EUFIRELAB : 
Euro-Mediterranean Wildland Fire Laboratory, 
a “wall-less” Laboratory 
for Wildland Fire Sciences and Technologies 
in the Euro-Mediterranean Region 

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Towards methods for studying the costs-to-benefits ratio 
of wildland fire prevention 

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SUMMARY

The whole question is to assess the costs and the costs-to-benefits ratio of the wildland fire suppression drawn from fire fighting.

The report presents a work on improving preventive equipment investment that took place at a local scale of wildfire management.

It is constituted of two parts.

The first one is a bibliographic review of wildfire assessment methods.
These assessments first deal with wildfire damages, then with presuppression (i.e. wildfire preventing) activities.
Studies have been grouped into those valuing the different damages caused by wildfires and the costs of the post fire restoration, and those evaluating various management measures.
It also focuses on the methods applied and the results obtained.

The second part is an attempt to implement a preventive investment choice method, based on a costs-to-benefits comparison.
This method relies on describing fire behaviour, for which potential fire occurrences are assessed according to different equipment levels.
This is a prototype tool that can be used for local decision making.
But the first steps in this methodological undertaking, while offering new perspectives, also highlighted the extent of the unresolved aspects in the decision-making process which need to be clarified.
1 FOREST FIRE VALUATION AND ASSESSMENT: A SURVEY

While the risk of forest fires has been a subject of study from different disciplines, its economic evaluation has received relatively little attention.

This text provides a literature review of studies dealing with the economic perspectives of wildfires and fire management regimes.

It focuses on the methods applied and the results obtained.

The studies can be grouped into those valuing the different damages caused by wildfires and the costs of the post fire restoration, and those evaluating various management measures.

The valuation method used and the values obtained by the different authors are reported in this text.

1.1 INTRODUCTION

Forest fires cause ecological but also economical and social losses.

The burned timber has less value in the market, houses and other premises can get damaged:
- many non-timber products are also affected, like mushroom or medicinal herbs production;
- recreationists experiment a loss in their welfare;
- the biodiversity of the area can be diminished;
- carbon stored by trees is released to the atmosphere;
- in hilly areas the risk of erosion increases significantly;
- people can experience health problem or even die.

Therefore, in addition to studies devoted to the different characteristics of forest fires (ignition, spreading, etc.) also studies on the economic and the social costs of forest fires are gaining more attention.

According to the objectives of such studies, they can be divided into two major groups.

The first group aims at an estimation of the economic value of different damages caused by forest fires and the post fire restoration cost, while the second group of studies is oriented towards the assessment of different management measures.

In addition, in this report, we will follow this pattern; first reviewing the studies related to wild fire damages and restoration costs, followed by a part on the management evaluation.

When valuing the different costs and benefits related to forest fires and forest fire management measures, people value various goods and services.

Some of them are traded in markets (e.g. effected timber, houses, and cars) and their values can be directly observed through market prices, while others the value is not directly observable in existing markets (e.g. fresh air, recreation, landscape aesthetics).

To value fire effects on such goods and services, different valuation methods were developed. Since some of the methods latter on appear in the text, a short explanation about them is given first.

A more detailed description and use of these methods could be found in Camp et al. (2003), among many other references.
1.2 ECONOMIC VALUATION METHODS

1.2.1 Valuation by market prices

One way to estimate the value of some of the goods or services affected by forest fires is by prices, when they are bought and sold in commercial markets.

This approach can be used to value changes in either the quantity or the quality of a good or service. Assuming changes are not big enough to change prices, it is just a matter of multiplying the number of units times the price, to obtain the overall value.

1.2.2 Hedonic Pricing

The first non-market valuation method to be applied was the hedonic price method.

It is used to estimate economic values for those goods and services that directly affect market prices of some other (related) goods or services.

The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics, or the services it provides.

For example, the price of a house reflects the characteristics of that house – size, age, comfort, location, air quality, etc. Therefore, we can value the individual characteristics of a house or some other good by looking at how the price people buy it for changes when the characteristics change.

The hedonic pricing method is most often used to value environmental amenities that affect the price of residential properties (ROSEN, 1974).

1.2.3 Travel Cost Method

The basic idea of the travel cost method is that the time and travel cost expenses that people incur on to visit a site represent the “price” of access to the site.

Since those “prices” are different for different individuals, a demand curve can be derived, and the consumer surplus (or benefit associated to the good consumption) calculated.

The travel cost method is used to estimate economic use values associated with ecosystems or sites that are used for recreation (HOTELLING, 1949).

1.2.4 Contingent Valuation Method

The contingent valuation method involves directly asking people, in a survey:
- how much they would be willing to pay for specific environmental good or services, or in some cases, people are asked for the amount of compensation they would be willing to accept to give up specific environmental services.

It is called “contingent” valuation, because people are asked to state their willingness to pay, contingent on a specific hypothetical scenario and description of the environmental service.

Contingent valuation is a way to assign monetary values to non-use values of the environment—values that do not involve market purchases and may not involve direct participation.

These values are sometimes referred to as “passive use” values.

They include everything from the basic life support functions associated with ecosystem health or biodiversity, to the enjoyment of a scenic vista or a wilderness experience, to appreciating the option to fish or bird watch in the future, or the right to bequest those options to your grandchildren.

It also includes the value people place on simply knowing that giant pandas or whales exist.

The contingent valuation method (CVM) can be used to estimate economic values for all kinds of ecosystem and environmental services (MITCHELL and CARSON, 1989).

1.2.5 Benefit transfer

The benefit transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context.

For example, values for forest recreation in a particular area may be estimated by applying measures of forest recreation values from a study conducted in another location.

Thus, the basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context.

Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed.

Among other factors, the quality of a benefit transfer exercise is limited to the accuracy of the initial study.
1.3 WILD FIRE DAMAGE ASSESSMENT

One of the main issues of economic studies related to forest fires, was the assessment of costs of wildfire suppression and the valuation of wild fire related damages (KLINE, 2004), aiming at the assessment of the damages caused by forest fires or the effectiveness of different forest fire mitigation measures.

The different damages and losses included in such studies can vary to a substantial extent. While some mainly aim at a precise valuation of the timber losses suffered due to wild fires, others include many different categories of losses and damages.

The major categories of damages and losses related to forest fires are: fire suppression costs, disaster relief expenditures, timber losses, property damage, economic activity losses, and human health effects.

Of course, also other potential costs and losses exist (e.g., lost wages, decreased quality of life, higher long-run fire fighting expenditures, landscape rehabilitation, and environmental degradation), but which are considered when estimating the overall impacts of forest fires, mainly depends on the availability and reliability of data.

In general, the economic aspects of the damages caused by forest fires occurring in proximity to settlements are difficult to measure and highly variable.

Some aspects are straightforward and relatively easier to measure, such as fire suppression expenditures or property losses.

Other aspects however are more complex, such as the effect on a regional economy, or changes in recreation and tourism, are easily confounded by other factors, such as general economic downturns or a shift of economic activity from one location to another.

One of the early attempts to present the losses related to the occurrence of wild fires in forests, is given in CROSBY (1977).

A set of value concepts and methods for appraising damages from wildfire is presented. Emphasis is placed on the effects (positive and negative) of forest fires in terms of their impacts on humans and forest management goal achievement.

In the next paragraphs, we are addressing some of the categories of forest fire related damages.

All values presented in the paper, are in 2004 EUR.

1.3.1 Damages of timber and other forest goods and services

Natural catastrophes such as wildfires can have short- and long-run effects on timber markets.

Short-run effects (one to two years) include the immediate destruction of valuable standing timber and economic disequilibrium associated with the flooding of markets with salvaged timber.

The big amount of salvaged timber drives prices downward temporarily, which affects owners of the killed timber, owners of undamaged timber, and timber consumers.

Long-run effects on timber markets can arise from the loss of a large portion of standing volume, a loss that tends to drive prices upward for extended periods and produce a windfall for owners of undamaged timber.

They also can create conditions favourable for a contraction in timber demand.

Therefore, large-scale catastrophes often redistribute wealth among producers and consumers and cause a net economic loss (PRESTEMON and HOLMES, 2004).

MERCER et al. (2000) calculated, due to the limited data available, only the economic effects of the wildfires on the northern Florida southern pine saw timber and pulpwood markets and not considering the hardwood markets.

Welfare effects were assessed based on the short-run losses and gains experienced by producers and consumers during the salvage period and the long-run losses and gains experienced by timber consumers and producers of undamaged timber.

Long-run losses and gains were calculated based on a 3% real discount rate.

It was calculated that the 1998 wildfires had overall negative effects on the northern Florida market for pine timber in the range from 322 million to 551 million EUR.

For the Indonesian 1997 forest fire, where an area of 5 million ha was burnt, 20% of which were forest, the total timber losses were estimated to 467.1 million EUR.

These losses take into account the official estimates of timber stock, growth estimates of forests and net international timber prices.

A net price of 47.3 EUR/m3 was used (EEPSEA, 1998).

In addition, fires can damage other goods and services.

Such as biodiversity, carbon sequestration, animal and plant habitats, recreation possibilities.

Very often the value of such goods and services are estimated in studies where the public support for a fire mitigation plan is explored.

Thus, LOOMIS and GONZALEZ-CABAN (1998) applied the contingent valuation method to obtain estimates of willingness to pay for reducing the number and extent of wildfires within spotted owl habitat of California and Oregon's old-growth forests.
Using a doubled-bounded dichotomous choice approach, the mean annual value per household for a fire management program in California was 74EUR and 43EUR for California and New England residents, respectively.

This study points out that households receive benefits from fire protection of old-growth forests in states other than their own.

In the report on the Indonesian forest fire (EEPSEA, 1998), several other categories of forest goods and services are included (see Table 1-1).

To calculate the direct forest benefits lost, a benefit transfer approach was used, drawing on average world values of tropical rainforest ecosystems, applying them only to the forest area in the sample (i.e. 1 million ha).

Values for culture, timber and climate control/regulation and genetic resources were removed to avoid double counting with independent estimates described elsewhere.

This yielded a net value lost of 501 EUR/ha/yr. It was assumed that non-timber forest products would be re-established after a period of 5 years.

For indirect forest benefits, a similar procedure to that described for direct forest services was applied, yielding a net value lost of 1,401 EUR/ha/year.

It was further assumed that the losses applied only to the area 'effectively burnt' of forest, which was 50% of the actual forested area.

It was assumed that indirect forest services would be re-established after 2 years.

Table 1-1: Other forest related losses for the Indonesian forest fire (in million EUR of 2004)

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Loss 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct forest benefits</td>
<td>667.0</td>
</tr>
<tr>
<td>Indirect forest benefits</td>
<td>1,019.0</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>28.4</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>257.4</td>
</tr>
<tr>
<td>Total</td>
<td>1,971.9</td>
</tr>
</tbody>
</table>

1 expressed in million EUR


The approach used to estimate the biodiversity lost was to value capturable biodiversity from Indonesia's perspective.

The figure takes a value of 284 EUR/km²-year, as an average of values found from various studies of willingness to pay to preserve tropical rainforest of various qualities.

Enormous quantities of carbon dioxide and methane were emitted during the fire.

Such emissions increase global warming, which in turn is assumed to cause economic damage.

From previous studies, for the Intergovernmental Panel on Climate Change, a value of up to 28 EUR on the damage caused by a ton of carbon emitted was estimated.

In this study, a value of 9.5 EUR/ton was used.

1.3.2 Property losses

Very often, forest fires also cause other property losses, in addition to the damages caused to the timber.

These might comprise private as well as public goods, including losses or damages to homes, business, infrastructure and other goods.

The value of such losses is generally calculated through market prices.

However, even in this case where it might seem easy to value damages, a considerable amount of damages could be missed due to incomplete data.

In the study conducted by MERCER et al. (2000), it was estimated that 340 homes, 33 businesses, and several cars and boats were damaged by the wildfires totalling between 9-11 million EUR.

But the estimates included only the losses to insured property and it was assumed, that the amount would double if also the losses to uninsured property would be included.

When calculating this category of damages for the Hynman fire, KENT et al. (2003) included only the value of all destroyed structures that had previously been listed on the County assessors' tax roles and decreased land values associated with the fire were included.

Property that was tax exempt and structures, which were not listed on County assessors' roles, were not included in the loss estimates.

According to the County assessors, private real property loss for the four Counties area directly impacted by the fire was valued at 20 million EUR, with an annual assessed value of 2.9 million EUR, resulting in an annual loss of revenue to the Counties of approximately 200,900 EUR per year.

Additionally, the damage to power lines was estimated at 742,900 EUR.

According to the insurance companies, the total damages caused by the fire to insured private property were estimated at 32.7 millions EUR.

1.3.3 Economic activity losses

Beside the direct property losses, forest fires can also influence the economic activity of a region.

To assess this influence, appropriate geographical impact areas, influenced economic activities, and industrial sectors have to be identified.

One of the procedures to estimate such influences is to collect and analyse data on the economic activities before, between and after the fire occurrence.

For the 1998 fire, which occurred in Colorado, decreased tourism and sales due to forced evacuations, road closures, and negative publicity were expected to reduce actual gross sales.

For the sales, it was found that in the analysed period, they were about 1,000 million EUR higher than one would have expected without the fires.

The increase was present only in the first part of the considered period, and corresponded to the height of the fire fighting costs.
A significant decrease in sales was detected in the last part of the analysed period. It appears that the fires forced increases in present consumption at the expense of future purchases (MERCER et al., 2000).

In the same research, the impact of the fire towards the tourism was calculated on basis of the hotel revenue data. A net lost of 55.6 million EUR in hotel revenues for the considered area was estimated; although only August total losses were statistically significant.

Further, if it was assumed an average tourist spends of 89 EUR per day (non-lodging related spending), with a loss of hotel nights of 70.3 million EUR in tourist spending during the analysed period (MERCER et al., 2000).

The direct impacts on the economic activities were also calculated for the Heyman fire. For this purpose, wages (including salaries), employment, and retail sales were used as the measures of economic activity.

The results showed that the employment increased for almost 0.5% in the main fire impact area during and after the fire, wages decreased a 3%, and retail sales per month increased for almost 4%. Similar conclusions were drawn when considering only the wages paid in the tourism related sectors (eating and drinking establishments, lodging and recreation establishments).

The authors could not prove that the fire had an overall negative impact on the regional economy. However, compared to the previous years, there were substantially more significant negative differences than significant positive differences.

This may indicate that, at least in some areas and sectors modelled, the Hayman fire did decrease economic activity (KENT et al., 2003).

### 1.3.4 Fire suppression costs

The suppression costs include the costs such as field camps, use of equipment, tools and supplies expended or lost, mobilization and demobilization costs, etc, and related logistic costs, like evacuations, emergency operations centres, debris removal, and so on.

