

Methodological Proposal for Analyzing the Vulnerability and Potential Gravity of Forest Fires Within the Framework of Civil Protection¹

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Summary

The circumstances which concur when a fire occurs cause situations of serious risk, catastrophe or public calamity, making fire a risk in general which should be covered under civil protection planning. It is considered as such under the Spanish Civil Protection Basic Regulations which establish that the risk of forest fires should be dealt with through special plans in regional areas which so require them. Considering the terms under which the basic directive defines the basic elements for planning, a proposal for methodology is presented which firstly assesses the vulnerability - or what amounts to the same thing - the degree of loss or damage which may be suffered as the result of a forest fire by the population, property and the environment and secondly assigns the level of potential gravity of a fire for each area of the region, depending on the intrinsic and extrinsic elements of the forest ecosystem, concerning available fire prevention resources. The analysis of regional distribution of vulnerability, the level of potential gravity of fires, and the elements which make these up will make possible adequate prevention measures – feasibility, fuel handling, and handling of other infrastructures and equipment – in order to be able to bring areas with a high potential for the gravity of forest fires down to lower levels of potential gravity.

Introduction

Forest fires constitute one of the main threats to our woodland, due both to the annual loss of forest surface area and the consequent loss of environmental, recreational and productive wealth which go hand in hand, as well as the harm and damage these fires cause immediately to both people and property.

The circumstances which concur in forest fires, as factors producing situations of serious risk, catastrophe or public calamity, as referred to in the Spanish Law 2/1985 on Civil Protection, qualify forest fires as a whole as a risk which should come under civil protection planning. This is indeed so in the Civil Protection Basic Regulation which in Section II, art. Six, determines that forest fire risk shall be the subject of special plans in regional areas which require these. These special plans should be drawn up in accordance with Civil Protection's Basic Directive on Forest

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Fire Emergencies, approved by Agreement of the Council of Ministers of 18th March, 1993 (BOE -Official State Bulletin of 15th April, 1993).

The Plans drafted as a result of this directive will refer to Civil Protection measures to reduce situations of catastrophic risk to people and property, since the basic principle of this Directive is that the protection of the life and safety of persons must prevail over any other value.

Vulnerability and potential gravity as basic elements in planning civil protection of forest fire emergencies

The Basic Directive indicates **the risk of fire, vulnerability, the periods of danger,** and the classification of forest fires by **level of potential gravity** as all being elements which are **basic to Civil Protection planning** on forest fire emergencies.

Although fire risk and periods of danger are aspects which were regularly included in fire protection planning and are determined using criteria defined in different methodologies, **vulnerability and level of potential gravity** are concepts which required be including in planning from the point of view of Civil Protection, and in the terms defining in the Basic Directive. Consequently, in 1993 the **methodology to be applied** was worked out to obtain these elements, bearing in mind all the factors determining them.

The knowledge of the **factors** which define **vulnerability and potential gravity**, and their interpretation through the different **indicators** enable us to put these elements into the geographical information systems (GISs) by integrating the data which characterize the subject and area studied and the knowledge of the subject's internal and external relations using rules and models.

The analysis of **regional distribution of vulnerability** and the **level of potential gravity of fires** will enable us to take **suitable measures on prevention** in order to reduce areas with high level gravity to **lower levels of potential forest fire gravity**.

Vulnerability

From the perspective of Civil Protection, the consequences of fires require quantitative analysis of vulnerable elements exposed to this phenomenon: **persons, goods and environment**.

The Basic Directive defines **vulnerability** as the **degree of loss or damage which may be suffered as the result of a forest fire by the population, property and the environment,** and in this regard Fire Protection Planning on forestry systems must include this focus as additional to that of the intrinsic value of the woodland.

The **life and safety of persons, infrastructures and inhabited areas,** the **overall economic value of the forest systems** and the **historical and artistic heritage** are the generic categories of wealth to be protected.

When planning within a geographically based information system, the GIS, the information on the different elements must refer to a grid square so that each of these

may be evaluated independently, later grouping them through a decision matrix, in order to achieve **overall vulnerability**.

Population

The vulnerability of the population can be interpreted from the three following indicators: **Occupancy**, **Interface** and **Dispersal** which, taken together, determine the **vulnerability of the population**.

In order to establish the intervals into which to group the values obtained from these indicators, we analysed the range of values determined, i.e. the difference between the maximum and minimum value. The mean value is constituted by the second benchmark statistical parameter, since the value which leaves, below or above, 50% of the values indicates the intermediate value of this range. Taking these two parameters - range and median - three classification intervals are established in such a way that they contain a homogenous number of values.

