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Remote sensing techniques in the mapping of vegetation and their application to runoff evolution in burnt areas

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ABSTRACT

South of experimental forested catchments named "Réal Collobrier" was destroyed by fire in August 1990. Partially or entirely burnt catchments became an interesting field to study links between vegetation and runoff. An experimental program was built on two axis :

- use of remote sensing techniques to map limits of burnt areas and recovery of vegetation, year after year.
- link between vegetation and runoff. The first investigations were done on two burnt catchments (Rimbaud and Meffrey), using a runoff model fitted with data before fire. This model has permitted to compare new data (observed after fire) with the ones we would have observed without fire, for the months just after fire (1990, direct effect of fire) and the year after (1991, effect of vegetation recovery).

Keywords : hydrology, runoff, remote sensing, forest fires.

1. INTRODUCTION

Hydrological influence of vegetation on runoff for small catchments is relatively little-known. It's one of the most important preoccupation of the Scientific Group Real Collobrier which tries to understand hydrological behavior of small Mediterranean catchments. The forest fire of august 1990 was a scientific opportunity to experiment these catchments in order to better understand the vegetation effects on runoff using remote sensing.

This project has two major objectives interesting the management of Mediterranean area : 1) possibility of characterizing the vegetation recovery after fire by remote sensing methods and 2) hydrological study of vegetation effects on runoff. Moreover, this technology offers synoptic and frequent views, which can be very useful for further regionalisations of results.

Here we present and discuss the firsts results obtained for two years of observation after fire.

2. GENERAL METHODOLOGY

The different stages of the study are :

- installation of experimental plots in the burnt area, in order to observe year after year, the evolution of vegetation;
- cartography of fire limits and annual cartography of vegetation after fire, using plots observations and remote sensing imagery ;
- link between these cartographies and runoff evolution.

2.1 Study area

These experiments are undertaken on the BVRE (Experimental and research basins) of Real Collobrier, in Maures Mountains (France), where, since 1966, the CEMAGREF has collected data through an important hydrological network (LAVABRE et al., 1991a). The area is a metamorphic one, and forest covered, essentially by pines, cork-oaks and chestnut-trees.

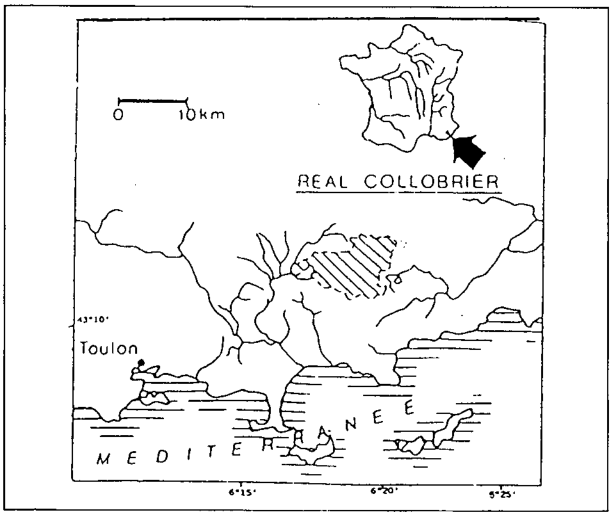

Figure 1. Real Collobrier basin

The annual rainfall is quite favorable (mean of 1000 mm) due to the mountainous character of the basin (70 to 800 m) and its proximity to Mediterranean sea (Lavabre, 1980). Since 1988 and 1989 were two years affected by drought, forest fires were larger in 1990. At the end of August 1990, fire spread over 8000 ha during 3 days and affected the south part of our experimental basins (LAVABRE et al. 1991b).

2.2 Hydrological data

The 100 km≤ of the Real Collobrier basins are covered with 17 rainjauges and a climatologic station. 11 flowjauges determine 11 small catchments from 0.7 to 70 km≤.

Table 1. Some characteristics of Rèal Collobrier catchments

N°	Basins	Area (km^2)	begin of data
1	Pont de Fer	70,6	1966
2	Collobrière	29,5	1972
4	La Malière	12,3	1965
5	Valescure	9,4	1967
6	Maurets	8,4	1968
7	Vaubarnier	1,5	1968
8	Rimbaud	1,4	1967
9	Davids	9,7	1966
10	Cogolin	5,5	1969
18	Boussicaut	0,7	1980
19	Meffrey	1,5	1985

2.3 Remote sensing data

We used multispectral SPOT data for this operation, due to their precise resolution (20*20m) and the possibility of satellite programming : one image just before fire, one just after, and then, one image each year at the same period

Table 2. SPOT images - XS KJ 52/263, 1B

Date incidence	Angle
21/08/90	17,5°(left)
04/09/90	10,1°(left)
26/07/91	8,8°(left)
13/07/92	8,3°(left)
16/06/93°	8,3°(left)

2.4 Geographical data

From previous works we had :

- two DEM (Digital Elevation Models) : a first one at 20 m of resolution, derived from IGN map at 1:25000 and covering only the 11 catchments ; a second one at 30 m of resolution, derived from IGN map at 1:50000 and covering the whole Maures Mountains;

- a cartography of forest species obtained by 1986 and 1989 SPOT images processing (WEESAKUL, 1992).

