APPRECIATION OF SNOW AVALANCHES POTENTIALITIES UNDER FOREST CANOPY

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ABSTRACT

The natural hazards and upland erosion control division proposes a gradation method of forests which have a protective function against natural hazards. This method is proceeding from analyses "issues-hazards" of the RTM (French acronym for Mountain Ground Restoration Service). It takes in count the kind and importance of the natural hazards (snow-avalanches, floods, etc...), the structure and mensuration parameters of forest crops and the socio-economic issues vulnerability. Thus forest intervention zones are determined. This real decision-making tool permits to give the cost of forest interventions necessary to the perennity of forest crops and to their protective function. The works of this division have also permitted to give criteria for the determination of potential snow-avalanches starting zones under forest canopy. A run-out distance statistical model, developped by the norvegian and adapted to the french geographic conditions by the snow engineering and avalanche control division, is used to appreciate the probable location of the stopping zones for these phenomena. The whole of these criteria permits to suplement the CLPA (French acronym for Snow Avalanche Probable Location Map) map. The crossing between these informations and the forest data schows that forests maintain these phenomena to a potential activity. But the understanding of this natural hazard forest control needs a better comprehension of snow-forest and snow cover-forest interactions. With this end in view, an experimental apparatus has been established to study the snow distribution in forest .

I INTRODUCTION

The general time history of these forests points out a general ageing correlated to a constant fatigue of the stands. Both tendencies are revealed by the increasing proportion since the begining of the 1950 's of the windthrows in the logging. Moreover, this double tendency -ageing and fatigue - is strengthened by the constant loss of profitability for the lack of skidding

roads in many mountain forests on the one hand, and an almost constant collapse of prices of the stumpage on the other hand. As a consequence, mountain logging became in the red for forests situated on steep slopes and in places difficult to access. By analogy with the agricultural sector, the concentration of the commercial forestry in the most propitious areas from an economical point of view, can be called 'land use changes'. It's for the forests with a protective function that the consequences of management surrender is the most important. It seems that forest stability plays a leading part against upland erosion on steep slopes and for protection of an unstable environment. Whereas, important researches to increase and better productivity do exist for a long time, optimization of a silviculture dedicated to other functions (biodiversity, protection ...) is based most often on empiric and qualitative knowledges. The forest manager has no means thus to justifie the importance of the role of his forest to control such phenomena. The only thing to aim may be for him to maintain the present state of the forest.

The natural hazards and upland erosion control division's works aim to specify the links forest-hazards, and to quantify relevant forester indicators from a goods and people protection point of view. Study of the role of the forests in snow avalanches control seems to be an original way of research in classical silviculture. None the less, in such a scope, it's actualy a way in which many mountainous areas are at stake, specially in Northern Alps.

II DEFINITION OF FOREST UNITS WITH A PROTECTIVE FUNCTION

II.1 The notion of protection - Recalls

Natural risks can be a threat for socio-economic issues, such phenomena thus generate natural hazards. They arise on the versants juting out threatened issues. Vegetative cover and the ways of management of these versants can influence the risks (starting, extant...) in a positive or a negative way, and consequently on the protection of threatened goods and people . This is not a recent established fact. The starting up of the RTM in 1860, is originated from it, throuth the tragic floods of the Isère, the Rhône, the Garonne and the Loire between 1856 and 1859. It has induced the public authorities to start turfing and reforestation works since the end of the XIXth century. Unfortunatly, this will to active protection (in a progressive suppretion of the phenomena themselves) became a politique of passive protection, in which the object is to secure directly the menaced issue ignoring the origine of the phenomenon.

Nevertheless, the best safety measures are obviously in prevention. That is why forest makes a so great asset.

II.2 Forest role - Notion of hazard control

Common analysis "issue-hazard" are profitable in that they link the notions of hazard with the notion of socio-economic issue, but they do not take in count a possible evolution of the issues (abandonment, extention...) and of the natural risks. In some cases indeed, the stands play the role of an active protection. If they come to desapear, we realize it... but to late. Missanticipating these evolutions, the forest manager dares to be permanently running after emergency, trying to supply them generaly at high costs. At the opposit an accomodated management would have fulfill or improve the protection function of these forests.