Expenditures are corresponding to the area burnt and the phase (initial or extended) in which the fire is extinguished (the severity of the fire) (KENT et al., 2003).

According to the fire reporting system used by the US Forest Service, the cost of suppression measures in Colorado varied from 123EUR to 1,088EUR per hectare.

A study conducted by the Rocky Mountain Research Station (RMRS) of the Forest Service, fires for the in fire years 1996 and 1997 in the western Forest Service regions of the United States showed that the costs averaged about 1,184 EUR per hectare, for fires greater than 2,000 hectares.

The range of values found went from 62.5EUR/ha up to 6,084 EUR/ha (KENT et al., 2003).

In the period 2000-2002, for the whole USA, suppression costs ranged from a low of 321EUR/ha in 2001 to 482EUR/ha in 2002 (OMI, 2004).

The suppression costs calculated for the 1998 Colorado fire reported in MERCER et al. (2001) were between 45 and 91 million EUR for the fire fighting related actions, while the emergency measures reached 18 – 23 million EUR.

KENT et al. (2003) presented a break down of fire suppression costs for the Heyman fire (occurred in the fire year 2002).

A summary of the costs is presented in Table 1-2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel compensation</td>
<td>7,727</td>
</tr>
<tr>
<td>Personnel travel</td>
<td>1,111</td>
</tr>
<tr>
<td>Supplies and services</td>
<td>25,299</td>
</tr>
<tr>
<td>Other</td>
<td>222</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34,359</strong></td>
</tr>
</tbody>
</table>

1 expressed in 1000EUR

The fire suppression costs mainly depend upon the fire size and severity.

In addition, other parameters may influence the total or per hectare suppression costs.

DONOVAN et al. (2002) tested whether the proximity to housing affects the suppression costs.

The hypothesis was that suppression costs would increase if there are more houses in proximity to wildfire, because fire managers would maybe use more resources to protect the threatened houses.

They tested several parameters, which might influence the costs (housing density and total number of houses within the perimeter of each wildfire, fire size, fuel moisture, terrain difficulty, relative scarcity of suppression resources).

Regression analysis showed that only fire size and extreme terrain conditions were significant.

While neither total housing nor housing density explained any of the observed variation in suppression costs.

The authors draw the attention to the fact that results should be interpreted with care.

Fire size is in relation to the suppression costs.

Therefore, this is not completely an exogenous variable, but rather costs and size are determined simultaneously.

On the other hand the insignificance of the housing parameters could be explained by a small size and the truncation of the sample, since cases without losses to houses were not available.
1.3.5 Other damages caused by wildfires

Wildfires produce smoke that contains air pollutants such as particulates, volatile organics (hydrocarbons), carbon monoxide (CO), and nitrogen oxides (NOx).

Depending on meteorological conditions, the emission could impact also the health and well being of those outside the fire regions.

The literature suggests that fires may have several different effects on the health and well-being of the population.

The exposure to smoke – much like exposure to air pollution – is likely to affect upper respiratory morbidity.

In particular, smoke can cause internal lung lesions and the airway’s natural response to such damage is generally increasing inflammation that evolves over time.

This inflammation reduces the size of the airway and can lead to more severe obstructive breathing disorders (FRANKENBERG et al., 2002)

For the extreme forest fires which occurred in 1997 in Indonesia, evidence of increased bronchial asthma and acute respiratory infection was found.

For example, a report from the Provincial Health Office of Jambi, KALIMANTAN showed a 51% increase in cases of respiratory disease in that province during the haze period (FRANKENBERG et al., 2002).

In another study (RUITENBEEK 1999) it was estimated, that 20 million people were at risk for this hazard and the short-term haze impacts resulted in over 946 million EUR of losses.

This impact occurred during the three-month haze episode in 1997, and excluded long-term health-related losses.

The calculation of losses included costs for increased treatments, lost workdays and individuals WTP to avoid illness.

For the Florida fire (MERCER et al., 2000) the yield of pollutant, were determined to be 8.5 kg/ton, 70 kg/ton, 12 kg/ton, and 2 kg/ton for total particulates, carbon monoxide, total hydrocarbons, and nitrogen oxides, respectively.

Emissions were calculated for the 1998 summer wildfires only for a limited area, but it was estimated that they accounted for over 85% of the wildfire related pollution.

To examine whether the extreme levels of wildfire in northern Florida could be linked to actual public health conditions, the admissions records for hospitals located in counties in the zone of greatest wildfire activity, were analysed.

Emergency department visits increased for asthma (91%) and bronchitis with acute exacerbation (132%).

However, the numbers of actual admissions were small and the frequency of some respiratory conditions even decreased, when compared to the previous year.

1.3.6 Post fire restoration measures

The economic analysis of post-fire restoration has received little attention.

Expenditures for rehabilitation and restoration of the burnt sites can be divided into two groups.

First, the burned area emergency rehabilitation treatments like, such as mulching, log erosion barriers, and seeding or scarification.

Those should be conducted within a short period after the fire (up to a year) since their objective is partly to prevent erosion and to control noxious weeds.

Second, the long-term rehabilitation and restoration project expenditures, such as reforestation, infrastructure reconstruction, or research projects (KENT et al., 2003).

The total burned area emergency rehabilitation costs for the Haynman fire were estimated to be around 11.8 million EUR.

In addition, other longer-term rehabilitation (1 to 5 years) and restoration projects were planned in connection with the fire.

These projects included:

1. land and facilities, like trail and road reconstruction, campground and heritage site reconstruction and restoration,
2. habitat restoration,
3. forest health, including noxious weed control,
4. planning and administration,
5. reforestation,
6. watershed restoration, and
7. research projects, such as analysing soil productivity and the effectiveness of rehabilitation.

Nearly 31.2 million EUR were estimated to be spent on those projects.

Some studies on forest restoration after fires have also examined the public’s interest in recovery management of burnt forests (e.g. KENT et al., 2003; CAROLL et al., 2000).

Even if not directly involving the economics of fire related actions, they give information on public preferences.
1.4 EVALUATION OF MANAGEMENT MEASURES

The second broad group of forest fire related studies are those dealing with the economic effectiveness of planned or applied prevention measures.

Prevention measures are basically fuel treatments, such as prescribed fires, thinning, pre-commercial harvesting and other measures (like chemical and mechanical treatments).

One of the principal economic questions is whether the resources spent to reduce the wildfire risk may result in a net economic gain.

Often, the objective of prevention measures on a given forest landscape is to maintain or enhance the annual flow of forest benefits and reduce costs associated with wild-fires, by reducing the intensity, severity, and likelihood of extreme wildfire events.

Investing in fuel treatments in a location implies implicit tradeoffs between the benefits and costs (KLINE, 2004), partly illustrated in table 1-3.

<table>
<thead>
<tr>
<th>Example costs</th>
<th>Example benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel treatment costs</td>
<td>Timber and non-timber forest products</td>
</tr>
<tr>
<td>Fire suppression costs</td>
<td>Grazing</td>
</tr>
<tr>
<td>Smoke from wildfires and prescribed burns</td>
<td>Ecological benefits: wildlife, fish, water quality, clean air</td>
</tr>
<tr>
<td>Fire-related damages to private property, public buildings, roads, and other infrastructure</td>
<td>Recreation, scenery and aesthetics</td>
</tr>
<tr>
<td>Post fire restoration and rehabilitation costs</td>
<td>Carbon sequestration</td>
</tr>
</tbody>
</table>

Although not guaranteed (see DONOVAN & RIDEOUT, 2003; RIDEOUT & ZIESLER, 2004), the expectation is that fuel treatments over the long term will result in lower fire suppression and post fire restoration costs, less smoke, less wildfire-related property damage, and fewer lost of socio-economic and ecological forest benefits.

Evaluating the changes in net benefits that can be expected from fuel treatments involves several things.

Among them, there is the reduction of the likelihood of extreme wildfire events.

This implies the reduction of wildfire intensity, severity, and scale, as well as the effects that treatments and wildfires have on forest management costs and the variety of forest benefits (KLINE, 2004).

Some of the studies concentrate on a detailed analysis of the costs of prevention measures and the comparison of the costs for different types of such measures.

For the Mediterranean forest ecosystems, RODRÍGUEZ (2004) compares the costs of prescribed burning with those of more traditional methods for eliminating excess fuel loading.

The traditional methods considered included clearance (either manual or mechanical), removal and piling, and the elimination of the waste product (by burning or shredding).

On the other hand, prescribed burning unifies the stages required by the former method into one single operation.

A comparison of costs per hectare (average slope and density conditions) between the two methods highlights the competitive advantage of prescribed burning (where the ecological conditions of the forest area are appropriate) over traditional methods.

Analysing the costs for different fuel types, the costs for prescribed burning are ranging form 228 EUR/ha (herbaceous fuel <60cm with low brush content) to 1,976 EUR/ha (debris), while the costs for the traditional system are ranging from 575 EUR/ha to 2,468 EUR/ha (in both cases for the same fuel types as before).

So the cost ratios between the traditional method and prescribed burning are between 1.25 and 2.51.

The per-hectare costs of different types of prescribed burning in different geographic and administrative regions were examined and compared in CLEAVES et al. (2000).

The data was collected by a questionnaire sent to the US Forest Service fuel management officers.

The questionnaire included questions about cost of prescribed burning and the factors influencing them.

In the responses, the officers stated the average, maximal and minimal costs and appointed them into planning and project costs.

Planning costs included burn-plan preparation, compliance with the legislation and public involvement, project planning appeals, post fire evaluation of effects, smoke management, interdisciplinary teamwork, and general overhead.

The project costs were composed of site preparation, ignition and maintenance, mop-up, post fire monitoring, contractor or co-operator costs, and other related activities.

Costs were summarised and compared across different regions, burn types and other parameters.

The results showed that slash burning is the most expensive (390 EUR/ha) type of prescribed burning, followed by prescribed natural fire (374 EUR/ha), while the management-ignited burns (182 EUR/ha) and brush, range and grassland burns (133 EUR/ha) were the least costly.
The largest part of the total costs was appointed to the in project activities, followed by planning costs with an average of 21% of the total costs.

It was also found that the main parameters influencing the cost differences within the same fire type were unit size, homogeneity of objectives, site characteristic, burning condition and management policy.

In the same line, OMI (2004) reports that increases in area to be burned result in lower unit costs of treatment execution.

The study estimated the average costs of prescribed burning projects in the US for the period 1994-1999 to be 85 EUR/ha during the recorded period, varying from a low of 37 EUR/ha to a high of 177 EUR/ha.

The estimates were based on the annual expenditures for these treatments, reported by different agencies in the US.

In addition to private costs, a complete economic analysis should include the relevant social costs and benefits associated with fires.

For example, it may appear that prescribed burning is more cost effective than mechanical treatments given the accounting costs per hectare, but if burning generates significant negative impacts, in the way of increased health costs from smoke and diminished aesthetics, for instance, the actual economic cost of burning may be higher than the cost of mechanical treatments.

Those impacts may be particularly relevant in high-use recreational areas.

However, this is not a great deal of studies focusing on the estimation of fire effects on non-market amenities.

In PRESTEMON et al. (2000), a public welfare maximization function is employed to simulate the publicly optimal level of prescribed burning in a county in Florida.

A wildfire production function was developed. It was based on spatial wildfire simulations and on assumed prices of wildfire damages and prescribed fire costs.

In the model, private decisions on the amount of applied prescribed fire in an individual forest stand were ignored.

Instead, it focused on how prescribed fire could be used to maximize the sum of discounted expected producer and consumer surplus for a region.

To find the optimal levels of vegetation management inputs, stochastic dominance techniques were used to maximize the discounted net present value of public welfare of each prescribed fire policy.

The estimated results showed that only the current year’s prescribed fire area was a statistically significant explainer of wildfire risk and that each 1 percent increase in prescribed fire area would lead to a seven-year reduction of the wildfire area by 0.07 percent.

Consequently, each 1 percent increase in current wildfire area would lead to a 1.4 percent decrease in future wildfire area over the period of seven years.

The simulation results showed that, in the range of the alternative stationary prescribed fire policies considered, probability distributions of the objective function values crossed in the ranges of 3,240 hectares per year to 4,860 hectares of prescribed burning per year.

The optimal policy was identified in 3,650 hectares per year.

The mean value of the objective function for 3,650 hectares per year was -30.18 million EUR, for 2,830 hectares per year of prescribed fire -30.23 million EUR, and for 4,450 hectares per year -30.20 million EUR.

Part of the explanation for the small differences among stationary policies in the 405-8,100 hectares per year, is the small differences in the reduced wildfire areas.

When comparing the policy of prescribed burning of 8,100 hectares per year wht the one where we burn 405 hectares per year, the gain in reduced wildfire area are only 365 hectares per year.

Nevertheless, because of the small cost of prescribed burning, the returns from doing the identified “best” level of prescribed burning compared to the smallest level consistent with the data are large.

There are 176,400 EUR of additional costs if we increase the area treated (by prescribed burning) from 405 hectares per year to 3,650 hectares per year.

At the same time the difference in the net value saved amounts to 3.2 million EUR - a marginal benefit to marginal cost ratio of 18.

Beyond 3,650 hectares per year, given the prices considered, the marginal benefits are lower than the marginal costs of conducting more prescribed burning.

LOOMIS et al. (2003) compared the benefits from reduced sediment with the costs of prescribed burning to generate a more frequent and low intensity fire regime in the wild land-urban interface of the San Gabriel Mountains of Southern California.

The aim of the comparison was to estimate the economics effects of prescribed burning under a frequency of 5 and 10 years.

For that, a cost-benefit analysis approach was undertaken.

A sediment yield model was developed, to test the influences of different fire frequencies on the debris quantity.

Data from the model were used as one of the inputs for the benefit-cost analysis.

The main benefit was the cost savings from reduced sediment yield, which lowers the costs of debris basin clean out.

The cost savings were estimated according to market prices.

Further, also the value of recreation at risk of forest fires was valued.

The approach chosen was a benefit transfer from previous studies.

Afterwards, a benefit cost comparison for the different prescribed fire regimes (5 and 10 years frequency) was conducted.
When only cost savings and recreation at risk of wildfires were considered, the net present values (NPV) for both regimes were positive, and the 5-year frequency preferred.

For the 5-year frequency the NPV was of 41,542 EUR/km², while for the 10-year frequency it amounted to 13,408 EUR/km².

A sensitivity analysis of the results showed that considering different prices of the clean-out and recreation losses due to prescribed burning could lead to a negative NPV for both regimes.

HESSELN et al. (2003) examined the effects of fire on recreation using the travel cost method.

The model was specified to calculate the consumer surplus and to indicate whether fire effects have an influence on visitation and value of trips taken, and how this differs between Colorado and Montana.