2.5 Experimental observations

In order to perform a significant image processing, it is important to have precise and representative land observations. So we have set up some observations plots with great care.

A first set of observation plots was proposed in 1991 and completed in 1992. The plot itself is a square of 20*20m corresponding to usual forested observations areas (BRETON, 1992) and also to the SPOT pixel. The criteria of selection are :

homogeneity : the plot must be chosen in an homogeneous area, minimum 60*60m, in order that an imprecise position does not affect the information. Indeed, in image processing we assume that localization is imprecise at more or less one pixel (20 m).

statistical representativity : plots of observation compose a sample as complete as possible for combinations of forest species, slopes, and aspects

precise localization : defined through 1:25000 IGN map and by using a GPS (Global Positioning System) ;
easy access

For each plot the observations are :
- topographical characteristics (high, slope and aspect on a 20*20 m square) ;
- geographical position ;
- percentage of bare soils or rocks ;
- description of vegetation : names, height, number or percentage of cover, and an index of burnt violence (0 to 5) assessed just after the fire ;
- local map of situation ;
- general information : forestworks, erosion .. ;
- snapshot.

For a complete description of vegetation, special floristic observations were done by St. Jerome University in Marseille (THINON et BRUGER, 1993), in summer 1993.

3. MAPPING BURNT AREAS AND VEGETATION RECOVERY

3.1 Preprocessing of satellite images

Several images of different dates must be combined to obtain vegetation recovery cartographies. Thus, the first step is to transform images into compatible forms by using geometrical and radiometrical corrections.

Geometrical corrections

The images are rectified using a common reference tool : the IGN map at 1:25000. Correction appears necessary in mountainous areas if the incidence angle is significantly different from zero. This correction has been done using a software which determines and eliminates the parallax effect using a DEM and a set of reference points - common points on map and image - (PROY, 1986 ; PUECH, 1993).

Radiometrical corrections

Two radiometrical rectifications have to be done.

- The first one concerns the relief effects on reflectance. These effects appear in mountainous areas when the solar elevation angle is low, and give sides lightened differently.

The elimination of this effect needs an internal correction of the images. The theoretical models of correction (YANG, 1990) were tested on burnt areas for the 09.1990 image but gave poor results (LEPORI, 1991). The reflectance in these burnt areas depends not only on slopes and solar angle, but also on intern shadows due to the structure of the cover, and these effects are difficult to integrate in theoretical approaches.

So we used an empirical correction, based on statistical links between CN (Numeric Counts) and AIS (solar incidence angle), on the burnt parts of the images, the correction being redefined for each image and each radiometric band (NGUETORA, 1993).

- the second is the atmospherical correction which is necessary, when two or more images are used.

Here too, the theoretical approaches are often not available due to the lack of information on atmospherical parameters. So, empirical approaches have been developed ; they are based on the assumption of a linear perturbation of atmosphere on radiometry, and on the existence of peculiar areas with radiometric stability all over the year, "invariant zones", such as bare soils or roads for instance (ABEDNEGO, 1989 ; SEGUIS et al. 1992). The comparison, band by band, of the CN (Numeric Counts) on these invariant zones permits a relative correction, by taking one image as the reference.

3.2 Cartographies

This first step give the external limits of fire, statistics on burnt areas in each catchment, and a discrimination of the different burnt areas on a criteria of violence of fire. It has been done using the 24/08/90 and 4/09/90 images and ground observations of July 1991.

Limits of fire

We first tried to subtract the two images of 1990, one just before fire, the other just after.

For the pixels inside the burnt area, the results are correct, but outside this zone, the problems of exact superposition of the two supports gave poor results (BRETON, 1992).

So we only used the image after fire, studying the histogram on the PIR band (Near infrared). Burnt areas appear to have the lower CN, and the discrimination is quite good.

Results indicate 19% of burnt areas inside the whole experimental zone, some catchments being intact (basins 2, 5, 6 and 7), some a few burnt (basins 1, 4, 9 and 10) and some quite integrally burnt (basins 8, 19) (Fig 3 et Tab 3).

