AKHALI GUDAURI

Potential avalanche exposure and corresponding hazard zoning

V0 31/10/2018

ENGINEERISK

PA Alpespace - Bât Cleanspace - 73 800 Sainte Hélène du Lac / FR

: + 33 (0)6 23 75 04 44 - Site Web : www.engineerisk.com

Siret : 499 774 032 000 27 - SAS au capital de : 11 870 €

Draft/validation by : Dr. Eng. Philippe BERTHET-RAMBAUD
: +33 (0)6 23 75 04 44
: philippe.berthet-rambaud@engineerisk.com
Visa:

Control by: Eng. Fanny BOURJAILLAT
: +33 (0)6 23 75 06 42
: fanny.bourjaillat@engineerisk.com
Visa :

This report contains 16 pages

Except alternative mentions: photos by Engineerisk & Geographic / North to the top of map
Reference: GEO07 - Version 0 – October 31th, 2018

REFERENCES

[1] General masterplan, ab architecture bureau, 2018

[2] Digital Elevation Model, dwg with contour lines + orthophoto, source : Geographic, 2018

[3] Snow and climate data: snowpack thickness at Jvari Pass (1955 – 2012), inventory of occurred avalanches (1995 – 2012) and winds measurements (1977 – 1992). Source: National Environmental Agency (NEA)

[4] Burkard A., Salm B., Die Bestimmung der mittleren Anrissmächtigkeit do zur Berechnung von Fliesslawinen/Estimation de l'épaisseur moyenne de déclenchement do pour le calcul des avalanches coulantes, rapport interne n°668, IFENA, Davos 1992

TABLE OF CONTENTS

1. INTRODUCTION

On request of Geographic, George Gotsiridze, the current report aims at assessing the exposure to avalanche of a potential expansion sector to Gudauri last developed zone (Along the bottom of Gudaura gondola).

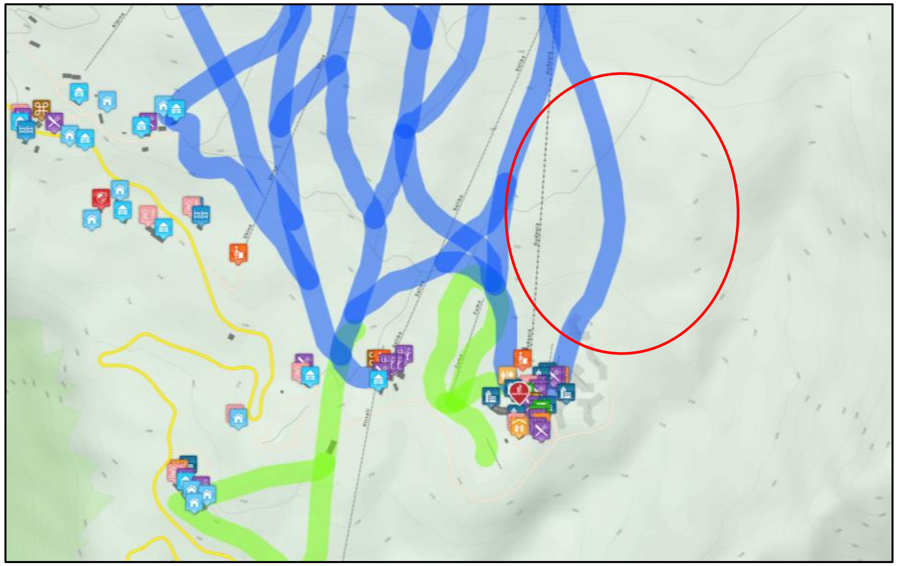


Figure 1 – General situation plan (source: www.gudauri.info)

The exact perimeter, situated between 2220m and 2380m, is given on Figure 2: it is surrounded by some steeper slopes to the North and to the East which may generate some avalanches and threatened some portions of this zone. Without exact data about known avalanches, most of the assessment is based on numerical modeling and expertise.

