ASSESSMENT OF MITIGATION WORKS BASED ON A SCENARIO ANALYSIS OF THE PERCHERTAL AVALANCHE

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GRADUATE COMMITTEE APPROVAL

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LIST OF SYMBOLS

α: Alpha

ß:Beta

d_0 3TNSS: Sum of Three Days of New Snow with a Statistical Return Period of 150 Years

CBR: Cost and Benefit Ratio

CBA: Cost and Benefit Analysis

DTM: Digital Terrain Model

DSM: Digital Surface Model

DFA: Dense Flow Avalanche

DFL: Dense Flow Layer

H: Height

HAÖ: Hydrologic Atlas of Austria

H Max : Maximum Height of the Release Zone

H Min: Maximum Height of the Release Zone

kPa: Kilo Pascals Pressure

ÖK50: Austrian Maps in the Scale 50000

PSA: Powder Snow Avalanche

PSL: Powder Snow Layer

R: Release Zone

RAMMS: Rapid Mass Movements Simulation

SAMOS AT: Snow Avalanche Modeling and Simulation

WLV: Austrian Service for Torrent and Avalanche Control

ZAMG: Central Institute for Meteorology and Geodynamics

SUMMARY

This avalanche investigation has been written to analyse the Perchertal avalanche that endangers the St. Hubertus Hotel. The hotel is located near the Bärenkopf Mountain which has several avalanche prone areas on its slopes. During the winter, these topographic circumstances constitute a hazardous situation for the hotel and the main road that passes in front of it that provides accessibility to Pertisau in Achensee, Tyrol.

In total, nine different scenarios were evaluated as dense flow avalanches and three different scenarios were evaluated as powder snow avalanches. Avalanche impact pressures, run-out length of avalanche and avalanche flow depths were calculated using avalanche simulation models. Three of the simulation results illustrated hazardous avalanche scenarios; the hotel and the part of main road could be affected by both dense flow and powder snow avalanches, however, hazard level of avalanches differ depending on the type of avalanches. As a result of this investigation, the hotel is located in the yellow zone on the new avalanche hazard map. Presented simulation results will help to estimate planning and design for protective countermeasures against the Perchertal avalanche. In brief, the objectives for this thesis were the following:

- to identify hazards from the Perchertal avalanche by using avalanche simulation models;
- to search alternative avalanche mitigation strategies based on simulation results if necessary;
- to estimate planning and design for avalanche protective measures;
- to determine the most effective and economic solution through cost and benefit analysis.

1. INTRODUCTION

Avalanches can be assumed as natural environmental factors and as well as dangerous events and can cause serious damages to settlements, properties, and types of transportation (railways, main roads) (Höller, 2007). Importantly, avalanches can also cause fatalities. For example, Galtür avalanche, which was the worst avalanche disaster in Austria in the last 40 years, killed 31 people in 1999 (BBC, 1999). Thus, in Austria, avalanches constitute a widespread hazard particularly in alpine areas where local people life and tourists from all over the world come to ski.

The authorities are aware of dangers that can be caused by avalanches and they are striving to avoid future avalanche damages. In this way, Austria has started to work on avalanche protection in 1880 by stabilization of the snow pack and by building types of snow rakes on starting zones in Tyrol and Vorarlberg (Sauermoser, 2009). After four years, the Austrian Forest Engineering Service for Torrent and Avalanche Control (WLV) developed projects on the basis of public interest services in alpine regions in 1884 .

The WLV currently prepares projects about natural hazard problems of the alpine communities in Austria. The tasks of the service organization of the Ministry of Agriculture, Forestry, Water and Environment include following (Sauermoser, 2009):

- to plan and build technical and forest biological measures against avalanches, torrents, rock fall and landslides;
- to maintain and control this work;
- to elaborate hazard maps for each community;
- to administrate the public funds (catastrophic fund);
- to support the local and government authorities in carrying out their sovereign tasks.

To a large extent, avalanches can be prevented and avalanche damages reduced with avalanche protection works. For this reason, avalanche protection can be recommended in order to ensure maximum safety of endangered objects. To achieve this goal, well-prepared plans or projects that include comprehensive concepts such as high precision data acquisition, deriving meaningful results based on inputs and implementing results are required. This master’s thesis has been written on the basis of concept shown above.

This master’s thesis consists of five parts:

The first chapter provides general information about avalanches, the importance of avalanches and technical protective works against avalanches in Austria.

The second chapter describes the investigation area and materials used such as avalanche simulation models, a hazard map of the relevant area and the chronological report of avalanche events for Perchertal.

The third chapter shows the steps followed in order in this investigation

The fourth chapter presents avalanche simulation results, a new hazard map of the relevant area and plan avalanche protection. Cost and benefit analysis is also included.

The fifth chapter includes risk assessments of different avalanche scenarios as well as recommendations to prevent future avalanche damages from the Perchertal avalanche.

1.1. AVALANCHES

An avalanche can be described as a falling mass of snow that may contain ice, rock, or soil (McClung and Schaerer, 2006). Topographic factors, vegetation factors and weather may be very important in the occurrence of avalanches. When these factors combined, avalanches can be triggered easily (Table 1).

Table 1. Major factors of avalanches [Himachal, 2011]

Item	Description	Factor
Prime Factors	**Topographic Factors**	• Inclination of slope • Shape of slope • Location (ridge line or top of the slope • Orientation of slope
	Vegetation Factors	• Vegetation cover and the height of trees • Vegetation cover and its thickness
Exciting Factors	**Weather Factors**	• Depth of snow cover • Depth of snowfall • Wind velocity • Atmospheric and snow temperatures
	Other Factors	• Vibration such as earthquake or the sound of gunfire • Increase in weight of snow cover

1.1.1 Avalanche Classifications

An avalanche can vary due to their form of motion, type of snow and type of occurrence. More information is shown in Table 2 and 3.

Table 2. Effective factors for avalanche classification [McClung and Schaerer, 2006; Himachal, 2011]

Classification Factor	Classification Factor	Definition
Type of Occurrence	**Loose snow avalanche**	Loose snow avalanches start at or near the surface and flow rapidly, spreading widely from a point normally small in scale.
	Slab avalanche	These avalanches are initiated by failure associated with a thin weak layer at the snow cover depth. They start to move suddenly over wide areas, and normally large in scale.
Type of Snow	**Dry snow avalanche**	Avalanches that contain no water.
	Wet snow avalanche	Avalanches that contain water.
Surface Layer Avalanche	**Surface layer avalanche**	Slip surface exists within snow cover.
	Full-depth avalanche	Slip surface occurs on the ground surface.

Table 3. Types and description of avalanches [McClung and Schaerer, 2006; Himachal, 2011]

Dry loose ***surface-layer*** **snow avalanche**	Dry loose avalanches commonly form under cold, relatively windless conditions during snowfalls and caused by small masses of snow falling from snow cornices, tree branches or exposed rock. They normally move down in loose layer.
Dry slab ***surface-layer*** **snow avalanche**	Dry slabs are responsible for most of the damage and fatalities from avalanches. Their release is characterized by a rapid propagation of fractures underneath the slab and at all boundaries of the slab. These often occur when new snow with a depth of more than 10cm falls over the existing snow cover during low atmospheric temperatures. Avalanches that flow rapidly, taking the form of loose snow powder and often reach several kilometers down the foot of the mountain.
Dry slab ***full depth*** **snow avalanche**	In regions of relatively high temperatures, this type of avalanche occurs extensively when the weight of a large quantity of snow falls quickly over existing snow deposits on a slope at low temperatures. In cold regions, snow layers near the ground tend to become collapsible and can slide into full depth if severe cold weather has continued for a long time. The dry, new surface snow layers tend to slide in the form of snow powder and often reach further down the foot of the mountain.
Wet, loose ***surface-layer*** **snow avalanche**	These are usually triggered by heavy melt due to warming by sun or rainfall on the snow pack. Wet loose-snow avalanches can occur at any time during the snow season and can involve snow of quite high density. When this avalanche occurs, it takes a wedge-shaped form and reduces in width.
Wet, slab ***surface-layer*** **snow avalanche**	Wet slab avalanches occur by means of three principal mechanisms: (1) loading from new precipitation (rain); (2) changes in the strength of a buried weak layer due to water; (3) water lubrication of a sliding surface. These avalanches do not take the form of snow powder but move in a smooth flow. In the case of a slab surface-layer avalanche, water reaches a weak layer, the strength of the layer will be reduced.
Wet, slab ***full depth*** **snow avalanche**	These can be caused when snow starts to melt in the early spring and may also result if temperatures rise in the winter season. These avalanches can occur on a rainy day or a warm day. These will not take the form of snow powder, and move in a smooth flow. This type of avalanche can often causes serious disasters.

Table 4. Characteristic features of avalanche movements [Himachal, 2011]

Powder snow avalanche	This type of avalanche might occur during at snowfall in low temperatures. A powder snow avalanche can move down the slope with high speed and its snow molecules mix with air. Therefore, the height of avalanche flow in the deposition area might be considerable depending on the velocity and mixture with air.
Wet snow (dense flow) avalanche	This type of avalanche appears to move as a flow of water over the snow surface. These are seen as full- depth avalanches occurring when atmospheric temperature increases.
Mixed avalanche	This is when powder type and flow avalanches occur in combination. This type of avalanche can occur quickly when a large quantity of snow falls over an unstable snow cover.

1.2 AVALANCHE PROTECTION

If an avalanche occurs in an area of no settlements, no property, or no traffic, it does not constitute a natural hazard. Hence, avalanche protection is not necessary in these safe places. On the other hand, if an avalanche hazard map of a certain area illustrates a hazardous situation such as a red zone, a decision has to be made quickly to ensure maximum safety of endangered objects in the zone. If the responsible authorities agree that avalanche protection works are required, suitable avalanche protections should then be planned and implemented that pose an acceptable risk of endangered objects.

Avalanche protection works may be divided into two classifications: temporary and permanent measures (McClung and Schaerer, 2006) (Table 5). Temporary measures are applied for short periods and only when it is required. Permanent measures are applied for long periods (McClung and Schaerer, 2006).

Table 5. Avalanche protection methods [McClung and Schaerer, 2006]

	ACTIVE	PASSIVE
Temporarily	• Avalanche control by explosives • Road closures • Precautionary evacuation	• Avalanche forecasting/warning • Seasonal occupation • Summer houses • Seasonal road closures • Organizational measures • Warning signs
Permanently	• Supporting structures • Snow fences • Deviations, retarding and catching dams • Retarding earth mound • Splitting wedges • Reinforced construction • Snow shed • Reforestation/forest protection	• Hazard mapping and land using

Permanent, active avalanche defense measures are used in the starting zone to prevent the release of avalanches (supporting structures) and in the avalanche track and run-out zones (avalanche sheds, deflecting and catching dams) to reduce the damaging effect of descending avalanches (Amman and Fohn, 1999).

1.3 HAZARD MAPPING

The mapping of avalanches and their consequences has had a long tradition in the alpine areas of the Austrian Alps (Karel, 2000). Currently, Austrian Service for Torrent and Avalanche Control (WLV) makes hazard maps for avalanches and torrents.

Hazard maps usually give an idea of the safety level of a certain area in regard to the risk of natural disaster (avalanches, rock falls, or torrents). In particular, avalanche hazard maps serve as basic documents for avalanche hazard evaluation with respect to land-use planning (Amman and Fonn, 1999). For example, according to Austrian law, if an existing avalanche hazard map of a certain area indicates a hazardous situation such as a red zone, construction is not allowed (Agriculture and Forestry Ministry, 2007); or, if an avalanche hazard map is drawn after a hotel has been built, the map can illustrate the hazard level of the relevant area and the hotel is in danger.

Two degrees are used in Austrian avalanche hazard maps to illustrate the situation for endangered areas (Table 6).

Table 6. Degrees of risk used in Austria [Agriculture and Forestry Ministry, 2007]

Zone	**Avalanche Impact Pressure**
Yellow [LG]	$1 \leq P < 10$ k N/m^2
Red [LR]	$P \geq 10$ k N/ m^2

Red illustrates the most dangerous zones on the hazard map and no construction should be allowed inside of the zone. In addition, required avalanche protection works should be performed to prevent possible avalanches or reduce any avalanche damages, as the illustrated red zone can be affected by avalanche impact pressure which has a value higher than 10 k N/m^2.

Yellow illustrate a hazardous zone as well but to a lesser extent then the red zone. Thus, any object that is already located in the yellow zone can be affected by avalanche impact pressure which has a lower value than 10 k N/m^2. In other words, yellow hazard zones indicate those areas where a permanent utilization for settlement and traffic purposes impaired by hazard processes (Fuchs, 2009).

To compare the red and yellow zones, empirical damage levels of avalanche impact pressure are presented below (Sauermoser, 2010):

- 1 kPa avalanche impact pressure can cause broken windows;
- 5 kPa avalanche impact pressure can cause broken doors;
- 30 kPa avalanche impact pressure can make houses move or wooden houses can be damaged.

The importance of decisive factor 10 k N/m^2 can be obviously seen in damage levels of avalanche impact pressures shown above.

2. MATERIAL

2.1 INTRODUCTION OF OBSERVED AREA

Austria consists of nine independent federal provinces: Burgenland, Carinthia, Lower Austria, Upper Austria, Salzburg, Styria, Tyrol, Vorarlberg and Vienna. Tyrol is the third largest Austrian province with 467 km^2 and it is the Land with most tourism with 43.8 million overnight stays per years, according to values of 2008 (Statistic Austria, 2011).

General information about Tyrol that was presented by Statistic Austria shown below:

- Total area (sq km): 12,640
- Population (01.01.2009): 704,472
- Capital: Innsbruck
- Administrative districts: 9
- Municipalities: 270

Figure 1. Administrative districts in Tyrol

The investigation area lies across the northern edge of the Alps in Tyrol that is located in the Community of Achensee.

Acheense is a natural lake located in the district of Schwaz in Tyrol. It is the largest of all the Tyrolean lakes and is 9 kilometers long, 1.3 kilometers width, and 133 meters deep at its deepest point. The lake’s water is of a purity equal to drinking water and is freely accessible all summer long (Achensee Tourismus, 2011).

Many local natives live in this nice community and there are many hotels due to the great number of tourists that come to the region (e.g. modern ski areas) during winter. The mountainous area of the region offers ideal conditions for winter activities (skiing, hiking). However, these topographic circumstances create a widespread hazard in the region due to possible avalanches.

The Perchertal avalanche has reportedly been threatening a hotel, St. Hubertus since 1948. This avalanche presents danger to the hotel, which is located nearly active avalanche paths and the part of main road that provides accessibility for Pertisau (Fig. 2). Therefore, guests can be in danger of injury or death due to an avalanche event.

Figure 2. Overview of endangered St. Hubertus Hotel (Photo: Kurt, 2011)

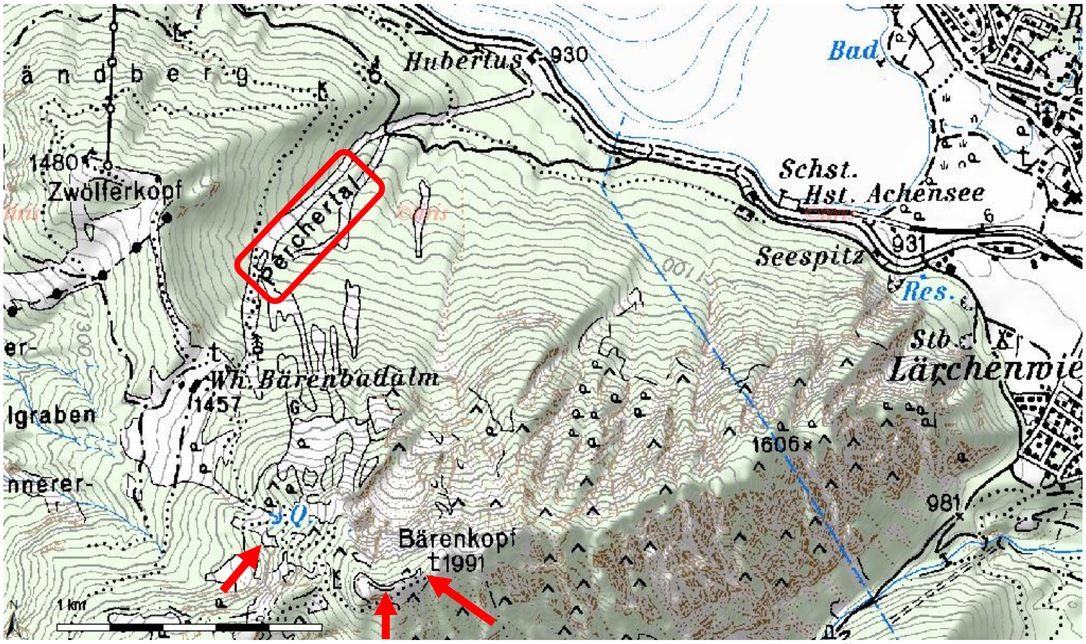

Figure 3. Overview of Perchertal and Ausmehler avalanche on the map (ÖK50)

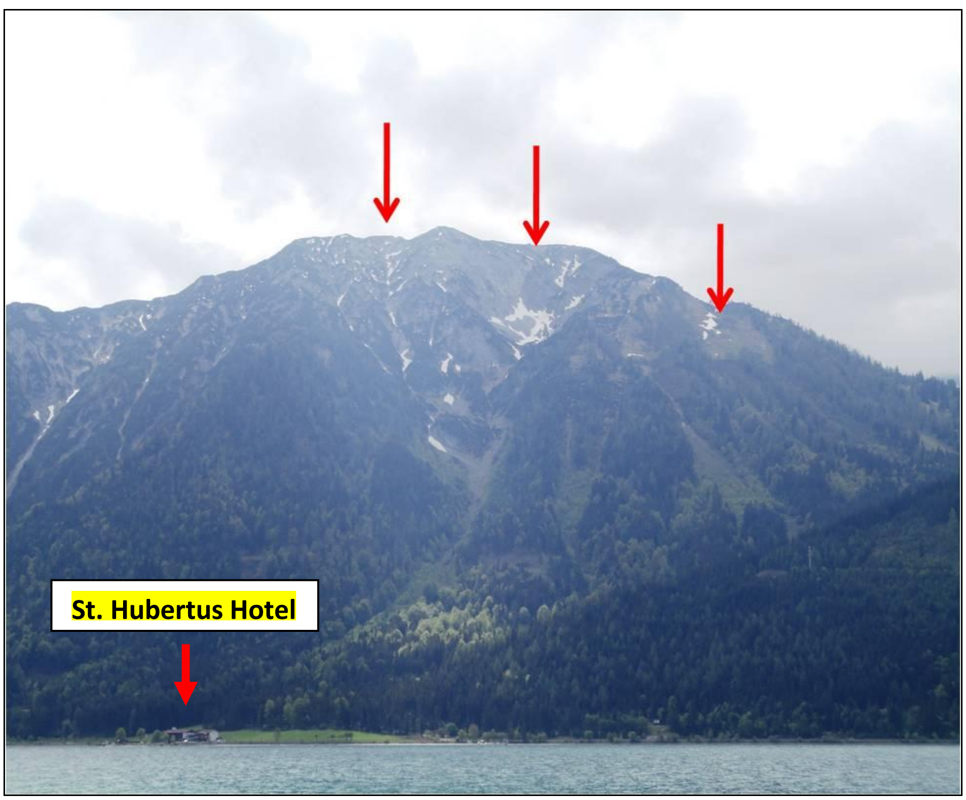

Figure 4. Overview of Perchertal avalanche tracks (Photo: Kurt, 2011)

2.1.1 Climate

Austria lies in a temperate Atlantic climatic zone. This is felt more strongly in the west and northwest (Austrian Foreign Ministry, 2011).

2.1.1.1 Annual Air Temperature

According to HAÖ, the mean annual air temperature of Achensee is between 4-6 ^{o}C (Fig. 5). During the year, the region is affected by warm southerly winds (Fig. 6).

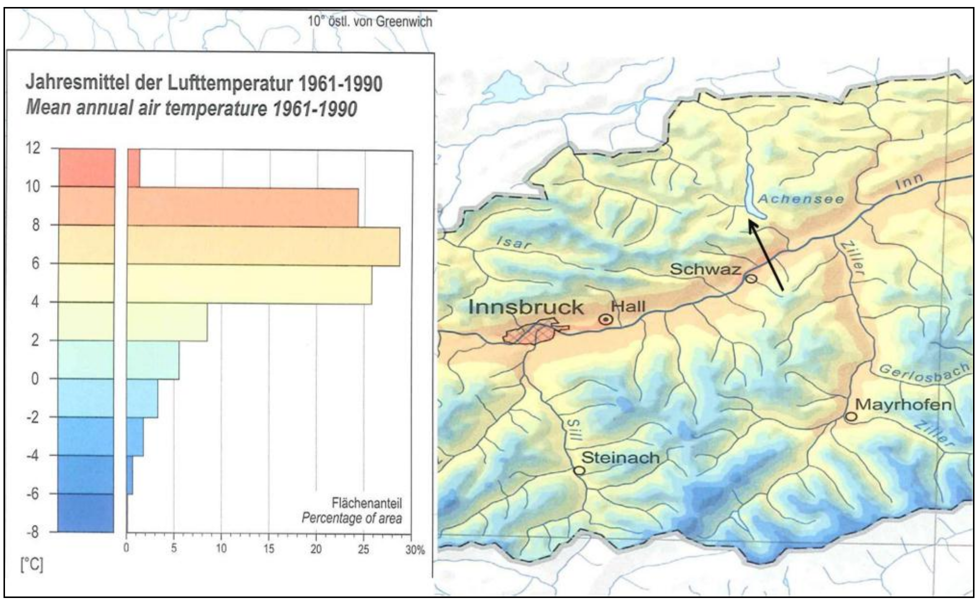

Figure 5. Mean annual temperature of Achensee (HAÖ)

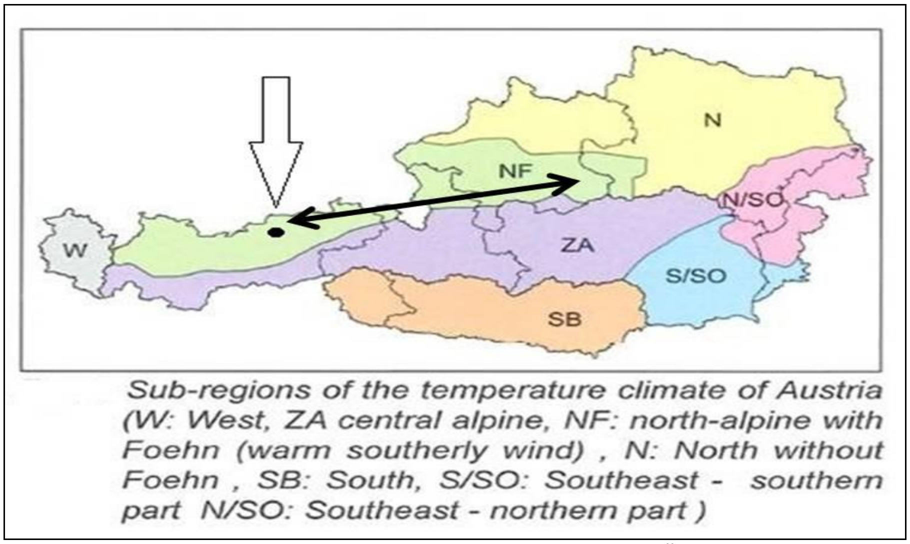

Figure 6. Temperature climate of Austria (HAÖ)

2.1.1.2 Annual Precipitation

Precipitation levels drop significantly from west to east and rise with the altitude as shown below (Fig. 7).

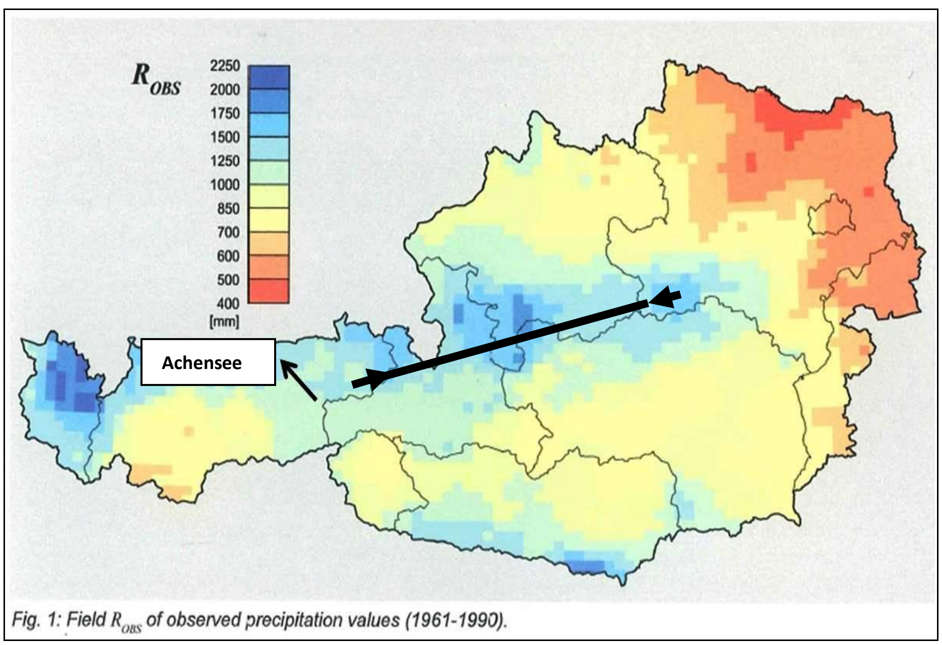

Figure 7. Observed precipitation values of Austria (HAÖ)

To assess the climatic conditions and simulations, data were taken from the extreme value statistics of the Central Institute for Meteorology and Geodynamics (ZAMG), Innsbruck.

The measured data from the Pertisau weather station (altitude 935 m) are as follows:

- Mean annual precipitation is 1526 mm for Pertisau weather station between the years 1900-1986 (Hydrographisches Jahrbuch, 2005) (See Appendix E).
- Sum of three days of new snow with a statistical return period of 150 years is 158 cm (Schellander, 2004).

2.1.1.3 Vegetation

Field study was done with the help of Mr. Hochreiter, on 18.05.2011, 19.05.2011, 20.05.2011 and 21.05.2011 in order to define vegetation type and create a forest map of the relevant area.

The age classification of trees, vegetation, and soil regimes were defined and recorded for the whole forest as it was thought that the forest stand structure might be a source of relevant information for the avalanches. For example, description of stand structure by age classification, tree heights can define if the stand is affected by an avalanche or was affected by an earlier on (Fig. 8). Broken branches, uprooted or curved tree stems can be assumed as silent witnesses for the relevant avalanches.

Figure 8. Silent witnesses on the avalanche tracks (Photos: Kurt, 2011)

Moreover, tree heights, canopy cover (stand density) can give an idea about if the relevant area can be assumed as resistance area against avalanches. According to Mr. Tollinger who is responsible person for avalanche simulations at the WLV office in Schwaz, if trees are higher than 15 meters and stand density is higher, relevant area can be defined as resistance area for avalanche simulations. In other words, can the relevant forested area play an important role to prevent avalanches? In order to response this question and get knowledge about terrain (e.g. about vegetation) field study was done.

More detailed information of types of vegetation presented in Appendix A.The vegetation type can be described as moderately forested area. High altitudes are usually dominated by dwarf mountain pine (*Pinus mugo)*. Spruce (*Picea abies*), beech (*Fagus slyvatica*), and larch (*Larix deciduas* and *Abies alba*) are visible on the lower side of the area.

2.2 CHRONOLOGY OF AVALANCHE EVENTS

According to an historical map from the nineteenth century, a charcoal burner house was located in the Pertisau area where the St. Hubertus hotel is currently located (Fig. 9). The charcoal burner house was turned into a hotel when the Achensee was discovered by tourists.

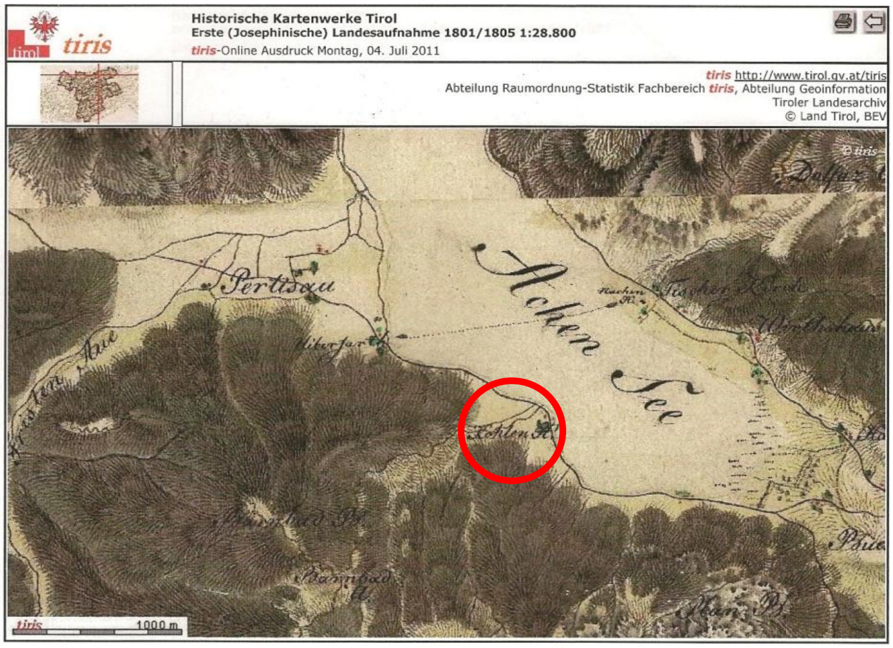

Figure 9. Historical map of Achensee (ÖK50)

The avalanche report of Perchertal avalanche, which was written by DI Stepanek and DI Skolaut in the WLV office in 2001 gives information about where avalanches occurred in Pertisau between 1945 and 1988. All of the avalanches reported were of the dense flow type. Mr. Wöll, who is responsible for avalanche control in Pertisau, reported that so far, the largest known avalanche occurred in 1973 as a wet snow avalanche after warm air had remained through the day. This avalanche went up to 250 meters above the main road and the hotel was not destroyed (Fig. 10).

On the following page more details are given as a timeline of avalanche events based on the avalanche commission report from the WLV office in Schwaz.

1973. 05.01: Avalanche Cadastre reported that:

A large, wet snow avalanche occurred at around 11:45 AM that went up to 250 meters above the main road. Boundaries of the avalanche deposition zone were defined as; approximately 700 m long, 20 to 50 m wide and up to 10 m height. The avalanche was heavily mixed with wood and there were high tress uprooted between 2 to 50 m tall. The reason was due to large snow masses that had been extremely heated by sun.

At 14.45 PM, two additional large, wet snow avalanches occurred in Perchertal.

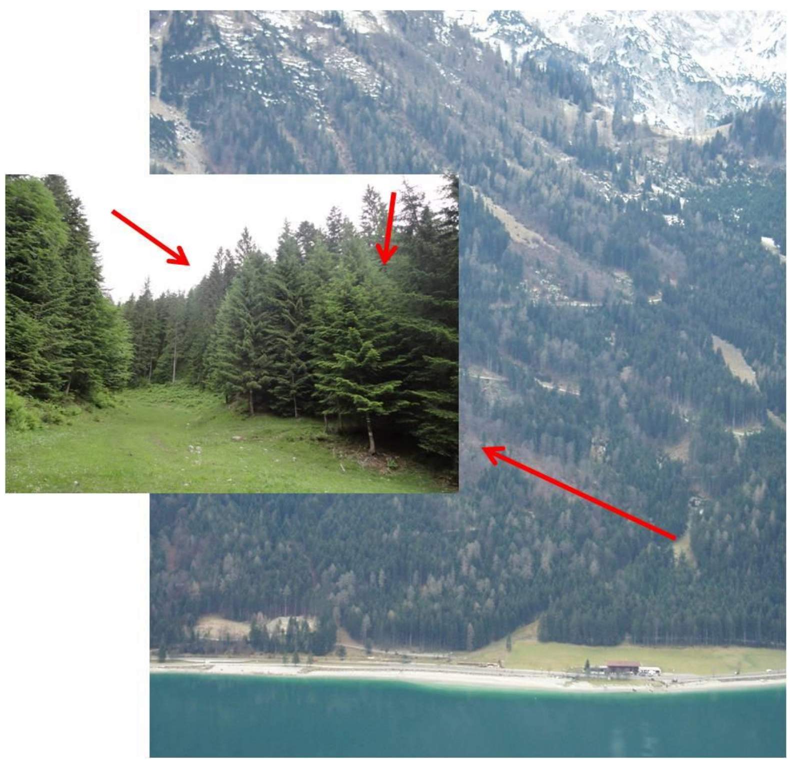

Figure 10. End point of the Perchertal dense flow avalanche occurred in 1973 (Photo: Kurt and Granig)

1973.05.02: Avalanche Cadastre reported that:

At around 17.00 PM another wet snow avalanche occurred after warm air lasted throughout the day. This time, the avalanche stopped about 400 meters above the main road. A large amount of old wood was seen on the edge of the avalanche path. The release zone was approximately 1600 m above sea level where the lower part of the *Patzlehnerkares*.

1981 Feb :

Avalanche-blasting ropeway was covered by snow after heavy snowfalls and strong winds from the north-west on 20.01 and therefore the ropeway could not work (Avalanche-blasting ropeway is not in use anymore)**.** In addition, at the end of February, an avalanche released from the *Lärchenwald* and *Ausmehler*, and stopped over the flat area of the *Perchertal* (Fig. 11). The starting zone was under *Karstandl* and the avalanche rose up to about 250 m above the main road as had occurred in 1973. The height of the deposit snow was 2, 44 m. This avalanche was different than others, because, it consisted of two arms on the left and right sides (Fig. 11).

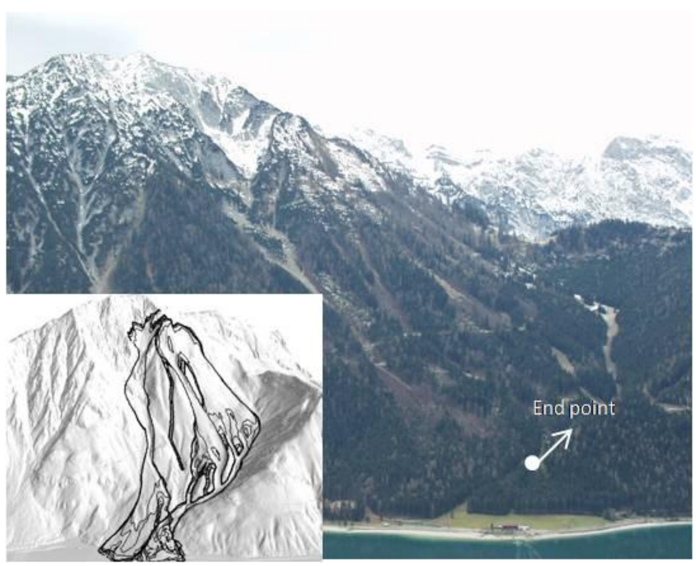

Figure 11. Overview of dense flow avalanche scenario occurred in 1981 February (Kurt and Granig, 2011)

1987.03.02:

After heavy rains, rain water passed through high altitudes, causing wet snow avalanche in *Breitlahner*. This wet snow avalanche reached a place higher than normal situations. It was a type of minor avalanche. The starting zone was above the left side of the main avalanche track, therefore most ski tracks were affected from this avalanche. In addition, the height of snow deposit was about 3-4 meters.

1988.03.19:

Three weeks after the heavy snowfalls, a wet snow avalanche occurred in *Breitlahner*, which lies on an altitude of 1100 m.

2.3 SIMULATION DATA AND PARAMETERS

The numerical simulations are based on a digital terrain model (DTM), which was created by the SUISSE PHOTO on behalf of the province of Tyrol and the WLV with airborne laser scanner measurement.

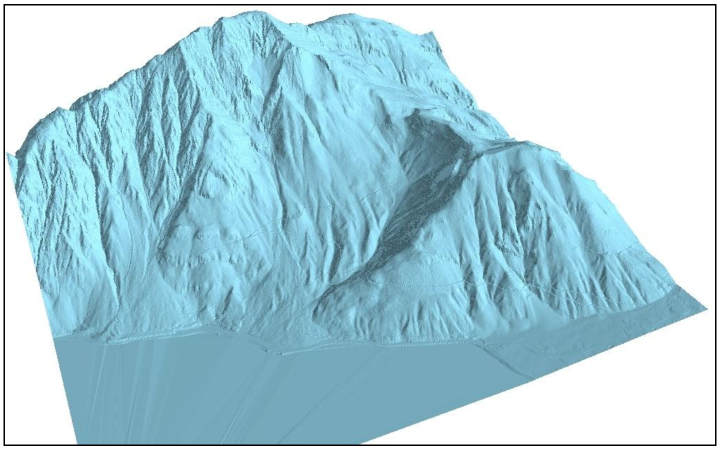

Figure 12. Digital terrain model (Kurt, 2011)

Digital terrain model (DTM) is a major component of geographical information processing that it helps to model, analyse and display phenomena related to topography or similar surfaces (Weibel and Heller, 1991). In order to simulate avalanche scenarios using Samos AT, Ramms model and performed required applications at the Arc Gis software, the DTM was thinned to a 5 m grid and used in this form. In brief, the DTM has enabled us to have applications as follows:

- Visualization of the terrain;
- Extraction of terrain parameters (calculating tree heights) and mass movements (avalanches).