As parameters describing the effect of fire, time since the last fire was used.

The results showed that the average number of individual trips taken per site in a no-fire situation in Colorado was 10.28 with individual net benefits per trip averaging 47.2 EUR.

The number of individual trips taken per site in Montana was similar (10.25), with individual net benefits of approximately 10.3 EUR.

It was also shown that the time elapsed since the prescribed fire had a slightly positive effect on visitation in both states.

With respect to fire effects, it was found that wild and prescribed fires have varying effects on recreation demand and benefit in each State.

The overall annual recreational value for the prescribed fire areas increased significantly in Colorado (346%), while in Montana the change was not significant (1.7%).

On the other hand, crown fires resulted in decreased recreational annual values of 69.3% in Colorado and 86.7% in Montana.

In another study, LOOMIS et al. (2001) looked at the effects of forest fires on the benefits from hiking and biking.

Visitors to National Forests in Colorado were surveyed to determine whether the time elapsed from the last fire and the presence of crown fires affected differently to the amount of hiking and mountain biking recreational visits and their benefits.

To estimate the latter, a count-data travel cost model combining actual and intended behaviour data was used.

The intended behaviour trip questions asked about changes in the number of trips due to the presence of a high-intensity crown fire, prescribed fire, and a 20-year-old high-intensity fire at the area respondents were visiting.

Using the estimated recreational demand function, the number of years since a non-crown fire had a statistically significant positive effect on the trip demand of hikers.

In contrast, presence of crown fires had no statistically significant effect on the quantity of hiker trips, but had a significant and negative effect on mountain biking trips.

Crown fires also had a large effect on the value per trip, with crown fires increasing the value per hiking trip but lowering the value per mountain biking trip.

KAVAL et al. (2004) interviewed Colorado residents living within the wild land urban interface to find out their preferences on various fire management prescriptions aiming at restoring Colorado forest natural ecosystem health.

In a CVM setting, the respondents were asked for their preference and WTP on three programs: fire suppression, fire prevention and prescribed burning.

The WTP questions were asked as dichotomous choices (willing or not willing to pay some given costs for the respective policies).

The hypothesis was that WTP would be higher if the perceived fire danger increased.

The results indicated that approximately 66% of the respondents would pay for prescribed fires and fire suppression, while 60% of the respondents would pay for fire prevention.

WTP values for the various fire prescription methods ranged from 435 EUR to 561 EUR annually per respondent.

The perceived fire danger influenced WTP. For prescribed fire, WTP was influenced by perceived fire danger (271 EUR) and perceived fire frequency (-6 EUR per year for each additional year of the fire interval).

Fire suppression WTP was not influenced by the degree of fire risk or fire frequency.

However, the WTP for prescribed fire was influenced by frequency (-6.9 EUR per year for each additional year of the fire interval).

Respondents were also asked which fire management technique they would like to see used if they only had one choice.

Over 85% of respondents stated that they would prefer prescribed fires.

LOOMIS and GONZALEZ-CABAN (1996) used a combined telephone contact-mail booklet-telephone interview of California and New England households regarding their willingness to pay for fire management in California and Oregon's old-growth forests.

The aim was to test hypotheses regarding the spatial extent of the public goods demand.

Using a multiple-bounded contingent valuation question, the study found that the annual willingness to pay by New England households for the California and Oregon programs was statistically different from zero.

This suggested that households receive benefits from fire protection of old-growth forests in states other than their own.

In this case study, limiting the survey sample to State residents where the National Forest is located would reflect about 20% of the national benefits.
However, using resident’s value as a proxy for non-residents would overstate the national benefits by 75%, since the values per household are significantly different.

This finding suggests that more emphasis should be put in future surveys on selecting an institutionally and economically relevant sample frame rather than an expedient one.

In another survey, conducted by Loomis et al. (2000), an attempt was made to determine the level of support of Florida residents ascribed to the Expanded Florida Fire Management Program according to the belonging to different ethnic groups and concerning their relative location to past large scale wildfire events.

The program contemplated three alternative mitigation strategies: prescribed fire, mechanical mitigation, and herbicide application.

An additional objective of this study was to compare knowledge and attitude responses concerning wild and prescribed fire with past surveys, across language groups, and after the introduction of educational information.

A dichotomous choice CVM approach was used to elicit the willingness to pay (WTP) for three alternative wildfire mitigation techniques.

The results of the survey are presented in Table 1-4. The negative median for the herbicide treatment indicates that half of the respondents would have to be compensated 125 EUR a year before they would support the program.

Table 1-4: The median and mean willingness to pay (WTP) for the different proposed treatments (in EUR of 2004, for household)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Median WTP 1</th>
<th>Mean WTP 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prescribed fire</td>
<td>153.79</td>
<td>162.83</td>
</tr>
<tr>
<td>Mechanical</td>
<td>90.00</td>
<td>142.32</td>
</tr>
<tr>
<td>Herbicide</td>
<td>-125.40</td>
<td>126.85</td>
</tr>
</tbody>
</table>

1 per household in EUR

With a cost of 0.9 EUR and 100 percent belief in the effectiveness of the program by all households, the percentage of votes in favour of the prescribed fire program would raise up to 89% only.

In addition, statistically significant differences appeared between knowledge and attitude from Hispanic and English respondents.

Hispanic respondents showed lower knowledge and a higher perception of risk toward wild and prescribed fire.

Even after the introduction of the educational information, which increased knowledge and improved attitude for the entire sample, the gap continued to exist.

However, race and living distance from past wildfires proved to be insignificant influences on the support rate for the three alternatives.

In Europe, Riera and Mogas (2004) also conducted a simulated referendum application.

They looked at the approval rate for financing a program that would lower the risk of forest fires in Catalonia (Spain) to half of the number of hectares burned on average yearly.

The cost was estimated to be of 6 EUR per person and year to be paid indefinitely.

The results showed that 63% of the respondents would support and pay for the programme.

The analysis also showed that people more likely to directly enjoy the forests are also more likely to agree to pay for the risk reduction program.

In addition, a positive relationship between the acceptance of the programme and the membership in an environmental organisation was found to be significant.

Furthermore, a significant correlation was found between the support of the programme and the age of the respondents, where older people were less likely to support the programme as the middle-aged and young people.

Also respondents living in larger urban areas (municipalities of >100 000 people) and those with a higher income were much likely to support the programme.

On the other hand it wasn’t found that gender significantly influences the support of the programme (Farreras et al., 2005).
1.5 CONCLUSIONS

The social and economic effects or consequences of forest fires can be extensive, long lasting, and complex to identify and value.

However, the challenge for the discipline of economics has not received the attention that issues related to ecological forest fire have (Rideout, 2003).

Some of the fire impacts that are relatively easy to determine, are those related to the destruction of private houses, public property, infrastructure, timber, and suppression costs.

It is a bit more demanding to estimate the recreational losses, although there are a relatively considerable number of studies estimating such values.

Other impacts, however, are more difficult to value (and even to predict) with confidence, since they will appear during the next several years.

This category of damages can include reduced property values, lost sales tax and business revenues, damage to the health of individuals and resulting costs, increased water treatment costs and other (non-market) costs (e.g. aesthetics, habitat damage, reduced biological diversity, or climate change, among others).

According to the diversity of goods and services, which can be damaged by forest fires, the economic studies have used and combined different valuation methods.

Different policies and management practices have been developed to lower the risk of the appearance of forest fires and the social cost they are causing.

These policies tend to require high amounts of public funds.

Consequently, some research has been conducted to check whether the funds bring the desired results (their effectiveness) and whether they are allocated efficiently (not wasting resources).

Some of the studies have taken a referendum type of approach, while others have conducted more formal cost-benefit analysis.

From the survey, it seems that more comprehensive studies, as well as specific ones, are needed.

The geographical concentration of the studies in the USA also suggests that more efforts are needed in other parts of the world.
2 METHODOLOGICAL APPROACH: PRESENTATION

The method is dedicated for help in decision-making in Land use planning aimed at protection against wildland fires.

The purpose here, using a case in France, is to present the basis of a reasoned methodology for making choices in preventive investment.

This method is grounded on a theoretical approach: risk theory in the field of economics.

Bridging the gap between the theoretical basis and the actual carrying of the practical application in all its complexity raises difficulties.

The first steps in this methodological undertaking, while offering new perspectives, also highlighted the extent of the unresolved aspects in the decision-making process which need to be clarified.

2.1 CONTEXT

In France, protection against forest wildfire combines two aspects, prevention and fire fighting.

Prevention seeks to limit the number of outbreaks and their spread, so reducing recourse to direct fire fighting and making it more efficient.

Direct fire fighting, which combats actual outbreaks, gives priority first to the protection of people, then to property and possessions and, lastly, to the forest.

The overall efficacy of the arrangements has proved their worth, given that over recent years the annual total area burnt out has decreased, despite the regular increase in woodlands and in the biomass per hectare.

It should be noted that there has been no attempt to determine how much of this relative success can be ascribed to the efficacy of prevention and fire fighting and how much to fairly favourable climatic conditions in any year.

However, the potential level of danger from fires in the future, that is to say the exposure threatening important or vulnerable sites, is rising.

Indeed, the increase in woodland areas has meant that zones harbouring inflammable matter have been encroaching on sensitive urbanised areas.

This major increase in the risk to ‘periurban’ areas – those on the outskirts of built-up areas – is highlighted by the massive wildfire around Marseille in 1997 and the fires during the 2003 season.

One can conclude, therefore, that to maintain the present level of protection against wildfire it will be necessary not just to maintain current means but, rather, to increase them and/or (which is the purpose of the present paper) try to improve the efficacy of the means presently available.

However, improving the efficacy of the prevailing arrangements supposes that there is a method available for deciding which of the possible land use measures will be the best.

At the present time no such tool exists beyond the assertions of expert opinion.
2.2 AIMS

The general aim is to propose a methodology enabling those concerned to justify all decisions concerning a choice in expenditure preventively geared to the improvement of land use as enhanced protection against forest fires.

Such a method should enable a choice to be made between the different technical solutions, keeping in mind the potential consequences of each of the various solutions on the one hand and, on the other, the cost of their implementation.

By way of illustration, the example of cutting DFCI tracks and roads is pertinent (DFCI – in French défense de la forêt contre l’incendie: defending forests against wildfire).

In a given woodland zone, the choice may be:
- either to do nothing,
- or to create new paths of a stipulated size,
- or to maintain the existing network in whole or in part.

The solution will have, of course^1, a direct effect on the efficacy of the protection designed for the area and it should be adopted keeping in mind the reality of the funding and the vital aspects under threat.

Decisions are thus dependent on a cost-benefit type of assessment of the investment decisions and the damage to be avoided.

One of the purposes of the present study is to show how it is possible to design tools to help public bodies make the right decisions.

The method is based on a monetary assessment whose credibility derives less from its technical accuracy in giving actual figures than from the consensus it can generate and the overall coherence of the approach.

Its finality should be the applied expertise producing a scheme for zoning and equipping a forested area or the assessment of specific investment aimed at prevention.

The method will thus enable choices to be justified in the light of the funding available and the protection objectives being pursued.

The notion of assumed risk will here acquire a new legitimacy as far as a locally made decision cannot be taken without regard to the means available.

2.3 GENERAL DESCRIPTION

2.3.1 Three series of difficulties

The overall risk can be defined as a cross between the ‘threat’ and ‘vulnerability’.

2.3.1.1 First series of difficulties

It arises from the fact that we have no scale for measuring the effectiveness of a method of prevention. Certainly it can be assumed that for a given technique efficacy will increase when investment is increased.

But doubtless the increase will not be proportional.

Thus, doubling the length of DFCI track and road will undoubtedly improve the prevailing situation but nothing guarantees that the increased effectiveness, measured in terms of burnt-out area, will be “doubled”.

This would indeed also be the case if the aim was to reduce the linear extent requiring upkeep: less upkeep would not necessarily mean more damage.

This non-proportional effect of action affecting a measure comes from the fact that the efficacy of a measure cannot be dissociated other than artificially from the effect of the overall scheme. Particularly on this account, then, it appears clear why it is difficult to compare two methods of prevention and decide which of the two to invest in.

2.3.1.2 The second difficulty

It is related to the requirement that the amount of prevention undertaken should logically be proportional to the level of threat.

Thus, just as logically, one needs to be able to assess exactly the threat that wildfire represents in a woodland area, zone by zone, in order to be able to compare such a threat within the given area, as well as between it and other woodland areas.

In fact, at present no method of risk assessment can lay claim to unchallenged scientific backing such that it can be adopted as the reference.

2.3.1.3 The third difficulty

It is connected to the economic dimension; it has two aspects:

First, the idea posited in economic terms is to optimise an investment function through land use techniques within budgetary constraints.

This presupposes that the costs of improvements are known.

Yet, this is not simple to attain because such costs are made up of indirect costs deriving from various services whose departments do not usually use analytic accounting.

The second aspect is trickier: it involves taking into account the “profits” deriving from methods of prevention.

This means evaluating the extent of the damage statistically avoided, then putting a monetary value on it.

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^1 The tracks in themselves are only a means, it is the way the firemen use them that makes them efficient. Strategies for prevention and fire fighting must not be dissociated.
This constitutes an important element in the investment decision because economic logic assumes that the “yield” on any investment be the highest possible.

The crux of the difficulty, as is well recognised, is that potential damage may involve *saleable goods or property* such as timber or assorted buildings but may also involve *non-commercial goods or property* such as landscape, historic or natural heritage … as well as human life.

The principle underlying the methodology proposed here has been to carry out an analysis of events which can potentially occur in the light of the level of existing, or indeed projected facilities so that it can be used to prepare a cost-benefit type analysis providing argued justification for decisions concerning the facilities in question.

As far as the question is much too complex to be tackled by various point-by-point analyses that are then reassembled into a final decisional model, we propose here to work directly on complex situations, which we call scenarios.

We define scenario as the description of a wildfire, which has occurred, or might occur, in a specific woodland area.

The scenario is made up of descriptive elements concerning the situation of the outbreak of wildfire, its spread, aspects of its extinction and the damage caused.

With a given scenario as the starting point, it is possible to imagine one or several new scenarios by the hypothetical modification of such factors as the presence or absence of improved features in land use, wind speed…

Drafting such scenarios involves several stages.

### 2.3.2 Choosing a site

It is necessary to start from a concrete situation to achieve the design and fine tuning of a method.

The scale of a site should match the area involved in land use decision-making.

We have therefore decided to address an area as circumscribed by a *PIDAF* (in French: Plan Intercommunal de Débroussaillement et d’Aménagement Forestier), meaning Intercommunity Plan for Clearing Brush and Undergrowth and Land Use Improvement in Woodlands.