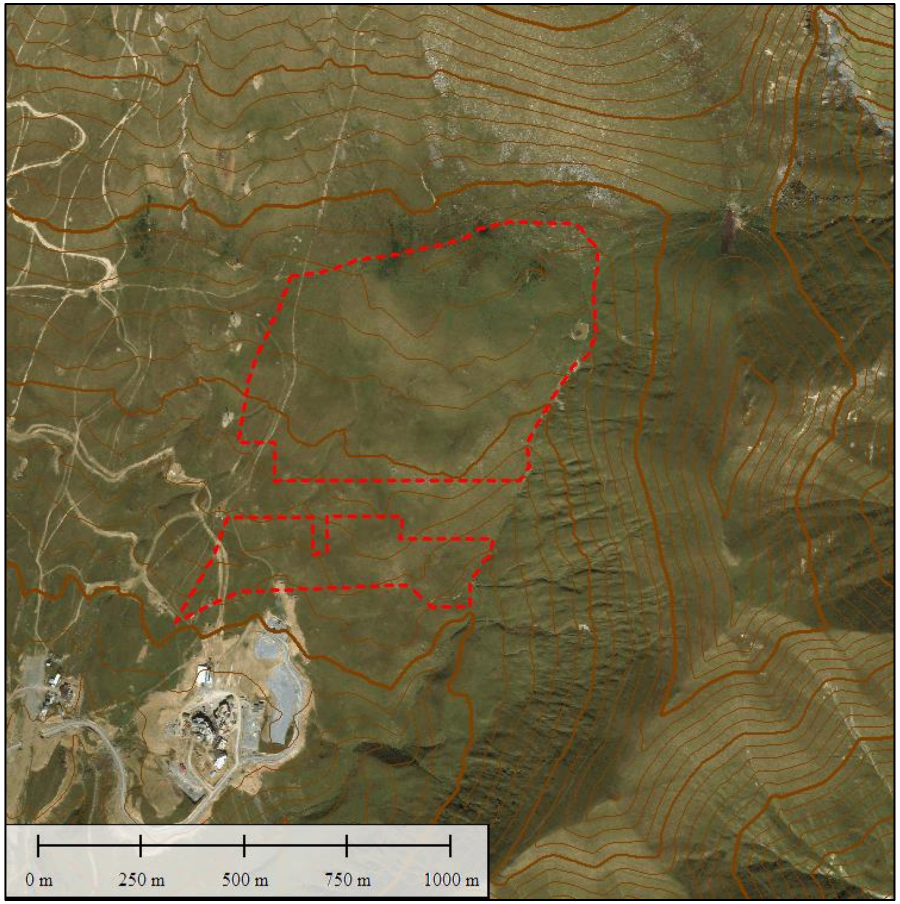


Figure 2 – Studied perimeter

2. GENERAL CONTEXT

A. SNOW SITUATION

Available weather data [3] in the close location of Jvari Pass (considered here as fully representative) were retreated statistically to properly obtain reference equivalent snowfalls by return periods and cumulated for 1, 2 or 3 days. The basic assumption [4] is that a x year return period avalanche comes directly from the corresponding mobilized snow thickness in the starting zone. This hypothesis is highly discussable as many other parameters may influence the final hazard but anyway, this is commonly agreed within avalanche engineering practices and constitutes the only systematic way to quantify corresponding loadings.

Some attention points are to be listed for this initial assessment of the statistical daily snowfalls :

- Available series are not always fully reliable : here, [3] positively provides data for more than 50 winters (Figure 3). However, only the total snowpack height is given which needs to additionally suppose that the difference from one day to the day after, if positive, corresponds to a new snowfall.
- It assumes also that the settlement and snowdrift at the measurements site are sufficiently neglectable during the period between two successive measurements. About that and instead of extracting cumulated snowfalls on 2 or 3 days by difference of the total snowpack height, they are obtained by summing 2 or 3 successive daily snowfalls (Figure 4).
- Statistical methods include all their own biases and extreme values are defined with some degree of inaccuracy. Here, the gradex method fitted to a usual Gumbel law is used (Figure 5 & Figure 6).

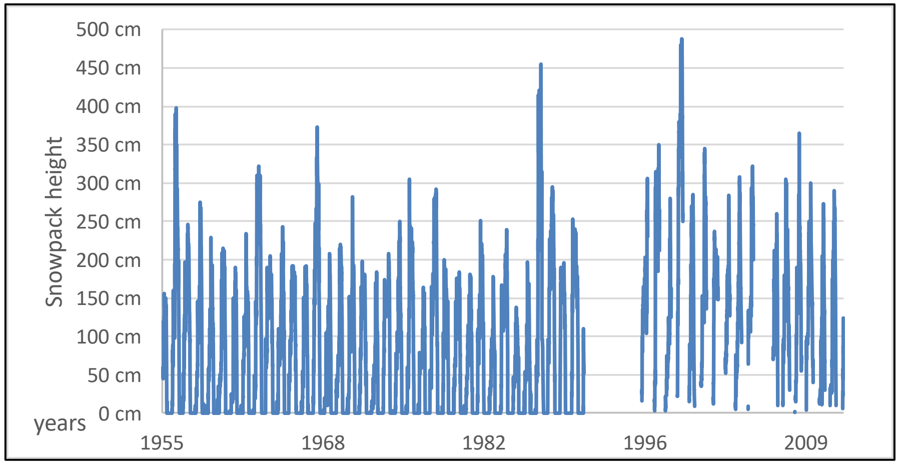


Figure 3 – Curve of available snowpack height rough data at Jvari Pass (2400m) [3]

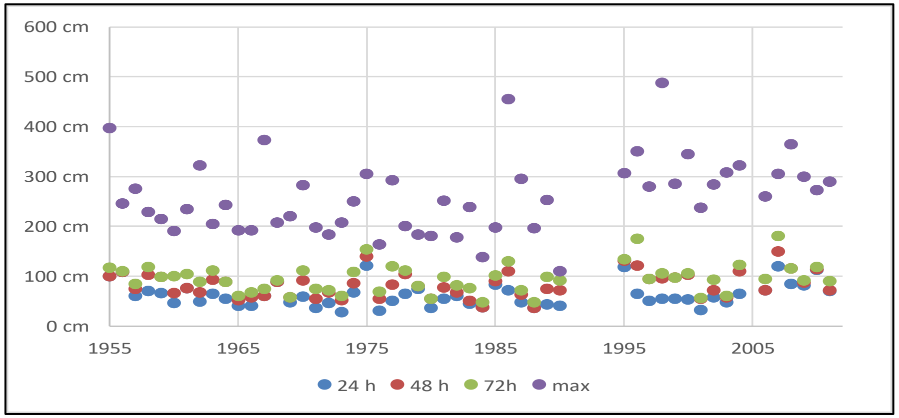


Figure 4 – Yearly maximum snowpack height (purple points) and deduced maximum daily equivalent snowfalls (blue points). 48h (red points) and 72h (green points) cumulated snowfalls are then obtained by sums.