Occupancy

The population within the forest system determines the greater or lesser degree of vulnerability of a specific territory.

$$\text{Occupancy} = \sum \text{Area of buildings in the forest surface area.}$$

Interprets the extension of the settlements in the forest systems: the greater the occupancy, the greater the presence of man-made buildings. (fig. 1) (table 1).



Figure 1—Occupancy.

Table 1—Assignment of the occupancy rate.

Occupancy	Value (m ²)	Index
Low occupancy	0-25,000	1
Average occupancy	25,001-50,000	2
High occupancy	50,001-205,000	3

Interface

From the Civil Protection perspective it is important to locate developed areas which border on (interface with) forest areas. The planning interprets this proximity through interface or common perimeter between forest and urban systems. The GIS enables

this analysis to be done using the map on land use, backed up by the layer of information on the buildings.

$$\text{Interface} = \sum \text{common forest/urban perimeter}$$

Interprets the proximity or contact between urban areas and woodland systems: the greater the proximity (interface), the greater the vulnerability. (table 2).

Table 2—Assignment of the rate of interface.

Interface	Value (Km)	Index
Little interface	< 5	1
Average interface	5.1-25	2
High interface	25.1-115	3

In order to fix the guidelines and priorities for protection, the GIS can locate, analyse and classify settlements depending on the percentage of its interface perimeter with forestland surface area. This forestland-urban interface provides very useful information for establishing the priorities of prevention action and will basically back up the nature and urgency of lower level plans – district, local and self-protection.

The GIS can classify interfaces in the following way:

Type 1 or length of the perimeter corresponding to urban surface area which is completely surrounded (75-100 percent) by forestland

Type 2 or length of the perimeter corresponding to urban surface area which is surrounded between 50-75 percent by forestland

Type 3 or length of the perimeter corresponding to urban surface area which is surrounded less than 50 percent by forestland

Dispersal

The proximity or distance – dispersal - between the different settlements in the forest systems also has an influence over vulnerability and will dictate the degree of concentration of preventive measures.

The GIS will make it possible to determine the distance between the centres of gravity of the different polygons which correspond to the buildings located on forestland (fig.2).

$$\text{Dispersal} = \frac{\sum \text{distance between centres of gravity on forestland}}{\text{Number of polygons}}$$



Figure 2—Dispersal.

Interprets the degree of proximity or distance from the settlement on forestland: the greater the dispersal the greater the separation between the population (*table 3*).

Table 3—Assignment of dispersal rate.

Dispersal	Value (km/number of estates)	Rate
Low dispersal	0-50	1
Average dispersal	501-500	2
High dispersal	500.1-2,100	3

The **vulnerability of the population** is established by a decision matrix which considers three factors, classifying this as **High, Medium and Low**.

Infrastructures and amenities

The impact that a forest fire may have on infrastructures and installations such as **roads, power lines, mobile telephony antenna, railway lines, airports, heliports, leisure parks, and camping sites** among others, makes it advisable to include them in fire protection planning.

The presence or otherwise of these elements shall determine the **vulnerability of infrastructures and installations** which shall be classified as **High, Medium, Low**.

The GIS allows us to intersect the infrastructure corresponding to the forestland and assign the highest vulnerability rate to each grid square. This is obtained by classifying each infrastructure category by damage or loss caused if affected by a fire.

Thus, for example, for roads, the following indexes are assigned: 3 : motorways and dual carriageways, 2: district or local roads and 1: tracks.

In the case of camping sites, recreational areas, hospitals and schools located in the area, the grid squares with high vulnerability of infrastructures and facilities will always be considered.

Vulnerability of infrastructures and facilities is defined through a decision matrix, bearing in mind for each square all the infrastructure present and its vulnerability index.

Overall Economic Value of Forest Systems

The Protection Plan interprets the vulnerability of the integral value of forest systems using the following three indicators: productive value, replenishment value, and

environmental value which by integration determine the **vulnerability of the overall economic value**, classifying this as **High, Medium and Low**.

The *productive value* is an estimate of the price of the forestland. This corresponds to what is calculated in the “technical fire report”.

The *replenishment value* estimates the cost for society of having to replace the burned forestry system – the value of the final cost of repopulation, along with probability and survival.

The *environmental value* is made up of the ecological and recreational value. It is the value which society assigns to its ecosystems – the contingent value of these, distributed superficially by an index based on expert opinion.

