HAZARD LEVELS WARNING FOR AVALANCHE DANGER ON DWELLINGS PROPOSAL

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ABSTRACT: Avalanches effecting or destroying dwellings are fortunately relatively rare. As such, when these events occur they are surprising and often devastating. To help mayors of the communes concerned make possible decisions regarding evacuations, 36 criteria pertaining to avalanche hazards for the protection of dwellings were recently identified and organized into six main groups. The determinants of danger are rather different than those concerning the skier, hiker or out-tracker. The source of the danger is distinguished by determining also the nature of the danger. Firstly, a hierarchical organization is proposed. A fast visualization of the target area allows the evaluation of the hazard level concerned. Examples are proposed for hazards that are either exceptional (period of return greater than 100 years), strong, or “moderate.” The European avalanche scale of risk is not sufficient for these characterizations. A genuine technical preparation in the event of a possible intense degradation of the snow-weather conditions appears essential to the adequate management of a crisis avalanche impacting dwellings.

KEYWORDS: Avalanche, hazard, level, warning, dwelling.

1 SCENARI: BRIEF DESCRIPTION

Snow avalanches are the result of variable combinations of multiple factors of diverse origins and of changing form. The evaluation of risk passes through a construct of avalanche scenarios. Many criteria necessary to its production can be gathered. The criteria which identify the different sources and nature of the danger are organized in 4 main groups:

➔ Source of the danger:
- ❶ Geography/ Morphology of the site;
- ❷ Snow-meteorology;

➔ Nature of the danger:
- ❸ Avalanche history in the site;
- ❹ Dynamic of the dreaded avalanche.

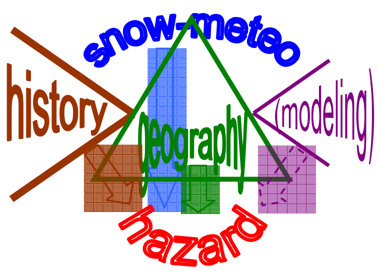

Figure 1: Fundamental elements of avalanche hazard.

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2 MAIN INFLUENCING CRITERIA

2.1 The site morphology

These parameters tend not to evolve or do so very minutely over time. Despite this they are often poorly identified. See Table 1-Up (following page).

Of course the conjunction of unfavorable factors increases the hazard. Examples:

➔ great surface of starting zone + considerable average slope + profile with projection;

➔ strong ratio of arrival and starting zone + great possible starting zone to the top of that known.

2.2 The snow-meteorology

These factors evolve sometimes very quickly over the course of the winter. They can be rather well known on the level of the concerned massif; however, they are seldom specified on the level of each avalanche path. See Table 1-Down (following page).

Other criteria certainly influence determination but they are either less in measurement or are more difficult to access:

➔ Initial characteristics of the snow cover:
- Height: if ➚ then hazard ➚;
- Stratification: if ➚ then hazard ➚;

➔ Quantity of snow:
- Intensity of the fall: if ➚ then hazard ➚;
- Speed of compressing: if ➚ then hazard ➘;

Table n°**1**: Main morphological and snow-meteorological criteria of the sites and possible consequences