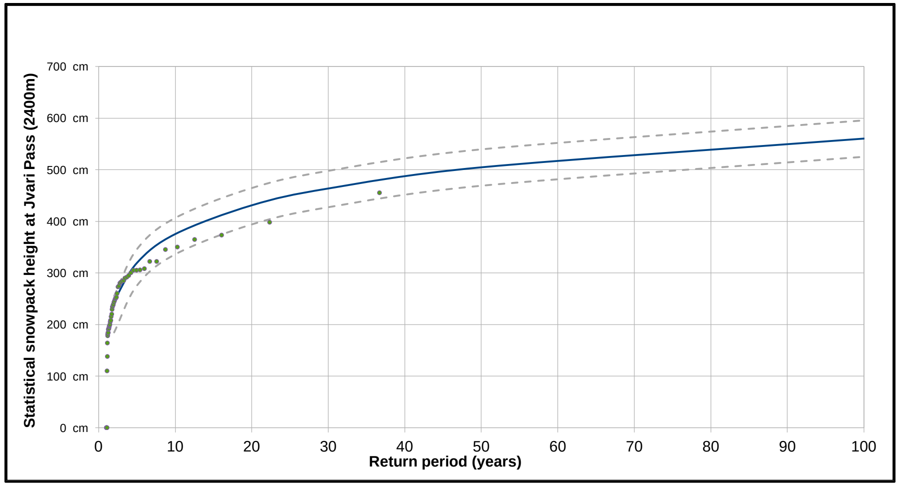


Figure 5 – Statistical snowpack height at Jvari Pass by return period

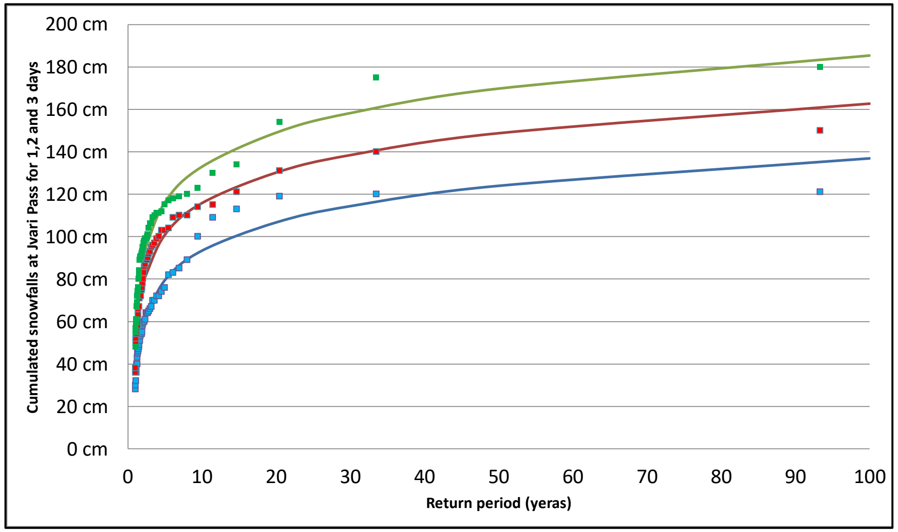


Figure 6 – Statistical cumulated snowfalls for 1 (blue), 2 (red) and 3 (green) days at Jvari Pass by return period

These two last figures and Table 1 confirm that this place is very snowy all the more these results at Jvari Pass (2400m asl) on a supposed flat terrain need to be converted to the potentially mobilized thickness in avalanche starting zones.

		Return period			
		10 years	**30 years**	**100 years**	**300 years**
Cumulated snowfall height	**1 day**	93 cm	114 cm	137 cm	160 cm
	2 days	116 cm	138 cm	163 cm	194 cm
	3 days	133 cm	158 cm	185 cm	221 cm

Table 1: Statistical cumulated snowfalls values for 1, 2 and 3 days at Jvari Pass by return period (10, 30, 100 and 300 years)

The usual process to do this conversion is detailed in [6]:

- At first, a natural settlement is included: for 3 days, a 20% conservative value can be admitted, independently from altitude. 12% for 2 days.
- Secondly, values are extrapolated to the altitude of the departure zones, generally different and higher than that of the measurement site. For 3 days, [4] provides snow gradient gradients between 3 and 7cm for 100m. Without more precise data, an average value of 5cm / 100m is rounded to 1.5cm / 100m / day also considering the settlement.
- Thirdly, the possible contribution (positive or negative) of the transport of snow by the wind can be included by expertise. Here, the available wind rose (Figure 7) is naturally aligned on Jvari Pass axes but which is almost parallel to surrounding ridges. For the current purpose, this phenomenon is considered as compensated ''in average'' (as much erosion as accumulation in the same avalanche sub-system)

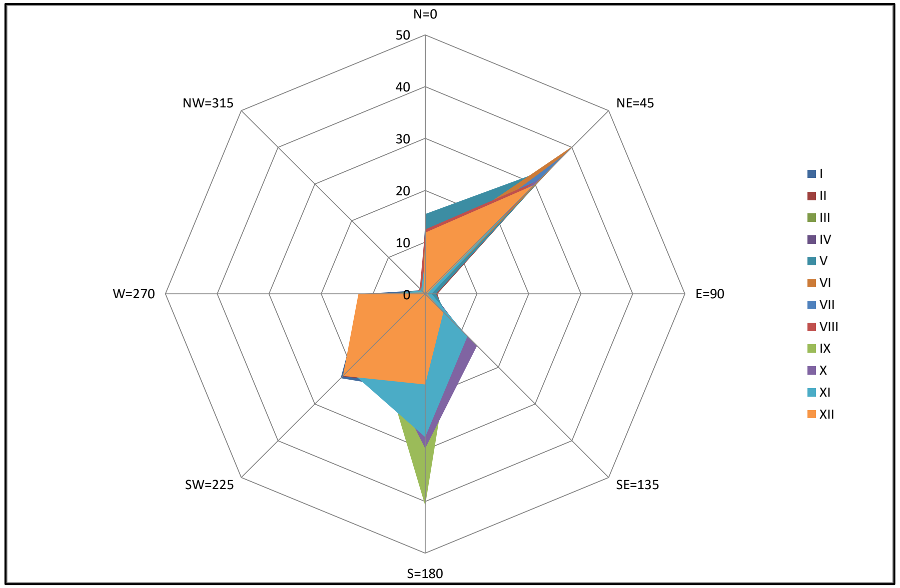


Figure 7 – Wind rose at Jvari Pass [3]

- Finally, considering the slope: beyond 28 ° (limit value below which the stability of the snowpack is considered to be acquired), the stability decreases with an increase of the slope. In other words, mobilizable accumulations will have more and more difficulties to grow during the snowfall episode until they are considered to be regularly purged beyond 55 °. [4] thus evaluates a slope factor according to the values of the following table which is applied to the "stable" thickness at 28 °.