The documents involved in designing a *PIDAF* are of great interest in the description of the initial situation and also for the taking into account of land use projects, whether carried out or not.

Furthermore, stakeholders and others involved locally have experience that makes it possible to validate the relevance of the proposed scenarios.

### 2.3.3 Interconnecting scenarios through a cascade

What is required is to design scenarios that could really happen, beginning either with actual events or with descriptions already featuring in the *PIDAF* documents or, indeed, with wholly imagined situations.

Such scenarios represent different degrees of catastrophe, going from an outbreak quickly put out and having no impact to highly destructive blazes raging out of control.

#### 2.3.3.1 A cascade of branch streams

The scenarios take shape from an ensemble of dynamic situations resulting from external factors such as weather conditions, along with factors connected to decision-making such as when to launch intervention activity and how to carry it out.

Thus the scenarios are inter-related in an overall cascade of branch streams in which the intersections represent divergence in the external or the decision-making factors.

It will thus be possible to reconstitute the cascade of interconnections, from the most uneventful to the most catastrophic, articulated by derivations, which represent alternatives deriving from factors governing the development of the wildfire.

Clearly, scenarios and their cascading relationships will in practice have been built up simultaneously.

The advantage of building up such cascades when compared to a simple cross-section of scenarios is that first of all a cascade, given the infinite number of possible cases, enables us to visualise how the scenarios have been chosen and described.

Further, the cascading scheme represents, or at least symbolises, a scale of possible cases in the sense that, between two extreme scenarios, variations in factors generate intermediate scenarios in terms of damage sustained.

Finally, the divergence of the events represented in the cascading scheme, which allows all the different chosen scenarios to be worked out, makes it possible to visualise the branching out of alternatives that arise from the conjunction of different factors or decisions, both favourable and unfavourable, at a particular point in time.

Each branching off must be ascribed a localised probability whose assessment on the way to attaining a given scenario gives a measure of the overall probability of the scenario.

Once the wildfire scenarios have been reconstituted, the damage consequences of the wildfire will have to be evaluated.

This stage forms an integral part of working out the scenarios but given the difficulty of carrying it out it merits special treatment. In fact, the damage takes into account the incidence of wildfire, but also the intensity of the fire at the time it travels through.

Whenever destruction is only partial, its assessment is difficult.
2.3.3.2 Assessing the probability of scenarios

Protection against risks must take into account the fact that catastrophic events, that is to say the most destructive, are the most rare.
- very high level of investment to counteract them
- a need to assess the probability of such scenarios
- cost-benefit comparison dependent on such assessment, based on the different diverging options.

To assess the probability of a scenario is thus to follow the path taken in designing the scenario, taking into account the independence or dependency of the successive events.

The results of this stage are difficult to validate.

2.3.3.3 Submitting to expert opinion

The actual likelihood of proposed scenarios has been submitted to the appreciation of experts whose experience can to some degree help obviate mistakes in assessment due to lack of hands-on knowledge in the field.

Such submissions have also to some degree, depending on the differences of appreciation recorded during discussions, made it possible to evaluate what derives from an arbitrary aspect of a decision as opposed to what derives from a real understanding of the phenomena as generally agreed.

An individual study has also been carried out to determine what fire fighting strategy and means were actually deployed in the area under consideration.

2.3.4 Economic assessment of the scheme

The relevance of investment decisions and their efficacy in the light of the stated aims necessarily brings into play economic, or simply financial, criteria, though these are not the only factor in making choices.

For a given budget, it is rational to get the best possible out of those preventive land uses chosen.

Such economic criteria are, on the one hand, the expenditure incurred and, on the other, the benefits hoped for or actually observed.

It is thus necessary to draw up the basis for the application of a cost-benefit methodology to the area forming the object of study.

The design of scenarios, having facilitated the description of real or potential wildfire situations, including, in particular, the damage caused but also the likelihood of occurrence, forms the basis for an attempt to give economic indications of a cost-benefit type.

It is not a matter here of making use of a cumbersome method of analysing the costs involved in preventive schemes and facilities and it is even less a question of putting an estimate on the “value” of forests and its derived products.

The aim here is to determine the level of accuracy required in these investigations such that that they fit homogenously with the level of uncertainty involved in the description of the scenarios.

Thus, the exact knowledge of the value of vulnerable property is of little interest if we have not ascertained the probability of destruction.

We are proposing a global, homogenous method, validated by users and with a measurement of the degree of progress accruing from it.

2.3.4.1 Methods of assessing the “profits” connected to forests

The evaluation of the losses avoided (evaluation of the benefits resulting from the application of methods of protection) is a tricky operation because generally it is not possible to ascribe the sparing of the damage to a single method of protection taken in isolation.

Moreover, the definition of benefits remains problematic for everything involving non-commercial goods or property (for example, landscape), or moral damages (representations).

Methods of economic assessment in these fields are complex and controversial.

In the context of the present work, assessment of such “profits” was only possible using certain data cited in the relevant literature and whose stated values corroborate each other such that, while not proving reliability, do still provide a minimal consensus.

2.3.4.2 Analysis of the costs of DFCI (defending forests against wildfire) and fire fighting

An evaluation of the direct cost of any given method will be inadequate if the method is not put into its context A quick evaluation of the overall costs of protection was therefore undertaken.

It seemed necessary to take into account the costs of fire fighting in the same way as the costs of prevention, given the interconnectedness of the schemes and facilities and the reciprocal effects of the strategies in each of these two facets.

2.3.5 Envisaging alternative scenarios

It is possible to conceive of varying scenarios by introducing hypotheses about the extent of preventive equipment in the area under study.

At a theoretical level, this poses no special problem since it amounts to re-utilising, as it were, the approach worked out in a slightly different case in which a parameter concerning equipment varied.

At a practical level, however, a real difficulty arises because it is necessary to discriminate between events connected to circumstances displaying little difference and then assess their physical and economic consequences.

Therefore, in an early stage it was necessary to choose differences clear enough to avoid their being covered over by the level of general error inherent in the method’s imprecision.

The importance of this issue at this stage is critical because the credibility of the results obtained conditions the emergence of a powerful tool for helping in the decision-making process. In fact, being able to compare two differently equipped situations is tantamount to having a tool for simulation that enable a decision to be explained rationally or at least justified.

This can be useful when the context of decisions by public authorities involves a legal liability.
3 METHODOLOGICAL APPROACH: APPLICATION

3.1 GATHERING DATA

3.1.1 The area of application – the PIDAF de la Côte Bleue

To verify the applicability of a method under enquiry, it needs to have been designed starting from a concrete situation.

The choice here was of a PIDAF, which is a unit for the technical management of prevention and a unit for the scheduling of the corresponding expenditure.

The choice of the PIDAF de la Côte Bleue, in the Mediterranean region in the Bouches-du-Rhône department near Marseilles, results from the fact that this PIDAF is in the process of being carried out.

Its technical application and follow-up has been made the responsibility of the ONF (the French National Forestry Commission). The description of this programme has been detailed in a document entitled PIDAF Côte Bleue (ONF 1993), which is the source of the main characteristics described below.

The PIDAF covers an area of 13,000 hectares located across seven municipalities (Carry le Rouet, Châteauneuf-les-Martigues, Ensuès la Redonne, Martigues, Les Pennes Mirabeau, Le Rove and Sausset les Pins).

The PIDAF covers only 63% of the municipalities’ total area, and 78% of the PIDAF is unoccupied natural land.

A typically Mediterranean climate prevails along this coastal area, which is very arid, with irregular rainfall and very little in summer.

Geologically, the limestone La Nerthe Mountains structure the area, forming a platform at 250m above sea level to the east, dropping off westward to 150m.

There are 9 zones classified in the natural heritage inventory as terrestrial ZNIEFF (flora and fauna of major importance or interest).

The demography of the area has undergone a massive and invasive increase over recent decades. At the same time, agricultural activity has all but disappeared.

Together, these aspects increase the threat to the area, although it is not much frequented despite its proximity to Marseille.

3.1.1.1 The tree stands

At the time the PIDAF was being drawn up, 60% were pine forests of which half were dense.

These are fairly badly deteriorated due to various human activity and wildfires. 46% of the stands are patchy stands covering only 10%-40% of the soil.

3.1.1.2 Wildfire in the area

During the period 1973 – 1990 there were:
- outbreaks of which 402 (70%) were in summertime
- hectares burnt out of which 4,770 ha (90%) burned in summertime
- fires < 1 ha
- 17 fires> 50ha representing 3% of wildfires and 82% of burnt-out area (4,382 ha).

Four sites are considered to be ‘tinderboxes’. They are urbanised zones located in the north of the area bordering on natural land areas.

The road network (motorways, main and secondary roads) throughout the natural land areas adds up to 75 kilometres.

The EDF (national electricity grid) lines carrying different strengths of current add up to 143 km.

Because the area is not classified (in the meaning of article L. 321-1 of the French Forestry Code), the EDF (French National Electricity Board) does not have to clear undergrowth 10 m wide below the lines.

Finally, there are 27 km of railway lines, mostly in the south of the region apart from the incline up to Martigues.

3.1.1.3 DFCI (fire fighting) facilities

Tracks and access

328 km of tracks are accessible to light vehicles of which some 40 km of public ways are bordered by a safety strip cleared of undergrowth (Bande débroussaillée de sécurité - BDS).

This represents a density of tracks of 3.1 km per 100 ha, which is higher than the accepted norm (1.5 km/100 ha).

In fact, the diagnosis of the prevailing situation is very negative: “bad state of the road surfaces, width often insufficient, numerous dead-ends”.

Tanks

16 aboveground tanks of 60 m³ situated throughout the area, one of 120 m³

This equipment does not need to be added to in the immediate future.

Surveillance by DFCI patrols

Three permanent teams, Côte Bleue, Martigues and Arbois, patrol the area.

But there are some zones without fire watches, particularly in the northern foothills where outbreaks of wildfire are very dangerous.
3.1.2 General aims defined in the PIDAF

The general aims defined in the PIDAF form the basis of the investment plan for the whole area.

The equipment and facilities represent given and fixed data for the drafting of scenarios.

The other aspects remaining to be carried out can be updated each year taking into account the general aims but also any new constraints, especially budgetary ones.

The PIDAF presentation report expounds its general aims in the following terms:

- the priority is to reduce the area burnt out and extend the rotation periods thanks to the protection and the optimal use of the area through recourse to innovative, dynamic solutions
- the aim is to facilitate the reappearance of a forest ecosystem that will be richer biologically but also more resistant to wildfire than the garrigue, the typical Mediterranean bushland
- all this while seeking to keep costs reasonable so that the project will be seen as viable.

Following these aims, “action to be undertaken” is detailed in some twenty pages which form a real ‘guide’ to DFCI (preventing and combating wildfire).

However, the various facets of this “action to be undertaken” are not ranked in importance: priorities do not stand out clearly.

It is the purpose of the programme here to propose a method for determining such priorities.

Furthermore, certain aspects of the prescribed action involve decision-making beyond the simply local level.

There then follows thereafter the planning for the various projected undertakings with their estimated costs, listed municipality by municipality.

The bulk of the action consists in the opening up and maintenance of tracks, creating a funnelling network and cleared safety strips (BDS).

The underlying idea is to try to avoid the spread of “catastrophic” fires.

To this end the first objective has been to partition the area into 500ha plots.

Essentially this is done with tracks running north-south, the direction of the Mistral the prevailing wind, to facilitate the lateral channelling of the fire.

The forecast investment stated in the PIDAF start-up document is 3,643,226 Euros exclusive of taxes, or 4,357,299 Euros taxes included over 10 years.

This works out at 16 Euros per hectare of PIDAF woodland per year over 10 years.

3.1.3 Survey of the means applied locally

The putting together of the cascade of scenarios revealed one cannot envisage a strategy for prevention separate from a strategy for direct fire fighting.

Designing a policy for opening up and maintaining tracks presupposes that there has been an analysis of the emergency means.

Furthermore, the choice of working in a real situation, that is to say on the scale of a PIDAF, required taking into account the local conditions of the protection scheme from both a prevention as well as a direct fire fighting perspective.

A survey was thus carried out of the equipment available to the fire brigades (SDIS 13, Centre de Secours, Martigues, area headquarters (COZ), and the authorities involved in prevention: the departmental section of the state agricultural and forestry service (DAAF) and the French Forestry Commission (ONF).

A synthesis of the six interviews is follows below.

3.1.3.1 Set-up and means available for direct fire fighting

- On the ground

The manpower, facilities and equipment available in the PIDAF zone

There are 4,500 firemen in the Bouches-du-Rhône department of whom 1,000 are professionals and 3,500 volunteers, stationed at 68 centres across the area.

From the beginning of July, there is a round-the-clock presence of four people in each fire station.

270 firemen are on call in groupes d’attaque for fast intervention.

A groupe d’attaque is made up of four vehicles + a command vehicle.

Throughout the whole department, it is possible to call on 16 groupes d’attaque of 18 people each.

Two emergency centres cover the PIDAF zone.

Martigues Main Station: 5 big fire engines, 4 CCF fire fighting tanker trucks 2,000-4,000 litres, one of 11,000 l. (9,000 l. water + 600 l. retardant) + 1 CCGC (8,000 l.).

The advance post at La Couronne is staffed year long with 4 people and 1 big fire engine.

Surveillance is organised based on a grid system with vehicles allocated to each plot section.

There are a total of 60 light water-carrying vehicles (capacity up to 800 l.) in the Bouches-du-Rhône.

The forces available are either the GIFF – Groupe d’intervention Feux de Forêt, with heavy equipment (4 big fire engines, 2 with very large capacity) or fast action groups (2 CCF machines of medium size). Of these latter the Bouches-du-Rhône department has some 25-30.

In the PIDAF de la Côte Bleue the only pre-positioned equipment is that of the SDIS – the fire and safety service of the Bouches-du-Rhône Departmental authority.

Forestry firemen carry out the fire watch patrols.
There are light vehicle patrols without water (VLS), 0 to 2 in the PIDAF area (possibility of 2 half-groups with 2 vehicles).

5 VSI’s (surveillance and intervention vehicles), 2 persons per patrol with 600l. of water.

In addition to these patrols, there are 8 others for raising public awareness and policing; also sworn-in ONF or DDAF officers during high-risk periods only, 8 x 2 days a week depending on the threat.

5 VSI patrol vehicles along the Côte Bleue (forestry firemen).

Lastly, it is possible to call on army patrols for dissuasion / prevention: a trial in 2002 seems to have had an influence on the number of outbreaks.

The patrols do their rounds from 11h. to 19h; but ordinarily stop for the night.

The fire brigades would like longer schedules. Very few outbreaks occur before 11 h.

At night, watchmen have difficulty detecting outbreaks because at the start, they give out only faint light and the smoke is not visible.