Criteria	Characteristic	**Possible consequence about**:			
		the **phenomena**		the **hazard**	
		Spreading-out / trajectory	**Speed**	**Frequency**	**Intensity**
Surface (S) of the starting zone	Large (S> 100 000 m²)	Lengthy / enlarged / overburdened	Very great	↗↗	↗↗
	Average (2 < S ≤ 10 ha)		Variable	↗	↗
Ratio (R) **starting / deposit surfaces**	Great (R> 3)	Lengthy / enlarged / overburdened	-	↗↗	↗
	Average (2 < R ≤ 3)		-	↗	-
Altitude (A) known starting zone	High (A> 2200 m)	Lengthy	-	↗	↗
Global **slope angle** (S)	Great (S> 30°(≈ 58%))	Lengthy	Great	↗	↗↗
	Considerable (25°< S ≤ 30°)	-	Variable	-	↗
Starting zone maxi **slope angle** (S_{max})	Low (28° ≤ S_{max} < 31°)	Rare	-	↘	↗↗
Field shape	Confined path	Overburdened / lengthy	Great	↗	↗
	Length profile with rise	Lengthy	Variable	↘	↗↗
	Winding	Overburdened	-	↗	↗
Possible **starting zone** connected with its known	Above	Lengthy / enlarged / overburdened	Very great	↗↗	↗↗
	Lateral		Great	↗	↗↗
Snow : quantity= Height (h fallen in 3* days = 72 hours)	Very great (h > 150*cm)	Lengthy / enlarged	Very great	↗↗	↗↗
	Great (100* < h< 150*cm)	Lengthy / enlarged	Great	↗	↗↗
	Considerable (50* < h ≤ 100*cm)	Enlarged	Variable	↗	↗
Snow: quality= Temperature (T)	Low (T < -12°C)	Lengthy / enlarged	Great	↗↗	↗
	Usual (-12°< T < -3°C)	with digitations	Variable	↗	-
	High (-3°C < T)	Angular	Low	-	↗
Wind in the leeward starting slope	Intensity: hard (v >15 m/s)	Lengthy / enlarged	Variable	↗↗	↗↗
	Duration: lengthy (t > 4 h)	Lengthy / enlarged	Variable	↗	↗
Weak layer inside the snow pack	Presence: yes	Limited	Variable	↗↗	-
	Quality: major	-	Variable	↗↗	↗
Avalanche danger **European scale**	Level 5 for the concerned massif ; number of days	Lengthy / enlarged	Variable	↗↗	↗↗
French natural hazards **weather warning**	Red (maximum)	Lengthy / enlarged	Great	↗↗	↗↗
	Orange			↗	↗↗

↗ Increase (strong if ↗↗) (or ↘ reduction) in the dangerousness of the parameter

*: variable value according to the snow-meteorological massifs, the sites and snow-meteorology

- Mass of moving snow (synthesis of quantity at the beginning and entrained in flow, according to the snow quality): if ↗ then hazard ↗;

➔ The quality of snow:

- Density: if ↗ then frequency ↘ but intensity ↗;
- Cohesion of snow at the beginning: very important for the risk of the skier (ex: existence of slab), but not determining for the hazard on dwellings;

Of course the conjunction of unfavorable factors increases the hazard. Examples:

➔ Great height of snow recently fallen + snow temperature (very) low;

➔ Considerable height of snow recently fallen + strong wind, for a long time, overloading a starting zone.

2.3 Avalanche history of the site

Along with the weather warnings signals, the avalanche history of the site constitutes a dominating factor of the legal determination of the hazard. The criteria suggested here are particularly reduced in the aim of simplification. See Table 2-Up.

2.4 Avalanche dynamic

The morphological typology of the avalanches distinguishes several criteria on each of the three usual avalanche zones (starting, flowing and deposit). See Table 2-Down for the avalanche dynamic criteria for the determination of the hazard on dwellings.

Obviously when an avalanche is moving it is almost too late to take any safety measure: the table n°2-Down shows only what is most necessary to fear.

Table n°**2**: Main avalanche historical and dynamical criteria of the sites and possible consequences

		Possible consequence about:			
		the **phenomena**		the **hazard**	
Criteria	**Characteristic**	**Spreading-out / trajectory**	**Speed**	**Frequency**	**Intensity**
Knowledge of avalanche(s) **having reached a dwelling**	Yes: many times	Lengthy / enlarged	Great	↗	↗↗
	Yes: one time		Variable	-	↗
Irregularity of running	Strong	Lengthy / enlarged	Variable	↗	↗
Data quality (reliability / duration)	Bad (hard uncertainty)	Lengthy / enlarged	Variable	↗	↗
Avalanche **period**	Multiple releases near in time and in space	-		↗↗	↗
Moisture content (starting snow)	Nil (ball: impossible)	Lengthy*	Great	↘	↗↗
	Considerable (damp ball)	With digitations	Variable	↗	↗
	High (soaked ball)	Angular**	Low	-	↗
Snow particles cloud (flowing and deposit zones)	With, at the head	Rectilinear / bobsleigh effect / enlarged	Great	↘	↗↗
	With, behind the head	Undulating	Variable	↗↗	↗
	Without	Winding	Low	↗	↗↗
Entrained snow (flowing zone)	With	Lengthy	Increasing	↗	↗↗
Preliminary avalanche **deposit**(s)	With	Overflowed / Lengthy		↗↗	↗

↗ Increase (strong if ↗↗) (or ↘ reduction) in the dangerousness of the parameter

*: ex: way over a rise ; on the opposite side ; **: ex: upon a crossing inclined road ;

Of course the conjunction of unfavorable factors increases the hazard. Examples:

➔ Powder snow avalanche + strong and long entrained snow;

➔ Presence of large deposit + new avalanche.