III. MAPPING OF THE PRIORITY FOREST INTERVENTION ZONE

One of the steps in mapping of forests which have a protective function is to evaluate the actual level of natural hazard control by forest crops and its probable evolution (gain or lost) in the future if all managements were given up.

III.1 General principles

The evaluation of the natural hazard forest control level is based upon an estimation of a Hazard Mastership Index (IMA in French) dependent upon types of natural risks (frequency, intensity, origin in regard to forest crops) and forest crops (value of the canopy) involved, together with the degree of protection provided by stable tree population patterns. So we have been able to obtain an indexation, in terms of relative values, ranging from 0 to 5. 0 represents populations offering no control (no protection in fact) and 5 those where the control is at the maximum. The crossing of this index with the importance of the issues involved and the stability of the forest crops allowes us to pont out forest interventions emergency (in function of the forest crop state) and priority (in function of the type and the importance of the issue). Then their financing can be graded (fig. 1). Such unities are called Priority Forest Intervention Zone (ZIFP in French).

This method has been used to do the zoning of forests which have a protective function against risk in the French departement of SAVOIE. This study is based upon cartographic documents which are the bases of the thought and constitute the final point of this study. The use of our classification key began with cartographically crossing maps locating probable areas

of natural risk with forest maps. This first zoning has given us a synthesis map of forest units with natural risks (UFR in French). These units have been analyzed by investigations with local forest managers. All the information gathered has been digitalized using the GIS Arc/Info. This software was also used to do cartographic crossing. Two small management systems, using commands such as 'If yes then goto', have been prepared, permitting a further exploitation of statistics so as to provide automatically the IMA and ZIFP calculation of each UFR.

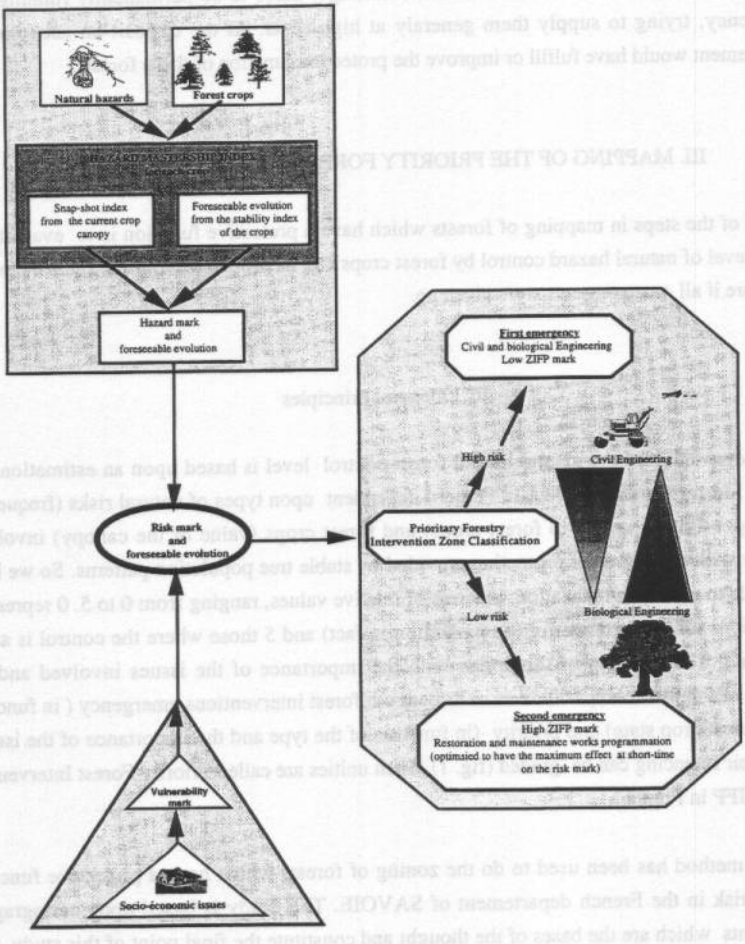

Fig.1: Principle of IMA classification

There are two types of probable location of natural hazard maps used :

- the RTM's maps, which index natural hazard other than snow avalanches, in particular : stream flooding, landslips, gullying and falling rocks. These maps record potential and active phenomena. They also give information about frequency and intensity of these phenomena. Geologists make them by field and historical investigations.

