WILDFIRE

- Case study: wildfire event occurred in Central Alps (Sorico, CO), in January 2019.
- Monitoring: October 2019-today.
- Burnt Area: 0.3 km^2.
- Vegetation: pine woods and grasslands.
- Geology: LGM glacial deposits and recent colluvial deposits over a gneiss bedrock (Bellinzona-Dascio zone).



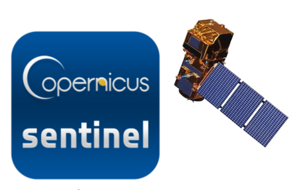
Sept 2011 → Wildfire → Jan 2019 → Oct 2019 → Nov 2020 → May 2021



COMPLETE RECOVERY?

3. STRUCTURE OF OUR RESEARCH

Laboratory tests: rainfall simulations | Field monitoring: infiltrometric tests | Remote-sensing imagery analysis



GEO-HYDROLOGICAL MODEL

Water Balance Equation

$$\frac{\Delta h_{water}(t)}{\Delta t} = P(t) - ET(t) - L(t) - R(t)$$

Soil Moisture Evaluation

$$Sr(t) = \frac{V_{water}(t)}{V_{voids}} = \frac{h_{water}(t)A}{\phi\, h_{terrain}\, A} = \frac{h_{water}(t)}{\phi\, h_{terrain}}$$

- Predictions about the recovery time of the burn site,
- Estimation of the saturation level of the terrain,
- Rainfall thresholds and slope instability triggering.

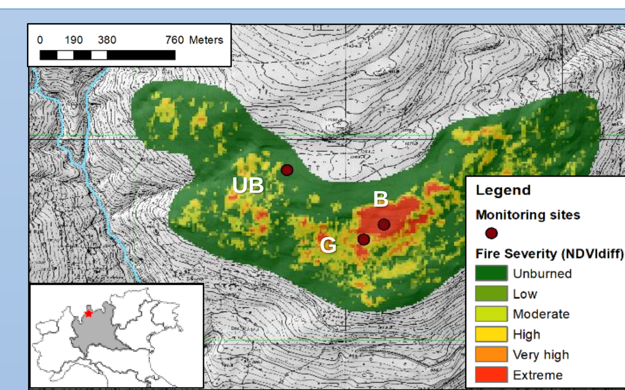
4. METHODS

Remote and field monitoring

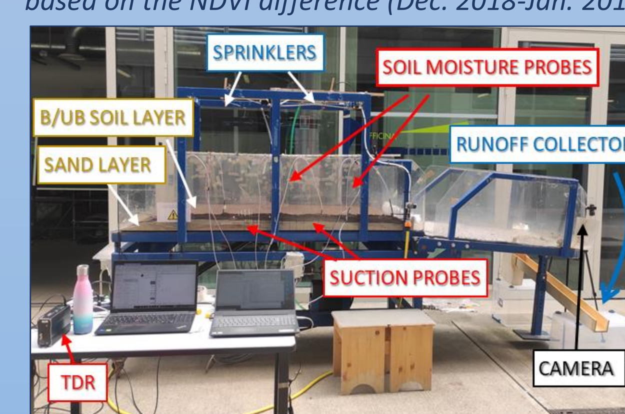
Monitoring activity distributed over three sub-areas:

1. **Burnt woods:** bare soil (mostly) and dead trees,
2. **Burnt grassland:** recognisable fire prints, but living vegetation (ferns, grass, shrubs),
3. **Unburned woods:** conifer woods outside the wildfire area (control site).

- Evaluation of different remote sensing indices for these three areas over time, using **Copernicus Sentinel-2** bands → identification of a *recovery trend* of the burnt area,
- **Laboratory permeability tests** on burnt and unburned soil collected in October 2019 → saturated hydraulic conductivity estimation,
- Single ring and double ring falling-head **infiltration tests** performed on the field over time → evaluation of the *local change of the infiltration parameters*,
- **Rainfall simulations** on burnt and unburned soil on an inclined (30°) surface, measuring of runoff, soil moisture and suction.



