Linear firebreak infrastructures in the Valencian Community. Updating of the width calculation methodology

Authors: Botella Martínez M.A. (1); Barberá Bisbal M.J. (1); Soriano Sancho J.L. (1); Cervera Montero A. (1); Orozco Bagou D. (1); Estéfano Oláiz M. (1); García Post R. (2); Navarro Baixauli F. (3); Sapiña Salom G. (3); Arribas Cobo J.L. (3).

(1) Technical Unit of Analysis and Prevention of Forest Fires. VAERSA. Generalitat Valenciana.
(2) General Directorate of Forest Fire Prevention. Generalitat Valenciana.
(3) Project Department. VAERSA. Generalitat Valenciana.

Objectives: to update the methodology for calculating the width of **firebreaks** in the Valencian Community, defining them as **active infrastructures** in which land firefighting means can **work safely** while optimizing the investment in their execution and maintenance.

Materials and Methods: the methodology for calculating the widths was based on the concept of **safety distance** (Butler&Cohen, 1998), but applied to linear firebreaks (Samper, 2022). For this calculation, a solid flame front that emits energy radiation uniformly over its entire surface was assumed. The mathematical expression results in an incident heat flux value that depends, among other factors, on the distance to the element receiving the radiation. By applying a **maximum radiation threshold** for the personnel, the minimum working distance can be obtained and, therefore, the **width of the infrastructure**.

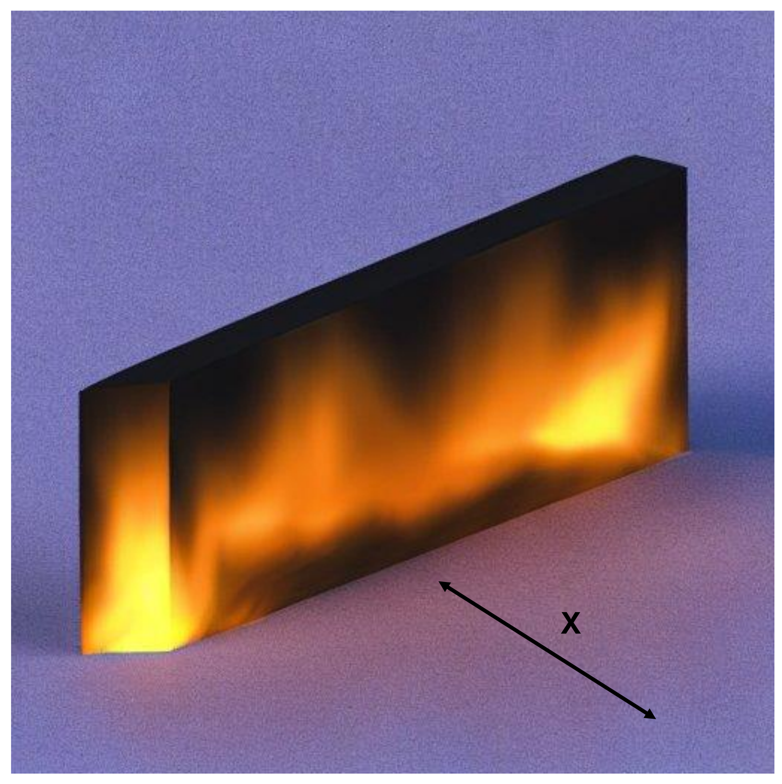

Figure 1. Render of a solid flame front with a flat surface. Source: Adapted from a Stable Diffusion AI generated image.

The thermal radiation reaching a target located at a distance “X” from the flames is estimated using the following expression (TNO, 2005):

$$Qr = Ef \cdot \tau \cdot F$$

Qr= incident heat flux (W/m2).

Ef = flame emissive power (W/m2).

τ = atmospheric transmissivity (dimensionless).

F = geometrical view factor (dimensionless).