The maps shown below were created using Arc Gis software and presented on the following pages:

- Inclination map of the terrain;
- Contour map of the terrain;
- Tree heights on the resistance areas.

Calculations of tree heights were performed using the DTM and DSM at the Arc Gis software (Fig. 13). Vegetation, buildings and other man-made (artificial) features are removed digitally and there is only underlying terrain at the DTM. On the other hand, digital surface model (DSM) that usually the main product produced from photogrammetry, that contains vegetation, buildings and all kind of man-made features (Technion, 2011).
Figures 15 and 16 illustrate the forested areas where the trees were higher than 15 m. These areas were assumed for additional resistance to be used in modeling.

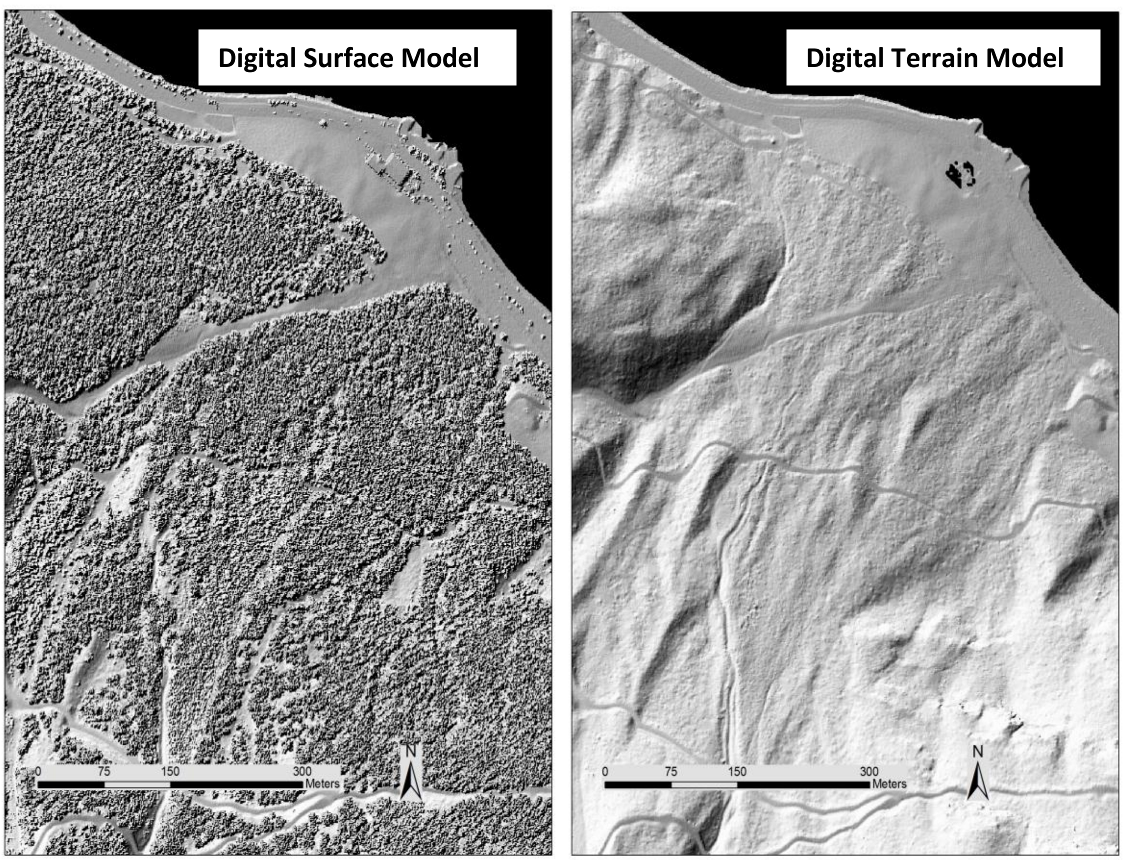

Figure 13. Comparison of Digital Surface Model at the left side and Digital Terrain Model at the right side (Kurt, 2011)

Avalanche starting zones were defined on the basis of the inclination map, orthophotos and mapped using Arc gis software (Fig. 17)

Meteorological data was taken from the Perstisau weather station, ZAMG. In order to calculate *snow accumulations* for each release zones that have different slope inclinations, a map (height gradient for sum of three days of new snow for Tyrol) was used (Fig. 20).

More detailed information are provided on the following pages.

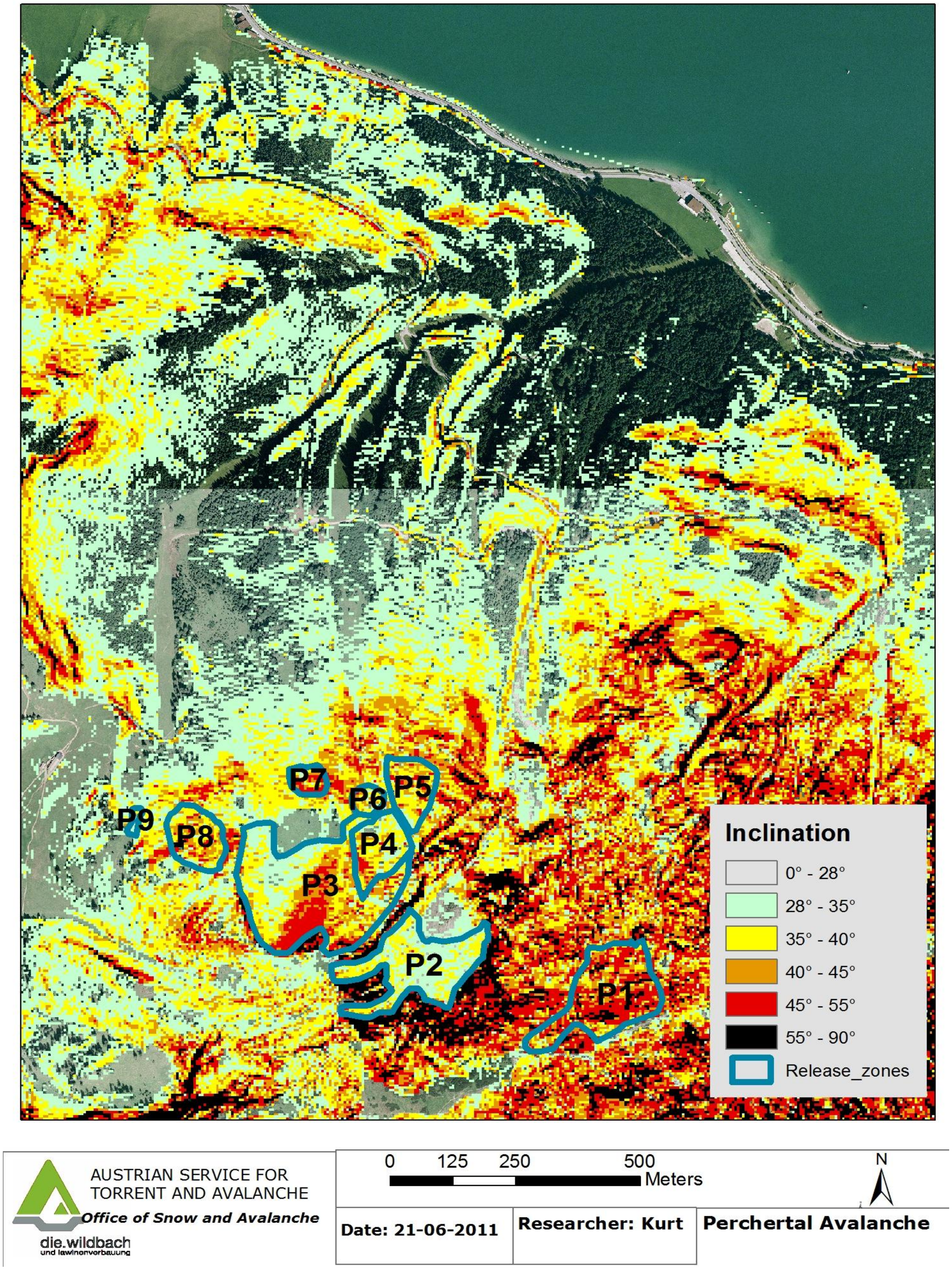

Figure 14. Inclination map with release zones

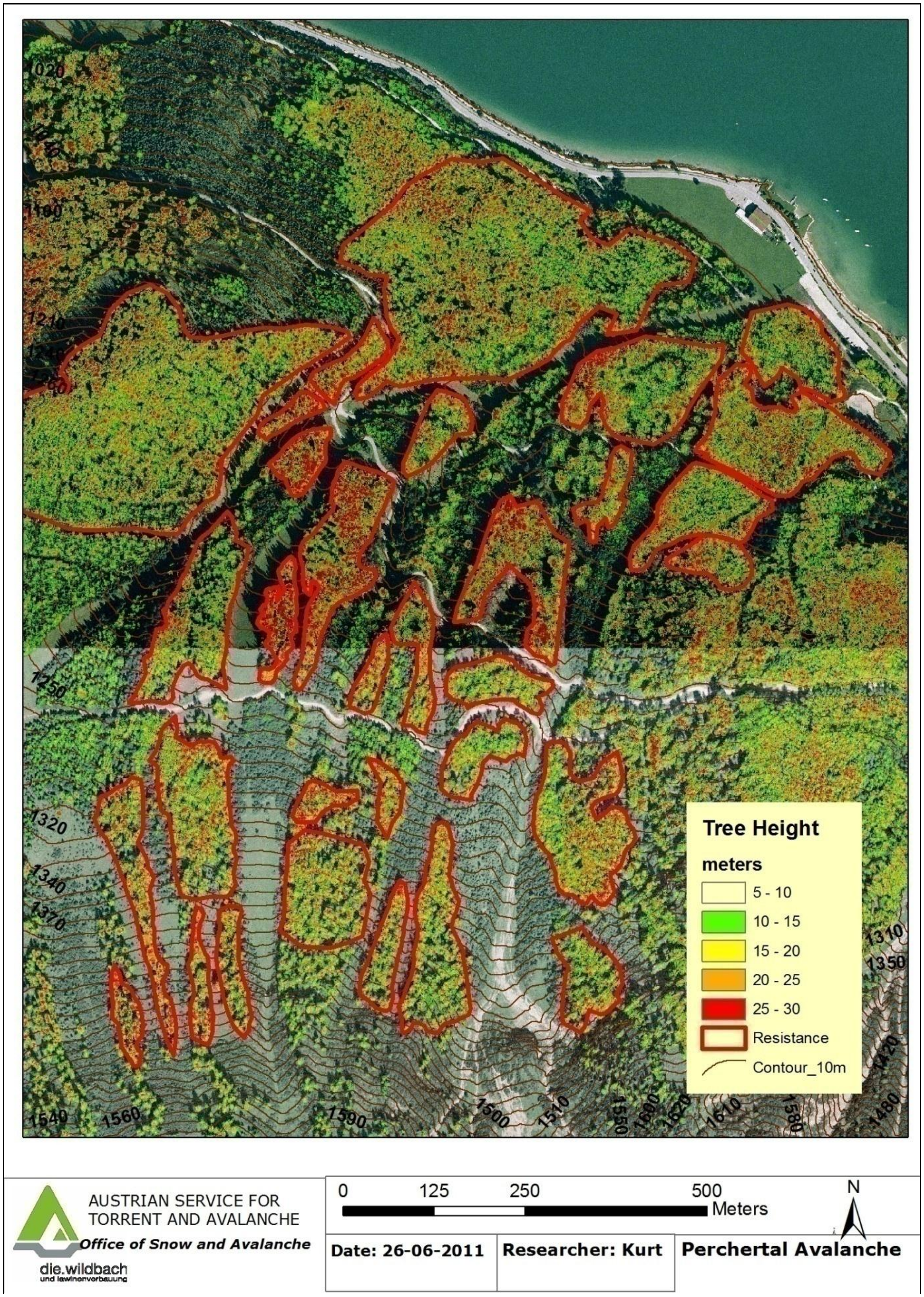

Figure 15. Overview of tree heights on resistance areas

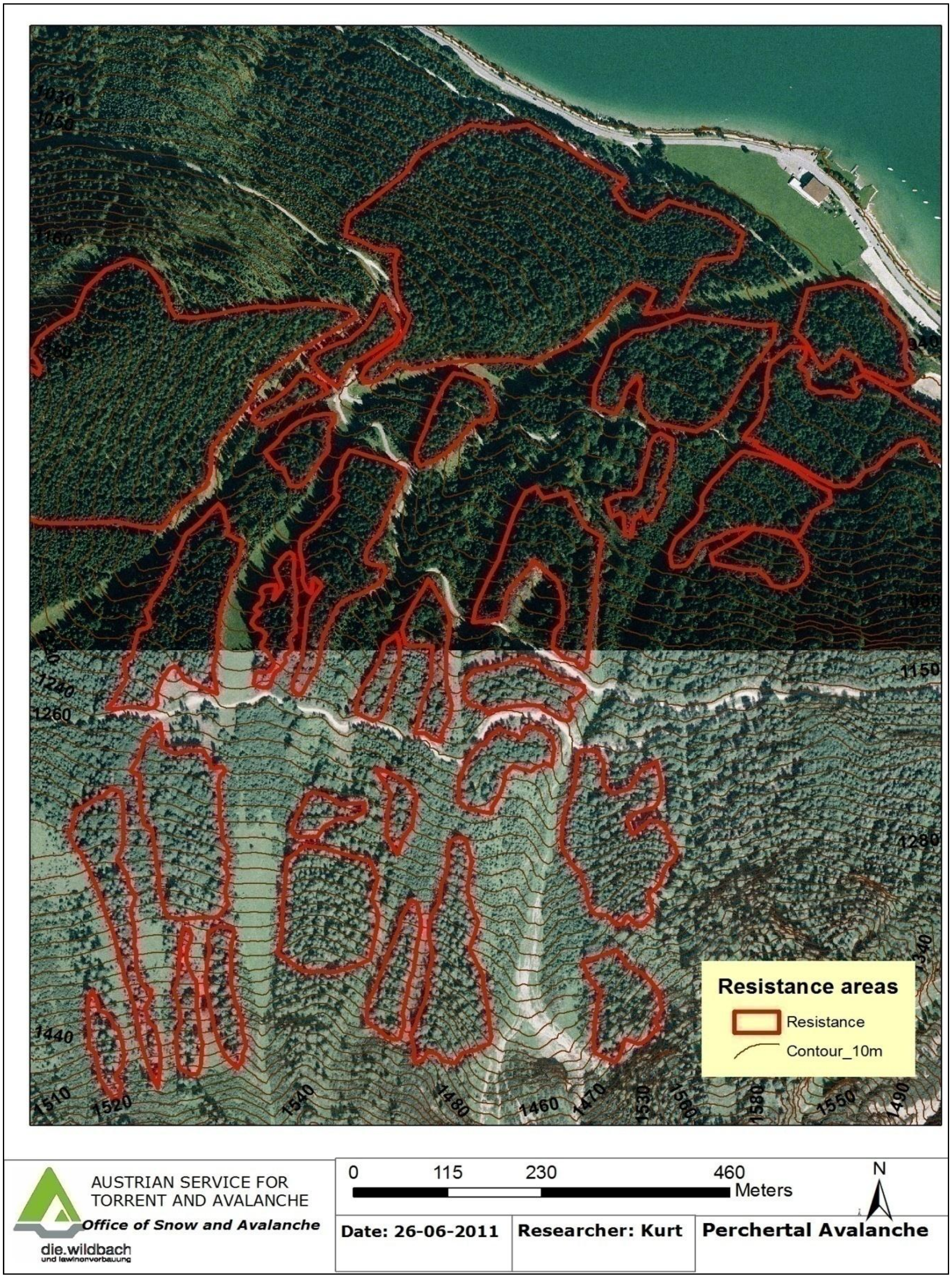

Figure 16. Overview of the resistance area

2.3.1 Starting Zones

The starting zones were defined with the help of field supervisor, Mr. Granig, on June 7, 2011, on the basis of an inclination map, orthophotos and some chronological information received from Mr. Wöll and Mr. Moser, who is in charge of forest management in Pertisau. Figures 14 and 17 give an approximation of the starting zones in regards to both inclination and entrainment areas. Wind-drift factors were also defined for each release zone based on the main wind direction and is shown in Table 7. Entrainment areas were mapped and mainly consisted of areas without trees on avalanche tracks.

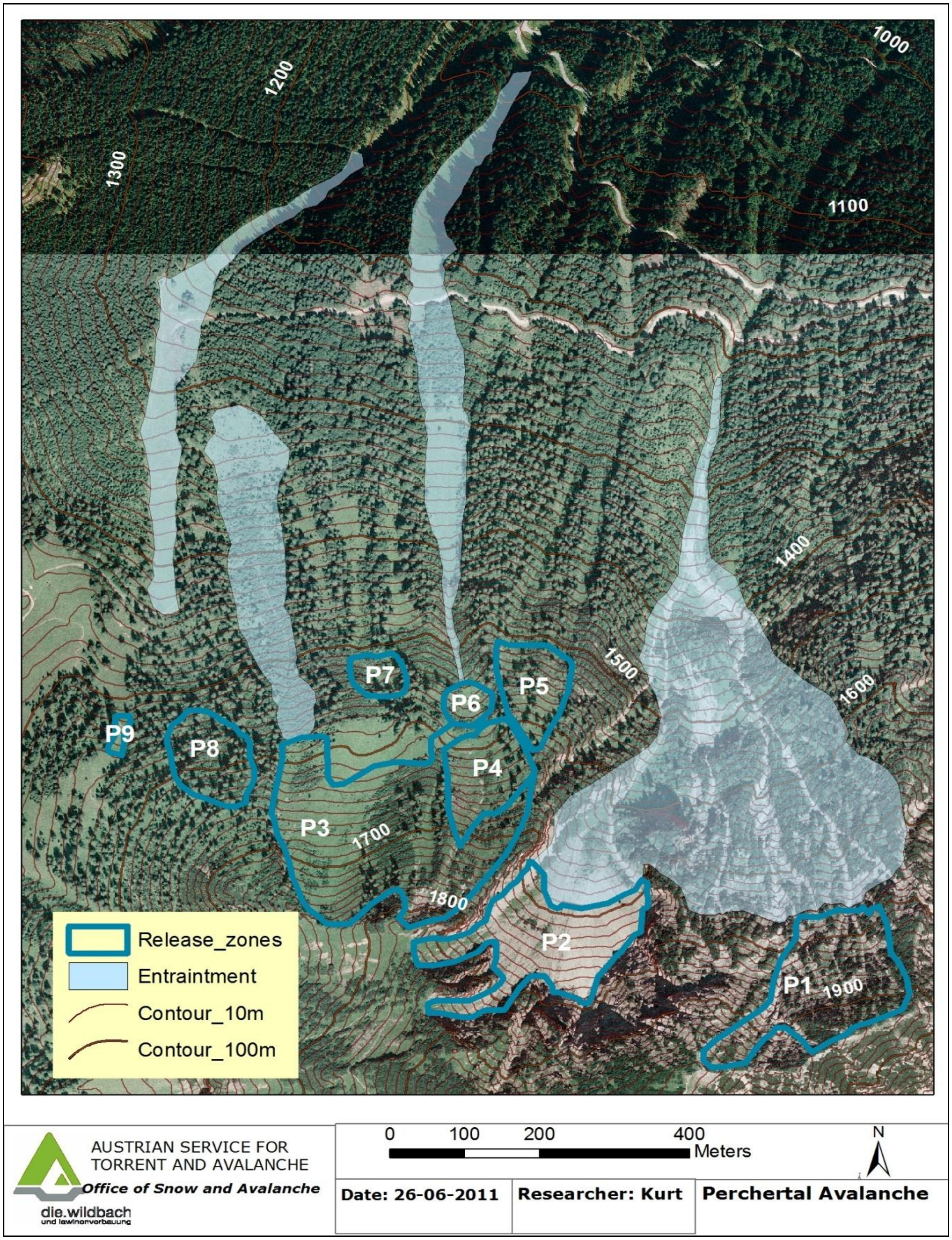

Figure 17. Avalanche release zones with snow entrainment areas

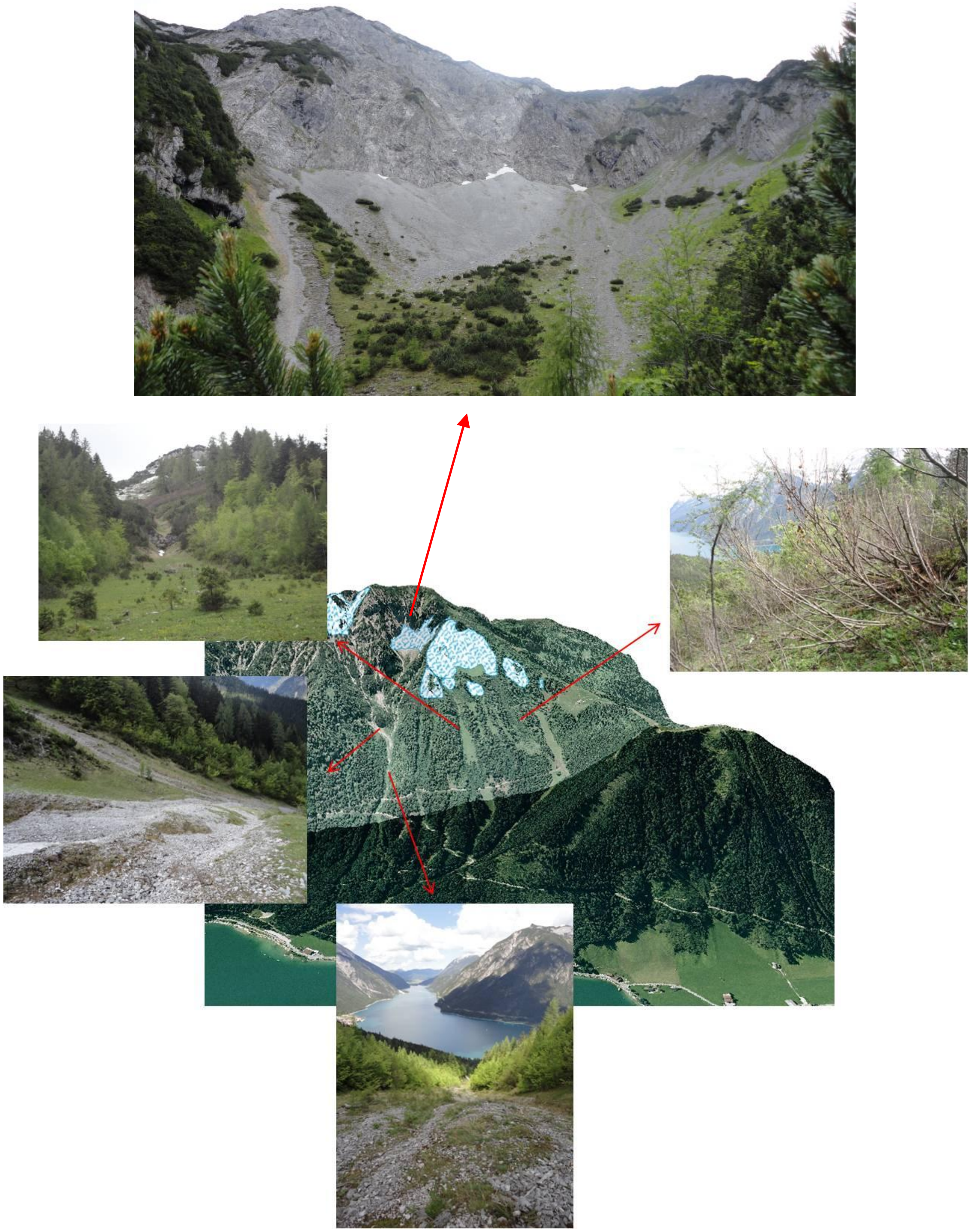

Figure 18. Overview of the avalanche tracks on Bärenkopf Mountain (Kurt, 2011)

2.3.2 Snow Accumulation

Meteorological values were provided by the Pertisau weather station, which was located 935 m above sea level (Fig. 19). The timescale was a hundred years (1900 -2000) for recorded values. Wind-drift factors were defined with the help of Mr. Graning for each release zone, and the main wind direction and position of the release zone on each slope were considered and are shown in orange in Table 7.

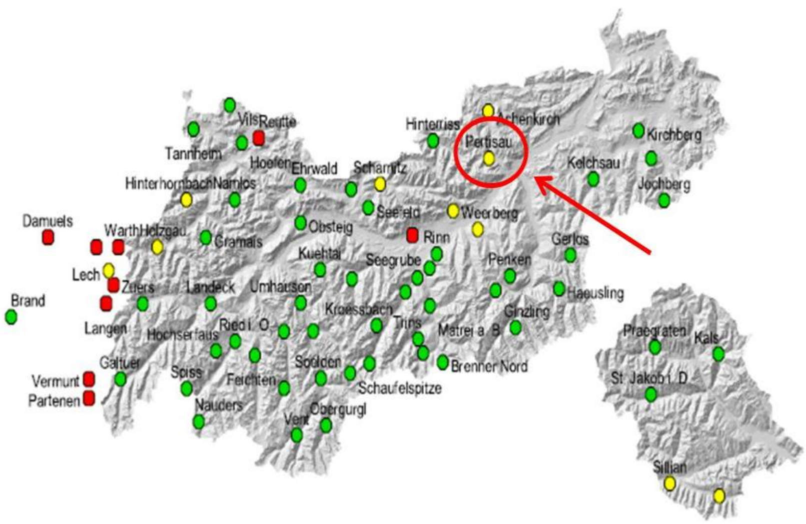

Figure 19. Overview of the location of Pertisau weather station in Tyrol (Schellander, 2004)

In Austria, precipitation events that are relevant for the estimation of design protective measures are the sum of three days of precipitation with a statistical return period of 150 years (Johannesson et al. 2009). Therefore, the average amount of snow accumulation over the past 150 years was extrapolated based on the mean heights of release zone, slopes, and meteorological data to be used as simulation parameters. Meteorological data from the Pertisau weather station shows that the amount of three days of new snow is 158 cm for Pertisau; however this value is valid only for flat, non-inclined surfaces as the amount of snow accumulation depends on different slope inclinations. In order to calculate snow accumulations for release zones that have different slope inclinations, an additive constant of +/- 9 cm per 100 m was applied to the calculations based on the map shown in Figure 20.

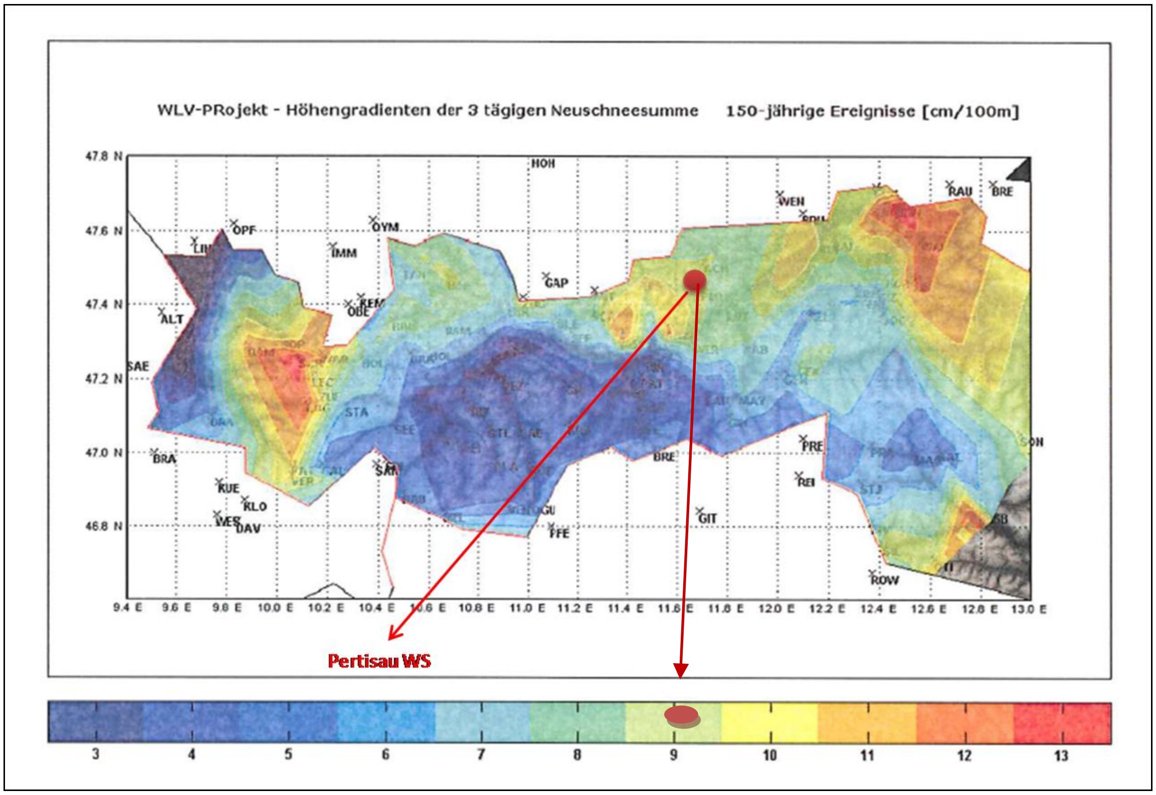

Figure 20. Height gradients for sum of three days of new snow for Tyrol (Leichtfried, 2010)

In order to calculate snow accumulations for release zones that have different slope inclinations, an additive constant of +/- 9 cm per 100 m was applied to the calculations.

Table 7. Values for snow accumulation (Pertisau weather station=935 meters above sea level , TNSS=140 cm)

Starting zone	P1	P2	P3	P4	P5	P6	P7	P8	P9
H max [m]	1.975	1.865	1.830	1.710	1.625	1.580	1.570	1.650	1550
H min [m]	1.765	1.680	1.580	1.580	1.510	1.540	1.510	1.520	1515
Mean H of release area [m]	1.870	1.773	1.705	1.645	1.568	1.560	1.540	1.585	1.533
Altitude of station [m]	935	935	935	935	935	935	935	935	935
Height difference between mean of release area and station [m]	935	838	770	710	633	625	605	650	598
Release snow depth [cm]	84	75	69	64	57	56	54	59	54
Inclination (rounded) [°]	46	35	39	37	39	38	42	40	32
Slope factor	0,5	0,71	0,62	0,66	0,62	0,64	0,56	0,6	0,81
Area [ha, planar]	3,10	3,07	7,23	1,30	1,07	0,32	0,39	1,19	0,09
Area [ha]	4,58	3,82	9,43	1,65	1,39	0,40	0,54	1,59	0,12
d_0 3TNSS [cm]	158	158	158	158	158	158	158	158	158
d_0 3TNSS [cm] 28°	140	140	140	140	140	140	140	140	140
Slab thickness [cm]	112	153	129	134	122	125	109	119	157
Incl. winddrift 30 [cm]	127	174	148	154	140	144	125	137	181
Incl. winddrift 50 [cm]	137	188	160	167	153	157	137	149	197
Cubature d_0 [m³]	**62.667**	**58.280**	**139.620**	**25.418**	**19.514**	**5.011**	**5.865**	**18.890**	**2.170**

2.3.3 Parameters for Alpha-Beta Model

The one-dimensional model was developed in Norway and is based on topographic parameters and empirical assumptions. The model was modified and titled “Alpha-Beta” to be used for avalanches in the Austrian Alps and requires data of the longitudinal profile of the avalanche track (Lied et al. 1995).

The calculations were done with the two-parameter equation as shown below:

α=0,946*β-0, 83°

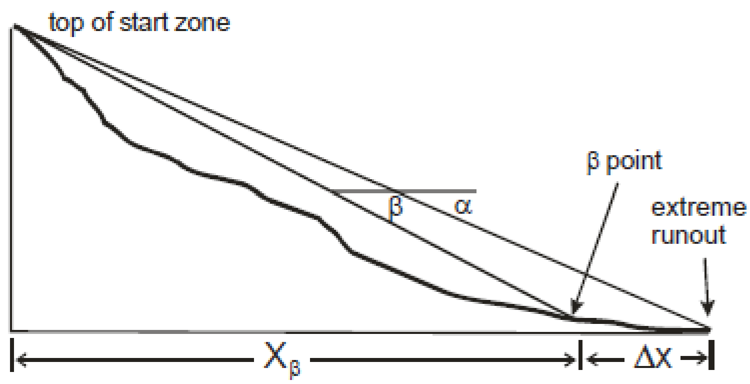

Figure 21. Terrain parameters used in Alpha-Beta model (Jamieson et al. 2009)

Avalanche gradient of the path ***α****:* The angle of a straight line between the maximum observed outer end of avalanche debris and the starting point.

Avalanche gradient ***β****:* The angle of the straight line between the point on the terrain profile where the slope angle equals 10, and the starting point (Lied et. al, 1995).In other words, the β point is defined to be where the slope angle decreases to 10° while descending the path (Jamieson et. al., 2009).

X_β: The measured horizontal distance from the top of path to the beta point (Jamieson et al. 2009).

ΔX: The predicted distance (m) between the beta point and the extreme run out position.

2.3.4 Parameters for Samos AT Model

Samos AT (Snow avalanche modeling and simulation) is a type of simulation model used for dense and powder snow avalanches. It describes both the dense flow layer and the powder snow layer of an avalanche, as well as the interaction between them (Sampl and Granig, 2009). Therefore, we used it for dense flow avalanche scenarios as well as powder snow avalanches. The Samos AT dense flow model reacts sensitively to the surface topography (Granig, 2009) and is used routinely by the WLV for hazard zoning.

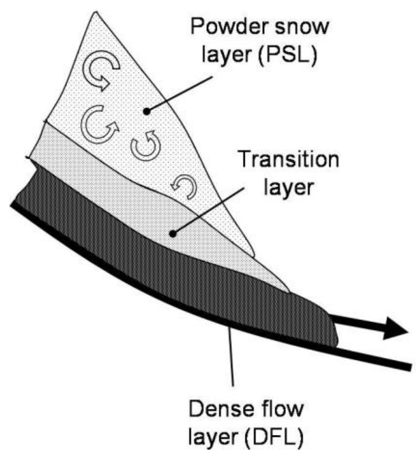

Figure 22. Samos AT simplification (Sampl, 2011)

Inputs shown below were used to simulate avalanche scenarios with Samos AT model:

• a digital terrain model;

• the outline of the release areas together with snow depths and densities;

• optionally outlines and properties of areas with increased friction (vegetation etc.);

• the density of the flowing dense snow.

The parameters of the Samos AT model were verified in the model calibration by Oberdorfer and Granig (2007) and based on 22 reference avalanches. As part of the recalibration of the Samos AT model, 20 additional references were checked to calibrate to the new suspension model (Jörg and Granig, 2010). The calculations were based on the current model version of SamosAT-Apr10. These parameters were used as shown below for the Perchertal avalanche:

⇒ Friction law:	Dense flow layer (Bottom friction model)
	Powder snow layer
⇒ Flow density [kg/m³]:	200
⇒ Particle diameter [m]:	0,0008
⇒ Psa Meshes [m]:	15/15/4/H=500
⇒ Flow resistance (reff: forest):	0 / 150
⇒ Entrainment [cm] (Zero-/ Entrainment variant):	0
⇒ Particle restitution coefficient (c_{pr})	0,965

The dense flow layer model of Samos AT model is based on an equation (Bottom friction model) as follows (Sampl and Granig, 2009):

$$\tau^{(b)} = \tau_0 + p^{(b)}\mu\left(1+\frac{R_{s0}}{R_{s0}+R_s}\right)+\frac{\rho\|\bar{u}\|^2}{\left(\frac{1}{\kappa_D}\ln\frac{h}{R_D}+B_D\right)^2}$$

Figure 23. Dense flow layer model at the Samos AT (Sampl and Granig, 2009)

- τ_0 is a yield stress;
- μ is the Coulombian bed friction coefficient: 0.155;
- R_s is a “fluidization factor”, and it is defined as the ratio of dispersive stresses to the effective bottom pressure:

$$R_s = \frac{\rho\|\bar{u}\|^2}{p^{(b)}}$$

Figure 24. Ratio of dispersive stresses at the Samos AT (Sampl and Granig, 2009)

The R term serves to increase the Coulombian bed friction at low fluidization, so as to stop slow avalanche parts already in terrain steeper than atan(μ) and to prevent spreading when mass is close to stopping (Sampl and Granig, 2009).

- R_D the surface roughness;
- Rs_0, K_D and B_D empirical constants. The values used for Rs_0, K_D, RD and BD are 0.222, 0.43, 0.1 m, and 4.13, respectively (Sampl and Granig, 2009).