Monitoring sites locations and fire severity map, based on the NDVI difference (Dec. 2018-Jan. 2019).

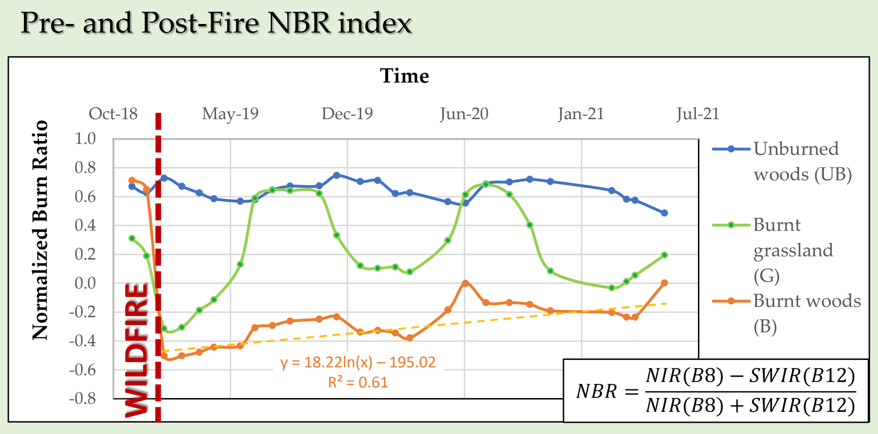


Experimental setup.

5. RESULTS

Remote sensing monitoring:

Pre- and Post-Fire NBR index

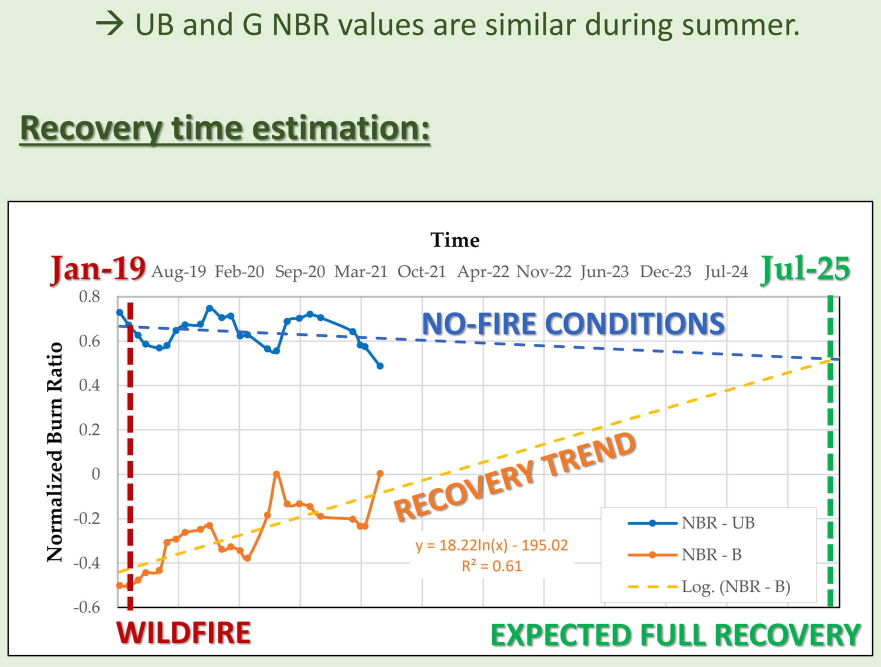


$$NBR = \frac{NIR(B8) - SWIR(B12)}{NIR(B8) + SWIR(B12)}$$

NBR: highlights burnt areas in large fire zones
→ **darker pixels = burnt areas.**

- **Before wildfire** → UB and B areas share similar NBR values;
- **After wildfire** → Logarithmic **recovery trend** in the B area.
- **UB presents constant NBR values**
  → conifer woods: constant leaf reflectance over the year;
- **G** presents a **seasonal trend**
  → UB and G NBR values are similar during summer.