Table 3. Burnt areas on each catchment

N°	Basins	Burnt Area	
		(ha)	(%)
1	Pont de Fer	1294	18 %
2	Collobriére	0	-
4	La Maliére	458	37 %
5	Valescure	0	-
6	Maurets	0	-
7	Vaubarnier	0	-
8	Rimbaud	127	82 %
9	Davids	309	32 %
10	Cogolin	130	20 %
18	Boussicaut	0	-
19	Meffrey	141	89%
	Total	1603	19%

Statistics on burnt vegetation

Each forest specie has a different behavior (Tab 4). For example, pines are well burnt, but chestnut trees are not. Three years after fire, ground observations on burnt areas indicate that, in the burnt area, pines have completely disappeared and that it remains only three land components in variable proportions : cork-oaks, shrubs and grass, bare soils and rocks.

Table 4. Burnt areas by soil occupation

Soil occupation	burnt Areas Ha	% burnt(*)	% burnt(**)
Chestnut trees	39	5 %	2 %
Chestnut+ oaks	83	10 %	5 %
Oaks	514	18 %	32 %
Oaks+Pines	334	43 %	21 %
Pines	377	49 %	23 %
Pines + chestnut	7	34 %	0 %
Tracks+bushes	207	5 %	13 %
Vineyard	32	0 %	2 %
Urban areas	0	22 ,%	0 %
Burnt area 1986	10	3 %	1 %
Total	1603		100 %

(*) in reference of the same soil occupation
(**) in reference of the whole study area

Cartography of recovery

This cartography has been done for each image after fire by using data collected each year on experimental plots.

Due to the fact that, after fire, the pixels of burnt area are no more homogeneous, we used a sub pixel processing. The process define each pixel as a mixing of pure entities : bare soil, herbaceous, shrubs and trees.

Results are cartographies of recovery year by year : percentage and localization of each entity. Statistics by catchment can be obtained. For example, remote sensing processing give for 1993 image, a mean of 43 and 38 % of bare soils, respectively for the Rimbaud and Meffrey burnt catchments This is consistent with ground observations on a few plots (tab 5).

Table 5. Mean percentage of bare soil and herbaceous (ground observations)

Catchment	1990	1991	1992	1993
Rimbaud	90	80	65	50
Meffrey	90	70	50	40

The differences between catchments are of great importance to understand the different hydrological behaviors after fire.

4. EVOLUTION OF RUNOFF AFTER FIRE

To characterize evolution of hydrology before and after fire, the direct study of chronicles is not good enough, because climatologic perturbations have a great importance on runoff.

We study these evolutions for events and at monthly and annual time steps.

The method of comparison uses two ways :

- a direct comparison between runoffs on reference basins and runoffs on burnt ones ;

- use of an hydrologic model fitted on years before fire and applicated to years after fire, in order to study the differences between calculated and observed runoff values. This has been done on burnt and not burnt basins all together.

The two burnt basins studied are "Rimbaud" and "Meffrey" and the reference (not burnt basin) is "Valescure". The characteristics of these 3 basins are shown in tab 6.

Table 6. Characteristics of the 3 basins (in WEESAKUL, 1992 and BRETON, 1992)

	Rimbaud	Meffrey	Valescure
Surface (km^2)	1.5	1.5	9.4
Mean altitude	550 m	274 m	466 m
Mean slope	9°	17°	21°
Mean aspect	235°	203 °	195°
Bed rock	Gneiss°	Phyllade	Micaschiste
Vegetation	Bushes + Chestnut	Pines + Oaks	Oaks+ Chestnut

The reference period before fire is 1967-1990, the hydrologic year is considered from august year i to July year i+1. For more information on reconstitution of rains and runoffs see BRETON (1992).

Table 7. hydrologic characteristics of catchments

Basins	Rimbaud	Meffrey	Valescure
begin of observations	**1967**	**1985**	**1967**
PA (1967-1989)	1186		1200
PA (1985-1989)	901	655	913
LA (1967-1989)	664		523
LA (1985-1989)	474	105	332
PA 1990	983	948	1171
LA 1990	645	198	312
PA 1991	755	692	859
LA 1991	359	29	60

PA: mean annual rainfall (mm)
LA: mean i.e. LA = volume of flow/surface annual high of flow (mm)

4.1 Events

Fire increased considerably the runoffs in the few months after fire

- On "Rimbaud" basin a first study has been done by Lavabre et al. (1991b) giving some information on its behavior during the months after fire. Lavabre and al (1991b) indicate that, for the 3 months after fire, runoff overpassed 3 times the decennal value
- On Meffrey catchment, for the same period, runoff overpassed 6 times the maximum observed since 1987,

These exceptional runoffs occured with normal rain events.