Flow density [kg/m³] is strongly dependents on the characteristics of snow (dry, wet and crystal size) (Bacher, 2010). It is a parameter that has great variability of the density of flowing snow. A vertical three-layer-structure (Fig. 21) is assumed in an avalanche, the layers being identified by different ranges of the mixture density (Sampl and Granig, 2009):

- a dense flow layer (DFL) with 200 to 300 kg/m³ at the bottom;
- a powder snow layer (PSL) with 1 to 10 kg/m³ at the top;
- a transition layer in between.

The particle diameter (Ice particle) is assumed in the range 0.5 to 1 mm (Sampl and Granig, 2009).

Psa meshes (The numerical powder snow layer*)* is created by extruding a regular grid (resolution typically 15 m) in direction of the average terrain normal (Sampl and Granig, 2009). About 20 cell layers with increasing depth are added, with the depth of the first approximately 4 m (Sampl and Granig, 2009).

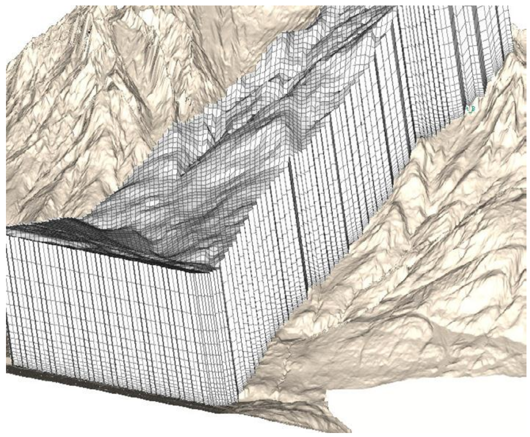

Figure 25. Calculation mesh powder part at the Samos AT (Sampl and Granig, 2009)

Resistance force to break entrained snow from the ground can be considered optionally. The resistance force due to obstacles like trees in a forest or fields of boulders, defined by a characteristic obstacle height h_{res}, diameter d_{res}, average lateral distance s_{res}, and shape resistance coefficient c_w is computed as a equilibrium shown below (Sampl and Granig, 2009):

$$F_i^{(res)} = -c_w \rho \frac{\|\vec{u}\|^2}{2} d_{res} \min(h, h_{res}) \frac{A}{s_{res}{}^2} \frac{u_i}{\|\vec{u}\|}$$

Figure 26. Resistance force equilibrium at the Samos AT (Sampl and Granig, 2009)

Snow entrainment is considered at the dense flow layer front and specified by q_{ent} , the entrainable mass per unit surface area (Sampl and Granig, 2009). The front width w_f within an element, measured normal to the flow direction, is zero for elements not at the front (Sampl and Granig, 2009). If the mass transferred to the powder snow layer per unit surface area is termed j_s and the time t, the mass balance for an element can be written as below (Samp and Granig, 2009):

$$\frac{dm}{dt} = w_f q_{ent} \|\vec{u}\| - j_s A \,.$$

Figure 27. Snow entrainment equilibrium (mass balance for an element) at the Samos At (Sampl and Granig, 2011)

2.3.5 Parameters for Ramms Model

The Ramms model was developed at the Snow and Avalanche Research (SLF) department of the Swiss Institute in Davos. The model is a development of one-dimensional numerical model Aval1D. Inputs shown below were used to simulate avalanche scenarios with Ramms model (Christen et al. 2008):

- digital elevation model;
- release zone area and fracture heights plus snow cover entrainment heights;
- model friction parameters (Friction parameters can be described manually or alternatively, automated procedures have been developed using GİS software).

These parameters that were used are shown below:

⇒ Density [kg/m³]:	300 AD/FD
⇒ Friction law:	Voellmy
⇒ Annuality:	100
⇒ Avalanche size (Kubatur)	Large

Ramms model employs a *Voellmy fluid friction model*. This model has found wide application in the simulation of mass movements, especially snow avalanches (Christen et al. 2010). It is based on an equation as shown below:

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

Figure 28. Voellmy fluid friction model

- G is gravitational acceleration;
- ρ is the flow density;
- Ø is the slope angle;
- H is the flow height;
- U is the flow velocity.

As mentioned earlier, in Austria, precipitation events that are relevant for the estimation of design protective measures are the sum of three days of precipitation with a statistical return period of 150 years (Johannesson et al. 2009). However, annuality factor was assumed as statistical return period of 100 years for simulations at the Ramms due to its concept.

Avalanche size factor gives an idea about avalanche volume category. The Perchertal avalanche was assumed as large size avalanche due to much snow accumulations on the release zones (Table 7).

2.3.6 Hazard Map

The official hazard map that was used was provided by the WLV office in Schwaz for the Perchertal avalanche before studying the avalanche simulations. This map indicates that the hotel and part of the main road that passes in front of hotel are located entirely in the red zone (Fig. 29). After the simulation results were obtained, a new hazard map was drawn and is presented on the following pages.

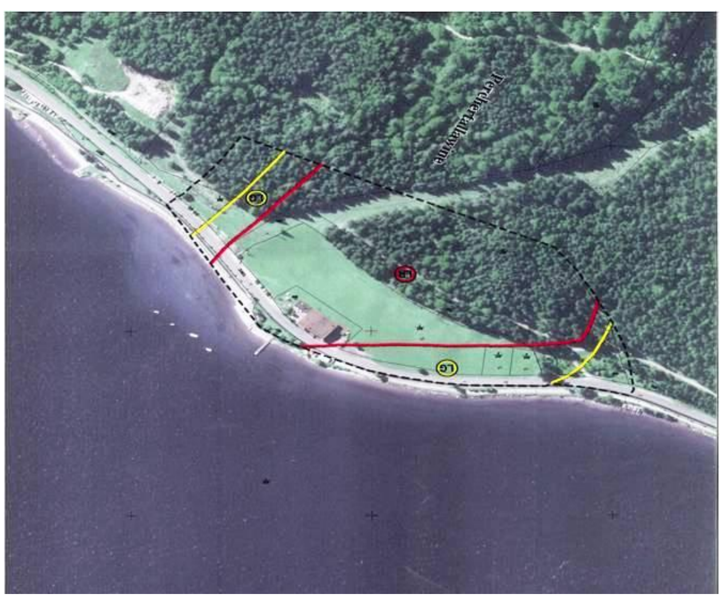

Figure 29. Official hazard map of Perchertal avalanche (The WLV)

3. METHODOLOGY

This thesis is comprised of practical part and written study. The practical study was performed at the WLV Snow and Avalanche Office in the district of Schwaz, Tyrol. During the field studies, a 1:2000-scaled orthophoto map was used. Required materials (e.g. avalanche simulation models) were provided by the WLV office. In total, the practical study which included field trips and office work lasted for three months in Tyrol. The goal of the investigation is to reduce the future impacts of the hazard (Perchertal avalanche) including loss of life, property damage, and environmental damage.

The concept behind the thesis is based on risk assessment steps as follows (Fuchs, 2009):

1. to identify hazards;
2. to decide who might be harmed and how;
3. to evaluate risks (risk analysis) and decide on precautions.

As a first step, we visited the area where Perchertal avalanche occurred with Mr. Plank the local WLV office director in Schwaz. He gave information on avalanche tracks, vegetation, and the environment. on 13.05.2011.

Between 18.05.2011-21.05.2011, field study was carried out to create a forest map the relevant area with the field supervisor Mr. Hochreiter. Age classification of trees, vegetation, and soil regimes were defined and recorded for the entire forest (Appendix A).

Figure 30. Determination of tree ages (Photo: Kurt, 2011)

Perchertal avalanche presents danger to the hotel, which is located nearly active avalanche paths and the part of main road that provides accessibility for Pertisau. Therefore, guests in the hotel and passengers passing by the main road can be in danger of injury or death due to an avalanche event. Therefore, cost and benefit analysis was performed in order to decide who might be harmed and how as well as most economical solution (vulnerability assessments).

To evaluate risks and decide on precautions, field and office works were performed respectively over the following days. For example, the starting zones were defined with the field supervisor Mr. Granig on the basis of slope mapping, orthophotos and the report from local avalanche commission. Entrainment areas were described and forest areas were assumed for additional resistance.

Next, avalanche scenarios were simulated with the support of Mr. Tollinger and Mr. Jörg using the Alfa-Beta, Samos AT and Ramms models to determinate severity level of a Perchertal avalanche. The accuracy of simulation results were discussed with Mr. Granig and Mr. Tollinger and chronology, maps and experiences gained from the excursions were all considered. Thus, on 04.07.2011, feasibility of avalanches were evaluated by comparing the topographic circumstances of both field and simulation results

A hazard map of the relevant area was re-drawn according to on simulation results and topographic situations after discussions with Mr. Plank. The new hazard map included alternative avalanche protection that was considered thereafter.

Ultimately, alternative mitigation measures were assessed and recommendations were shared in order to ensure a maximum safety level for the hotel and the part of the main road.

4. RESULTS

4.1 SIMULATION RESULTS

As a first step, nine possible avalanche scenarios were simulated as dense flow avalanches using the Samos AT model. The results illustrated that especially three avalanche falls from R1, R2 and R3 constituted a particularly risky situation for the hotel and part of the main road (Fig. 31). The other six avalanche scenarios results (R4, R5, R6, R7, R8, and R9) were assumed to be dangerous mainly for ski tracks as they are minor avalanches. Therefore, for the next simulations only R1, R2 and R3 were taken into the consideration and presented on the following pages.

Figure 31. The hotel was endangered due to an avalanche (Photo: Kurt, 2011)

As a second step, three avalanche scenarios R1, R2 and R3 were simulated as dense flow avalanches using Ramms model. These results were similar to the Samos AT model results and were acceptable.

In spite of the chronology of avalanche events in Pertisau and the fact that powder snow avalanche has not occurred between 1948-2011, we created scenarios where a powder snow avalanche might be released from R1, R2 and R3 and simulated them using Samos AT model to compare dense flow and powder snow avalanches.

Results indicated that in case of powder snow avalanche, the covered deposition areas could be more widespread.

In addition, avalanche run out distances were calculated with Alpha-Beta model.

More details on the different type of avalanches and different type of avalanche programs are provided on the following pages.

4.1.1 Results from Alpha-Beta Model

The avalanche's run out distances of R1, R2 and R3 were calculated by Alfa-Beta model. This means that the model illustrated where the Perchertal avalanche could stop in the run out zone. Parameters were entered into the model with the help of Mr.Granig.

Results from Alpha–Beta model for R1, R2 and R3 can be seen separately on the following pages.

According to simulation result from Alpha-Beta model for R3**,** an avalanche is able to reach any object at 949.8 m.a.s.l. Run out distance is 1849.3 m for R3. Detailed calculations were presented in Appendix C.

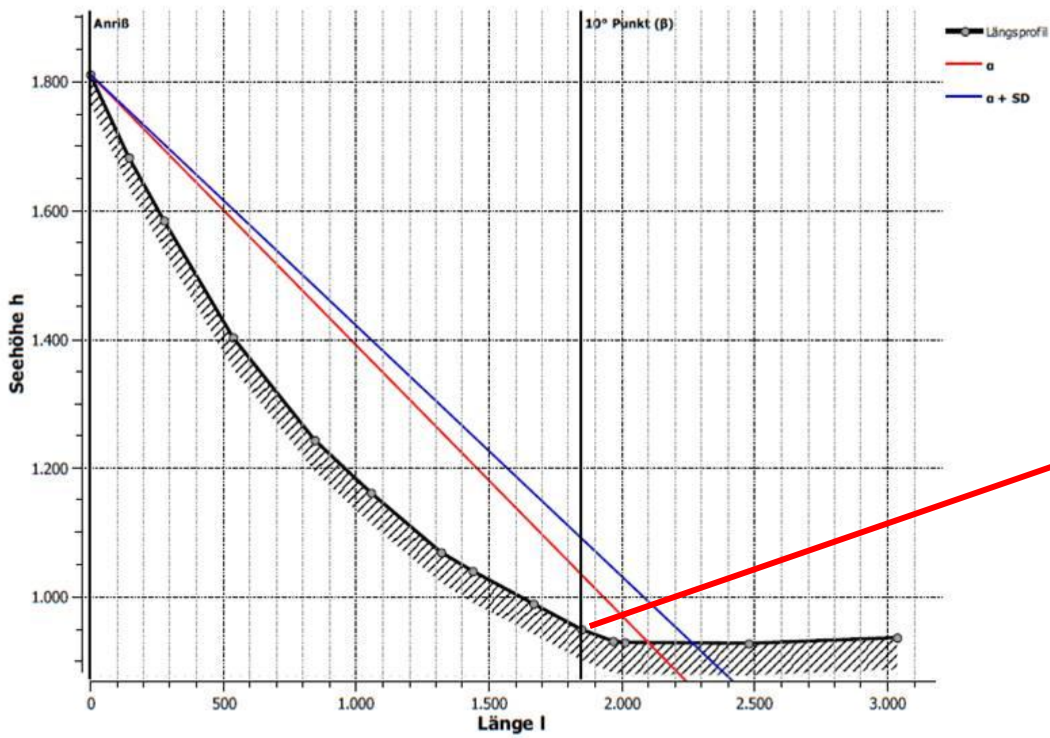

Figure 32. Simulation result from Alpha-Beta model for **R3**

Figure 33. Overview to the endpoint of an avalanche from R3 according to Alpha-Beta model

According to simulation results from Alpha-Beta model for **R2,** an avalanche is able to reach any object at 930.3 m.a.s.l. Run out distance is 1728.7 m for R2. Detailed calculations were presented in Appendix C.

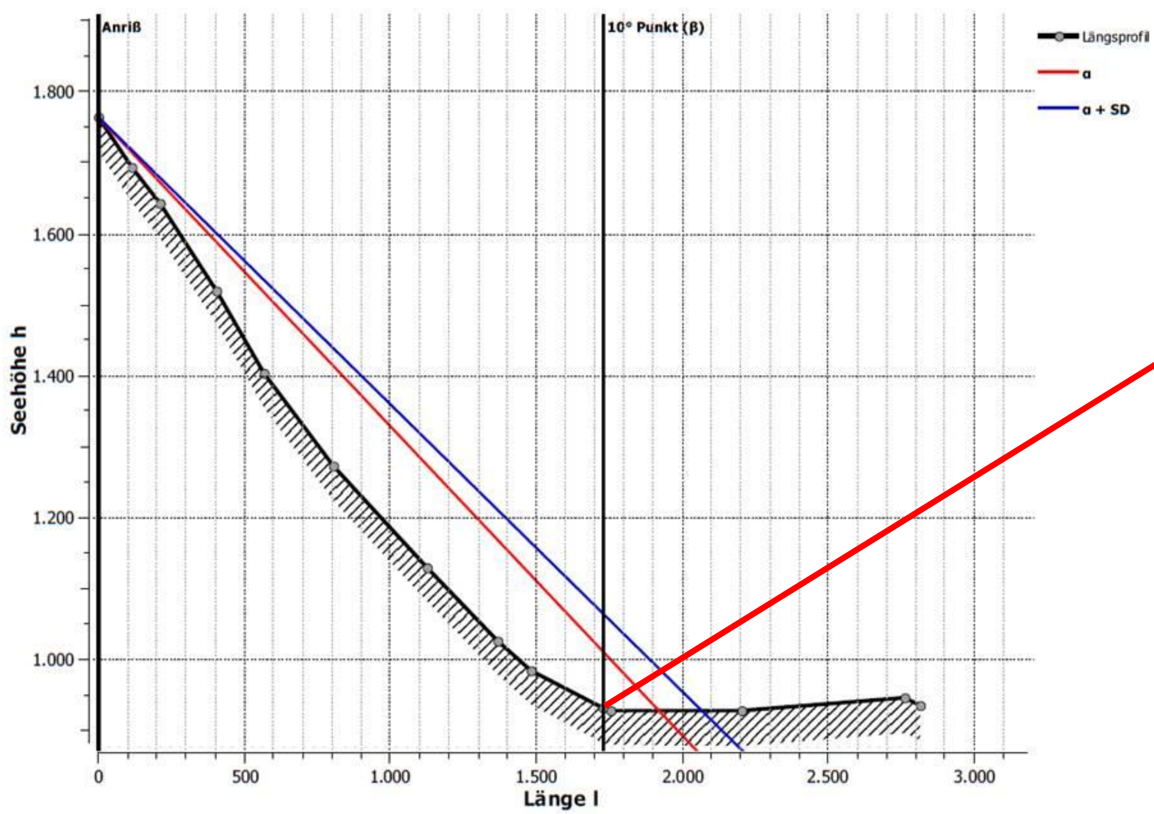

Figure 35. Simulation result from Alpha-Beta model for **R2**

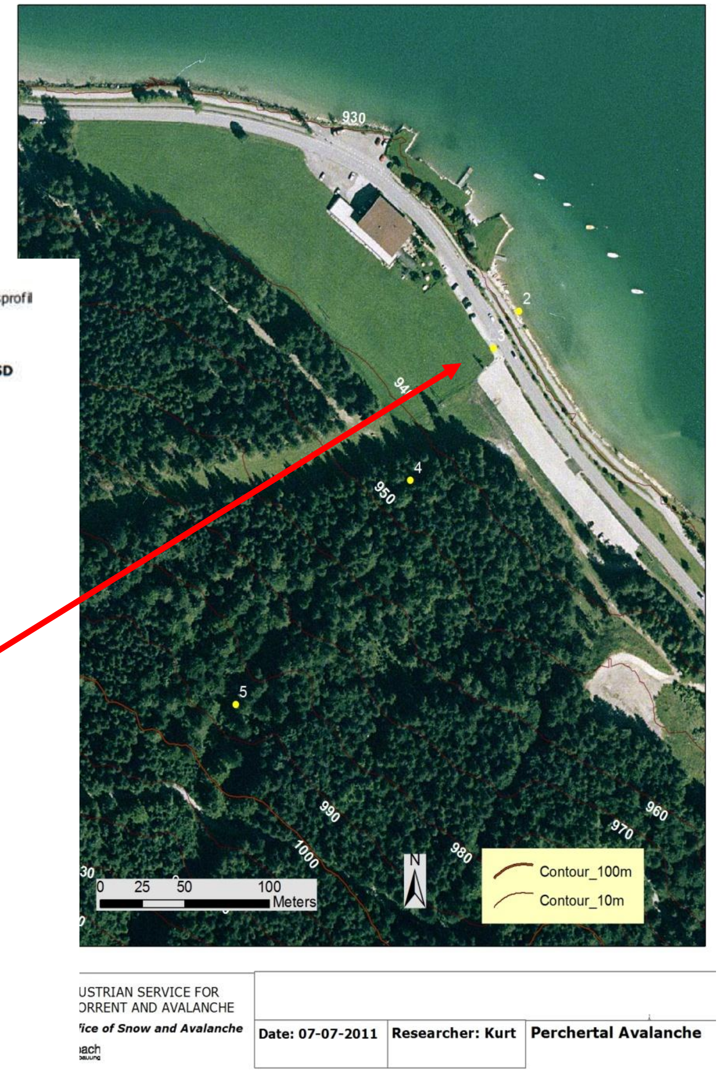

Figure 34. Overview to endpoint of an avalanche from R2 according to Alfa-Beta model

According to simulation result from Alpha-Beta model for **R1,** an avalanche is able to reach any object at 940.7 m.a.s.l. Run out distance is 1713 m for R1. Detailed calculations were presented in Appendix C.

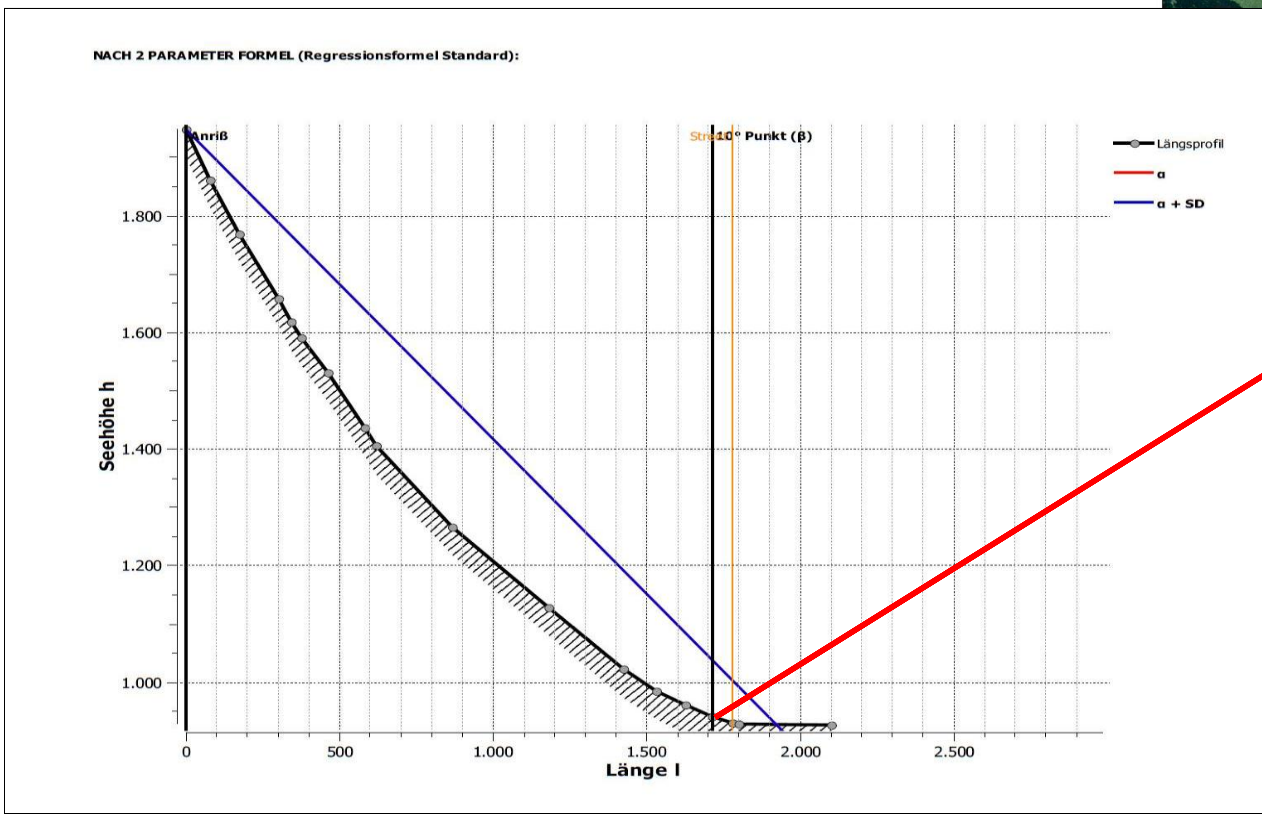

Figure 36. Simulation result from Alpha-Beta model for **R1**

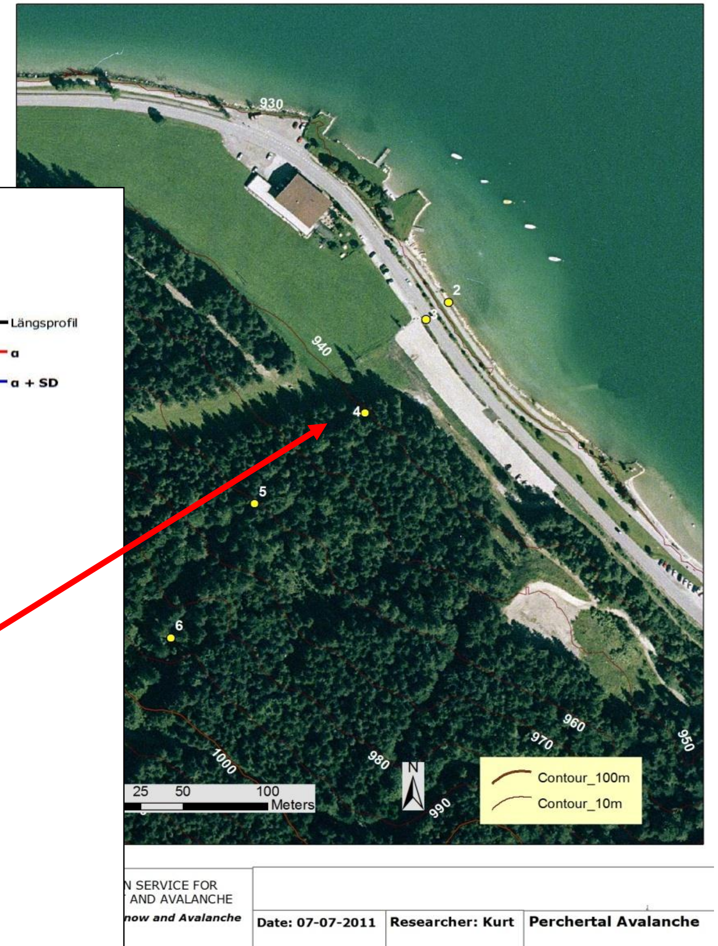

Figure 37. Overview to endpoint of an avalanche from R1 according to Alfa-Beta model

4.1.2 Results from Samos AT Model

Nine different scenarios were calculated with the Samos-AT model for dense flow avalanches. Simulation results of R1, R2 and especially R3 illustrated that the St. Hubertus hotel and the main road might be affected in event of a dense flow avalanche. Six other release zones created minor avalanches, which mainly affected for ski tracks based on simulations.

Although a powder snow avalanche has not occurred on Bärenkopf Mountain between 1948- 2011, they were simulated using by the Samos AT model in order to compare to dense flow avalanche results and severity level of powder snow avalanches scenarios. According to the results of R1, R2 and R3, the hotel is located in the yellow zone where it might be affected by 3 kPa avalanche impact pressure. On the following pages, more details are provided according to different types of avalanches and different type of avalanche programs.

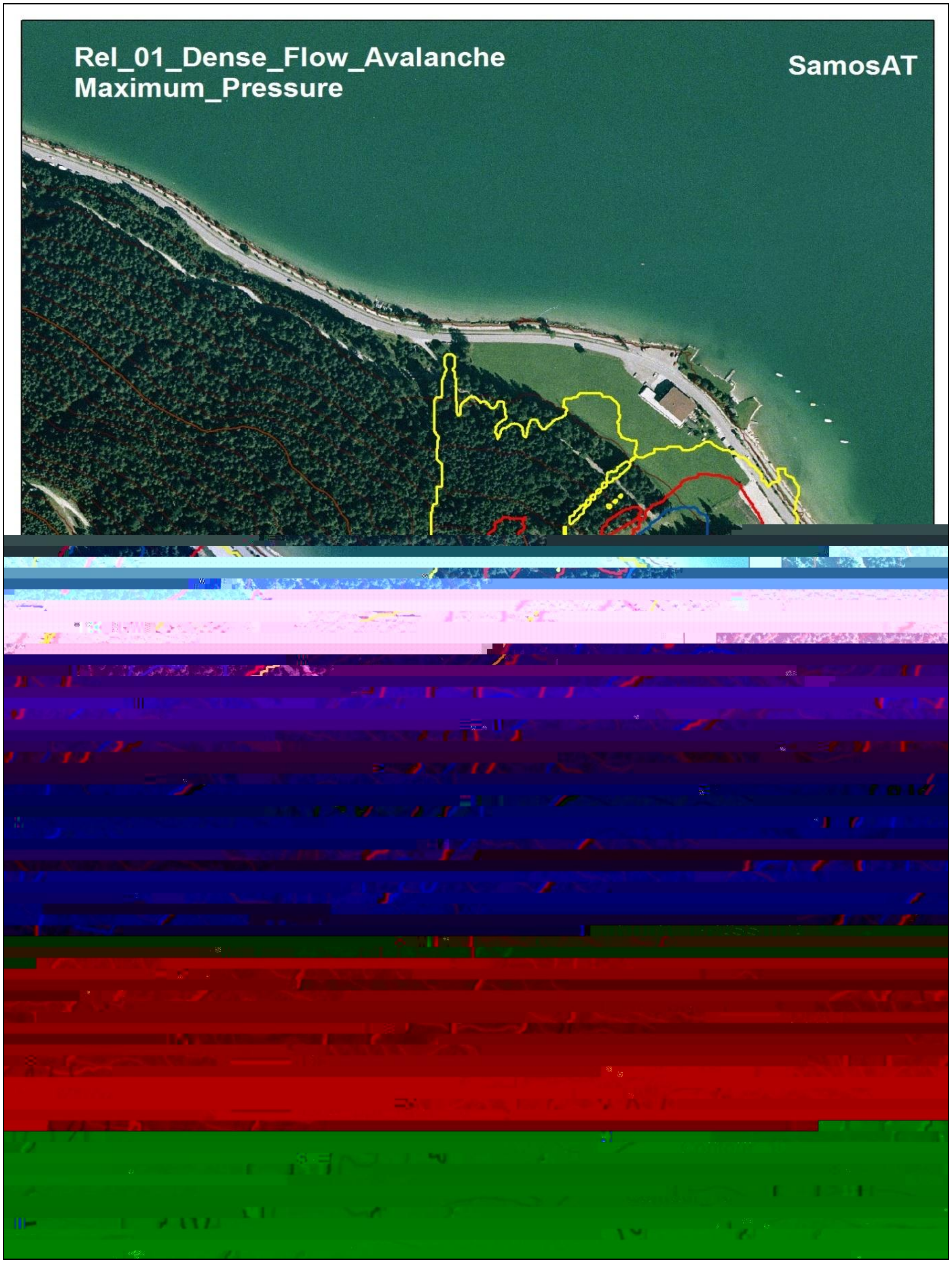

Figure 38. Maximum pressure of R1 as a dense flow avalanche with Samos AT model

Figure 39. Maximum pressure of R2 as dense flow avalanche with Samos AT model

Figure 40 shows the most dangerous dense flow avalanche scenario for the hotel and main road. The avalanche flow can come from a wide form of avalanche tracks and crash into the hotel and continue on into lake. In addition, the maximum flow height and velocity of R3 are presented on the following pages.