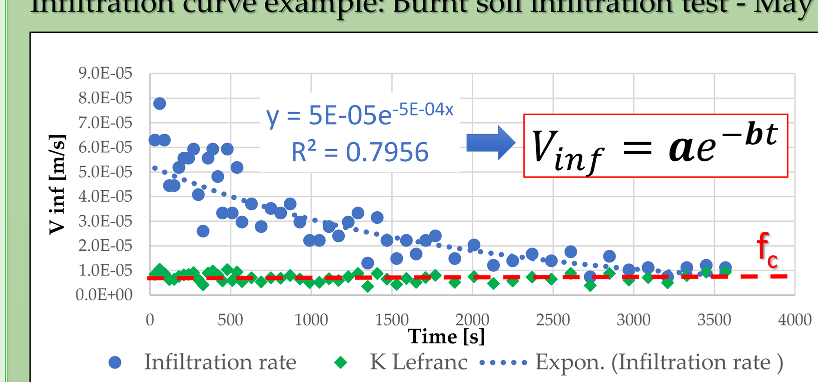
Recovery time estimation:

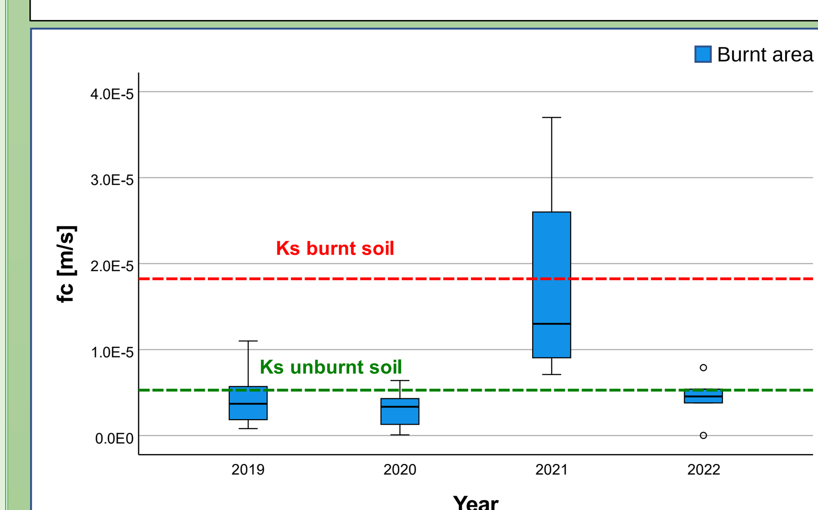


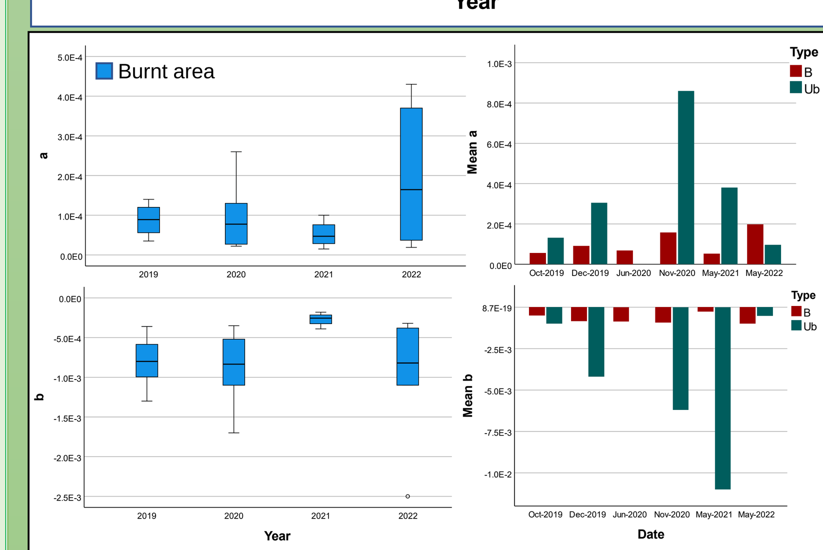
- Post-fire recovery: **logarithmic trend** equation,
- Complete vegetation recovery expected in **July 2025** (**7 years** after the wildfire event).