3 HOW TO BUILD THE AVALANCHE HAZARD FOR INHABITANTS ?

When confronted with the urgency of a very evolutionary winter situation and the safety of inhabitants at risk, a local decision maker must initially collect the maximum amount of possible information to best choose from a set of avalanche scenarios. He then determines the avalanche hazard corresponding as close as possible to the lived situation. This choice does not correspond to a resolution of physic-mathematical problem but is an expert technical appreciation that obliges to argumentation rather then demonstration. Thus, it is often the case that the decision maker surrounds himself with an adept structure of council.

The hazard is defined as the probability of an accidental phenomenon producing few given effects during a given period in a given point. It thus expresses for a given area a possible prediction of the phenomenon starting from known past elements. However, in the case of avalanches, the nature of these elements is particularly variable:

- In space, according to the acuity of the geographical criteria and the dynamics of the phenomenon; this corresponds to the initial conditions (ex: more or less strong slope in a leeward or not zone) but also to the conditions of flow and stop (ex: according to local topography and the presence of entrained snow);
- In time, with new information; this corresponds to either a few hours depending on the evolution of the snow-weather conditions, or a few minutes, in the occurrence of an exceptional avalanche announcing a rising; this estimation is even more difficult when the lived situation deviates from the recent events.

According to the French methodological guide for the plans of prevention of foreseeable natural risks on dwellings, the hazard locates and treats the frequency and the intensity of the phenomenon (the avalanche) on a hierarchical basis. Thus for inhabitants, the risk is then determined independently of the vulnerability.

The history of the events and the modelisation can make it possible to estimate the frequency. A high frequency (ex: biennial) of avalanche strongly influences the skiable field to close or open a ski-track, but seldom places urbanized locations in the downstream (except restaurant in altitude). A rare frequency (ex: centennial) slightly affects the tracks, most probably closed at the bad weather but much more of the inhabited areas

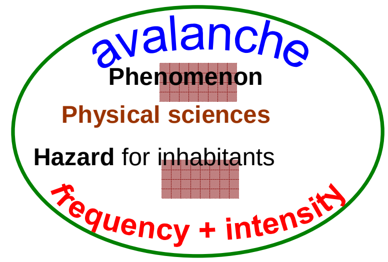

Figure 2 : Phenomenon and hazard

The examination of the caused damage and of the modeling can make it possible to estimate the intensity. Through the classically developed pressure measure, expressed in kiloPascal, kPa (10 kPa ≈ 1 T/m^2). This measure depends initially on the speed and then on the density of the avalanche. Cohesion is also a factor of consideration. The degree of the impact is dependent on the thickness of the flow.

In a given area, a rare avalanche often develops a much stronger intensity than that of a more frequent avalanche. But this correlation is not systematic.

Finally, the avalanche hazard determination processes for an inhabited site is carried out in mountain regions throughout the winter and with various stages of temporary defense measures (see fig. 3):

- The variation of the snow-weather conditions constitutes the origin of alarm;
- The collection of various necessary information, the selection of an avalanche scenario and the determination of the hazard constitute the course of action;
- The suitable reactions are influenced by the required level of safety.

The avalanche hazard is operationally determined according to a combination of many different criteria, organized in 3x2 = 6 groups. The first 4 groups were seen in the avalanche scenarios while the last 2 are “Choice” and “Over check” (See figures 4 and 5).

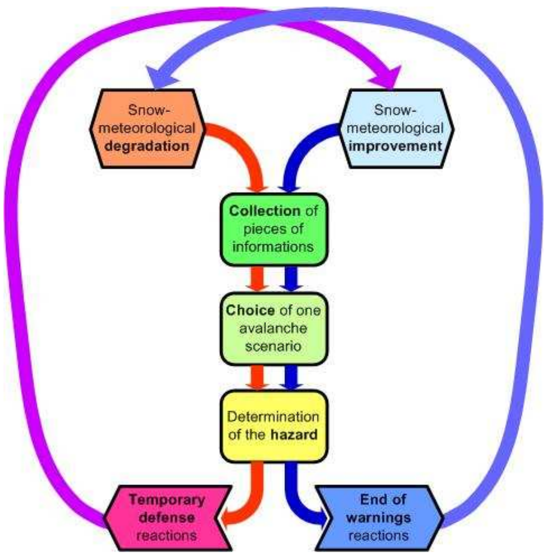

Figure **3**: The heart of the process “Hazard and temporary defense”