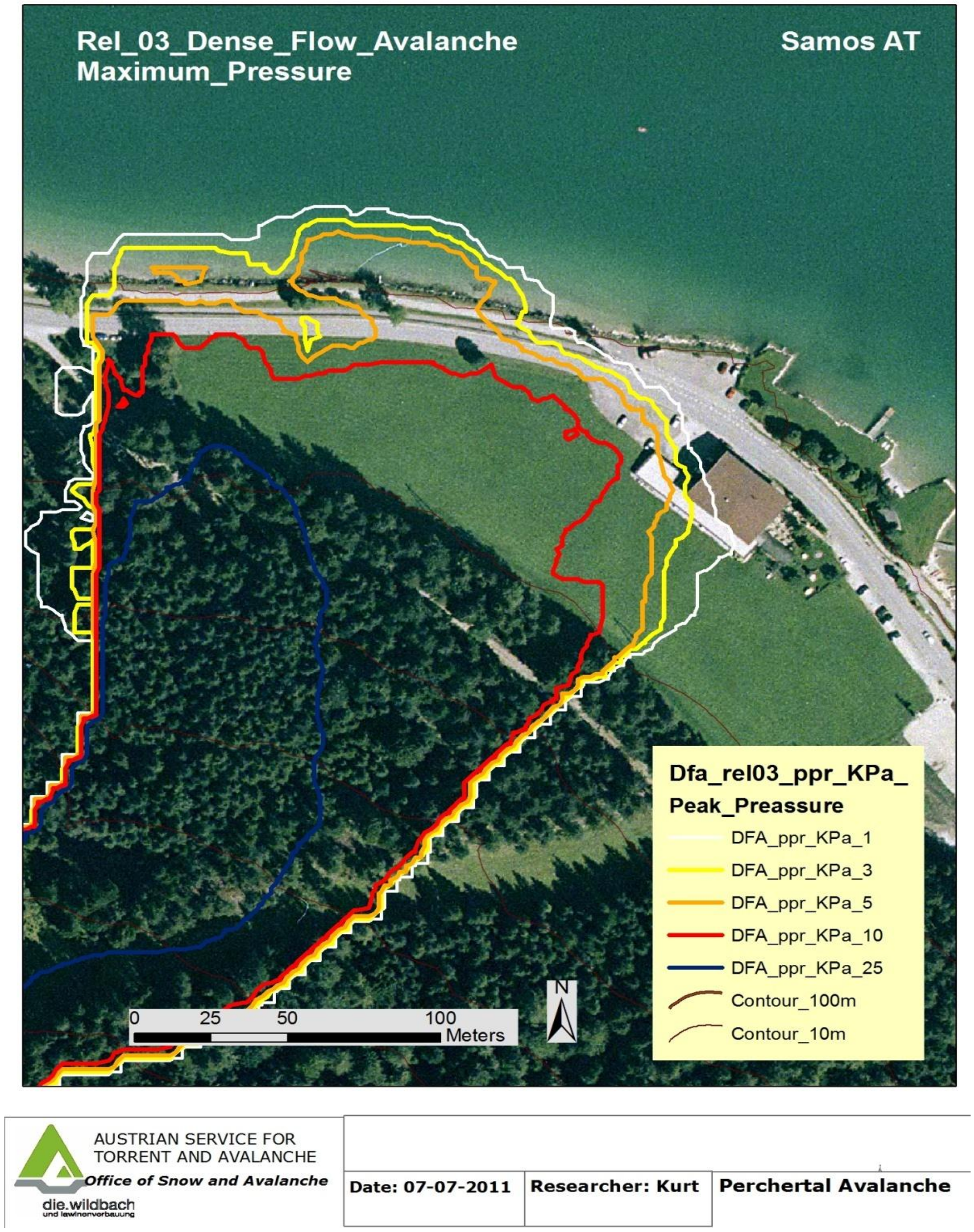

Figure 40. Maximum pressure of R3 as dense flow avalanche with Samos AT model

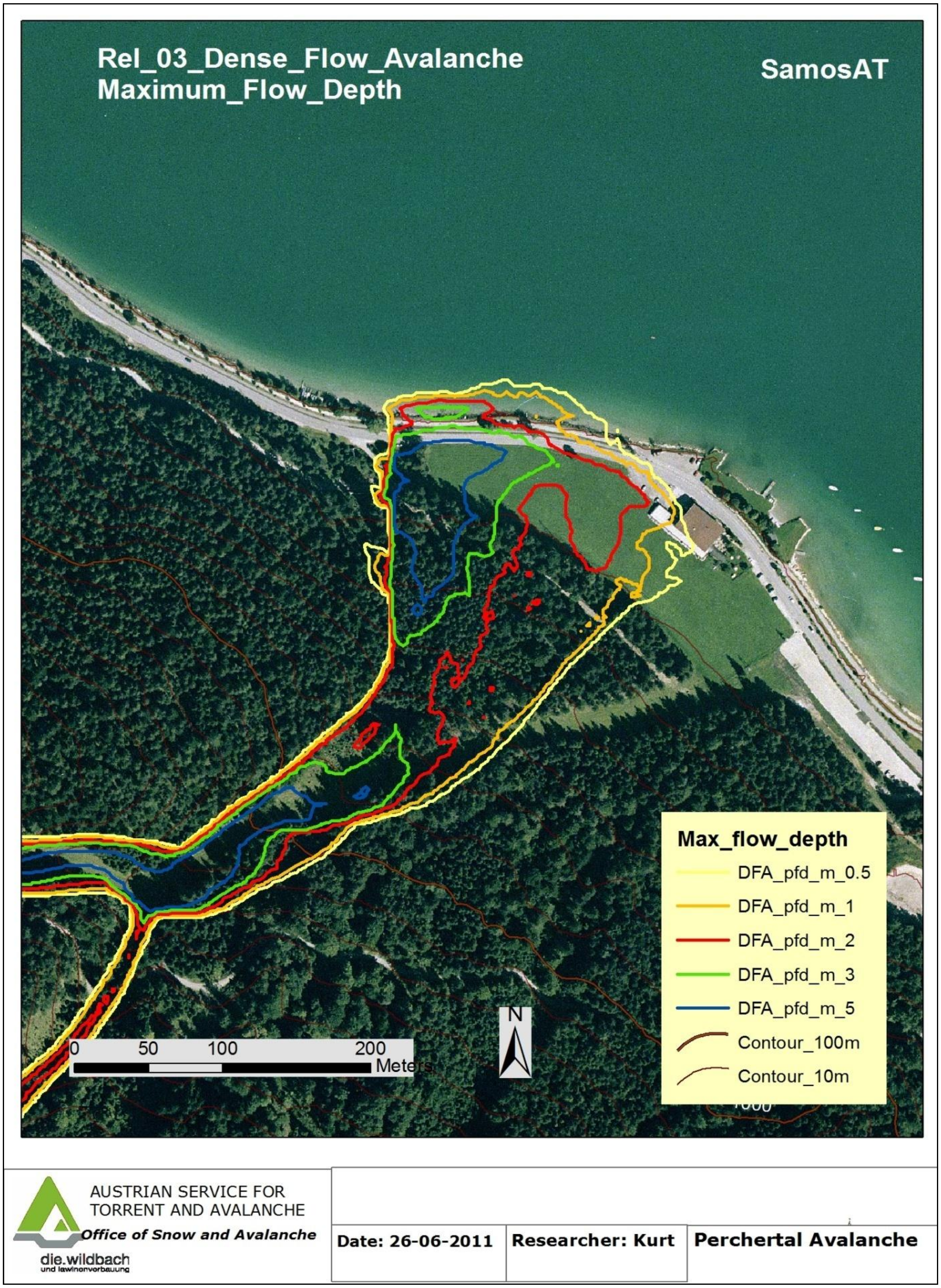

Figure 42. Maximum flow depth of R3 as dense flow avalanche with Samos AT model

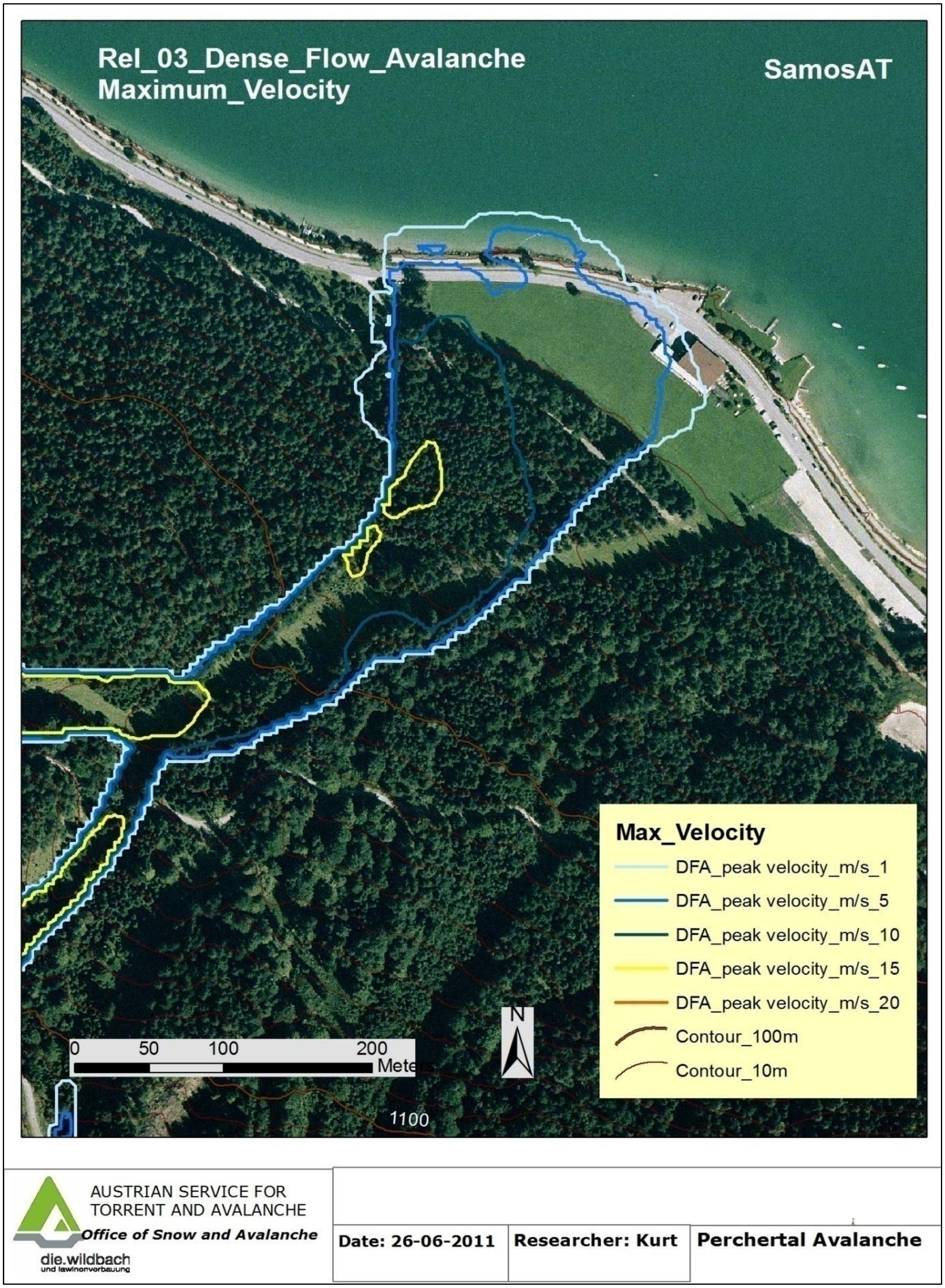

Figure 43. Maximum velocity of R3 as dense flow avalanche with Samos AT model

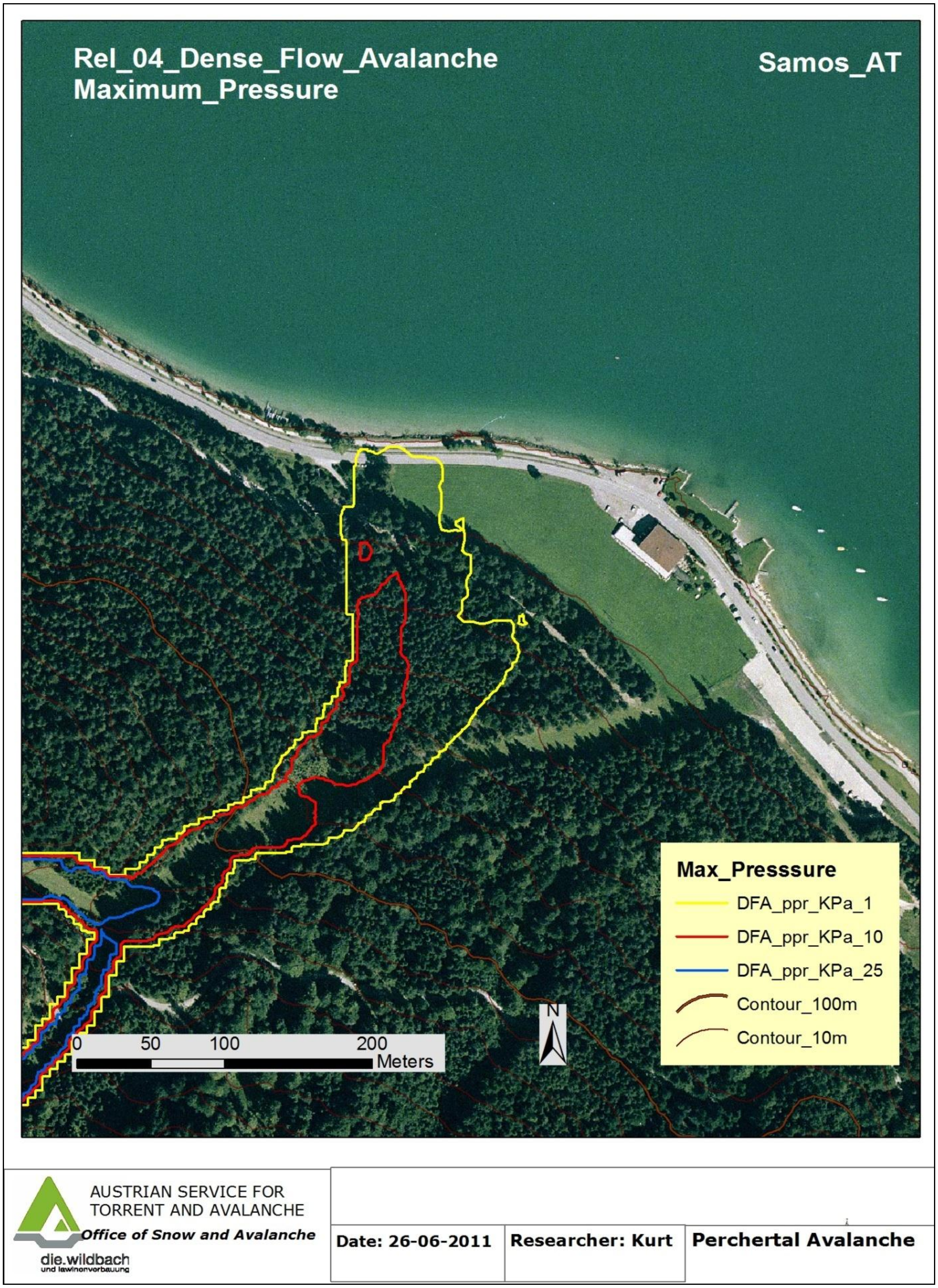

Figure 44. Maximum pressure of R4 as a dense flow avalanche with Samos AT model

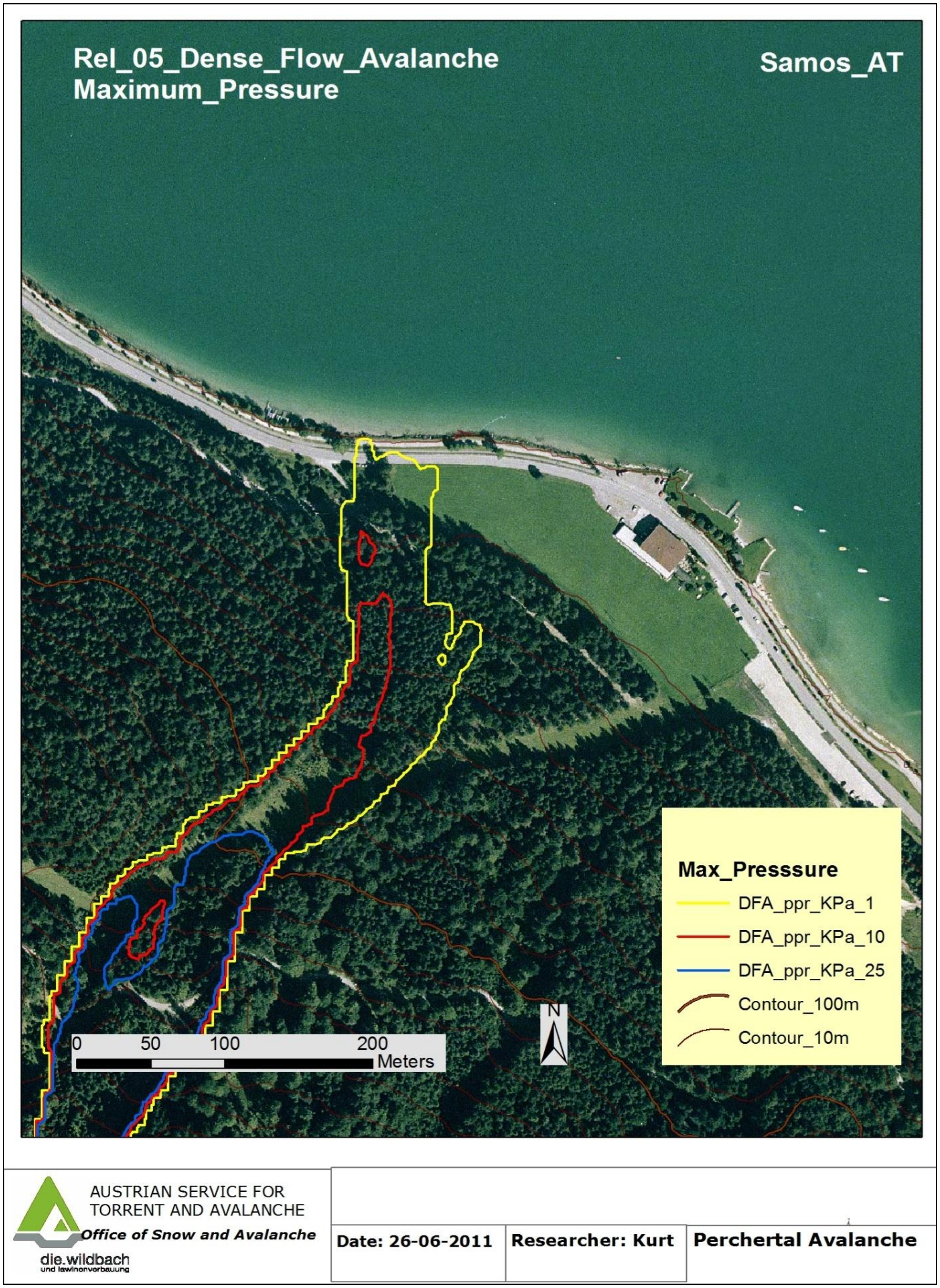

Figure 45. Maximum pressure of R5 as a dense flow avalanche with Samos AT model

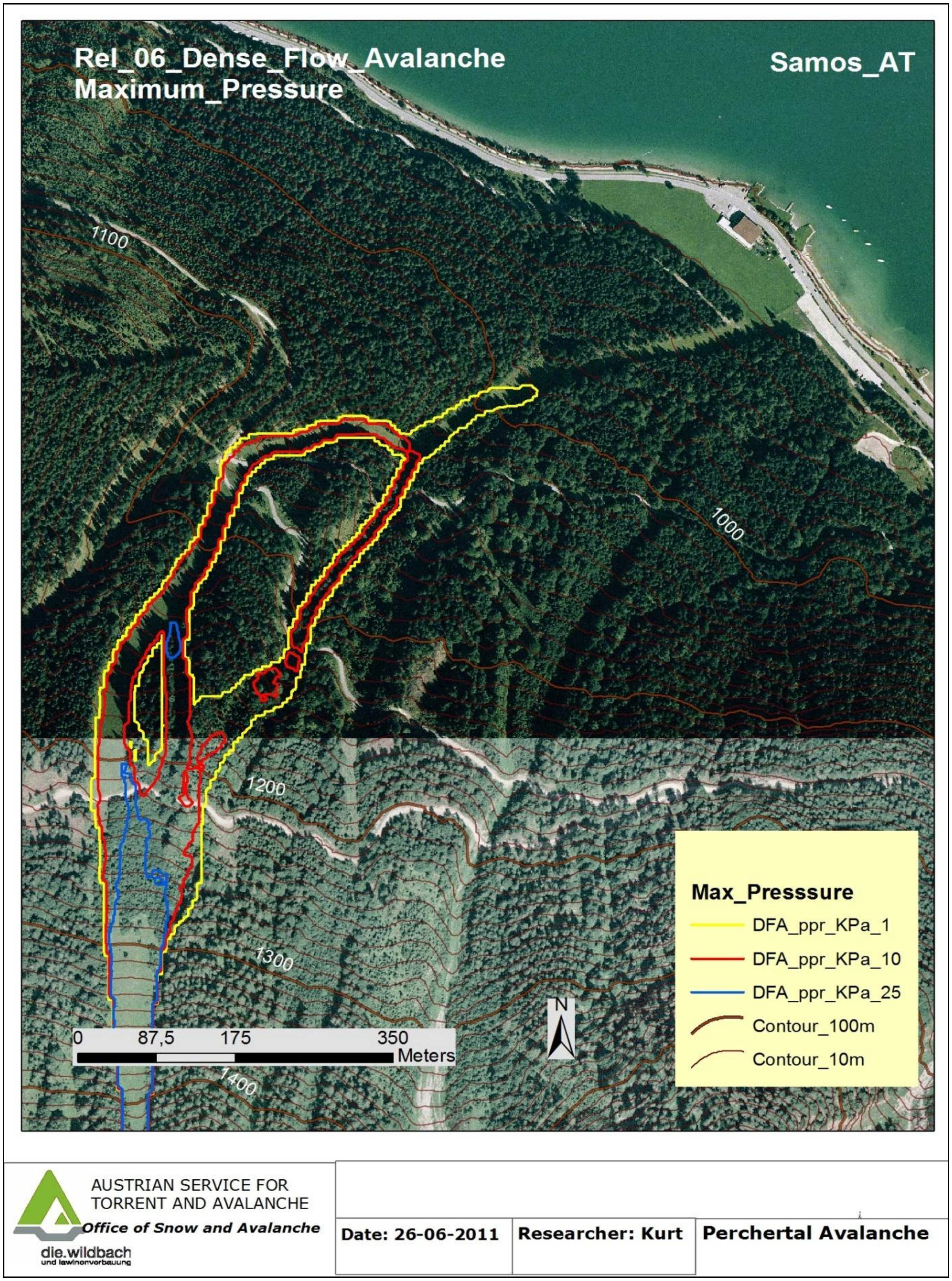

Figure 46. Maximum pressure of R6 as dense flow avalanche with Samos AT model

Although a powder snow avalanche has not occurred on Bärenkopf Mountain between 1948- 2011, powder snow avalanche scenarios were simulated using Samos AT which considered both resistance and without resistance area. The most effective and dangerous avalanche scenario was created from R3. Maximum peak pressure, maximum flow height and maximum velocity of R3 are all represented on the following pages.

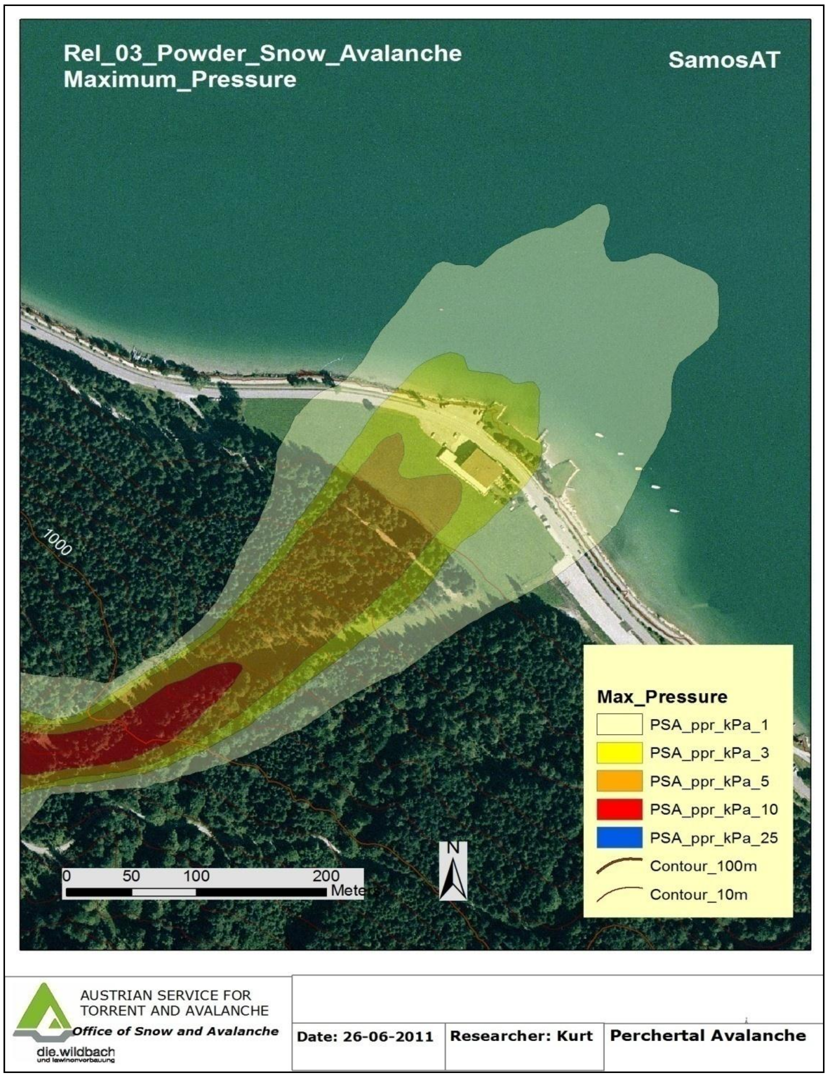

Figure 47. Maximum pressure for R3 without resistance as Psa with Samos AT model

There is not a significant difference as seen in the following pages between results for resistance and without resistance areas for powder snow avalanche scenarios.

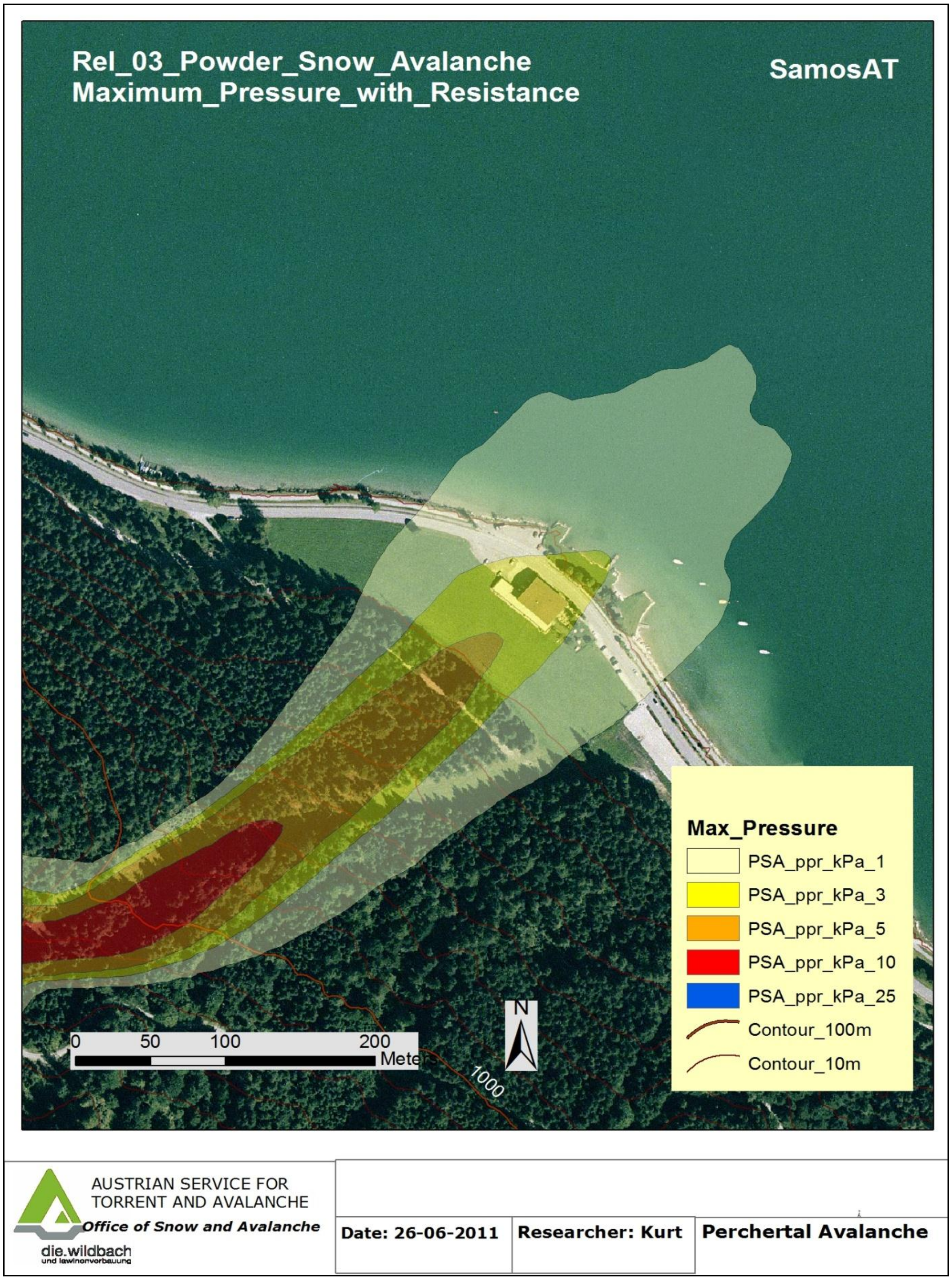

Figure 48. Maximum pressure for R3 with resistance as Psa with Samos AT model

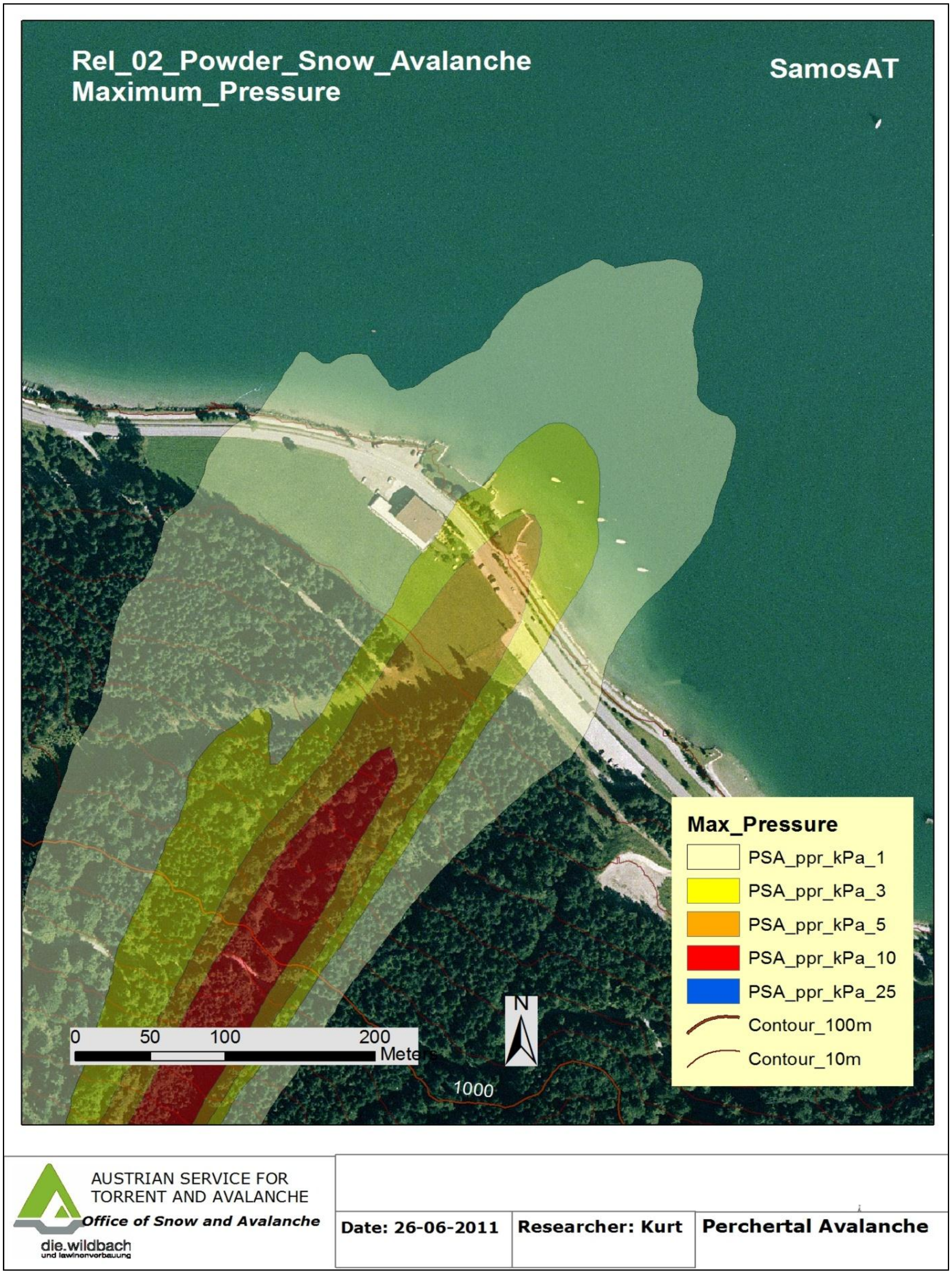

Figure 49. Maximum pressure for R2 without resistance as Psa with Samos AT model

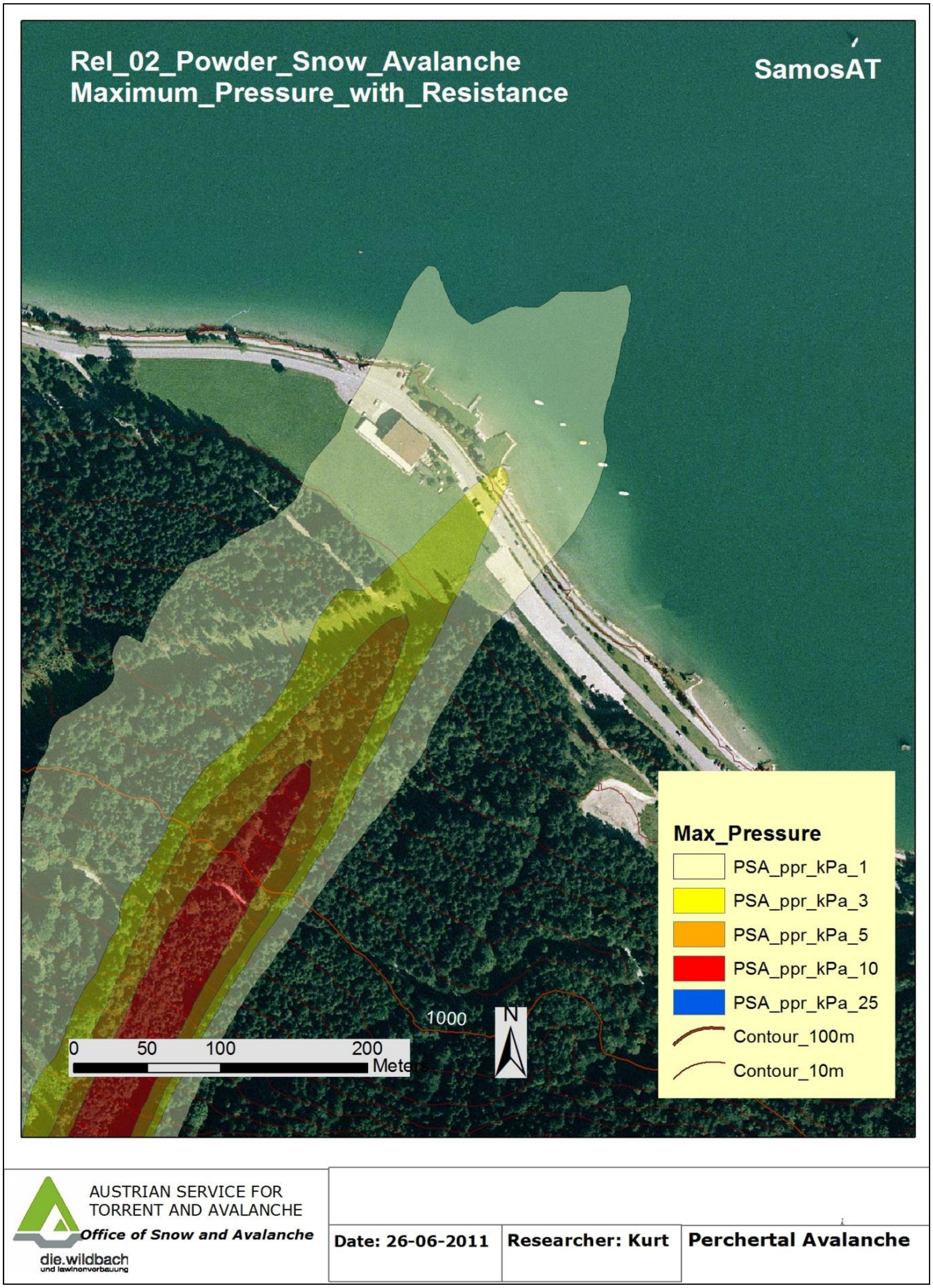

Figure 50. Maximum Pressure for R2 with resistance as Psa with Samos AT model

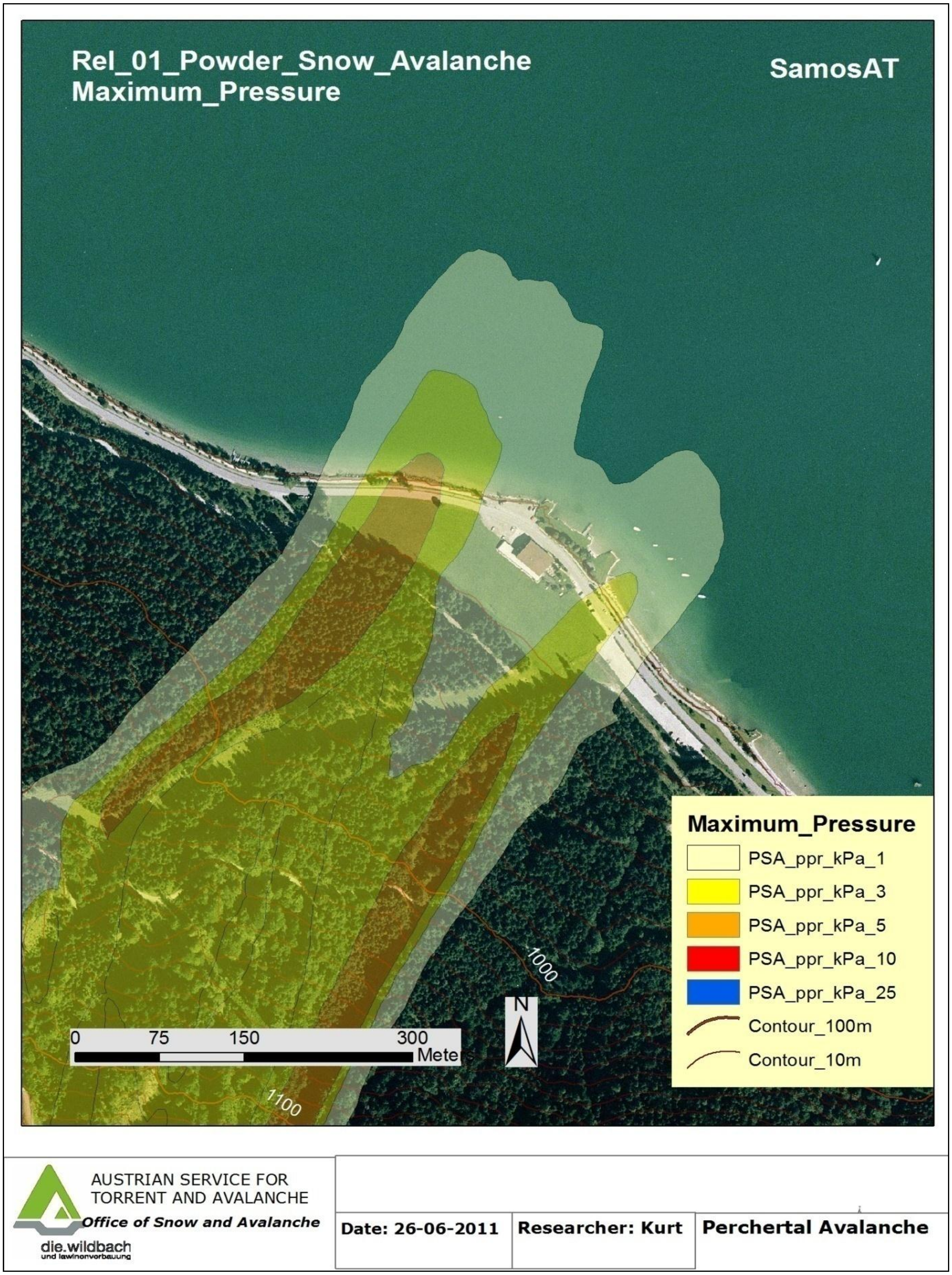

Figure 51. Maximum pressure for R1 without resistance as Psa with Samos AT model

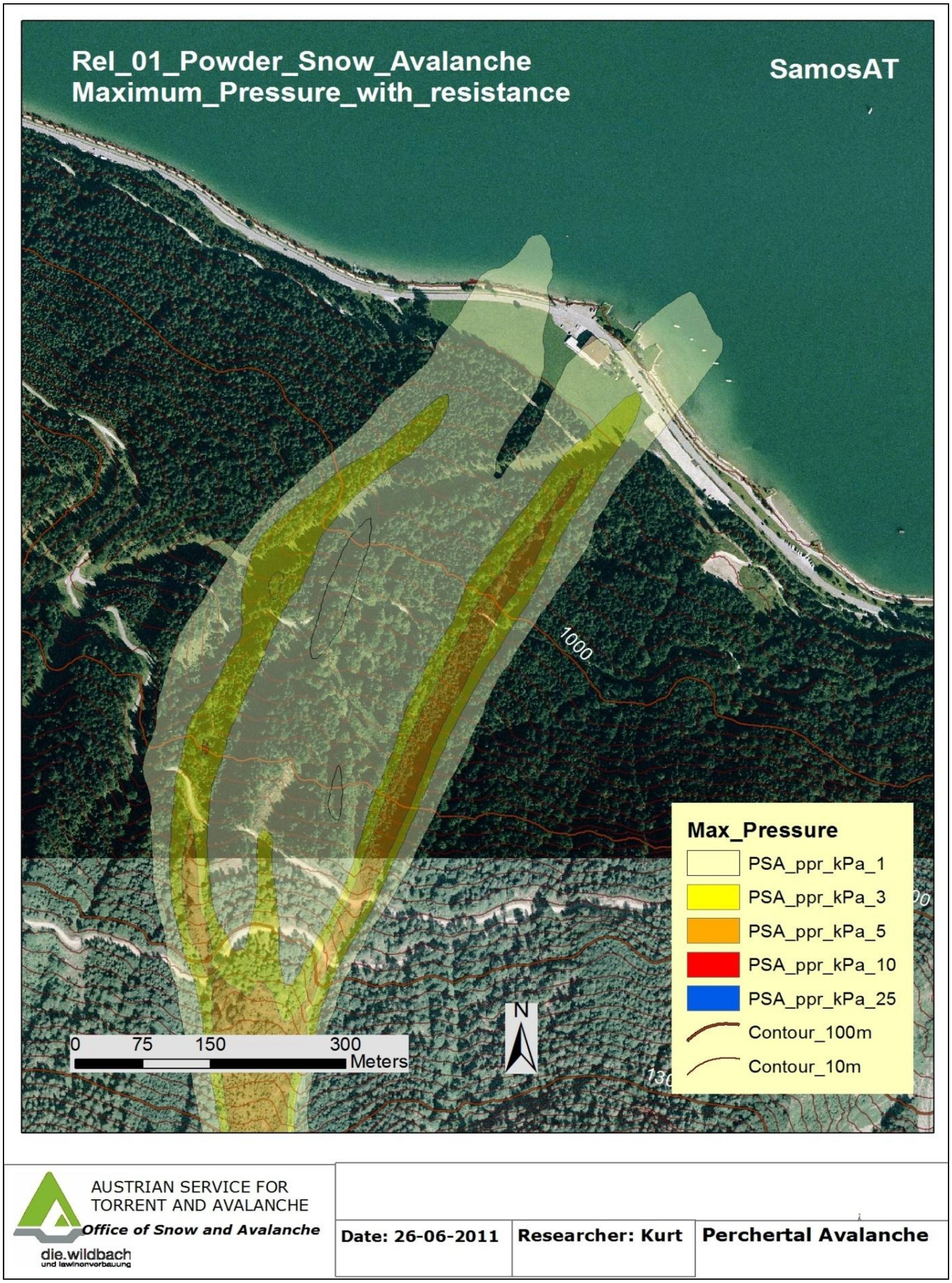

Figure 52. Maximum pressure for R1 with resistance as Psa with Samos AT model

4.1.3 Results from Ramms Model

Ramms is a type of numerical simulation model to calculate the motion of geophysical mass movements (snow avalanches, rockslides, debris flows, and shallow landslides) from initiation to run out in three-dimensional terrain (Christen et al. 2010).