This makes intervention difficult.

At night the firemen often get to a fire at the same time as, or before, the patrols, which make such patrols less useful.

There is no pre-positioning of forces in wintertime: though possible, it remains rare.

During this season, the Fires Service’s emergency centres intervene.

Similarly, during February-March patrols are possible in the event of the Mistral wind.

Pre-positioning strategy is based on optimising the speed of access to any potential outbreak location.

The Bouches-du-Rhône department has been divided into 7 weather zones.

The road network is a vital link in the pre-positioning scheme, which is established depending on the likelihood of outbreaks: low (no means made available), normal, severe, very severe, exceptional.

Pre-positioning forces assumes that owners have given permission, which implies reliable network of locations.

Vulnerability to threat is not “taken into account” in pre-positioning, but is factored in during the monitoring as the wildfire evolves.

**Time lag before intervention**

Some experts consulted have given 7 minutes as an average time lag before intervention.

This period varies depending on the location and traffic jams.

10 minutes is also given for the pre-positioned forces.

Firemen in groups progress at the rate of 1km / minute.

**Fire watch groups**

In the department 28 lookout patrols detect and confirm outbreaks.

Their mobilisation is planned according to the threat of fire.

Coordination is done by the fire tower group at Grand Puech where all information is channelled and assessed before transmission to the CODIS.

The fire watch group at Istres is responsible for the Côte Bleue and the group at Arbois for the north of the area, though this group is quite far away.

- Airborne lookouts with water-bearing aircraft

The strategy with airborne means is based on the triad: Risk assessment, Mobilisation, Applying the means.

- Assessment. Assessing the threat of wildfire has made great strides forward over a short time and it is largely for this reason that overall progress has been achieved. Assessment involves 4 parameters: the weather for 90%, dryness of conditions, the vegetation, analysis of the operational means available.

- Preventive readiness. Attacking a new outbreak is in the hands of the pre-positioned ground forces (firemen, forestry personnel, military). Airborne equipment (28 aeroplanes) is based at 5 locations across the area. In the high-risk period an Airborne Watch with loaded aeroplanes is maintained. It is expensive.

- Means. In 2001, there were 100 airborne watches during the campaign. However, on average they operate 70-80 days. 12 Trackers, 2 Fokkers and 11 Canadairs. There are some aircraft belonging to the department. Altogether there are 45 aircraft in the 15 departments. The flight routing and schedules (Trackers) are predetermined by the COZ (zone operations headquarters).

**3.1.3.2 Intervention**

**Airborne means**

The absolute priority for committing them is the containment of new outbreaks.

The principle is to carry out a massive attack, bigger than need be, thus short.

“We send in 6 Canadairs to deal with the threat in 1/2 hour”.

The second principle is that of the variability of the airborne means: they may not be available because already dispatched elsewhere.

Nevertheless, in 90% of the cases they meet requirements, thanks in particular to good assessment of the threat.

In fact, during a campaign there are only two or three problem days.

In 80% of cases, the ground forces in the department suffice.

The COZ is called on in 20-25% of outbreaks; the ground forces put out mainly the small fires.

There is never any airborne intervention without accompaniment by ground forces.
An aeroplane never completely extinguishes a fire. The fire brigades completely drown the fire even if has been stopped.

The intervention strategy takes into account the fire's rate of spreading, the existence of suitable zones “for stabilising the fire”, the occurrence of multiple fires. The airborne means are deployed to attack or channel wildfire, which has “gotten out of hand” or is very big.

Ground forces are used on the whole for the protection of property and for smaller fires.

- Interaction between fire fighting

**What facilities should be added in priority in the PIDAF area?**

The experts consulted mentioned: improving the signposting between tracks; improving the upkeep of the tracks; more compartmentalising of the whole area concerned; and adapting the security zones.

In the Bouches-du-Rhône department there are no plans to extend the tracks (present network is 2,000 km), fire watch groups or sources of water (600 at present).

The department is considered as heavily equipped.

The most sensitive problem is the maintenance of the equipment and facilities, notably the clearance of scrub around buildings and along the tracks.

A priority is work to be done on the residential / woodland interface.

Improvements are needed to access from the urbanised zones into the forested areas and the implementation of the legislation on clearing vegetation needs to be more robust.

### 3.1.4 Committee of experts

It has two purposes:
- to validate the first work done as a result of construction of the cascades of scenarios,
- to propose the main changes and modifications that would have to be tested.

Its principal conclusions are as follows:

#### 3.1.4.1 Concerning hypotheses on the construction of the cascades of scenarios:

One should not speak of the DFCI equipment and facilities available for cross deployment, rather it is the use of such equipment and facilities, which is in fact dependent on the possibility of mobilising the direct fire fighting means (see the next point)

In very severe conditions (as well as in severe conditions with a very extensive area under threat) it is necessary to introduce the issue of urban priorities: the level of lateral redeployment of equipment and forces drops whenever it is question of urban interests, which the fire-fighters protect as a priority

The evaluation of the surface area spared thanks to DFCI equipment and facilities can be achieved by a study of the most recent 10 largest wildfires in the PIDAF area.

This conclusion was adopted as a working hypothesis.

A study of 10 fires was carried out to enhance the evaluation on the basis of expert opinion, of the surface area spared from burning by the presence of the equipment and facilities in question (annex 4.2).

#### 3.1.4.2 Concerning scenarios of interest tested in order to improve the efficacy of the proposed method (cost-benefit type analysis)

Two suggestions were made:
- the introduction of a clear cuts / separated plots / clear cuts interface
- a reduction in the density of maintained DFCI fire fighting facilities, particularly the tracks.

### 3.1.5 Data on the wildfire concerning the distribution of outbreak locations

For the area formed by the municipalities of the Côte Bleue, detailed information on the localisation of the outbreaks was obtained for the period 1997 – 2002.

46 wildfires were identified and described in reports on wildfire submitted by forestry professionals after each incident and filed with the Bouches-du-Rhône Agricultural and Forestry Service (DDAF).

The details available on the cause and the origin of the outbreaks were logged, as well as their exact location as indicated on paper map, each outbreak location being digitalised.

The origin of the fires studied, be it known or assumed, features in the reports.

Thus, it can be stated that for the area during this period 1997 – 2002 (LAMPIN, 2003):
- 2% of the fires were natural occurrences (lightning)
- 4% were due to imprudent behaviour (campers, children)
- 8.5% had an accidental origin (clearing operations, work on electricity poles, and breaking of electricity cables)
- 85.5% of fires started at the side of some kind of way (road, track, trail)

Such statistics highlight the significance of considering the distance separating the outbreak points from the road network.

It has been shown that the number of fires decreased when the distance from buildings increased.

A relation has been established between the distances separating each outbreak location from an existing network (road, electricity…). In the context of the present work, distances were measured from each point to the various networks but only the shortest was used for the purposes of analysis.

Thus each outbreak point was counted only once.
3.2 COST AND DAMAGE

3.2.1 Cost of the protection against wildfire

The aim of the cost analysis is to enable a comparison to be made between the estimated value of the damage avoided and the level of investment related to it.

However, the model produced here has not been able to achieve such a degree of complexity. It has been limited to a comparison of estimates of the spared damage in different situations of prevention.

Work on giving figures for the costs has been done and the main results are summarised below.

3.2.1.1 Difficulties of analysis

Costs related to prevention cannot be dissociated from those related to actual fire fighting.

Preventive equipment and facilities are only effective or indeed are only used as a consequence of a given fire fighting strategy.

An example is the use of DFCI access tracks which are mobilised differently depending on whether the priority is combating fire to protect lives, goods and property or the forest itself.

Determining the cost of protection against wildfire presents several difficulties.

A guideline scheme for attributing costs is necessary.

The most directly applicable is the cost per hectare of woodland.

The cost of wages for government employees has not been taken into account.

The costs cited should thus only be seen as localised indications.

3.2.1.2 Area under woodlands:

The wooded areas taken into consideration in attributing costs are as follows:
- French forests: 15,200 thousand hectares,
- CFM (Centre for Mediterranean Forest Conservatory) zone: 4,200 thousand ha of which 2,426 are considered as fire-sensitive,
- Provence-Alpes -Côte d’Azur Region: 1,210 thousand ha,
- Bouches-du-Rhône: 96.8 thousand ha,
- PIDAF Côte Bleue: 416 thousand ha of which 2,000 ha form discontinuous patchwork (10%-40%).

It is estimated that 7 million hectares are regularly exposed to wildfire of which 4.2 are in the Mediterranean area and 1.5 in South-West France, a total of 5.7 million ha. for the two main areas concerned.

3.2.1.3 Budget devoted to prevention and fire fighting

The financial sums given are from 2001 converted into Euros. Funding is tending to decrease.

Thus, the figures are overestimated compared to current costs.

Funding from the European Community.
For 2000-2001 the contribution averaged 1,676,939 Euros and was spread over 5.7 million hectares of protected woodlands: 0.29 EUR/ha.

Funding from the Ministry in charge of forests.
The contribution was around 31,500,000EUR. 25,621,140 EUR were devoted to Mediterranean woodlands, 1,772,677 being for general, not local, allocation.
For the 5.7 million hectares to be protected this allocation that does not devolve locally represents 0.31 EUR / ha.

Funding allocated at the Regional level
Of the 25.6 MEUR allocated by central government to the Mediterranean area, 13.31 MEUR, went to the Provence-Alpes-Côte d’Azur Region (PACA).
More or less the whole sum was shared out between the departments.
The PACA Region allocated 4,764,377 EUR under its forestry policy: a part concerns the direct subsidies given to the PIDAF in the Region: 220,839 EUR
This sum was spread over the departments which make up the Region.
The Bouches-du-Rhône received 1,652 MEUR over and above the PIDAF grants.
The part of the Regional sum that cannot be re-allocated is 1,024 MEUR.
For the 1,210 ha of regional woodlands, this amounts to (exclusive of PIDAF grants) 0.85 EUR / ha.

Funding allocated at the Departmental level
This is the largest contribution:
- CFM and other state financing: 3,416,970 EUR
- Regional grants: 1,651,785 EUR
- Departmental Council : 11,433,676 EUR
- Total of 16,502,43 EUR which, when distributed across the 96,800 hectares of woodlands in the department represents 170.48 EUR/ha.

Funding of the PIDAF de la Côte Bleue
The funding of investments comes from Regional and Departmental resources on the one hand and from municipal contributions, representing 20% of the sums invested, on the other.
This represents 35.10 EUR/ha to which must be added 10.99EUR for running costs.
Local investment represents 46.09 EUR/ha/year.

Total cost of prevention for the PIDAF de la Côte Bleue over the period 2000-2001
The cost of the PIDAF after totalising reaches 906,963 EUR in 2001, making 218.02 EUR/ha.

Total cost of direct fire fighting
The expenditure quoted by the Ministry is 79.81 MEUR not including wages and salaries.
The cost per hectare based on the 7 million ha referred to above works out at 11.40 EUR/ha.

We can try to weight this cost in accordance with the degree of intervention (hectares burnt) even though the strategy of attacking fresh outbreaks means there can be no exact correlation.
Over the last 12 years, an average of 24,000 ha burn per year. 

Seen in terms woodland burnt, the costs averages out at 3,325 EUR/ha. 

The efficacy of the direct fire fighting raises this cost per hectare burnt (the less there burns, the higher the cost). 

To obviate what thus appears as a paradoxical effect, the area burnt out can be weighted by reference to the total woodland area of the department. 

For 2,500ha/yr burnt in the Bouches-du-Rhône, the average amount committed annually, as the proportion 2,500/24,000 of national expenditure (79.81 MEUR), is 8.31 MEUR, which, for 1 ha of Departmental forest (96,800 ha), represents 85.88 EUR/ha. 

This Departmental level displays certain coherence since this level is vital in the organisation of the actual fire fighting. 

We can attempt to pursue at the level of the PIDAF the logic of a calculation based on the burnt-out hectare. 

The burnt-out surface in the area under study was 5,322 ha between 1973 and 1990, giving 296 ha/yr and a protection cost of 3,325 EUR/ha x 296 ha = 983,226 EUR which, for the PIDAF forested area (4,160 ha) represents 236 EUR/ha. 

In the PIDAF area from 1996 to 2001, 111 wildfires burned 1,943 ha: an average of 18 fires and 323 hectares burnt per year. Since 1996, the burnt-out land has amounted to one half of the forested area. 

Assuming that wildfire cannot invade the same area twice within several years, it appears that the woodland area to be taken as the basis for the calculation should not be the 4,160 ha of acknowledged forest but, temporarily, the remaining area, some 2,200 ha! 

Calculating the cost is thus linked to the level one is working at and to the basis selected in relation to it. 

3.2.2 The profits or the damage avoided: 

The “profits” have been assessed for: 
- non-commercial functions of woodlands 
- goods and property exposed to fire 

This facet of the study was not specifically investigated; data from previous projects was gathered. 

3.2.2.1 Non-commercial functions of woodlands 

In the Côte Bleue area in which there is almost no output of saleable forest products, an assessment of the damage avoided can be limited to the non-commercial functions of woodlands. 

This situation, common in the coastal portions of Mediterranean woodlands, needs to be taken with slight adjustments. 

MICLET (2000) synthesised the non-commercial functions of woodlands 

The results that follow here have been taken from this work. 

The author emphasises that the economic analysis only takes into account the “roles” (which are determined by the perception of the people involved) of the woodlands and not their “functions”. 

He described them as “goods and services” classed as follows: 
- private goods and services which are not the object of commercial transactions (but which could be, by their nature) : hunting, gathering and collecting… 
- publicly-owned “goods” produced by the forests depending on what users do there : direct use (walking, sports or leisure activities…) or indirect (anti-erosion protection, water stocks, absorption of pollution…). 

Several economic tools exist for measuring the different forms of value attributed to public goods (see the bibliographical rundown published by the Autonomous University of Barcelona). 

A willingness to pay for such goods was very often confined to levels around 15-30 euros, however the question was phrased. 

Such sums correspond to amounts generally contributed in support of humanitarian causes. 

The Côte Bleue is distinguished by the low proportion of natural wooded areas (largely formed of garrigue, the typical Mediterranean shrub land, that recovers fairly rapidly after the passage of wildfire) and by its marked periurban localisation (vicinity of Marseille). 

We have adopted a level of willingness to pay of 20 EUR. 

This amount should be linked to the number of households concerned in the area under study. 

Effectively, the willingness to pay should be considered not as the act of an individual such as a gift but rather as a possible tax to be paid by each household. 

Taking as a basis the 1999 census carried out by the INSEE (the nation’s official statistics body), there would be about 150,000 “households” involved including some tourists beyond those owning holiday homes. 