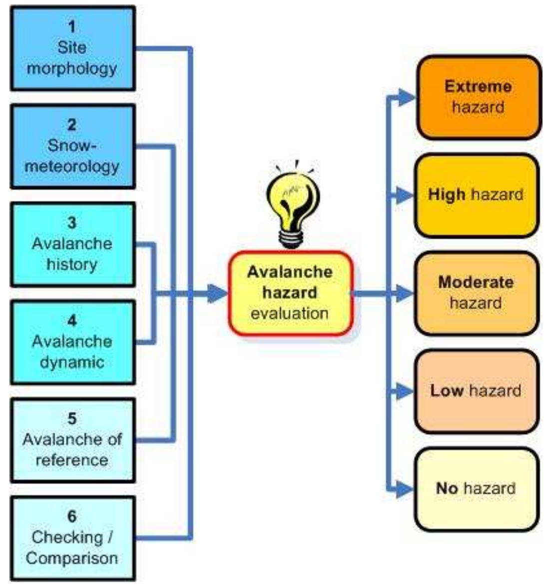

Figure **4**: Groups of criteria for the avalanche hazard determination and levels

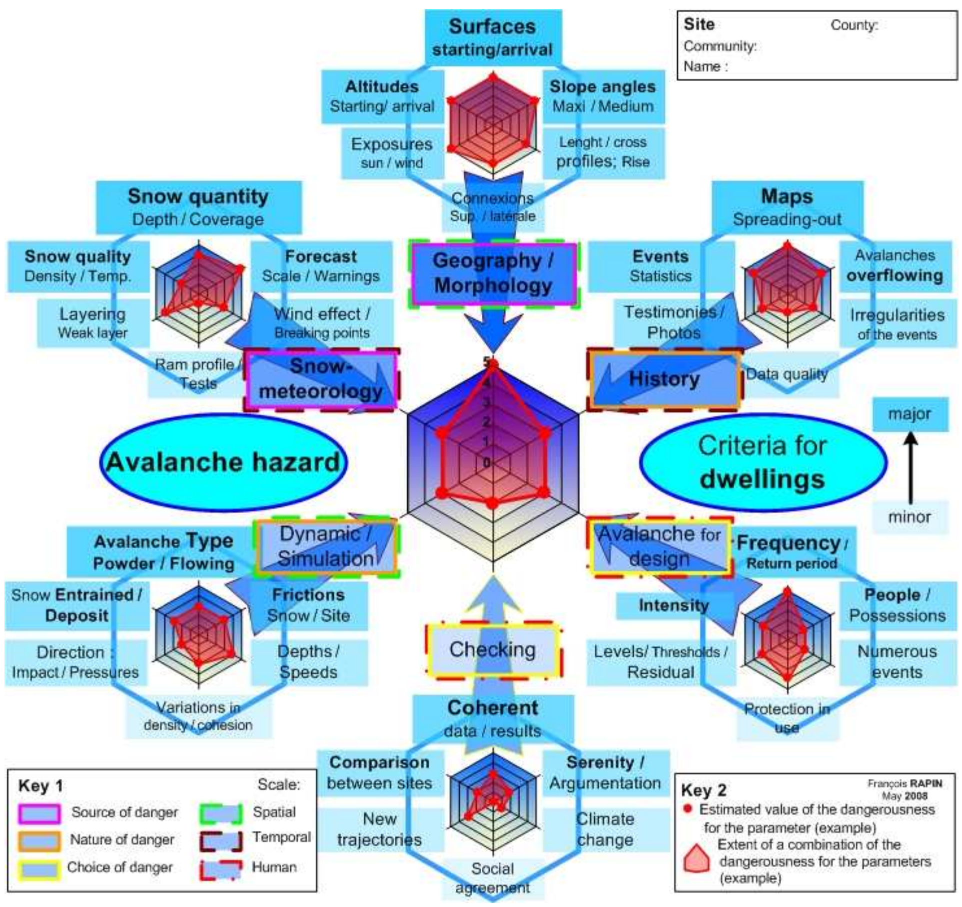

Figure **5**: **Avalanche hazard flake**: Synthesis for avalanche hazard on dwellings

The morphology of the site and the snow-meteorology remain essential. But this global group allows diversity to reach a certain overall coherence. In order to reduce the determination of the avalanche hazard only one of these groups of criteria is significantly revealing. Moreover the list of the possible criteria can be rather long, therefore multiple combinations exist. As a test towards a certain popularization, it is possible to limit them, then to gather them by level: the simultaneity of several criteria, not inevitably of all, then establishes the membership of the announced level.