Avalanche scenarios that might be created by R1, R2 and R3 were simulated separately using Ramms as a dense flow avalanche. Because we wanted to compare results to Samos AT dense flow simulation results. Maximum pressures, flow heights and velocities of avalanche flows were all calculated. It can be seen that; the dense flow avalanche results of Ramms model and Samos AT model are similar in that the most dangerous avalanche scenarios were created by R3. Results of Ramms model are presented in detail on the next pages.

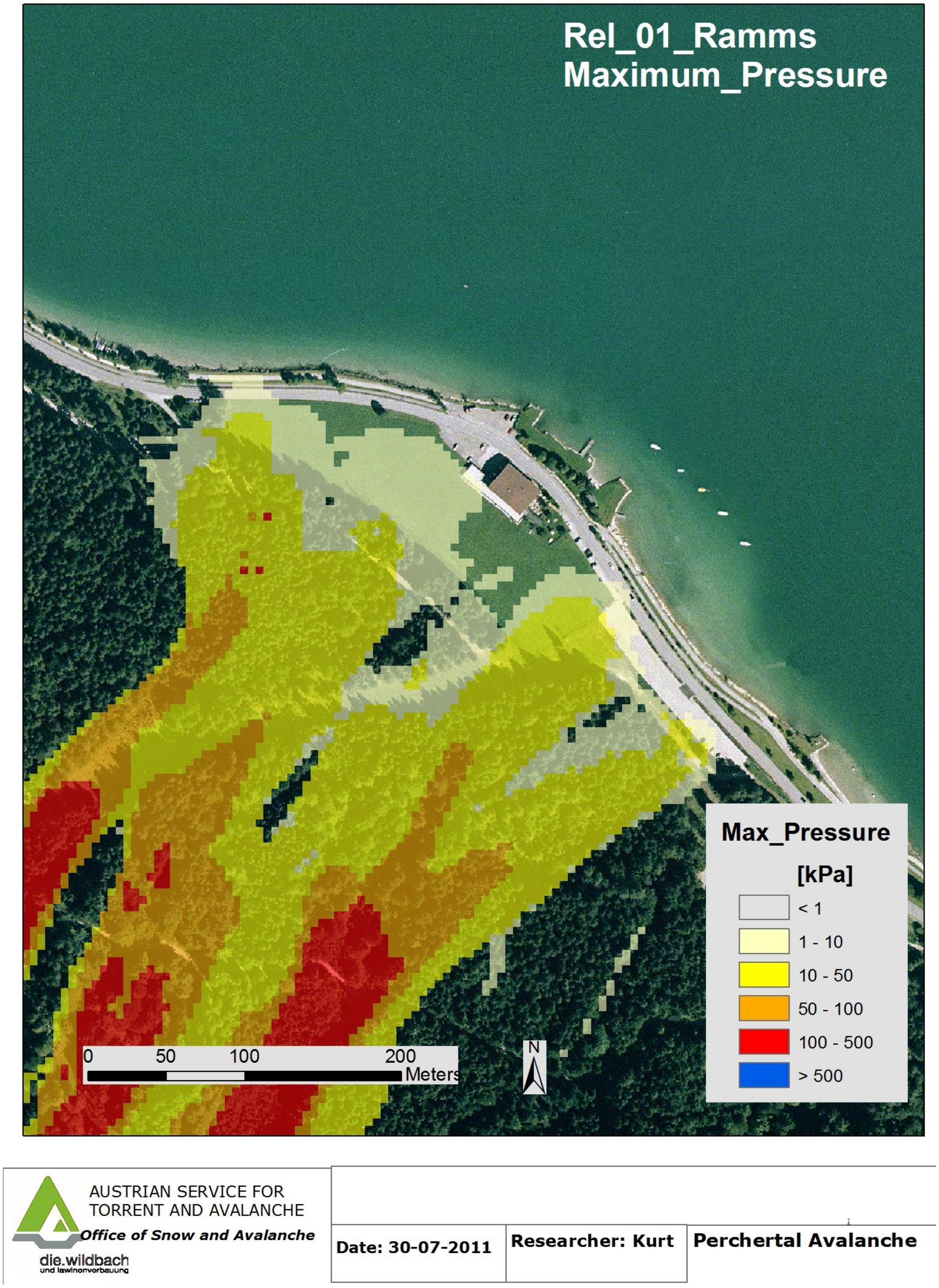

Figure 53. Maximum pressure for R1 with Ramms model

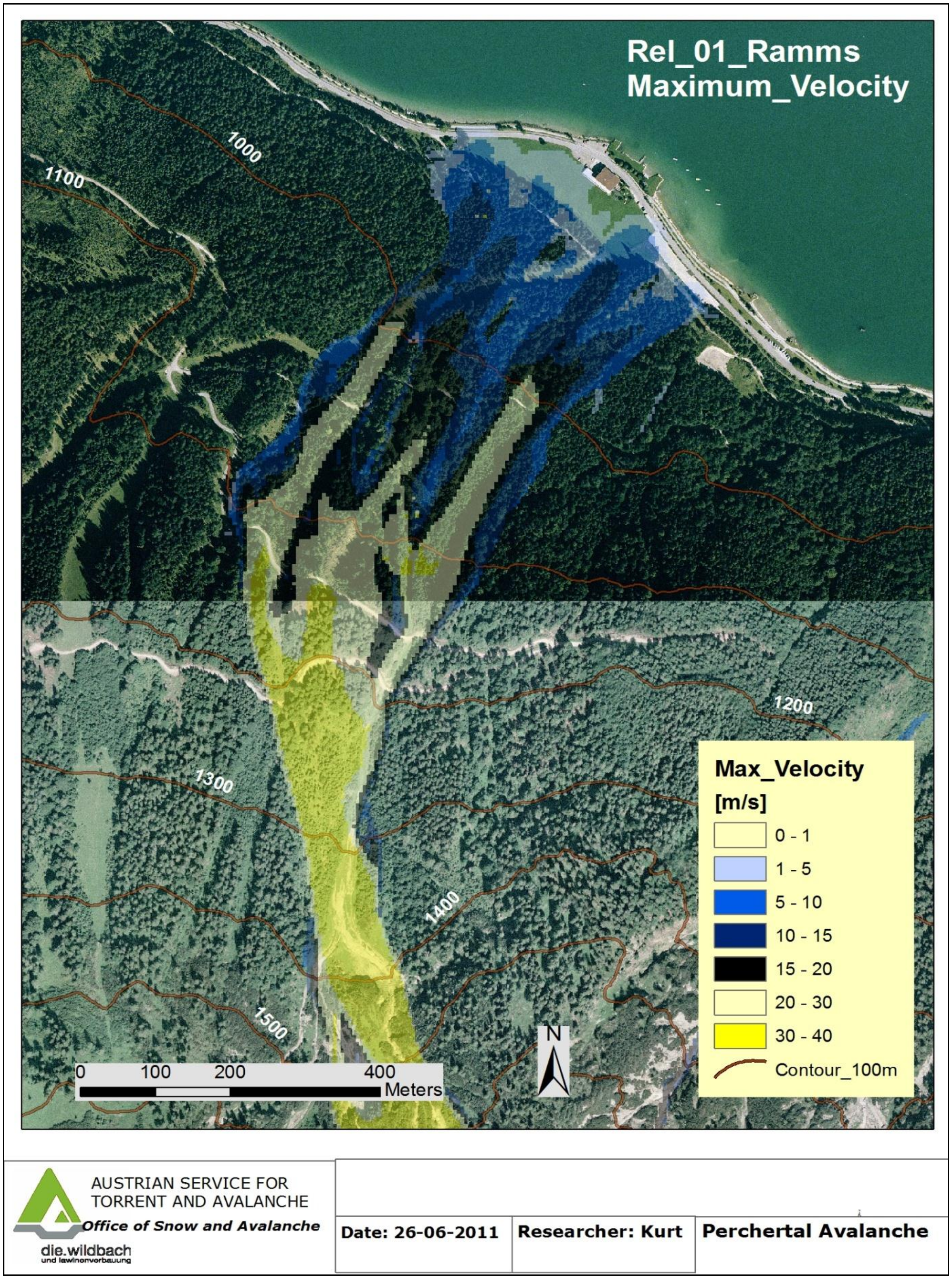

Figure 54. Maximum velocity for R1 with Ramms model

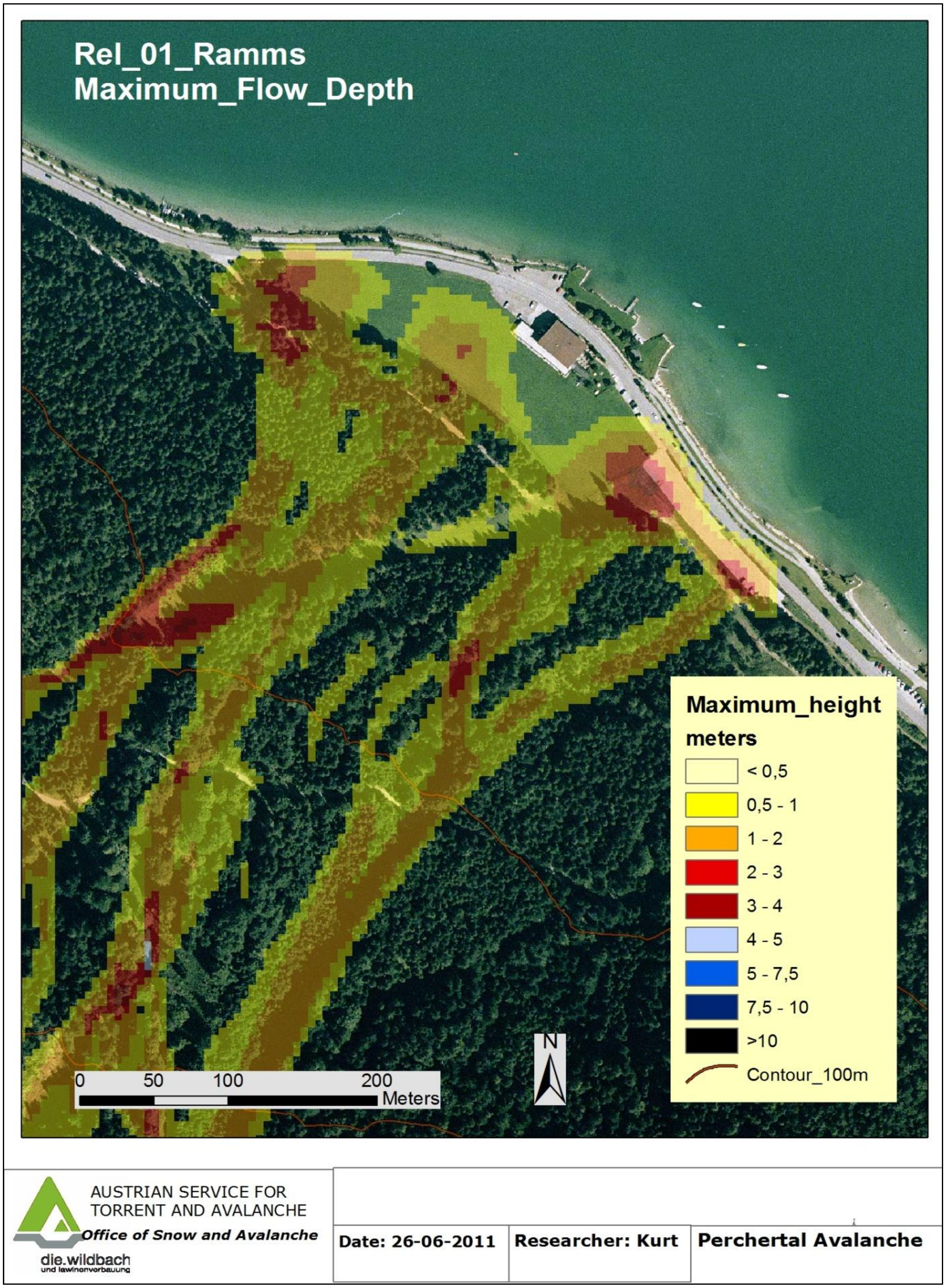

Figure 55. Maximum flow depth for R1 with Ramms model

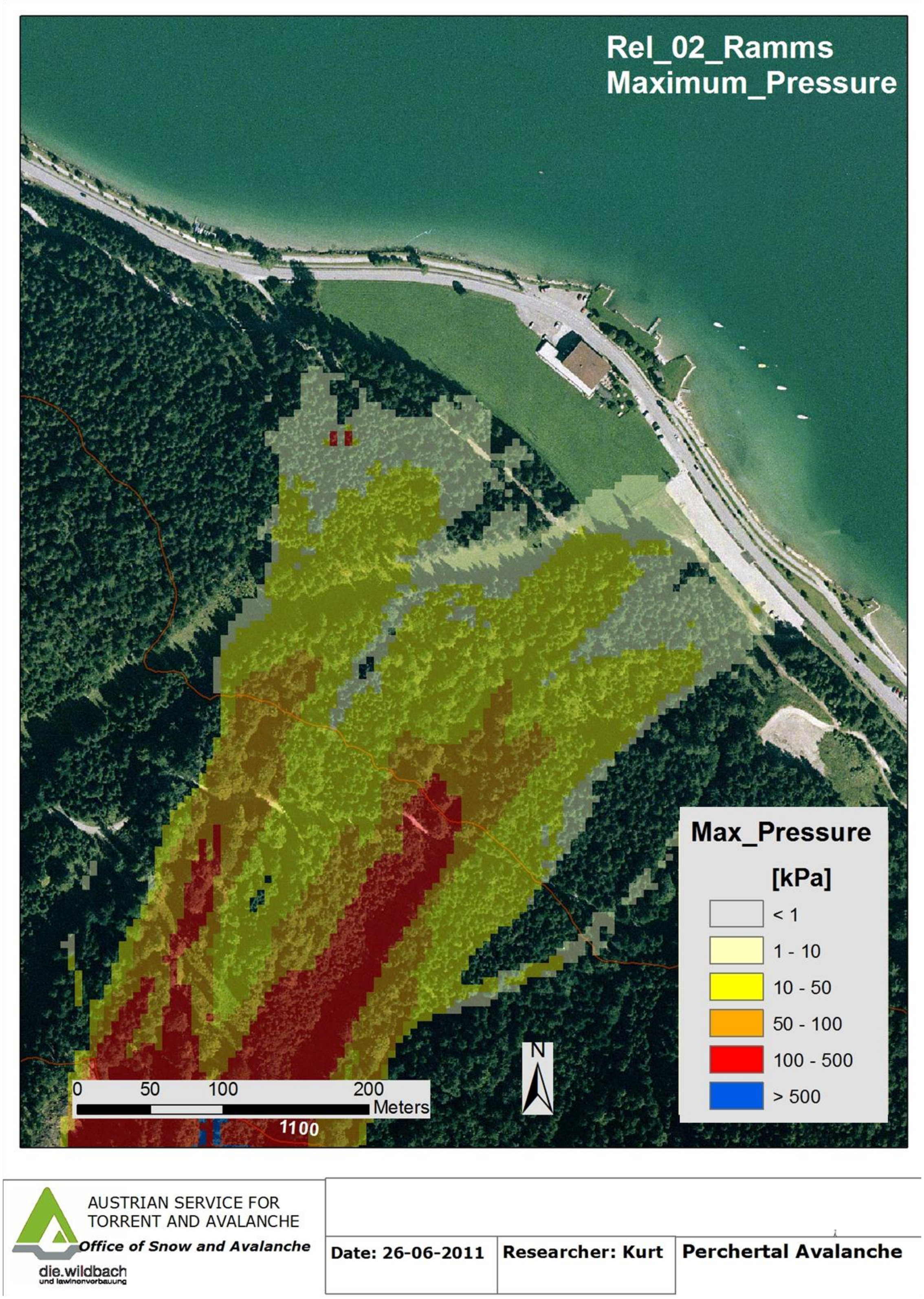

Figure 56. Maximum pressure for R2 with Ramms model

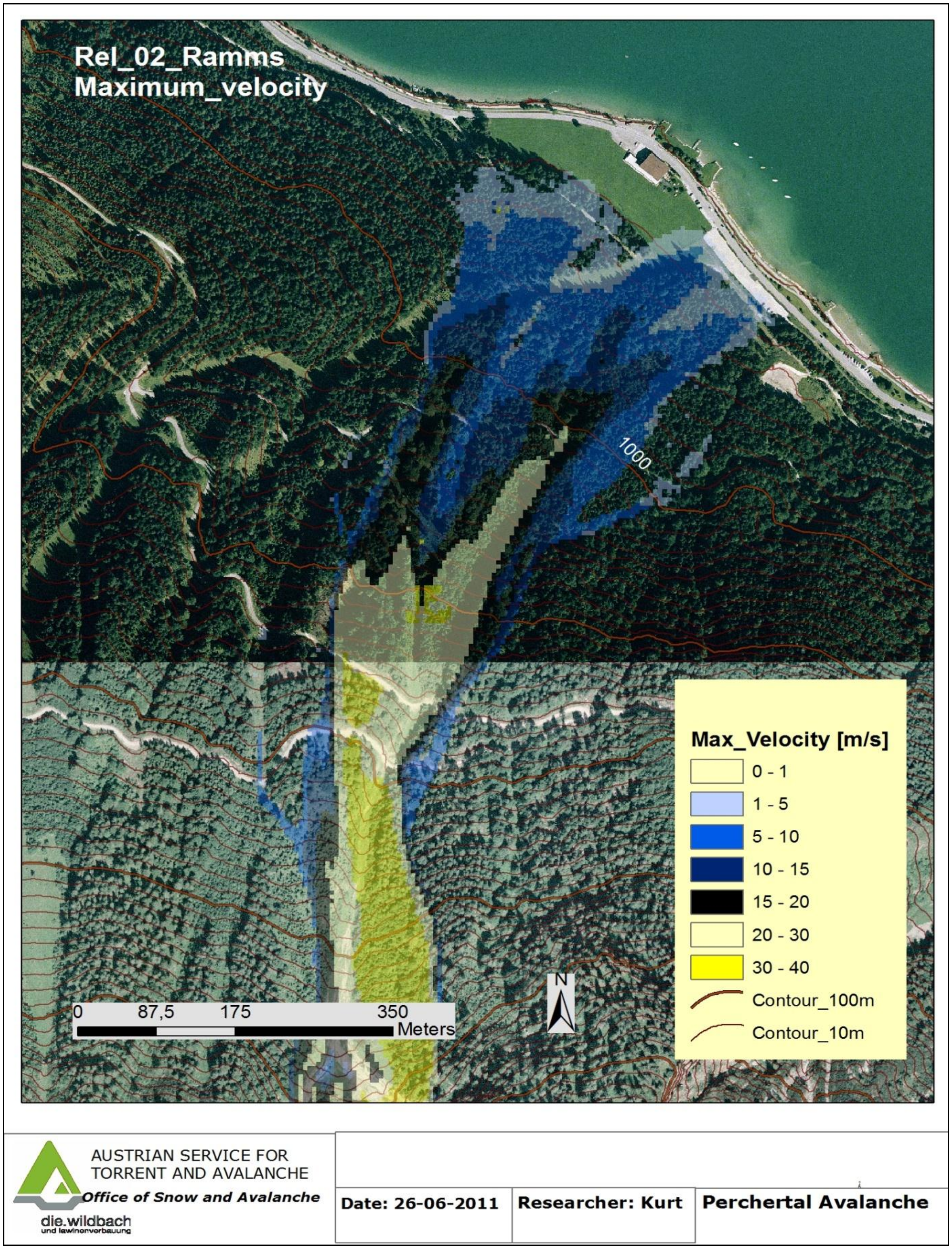

Figure 57. Maximum velocity for R2 with Ramms model

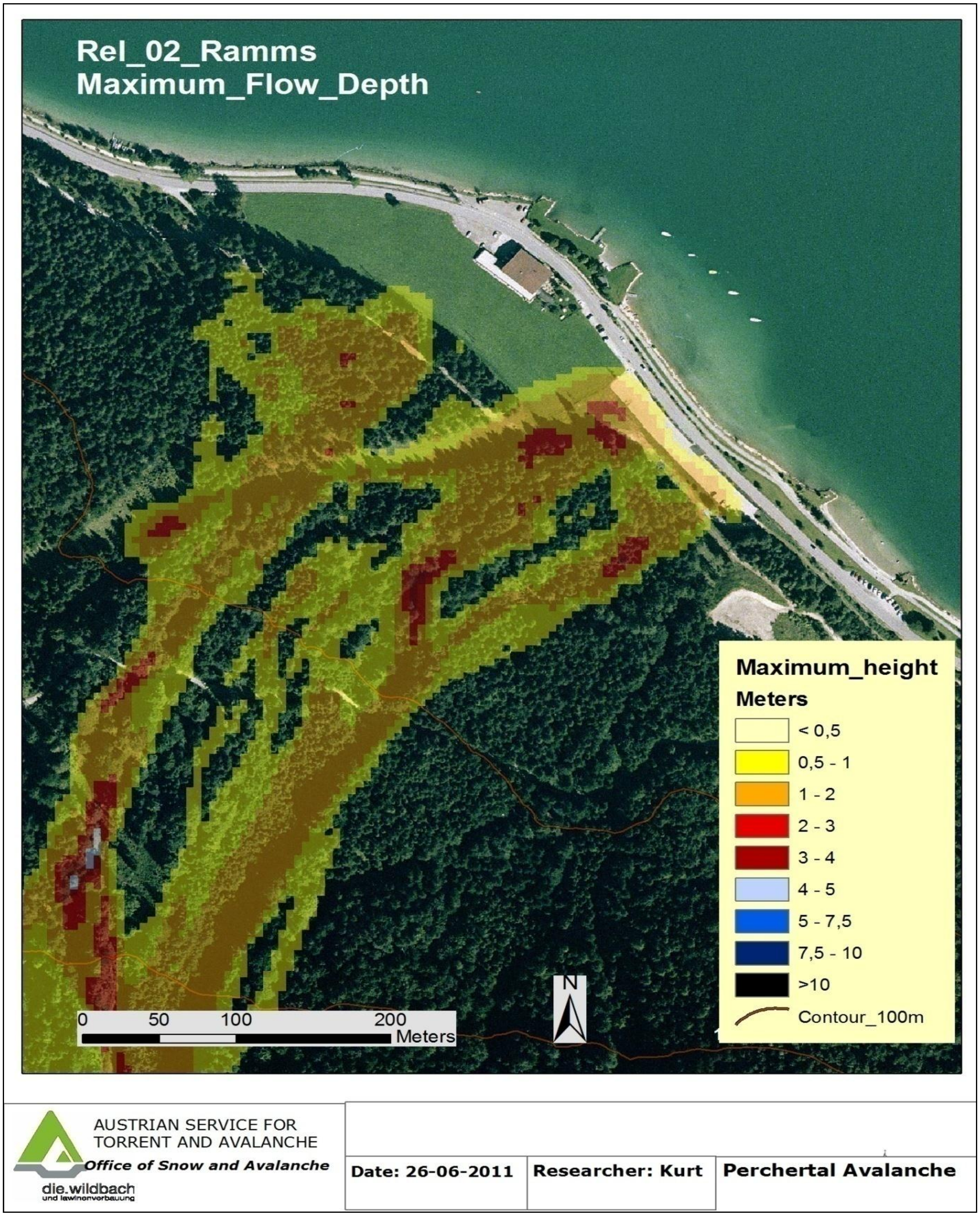

Figure 58. Maximum flow depth for R2 with Ramms model

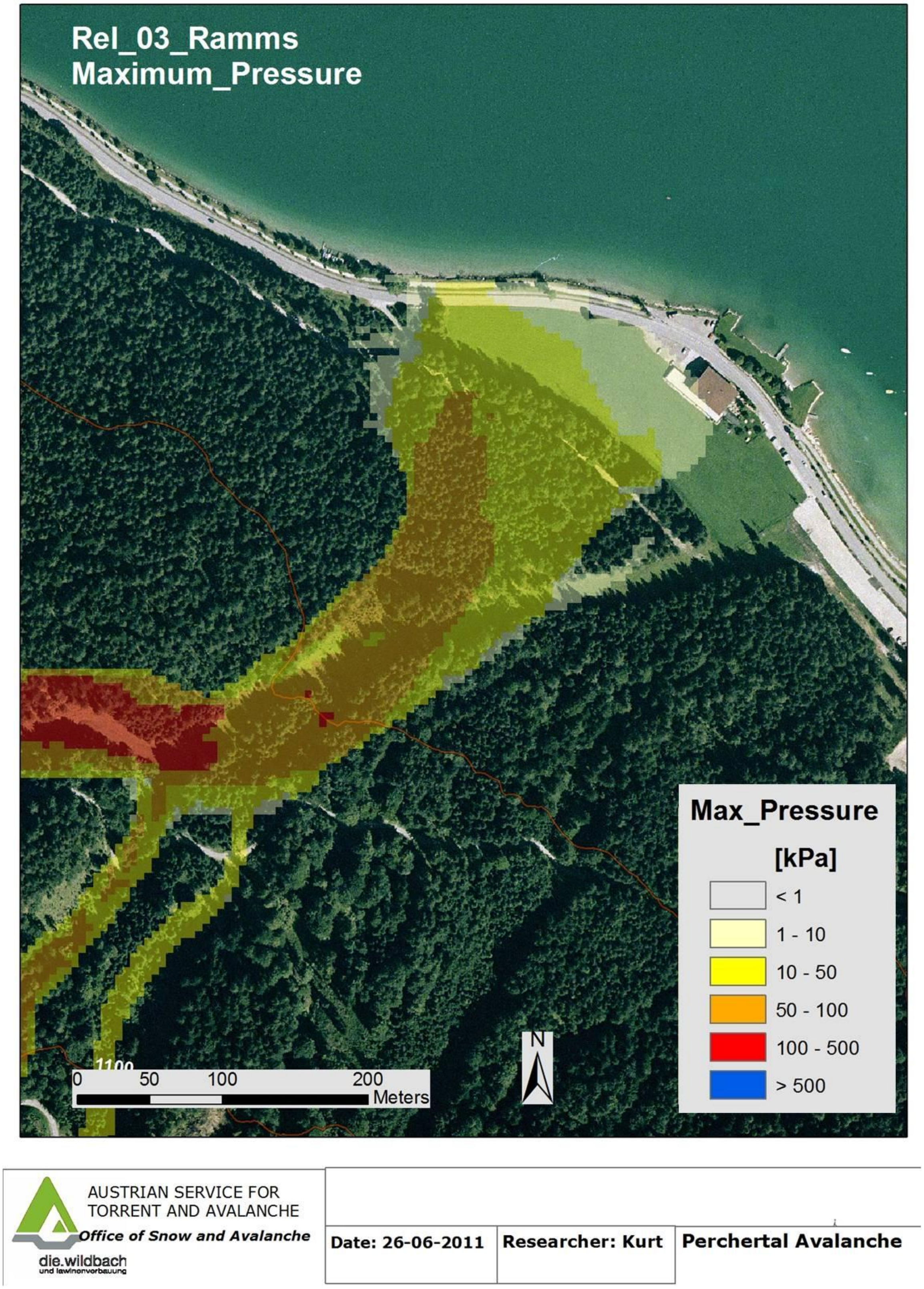

Figure 59. Maximum pressure for R3 with Ramms model

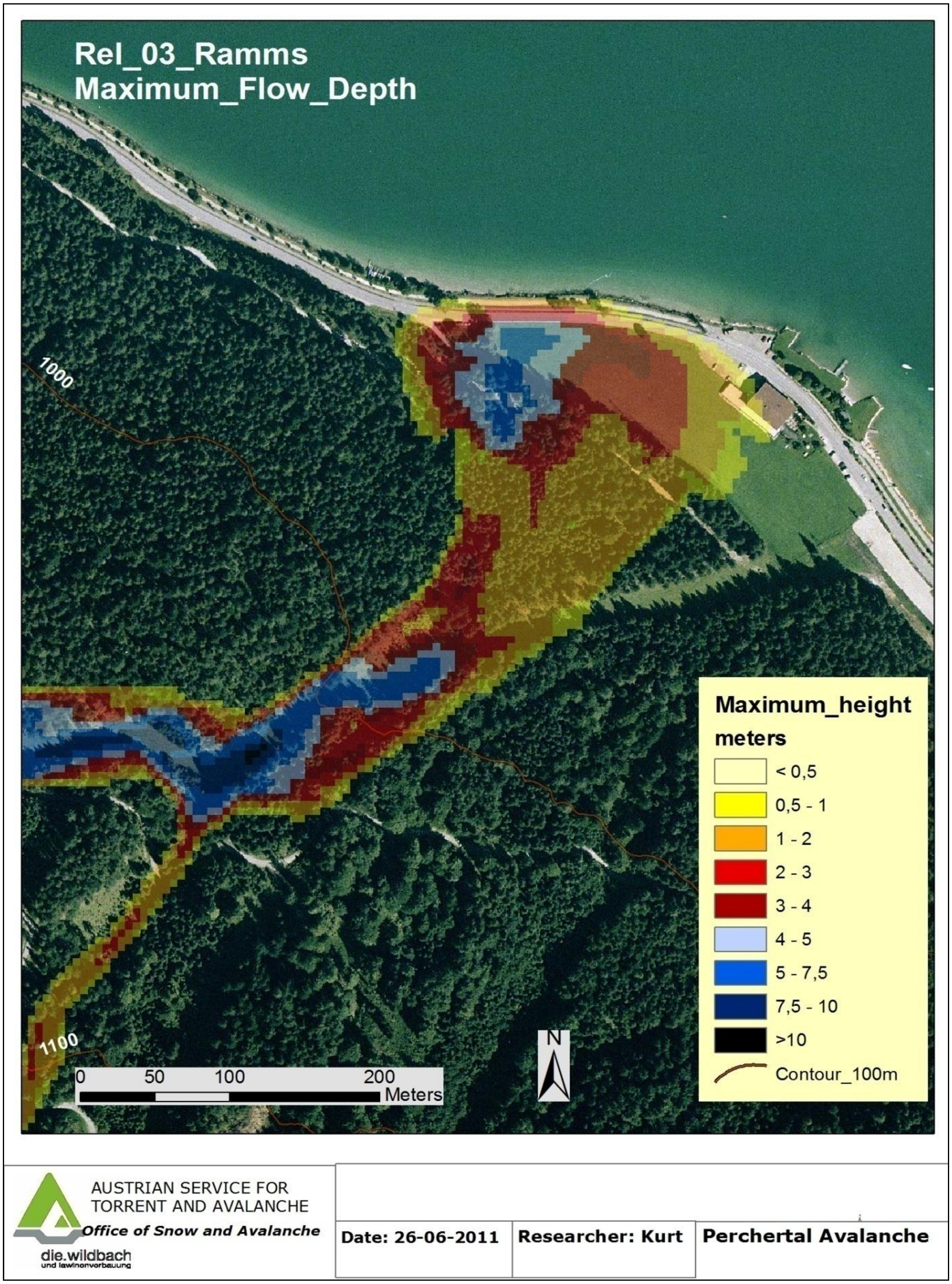

Figure 60. Maximum flow depth for R3 with Ramms model

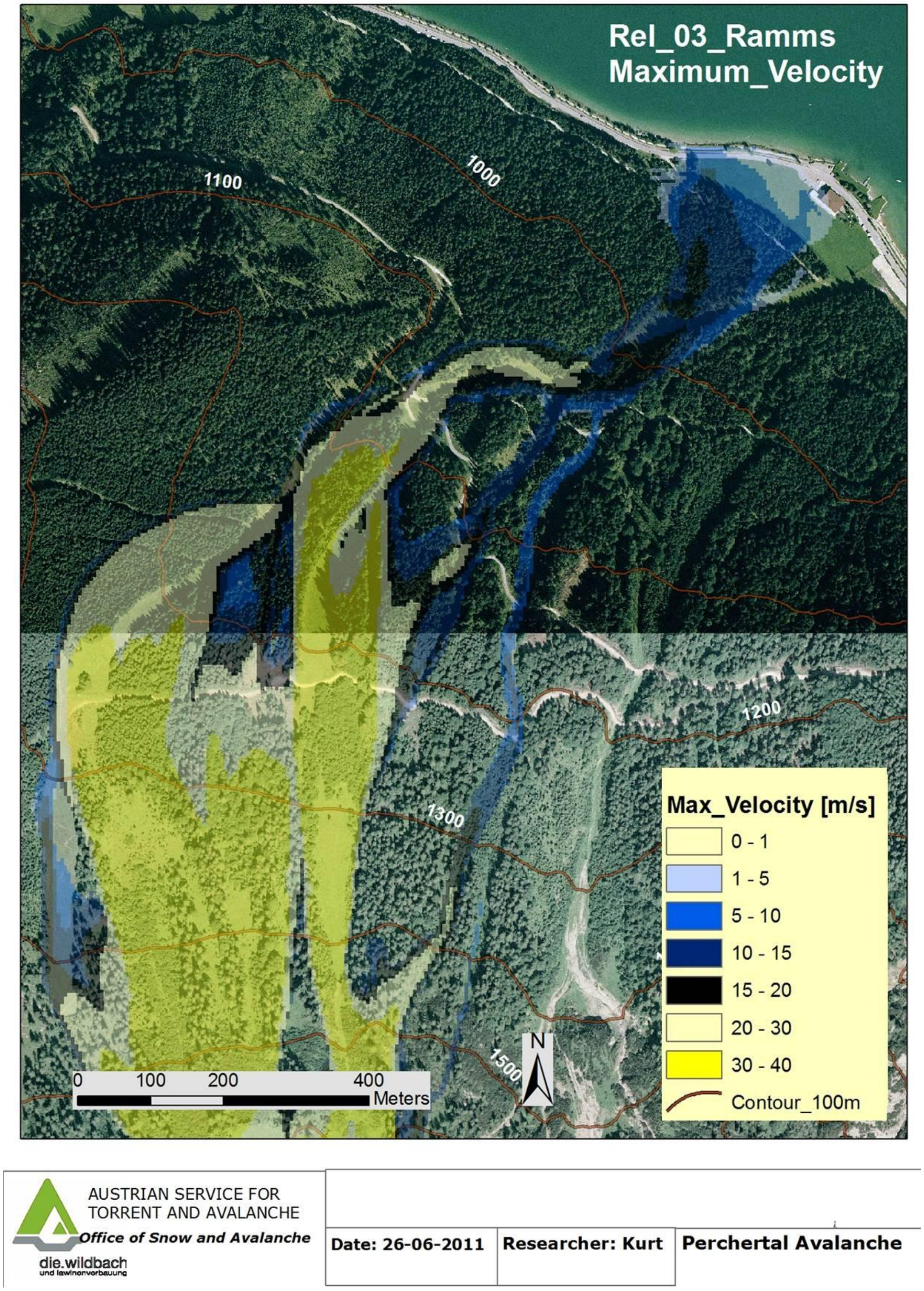

Figure 61. Maximum velocity for R1 with Ramms model

4.2 A NEW HAZARD MAP FOR THE OBSERVED AREA

A hazard map of the relevant zone was re-drawn based on simulation results and discussions with Mr. Plank. Two different avalanches (Perchertal and Ausmehler) play an important role on the new hazard map, such as in different starting zones and avalanche tracks than each others.