φ	28	30	32.5	35	37.5	40	45	50
$f(\varphi)$	*1*	*0.9*	*0.79*	*0.71*	*0.65*	*0.6*	*0.52*	*0.46*

Table 2: slope factor (ψ in degrés [6])

From that and a given return period, the potential mobilized thickness in a starting zone is calculated considering the average altitude and slope. Next table gives an example for a 38° slope at 3000m asl.

		Return period			
		10 years	**10 years**	**10 years**	**10 years**
Potential mobilised thickness	**1 day**	56 cm	68 cm	80 cm	95 cm
	2 days	64 cm	75 cm	87 cm	105 cm
	3 days	70 cm	81 cm	94 cm	114 cm

Table 3: Example of mobilized thickness for a 38° slope at 3000m asl by return period

B. TERRAIN ANALYSIS

As mentioned in introduction, the overall terrain is rather flat (Figure 8: slopes between 0 and 15-20°) so without any ''internal'' avalanche or snow gliding problems (Figure 10 & Figure 12). But, it is bordered by some ''sufficiently'' steep (>30°) small zones either to the north or to the East which may flow within the perimeter (Figure 11 and Figure 13).

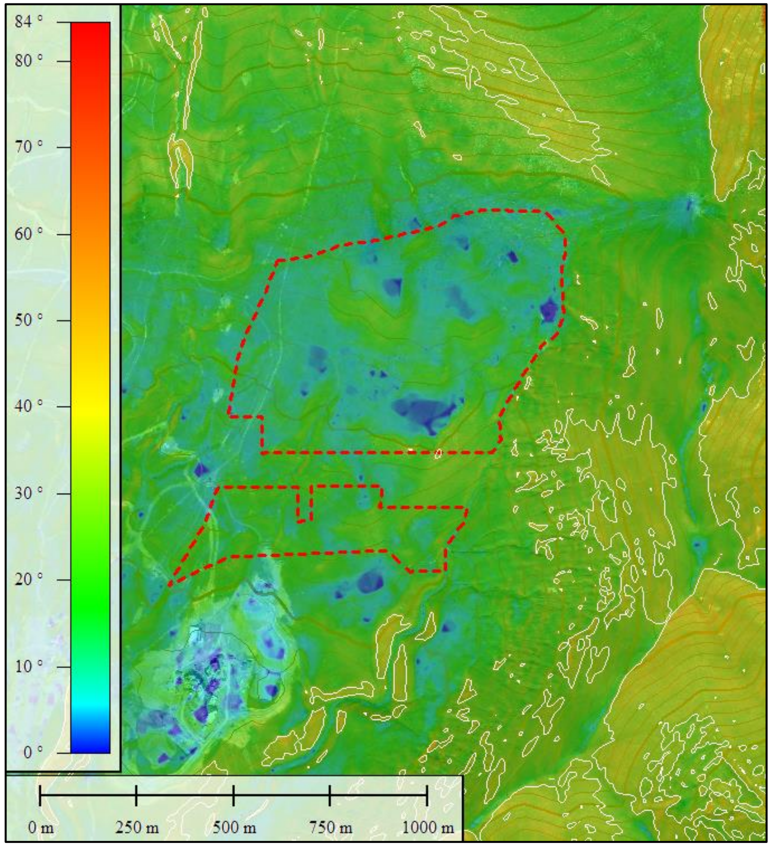


Figure 8 – Slope map [3] and limit of 30° steepness (in white)

At the same time, the eastern limit of the perimeter also corresponds to a well-shaped talweg (cover picture and Figure 9) with a deepness till 10 meters and which may constitute a natural protection:

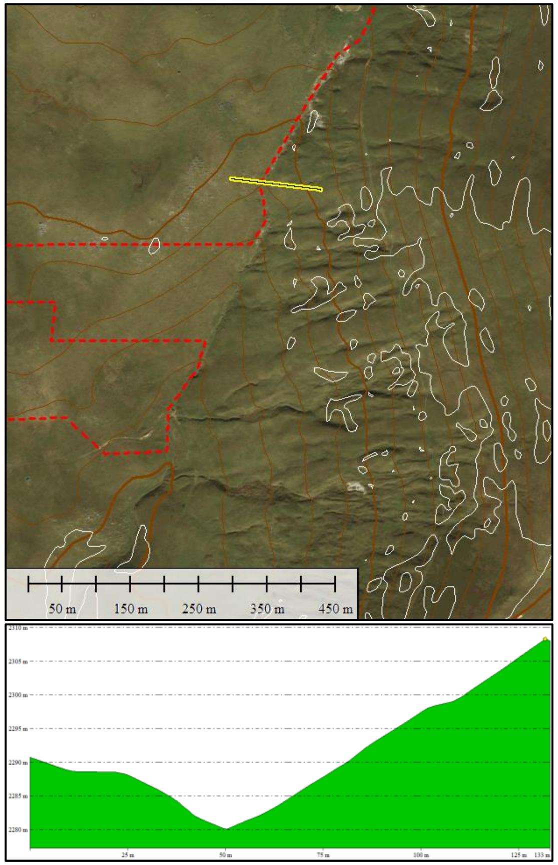


Figure 9 – View of the lateral/eastern talweg and crossed-profile (along the yellow line)


Figure 10 – View to the East [2]


Figure 11 – View to the south-east[2]


Figure 12 – General view to the South [2]


Figure 13 – General view to the North-West [2]

Other surroundings slopes are clearly too gentle to constitute any threat.