4.2 Monthly runoff

We used a mathematical model of runoff : the GR3M model (MICHEL, 1991), a conceptual model using 3 parameters and a monthly period. It was fitted on data before fire (Tab 3), then used on months after fire.

At this period of time, comparison between calculated and observed values gives the following results :

- for the Rimbaud catchment (Fig 4) a great increase in runoff is observed just after fire (09.1990) and confirms the global increase for the whole year 1990; *the observed values remain greater than calculated values for more than one year, but, after December 1991 they become lower* ;

- for the Meffrey catchment (Fig 5) an increase is also observed just after fire, but after April 1991 (i.e. 6 months after fire), *the observed values become lower than calculated ones.*

The difference in behavior of these two catchments is interesting for many reasons :

- first, it reveals a great increase in runoff just after fire; this was expected and has been yet observed on daily data

- secondly, it reveals a rapid evolution of runoff conditions on these burnt areas. After a few months the increase disappears and the runoffs are lower than before fire. Furthermore, the duration of the period of increase appears different from one catchment to the other: it seems difficult to describe catchments after fire by a unique state and we must consider transitory states, rapidly variable.

Exact reasons for these differential evolutions are difficult to establish perfectly with so few observations, but it seems logical to attribute the evolution of runoff conditions to vegetal growth, which can restrain runoffs during the first spring after fire.

4.3 Annual runoff

At annual time step, no precise evolution is observed.

- the two burnt catchments present opposite results : small increase for Rimbaud catchment (fig 6 : 20% in 1990 and a few percents in 1991), and decrease for Meffrey ;

- not burnt catchments present a decrease in 1990 and 1991

At annual time step (fig 7) two effects are combined : a decrease due to dry years just before fire, and an increase due to fire conditions.

Moreover, a cover without no vegetation at all (giving great runoff) lasts just a few months. After one month many plants have begun their growing, and at the first spring the herbaceous strata is sufficiently important to influence hydrological behavior. It is not possible to consider catchments covered with bare soils for the whole year after fire.

So we conclude that an annual interval is too long to define a clear evolution.

The differential evolutions observed at annual time step explain that *annual values cannot be simply related with percentage of burnt areas.*

5. CONCLUSIONS AND PERSPECTIVES

These results already allow us to tell that a precise maps of soils cover can help runoff studies. For this, remote sensing techniques appear as an appropriate tool. Here, we only used information about total surface of burnt areas by basins, but we have planned to define finer maps of vegetal recovery, year by year.

It appears a great increase of runoff just after fire. This increase is observed during several months, but its duration depends on the catchments : it can be greater (Rimbaud) or smaller (Meffrey) than a year. After this period, we observe a decrease of runoff, with values possibly lower than the ones before fire.

These strong differences in runoff evolution from one basin to the other, during the months after fire, explain that at annual time step, no clear evolution can be observed, due to changes quicker than a year.

It is then important to notice the rapidity of evolution :

- vegetation recovery concerns herbaceous for the first year ; In the years after, progressively bushes take the place of herbaceous strata ; trees grow much more slower and their evolution is not sensitive in the first 3 or 4 years after fire.

- hydrological response increases during maximum 2 years, depending on the catchment ;

- erosion increase during the first months and is completely stopped after one year.

These observations shows the importance of herbaceous strata on runoff conditions; Two others conclusions can be defined :

- at annual rate (or more) it appears impossible to define hydrological conditions of basins after fire by a unique state

- it would be dangerous to conclude on evolution of runoff conditions by analyzing only one burnt basin.

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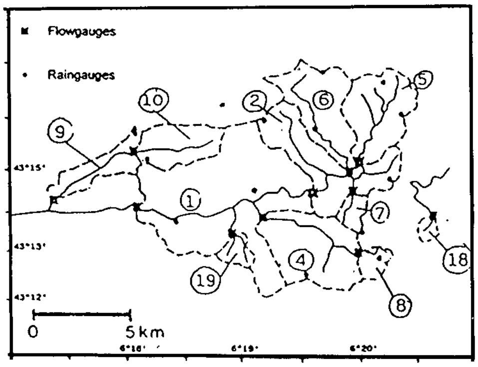