If the avalanche starts falling from the left side of the Bärenkopf Mountain (R3), it is the Ausmehler avalanche and it has different avalanche tracks than the Perchertal avalanche as roughly shown on Figure 62.

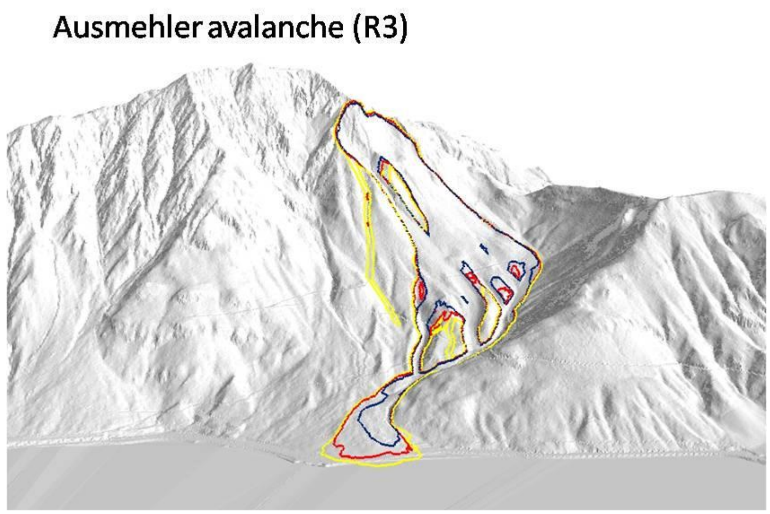

Figure 62. Overview of the Ausmehler avalanche scenario (Kurt, 2011)

On the other hand, if an avalanche starts from the right side of the Bärenkopf Mountain, it is known as the Perchertal avalanche as shown on Figure 63 and its tracks are different than Ausmehler avalanche.

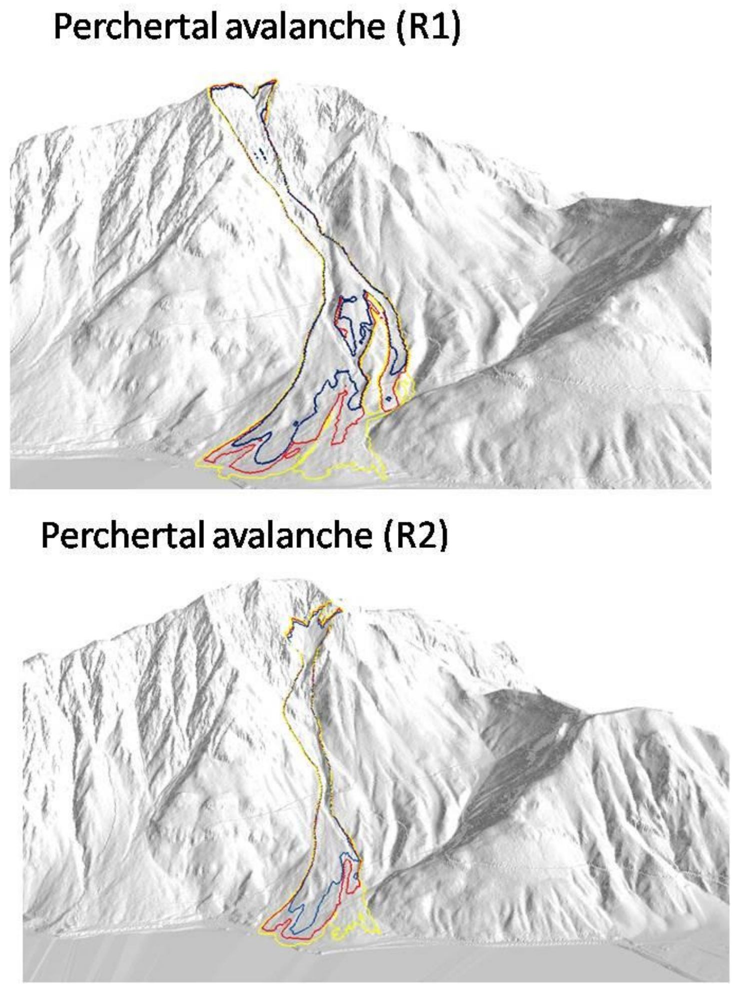

Figure 63. Overview of Perchertal avalanche scenarios (Kurt, 2011)

The new avalanche hazard map was drawn that takes these two different avalanches scenarios into consideration and is presented on the following page (Fig. 64). Differences between the previous hazard map and new hazard map can be clearly seen. The hotel and part of the main road that passes in front of hotel were located entirely in the red zone in previous hazard map (Fig. 29). However, according to the new hazard map, the hotel is located entirely in the yellow zone which covers a widespread area on the both ride and left side of the building.

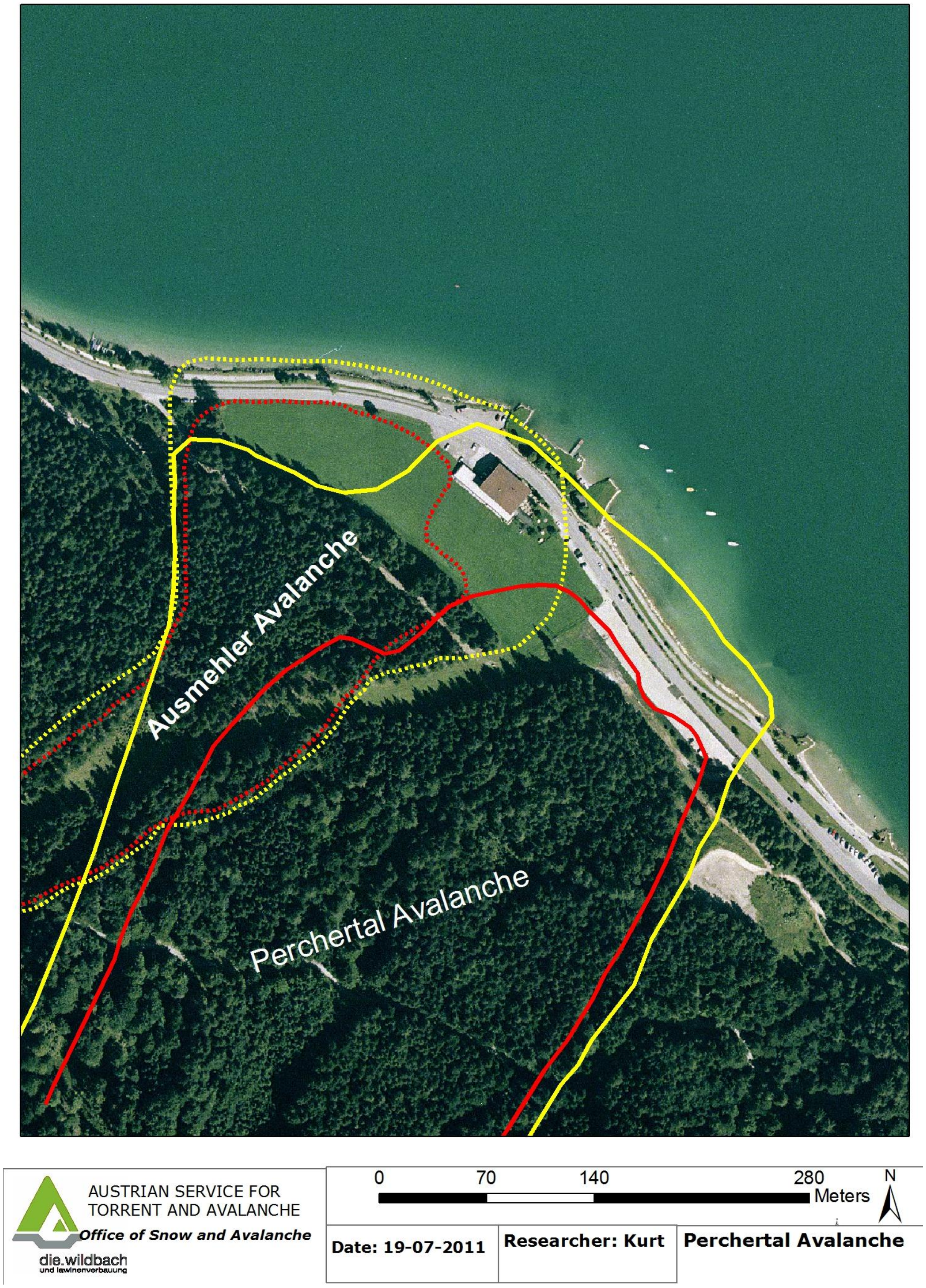

Figure 64. Actual hazard map for the area of investigation

4.3 DESIGNING THE AVALANCHE PROTECTON MEASURES

Forests are generally considered most effective factors against avalanches. However, their protective effect might not always be sufficient against avalanches, particularly in cases that help prevent avalanches before they stop spontaneously flowing. Therefore some additional protection structures can be used in the avalanche release zones such as wood or steel structures; or defensive structures in deposition zone may be used to ensure maximum safety of endangered objects. In other words, damages from the avalanches might be prevented by controlling them. However one point should be kept in mind; avalanche protection does not eliminate all risks (Mclung and Scharer, 2006).

In this investigation, protection measures were evaluated that take a hazard map of the relevant area and acceptable risks of the endangered hotel into consideration. Required information was presented in the previous sections as chronological events and hazard mapping. The hotel (which represents human lives) and the main road that passes in front of it were in danger due to avalanches that occur during winter. There are no avalanche control structures on both the release and deposition area except in the densely forested area; therefore, structures in both the release and the deposition area can be considered as options to cope with possible future damage caused by the avalanches.

4.3.1 Snow Bridges in the Release Zone

The aim of supporting structures is to prevent the start of avalanches or limit the snow motions that can be triggered by snow motions due to steep slopes in release zones (Amman and Fohn, 1999). In addition, these kinds of solutions provide the control measures and, in particular wooden supports to protect against gliding snow can reduce snow movement and let trees grow over the timber line (WLV, 2007).

Figure 65. Snow bridges at the release zone (Photo: Kurt, 2011)

Three big release zones of Bärenkopf Mountain are illustrated on the following pages in regards to the Perchertal and Ausmehler avalanche (Fig. 66). No avalanche control structures are on these three release zones. In order to prevent avalanches starting from R1, R2 and R3, snow bridges were planned and presented. More details are given on the next pages.

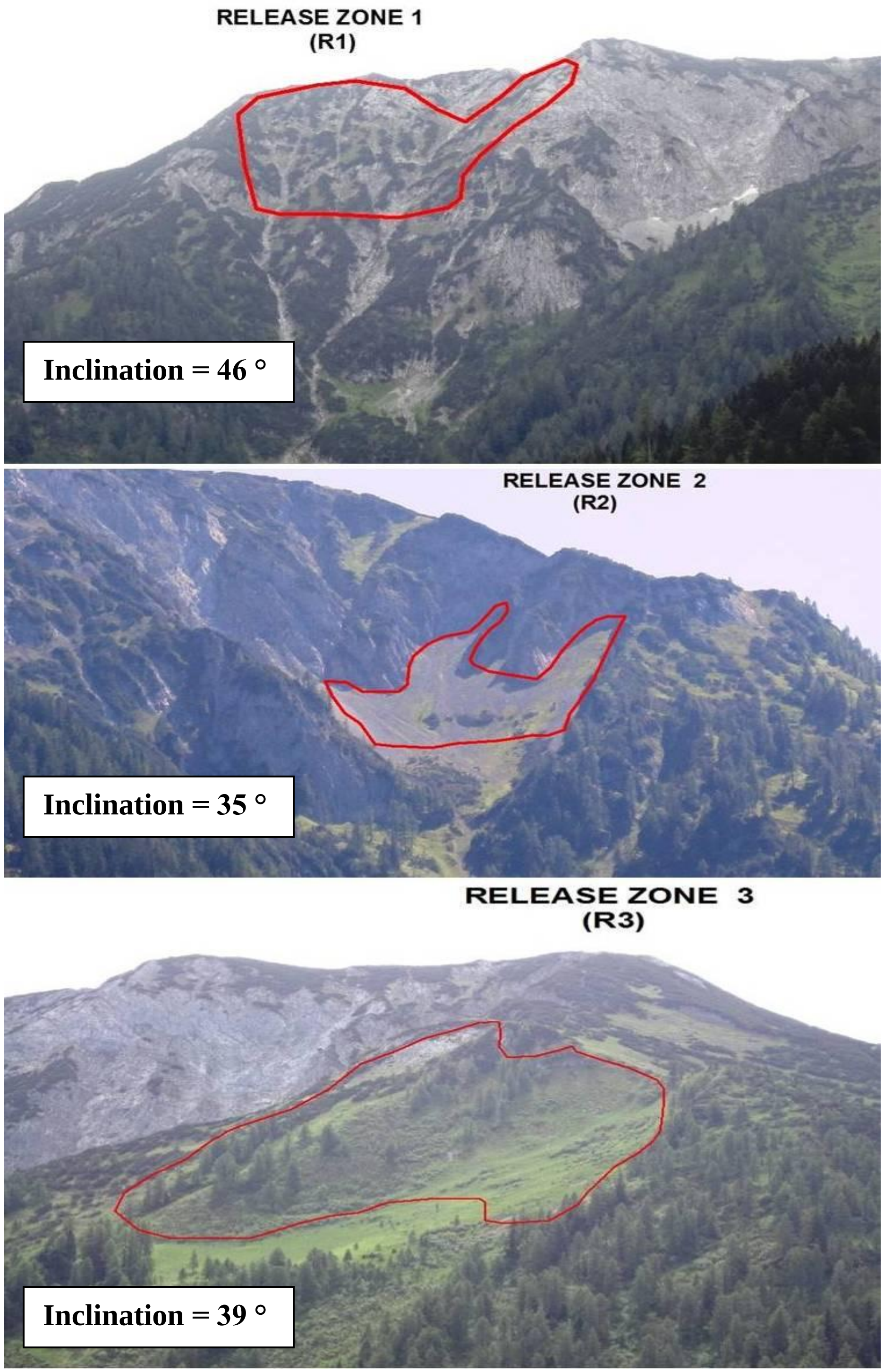

Figure 66. Overview of the R1, R2 and R3 (Photo: Kurt, 2011)

4.3.1.1 Calculations for Snow Bridges

4.3.1.1.1 Extreme Snow Height

The heights of the snow bridges were determined by a calculation table (Table 8). This calculation table is based on meteorological, topographical, and empirical parameters such as wind effect, snow accumulation, and inclination of the release zone (Leichtfried, 2010).

Table 8. Calculation of extreme snow height for R3 [Leichtfried, 2010]

Calculation of the Extreme Snow for Tyrol and Vorarlberg

Return period: 150 years

Input: Please enter data for the planned obstruction in green boxes

Caution: do not change red areas!

No. 1: Zone read out of the zone map
No. 2: Elevation of the proposed works (450m-3050m scope)
No. 3: Wind: blown = 1, no wind effect = 2, blown in=3, blown extreme = 4
No. 4: Exposure: Select average slope direction, the exposure value from the right table
No. 5: Region: Right from the Region list select
No. 6: Slope in degrees

Nr.	Factor	Input	Selection
1	Zone	4	[1-5]
2	Elevation	1830	[m]
3	Wind	3	[1-4]
4	Exposition	1	[1-8]
5	Region	4	[1-13]
6	Slope	39	[°]

Region List	
Region	Nr.
Arlberg	1
Ausserfern	2
Bregenzer Wald	3
Inntal/Mitte & Ost	4
Inntal/West	5
Montafon	6
Osttirol Ost	7
Osttirol Südwest	8
Ötztaler Alpen	9
Silvretta	10
Kitzbühler Alpen	11
Zillertaler Alpen	12
Sonstige	13

Exposure Table	
Exposition	Value
North	1
Northeast	2
East	3
Southeast	4
South	5
Soutwest	6
West	7
Northwest	8

Extreme Snow Depth from Zone Map:	509 cm	150-Year Event, Total Snow Depth:	
Wind correction filter:	36 cm	Wind Correction:	7%
Correction filter height level:	0 cm	Altitude correction:	0%
Correction filter region:	-1 cm	Region-correction:	0%
Exposure correction filter:	26 cm	Exposure Compensation:	5%
Total corrections by filtering:	**61** cm	**Total corrections:**	**12%**
Extreme Snow Depth with correction filter	570 cm	150-year event, corr. Total snow height	
Recommended Structure Height	443 cm	150-year event, snow thickness	

For each release zone, parameters were written separately into to the calculation table (green zone) depending on climatic and topographic conditions of each release zone.

For example, zone factor is 4 in green input zone due to an area map of the extreme snow heights for Tyrol, Achensee (Fig. 67). In addition, mean elevation of the release zone is 1830 m and inclination (rounded) of release zone 3 is 39°.

Concepts of calculations of maximum snow height and extreme snow height were based on the formula as shown below (Jóhannesson, 2009).

$$H_{ext} = H_{max} \frac{\overline{H}_{ext}}{\overline{H}_{max}}$$

H_{max} = Maximum snow height (maximum snow height during the winter at a particular point).

$\overline{H}_{max}$ = Maximum snow height averaged over the area (average of the maximum snow heights).

$\overline{H}_{ext}$ = Extreme snow height averaged over the area (average of the extreme snow heights).

The required measurement series were taken from the Pertisau weather station. Large-scale distribution of the area averages of the extreme snow heights was used as a parameter for the calculation table to determine extreme snow heights for each release zone (Fig. 63).

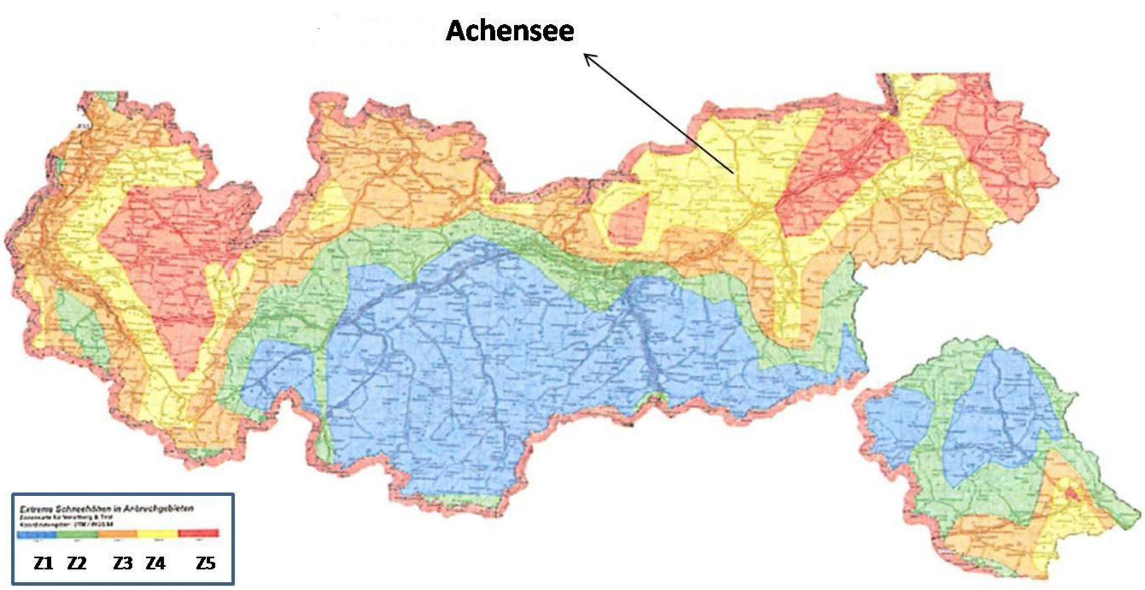

Figure 67. Area of the extreme snow heights for Tyrol (Leichtfried, 2010)
According to an area map of the extreme snow heights for Tyrol, and Achense is located in zone 4.

Obtained calculations indicated that the minimum construction height should be 4,81 meters (Table 9).

Table 9. Recommended height of snow bridges

Release area	**Altitude (m)**	**Extreme snow height $\bar{H}_{ext}$ (in cm)**	**Recommended structure height (in cm)**
R1	1975	553	438
R2	1865	520	481
R3	1830	509	443

4.3.1.1.2 Distance between Structures

The distances between the steel snow bridges were calculated using a figure provided by the Austrian Standards Institute (Fig. 68).

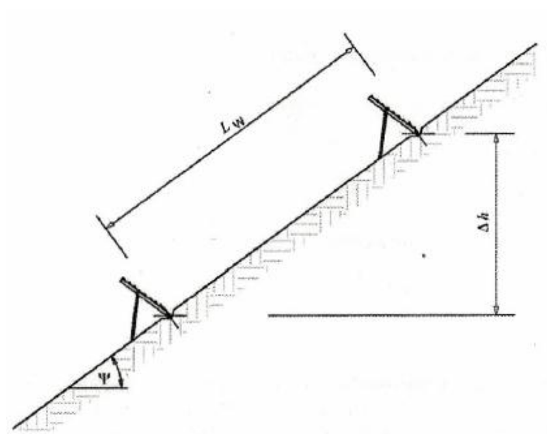

Figure 68. Overview to the row distances the plan view (ONR, 24806)

The diagram shown below consists of a component of inclinations of the releases zones and ΔH (distance factor depending on ground surface condition of release area).

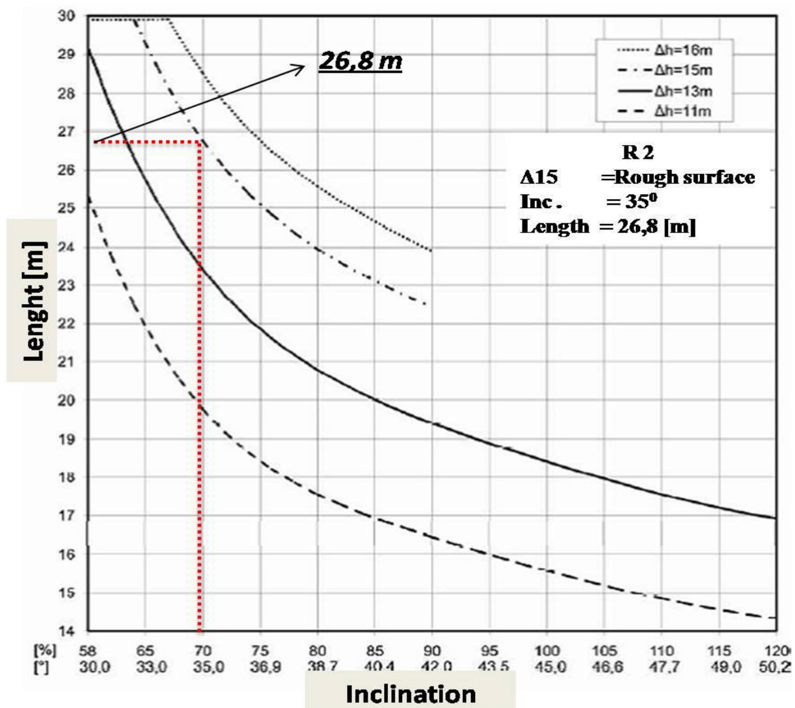

Figure 69. Fixed distances of snow bridges according to inclination and ground surface conditions (ONR, 24806)
The lowest rows of snow bridges should be installed up to the point where the inclination is definitely under 30

Determination of ΔH parameters generally depends on the ground surface of the relevant release zone and the type of protection measure planned (Table 10).

Table 10. Determination ΔH parameters (distance factors according to the ground surface condition of release areas)

ΔH=16 meters	Value to ensure maximum level of safety
ΔH=15 meters	In cases of rough ground surface for the release zone
ΔH=13meters	In cases of smooth ground surface for release zone
ΔH=11 meters	In cases of a decision to build a wooden structure

ΔH factor chosen of each release zone for this investigation are in the following page.

- ΔH values of R1 and R2 were considered 15 meters due to the rough ground surface (with *Pinus mugo*).
- ΔH value of R3 was considered 13 meters due to the smooth ground surface.

The calculation of the rows distances of snow bridges were performed based on the calculation steps shown below:

An example to calculations for R2

ΔH=15 meters (rough ground of R2)

Mean inclination= 35^0= %70

Distance between rows= Lw= 26,8 [m]

Distance between structures in plan view = Δh => Cos 35* 26,8= 21,95 [m]

100 m/ 21,87 m =4,56 m. => 10% less => 4,10 [m]

Leaving space between rows of snow bridges sometimes is essential due to large rocks or other obstructions. Therefore, required value was minimized to 10% less for calculations as mentioned above.

410 m * 3,07 (Total area of R3)=**1230** [m]

This mean that 2130 meters of steel snow bridges are required for whole R2.

The height of snow bridges was defined as 4,81 meters based on calculations. More detailed information is shown below.

Table 11. Calculated distances between snow bridges

Release Zone	Structure height H_K [m]	Inclination (rounded)	Distance between rows [in m]	Distance between structures in plan view [in m]
R1	4.38	46°	21,2	14,7
R2	4.81	35°	26.8	21.87
R3	4.43	39°	20.8	16.9

4.3.1.1.3 Type of Anchoers

Foundations may consist of anchors, micro piles, prefabricated foundations (ground plates) or concrete foundations for permanent supporting structures in loose ground (Johannesson et al. 2009). In general, two separate foundations are used: an upper and a lower foundation. On the upper part, a ground anchor and micro piles are planned while on the lower part, a ground plate is often used in transporting the stress to the ground (Johannesson et al. 2009). Micro piles are relatively short, drilled, load-bearing elements of small diameter that are usually subject to compressive loading (Fig. 70). A field trip was organized by Mr. Granig on 15/06/2011 to gain experiences with respect to construction side of snow bridges.

Figure 70. Compressive loading for an anchor (Photo: Kurt, 2011)

To determinate the size of ground plate, R1 and R2 soil properties were assumed, therefore, the soil type was rocky thus ground plate sizes should be 40 x 40 cm. R3 soil property was assumed as loose soil, thus ground plate size should be 60 x 60 cm.

Table 12. Determination of ground plate sizes of snow bridges [Sauermoser, 2010]

Ground Plate Size	Soil Property
40 x 40 cm	Soil with rocks
60 x 60 cm	Loose soil
80 x 80 cm	Very loose soil

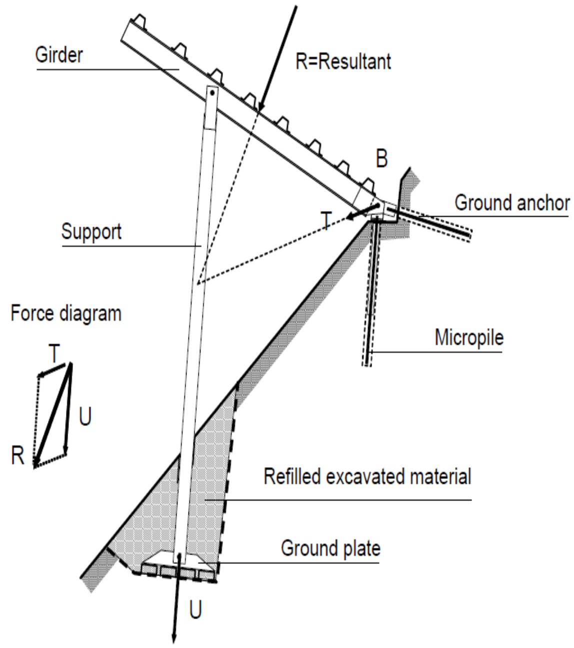

Figure 71. Components of a steel snow bridge (Margreth, 2007)

4.3.2 Defensive Structures in the Avalanche Run Out Zone

Some types of defensive structures on the deposition area were evaluated as solution to protecting the hotel against future avalanches as defensive structures can divert avalanches away from the hotel or cause them to stop before reaching the hotel (Jóhannesson at al., 2009). But the design of protective measures in the run-out zones needs to be based on an understanding of the dynamics of granular flows against obstructions (Jóhannesson, 2009). Therefore, in the field with Mr. Granig, Mr. Tollinger and Mr. Hochreiter on 14.07.2011, the feasibility of avalanches was assessed by comparing topographic situations with simulation results.

Two types of defence structures were considered for the deposition area (deflecting and catching dam).

4.3.2.1 Deflecting Dam

Deflecting dams can be used to divert avalanches away from objects at risk (Jóhannesson et al. 2009): therefore it was assumed one of the alternative solutions for this investigation as there was enough space to divert avalanches away from the hotel on both left and right side. In addition, there is not much traffic most days on the road in front of the hotel. A deflecting dam was designed on the deposition area to prevent damages from both the Perchertal and Ausmehler avalanches, taking into account the avalanche velocities and flow depths as well as deflecting angle of avalanche flow. According to principles of designing deflecting dam, maximum deflecting angle should be 20^0 (Jóhannesson et al. 2009). After discussions with Mr. Plank, suitable location for deflecting dam was determinated and its dimensions were presented (Figs.72 and 73).

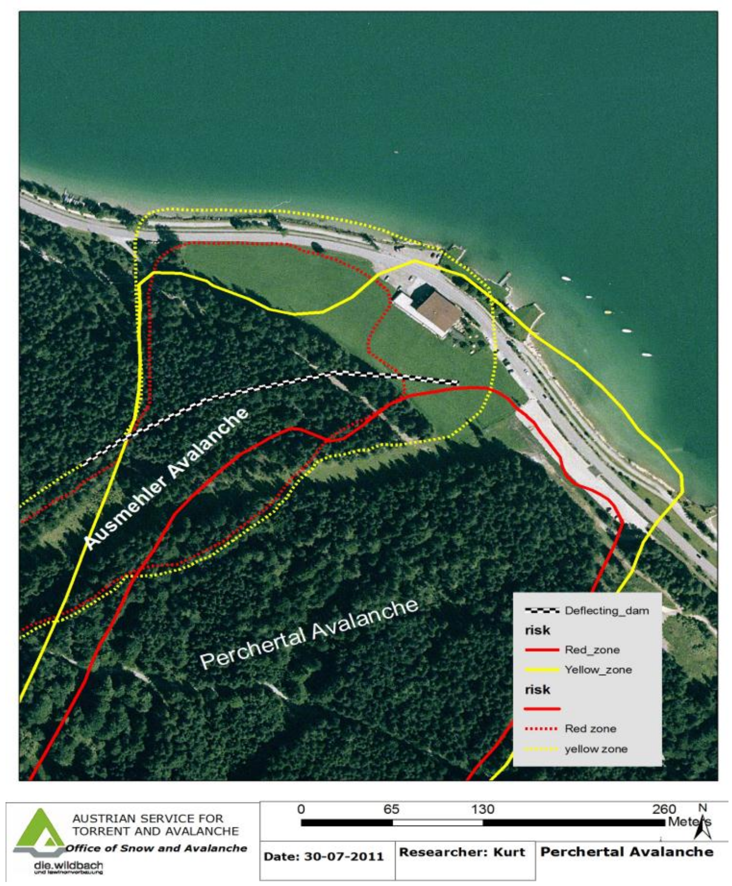

Figure 72. Proposed location of deflecting dam

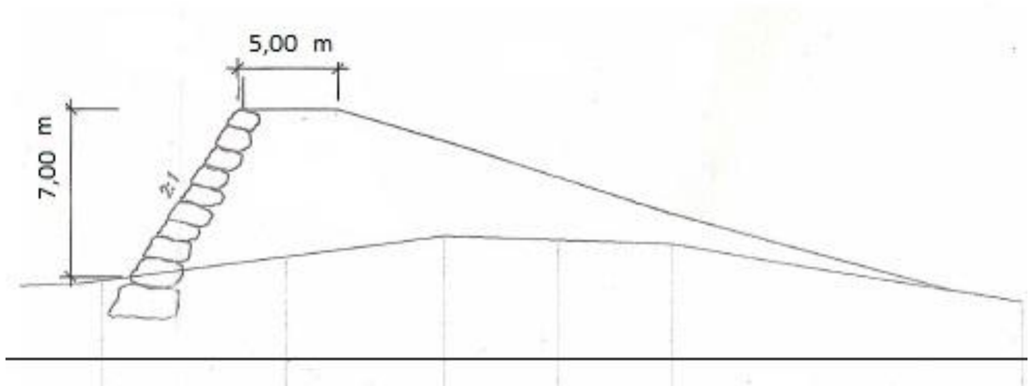

Figure 73 Profile of planned deflecting dam

Principles for calculating the design and dimensions of the dam are as follows (Jóhannesson, 2009):

HD = h_u +h_f +h_s ,

HD= Height of the deflection dam

h_u = Required height of the dam depending on the avalanche velocity of and deflection of flow angle. The equilibrium shown below was used to determine the *Hu for deflection dams.*

$$h_u = \frac{(u \sin \varphi)^2}{2g\lambda}$$

u= Velocity of flowing avalanche [m/s] **15 [m/s]**

g = Gravitational acceleration [m/s] **9, 81 [m/s]**

λ=Neglecting momentum loss **1**

φ = Deflecting angle [°] **20 [°]**

h_u = **1,34 m.**

h_f= Flowing depth of avalanche **2 m**

h_s = Thickness of snow **(1,58 m)** and previous avalanche ground deposits on the upstream side of the dam prior to the avalanche release **(2 m)**.

HD=.Recommended height of deflecting dam **7 m**

Total volume= 51.300 m^3

Length of dam= **285 m**

4.3.2.2 Catching Dam

If the hotel and part of the main road need to be protected against avalanches with a permanent protection measure in the deposition zone, a catching dam may be another solution. Catching dams are intended to stop avalanches before they reach objects at risk (Jóhannesson, 2009). However, according to calculations, the price of building a catching dam is much higher than the price of building a deflecting dam due to the necessary distance and height of the catching dam. A proposed location for the catching dam is presented in Figure 74.

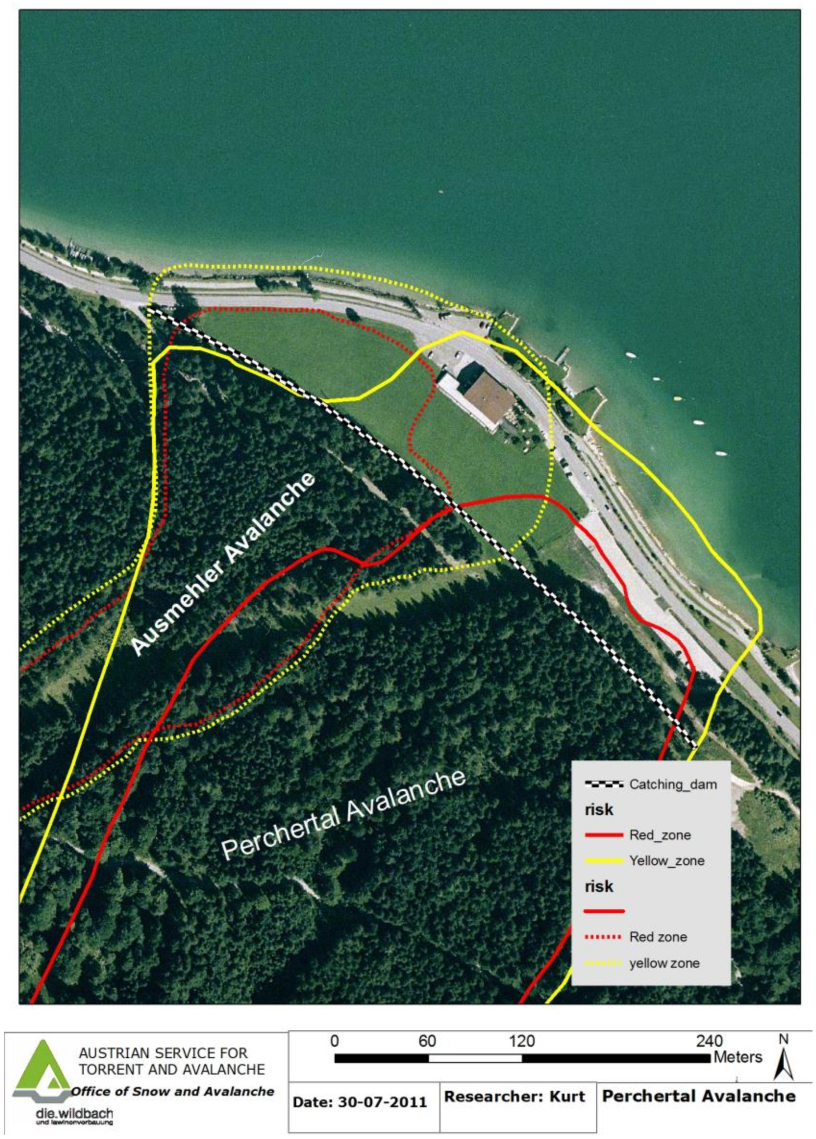

Figure 74. Location of proposed catching dam

Principles for calculating the design and dimensions of the catching dam are as follows (Jóhannesson, 2009):

HD = hu+hf +hs ,

HD= Height of the catching dam

hu = The required height of the dam depends on velocity of the avalanche and its deflection angle. The equilibrium shown below is used to find *Hu for* the catching dam.

$$hu = \frac{u^2}{2g\lambda}$$

u= Velocity of flowing avalanche [m/s] **10[m/s]**

Velocity value for deflecting dam was assumed as 15 [m/s]. Because, half section of the deflecting dam was planned over higher altitude than location of catching dam. This means that some part of the deflecting dams is able to get effected by avalanche flow which has higher velocity value (Figs. 32 and 50). Therefore, velocity value of deflecting dams was assumed 15 [m/s]. And according to Samos AT (velocity of dense flow results), proposed location of catching dam can be affected by an avalanche flow that its velocity is 10[m/s].

g =Gravitational acceleration [m/s] **9, 81 [m/s]**

λ=Neglecting momentum loss **1**

φ=Deflecting angle [°] **90 [°]**

hu = **5,1 m**

hf= Flowing depth of avalanche **2 m**

hs = Thickness of snow **(1,58 m)** and previous avalanche ground deposits on the upstream side of the dam prior to the avalanche release **(2 m)**.