- the Snow Avalanches Probable Location maps. The CLPA record only active phenomena. They are only past phenomena inventory maps without any information about their frequency and intensity. As the RTM's maps, they are made by field, historical investigations and aerial photography interpretation. The aerial photography interpretation study aims at looking at past avalanches field signs (deposits, erosion, destructions, etc...). For the forest area, the anchoring of the snow is considered as well done and the forest canopy masks all the avalanches activity signs. So only the avalanches paths, which are visible in forest (due to the lacks of forest vegetation), are mapped.

III.2 Results and conclusions for the department of Savoie

For this french departement, 43% of the whole forest area inventoried (60 020 ha) have a protective function against natural risks. The logging deficit is about 108 F/m3 (1994 French Francs) for the next 5 years. During this survey, the forest managers were directed to update the probable location natural risks map with new active and potential risks not yet inventoried. So, on the whole natural risks mapped in forest, only 5% have been considered as potential by the forest managers. Potential snow avalanches represent only 2.5% of the entire natural risks inventoried in forest. In fact, these phenomena are well recorded by CLPA maps, but their frequency and/or intensity are very low. By consequence, the forest masks potential avalanches zones and forest managers are not able to appreciate the potentialities of these phenomena under forest canopy. Generally, people consider that there isn't any avalanche where the forest is. But, if the forest cover disappeared, what could happen?

The forest offers the maximal protection when it maintains a natural hazard to a potential activity. Such a protection is called : active defence. This kind of protection belongs to the long-time, its keeping needs a regular maintenance of the forest crops as well as immediate and emergency actions in order to avoid their distabilizing and vanishing. If we want to certify the perenity of this function, we should be able to locate the zones where the forest masters snow avalanche harzard.

This location requires :

- on the one hand to determine the avalanche potential starting zones under forest canopy;
- on the other hand to imagine a catastrophic scenario (destruction of the whole forest cover), for which the phenomenon would become active, and so to be able to appreciate the zones probably reached by it.

Complemetary studies, at more detailed scales, have been done. Their aims were to define more precisely the interaction between forest crops and the potentiality of avalanches. The principle objectives of these studies were :

- to determine simple location criteria of snow avalanches starting zones, based on the study of the active one's;
- to estimate the avalanche forest control comparing the avalanche potential starting zones location map with the forest and CLPA maps;
- to determine the probable run-out zones of these potential phenomena and then to be able to estimate the protective function of these forests;
- to select and equip experimental plots in order to better understand forest-snow interactions.

IV FOREST AND AVALANCHES POTENTIALITIES

IV.1 Location criteria of snow avalanches starting zones

There are different types of snow, due to the different factors which modify the quality of the snow cover. The snow cover is the result of the snow spatial organisation in layer. Its visco-plastic properties depend on the ice grain cohesion in a layer and between layers. When it's built on slope area, this edifice can move. The snow cover heterogeneity makes that the knowledge of the releasing factors is difficult. In fact, many factors determine snow cover stablity or unstability. The forest is one of the stabilizing factors. The movement of the snow cover is first of all conditionned by the ground slope value on which it's formed.

Otherwise, the estimation of the protective function of the forests is done comparing the observed activity of a natural hazard in forest with its probably activity for the same area but without any vegetation. But this comparison is possible if you know the location of this natural hazard starting zone. Therefore, we decided to take in count only topographic criteria. The wind has an important effect on the snow deposit. Its action depends on the aspect of the versant, the presence of convex and concave areas, obstacles and meteorological conditions. The forest

modifies the action of the wind. Under forest crops there is no wind. In order to realize in the best conditions our comparisons, we have decided not to take in count the effects of the wind.