For the total 10,000 ha concerned, the average value per hectare estimated on the following basis: 

20 EUR x 150,000 / 10,000 = 300 EUR/ha 

3.2.2.2 The goods and property exposed to wildfire 

In the Côte Bleue area, especially on the southern edge, assessment of the goods and property spared can be limited to buildings situated at the interface with the wooded zones, including their outbuildings or the goods and possessions associated with them (for example, vehicles). 

An exhaustive study would have to take into account other important elements such as certain industries or some farming operations.
Recent research on damage caused to buildings has been done in the Bouches-du-Rhône by
- CEMAGREF (research body for rural mechanisation, hydraulic engineering and forestry),
- MTDA (independent consultancy SME) and
- Ecole des Mines (mining engineering institute) (CEMAGREF et al., 2002).

The following results have been extracted from this work.

The research was limited to three major aspects likely to be affected by wildfire.

Insured values
That means everything that has been insured against damage from fire.

Such values reflect the evaluation of the vulnerable goods and property according to expert opinion as well as the forecast by agents of the likelihood of risk (it can be assumed that a high probability will tend to increase the range of things insured).

Property values
Aversion to taking risks, a general feature of the population, can well have an effect on the value represented by property and buildings.

Economic activity
It is a question here of assessing the direct and indirect losses generated by a fire.

Beyond buildings, goods and belongings, whenever an activity depends on the exploitation of the natural environment (tourism or forestry, for example) the destruction of the environment can lead to losses in income or in jobs that can be factored into the vulnerability audit.

The insured values are those, which clearly appear as those most at issue in the case of the Côte Bleue. They essentially involve direct damages:
- to property (dwellings, shops…)
- to possessions (vehicles, machinery…)
- to persons (injury, burns, air poisoning…)

Two types of approach were combined for their assessment:
- reference to the records of incidents kept by insurance companies involved in evaluating material and non-material damage, after first having previously cross-checked geographic indications;
- questioning of a cross-section of landowners affected by previous fires to obtain the amounts received in damage claims. Coordinating inspection of the limits of the burnt areas, aerial photographs and the land registry identified the landowners.

The data from the insurance companies are the following:
- the number of buildings “affected”, proportional to the number “involved” in the fire, around 50%,
- the main damage involved dwellings: damage to vehicles was fairly rare (9% of cases).

It is the outbuildings (garden sheds, huts…) and “moveable” goods (outside furniture…) that appear as most vulnerable, the least well protected and the least well insured.

These last are destroyed in the great majority of cases whereas the main residence rarely is.

The average amount of reimbursed damages was some 4,645 EUR per claim; compared to the number of buildings potentially at risk, the average amount of a claim settlement per threatened building is 2,411 EUR.

Such claims settlements do not cover the totality of damage suffered: some people were not insured against fire (5% had no insurance whatsoever, more than one third had no insurance for the outbuildings).

In a first approximation, one can concentrate on buildings standing in the vicinity of the forest/residential interface, situated from each other at intervals estimated for the Côte Bleue to be about 50 m, with an average vulnerable worth of 2,500 EUR.

For the whole of the interface zone involved the average value of potential damage per 100 m can be estimated on the basis of 2 residences per 100 m, thus:

\[ 2,500 \text{ EUR} \times 2 = 5,000 \text{ EUR} \]
4 METHODOLOGICAL APPROACH: CONSTRUCTING AND USING THE CASCADE

4.1 DECISION-MAKING CASCADE

4.1.1 Decision-making cascade

4.1.1.1 Method of analysis of a decision-making process by the construction of a cascade.

In decision-making cascades two types of intersection are distinguished and represented by circles for one type and squares for the other.

A square corresponds to the taking of a decision between the various branches, which stem from it and which represent control variables.

The circles represent phenomena that are not controlled by the decision-maker: it will be necessary to take into account all the branches that derive from them and thus consider the whole range of possible consequences.

Two ways can be distinguished for solving a problem in coming to a decision: static or dynamic. In the static option, the succession of circles and squares is irrelevant.

With the dynamic option, on the contrary, the succession is crucial because the outcome desired is that every partial decision be conditioned by the information available.

4.1.1.2 Construction of a decision-making cascade.

The building up of a cascade is achieved by imitating an account of what has been learned from experience.

However, this experience will have been fictional, not observed, though it might have occurred.

The procedure is inductive, that is: a starting date is chosen and the various decisions taken, or that might have been, are then described successively along with the events that have been, or that might have been, observed.

The whole is displayed as a diagram in the form of a cascade of branching streams.

In every case, a number can be given to the branches coming out of the circles, representing their relative importance for the decision-maker.

The numbers indicate percentages.

These can be added together if the relative importance of two branches is the sum of the relative importance of each one; in such cases, it is a question of measuring "probabilities".

If such numbers cannot be added up, it becomes a question of "capacities".

In applications, the attribution of probabilities to the events results from:

- either a calculation made starting with a measurement of a relation (the surface area under threat compared to the total area), or
- a scientific measurement based on the frequency of errors compared to a law of physics (meteorological, for example), the opinion of an expert (subjective).

While the calculations based on such probabilities are identical, their interpretation as well as their reliability are as a rule not the same.

In many situations, it is difficult to know whether a circle precedes or follows a square, or in which order several circles follow each other.

It often happens that a decision may be taken at the same time as an uncontrolled phenomenon is taking place.

When the decision-making problems are dealt with in a static manner, that is to say strategies are envisaged globally without taking into account the arrival of information, the order in which the derivations in a cascade figure has not significant.

On the other hand, if a problem is tackled dynamically, that is to say if the strategies stipulate the action to be taken in the light of available information, and then the correct representation of time is fundamental.

Generally speaking, the integrated accumulation of possibilities is obtained by means of an average.

Obviously this can only be done when the consequences, such as their uses, are represented by figures.

However, even when the consequences are financial, it is not generally useful to obtain a simple average.

Furthermore, it is important not to overlook the fact that in a decision-making cascade, probabilities often depend at the same time on events that have already occurred before the one being assessed and on decisions that have been made.

4.1.2 Levels considered and construction.

The building up of a cascade was carried out in successive stages by comparing:

- the "objective data" obtained from statistical or geographic analyses done during this study (or which were already available elsewhere) with
- "expert opinions", indispensable each time that technical knowledge was inadequate.

For example, easy as it was to ascertain the relative size of wildfires in winter and in summer by means of calculations, the incidence of the reduction of the linear extent of tracks on the average area affected by fire could only be estimated empirically.

The main sources of the information used were:

- the Prometheus data base
- the paper records going back to the 1960s
- meteorological data related to wildfire outbreaks
- a cartographic study giving for each point in the area the risk involved, including the fire extent and the linear disposition of the threaten dwellings
- a previous study on a fire which affected the city of Marseille and which enable the evaluation of the extent of the damage suffered by the dwellings.
The statistical data used concerned the following eight municipalities: Carry-le-Rouet, Châteauneuf-les-Martigues, Ensuès-la-Redonne, Martigues, Les Pennes-Mirabeau, Le Rove, Sausset-le-Pins and Gignac-la-Nerthe.

The city of Marseille was excluded from the study.

A comparison of several periods revealed a certain stability of the phenomenon, with an almost annual occurrence of wildfire that is difficult to control (overlapping of periods comes from the difference in the sources used): Table 4-1

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of fires/year</th>
<th>Area burnt yearly</th>
<th>Average area burnt</th>
<th>Maximum area burnt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960-1989</td>
<td>17 fires/yr</td>
<td>371 ha/yr</td>
<td>22 ha</td>
<td>1520 ha</td>
</tr>
<tr>
<td>1973-1995</td>
<td>33 fires/yr</td>
<td>245 ha/yr</td>
<td>8 ha</td>
<td>1500 ha</td>
</tr>
<tr>
<td>1996-2002</td>
<td>30 fires/yr</td>
<td>314 ha/yr</td>
<td>10 ha</td>
<td>624 ha</td>
</tr>
</tbody>
</table>

Two aspects need to be emphasised.

The cascade will be built up based on “a constant yearly average number of fires”, which means that parameters linked to the causes are not factored in effective reduction due to preventive action (eliminating the accidental causes, information campaigns, surveillance…) or, on the contrary, rises due to external factors (opening up of new routes access, general increase in delinquency…).

The damage recorded, based on statistical values, factors in the present level of facilities and equipment in the area under study, in particular those that enable the initial attack against outbreaks or the “lateralisation” of a fire: such damage constitutes, therefore, a “state of reference” against which alternative scenarios must be compared.

4.1.2.1 Level 1: Winter - Summer

The first dichotomy retained in the cascade is that of the season.

Summer (understood from July to September) corresponds to:
- 57% of wildfires
- 84% of burnt-out area
- 7/8 of fires larger than 100ha.

Summertime (a period that varies depending on the threat observed in September) is the time when a prevention scheme is put in place that does not exist at other times of the year.

Given the almost total absence of fires out of control outside the summer season (the two biggest such fires of some 100 ha in size date back to the ‘70s-’80s), the branch stream “rest of the year” has not been developed.

Figure 4-1: Map of the studied area
4.1.2.2 Level 2: Daytime- Night time:

The second dichotomy retained for the cascade is that of the time of day. Daytime (understood as between 11:00h and 20:00h) corresponds (in summer) to:
- 68% of wildfires
- 74% of burnt-out area
- 5/6 of fires larger than 100ha.

Daytime (a period that varies depending on the threat observed in the late afternoon) is the time when a prevention scheme is put in place that does not exist at other times.

Given the almost total absence of fires out of control outside the summer season (the two biggest such fires of some 100ha in size date back to the ’70s-’80s), the branch stream “rest of the year” has not been developed.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of days per zone (%)</th>
<th>Number of fires (%)</th>
<th>Avge area per fire</th>
<th>Biggest fire</th>
<th>Proport’n fires &gt; 100 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm</td>
<td>12  12  12  12  12</td>
<td>6</td>
<td>0,7</td>
<td>28</td>
<td>0%</td>
</tr>
<tr>
<td>Springlike</td>
<td>42  48  41  40  37</td>
<td>23</td>
<td>4,2</td>
<td>770</td>
<td>1%</td>
</tr>
<tr>
<td>At risk</td>
<td>41  36  41  42  45</td>
<td>54</td>
<td>7,3</td>
<td>2087</td>
<td>1%</td>
</tr>
<tr>
<td>Explosive</td>
<td>5   4   6   6   7</td>
<td>17</td>
<td>56,6</td>
<td>4965</td>
<td>7%</td>
</tr>
</tbody>
</table>
The third level of cascade streaming involves the meteorological conditions, considered fundamentally important in the development of a fire (conditioning also the arrangements set up in anticipation of an event).

The Departmental chart below displays the dividing up of the department into 4 meteorological type-zones (results obtained for a period stretching from April to October including all the fires that occurred in the Bouches-du-Rhône department).

Obviously the “Spring like” situation should be eliminated.

The remain 3 type-situations (the number of fires for each situation is divided up in the following way as a function of the area – summer, Côte Bleue, the period 1973-1990):

- **Situation 1, “calm”**
  - (12% of the fires and 12% of the days between April and October), corresponds to gentle or no wind (maximum momentary wind speed of 30km/h) whatever the level of moisture in the soil.
  - The likelihood of an outbreak of fire is 0.5 (ratio between the number of fires and the number of days), making one fire every two days.
  - All the wildfires were brought perfectly under control: the average burnt area per fire was minimal (0.4ha), the biggest spreading over 5ha

- **Situation 2; “at risk”**
  - (72% of the fires and in general just over 40% of the days) includes the situations where only a single parameter (ground moisture and wind) reaches an extreme level, the other remaining at a moderate level.
  - The likelihood of an outbreak rises to 1.3.
  - The average burnt area per fire goes up to 7.2ha, the biggest spreading over 742ha (with a real threat of the fire getting out of control).
  - The likelihood of a large fire equal to or bigger than 100ha is around 1%.

- **Situation 3, “explosive”**
  - (16% of the fires and in general just over 5% of the days, making an average 10 days per year - 0 in some years such as 1977, rarely more than 20 as in ’79 or ’89) involves situations where the two parameters reach extreme levels (the level of moisture in the soil less than 40mm and maximum momentary wind speed above 65km/h).
  - The likelihood of an outbreak rises to 3 (which means there are 3 wildfires a day).
  - The average burnt area per fire goes up to 53.2ha, the biggest spreading over 1,500ha.
  - It is on such classic “red alert” days that the fires are “catastrophic” and the damage and destruction greatest.
  - The likelihood of a large fire equal to or bigger than 100ha is around 6%.
  - There is thus a very great risk of the fire getting out of control.
  - In fact, the risk is even bigger in so far as wildfires, which really do threaten a woodland area of more than 100ha, represent less than half of the total number of fires.
Table 4-3

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Area (ha)</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>31</td>
<td>143</td>
<td>23</td>
<td>1</td>
<td>30</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>31</td>
<td>5</td>
<td>1</td>
<td>30</td>
<td>36</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>17</td>
<td>4</td>
<td>1</td>
<td>30</td>
<td>39</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>30</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>60</td>
<td>1</td>
<td>30</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>3</td>
<td>75</td>
<td>1</td>
<td>30</td>
<td>75</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>2</td>
<td>79</td>
<td>1</td>
<td>30</td>
<td>79</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>80</td>
<td>1</td>
<td>30</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>1</td>
<td>81</td>
<td>1</td>
<td>30</td>
<td>81</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>2</td>
<td>85</td>
<td>1</td>
<td>30</td>
<td>85</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>136</td>
<td>1</td>
<td>30</td>
<td>136</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>185</td>
<td>1</td>
<td>30</td>
<td>185</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>1</td>
<td>279</td>
<td>1</td>
<td>30</td>
<td>279</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>1</td>
<td>640</td>
<td>1</td>
<td>30</td>
<td>640</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>1</td>
<td>742</td>
<td>1</td>
<td>30</td>
<td>742</td>
<td>1</td>
</tr>
</tbody>
</table>

In figures these three meteorological situations correspond on the Côte Bleue to the following values (summertime, weather no.5, period 1973-1990)

Table 4-4

<table>
<thead>
<tr>
<th>Situation</th>
<th>Number of fires</th>
<th>Number of fires (%)</th>
<th>Total area burnt</th>
<th>Total area burnt (%)</th>
<th>Average area per fire</th>
<th>Largest fire</th>
<th>Number of fires &gt; 100 ha</th>
<th>Proportion of fires &gt; 100 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>12%</td>
<td>14</td>
<td>1%</td>
<td>0.4</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>232</td>
<td>72%</td>
<td>1674</td>
<td>37%</td>
<td>7.2</td>
<td>742</td>
<td>3</td>
<td>1%</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>16%</td>
<td>2822</td>
<td>62%</td>
<td>53.2</td>
<td>1500</td>
<td>3</td>
<td>6%</td>
</tr>
</tbody>
</table>

Figure 4-5:

Summer Daytime
100% of wildfires
Avge Area 12ha

Situation calm 12% of wildfires
Avge Area 0.4ha

Situation at risk 72% of wildfires
Avge. Area 7.2ha

Situation explosive
16% of wildfires
Avge Area 53.2ha

The thresholds defined are close to those, which trigger intervention at the different levels of preventive mobilisation that is (according to the information communicated by the SDIS and the ONF)
### Table 4-5:

<table>
<thead>
<tr>
<th>Period</th>
<th>Lookouts</th>
<th>Forest patrols</th>
<th>Attack groups</th>
<th>Loaded aircraft on watch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter (as reference only)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Summertime/Night (as reference only)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Summertime/Day/Situation calm</td>
<td>Yes</td>
<td>Yes</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Summertime/Day/Situation at risk</td>
<td>Yes</td>
<td>Yes</td>
<td>2 half groups</td>
<td>No</td>
</tr>
<tr>
<td>Summertime/Day/ Situation explosive</td>
<td>Yes</td>
<td>Yes</td>
<td>2</td>
<td>Yes</td>
</tr>
</tbody>
</table>

It should be emphasised, in parenthesis that this third level in the cascade contains a “hidden decision” in that the means brought into play for each situation were decided on at the level of the department.