3. REFERENCE SCENARIO, METHODOLOGY AND MODELING RESULTS

A. Reference scenario and RAMMS software

Here, without obvious data or testimonies, the goal is precisely to refine snow-avalanches potential threat. For that and as usual for urbanism questions, a 100-year return period scenario is considered as reference assuming also that natural avalanches are possible.

This scenario is quantified by numerical modeling thanks to RAMMS software (http://ramms.slf.ch/ramms/) which is used for dense flows (no powder avalanches possible there) as the main international reference tool : developed to simulate flowing snow avalanches in complex terrain by the Swiss SLF Institute at Davos, its application has been successfully tested in many mountain ranges including Caucasus.

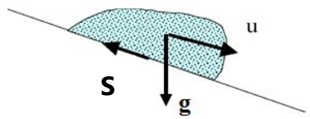
The core of the program is an efficient second-order numerical solution of the depth-averaged avalanche dynamics equations. Avalanche flow heights and velocities are calculated on three-dimensional digital terrain models. Single or multiple release areas are easily specified using GIS type drawing features. Users are provided with useful overview information of simulations, including all-important information of the release area (mean slope, total volume), flow behavior (max flow velocities and heights) and stopping behavior (mass flux). Maps and remote sensing imagery can be superimposed on the terrain models to aid the specification of input conditions and calibrate the model with known events.

The model still relies on the two-parameter Voellmy model widely used : Voellmy (1955) modeled the dense snow avalanche as a fluid using two parameters: μ for Coulomb (dry or sliding) friction at the base of the avalanche and ξ for "turbulence", which is multiplied by velocity squared (u^2) in the differential equation of motion:

$$\frac{1}{2}\frac{du^2}{dx} + u^2\frac{g}{\xi h} = g\cos\theta\left(\tan\theta - \mu\right)$$

Although ξ represents turbulence in fluids, it can also include air drag or ploughing resistance in avalanche flow, which also resist motion according to u^2. Retaining the two friction coefficients, μ and ξ, the model was adapted to better fit observed runouts and include back-pressure due to deceleration in the runout zone and became known as the Voellmy-Salm model.

$$S = \mu\rho H g\cos\phi + \frac{\rho g U^2}{\xi}$$



To calibrate the RAMMS Voellmy-model, SLF used data from their real scale avalanche test site in Vallée de la Sionne and provides full sets of friction parameters also to account for variable surface roughness, vegetation and flow in forests. Additionally, the last version (since 1.7.20) introduces the snow cohesion in the main equation as follows:

$$S = \mu N + (1-\mu)C - (1-\mu)C\exp\left(-N/C\right) + \frac{\rho g U^2}{\xi}$$

In that way, dry snow flows (C=0) can be modelled as well as wet snow cases (C between 100 and 300 Pa). Consistently with the current context, only dry snow is considered here to induce highest speeds/pressures and longest runouts.

Additional hypotheses can be listed as follows :

- consistently with the reference scenario, full sets of parameters as defined in Table 4 are used without any modifications

- calculations are based on a regular 5m ascii grid representing the terrain [2].

- starting zones are defined and drawn according to the slope (between 30 and 55°), curvature and field observations. In most cases, all potential starting zones are considered also to include the possible overall release of a mountain side.

- mobilized thicknesses modulated in comparison to altitude according to the same process of table 3.

In fact, and beyond this value of thickness in the starting zone, the choice of the volume category that will govern the behavior of the avalanche will be preponderant as for the results. This volume must be understood as the one that will '' interact with itself '' within the flow lines and for this reason, Ramms allows the choice between '' tiny '' (<5000m^3 = T), '' small '' (<25000m^3 = S), '' medium '' (<60000m^3 = M) and '' wide '' (> 60000m^3 = L). In this case, the volume category has been adapted depending on the refined terrain configuration: tiny and small are tested.

Large avalanche (> 60'000 m^3)		300-Year		100-Year		30-Year		10-Year	
	Altitude (m.a.s.l.)	μ	ξ	μ	ξ	μ	ξ	μ	ξ
unchannelled	above 1500	0.155	3000	0.165	3000	0.17	3000	0.18	3000
	1000 - 1500	0.17	2500	0.18	2500	0.19	2500	0.2	2500
	below 1000	0.19	2000	0.2	2000	0.21	2000	0.22	2000
channelled	above 1500	0.21	2000	0.22	2000	0.225	2000	0.235	2000
	1000 - 1500	0.22	1750	0.23	1750	0.24	1750	0.25	1750
	below 1000	0.24	1500	0.25	1500	0.26	1500	0.27	1500
gully	above 1500	0.27	1500	0.28	1500	0.29	1500	0.3	1500
	1000 - 1500	0.285	1350	0.3	1350	0.31	1350	0.325	1350
	below 1000	0.3	1200	0.315	1200	0.33	1200	0.345	1200
flat	above 1500	0.14	4000	0.15	4000	0.155	4000	0.16	4000
	1000 - 1500	0.15	3500	0.16	3500	0.17	3500	0.18	3500
	below 1000	0.17	3000	0.18	3000	0.19	3000	0.2	3000