In order to determine the vulnerability of the values: production, replenishment, and environmental - which correspond to each of the grid squares, this average value and its forestland is taken into consideration.

Historical and Artistic Heritage

The historical and artistic heritage in specific regions constitutes a major generic type of value to be protected.

The GIS interprets this heritage as the presence or absence of monuments and archaeological remains. This gives us the **vulnerability of the Historic and Artistic Heritage** and is classified as **High or Low**.

Overall vulnerability

Overall vulnerability is defined by bringing together four indicators we defined earlier, classifying the forestland as **Extremely vulnerable**, **Very vulnerable**, **Average vulnerable** and **Not very vulnerable**.

Classification of forest fires by their level of potential gravity

The assessment of human and material resources for fire extinction and, obviously, the protection of persons and property in relation to available resources, gives us a forecast of the gravity of the situation and a fire classification which corresponds to their **potential gravity level**.

Taking this valuation as a basis, a forecast is made of the gravity of the situation using the following scale:

Level 0: Refers to fires which may be controlled with planned fire fighting resources and which, even in the most unfavourable conditions, do not represent danger to persons unrelated to fire-fighting tasks, or to property other than that of the forest itself.

Level 1: Refers to fires which may be controlled with the Plan’s fire-fighting resources at local level but which, due to possible spread, the need to apply measures to protect persons and property which may be threatened by the fire is anticipated.

Level 2: Refers to fires which will require State-level resources not assigned to the local Plan for their extinction, and at the request of the local authorities

responsible for this, or fires which may involve emergency situations which affect national interests.

Level 3: Refers to fires which are declared by the central government as endangering national interests.

It is important to emphasize that fires are classified considering the elements involved in the **behaviour of forest systems in a fire, their reaction and resistance** in a static manner, i.e. at a specific time and as they figure in the data base, after inventory.

From the **Civil Protection** perspective, the assessment of necessary human and material resources is obtained from the **topographical conditions** of the area where the fire or simultaneous fires occur; the **extension and characteristics of the forestall systems** which are under threat; the **conditions of the infrastructures** – firewall areas, road network, water reserves and access points – as well as **prevailing weather conditions** and the **possible dangers or vulnerability of persons unrelated to fire-fighting tasks**.

When planning within a SIG, the information on the different elements refers to a grid square so that each of these is evaluated independently, later grouping these in order to establish the **level of potential gravity** for each one.

Topographic conditions

The topographic conditions have a direct bearing on the behaviour of forest systems in a fire so slopes therefore have an effect on the potential level of gravity a fire may reach.

The Planning interprets topographic conditions using the **forestland slope**. To do so, four groups of slopes are established from the digital model of the land, coded as follows (*table 4*):

Table 4—Assignment of gravity by slope group.

Slope Group	Gravity by slope
0-3 %	1
3-12 %	2
12-35 %	3
>35 %	4

Each grid square is assigned the maximum slope found on forestland.

Extension and Characteristics of forest systems

The extension and characteristics of the forest systems are interpreted through the following indicators: **fuel models, inflammability, continuous forestland and presence of firewall areas**.

Fuel Models

The fuel model determines the greater or lesser ease of forest fire propagation. Each of the squares is assigned the most dangerous model present there, with the

corresponding associated gravity, establishing models of high and thick scrubland as the most dangerous ones.

Flammability

Flammability or the speed with which plant species ignite in contact with a source of heat will affect the potential gravity of a forest fire. From the forest map each square of vegetation is assigned the flammability classification of the most inflammable species and to each grid square its corresponding gravity due to associated flammability.

Continuous forestland

Continuous forestland interprets the extension of the forest systems, an important factor to be borne in mind, since the greater the continuous forestland, the greater the potential gravity of the fire.

The GIS is able to determine forestland continuity and surface area using the forest map (fig.3).



Figure 3—Continuous forestland.

Establishing a number of continuous surface area ranges, each grid square is assigned gravity by continuous forestland surface area, depending on the value reached.

Existence of firewall areas

The scale of firewall areas is another factor to be borne in mind, since the greater the discontinuity of fuel, the less the gravity of the forest fire.

This factor is interpreted by analysing the kilometres of firewall which appear for each square kilometre of forestland, it being possible to establish a number of ranges from the result, to which a specific gravity level is assigned (fig.4).



Figure 4—Existence of firewall areas.

Each grid square is assigned a gravity rate depending on the presence of firewall areas.