Figure 2. Réal Collobrier Catchments

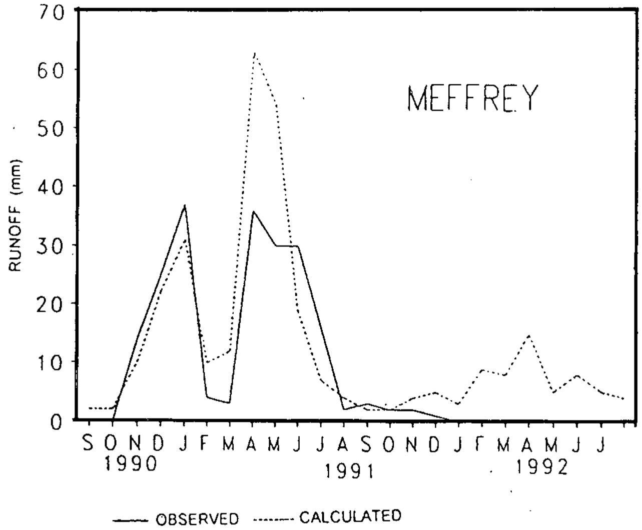


Figure 5. Monthly runoffs calculated and observed : Meffrey catchment

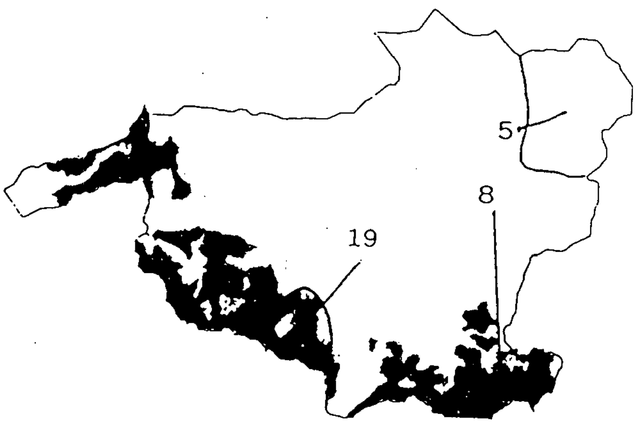


Figure 3. Cartography of burnt areas using histogram of the 09.1990 image.

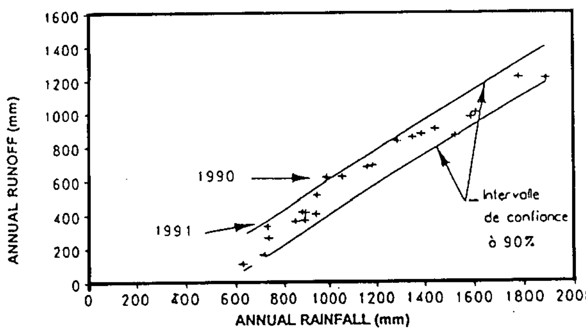
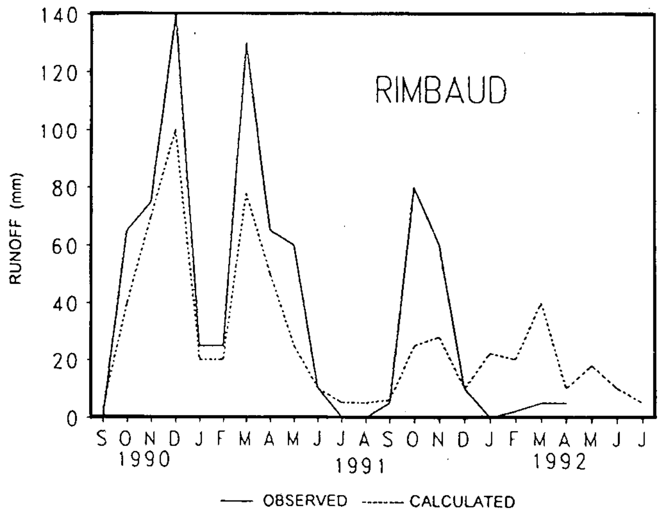


Figure 6. Linear link annual rainfall / runoff. Rimbaud catchment



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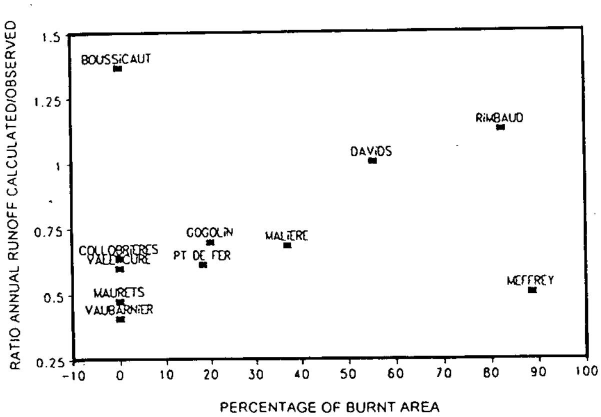

Figure 7. Annual runoffs calculated and observed in year 1990