Medium avalanche (25 - 60'000 m^3)		300-Year		100-Year		30-Year		10-Year	
unchannelled	above 1500	0.195	2500	0.205	2500	0.215	2500	0.225	2500
	1000 - 1500	0.21	2100	0.22	2100	0.23	2100	0.24	2100
	below 1000	0.23	1750	0.24	1750	0.25	1750	0.26	1750
channelled	above 1500	0.25	1750	0.26	1750	0.27	1750	0.28	1750
	1000 - 1500	0.27	1530	0.28	1530	0.285	1530	0.295	1530
	below 1000	0.28	1350	0.29	1350	0.3	1350	0.31	1350
gully	above 1500	0.32	1350	0.33	1350	0.34	1350	0.35	1350
	1000 - 1500	0.33	1200	0.34	1200	0.355	1200	0.36	1200
	below 1000	0.36	1100	0.37	1100	0.38	1100	0.39	1100
flat	above 1500	0.17	3250	0.18	3250	0.19	3250	0.2	3250
	1000 - 1500	0.19	2900	0.2	2900	0.21	2900	0.22	2900
	below 1000	0.21	2500	0.22	2500	0.23	2500	0.24	2500

forested area (mu=delta, xi=fix)	0.02	400	0.02	400	0.02	400	0.02	400

Small avalanche (5 - 25'000 m^3)		300-Year		100-Year		30-Year		10-Year	
	Altitude (m.a.s.l.)	μ	ξ	μ	ξ	μ	ξ	μ	ξ
unchannelled	above 1500	0.235	2000	0.245	2000	0.25	2000	0.26	2000
	1000 - 1500	0.25	1750	0.26	1750	0.265	1750	0.275	1750
	below 1000	0.265	1500	0.275	1500	0.285	1500	0.295	1500
channelled	above 1500	0.28	1500	0.29	1500	0.3	1500	0.31	1500
	1000 - 1500	0.3	1350	0.31	1350	0.315	1350	0.325	1350
	below 1000	0.31	1200	0.32	1200	0.33	1200	0.34	1200
gully	above 1500	0.37	1200	0.38	1200	0.39	1200	0.4	1200
	1000 - 1500	0.38	1100	0.39	1100	0.4	1100	0.41	1100
	below 1000	0.4	1000	0.41	1000	0.42	1000	0.43	1000
flat	above 1500	0.215	2500	0.225	2500	0.23	2500	0.24	2500
	1000 - 1500	0.23	2250	0.24	2250	0.245	2250	0.255	2250
	below 1000	0.245	2000	0.255	2000	0.26	2000	0.27	2000

Tiny avalanche (< 5'000 m^3)		300-Year		100-Year		30-Year		10-Year	
unchannelled	above 1500	0.275	1500	0.28	1500	0.285	1500	0.29	1500
	1000 - 1500	0.29	1400	0.295	1400	0.3	1400	0.305	1400
	below 1000	0.3	1250	0.31	1250	0.32	1250	0.33	1250
channelled	above 1500	0.31	1250	0.32	1250	0.33	1250	0.34	1250
	1000 - 1500	0.33	1180	0.34	1180	0.345	1180	0.355	1180
	below 1000	0.34	1050	0.35	1050	0.36	1050	0.37	1050
gully	above 1500	0.42	1050	0.43	1050	0.44	1050	0.45	1050
	1000 - 1500	0.43	1000	0.44	1000	0.45	1000	0.46	1000
	below 1000	0.44	900	0.45	900	0.46	900	0.47	900
flat	above 1500	0.26	1750	0.265	1750	0.27	1750	0.275	1750
	1000 - 1500	0.27	1600	0.275	1600	0.28	1600	0.285	1600
	below 1000	0.28	1500	0.285	1500	0.29	1500	0.295	1500

forested area (mu=delta, xi=fix)	0.02	400	0.02	400	0.02	400	0.02	400

Table 4 - Calibrated set of parameters included in RAMMS

B. GLOBAL RESULTS

As shown on next figures which give results as ''avalanche intensity'' (obtained by multiplying maximum height and pressure and representing like the equivalent force on a 1m wide obstacle), the difference is very limited between volume category tiny (Figure 14) and small (Figure 15), especially to the East: indeed, the existing talweg at this limit is reliable to stop all possible flows coming from the surrounding slopes.

To the North, results are naturally larger with the category ''small''.