HD=.Recommended height of the catching dam **11 m**

Total Volume: 117.400 m^3

Length of Dam =435 m

4.3.3 Avalanche Control with Explosives

Blasting mast is a type of temporary avalanche measure. Creating an artificial avalanche by using a blasting mast system was thought to release the Perchertal and Ausmehler avalanche under controlled conditions as the use of explosives frequently triggers smaller, less destructive avalanches. This technique involves the triggering of explosives by detonating charges above the snow surface. Remote controlled installations are placed in specific locations that generate an air blast above the snow pack in an avalanche starting zone (Fig. 75).

Figure 75. Blasting Masts (Photo: Unknown)

Distributions of planned avalanche-blasting masts are as follows:

- **1** piece of avalanche blasting mast on the R1
- **2** pieces of avalanche blasting mast on the R2
- **3** pieces of avalanche blasting mast on the R3.

4.4 COST AND BENEFIT ANALYSIS

Cost and benefit analysis (CBA) is a type of economic decision making approach that is generally used to determinate the most economical solution and eliminate risks (Thöni, 2010). For example, costs vary between each of the four protection measures evaluated in this investigation. To determine which one is more financially advantageous, a cost and benefit analysis is necessary.

The cost and benefit analysis was performed with a calculation table provided by Lebensministerium. In order to use this table, some parameters in regards to the endangered objects were required and written into calculation table. This was achieved with the support of Mr. Hochreiter who helped to input and obtain essential factors such as a cost and benefit ratio (CBR).

CBR values were obtained from the CBA calculation table and presented to compare alternative mitigation measures separately to find out most economical solution. In other words, the CBR can be defined as desiccation CBA value to find the best solution to the relevant problem. For example, the CBR value of deflecting dam is 2,25 and the CBR value of a catching dam is 0,86 based on calculations (Table 17). In this case, building a deflecting dam seems more advantageous due to its high CBR value. Hence, it can be recommended.

Some information shown below was used to determinate, economic value of the endangered objects:

- Two buildings; the hotel and an apartment near it for workers to stay overnights if there is damage from an avalanche.
- The Hotel can host 50 tourists each night and the rooms cost 35 € per person.
- The part of the main road that passes in front of the hotel may be buried under the avalanche. The endangered part of the main road is 500 m long, 6 m wide. If the main road is buried under the avalanche, it will take two days to reopen.

- There is a valuable forested area that could be damaged because of an avalanche on Barenkoph Mountain. The forested area covers approximately nine hectare and the types o trees include: *Picea Abies*, *Fagus Slyvatica* and *Abies*.

After these, abovementioned values were written into the calculation table, an assessment of benefits was obtained (Table 14).

Table 13. Assessments of benefits in monetary values for endangered areas

Damage to buildings (including inventory and outdoor facilities)	686.000 €
Damage to agriculture and forestry	1.500.000 €
Damage to transportation facilities	237.000 €
Damage to water supply and waste disposal facilities	23.000 €
Damages in commercial, industrial, trading and services sector	50.000 €
Intangible and indirect benefits	750.000 €
Predicted total value of benefits in monetary value	**3.347.500 €**

Table 14 illustrate that if the hotel is damaged due to an avalanche, restoration could be cost approximately 686.000 €, which could be saved with any avalanche protection. Another example is if the main road must be closed due to snow deposit from an avalanche, reopening it could cost 237.000 € as well as unknown losses.

Four types of avalanche protection (steel snow bridges, avalanche blasting masts per each release zone, deflecting dam, and catching dam on deposition zone) were evaluated to prevent the Perchertal and Ausmehler avalanche. The most effective but most expensive, solution is building steel snow bridges on the release zones as the snow bridges prevent a snow motion function before an avalanche is triggered. However, environmentalists have complained about this measure, maintaining these types of metal structures spoil aesthetic of natural environment. In spite of these kinds of negative opinions, according to local director of the WLV office in Schwaz, snow bridges are used most often as avalanche protections in Austria. Therefore, snow bridges to prevent possible avalanche releases from R1, R2 and R3 were evaluated first. Distribution of the snow bridges are as follows

- R1: Steel snow bridges were designed for whole area. Calculated cost: **1.900.000** €.
- R2: Steel snow bridges were designed for whole area. Calculated cost:**1.261.000 €.**
- Ground surface of R3 is considered as available space for afforestation; therefore, 40% of the total area was planned for afforestration; another 40% of the total area was planned for wooden structures and the rest of **the total area (20%)** was planned for steel snow bridges. Calculated costs of avalanche protection of R3 are as follows:

    - Total price of steel snow bridges on R3=776.000 €
    - Total price of afforestration on R3= 45.000 €
    - Total price of wooden structure on R3=570.000 €

In total, the combination of avalanche protection works that includes steel snow bridges, wooden structures, and afforestration for all three release zones cost approximately **4.552. 000 €.**

The cost of installing one avalanche blasting mast on the relevant release zone is approximately 100.000 €. **Six avalanche blasting masts** are required for all release zones. The total cost is **600.000 €.**

Building a catching dam can be acceptable as a permanent solution if there is sufficient and available space on the deposition area. A catching dam could ensure a maximum safety level for the hotel and the part of the main road. Calculations indicate that the length of an effective catching dam would be 450 m with a height of 11 m. The price of a **catching dam** was calculated to be **1.284.000€.**

Another alternative avalanche mitigation measure is building a deflecting dam on the deposition area. A deflecting dam could protect the hotel by diverting avalanche flows before they damage the hotel. According to cost calculations, the price of the **deflecting dam** designed is around **482.000 €,** which is cheaper than other mitigation measures.

The following prices parameters as shown on Table 15 were taken from Mr. Plank. They were used to calculate the cost of avalanche protection.

Table 14. Price parameters to build protective parameters

Excavation	€ 1,5-3 /m^3
Patching of moloid	€ 4,5 m^3
Rough stone wall:	€ 60-90 / m^2
Greening	€ 1,20 / m^2
Planting	€ 1,50- 8 / peace
Afforestation:	€ 10.000 / ha
Maintenance of afforestation	€ 30.000 / ha
Supporting steel structures on the release zone:	€ 1000 / m
Wooden Structures	€40.000/ ha

Table 15. Cost and benefit analysis for steel snow bridges [Lebensministerium, 2010]

Expected lifetime of structure	n	80 years
Interest rate percentage e%	p	3,50 %
Required time of project completion	nK	2 years

Discounted total cost of the project (according to calculations)	KNB	**€ 3.937.000,00**
Annual cost of the project	rKNB	€ 1.968.500,00
Restoration costs of structures within 40 years (without discount)	KW	€ 0,00
Total manufacturing cost without discount (new building and re-production)	KH	€ 3.937.000,00
Total annual maintenance cost (without discount)	rKI	€ 19.685,00
Restoration costs of structures for the first 80 years (without discount)	KI	€ 1.574.800,00
Total cost	K	**€ 5.511.800,00**
Sum of the discounted annual costs for new construction since the beginning of the project	KNB_O	€ 3.739.548,18
Restoration costs of structures for the first 40 years (without discount) in 2. Period	KW_O	€ 0,00
Sum of the discounted manufacturing costs (new building costs and recovery costs) within 80 years	KH_O	€ 3.739.548,18
Sum of the discounted maintenance costs on the date made within 80 years	KI_O	€ 526.549,65
Sum of the discounted total costs of the completed project (new-cost recovery + costs + maintenance costs) within 80 years	K_O	**€ 4.266.097,83**

Total benefits (benefits, according to questionnaire)	N	**€ 3.247.750,24**
Annual benefit after end of project	rN	€ 40.852,20
Benefit in the period between beginning of the project and project completion	N_{nk}	€ 57.871,33
Benefit from the completion of construction until the end of the study period, (discounted)	$N_{n\text{-}nk}$	€ 1.015.139,75
Sum of the discounted annual benefit from beginning of the project	N_O	**€ 1.073.011,08**

Capital value (No. - Co)	**KW**	**€3.193.086,75**
Benefit / cost ratio (No / Co)	**QN/K**	**0,25**

Table 16. Cost and benefit analysis for deflecting dam [Lebensministerium, 2010]

Expected lifetime of structure	n	80 Years
Interest rate percentage%	p	3,50 %
Required time of project completion	nK	2 years

Discounted total cost of the project (according to calculations)	KNB	**€ 482.700,00**
Annual cost of the project	rKNB	€ 241.350,00
Restoration costs of structures for first 40 years (without discount)	KW	€ 0,00
Total manufacturing cost without discount (new building and re-production)	KH	€ 482.700,00
Total annual maintenance cost (without discount)	rKI	€ 482,70
Restoration costs of structures for the first 80 years (without discount)	KI	€ 38.616,00
Total cost	K	**€ 521.316,00**
Sum of the discounted annual costs for new construction since the beginning of the project	KNB_O	€ 458.491,21
Restoration costs of structures for first 40 years (without discount) in 2. Period	KW_O	€ 0,00
Sum of the discounted manufacturing costs (new building and recovery costs) within 80 years	KH_O	€ 458.491,21
Sum of the discounted maintenance costs on the date made within 80 years	KI_O	€ 12.911,63
Sum of the discounted total cost of the completed project (new-cost recovery + costs + maintenance costs) within 80 years	K_O	**€ 471.402,85**

Total benefits (benefits, according to questionnaire)	N	**€ 3.247.750,24**
Annual benefit after end of project	rN	€ 40.852,20
Benefits from the beginning of the project until the end of the project	N_{nk}	€ 57.871,33
Benefits from the completion of construction until the end of the study period, (discounted)	N_{n-nk}	€ 1.015.139,75
Sum of the discounted annual benefit from beginning of the project	N_O	**€ 1.073.011,08**

Capital value (No. - Co)	**KW**	**€ 601.608,24**
Benefit / cost ratio (No / Co)	**QN/K**	**2,28**

Table 17. Cost and benefit analysis for catching dam [Lebensministerium, 2010]

Expected lifetime of structure	n	80 Years
Interest rate percentage%	p	3,50 %
Required time of project completion	nK	2 years

Discounted total cost of the project (according to calculations)	KNB	**€ 1.284.000,00**
Annual cost of the project	rKNB	€ 642.000,00
Restoration costs of structures for first 40 years (without discount)	KW	€ 0,00
Total manufacturing cost without discount (new building and re-production)	KH	€ 1.284.000,00
Total annual maintenance cost (without discount)	rKI	€ 1.284,00
Restoration costs of structures for the first 80 years (without discount)	KI	€ 102.720,00
Total cost	K	**€ 1.386.720,00**
Sum of the discounted annual costs for new construction since the beginning of the project	KNB_O	€ 1.219.603,72
Restoration costs of structures for first 40 years (without discount) in 2. Period	KW_O	€ 0,00
Sum of the discounted manufacturing costs (new building and recovery costs) within 80 years	KH_O	€ 1.219.603,72
Sum of the discounted maintenance costs on the date made within 80 years	KI_O	€ 34.345,43
Sum of the discounted total cost of the completed project (new-cost recovery + costs + maintenance costs) within 80 years	K_O	**€ 1.253.949,15**

Total benefits (benefits, according to questionnaire)	N	€ 40.852,20
Annual benefit after end of project	rN	€ 57.871,33
Benefits from the beginning of the project until the end of the project	N_{nk}	€ 1.015.139,75
Benefits from the completion of construction until the end of the study period, (discounted)	N_{n-nk}	**€ 1.073.011,08**
Sum of the discounted annual benefit from beginning of the project	N_O	€ 1.284,00

Capital value (No. - Co)	**KW**	**-€ 180.938,07**
Benefit / cost ratio (No / Co)	**QN/K**	**0,86**

5. CONCLUSION

Several different avalanche scenarios were simulated using different simulation models to illustrate the potential severity of Perchertal and Ausmehler avalanches. Vegetation over the whole area was defined in detail as a first step. Avalanche scenarios were then simulated and subsequent hazard map of the relevant area was drawn taking into account simulation results and topographic circumstances. To prevent avalanches various types of temporary and permanent technical protection works were evaluated as possibilities in the release and the deposition area. A CBA followed which determined the most economical and effective way to prevent avalanches.

In order to ensure a maximum safety level for the hotel and the part of the main road, possible avalanche protection measures were evaluated and the following recommendations can be given based on the simulation results and the CBA:

Potential snow accumulation on the R1 is 62.667 m^3 and R1 covers a total area of 3,10 hectare according to calculations. The area has a rocky ground surface as well as a dominant vegetation type of dwarf mountain pine *(Pinus mugo)*.

R1 does not usually trigger avalanches based on information received from Mr. Wöll. R1 can only trigger an avalanche, which is called Perchertal in the event of extraordinary weather conditions (e.g. heavy snowfall and strong wind from the north-east).

In order to prevent any avalanche fall from R1, afforestration is not recommended in terms of available space for tree growth due to its rocky ground surface.

Steel snow bridges can be assumed to be the most effective permanent technical protection measure to ensure maximum safety of the endangered hotel and main road against avalanche releases from R1. However, avalanche fallings are rarely seen from R1. Therefore building steel snow bridges are not immediately required. Also the CBR is not effective; thus steel snow bridges are not recommended.

Potential snow accumulation on the R2 is 58.280 m^3 and it covers a total area of 3, 07 hectare. If this release zone triggers an avalanche, it is called Perchertal avalanche as well. R2 can be assumed as the most active release zone due to minor avalanche releases every year. This situation is due to its slippery ground surface and presence of less surface vegetation and moreover the chronology of avalanche events supports this thesis. So R2 has the most realistic avalanche scenario among R1, R2 and R3.

To prevent avalanches afforestation is not a good idea for R2 due to its rocky ground surface as trees might not grow up under these rocky soil circumstance with minor avalanches. In this case timberline will drop below the rock or gravel zone (Fig. 76).

Figure 76. Moving gravel on the R2 (Photo: Kurt, 2011)

Building snow bridges on R2 could be the most effective avalanche protection system. However, according to calculations, the cost of the steel snow bridges is very high. In addition, a CBA does not recommend it due to its less CBR.

The biggest avalanche release zone is R3 on the Bärenkopf Mountain. Potential snow accumulation on the R3 is 139.620 m^3 and covers a total area of 7, 23 hectare. The accumulation triggers the avalanche, which is different than the Perchertal avalanche in terms of avalanche tracks (Fig. 62). R3 also seems to be an active release zone due to silent witnesses on the avalanche tracks that are affected by minor wet snow avalanche releases every year. These silent witnesses can be seen clearly on the avalanche tracks of R3 (Appendix A).

Due to R3's large area, a combination of avalanche protection measures (steel, wooden structures and afforestation works) was evaluated in order to reduce the costs of the works. For example, R3 has smooth ground surface that is covered by grass and some existing trees. For this reason, 40% of R3 was assumed for afforestration. However, minor avalanches might not let saplings (young trees) grow without any support structures on the release zone. Therefore, 40% of the area was evaluated for building wooden structures. The rest of the area (20%) where is very steep and rocky was evaluated for building steel snow bridges. In spite of these planned combination measures, calculations showed that price of protections works is still high and the CBR does not recommend this.

Avalanche blasting systems were considered for all three release zones as another temporary avalanche protection. However, only minor avalanches can be tolerated using this system. In other words, in areas with human residence, even a small probability of a larger avalanche is unacceptable. But is controlling avalanches with explosives acceptable in an area where a hotel is located? According to simulation results, none of the dense flow avalanche scenarios posed a very dangerous situation for the hotel. This issue was discussed with Mr. Moser who is responsible for management of forested areas in Pertisau.

He was not satisfied with this idea as he considered it a temporary solution and was not in favour of the avalanche blasting system.

The price of installing an avalanche blasting system was calculated to compare it with other protective measurements. In total, six avalanche blasting masts needed. One piece of avalanche blasting mast costs approximately 100.00 € and the total price is around 600.000 €. As a result, this system is not recommended.

Building catching dam can be an acceptable solution if there is sufficient and available space on the relevant deposition area. This partly depends on the economic situation of the authorities and their decisions. For example, if both the hotel and part of the main roads needed to be protected together against possible future avalanche fallings, a catching dam could be recommended, which would ensure maximum safety level for the hotel and the part of the main road.

During the field studies, there was no intense traffic on the main road and, according to the chronology of avalanche events, none of the avalanches that had occurred had ever reached the main road or destroyed the hotel. This means that protection for the main road is not immediately essential. Moreover, if a catching dam had been built, it would be very expensive and cost around 1.284.000 € due to the large dimensions needed about 485 long. Therefore, due to its low CBR value building catching dam is not recommended.

In the case of powder snow avalanche, the hotel can remain entirely in the yellow zone based on Samos AT model results. However, powder snow avalanches are unrealistic scenarios as mentioned earlier and building any control structure is not essential.

Building a deflecting dam seems to be the best solution among four choices, according to cost and benefit analysis. There is sufficient empty space where avalanche flows can continue and not cause damage. Moreover, a deflecting dam is not expensive to build. For these reasons, constructing deflecting dam can be recommended.

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APPENDICES

APPENDIX A: Vegetation of Type the Observed area

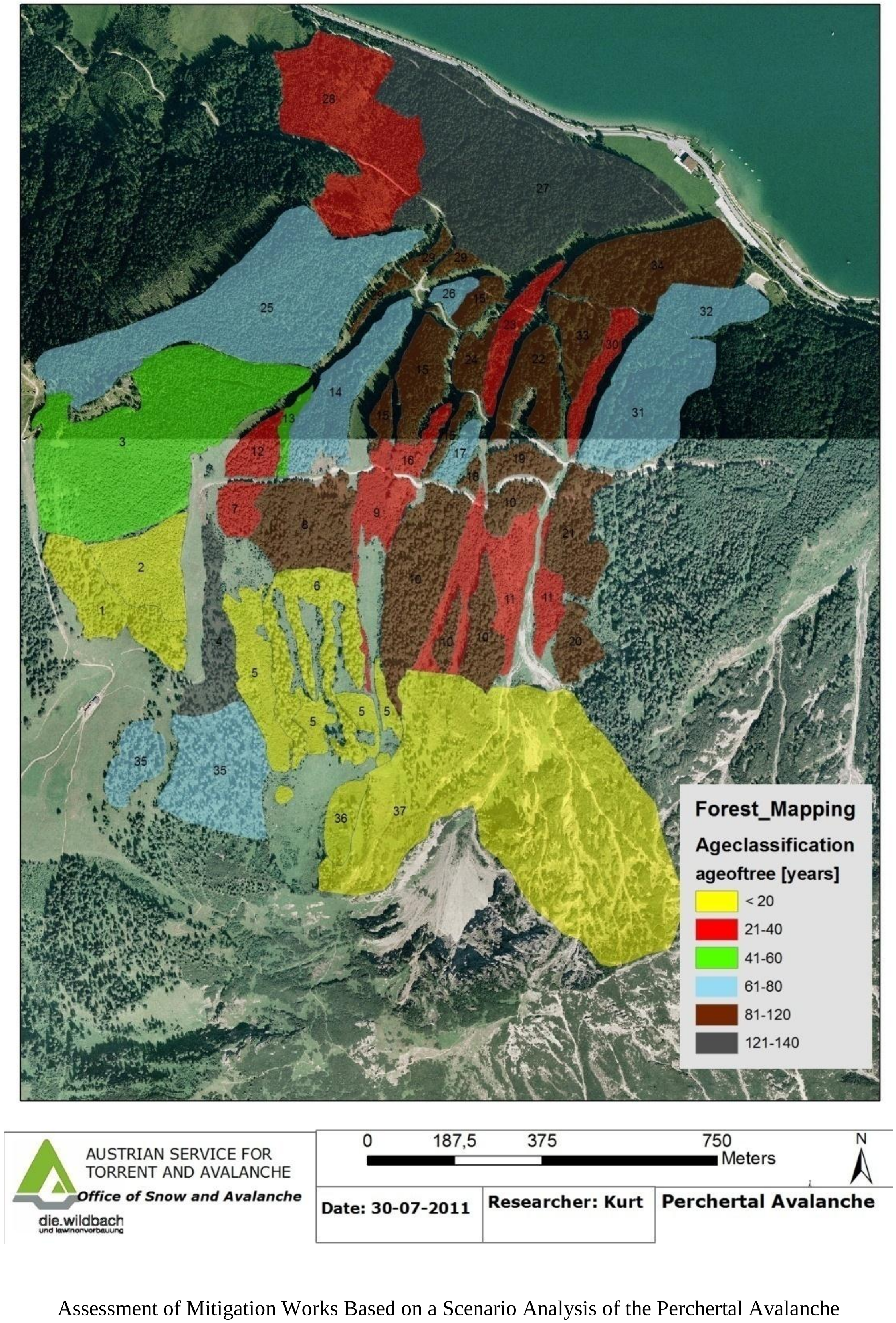
APPENDIX B: Calculation of Extreme Snow Height

APPENDIX C: Results from Alpha Beta Model

APPENDIX D: Results from Samos AT Model

APPENDIX E: Mean annual Precipitation Values for Weather Stations

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA



APPENDIX A: VEGETATION TYPE OF THE OBSERVERD AREA

Stand Description	Stand Number :1
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%50 < 20 years %20 21-40 %10 41-60 %20 121-140
Growth Classes	%10 Young growth to 1.3 m, %10 Thickening to larger than 1.3m, %30 Pole stand to 10-20 cm, %30 Timber stand to >20 cm, %20 Mature stand
Development Phase	Terminal phase
Canopy cover	4/10
Tree species	*Picea abies (L.).* *Larix deciduas (L.)* *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise
Notes: Damages can be seen due to cattle.	


APPENDIX A: VEGETATINON TYPE OF OBSERVERD AREA

Stand Description	Stand Number :2
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%70 < 20 years %30 21-40
Growth Classes	%70 Pole stand to 10-20 cm %30 Timber stand to >20 cm
Development Phase	Initial phase
Canopy cover	7/10
Tree species	%100 *Picea abies (L.).*
Stand structure	Two- storied
Tree species composition	Single

Notes: Cattle on the side of ski track.

APPENDIX A: VEGETATION TYPE OF THE OBSERVERD AREA

Stand Description	Stand Number :3
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 21-40 years %80 41-60
Growth Classes	%20 Pole stand to 10-20 cm %80 Timber stand to >20 cm
Development Phase	Initial phase
Canopy cover	8/10
Tree species	%100 *Picea abies (L.)*
Stand structure	Single-storey
Tree species composition	Single

Notes: Stand is too dense, thinning is important, cattle on avalanche track.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :4
Vegetation Type	Oxalis
Water Regime	Moderately Fresh
Age Structure	%20 21-40 years %30 61-80 %50 121-140
Growth Classes	%30 Pole stand to 10 -20 cm, %50 Timber stand to >20 cm, %20 Mature stand
Development Phase	Terminal phase
Canopy cover	7/10
Tree species	%50 *Picea abies (L.)* %20 *Abies alba (L.)* %10 *Larix decidua (L.)* %10 *Fagus sylvatica (L.)*
Stand structure	Two- storied
Tree species composition	Troop wise

Notes: Damages can be seen due to cattle.

APPENDIX A: VEGETATION TYPE OF THE OBSERVEDAREA

Stand Description	Stand Number :5
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%70 < 20 years %30 21-40 “
Growth Classes	%50 Young growth to 1.3 m, %40 Thickening to larger than 1.3m, %10 Pole stand to 10-20 cm,
Development Phase	Young growth phase
Canopy cover	8/10
Tree species	%40 *Alnus viridis (L.)* %30 *Larix deciduas (L.)* %20 *Sorbus Aucuparia (L.)* %10 *Picea Abies L.*
Stand structure	Two- storied
Tree species composition	Troop wise

Notes: Broken branches and curved tree trunks can be seen.


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :6
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%70 < 20 years %30 21-40
Growth Classes	%50 Young growth to 1.3 m, %50 Thickening to bigger 1.3m,
Development Phase	Young growth phase
Canopy cover	6/10
Tree species	%50 *Picea abies (L.)* %40 *Larix deciduas (L.)* %10 *Pinus Mugo (L.)*
Stand structure	Two- storied
Tree species composition	Groups wise

Notes: There is no *Alnus viridis.* they might be cut before, not often avalanche happened here.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :7
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 < 20 years %60 21-40 %20 41-60
Growth Classes	%20 Thickening to bigger 1.3m, %40 Pole stand to 10-20 cm, %40 Timber stand to >20 cm,
Development Phase	Initial phase
Canopy cover	9/10
Tree species	%80 *Picea abies (L.)* %20 *Fagus sylvatica (L.)*
Stand structure	Two- storied
Tree species composition	Single

Notes:

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :8
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 years %10 41 -60 %10 61 -80 %60 81 -120 %10 121 -140
Growth Classes	%10 Young growth to 1.3 m, %10 Pole stand to 10-20 cm, %20 Timber stand to >20 cm, %60 Prospective old mature stand
Development Phase	Optimal phase
Canopy cover	8/10
Tree species	%40 *Picea abies (L.)* %30 *Abies alba (L.)* %30 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: Hazard indicators can be seen.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :9
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 %80 21-40 %10 41-60
Growth Classes	%50 Thickening to bigger 1.3m %50 Pole stand to 10-20 cm
Development Phase	Initial phase
Canopy cover	8/10
Tree species	%10 *Picea abies (L.)* %90 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Single

Notes: Broken trees can bee seen. Place is kind of avalanche track

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :10
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 years %10 61-80 %80 81-120
Growth Classes	%10 Young growth to 1.3 m, %10 Timber stand to >20 cm, %80 Prospective old mature stand
Development Phase	Regeneration phase
Canopy cover	7/10
Tree species	%10 *Acer spp.* %60 *Picea abies (L.)* %10 *Larix deciduas (L.)* %10 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: Broken branches can be seen due to storms.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

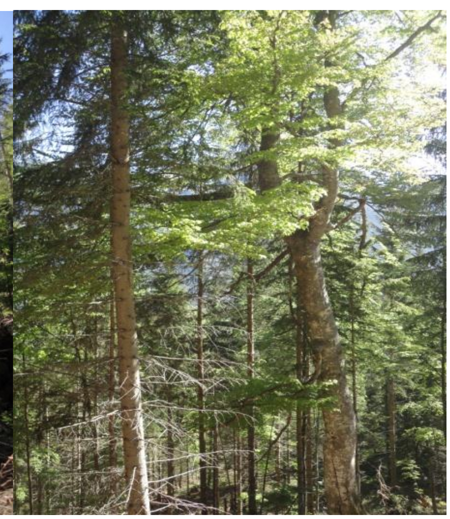
Stand Description	Stand Number :11
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%40 < 20 years %60 21-40
Growth Classes	%30 Young growth to 1.3 m %50 Thickening to bigger 1.3m %20 Pole stand to 10-20 cm
Development Phase	Young growth phase
Canopy cover	7/10
Tree species	%50 *Picea abies (L.)* %10 *Larix deciduas (L.)* %30 *Fagus sylvatica (L.)* %10 *Pinus mugo (L.)*
Stand structure	Two-layered
Tree species composition	Troop wise

Notes: Broken trees can be seen. The place is kind of an avalanche track.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :12
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 < 20 %50 21-40 %30 81-120
Growth Classes	%30 Thickening to bigger 1.3m, %30 Pole stand to 10-20 cm, %30 Timber stand to >20 cm, %10 Mature stand
Development Phase	Initial phase
Canopy cover	8/10
Tree species	%70 *Picea abies (L.)* %30 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Troop wise

Notes: Old fagus can be seen, there might have been an avalanche 45 years ago.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :13
Vegetation Type	Tall herb clear cutting
Water Regime	Fresh
Age Structure	%20 < 20 %20 21-40 %40 41-60 %20 121-140
Growth Classes	%10 Young growth to 1.3 m, %10 Thickening to bigger 1.3m, %30 Pole stand to 10-20 cm, %30 Timber stand to >20 cm, %20 Mature stand
Development Phase	Terminal phase
Canopy cover	7/10
Tree species	%50 *Picea abies (L.)* %50 *Larix deciduas (L.)*
Stand structure	Single-layered
Tree species composition	Hoard wise

Notes: Stand is too old stand.


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :14
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 21-40 %30 41-60 %60 61-80
Growth Classes	%20 Pole stand to 10-20 cm, %70 Timber stand to >20 cm, %10 Mature stand
Development Phase	Initial phase
Canopy cover	7/10
Tree species	%80 *Picea abies (L.)* %20 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: This zone was used as cable transportation. Avalanches do not happen often.


APPENDIX A: VEGETATION TYPE OF OBSERVED AREA

Stand Description	Stand Number :15
Vegetation Type	Oxalis
Water Regime	Moderately Fresh
Age Structure	%10 < 20 %10 21-40 %10 41-60 %10 61-80 %50 81-120 %20 121-140
Growth Classes	%20 Thickening to bigger 1.3m, %10 Pole stand to 10-20 cm, %10 Timber stand to >20 cm, %50 Mature stand %10 Prospective old mature stand
Development Phase	Terminal phase
Canopy cover	9/10
Tree species	% 60 *Picea abies (L.)* % 20 *Abies alba (L.)* % 20 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes:

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :16
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 years %90 21-40
Growth Classes	%80 Thickening to bigger 1.3m, %20 Pole stand to 10-20 cm,
Development Phase	Young growth phase
Canopy cover	8/10
Tree species	% 70 *Picea abies (L.)* %20 *Fagus sylvatica (L.)* %10 *Abies alba (L.)*
Stand structure	Multi-layered
Tree species composition	Group wise

Notes:


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :17
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 21-40 years %40 41-60 %50 61-80
Growth Classes	%20 Thickening to bigger 1.3m, %70 Pole stand to 10-20 cm, %10 Timber stand to >20 cm,
Development Phase	Initial phase
Canopy cover	8/10
Tree species	%80 *Picea abies (L.)* %20 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Troop wise

Notes:

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :18
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 21-40 years %10 41-60 %30 61-80 %60 81-120
Growth Classes	%30 Pole stand to 10-20 cm, %60 Timber stand to >20 cm, %10 Mature stand
Development Phase	Terminal Phase
Canopy cover	8/10
Tree species	%80 *Picea abies (L.)* %20 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Single

Notes:


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :19
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 years %10 21-40 %10 41-60 %20 61-80 %50 81-120
Growth Classes	%10 Thickening to bigger 1.3m, %20 Pole stand to 10-20 cm, %60 Timber stand to >20 cm, %10 Mature stand
Development Phase	Initial phase
Canopy cover	8/10
Tree species	%70 *Picea abies (L.)* %10 *Larix deciduas (L.)* %20 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: There was avalanche about 45 years ago. Hazard indicators were determined.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :20
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 years %10 21-40 %10 41-60 %30 61-80 %40 81-120
Growth Classes	%10 Thickening to bigger 1.3m, %30 Pole stand to 10-20 cm, %60 Timber stand to >20 cm, %10 Mature stand
Development Phase	Terminal phase
Canopy cover	7/10
Tree species	%60 *Picea abies (L.)* %10 *Larix deciduas (L.)* %30 *Fagus sylvatica (L.)* %10 *Alnus viridis (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: Snow gliding had effected the shape of trees trunk.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :21
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 21-40 years %10 41-60 %30 61-80 %50 81-120
Growth Classes	%40 Pole stand to 10-20 cm, %50 Timber stand to >20 cm, %10 Mature stand
Development Phase	Optimal phase
Canopy cover	9/10
Tree species	%60 *Picea abies (L.)* %10 *Larix deciduas (L.)* %30 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: Storms have made some trees fall..

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :22
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 < 20 %10 21-40 %10 41-60 %30 61-80 %40 81-120
Growth Classes	%5 Young growth to 1.3 m, %10 Thickening to bigger 1.3m, %35 Pole stand to 10-20 cm, %40 Timber stand to >20 cm, %10 Mature stand
Development Phase	Initial phase
Canopy cover	9/10
Tree species	% 90 *Picea abies (L.)* %10 *Fagus sylvatica (L.)*
Stand structure	Multi-layered
Tree species composition	Single

Notes:


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :23
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%20 < 20 %50 21-40 %20 41-60 %10 61-80
Growth Classes	%60 Thickening to bigger than 1.3m, %30 Pole stand to 10-20 cm, %10 Timber stand to >20 cm,
Development Phase	Initial phase
Canopy cover	6/10
Tree species	%90 *Picea abies (L.)* %10 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Troop wise

Notes: Around 30-40 years ago affected by avalanche.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :24
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%80 81-120 %20 121-140
Growth Classes	%80 Timber stand to >20 cm, %20 Mature stand
Development Phase	Optimal phase
Canopy cover	9/10
Tree species	%100 *Picea abies (L.)*
Stand structure	Single-layered
Tree species composition	Singly

Notes:

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :25
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%30 41-60 %70 61-80
Growth Classes	%10 Pole stand to 10-20 cm %90 Timber stand to >20 cm
Development Phase	Initial phase
Canopy cover	8/10
Tree species	% 100 *Picea abies (L.)*
Stand structure	Single-storey
Tree species composition	Single

Notes: Stand is too dense, thinning is important.


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :26
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 41-60 %70 61-80 %10 81-120
Growth Classes	%80 Pole stand to 10-20 cm, %20 Timber stand to >20 cm,
Development Phase	Initial phase
Canopy cover	7/10 light
Tree species	%90 *Picea abies (L.)* %10 *Fagus sylvatica (L.)*
Stand structure	Single-layered
Tree species composition	Singly
Notes:	

APPENDIX A: VEGETATINON TYPE OF THE OBSERVERD AREA

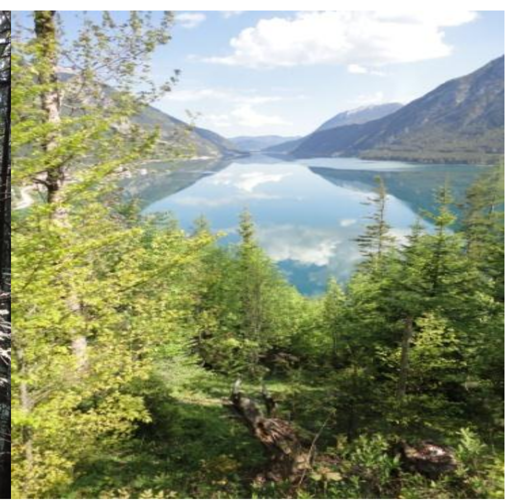
Stand Description	Stand Number:27
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%30 81- 120 %60 121-140 %10 >140 years
Growth Classes	%80 Timber stand to >20 cm, %20 Mature stand
Development Phase	Optimal phase
Canopy cover	9/10
Tree species	%95 *Picea abies (L.)* %5 *Fagus sylvatica (L.)*
Stand structure	Single-layered
Tree species composition	Single

Notes: Near the avalanche track it is possible to see the silent witness.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :28
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%30 < 20 %50 21-40 %20 41-60
Growth Classes	%10 Young growth to 1.3 m, %60 Thickening to bigger 1.3m, %30 Pole stand to 10-20 cm,
Development Phase	Initial phase
Canopy cover	5/10 light
Tree species	%50 *Picea abies (L.)* %20 *Fagus sylvatica (L.)* %10 *Acer spp.* % 10 *Larix deciduas (L.)* %10 *Abies alba (L.)*
Stand structure	Multi-layered
Tree species composition	Single

Notes:

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APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :29
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 61-80 %80 81-120
Growth Classes	%90 Timber stand to >20 cm, %10 Mature stand
Development Phase	Optimum phase
Canopy cover	9/10
Tree species	%90 *Picea abies (L.)* %10 *Abies alba (L.)*
Stand structure	Single -layered
Tree species composition	Single
Notes:	

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :30
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 < 20 %70 21-40 %10 41-60
Growth Classes	%40 Thickening to bigger 1.3m %60 Pole stand to 10-20 cm
Development Phase	Initial phase
Canopy cover	9/10
Tree species	%10 *Picea Abies (L.)* %90 *Fagus sylvatica (L.)*
Stand structure	Two-layered
Tree species composition	Single

Notes: Avalanche track

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :31
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%10 <20 %10 21-40 %30 41-60 %40 61-80 %10 81-120
Growth Classes	%20 Thickening to bigger 1.3m %60 Pole stand to 10-20 cm %20 Timber stand to >20 cm
Development Phase	Terminal Phase
Canopy cover	6/10
Tree species	% 60 *Picea Abies (L.)* %40 *Fagus sylvatica (L.)*
Stand structure	Troop wise
Tree species composition	Troop wise

Notes: Damages can be seen due to cattle.