The topographic criteria selected, after a bibliographic analysis, concern :

- the slope : on the whole, autors admit that starting zones are located on slopes between 28° and 55°. Under 28° there is no movement of the snow cover. Beyond 55° the snow doesn't stay on such slopes, and give birth to small slides without any importance. The minimum size of a starting zone is around 500 m^2.
- the slope breaking lines : concavities of the ground are compression areas. at the opposit, the convexities are tensile areas. The snow cover badly resists to tensile and schearing strenghts. So convex areas represent factors of unstability, while concav areas are factors of stability for the snow cover. The slope breaking lines must be horizontal and the breaking angle well marked. We have taken for the lower critical breaking angle value : 10°.

IV.2. Validity of these criteria and appreciation of the snow avalanches potential starting zones under forest canopy

We have tested the validity of these criteria researching them systematically for all the active snow avalanches sites of our studies areas. There are 70 observed avalanche pathes in the two studies areas (districts of Sainte Foy Tarentaise and Beaufort sur Doron in the Savoie department).This research has required slopes and slope breaking lines maps. They have been done with the GIS Arc/Info. This software has a module of triangulation, called TIN. It permits to obtain a triangular irregular network from a record file containing altimetric data, and then a Digital Elevation Model (DEM). This DEM is used to make automaticaly slope, aspect, low direction, etc... maps. For each sites, we have made a DEM and so obtained a slope map. By querying in the database Info we have also obtain a map of slopes between 28° and 55° with slope breaking lines. This map inventories all the snow avalanches starting zones (active and potential ones). The cartographic crossing of these map with the CLPA map has allowed us to test the validity of our criteria. It has also permitted to show the avalanches potential starting zones not yet inventoried by the CLPA map. For both sites, 98% of the CLPA snow pathes verify our location criteria. So they can be considered as correct.

From the maps and field data of the ONF (French acronym for Forestry National Office), we have made a map of the forest canopy using 4 canopy classes : $\leq 10\%$; $10\% < \leq 30\%$; $30\% < \leq 70\%$; $70\% <$. A low value of forest canopy ($\leq 10\%$)) can't prevent the avalanches release.The

crossing of this map with the snow avalanches potential starting zones map, permits to locate those which are under forest canopy. With this methodology, 51% of the Sainte Foy Tarentaise forest area and 55% for the Chornais verify our location criteria. Now, none avalanches activities are observed and mapped for these zones although all the topographic conditions required for a release are verified. Therefore, the forest as it stands, prevents the snow avalanches formation.

But a forest can only claims to have a protection function if natural hazard jeopardizes socio-economic interests. To appreciate this function, we must determine the phenomena run-out distances. By crossing this run-out distances map with the socio-economic issues map, we could say which ones are menaced - in other words, where there is a natural risk and where the forest is able to prevent it.

IV.3 Estimation of the probably run-out zones

General principles

A statistical model, developped by K.LIED et S.BAKKEHOI (-1980), has been used to estimate probably run-out distances from our potential starting zones in forest. This model, called the norvegian method, offers the avantage to break away from the choice of the flow parameters or friction coefficients. These parameters are often difficult to appreciate. It's based on the lineary regression of some topographic parameters to explain the ones describing the maximal avalanches (return period higher than 100 years) run-out distances. The authors consider that an avalanche path is assimilated to a profile and that a statistical law can give the average run-out distance in function of topographic conditions.

Putting to use for the site of Chornais

In 1928 and 1936, great storms have destroyed the forest cover of this versant. So, in 1936 a snow avalanche has been observed which had never been observed before. The starting zone of this phenomenon was in one of the deforested area by the tornados. Some houses were destroyed and a road snow-bounded. Reforestation works and racks against avalanches (among the first in forest in France) have been done. Now, the whole versant is wooded again and all avalanches activity has disappeared. But these forest stands are unstable (stems with a small diameter for a high stand height).In the case of a management surender, in 50 years we

should find the same unstability forest conditions than in 1928 and 1936. To place in a proeminent position the protection roll of these planting forests, we have used methods described previously. We have made, disregarding forest vegetation, probable location of avalanches potential departure and estimating location run-out zones maps. As we said before, a profile is required to use the norvegian method. Here again we have used GIS Arc/info fonctionalities. The TIN modul permits, over and above the realization of a DEM, the realization of profiles and the recoupment of their threedimensional coordinates.