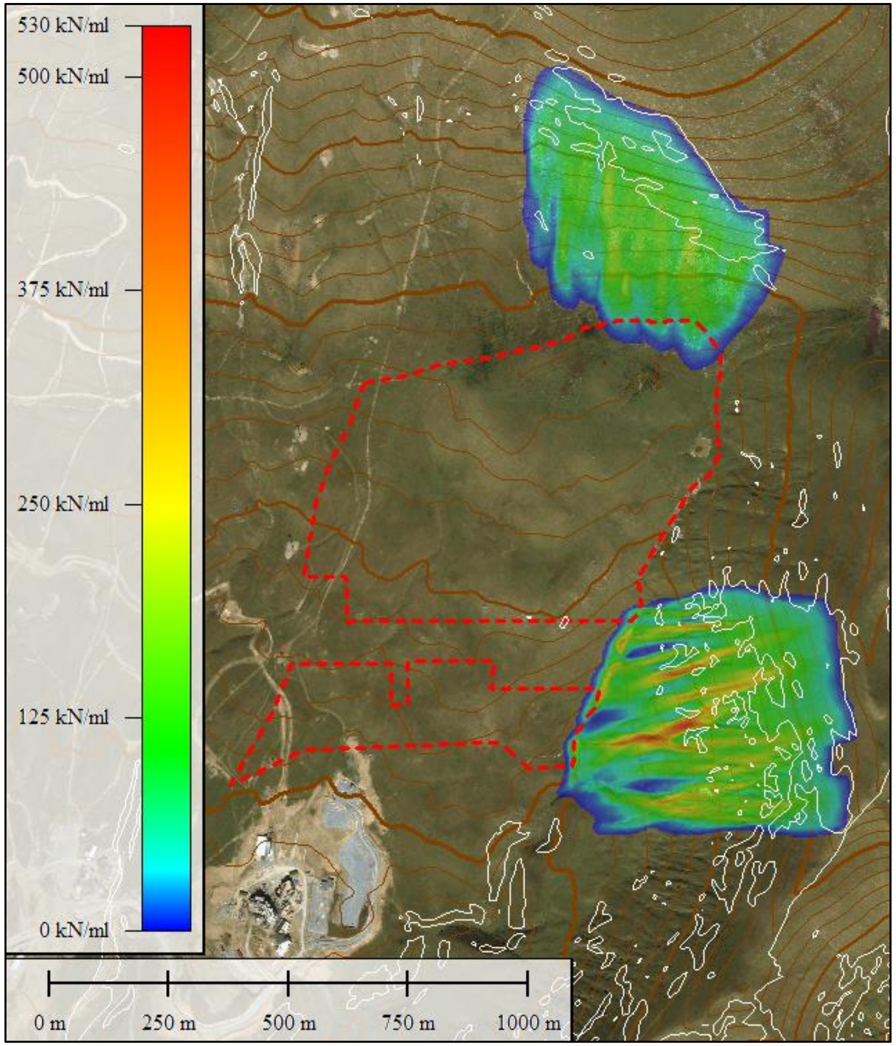


Figure 14 – Avalanche intensity map with volume category Tiny

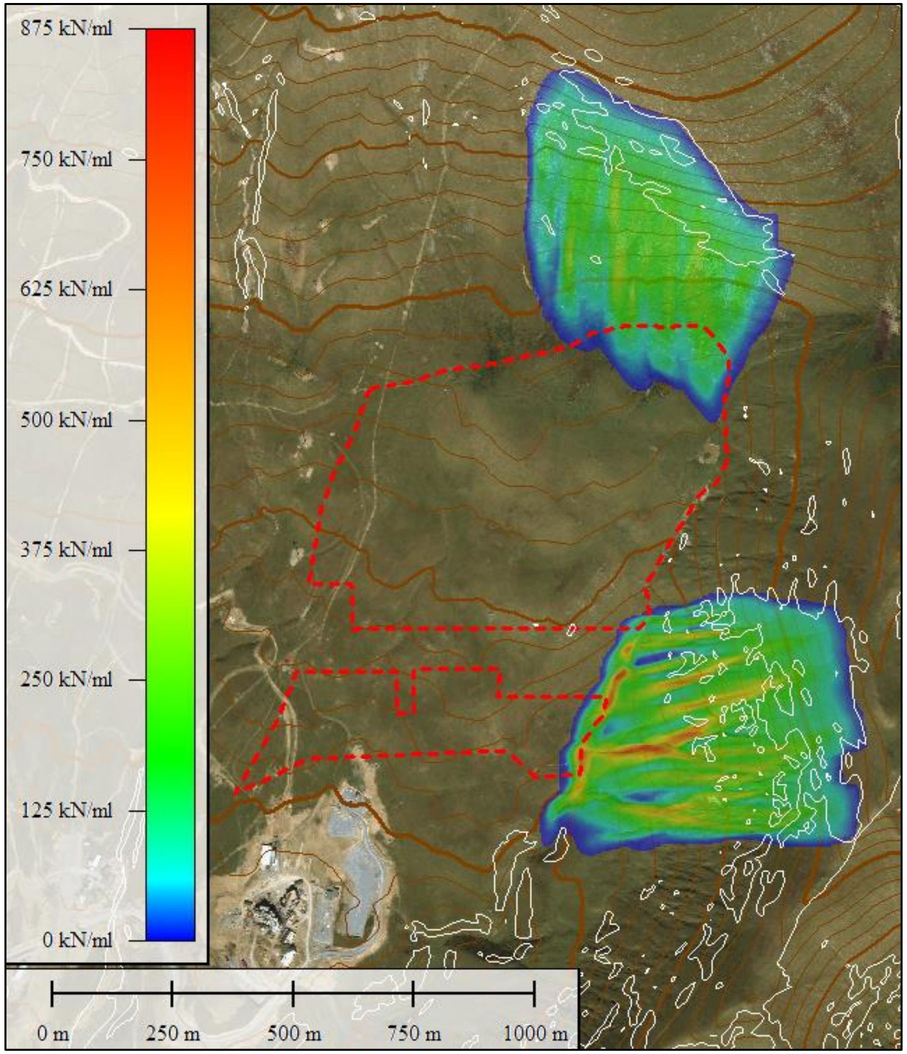


Figure 15 – Avalanche intensity map with volume category Small

4. LAND USE PLANNING AND HAZARD ZONING

Hazard zoning is the first management tool especially when space free of danger is easily available in the vicinity. It consists of a map, interpreted from previous analysis and corresponding prescriptions by zone as follows:

Note that it concerns:

- Only snow-avalanche hazards (equivalent zoning could be developed regarding other phenomena)
- Only ''urban'' buildings whatever their function. Other infrastructures such as roads, lifts, ski runs are not directly covered even if some recommendations may apply.

WHITE ZONES – UNTHREATENED ZONES

The white zones are building zones without any constraint. In the foreseen context, they are located outside any avalanche phenomena and don't need specific recommendations.