For zoning, the hazard is often summarized with qualifiers: nil, low, moderate, high and extreme.

For the protection of inhabitants the relevant levels are those corresponding to a rather rare avalanche and/or devastator: exceptional or strong, even moderate. With respect to a prevention plan of the natural risks, an “exceptional” avalanche will have a strong probability of traversing most of a restricted zone (often “blue”) even if this one is declared on the hazard map in a weak hazard. Conversely a “moderate” avalanche will have a strong probability of remaining confined in the forbidden red zone or of mostly being spread out marginally over the restricted blue zone.

Temporary defense measures are, by definition, implemented only when somebody reacts according to information available. Data collection, as complete and adapted as possible, thus constitutes the first and most essential step:

- Active research of all the relevant elements, largely improved by good preparation/ organization;
- Synthesis by site on each criterion.

Next the evaluation of the hazard, and then the organization of the risks into a hierarchy, generates the temporary defense reactions.

Finally the effectiveness of the temporary defense measures is particularly related to the appropriateness of the reaction. So this one must be:

✓ Anticipating: over the long run, an essential and always improvable organization/ preparation system, and on very short term, by integrating quick changes of the conditions;

✓ Rapid in time: immediate, with follow up actions within a few hours;

✓ Targeted/ treated on a hierarchical basis in space: located by indexed path because the level of danger is not the same for all at the same time;

✓ Multiple in its effects: any other operations (management of the evacuations, of the releases …) and intensity (activity of crisis).

Very often the anticipation constitutes the major difficulty:

- The experiment confrontation with multiple passed situations, is then determining; in the event of lacking resources, it is necessary to know where else to collect it;
- The integration of the vulnerability of conditions is then essential and restrictive; it should be even more anticipated when the vulnerability is large or “complicated.” The few failures of this aspect are often condemned by the population and/or by the judge. Only few successes are really rewarded by the decision maker. However his choice is often motivated by the confrontation of these vulnerability conditions and the perceived hazard level.

The “delicacy” of the warning choice is found in the 2 successive decisions:

- the release of temporary defense measures,
- the warning stop (raised prohibitions).

Then the parameters retained are not the same ones.

You find on the following pages (see tables 3 and 4) two different descriptive tables with proposals of different values for the exceptional and high avalanche hazard parameters. Others exist for moderate and low hazards.

Thus the idea is to give a numerical value to each possible solution, then to build a decision maker system to assist the local people at risk.

Table n°**3**: Proposal of different values for the avalanche parameters: **exceptional** hazard