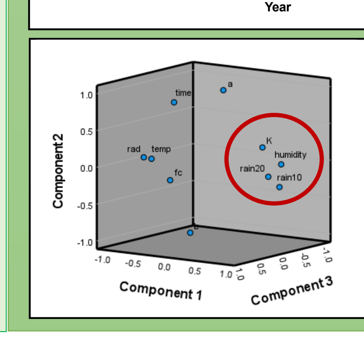
Field monitoring:

Infiltration curve example: Burnt soil infiltration test - May 2022









Component Plot in Rotated Space for burnt grassland

- The resulting data of the infiltration tests are exponential curves that follow Horton's model:

$$f = f_C + (f_0 - f_C)e^{-K_f t}$$

- Results fitted to simpler exponential curves → a, b, simplified f_c measured over time.
- Infiltration capacity (f_c) appears to be almost constant over the monitoring period for the entire **burnt area**

The median value of f_c is similar to the K_s of the unburned soil gained from the permeameter.

The hydraulic conductivity of soils was already similar in the monitored sub-areas ten months after the wildfire.

- A different shape of the curves in the three sub-areas is observed.
- a e b coefficients are **more variable in the unburned woods** than in the burnt area.

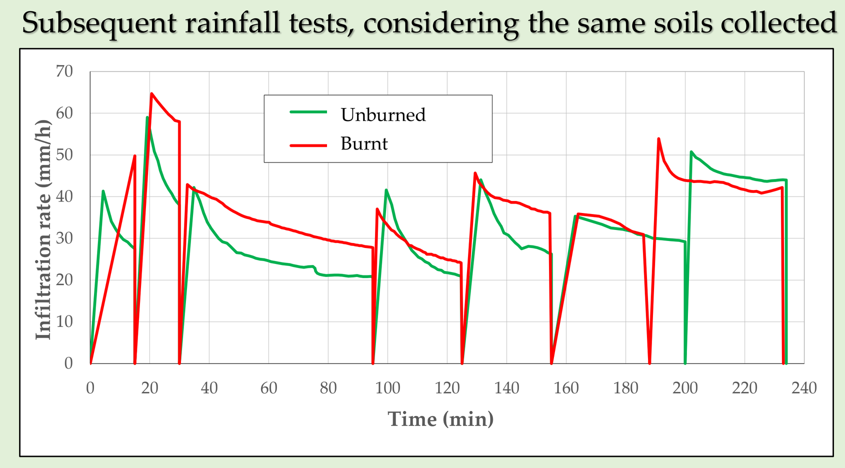
The **correlation matrix** gained from factor analysis shows:

- In the burnt woods: a weak correlation between f_c and some meteorological parameters (temperature and rainfall) + evolution of a and b over time,
- In the burnt grassland: a correlation between K and all the meteorological parameters,
- In the unburned woods: no significant correlations.

The conifers seem to protect soils from the meteorological variables, characteristic partially still present inside the burnt woods (burnt trees).

Laboratory rainfall simulations:

Subsequent rainfall tests, considering the same soils collected in October 2019

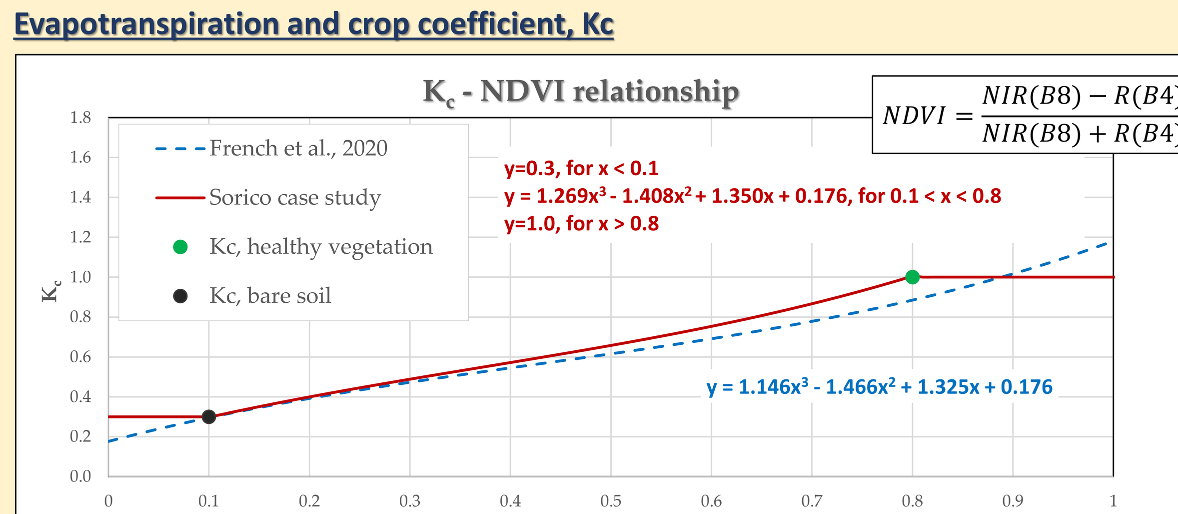


Cracks opening after rainfall test on burnt soil.

- **Unburned soil rainfall test:** less infiltration, high runoff;
- **Burnt soil rainfall test:** quick response to rainfall, less runoff and higher infiltration → slope instability;
- The differences between the responses of the two types of soils decrease test after test → dissolution of soil water repellency of the unburned soil.

6. GEO-HYDROLOGICAL MODEL – PRELIMINARY UPDATES

Evapotranspiration and crop coefficient, Kc



$$NDVI = \frac{NIR(B8) - R(B4)}{NIR(B8) + R(B4)}$$

Decrease of ET after wildfires: $ET(t) = K_C\, ET_0$

NDVI: index related to vegetation health (greenness) and correlated to crop coefficient, Kc (e.g., Nolan et al., 2014; French et al., 2020).

	Healty vegetation	Bare soil
NDVI	0.8 (Mean value in Sorico)	≤ 0.1
Kc	1.0 (FAO)	0.3

$$K_c = \begin{cases} 0.3, & NDVI \le 0.1 \\ a_0 + a_1 \cdot NDVI + a_2 \cdot NDVI^2 + a_3 \cdot NDVI^3, & 0.1 \le NDVI \le 0.8 \\ 1.0, & NDVI \ge 0.8 \end{cases}$$

Modified after French et al., 2020

Where a_0 = 0.176, a_1 = 1.325, a_2 = -1.466, a_3 = 1.146.

CONCLUSIONS

- **Wildfire effects** are **still recognisable** in the study area three years after the event.
- The coefficients of the exponential infiltration curves have different behaviours over time in the burnt area and in the unburned area: the field capacity appears to be **correlated with the meteorological variables** only in the burnt area.
- A more **direct response to precipitation** in the burnt area is still present, due to the absence of a complete restored vegetation coverage.
- A **logarithmic recovery trend** was derived from the remote sensing analysis, with an expectation of full recovery almost seven years after the wildfire event. This recovery is intended as a recovery of the **canopy protection**, an important parameter for soil protection from erosion.
- The rainfall tests showed a progressive **reduction of the soil water repellency** of the unburned soil without the canopy interception.
- A **crop coefficient (Kc) recovery** equation was calibrated for the evapotranspiration reduction. The assessment of alpha coefficient for the infiltration recovery is more complex, because its behaviour seems to depend on different factors that are not time-invariant and that may change seasonally.
- Regarding the Sorico case study, fire conditions seem to increase the soil infiltration and to decrease the overall stability of the slope under saturated condition, leading to a **higher risk** of shallow landslide triggering.

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