Ef = flame emissive power (W/m2): it is defined as the amount of heat emitted in the form of radiation per unit of surface area, calculated according to the following expression:

$$Ef = \sigma \cdot \varepsilon \cdot Tf4$$

Where:

σ = Stefan-Boltzmann constant = 5.67x10-8 (W/mK4)

ε = Emissivity (kW/m2)

Tf = Flame temperature (K)

The emissive power of the flame can be calculated assuming that ε=1. This implies the worst-case scenario, since in practice the existence of black smoke in the flame would decrease the average value of Ef. However, due to the lack of precision in establishing the fraction of the flame surface covered by black smoke, this conservative approach was considered more convenient (Zarate, et al. 2008), and it also adds a safety coefficient in the calculation of the distance for the firefighters.

Regarding flame temperature, a standardized value of 1200K was adopted (Butler&Cohen, 1998; Zarate, et al. 2008; Rossi et al. 2011).

τ = atmospheric transmissivity (dimensionless): it is the fraction of thermal radiation that is transmitted through the atmosphere, namely, that which is not absorbed or scattered by the existing medium between the emitting source and the receiver. It is a function of the water vapor contained in the atmosphere, the carbon dioxide concentration and the distance between the source and the receptor. It can be calculated using semi-empirical equations (Zárate, et al. 2008; TNO, 2005):

$$\tau = 1 - \alpha w - \alpha c$$

Where:

αw = water vapor absorbance (dimensionless)

αc = CO2 absorbance (dimensionless)

Simplified equations based on the partial pressure of water vapor were used in this calculation (Satyanarayana, et al. 1991).

F = geometrical view factor (dimensionless): it is a geometrical parameter that determines the fraction of the thermal energy flux emitted by a radiating surface which is directly impinging on a receiving surface. Its value depends on the dimensions and shape of the flame, as well as the distance and relative position of the two surfaces (TNO, 2005). It can be determined by analytical equations for simple geometries.

There are several geometric configurations that can be chosen when calculating the view factor. Figure 2 shows the one that was finally selected as being the most conservative (worst-case scenario).

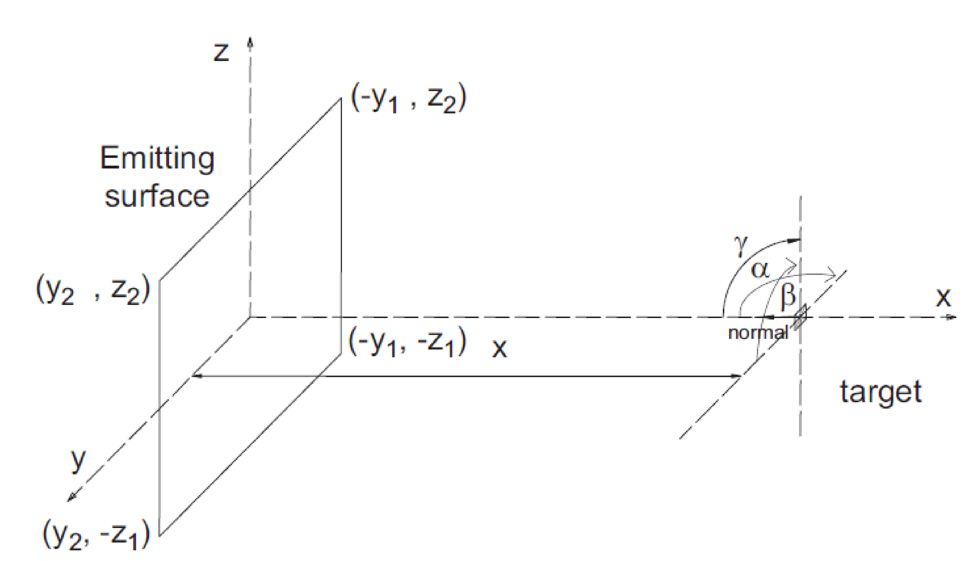

Figure 2. Emitting source with a rectangular area parallel to a differential receiving element located in front of its center. Source: Adapted from Zarate et al. (2008).

Qr threshold: the calculation of the geometrical view factor requires giving dimensions to the radiant surface. In this case, a flame front with a width (y-axis) of 20 m was assumed (Zárate, et al. 2008). Regarding the flame height (z-axis), this parameter can be derived from the **flame length**. Once the value of the flame length parameter has been calculated, it only remains to define the value of the distance "x" that complies with the **maximum threshold** of the incident heat flux (Qr) required, and which would therefore be equivalent to the **safety distance** (DS). The **maximum threshold** established was **7 kW/m2** for firefighters covered with Nomex safety clothing, (Butler&Cohen, 1998).