BLUE ZONES – LIMITED RISK ZONES

Blue zones are subjected to limited (occurrence, intensity) phenomena or correspond to the low intensity zone at the extremity/on the side of larger avalanches. They can be built but respecting certain recommendations. They may rarely need people evacuations or containment:

- Buildings can be erected provided they respect architectural measures. Regarding dense avalanches, it shall at least consist in (partly) blind reinforced uphill/exposed façades. The reference lateral pressure to consider is 30 kPa on a 3m high layer from the natural ground. No openings are allowed in this layer but are possible above.
- Main access inside the building shall be on unexposed faces.
- Buildings receiving public (like hotel, guest house) shall carefully respect protection and resistance measure as they shall shelter more people including containment cells.
- In details, architectural measures can be decreased/adapted for each case : for instance, if a building is hidden by another, the indirectly protected one is less constrained. Anyway, no new light construction is allowed and existing one should be reinforced consistently.

RED ZONES – HIGH RISK ZONES

Red zones concern all avalanche paths and runouts. They are normally forbidden for any new inhabited buildings. Existing ones or stakes like lift towers shall be analyzed and/or must be consistently reinforced, modified or protected.

Based on previous analysis, next figure shows the final hazard zoning :

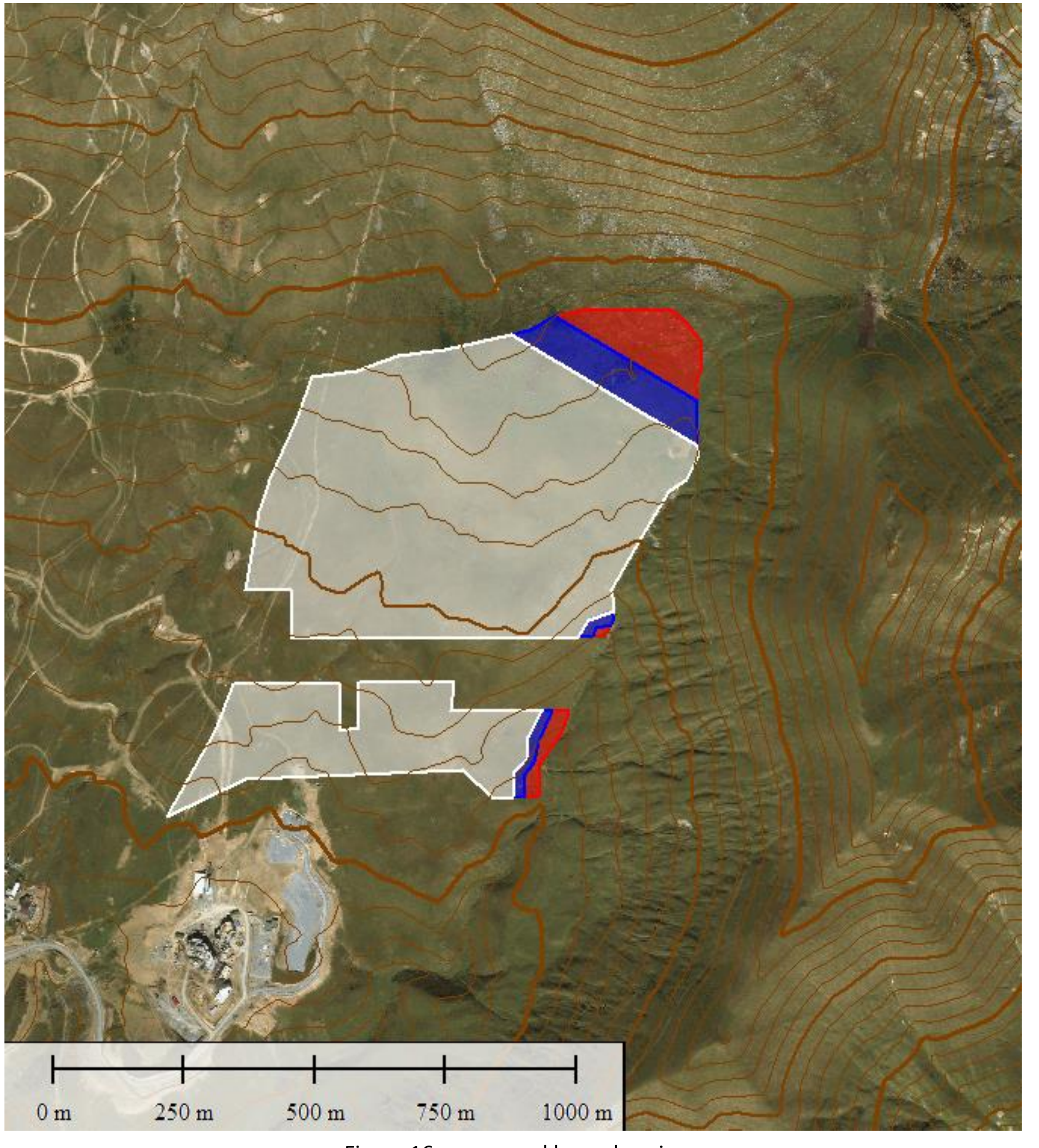


Figure 16 – proposed hazard zoning

5. CONCLUSIONS

As shown previously, the majority part of the studied area is open for buildings except small red zones:

- The ones at the eastern limit cannot be properly modified as they correspond to the talweg natural protection: additional protections would have non-reasonable sense as anyway, this place is not the most suitable (small slopes)
- The one to the north could be easily reduced by adding to the masterplan project an earth dam. To give an idea (to be refined with the exact location), the necessary height would be 6m to reduce the red zone by 50% and at least 8-10m to remove it completely.

But with many available space also to the west, the best advice is to avoid any colored zones to prefer free/white ones.