A network of profiles is selected from the avalanches potential starting zones of this site. Their threedimensional coordinates have supplied the norvegian model. Previously, this model has been adapted to the french topographic conditions. Breaking and run-out points for two confidential intervals (for 9 avalanches on 10 and for 99 on 100) are calculated. These different points, set on profiles, permit to propose a potential risk zoning. Effectively, we determined a departure zone, a transit zone and run-out zones in function of the confidential interval choosen. The validity of this zoning is tested with data of the 1936, snow avalanche. In the "cover" of this phenomenom, mapped by the CLPA, we have been able to point out the existence of a starting zone verifying our criteria. Then we have drawn a profile from this zone and following the line of steepest slope. For a confidential interval of 99%, we have obtain the same run-out distance than the ones observed.

The cartographic crossing of run-out zones with the socio-economic interests map shows that all the roads going to the ski resort of "le Planey", a holliday center and all the houses are put in jeopardy by potential snow avalanches. But none activity is observed. therefore the presence of forest planting on the potential starting zone offers a maximal protection against this natural hazard.

V SNOW/FOREST INTERACTIONS STUDY

The method that we propose, permits to better inventory geographic areas where forest prevents snow avalanches releasing. This mapping is very important for the forest managers. Effectively, they must adapt their sylviculture in function of the natural hazards. But it doesn't permit to fix forestry rules to manage these plantings. To elaborate such rules, the forest manager should have a good knowledge of the relationship between snow avalanches and forests. In other words, in which cases a forest planting (density of stems, basal area, etc...) inhibates the releasing of snow avalanches? The forest managers translates his interrogations by the question : for which size of gap in forest can we observe an avalanche releasing? This

question is very important in mountain sylviculture. Frequently, the manager must open gap to regenerate the forest, but on a potential avalanche zone what are maximal sizes of these regeneration gaps ?

To give an answer to this question, we selected 5 experimental plots (50 m width on 50 m long) to study the snow distribution in forest. Each of them is equiped with snow-poles network (one each 12.5m) The useful height is 3,50m. During the winter 94-95, we have made a snow-level and snow density reading for each snow-pole. For each experimental plots, an inventory of all the stems and their crown projection on the ground have been done. So, we have calculated for each snow-poles the value of the forest canopy for circles of radius going from 0.5 to 10 m, with a step of 0.25 m. Some witness snow-poles have been installed in non forest areas. We have used lineary regressions to explain snow level under forest canopy in function of the forest parameters. It results of these computations that the observed height of snow in a point depends on the forest canopy calculated with both radious of 2.50 m and 8.75 m around it. So, a tree effect (radius = 2.5 m) and a forest crop effect (radius = 8.75 m) are pointed out. For this versant the maximal interception by the forest canopy is 70% of the snow fall. The swiss research workers schow that the minimal sizes of a starting zone non locate under forest canopy are : 10 m width on 50 m length for a slope less than 35° and 10 m on 30 m for a slope greater than 35°. Taking in count our results about the canopy effect on the snow distribution we can propose for regeneration gaps the following dimensions : 28 m on 60 m for a slope less than 35° and 28 m on 40 m for a slope greater than 35°.

These results must be taken with care because we have for the moment only one season field investigations.

VI CONCLUSION

Building upon the GIS Arc/Info system, we have thus created a genuine forestry GIS dedicated to the natural risk in forest management. Apart from mapping, zoning and programmation aspects, using scenarii identified by forestry managers, this aid for decision-making tool can also pick out future trends in the evolution of forest crops. But many questions concerning natural hazards releasing and propagation under forest canopy haven't yet answers. So, our tool can only progress if these questions found replies. It's why, forestry managers and scientists must work together to increase the knowledge of these phenomena.