Given the total absence of uncontrolled fires in situation 1 (the largest fire in the period burned 5ha, in the 1980s), the branch Situation 1 has not been developed.

#### 4.1.2.4 Level 4: Surface area under threat:

The potential damage due to forest fires, particularly the area burnt out is very closely dependent on the location of the outbreak: this is the fourth level in the cascading.

The information used here was taken in large part from the Departmental atlas of wildfire risk made at the request of the DDAF (Departmental agricultural and forestry service).

The two graphs below indicate the conditions of reference used for the digital simulations, which enabled the department to delineate for every location in the area under study the extent of land under threat from an outbreak of wildfire.

Figure 4-6: Wind direction during the massive fires in the Bouches du Rhône (fires bigger than 100 ha)
The conditions in these simulations were as follows:
- 1 fire simulated for every 500m x 500m (371 simulations for the zone studied)
- wind speed 50km/hr (gusts potentially reaching or exceeding 80km/hr)
- wind direction 340°
- air humidity 15%
- duration of spread (without intervention) 2hrs

The graph below shows the area extend of the Côte Bleue corresponding to the surface area under threat.

**Figure 4-8: Area extend of the Côte Bleue**
Given the almost north/south direction of the prevailing Mistral wind, the fires spread along the axis of the area's width, covering a maximum 1,500ha.

This order of size is that both of the biggest fire recorded in the area (01/08/1989) and of the biggest simulated fire (1,681ha).

These raw values have been classified in the following manner (values used as the basis for the Departmental atlas of risk covering the whole of the Bouches-du-Rhône)

<table>
<thead>
<tr>
<th>Class</th>
<th>Threatened area</th>
<th>Force of fire front</th>
<th>Mastering the fire</th>
<th>&quot;Hazard&quot; induced</th>
<th>% of area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less than 85 ha</td>
<td>Less than 4,000 kW/m</td>
<td>Possible, sometimes with major means</td>
<td>Little</td>
<td>42%</td>
</tr>
<tr>
<td>2</td>
<td>85 to 530 ha</td>
<td>4,000 to 10,000 kW/m</td>
<td>Difficult, often limited to the flanks of fire</td>
<td>High</td>
<td>43%</td>
</tr>
<tr>
<td>3</td>
<td>More than 530 ha</td>
<td>More than 10,000 kW/m</td>
<td>Impossible, numerous leaps</td>
<td>Very high</td>
<td>15%</td>
</tr>
</tbody>
</table>

Figure 4-9:

Figure 4-10

Summer Daytime Situation 2
100% of wildfires
Avge. Area 7.2ha

Surf. threatened small
72% of wildfires
Avge.Area 6ha

Surf. threatened high
18% of wildfires
Avge.Area 25ha

Surf. threatened very high
10% of wildfires
Avge. Area 84ha
In a first approach, it can be implicitly assumed that points of outbreak will be spread quite uniformly throughout the area, that is to say in a manner independent of the potential area under threat.

This means that the percentage of area and the percentage of the number of fires can be subsumed as one.

In reality, such a hypothesis leads to more or less doubling the average area of the wildfires, showing indirectly that the locations of outbreaks are concentrated on the edges of the woodland areas and in the sectors where the wooded areas are small in extent.

Consequently, for the Côte Bleue it was decided to divide by 2 the surface area under threat from wildfire breaking out in each of the 3 categories (same thresholds as previously)\(^1\)

The accompanying map, taken from the Departmental atlas of wildfire risk made at the request of the DDAF (Departmental agricultural and forestry service) localises the 3 classes of threatened area.

\(^1\) The factor is in fact greater than 2 since for the moment only fires in “unhindered progress” are being considered.
4.1.2.5 Level 5: Time lag before intervention

The introduction of the time lag before intervention as the fifth level of dichotomy is justified by virtue of the priority given at national level to the rapid attack of new outbreaks.

Forming the basis of the strategy for prevention and fire fighting, the speed of initial intervention - which can also be assessed in terms of the area under fire at the time of the first attack - is especially fast in the Bouches-du-Rhône department.

For several fires breaking out in very severe conditions during the summer of 1990 this first attack was assessed as happening on average 6 minutes after the first alert.

This time lag has been adopted as the threshold in Situation 3.

It has been doubled (12min) in Situation 2.

A time lag will be considered as “short” if it is less than the threshold adopted for the corresponding situation; “long” if it is greater.

Figure 4-13

In order that the long time lag be set at the maximum value, we have adopted an unchanged burnt-out area in this case and, in the case of a short time lag, a burnt-out area equal to a half (S/2).

S can have the following values: 6ha, 25ha, 31ha, 84ha, 125ha, 418 ha

The area of territory corresponding to each of these time lags in each situation has been calculated by mapping.

Because the study is one of methodology, these calculations have been done “as the crow flies”, assuming a driving speed for the fire trucks of 60km/hr and applying a coefficient of 1.4 to compensate for actual distances.

The GA (groupes d’action) were stationed: the first at Le Pas de la Fosse (Châteauneuf-les-Martigues), the second at the go-kart track (Martigues).

Figure 4-14
4.1.2.6 Level 6: Important urban goods and property threatened

Apart from the surface areas burned, the potential damage resulting from a forest fire also includes that caused to material goods, particularly buildings located along the woodland/residential interface.

Such damage also depends on the exact position of the outbreak.

But this criterion has also been taken into account indirectly to convey the following fact: when urban goods and property are under threat, emergency efforts are in large part directed at their necessary protection.

In this way the protection of woodlands and direct fire fighting to stop the spread of the wildfire are no longer ensured, reducing considerably the use and the effect of the existing network of DFCI facilities which results, in the final analysis, in a larger area being burnt.

As for the threatened area, the information used here was taken from the Departmental atlas of wildfire risk made at the request of the DDAF (Departmental agricultural and forestry service).

The accompanying map localises throughout the whole woodland area the linear interface under threat.

The raw values have been divided into classes as follows (values used for the Departmental atlas of wildfire risk for the whole of the Bouches-du-Rhône):

<table>
<thead>
<tr>
<th>Class</th>
<th>Linear interface under threat</th>
<th>“Hazard” induced</th>
<th>% of area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less than 700m (average: 434m)</td>
<td>Low</td>
<td>42%</td>
</tr>
<tr>
<td>2</td>
<td>700 to 1800m (average: 1267m)</td>
<td>High</td>
<td>43%</td>
</tr>
<tr>
<td>3</td>
<td>More than 1800m (average: 4996m)</td>
<td>Very high</td>
<td>15%</td>
</tr>
</tbody>
</table>

We have tried to estimate the extent of area saved from burning thanks to the use of the track network using as a basis the last 10 large fires situated in the PIDAF zone.

The details featuring in annex 4.2 as well as the summary chart below highlight the real difficulty in ascribing a value on the basis of these few examples.

<table>
<thead>
<tr>
<th>Fire studied</th>
<th>Daytime fires</th>
<th>Night time fires</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tracks</td>
<td>No saving – Fire 1</td>
<td>Saving linked to the use of other access roads 30 ha – Fire 3</td>
</tr>
<tr>
<td>Tracks present</td>
<td>No saving – Fire 4</td>
<td>Saving linked to the use of tracks 50 ha – Fire 2</td>
</tr>
<tr>
<td></td>
<td>Saving linked to the use of tracks 500 ha – Fire 6</td>
<td>1500 ha – Fire 5</td>
</tr>
<tr>
<td></td>
<td>1500 ha – Fire 8</td>
<td>500 ha – Fire 9</td>
</tr>
<tr>
<td></td>
<td>Saving linked to the use of other access roads 500 ha – Fire 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500 ha – Fire 10</td>
<td></td>
</tr>
</tbody>
</table>

Given the lack of precise data, the working hypothesis was that whenever the threat to important urban goods and property was low (for simplicity, classes 2 and 3 were grouped as “high level elements”), the use of DFCI facilities making a degree of lateralisation of the fire possible led to a saving of 25% of the total area burnt.
This 6th level was not applied when there was no clear thinning out of the means:
- in Situation 2 when the surface area under threat was low or moderate,
- in Situation 3, when the surface area under threat was low.

4.1.2.7 Level 7: Density of the track network

The density of the DFCI (firefighting) facilities and equipment available for use in controlling wildfire was calculated using as a reference the BD DFCI of the DDAF (Departmental agricultural and forestry service).

For the sake of simplicity, two classes were distinguished:
- a high level density indicating that at least one DFCI track “up to standard” was accessible at less than 300m
- a low level indicating the opposite.
This 7th level was only applied when the threat to urban elements was low (use of DFCI facilities possible).

4.1.3 Calculating the figures

Once the probabilities at each intersection of the branching cascade have been defined, the 33 final situations were characterised by two parameters linked to damage:
- the average burnt-out area corresponding to the situation, determined on the basis of situations filed in the GIS then quantified by an estimate of the average value of one hectare of the natural land area (300 EUR/ha),
- the length of the woodland/residential interface, determined on the same basis then quantified by an estimate of the average damage caused to dwellings by the fires (5,000 euros/100 m).

The values obtained are relatively coherent:

<table>
<thead>
<tr>
<th>Type of damage</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Average value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area burnt</td>
<td>0.5 ha</td>
<td>418 ha</td>
<td>9.0 ha</td>
</tr>
<tr>
<td>Interface affected</td>
<td>0 hm</td>
<td>74 hm</td>
<td>4.2 hm</td>
</tr>
</tbody>
</table>

* weighted for the probability of the event

The overall coherence of the cascade was verified by combining the probabilities of each branching stream (assumed to be independent).

This was achieved by applying a multiplying factor over the whole of the cascade.
4.2 USING THE CASCADE: ALTERNATIVE SCENARIOS

4.2.1 Hypotheses envisaged

The hypothesis tested was that of a decline in the maintenance work on the tracks in the PIDAF zone (cf. paragraph 2.1.4. above).

Such inadequate upkeep would have an effect on the possibility of access available to the fire fighting teams and on the intensity of the wildfire.

It can be postulated that:
- the prevention costs would be untouched,
- extra costs would be entailed by a larger mobilisation of fire fighting means,
- additional damage would result.

4.2.2 Modifying the cascade

Two modifications to the cascade of branch streams were tested, representing scenarios for adapting land use.

The first modification consisted in reducing by 50% the extent of usable tracks (stopping upkeep, thus leading eventually to the more or less total impossibility in case of wildfire of using them in attempts to limit sideways spread on the fire's flanks).

The results obtained figure in the table below:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Avge area ha</th>
<th>Avge interface hm</th>
<th>Damage to woodland EUR</th>
<th>Damage to buildings EUR</th>
<th>Average damage per fire EUR</th>
<th>Average damage/year EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>9.0</td>
<td>4.2</td>
<td>2707</td>
<td>21182</td>
<td>23888</td>
<td>716647</td>
</tr>
<tr>
<td>Reduction of 50% in the extend of tracks</td>
<td>9.2</td>
<td>4.2</td>
<td>2750</td>
<td>21117</td>
<td>23928</td>
<td>717834</td>
</tr>
<tr>
<td>Upkeep of 50% of the woodland/residential interface</td>
<td>8.9</td>
<td>3.9</td>
<td>2662</td>
<td>9736</td>
<td>12398</td>
<td>371944</td>
</tr>
</tbody>
</table>
4.2.3 Conclusion

The changes noted go in the right direction: increase in the damage with a reduction in the extent of the track network and reduction in damage with the creation of a network of woodland/residential interfaces.

Nevertheless, some remarks are called for in the light of this experiment.

The impact of wildfire in the Côte Bleue region, expressed in figures, totals yearly on average more than 700,000 Euros, making about 70 EUR/ha/yr. This figure needs to be compared to the average cost per hectare of preventive measures undertaken across the whole area.

The damage to buildings is much greater than the damage to forests (in fact to woodlands or natural land, forest stands being rare in this study area). Certainly the figures for the damage are only rough values, but the difference obtained is large (to the power of 10).

This spread, however surprising at first sight, actually corresponds quite well to the difference in impact on the media between a wildfire running across only natural woodland areas and a fire that materially threatens dwellings in forward areas.

The method employed led to distinguishing 33 relatively contrasting situations.

Despite the difficulty in finding all the requisite data needed to build up a cascade, the method of reasoning used and the work done with those involved in the field made it possible to develop a logical structure integrating seven basic parameters.

Thus, its first merit is above all that it forces us to ask the “right questions”.

The application of the method to a genuine case would need considerable further investigation.

The situations obtained can be considered as quite representative of reality in spite of the large number of hypotheses that it was necessary to formulate.

But while is admissible to use values that are sometimes empirical estimates for an exploratory study, when confronted with an actual case it would be indispensable to previously undertake essential research in order to obtain values with a certain accuracy on several key issues: the time lag preceding intervention, the use of tracks…

The attempt to construct alternative scenarios has shown up the weak influence of preventive measures.

For example, the reduction of tracks leads to a saving in damage of scarcely more than 1,000 EUR/yr. Two reasons at least can account for this response by the “model”:

- the absence of detail for wildfires in winter and at night-time, these two cases represent more than 40% of total damage; and
- the reasoning adopted in the cascade on the subject of the use of tracks, whenever urban elements to be directly protected are in sufficiently low numbers that the emergency forces do not have to deviate towards them.

The adaptive land improvement designed to protect residential zones appears to be much more “profitable” than that aimed at the straightforward defence of woodland areas.