Flame length calculation: BehavePlus software (USDA Forest Service) was used to perform simulations using the Scott&Burgan fuel models. Moisture of fine dead fuels was calculated based on the Fosberg (1971) model. The live fuel moisture was determined using the LFM sample readings database from the Fire Prevention Service. For the definition of the weather parameters used in the simulations, a **climatology** was elaborated for the 11 meteorological zones (AEMET, 2018), using the **ERA-5** climate reanalysis database.

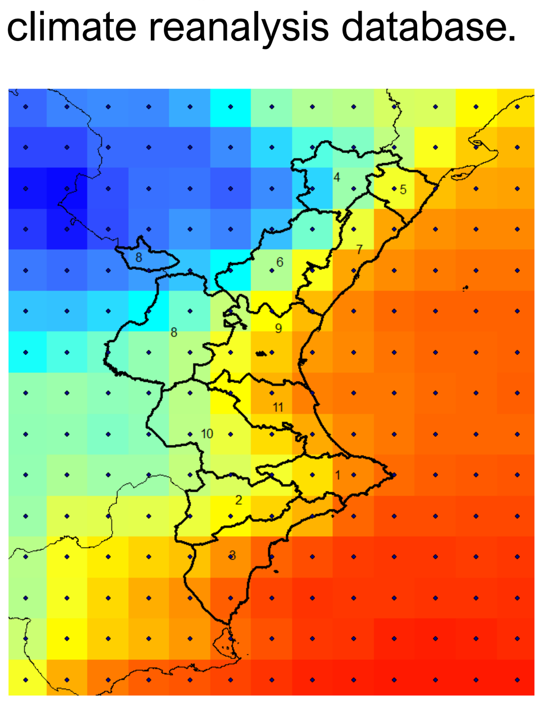

Figure 3. Map of the spatial distribution of the pixels from the ERA-5 (Copernicus) climate database (25 km resolution), in relation to the AEMET meteorological zones. Source: Own elaboration.

Meteorological scenarios: based on the values obtained in the ERA-5 climatology, the definitive meteorological scenarios for the execution of the fire behavior simulations for each of the zones had to be determined (worst-case scenario for wind direction and percentiles for each variable). For this purpose, a study of **historical fires** was carried out. Wind speed and direction, temperature and RH conditions at the start time of fires of more than 30 ha were analyzed at the meteorological zone level (statistics 1993-2020). To complete the study, the meteorological conditions for the first 6 hours of spread of fires of more than 1.000 ha occurred in each of the meteorological zones were also analyzed.