Hazard	Example N°	Possible combination of criteria :	
		Type	**Characteristic and "value"**
Exceptional (Frequency ≥ **100 years** or Intensity ≥ 50 kPa)	**EX1**	**Snow-meteorology**	● **snow** fall **height** in 3 d : **very great** (>150 cm) ● **temperature** (starting snow): **low** (≤ -12℃) ● wind **surcharge** in 3 d: **great** (75%< snow height increasing ≤ 100%) ● known **weak layer**: **yes**, moderate ● European **avalanche scale**: n°**5** (maxi)) ≥ **3** days ● **weather warnings**: **severe** ≥ **2** days
		Site morphology	● **surfaces** : starting zone: **great** (10 < ≤ 30 ha) Runout known zone: average (1 < ≤ 5 ha) ● possible **starting altitude**: very high (> 2500 m) ● possible **difference** in **height**: great (900 < ≤ 1200 m) ● average global **slope**: **very great** (> 80%) ● **field shape** of the flowing area: **winding** ● possible starting **zone above**: surface: great (5 < ≤ 15 ha) (1 ha = 10 000 m^2)
		History	● known **avalanche(s)** over one dwelling : no ● data **quality** : high uncertainty ● **other(s)** nearby natural **avalanche(s)** < 4 h : **yes**, ≥ 1
		Dreaded avalanche type	● **powder**, with overburdened ● impact **intensity** : very high (I > 100 kPa)
	EX2	**Snow-meteorology**	● **snow** fall **height** in 3 d: **great** (100 < ≤ 150 cm) ● **temperature** (starting snow): **low** (≤-12℃) ● wind **surcharge** in 3 d: **very great** (snow height increasing > 100%) ● known **weak layer**: **yes** , major ● European **avalanche scale**: n°5 (maxi) ≥ 2 days ● **weather warnings**: **severe**, 1 day
		Site morphology	● **surfaces** : starting zone: **very great** (> 30 ha) Runout known zone: average (1 < ≤ 5 ha) ● possible **starting altitude**: high (2200 < ≤ 2500 m) ● possible **difference** in **height**: very great (> 1200 m) ● average global **slope**: **great** (65 < ≤ 80%) ● **field shape** of the flowing area: length profile with **projection** ● possible starting **zone above**: surface : moderate (1 < ≤ 5 ha) (1 ha = 10 000 m^2)
		History	● known **avalanche(s)** over one dwelling: **yes**, > 2 ● **Irregularity of running**: strong ● **other(s)** nearby natural **avalanche(s)** < 4 h : **yes**, > **2**
		Dreaded avalanche type	● **powder** ● impact **intensity** : medium (50< <100 kPa)

Table n°**4**: Proposal of different values for the avalanche parameters: **high** hazard

Hazard	Example **N°**	**Type**	**Possible combination of criteria** : **Characteristic and "value"**
High (**30 years** ≤ Frequency < **100 years** or 30 kPa ≤ Intensity < 50 kPa)	**H1**	**Snow-meteorology**	● **snow** fall **height** in 3 d : **great** (100 < ≤ 150 cm) ● **temperature** (starting snow): **usual** (-12°< ≤ -3°C) ● wind **surcharge** in 3 d: **strong** (50%< snow height increasing ≤ 75%) ● known **weak layer**: **yes**, moderate ● European **avalanche scale**: n°**5** (maxi) ● **weather warnings**: strong ≥ 2 days
		Site morphology	● **surfaces** : starting zone: **moderate** (2 < ≤ 10 ha) Runout known zone: small (0.25 < ≤ 1 ha) ● possible **starting altitude**: very high (> 2500 m) ● possible **difference** in **height**: great (900 < ≤ 1200 m) ● average global **slope**: **great** (65< ≤ 80%) ● **field shape** of the flowing area: profile with projection ● possible starting **zone above**: surface: very great (>15 ha) (1 ha = 10 000 m^2)
		History	● known **avalanche(s)** over one dwelling : yes, >2 ● data **quality** : doubtful ● **other(s)** nearby natural **avalanche(s)** < 4 h : **yes**, ≥ 1
		Dreaded avalanche type	● **dry flowing**, ● impact **intensity** : high (50< I ≤ 80 kPa)
	H2	**Snow-meteorology**	● **snow** fall **height** in 3 d: **very great** (> 150 cm) ● **temperature** (starting snow): high (-3°C< ≤ 0°C) ● wind **surcharge** in 3 d: low (20%< snow height increasing ≤ 50%) ● known **weak layer**: **yes** , major ● European **avalanche scale**: n°5 (maxi) ≥ 2 days ● **weather warnings**: **severe** 1 day
		Site morphology	● **surfaces** : starting zone: **great** (10 < ≤ 30 ha) Runout known zone: small (0.25 < ≤ 1 ha) ● possible **starting altitude**: moderate (1800 < ≤ 2200 m) ● possible **difference** in **height**: moderate (600< ≤ 900 m) ● average global **slope**: **very great** (> 80%) ● **field shape** of the flowing area: **confined** track ● possible starting **zone above**: surface : small (0.25 < ≤ 1 ha) (1 ha = 10 000 m^2)
		History	● known **avalanche(s)** over one dwelling: **yes**, > 2 ● **Irregularity of running**: strong ● **other(s)** nearby natural **avalanche(s)** < 4 h : **no**
		Dreaded avalanche type	● **wet flowing,** with overburdened ● impact **intensity** : "moderate" (30< <50 kPa)