On the basis of an average cost of maintaining brush clearing of 300 EUR/ha/yr, the drop of 50% in the network of 150 km of tracks (cleared for 2x25 m) would generate a saving of some 112,500 EUR/yr (for an increase in damage of 1,187 EUR).

The upkeep of 50% of the 1,900 km of linear interface (cleared of brush to 50m) would generate an extra cost of 2,850,000 EUR/year for a reduction in damage of 344,703 EUR.

A euro invested in the woodland/residential interface is 10 times more “efficient.”
The construction of a cascade of branch streams describing possible evolutions of a wildfire in the chosen zone took place in several stages:
- selection of the various elements capable of affecting the evolution of wildfire,
- elimination of situations without danger or much too infrequent,
- simplification of the cascade, keeping only the most significant branch streams.

A certain number of difficulties appeared.
In the first part, we talk about the list of possible action.
The difficulties encountered in actual practice are numerous.
In the second part, we consider problems in working out the figures, problems involved with collecting data and the assessment of “possibilities” attributed to the branch streams.

5.1 STRUCTURE OF THE DECISION-MAKING CASCADE

The time frame, that is to say the arrival of new information, which can lead to new decisions, is a structuring factor.
The other structuring factor is the analysis of the different branch streams.

5.1.1 Decisions and constraints

After the arrival of information, especially concerning the outbreak of fire and weather conditions, action is undertaken.
The expertise and the experience of the fire fighting services trigger a number of reactions, which appear to be automatic because they are decided in advance and have often been practised.

These reactions are justified; this does not however mean that they must be considered systematically as constraints for other decisions.
In effect, if the law or regulations compel in such and such circumstances the specific deployment of fire fighting means, it is indeed a constraint, which restricts the totality of possible decisions.
The priority given to the protection of people and possessions is such an example.
On the other hand, the number and the type of vehicle sent is not, a priori, a constraint even though this norm has been adopted through experience.
It is effectively a matter of a decision, even if it was taken automatically.

Among the constraints, which mask the decisions taken, the most obvious concern the means available.
Others are more difficult to bring to light, this is the case for adequate infrastructure such as access tracks whose extent and upkeep condition the strategic decisions that may be taken.

Finally, hidden decisions whose impact on the consequences may be all-important are those involving land use planning, political decisions decentralised down to the municipal or personal level.

It appears desirable, therefore, that in the course of building up the cascade each of the data be analysed so that, if need be, the fact of removing such constraints or relaxing them can be integrated into the scheme a decision needing to be taken.
The conversion of a constraint or of a previous decision into a possible decision modifies the construction of a decision-making cascade by making it more complicated.

5.1.2 Threats and decisions

It may seem obvious and simple to distinguish random data, uncontrollable variables, from decisions over which one has control.
The analysis of a decision-making cascade shows that this is not so. In fact, the context in which an outbreak occurs will be considered in the cascade, a priori, as a random fact: in a rocky or a wooded environment, the consequences will not be the same if the location is accessible or not so. Improvements to land and infrastructure will also modify the consequences.

Yet these correspond for the most part to decisions previously taken.
When such infrastructure is not called into question it will indeed be possible to think that finding such infrastructure present or not at the location of the outbreak is a random fact.
It will be possible, for example, to measure the likelihood of finding a water tank or a track.
On the other hand, if one wants to assess the relevance of such infrastructure, the branch stream intersection characterising a source of incertitude (circle) will be replaced by a (square) intersection giving rise to various decisions such as its suppression, retention or development.

In practice, with the exception of a few aspects such as the weather and the time of the year, just about all intersections considered as random in the first instance can be broken down into hidden decisions, which can be called into question in alternative scenarios.

Taking an overall view of the cascade of branch streams makes it possible right at the start to eliminate those derivations whose consequences are so weak or so rare that they will not be able to influence decisions.
Thus only the summer season has been included because the damage done in winter is relatively insignificant; this can be reviewed and questioned.

Though intermediate decisions are not observable, for example the level of maintenance on equipment, they should not be registered as such in the cascade.
Even though they are decisions, they belong to what we call “uncontrolled variables” or random facts.
People involved control such variables, but we cannot observe them.
The incorporation of these variables as if they were random corresponds to the reality that we can observe.
5.2 CALCULATING THE FIGURES FOR A DECISION-MAKING CASCADE

A decision-making cascade can be restricted to a qualitative approach.
If a more precisely accurate decision-making tool is desired, calculating the related figures is necessary.
This involves two levels: on the one hand, the consequences of the random facts and the decisions; and, on the other, the assessment of the probability of the different alternatives.

5.2.1 The consequences

5.2.1.1 Quantifying the consequences

The construction of a decision-making cascade necessarily involves a thinning down of reality.
The choice of explanatory variables in this model is aimed at separating the essential from the subsidiary.
In an ideal situation, reliable and relevant data would enable us to include the whole range of significant variables to the exclusion of all others.
Progress in the modelling of a real phenomenon often follows a quantitative and qualitative step forward concerning the available data.
Gathering data is time-consuming and expensive.
The choice of variables retained in the modelling reflects a double criterion: their impact on consequences must be both significant and measurable.
In the results presented here we are able to distinguish three types of variable.
The impact of the first type can be measured statistically.
This is the case for the divisions such as summer-winter and day-night...
For the second type, it is necessary to have recourse to qualitative studies of a limited sample of damage in order to propose an estimate of their impact that will obviously be less precise than for the previous type.
Here this has been the case for the impact of the time lag in intervention.
Finally, there is the third type of variable: such variables have not been included in the calculation of figures in so far as no satisfactory form of measurement could be found for them: the simultaneous existence of several fires is an example.
The failure to take this type of variable into account is a limitation to the validity of this analysis.
The introduction of alternative scenarios entails the renewal of measurement work.
While the development of brush clearance at interfaces has an obvious influence on the extent of damage, there remains the task of measuring its impact on burnt-out areas.

5.2.1.2 Evaluating the consequences

Taking a decision requires measuring every element involved in a choice with the same unit such that they can all be put in the balance.
This common unit is currency.
The evaluation of the quantitative consequences poses more or less difficulty depending on the nature of the goods in question.
For saleable goods (traded on a market) the price reflects their value.
For non-commercial goods it is customary to evaluate their worth as being their production cost.
Calculating costs involves specific problems.
The first is related to the distinction between investment and running costs.
Breaking down the annual cost requires knowing a thing’s economic life expectancy and the choice of a discount rate.
The second problem is much too complex to solve.
It concerns defining the limits of relevant expenditure and the guidelines for apportioning these costs.
This issue includes in particular the apportioning to the different activities in a company a share of the structural costs.
This type of problem is avoided with cost-benefits analysis.
Such a method seeks to assess projects, which is to say variations in averages.
It is thus not usually useful to know total expenditure but rather the additional costs which will of necessity be allocated to a project.
Natural, non-commercial goods constitute a third type. In our context they are of especial importance.
Different approaches enable a market value to be attributed to this type of “goods”: contingent assessment, hedonistic method...
5.2.2 Determining probabilities

The limits that data impose on account of their very nature weigh most heavily in determining the probability given to the different random variables in a decision-making cascade.

The database can in some situations make it possible to calculate frequency.

This is the case for weather conditions.

The "weather situation" variable is the object of complex treatment because the various configurations (wind force and moisture content) are distributed across four classes corresponding to types of relevant situation.

However, the figures show an evolution that it is difficult to attribute merely to chance: situations labelled "at risk" correspond to average areas burnt which have decreased over time whereas the "explosive" situations show an increase in average areas burnt.

A change in means can explain the first evolution.

The second can stem from an extension of forest, which leads to a rise in damage in cases where the wildfire cannot be contained.

There may also be interdependence between these two cases when the drop in "little fires" leads to the preservation of greater areas, which will ultimately be burnt by a wildfire spreading out of control.

Such evolutions could lead to using only recent data but such a limitation in the size of the sampling has the disadvantage of reducing the statistical validity of the estimates.

Whenever calculations of frequency are not possible, it is necessary to have recourse to more specific methods.

In some situations, it is possible to determine the reality of a hypothetical event by calculations of proportion.

Take the example of the density of tracks.

Fixing the norm between "high density" and "low density" involves expert appraisal.

It is then possible to measure the area corresponding to each density.

Should such calculations be impossible the final recourse is the subjective statement of probability by "experts".
6 METHODOLOGICAL APPROACH: CONCLUSION

The technical analysis of the phenomena was concentrated within a limited area: the territory involved in the PIDAF de la Côte Bleue.

The tools brought into play are numerous, three above all should be emphasised.

The first is a tool providing help in analysing wildfire and the investments related to prevention and to the means directly employed in fire fighting.

This tool consists in the design of a cascade of branch streams permitting the analysis of the elements involved in the description of wildfires and the decisions taken prior to and during the actual fire fighting period.

As a complement to such cascades, a method for calculation in the overall assessment of each alternative scenario was developed.

It can be broken down into calculations of probability (or of relative importance) of the different occurrences, into methods for assessing damage (or profits, understood as damage avoided) corresponding to the various impacts, and lastly a method for assembling these different values in order to obtain an overall assessment.

The resulting cascade is a tool for help in decision-making. In the examples used, the decisions involved the existence of DFCI (direct fire fighting) tracks in particular but such decisions could also involve other infrastructure or, notably, fire fighting means.

Decisions concerned with investment or with the means to be applied can indeed be guided by a comparison of the cascades defining the alternative scenarios.

The calculations in the assessment of different impacts permit the simulation of forecast results.

Such calculations highlight the sensitivity of the results to the often-implicit hypotheses made in the course of designing the cascades.

For example, the value attributed to human dwellings in comparison to that attributed to forests modifies the assessment of the different lengths of track required.

The methodology proposed can be adapted to other situations than that prevailing in the PIDAF area studied here.

It leads to methods of description, calculation and, indeed, to decisions involving areas where the risk of wildfire may be very different.

Such methods call for supplementary work of a technical nature, which can only be undertaken, with the approval of decision-making bodies concerning the basic principles outlined here.

The methodology and the tools it proposes have been discussed at meetings held with the parties concerned (forestry, agricultural and fire fighting professionals, in particular), a fact which does not constitute recognition of its validity but has meant that its relevance has been made more acute.

Similarly, the use of the tools presented here can only be envisaged within the framework of a well-defined decision-making context.

In any event, such use could never be made without prior discussion on the criteria for decision-making nor without the validation by outsiders of the data included.

The data on the investment costs in methods of prevention and in direct fire fighting, as well as those concerning damage, are too insufficient.

It would be desirable to establish protocols for gathering such data.
7 REFERENCES

7.1 GENERAL REFERENCES – FOREST FIRE
VALUATION AND ASSESSMENT


HOTELLING, H. (1949) "Letter to the Director of the National Park Service" in Roy A.


7.2 METHODOLOGICAL APPROACH FOR MANAGEMENT MEASURES

7.2.1 Economical theory for risk valuation


7.2.2 Other references


8 ANNEXES

8.1 PIDAF COTE BLEUE MAP

Fire fighting was carried out exclusively by airplane, only a small part of the N568 and a path were used.

Figure 8-1
8.2 FIRES IN THE PIDAF AREA ALREADY STUDIED

Interview with officials from the ONF responsible for managing the PIDAF Côte Bleue: the last ten large fires

Estimates, for each of the 10 fires listed below, of the area saved from burning thanks to the use of DFCI tracks by those involved in the fire fighting.

N.B.: N = main road (national) e.g. N568

8.2.1 19/07/1997 – Le Rove – 24ha
Fire no. 1 – ID 43 – Daytime fire
Inaccessible, no tracks.

8.2.2 25/07/1997 – Le Rove – 460ha
Fire no. 2 – ID 44 – Daytime fire
This fire took hold at the same time as the Etoile fire: the airplanes were not always available.

The tracks were used but the wildfire spread beyond them.

The saving in burnt area was small, an estimated 50ha corresponding to the surface to the west of the fire between the shopping centre and the track.

8.2.3 21/08/1997 – Carry-le-Rouet – 126ha
Fire no. 3 – ID 26 – Night-time fire
Located at the heart of the hill country in an inaccessible zone.

To the east of the fire, the firemen managed to lateralise the wildfire by stationing themselves on a path accessible from the track.

The area saved was in the order of 30ha.

On the western side of the fire, the firemen’s position on the plateau probably enabled them to contain the fire which might otherwise have spread as far as the CD5 (road).

8.2.4 9/07/1998 – Le Rove – 49ha
Fire no. 4 – ID 33 – Daytime fire
Fast start rising up to the cliff.

Pushing the fire sideways was undertaken:
- to the east from the D84 (secondary road);
- to the west with the use of some farm tracks.

The fire was stopped by Canadairs. No saving due to tracks.

8.2.5 7-8/10/2000 – Châteauneuf-les-Martigues – 7ha
Fire no. 5 – ID 20 – Night-time fire
The equipment deployed on the track to the south was vital, as was the existence of a track to the east.

To the south, the area that was saved can be estimated as 1,500ha.

8.2.6 27/07/1997 – Ensues-la-Redonne – 10.5ha
Fire no. 6 – ID 41 – Daytime fire
Slow-burning fire located below an electricity line, with a south wind.

8.2.7 10/09/2001 – Martigues – 200ha
Fire no. 7 – ID 12– Daytime fire
In the vicinity of the outbreak, the fire descended that went back up the hill.

The path situated to the east (along the eastern edge of the fire) facilitated the lateralisation of the wildfire.

The area saved from burning to the east can be put at 500ha.

8.2.8 25/07/2002 – – Martigues – 240ha
Fire no. 8 – ID 1 – Daytime fire
The ground forces finally extinguished the fire but major work done by the Canadairs.

The network of tracks to the north-east (on the Escourillon plain) enabled containment of the fire to the east.

Thus, 2,500-3,000ha were able to be saved (down to the main through road). The input from the Canadairs alone would not have sufficed.

8.2.9 4/09/2001 – Le Rove – 624ha
Fire no. 9 – ID 14 – Night-time fire
The fire spread in two stages one of which corresponded to a renewed outbreak the next day at 1p.m.

The action undertaken on the track to the east of the fire at a place known as Gossimond was decisive.

The area it made possible to save from burning corresponds to the area situated to the north of the track as far as the road and the motorway running farther to the east.

8.2.10 10/08/2001 – Les Pennes Mirabeau – 360ha
Fire no. 10 – ID 15– Daytime fire
Canadairs intervened at the point of outbreak in a steep zone difficult of access.

The firemen on the ground played a decisive role in pushing the fire sideways:

- On the western flank: use of an existing path (by the gas pipeline) accessible from a municipal backroad reached from a track.
- On the eastern flank: use of a pre-existing way.

The area saved from burning can be put at 50ha, situated to the north-west of the fire by the motorway.