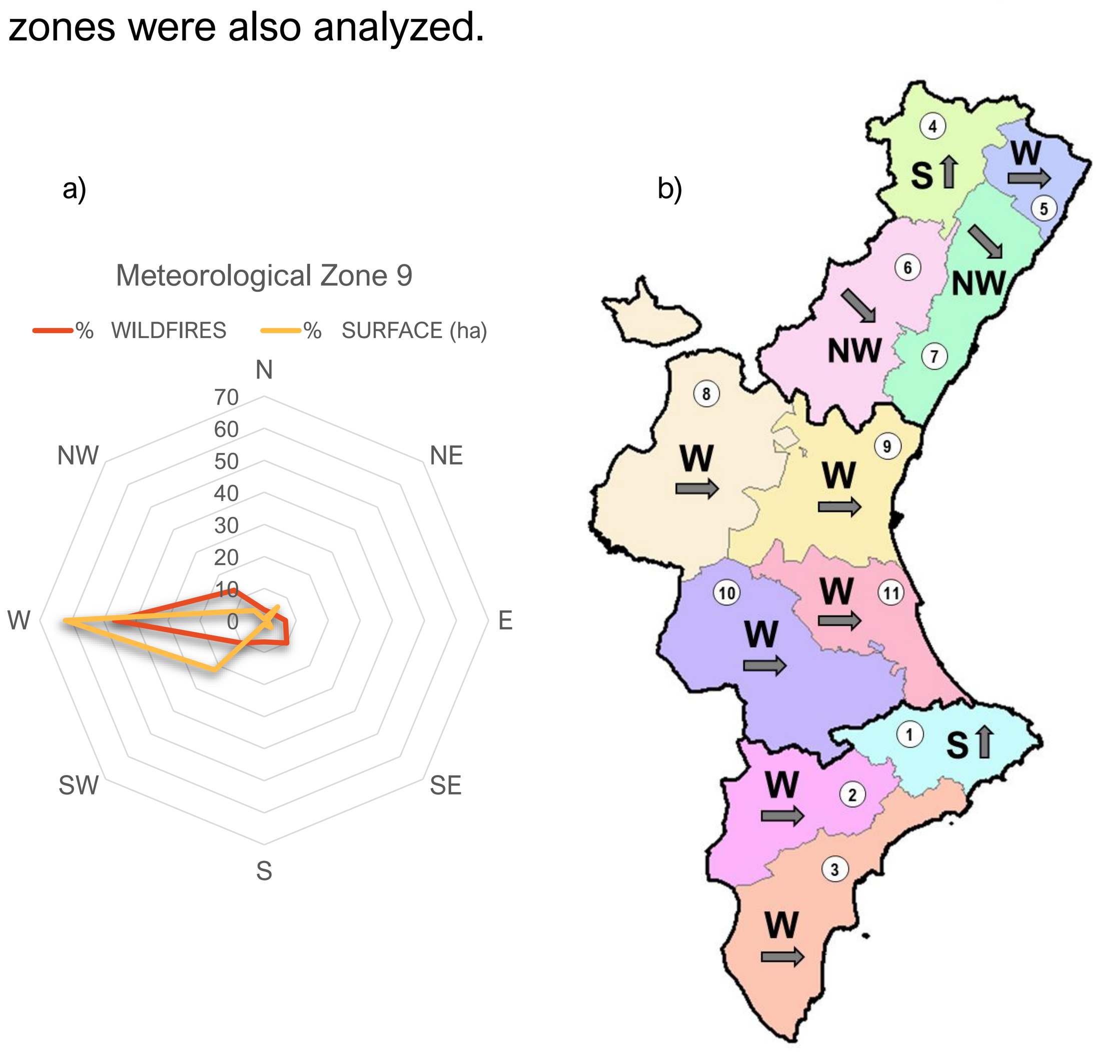

Figure 4. a) Results of the analysis of historical fires for meteorological zone 9 (worst-case scenario for wind direction). Percentage of number of fires and area burned for each wind quadrant. b) Distribution map of the AEMET meteorological zones together with the wind scenarios selected as the most adverse, based on the analysis of historical fires. Source: Own elaboration.

Results: as an example, the safety distances (SD) resulting from the calculations for meteorological zone 8 are shown in Table 1.

Table 1. Safety distances (SD) determined for meteorological zone 8, depending on fuel models and slopes (both positive and negative). Values in meters. Source: Own elaboration.

Meteorological Zone 8. Safety Distances (SD) in meters				
Fuel Model	Positive Slope		Negative Slope	
	<45%	>45%	<45%	>45%
GR1	8,0	13,0	5,0	5,0
GR2	16,0	29,0	10,0	6,0
GR4	26,0	43,0	16,0	10,0
GR7	39,0	64,0	24,0	15,0
GR8	44,0	72,0	28,0	17,0
GS1	13,0	22,0	7,0	5,0
GS2	17,0	30,0	10,0	6,0
SH1	10,0	18,0	6,0	5,0
SH2	15,0	27,0	9,0	6,0
SH3	10,0	17,0	6,0	5,0
SH4	21,0	35,0	13,0	8,0
SH5	32,0	52,0	20,0	13,0
SH9	34,0	54,0	21,0	13,0
TU1	20,0	54,0	16,0	10,0
TU2	37,0	54,0	25,0	16,0
TU3	40,0	58,0	26,0	17,0
TU5	47,0	69,0	32,0	20,0

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