Conditions of the physical environment and infrastructures

The conditions of the physical environment and infrastructures which have an effect on the gravity level of forest fires are interpreted through the *road network, water access points, foreseeable fire sites, land and air isochrones, visibility* and *access areas*.

Road Network

The road network is interpreted through the **road density** indicator: kilometres of roads which appear per square kilometre of forestland. The lower the road density the greater the potential gravity.

Each grid square is assigned a rate of gravity per road density, obtained from the road infrastructure in its particular forestland surface area.

Water access points

The water available for extinction, interpreted as available volume, or at access points classified according to type of water source, makes it possible to assign a lower potential gravity rating, since this is an element which affects fire resistance.

Each square is assigned a potential gravity rating according to available water. The greater the amount of available water, the lower the potential gravity of forest fires.

Foreseeable fire sites

Planning must consider all points which are potential fire sites: sanitary landfills, industries with inflammable material, assigning each square a **very high gravity rating** if at least one of these fire sites is present.

Land and air isochrones

From the viewpoint of the potential gravity of forest fires, a major parameter to be borne in mind is the **attack time**. The land and air isochrone maps which give the attack time for each point in the area, assign each grid square a gravity rating by attack time (fig.5).



Figure 5—Land and air isochrones.

Visibility

Another very important parameter related to the gravity of fires is the detection time. The visibility map classifies the forestland as visible and not visible, at least from a

fixed point in the surveillance network, so that to establish the potential gravity of this indicator the non-visible forestland surface area may be used.

For each one of the grid squares the non-visible forestland surface area is obtained, thus establishing intervals to which the potential gravity due to non-visibility can be applied.

Accessibility

We define the *accessible forest area* as the area which may be reached by water. Using GIS, a width of 300 metres may be obtained on each side of the road and from the constructed perimeter – 300 metres is the length the hose stretches (*fig.6*).



Figure 6—Accessible Forestland area.

Each grid square is assigned a potential gravity rate, depending on its available surface area.

Weather conditions

Weather conditions directly affect the level of potential gravity a forest fire may reach. These conditions are interpreted through weather risk, assigning the greatest weather risk present for each grid square.

Possible dangers for persons unrelated to fire extinction

From the point of view of potential forest fire gravity, Civil Protection pays great attention to the possible dangers for persons unrelated to fire fighting tasks. For this reason the Plan interprets this factor through indicators such as: **occupancy rate, buildings difficult to evacuate, presence of recreational areas and camping sites, and their difficulty of evacuation**

Occupancy

In the same way as for vulnerability, each grid square is assigned a gravity rating per occupancy rate, depending on the area occupied by buildings in the forestland.

Buildings, recreational areas and camping sites, which are difficult to evacuate.

The population requires special attention in cases of fire. Buildings must be absolutely accurately located, whether isolated houses or housing estates. In the case of fire there are major problems for their evacuation, as happens in recreational areas and camping sites. In these areas **self-protection schemes** must be developed.

The **difficulty of evacuation** is interpreted from the indicator: *number of buildings surrounded 100 percent by forestland, with difficulty of evacuation*, considering as such:

- Isolated houses in the hills in which there is supposedly an access road but which does not figure on maps.
- Houses with only one exit route.
- Houses with one exit route and one or more roads which terminate in the hills.
- Housing estates with only one exit route.

Recreational areas and camping sites are classified by difficulty of evacuation as *dangerous*, which have only one exit route or several which terminate in the hills, or *not dangerous* which have more than one exit route and are close to a centre of population or an agricultural area (fig.7).

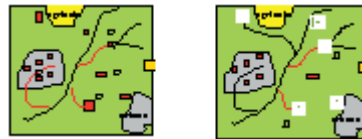


Figure 7—Inhabited areas difficult to evacuate.

Obtaining the Potential Gravity Level for Forest Fires

From a **parametric model** which includes all the above analysed variables, the **potential gravity level** is obtained. This may become a forest fire in each one of the grid squares.

$$\text{POTENTIAL GRAVITY} = \sum_{i=1}^{i=18} k_i \times V_i$$

Each variable is affected by a coefficient which varies depending on its importance in the area considered and adds or subtracts gravity depending on whether it relates to the element which contributes reaction or resistance to the fire.

The analysis of the regional distribution of the level of potential forest fire gravity will make it possible to take suitable **prevention** measures to reduce areas of **potentially high level forest fire gravity** to **lower level gravity potential**.

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