APPENDIX A: VEGETATINON TYPE OF THE OBSERVERD AREA

Stand Description	Stand Number :32
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%20 41-60 %60 61-80 %20 81-120
Growth Classes	%80 Pole stand to 10-20 cm, %20 Timber stand to >20 cm,
Development Phase	Terminal Phase
Canopy cover	8/10
Tree species	%90 *Picea abies (L)* %10 *Fagus sylvatica (L.)*
Stand structure	Single-layered
Tree species composition	Troop wise

Notes:

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :33
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%40 61-80 %60 81-120
Growth Classes	%80 Pole stand to 10-20 cm, %20 Timber stand to >20 cm
Development Phase	Terminal Phase
Canopy cover	7/10
Tree species	%10 *Picea abies (L.)* %90 *Larix deciduas (L.)*
Stand structure	Single-layered
Tree species composition	Troop wise
Notes:	

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :34
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%80 121-140 %20 >140
Growth Classes	%90 Timber stand to >20 cm, %10 Mature stand
Development Phase	Optimal phase
Canopy cover	9/10
Tree species	%90 *Picea abies (L.)* %10 *Larix deciduas (L.)*
Stand structure	Single-Layered
Tree species composition	Single

Notes: Damages can be seen due to cattles.


APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :35
Vegetation Type	Grass
Water Regime	Fresh
Age Structure	%10 < 20 %10 21-40 %20 41-60 %30 61-80 %30 81-120
Growth Classes	%10 Young growth to 1.3 m, %10 Thickening to bigger 1.3m, %20 Pole stand to 10-20 cm, %30 Timber stand to >20 cm, %30 Mature stand
Development Phase	Regeneration phase
Canopy cover	6/10
Tree species	%10 *Picea abies (L.)* %90 *Larix deciduas (L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise

Notes: If slope is assumed to be steep, there might be snow gliding. Cattle damage can be seen. It is kind of an avalanche track.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :36
Vegetation Type	Oxalis
Water Regime	Fresh
Age Structure	%90 < 20 %10 41-60
Growth Classes	%90 Thickening to bigger 1.3m %10 Timber stand to >20 cm,
Development Phase	Regeneration Phase
Canopy cover	9/10
Tree species	%90 *Alnus viridis (L.)* %10 *Larix deciduas (L.)*
Stand structure	Multi-layered
Tree species composition	Group wise

Notes: Avalanche impacts can be seen on the avalanche sides.

APPENDIX A: VEGETATION TYPE OF THE OBSERVED AREA

Stand Description	Stand Number :37
Vegetation Type	Clear cutting
Water Regime	Fresh
Age Structure	%40 < 20 %30 21-40 %10 41-60 %10 61-80 %10 81-120
Growth Classes	%40 Young growth to 1.3 m, %40 Thickening to bigger 1.3m, %10 Pole stand to 10-20 cm, %10 Timber stand to >20 cm,
Development Phase	Initial phase
Canopy cover	6/10
Tree species	%10 *Picea abies (L.)* %10 *Alnus viridis (L.)* %20 *Larix deciduas* %60 *Pinus Mugo(L.)*
Stand structure	Multi-layered
Tree species composition	Troop wise
Notes:. Cattle damages can be seen. Kind of avalanche track	

APPENDIX B: EXTREME SNOW HEIGHTS OF R1 [Leichtfried, 2010]

Calculation of the Extreme Snow for Tyrol and Vorarlberg

Return period: 150 years

Input: Please enter data for the planned obstruction in green boxes

Caution: do not change red areas!

No. 1: Zone read out of the zone map
No. 2: Elevation of the proposed works (450m-3050m scope)
No. 3: Wind: blown = 1, no wind effect = 2, blown in=3, blown extreme = 4
No. 4: Exposure: Select average slope direction, the exposure value from the right table
No. 5: Region: Right from the Region list select
No. 6: Slope in degrees

Nr.	Factor	Input	Selection
1	Zone	4	[1-5]
2	Elevation	1975	[m]
3	Wind	3	[1-4]
4	Exposition	1	[1-8]
5	Region	4	[1-13]
6	Slope	46	[°]

Region List

Region	Nr.
Arlberg	1
Ausserfern	2
Bregenzer Wald	3
Inntal/Mitte & Ost	4
Inntal/West	5
Montafon	6
Osttirol Ost	7
Osttirol Südwest	8
Ötztaler Alpen	9
Silvretta	10
Kitzbühler Alpen	11
Zillertaler Alpen	12
Sonstige	13

Exposure Table

Exposition	Value
North	1
Northeast	2
East	3
Southeast	4
South	5
Soutwest	6
West	7
Northwest	8

Extreme Snow Depth from Zone Map:	553 cm	150-Year Event, Total Snow Depth:	
Wind correction filter:	39 cm	Wind Correction:	7%
Correction filter height level:	12 cm	Altitude correction:	2%
Correction filter region:	-1 cm	Region-correction:	0%
Exposure correction filter:	28 cm	Exposure Compensation:	5%
Total corrections by filtering:	**78** cm	**Total corrections:**	**14%**
Extreme Snow Depth with correction filter	630 cm	150-year event, corr. Total snow height	
Recommended Structure Height	438 cm	150-year event, snow thickness	

APPENDIX B: EXTREME SNOW HEIGHTS OF R2 [Leichtfried, 2010]

Calculation of the Extreme Snow for Tyrol and Vorarlberg

Return period: 150 years

Input: Please enter data for the planned obstruction in green boxes

Caution: do not change red areas!

No. 1: Zone read out of the zone map
No. 2: Elevation of the proposed works (450m-3050m scope)
No. 3: Wind: blown = 1, no wind effect = 2, blown in=3, blown extreme = 4
No. 4: Exposure: Select average slope direction, the exposure value from the right table
No. 5: Region: Right from the Region list select
No. 6: Slope in degrees

Nr.	Factor	Input	Selection
1	Zone	4	[1-5]
2	Elevation	1865	[m]
3	Wind	3	[1-4]
4	Exposition	1	[1-8]
5	Region	4	[1-13]
6	Slope	35	[°]

Region List

Region	Nr.
Arlberg	1
Ausserfern	2
Bregenzer Wald	3
Inntal/Mitte & Ost	4
Inntal/West	5
Montafon	6
Osttirol Ost	7
Osttirol Südwest	8
Ötztaler Alpen	9
Silvretta	10
Kitzbühler Alpen	11
Zillertaler Alpen	12
Sonstige	13

Exposure Table

Exposition	Value
North	1
Northeast	2
East	3
Southeast	4
South	5
Soutwest	6
West	7
Northwest	8

Extreme Snow Depth from Zone Map:	520 cm	150-Year Event, Total Snow Depth:	
Wind correction filter:	36 cm	Wind Correction:	7%
Correction filter height level:	5 cm	Altitude correction:	1%
Correction filter region:	-1 cm	Region-correction:	0%
Exposure correction filter:	26 cm	Exposure Compensation:	5%
Total corrections by filtering:	**68** cm	**Total corrections:**	**13%**
Extreme Snow Depth with correction filter	587 cm	150-year event, corr. Total snow height	
Recommended Structure Height	481 cm	150-year event, snow thickness	

APPENDIX C: RESULTS OF ALPHE-BETA MODEL FOR R1

LAWINENAUSLAUFLÄNGE - α/β Modell

Alpha/Beta-Modell nach Lied K., Hopf H., Bakkehoi S., Weiler Ch. (1995)

modifiziert nach Granig M., Sandersen F. (2006)

Programmversion: 2.03

(c) 2006-2009 Stabstelle für Schnee und Lawinen - WLV

Datei: Percher_avalanche_profile1_Sim1.pdf

PROJEKT:

Name: Percher Avalanche profil 1

Ort: Eben am A chensee/Tyrol

Bearbeiter: Granig/ Kurt

Datum: 29.06.2011

Herkunft des Längsprofils: aus GIS importiert

Kommentar:

10° Punkt	β	ψ
l = 1713.1m, **h** = 940.7m	30.5°	46.1°

ERGEBNIS NACH 2-PARAMETER FORMEL NACH LIED ET AL.

Regressionsformel: Standard

k1 = 0.946, **k2** = -0.830, **s** = 1.50

α = k1*β + k2 = 28.0°

α + SD = 28.0°

n = 0

SD = n*s = 0.0°, **s** = 1.5°

Schnittpunkt α: Länge l = 1919.4m, Seehöhe h = 928.3m

Schnittpunkt α + SD: Länge l = 1919.4m, Seehöhe h = 928.3m

APPENDIX C: RESULTS OF ALPHE-BETA MODEL FOR R1

ERMITTLUNG DER ANZAHL DER STANDARDABWEICHUNGEN:

Bestockung von Hochwald in der Lawinenbahn
Bestockung unter 40% der potentiellen Lawinenbahn
× Bestockung zw. 41-70% der potentiellen Lawinenbahn
Bestockung über 71% der potentiellen Lawinenbahn **-1**

Neigungsverhältnisse im Anbruchgebiet
Durschnittl. Neigung zwischen 30-35°
Durschnittl. Neigung zwischen 35-45°
× Durschnittl. Neigung über 45° **-1**

Topographische Geländeausformung im Anbruchgebiet
Schüsselförmige Ausprägung
Gleichförmige Ausprägung
× Gegliederte (rauhe) Ausprägung
Konvexe Ausprägung **0**

Größe der Anbruchfläche
Groß - > 6ha
× Mittel - zwischen 2 - 6ha
Klein - zwischen 1 - 2ha **0**

Ausformung der Lawinensturzbahn (Längsprofil)
× Parabelförmige Sturzbahn
Geradlinige Sturzbahn
Leicht gegliederte Sturzbahn
Stark gegliederte Sturzbahn **2**

Ausformung der Lawinensturzbahn (Querprofil)
Stark kanalisiert
× Schwach kanalisiert
keine Kanalisierung
Konvex **0**

Wind-Exposition des Anbruchgebietes
Windabgewandte Seite (Lee)
× Windeinfluss ohne Schneeverfrachtung
Windexponierte Seite (Luv) **0**

Schneenährgebiet für Schneeverfrachtung in das Anbruchgebiet
Große Nährgebiete
Mäßige Nährgebiete
× Geringe Nährgebiete **-1**

Mittlere Jahres-Niederschlagssumme
Größer 1600mm
× Zwischen 1600mm - 1200mm
Zwischen 1200mm - 800mm
Kleiner 800mm **0**

Summe der Punkte (F):

$F = \Sigma T_i + \Sigma K_i = -1$

Anzahl der Standardabweichungen (n):

n = 0

Verteilungsschlüssel:

F	**> +10**	**+9 bis +7**	**+6 bis +3**	**+2 bis -2**	**-3 bis -6**	**-7 bis -9**	**< -10**
n	-3	-2	-1	**0**	1	2	α≈30°
		Große Auslaufweite <-			-> Kleine Auslaufweite		

Punkteverteilung F:

-13 < F < +11

APPENDIX C: RESULTS OF ALPHE-BETA MODEL FOR R1

LÄNGSSCHNITT:

Seehöhe	Länge	Neigung	Sch.Länge	dl
1948.06	0.00	0.00	0.00	0.00
1861.37	76.63	48.53	115.70	76.63
1769.00	172.40	43.96	133.06	95.78
1658.22	302.56	40.40	170.92	130.16
1617.74	343.80	44.47	57.79	41.24
1590.98	375.17	40.47	41.24	31.37
1530.06	464.15	34.40	107.84	88.98
1436.15	583.75	38.14	152.06	119.59
1405.43	618.47	41.50	46.35	34.72
1266.71	867.98	29.07	285.49	249.52
1128.67	1182.29	23.71	343.28	314.30
1023.02	1424.96	23.53	264.67	242.67
985.34	1530.56	19.64	112.12	105.60
960.57	1626.92	14.41	99.50	96.36
940.72	**1713.06**	**12.98**	**88.39**	**86.14**
930.38	1780.82	8.67	68.55	67.77
929.20	1797.92	3.94	17.13	17.09
926.87	2099.19	0.44	301.28	301.28

APPENDIX C: RESULTS OF ALPHE-BETA MODEL FOR R2

LAWINENAUSLAUFLÄNGE - α/β Modell

Alpha/Beta-Modell nach Lied K., Hopf H., Bakkehoi S., Weiler Ch. (1995)

modifiziert nach Granig M., Sandersen F. (2006)

Programmversion: 2.03

(c) 2006-2009 Stabstelle für Schnee und Lawinen - WLV

Datei: Percher_avalanche_profile2_Sim2YENİ.pdf

PROJEKT:

Name: Perchertal_Avalanche_Profil2

Ort: Eben am Achensee

Bearbeiter: Kurt

Datum: 29.06.2011

Herkunft des Längsprofils: aus GIS importiert

Kommentar:

10° Punkt	β	ψ
l = 1728.7m, **h** = 930.3m	25.7°	30.0°

ERGEBNIS NACH 2-PARAMETER FORMEL NACH LIED ET AL.

Regressionsformel: Standard

k1 = 0.946, **k2** = -0.830, **s** = 1.50

α = k1*β + k2 = 23.5°

α + SD = 22.0°

n = -1

SD = n*s = -1.5°, **s** = 1.5°

Schnittpunkt α: Länge l = 1921.2m, Seehöhe h = 927.6m

Schnittpunkt α + SD: Länge l = 2068.7m, Seehöhe h = 927.1m

APPENDIX C: RESULTS OF ALPHA-BETA MODEL FOR R2

ERMITTLUNG DER ANZAHL DER STANDARDABWEICHUNGEN:

Bestockung von Hochwald in der Lawinenbahn
Bestockung unter 40% der potentiellen Lawinenbahn
× Bestockung zw. 41-70% der potentiellen Lawinenbahn
Bestockung über 71% der potentiellen Lawinenbahn **-1**

Neigungsverhältnisse im Anbruchgebiet
× Durschnittl. Neigung zwischen 30-35°
Durschnittl. Neigung zwischen 35-45°
Durschnittl. Neigung über 45° **1**

Topographische Geländeausformung im Anbruchgebiet
× Schüsselförmige Ausprägung
Gleichförmige Ausprägung
Gegliederte (rauhe) Ausprägung
Konvexe Ausprägung **2**

Größe der Anbruchfläche
Groß - > 6ha
× Mittel - zwischen 2 - 6ha
Klein - zwischen 1 - 2ha **0**

Ausformung der Lawinensturzbahn (Längsprofil)
× Parabelförmige Sturzbahn
Geradlinige Sturzbahn
Leicht gegliederte Sturzbahn
Stark gegliederte Sturzbahn **2**

Ausformung der Lawinensturzbahn (Querprofil)
Stark kanalisiert
× Schwach kanalisiert
keine Kanalisierung
Konvex **0**

Wind-Exposition des Anbruchgebietes
Windabgewandte Seite (Lee)
× Windeinfluss ohne Schneeverfrachtung
Windexponierte Seite (Luv) **0**

Schneenährgebiet für Schneeverfrachtung in das Anbruchgebiet
Große Nährgebiete
Mäßige Nährgebiete
× Geringe Nährgebiete **-1**

Mittlere Jahres-Niederschlagssumme
Größer 1600mm
× Zwischen 1600mm - 1200mm
Zwischen 1200mm - 800mm
Kleiner 800mm **0**

Summe der Punkte (F):

$F = \Sigma T_i + \Sigma K_i$ = 3

Anzahl der Standardabweichungen (n):

n = -1

Verteilungsschlüssel:

F	> +10	+9 bis +7	+6 bis +3	+2 bis -2	-3 bis -6	-7 bis -9	< -10
n	-3	-2	-1	0	1	2	α≈30°
		Große Auslaufweite <-			-> Kleine Auslaufweite		

Punkteverteilung F:

-13 < F < +11

APPENDIX C: RESULTS OF ALPHA-BETA MODEL FOR R2

LÄNGSSCHNITT:

Seehöhe	Länge	Neigung	Sch.Länge	dl
1764.07	0.00	0.00	0.00	0.00
1693.56	114.31	31.67	134.31	114.31
1642.17	211.41	27.89	109.86	97.10
1519.35	403.45	32.60	227.96	192.04
1402.28	565.36	35.87	199.80	161.91
1271.70	807.13	28.37	274.78	241.77
1129.64	1125.00	24.08	348.17	317.87
1026.27	1369.02	22.96	265.01	244.01
984.49	1480.53	20.54	119.09	111.51
930.30	**1728.69**	**12.32**	**254.01**	**248.16**
928.14	1754.19	4.85	25.59	25.50
926.65	2202.62	0.19	448.43	448.43
944.98	2764.14	1.87	561.82	561.52
934.53	2816.26	11.34	53.16	52.13

APPENDIX C: RESULTS OF ALPHA-BETA MODEL FOR R3

LAWINENAUSLAUFLÄNGE - α/β Modell

Alpha/Beta-Modell nach Lied K., Hopf H., Bakkehoi S., Weiler Ch. (1995)

modifiziert nach Granig M., Sandersen F. (2006)

Programmversion: 2.03

(c) 2006-2009 Stabstelle für Schnee und Lawinen - WLV

Datei: Percher_avalanche_profile3_Sim1new.pdf

PROJEKT:

Name: Perchertal Avalanche Profil3

Ort: Eben am Achensee

Bearbeiter: Kurt

Datum: 29.06.2011

Herkunft des Längsprofils: aus GIS importiert

Kommentar:

10° Punkt	β	ψ
l = 1849.3m, **h =** 949.8m	25.0°	42.0°

ERGEBNIS NACH 2-PARAMETER FORMEL NACH LIED ET AL.

Regressionsformel: Standard

k1 = 0.946, **k2 =** -0.830, **s =** 1.50

α = k1*β + k2 = 22.8°

α + SD = 21.3°

n = -1

SD = n*s = -1.5°, **s =** 1.5°

Schnittpunkt α: Länge l = 2100.3m, Seehöhe h = 928.5m

Schnittpunkt α + SD: Länge l = 2266.5m, Seehöhe h = 927.6m

APPENDIX C: RESULTS OF ALPHA-BETA MODEL FOR R3

ERMITTLUNG DER ANZAHL DER STANDARDABWEICHUNGEN:

Bestockung von Hochwald in der Lawinenbahn
Bestockung unter 40% der potentiellen Lawinenbahn
× Bestockung zw. 41-70% der potentiellen Lawinenbahn
Bestockung über 71% der potentiellen Lawinenbahn **-1**

Neigungsverhältnisse im Anbruchgebiet
Durschnittl. Neigung zwischen 30-35°
× Durschnittl. Neigung zwischen 35-45°
Durschnittl. Neigung über 45° **0**

Topographische Geländeausformung im Anbruchgebiet
Schüsselförmige Ausprägung
Gleichförmige Ausprägung
× Gegliederte (rauhe) Ausprägung
Konvexe Ausprägung **0**

Größe der Anbruchfläche
× Groß - > 6ha
Mittel - zwischen 2 - 6ha
Klein - zwischen 1 - 2ha **2**

Ausformung der Lawinensturzbahn (Längsprofil)
× Parabelförmige Sturzbahn
Geradlinige Sturzbahn
Leicht gegliederte Sturzbahn
Stark gegliederte Sturzbahn **2**

Ausformung der Lawinensturzbahn (Querprofil)
× Stark kanalisiert
Schwach kanalisiert
keine Kanalisierung
Konvex **1**

Wind-Exposition des Anbruchgebietes
Windabgewandte Seite (Lee)
× Windeinfluss ohne Schneeverfrachtung
Windexponierte Seite (Luv) **0**

Schneenährgebiet für Schneeverfrachtung in das Anbruchgebiet
Große Nährgebiete
× Mäßige Nährgebiete
Geringe Nährgebiete **0**

Mittlere Jahres-Niederschlagssumme
Größer 1600mm
× Zwischen 1600mm - 1200mm
Zwischen 1200mm - 800mm
Kleiner 800mm **0**

Summe der Punkte (F):

$F = \Sigma T_i + \Sigma K_i = 4$

Anzahl der Standardabweichungen (n):

n = -1

Verteilungsschlüssel:

F	> +10	+9 bis +7	+6 bis +3	+2 bis -2	-3 bis -6	-7 bis -9	< -10
n	-3	-2	-1	0	1	2	α≈30°
Große Auslaufweite <-					-> Kleine Auslaufweite		

Punkteverteilung F:

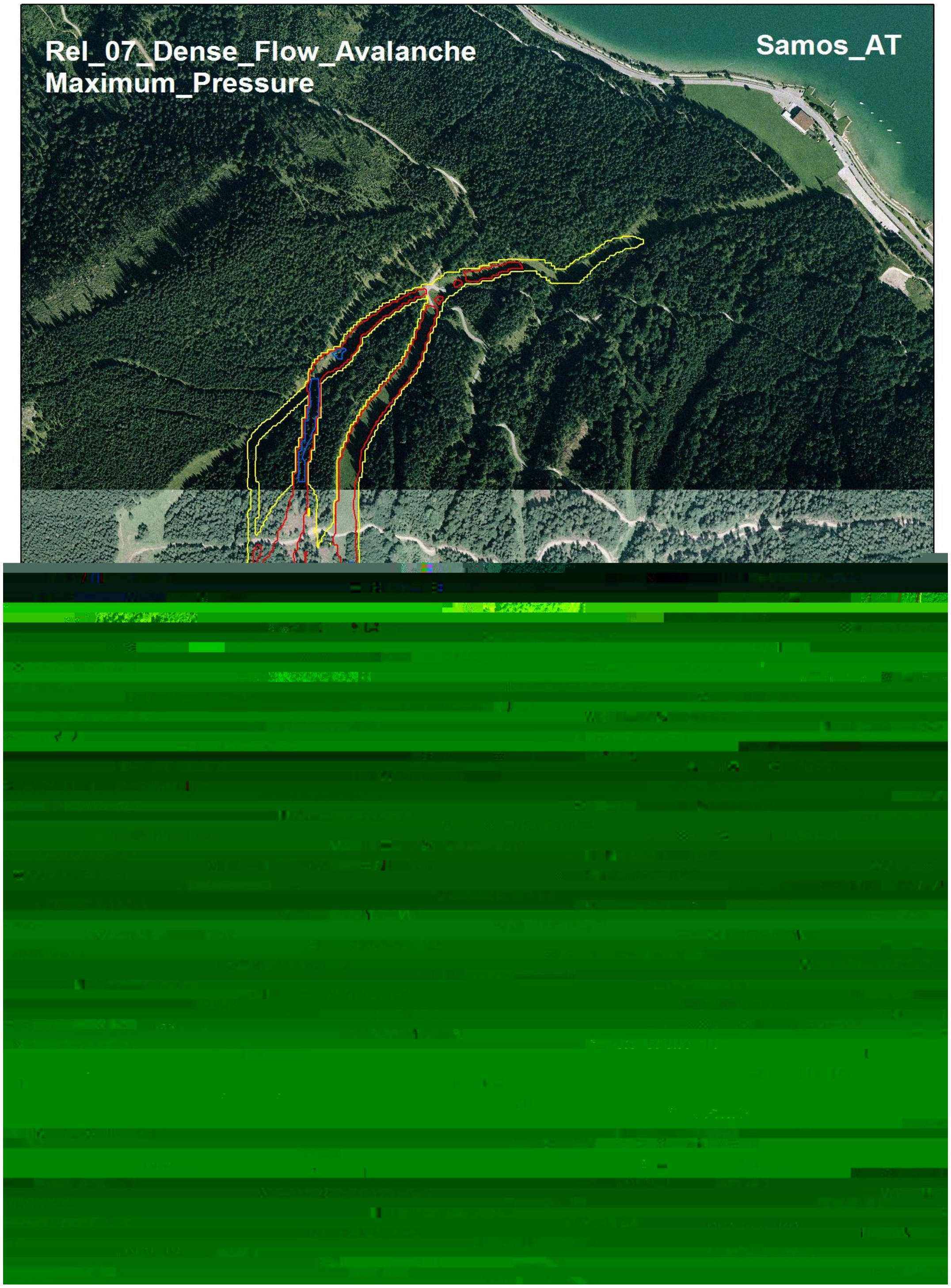
-13 < F < +11

APPENDIX C: RESULTS OF ALPHA-BETA MODEL FOR R3

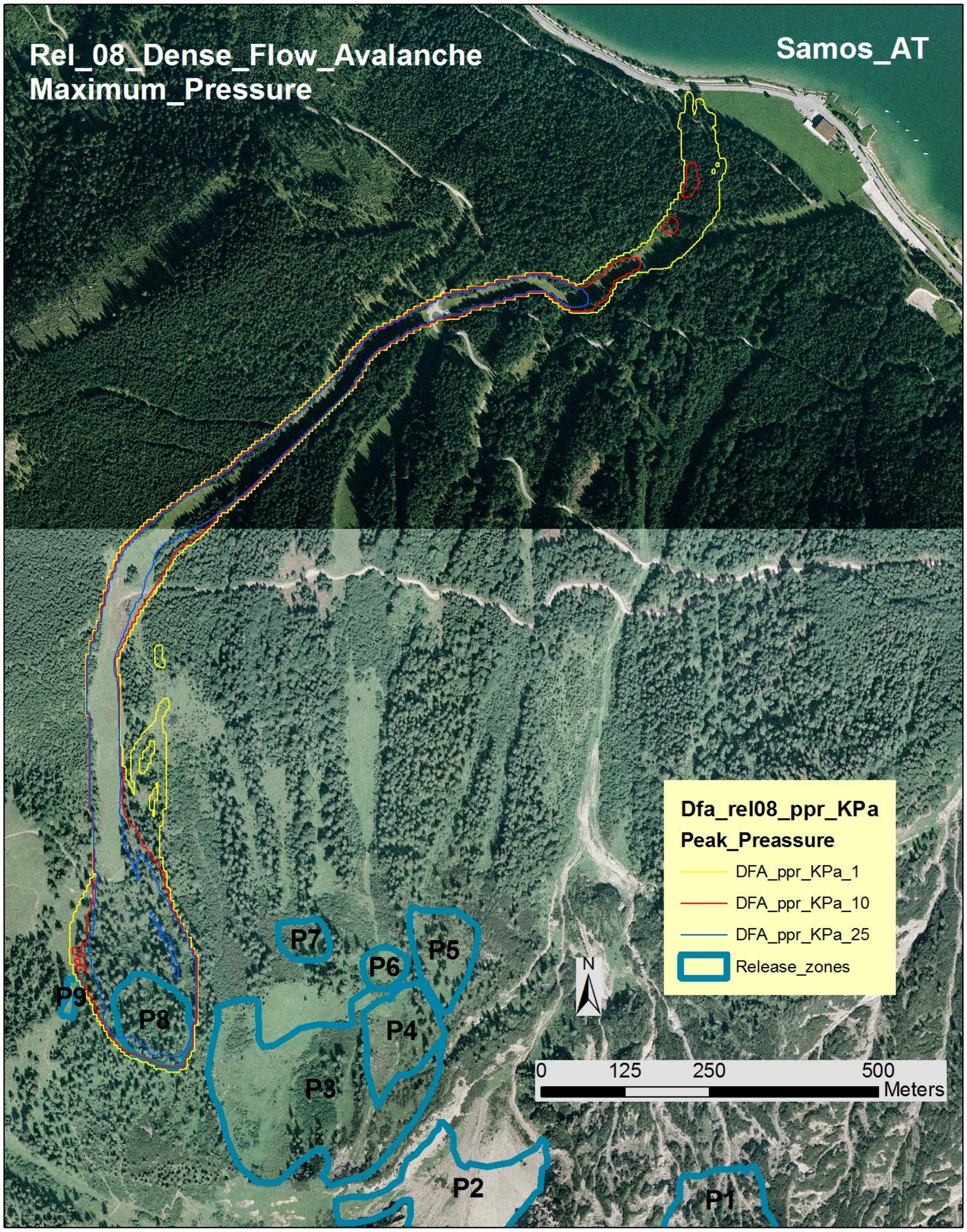
LÄNGSSCHNITT:

Seehöhe	Länge	Neigung	Sch.Länge	dl
1811.66	0.00	0.00	0.00	0.00
1682.17	143.95	41.97	193.62	143.95
1584.08	277.04	36.39	165.33	133.09
1402.68	537.30	34.88	317.24	260.27
1243.14	845.69	27.35	347.21	308.39
1161.12	1056.02	21.30	225.76	210.33
1069.59	1319.96	19.13	279.36	263.94
1039.81	1437.31	14.24	121.07	117.35
989.78	1666.42	12.32	234.51	229.11
949.84	**1849.29**	**12.32**	**187.18**	**182.87**
930.84	1967.44	9.14	119.67	118.15
928.90	2012.50	2.46	45.10	45.06
926.57	2478.63	0.29	466.14	466.13
936.28	3033.20	1.00	554.65	554.57

APPENDIX D: RESULTS OF SAMOS AT MODEL FOR R7

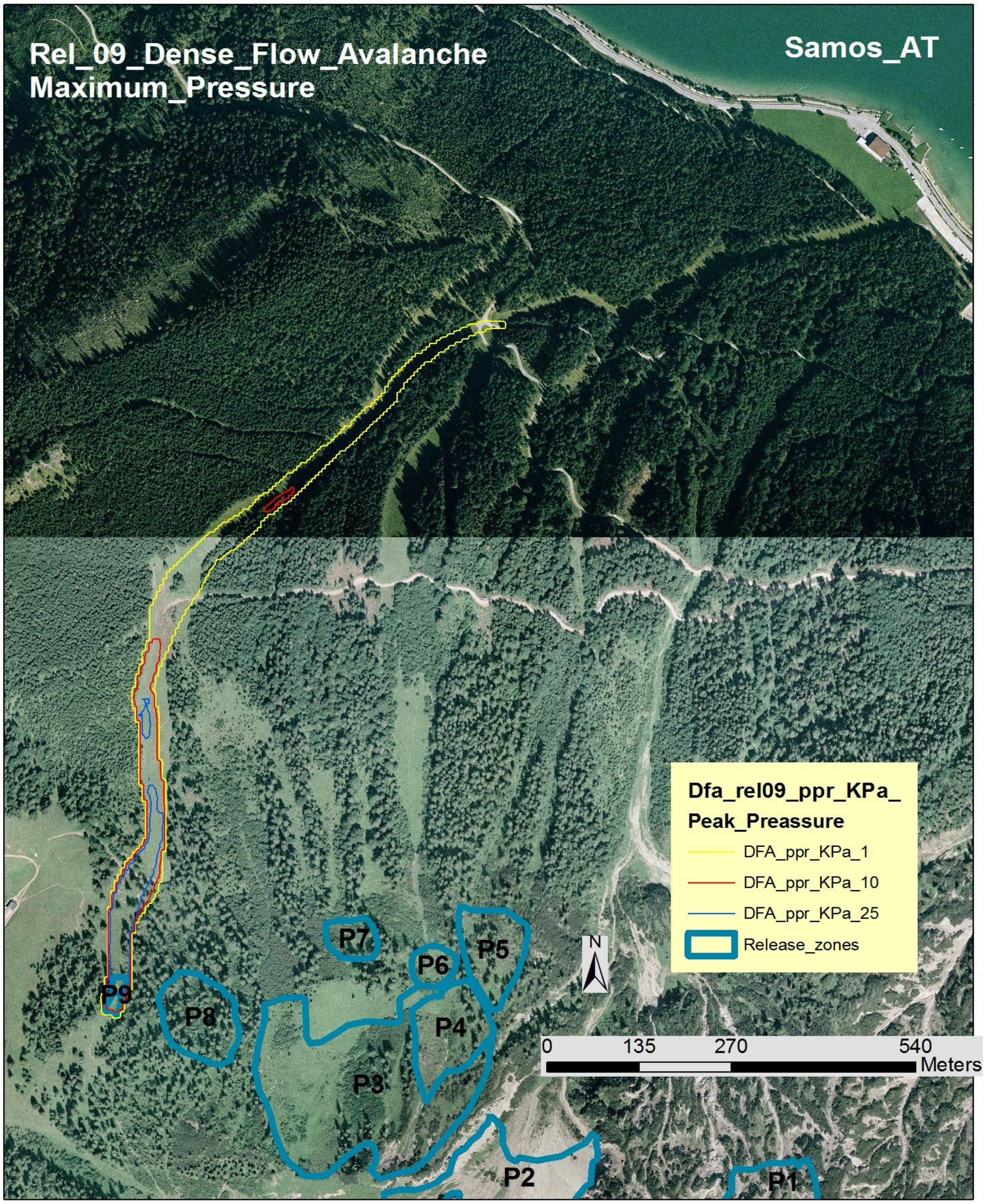


APPENDIX D: RESULTS OF SAMOS AT MODEL FOR R8



AUSTRIAN SERVICE FOR TORRENT AND AVALANCHE *Office of Snow and Avalanche* die.wildbach und lawinenverbauung			
	Date: 30-07-2011	**Researcher: Kurt**	**Perchertal Avalanche**

APPENDIX D: RESULTS OF SAMOS AT MODEL FOR R9



AUSTRIAN SERVICE FOR
TORRENT AND AVALANCHE
Office of Snow and Avalanche
die.wildbach
und lawinenverbauung

Date: 30-07-2011	Researcher: Kurt	Perchertal Avalanche

APPENDIX E: MEAN ANNUAL PRECIPITATION VALUES FOR STATIONS

2005

NL 17

Monats- und Jahressummen der Niederschläge
mit Normalzahlen und Tagesmaxima

Nr.	Messgerät	Messstelle / Messstellennummer	Höhe m ü.A.	Einzugsgebiet	I / VII	II / VIII	III / IX	IV / X	V / XI	VI / XII	Jahr	% der Normalzahl / mm	Beobachtetes Tagesmaximum im und vor dem Berichtsjahr mm	Datum	Größte beobachtete Monatssumme vor dem Berichtsjahr mm	Datum
86		Möggers		Leiblach	102	143	115	162	193	132		90	78,3	22.08.		
		100792	1010		231	**269**	92	74	**53**	134	1700	1893	174,7	10.07.1956	511	07.1957
		DONAUGEBIET OBERHALB DES INN														
87	=	Baad		Iller	213	165	108	122	216	160			171,4	22.08.		
		101543	1305		227	**407**	131	69	**54**	146	2018		142,3	21.05.1999	479	02.1999
88	⊖	Zug		Lech	104	105	64	74	160	119			140,0	22.08.		
		100966	1500		197	**336**	85	44	**42**	118	1448		95,8	21.05.1999	386	02.1999
89		Lech		Lech	139	103	61	63	176	133		96	139,2	22.08.		
		101121	1480		213	**334**	97	46	**39**	129	1533	1602	122,6	21.05.1999	390	02.1970
90	=	Zürs		Lech	117	92	63	63	154	140		85	123,3	22.08.		
		101113	1720		222	**327**	97	45	**41**	149	1510	1779	144,1	20.03.1978	418	02.1970
91	⊖	Warth		Lech	170	124	90	90	181	147			179,0	22.08.		
		101568	1475		219	**398**	106	51	**46**	134	1756		139,7	21.05.1999	481	02.1999
92		Holzgau		Lech	129	71	60	50	139	107		95	150,5	22.08.		
		101154	1100		169	**303**	87	42	**27**	99	1283	1354	116,9	09.01.1914	379	12.1918
93	O	Gramais		Lech	109	75	49	64	122	103		97	77,7	22.08.		
		101162	1320		195	**255**	77	43	**36**	102	1230	1274	93,8	21.05.1999	339	07.1903
94		Boden		Lech	120	86	66	76	133	78		97	97,3	22.08.		
		101170	1355		199	**283**	78	**40**	47	107	1313	1355	110,5	21.05.1999	312	06.2001
95	O	Hinterhornbach		Lech	185	111	76	72	161	98		98	125,2	22.08.		
		101188	1100		244	**327**	108	47	**42**	124	1595	1633	150,2	16.11.1964	514	11.1944
96	E	Vorderhornbach		Lech	129	84	47	75	148	94		96	94,5	22.08.		
		101196	960		179	**255**	84	**37**	38	102	1272	1320	107,5	31.07.1994	452	11.1944
97		Namlos		Lech	147	100	84	91	187	123		108	160,8	22.08.		
		101204	1260		201	**379**	99	**36**	62	131	1640	1520	126,0	21.05.1999	340	02.1970
98		Forchach		Lech	111	68	54	78	164	78		101	128,6	22.08.		
		101212	910		185	**287**	86	44	**40**	99	1294	1283	135,6	21.05.1999	335	05.1999
99	=	Höfen-Oberhornberg		Lech	119	98	83	91	161	76		103	130,1	22.08.		
		101220	870		218	**326**	84	**39**	55	129	1479	1439	169,0	21.05.1999	392	05.1999
100	=	Hahnenkamm-Reutte		Lech	226	152	128	116	233	88			178,5	22.08.		
		101501	1670		231	**464**	109	**50**	88	192	2077		180,0	21.05.1999	465	05.1999
101	⊖	Reutte		Lech	84	81	78	80	154	93		104	189,3	22.08.		
		101238	870		176	**408**	87	**40**	55	80	1416	1360	212,5	21.05.1999	446	05.1999
103	=	Berwang		Lech	157	108	86	83	171	109		113	130,8	22.08.		
		101246	1295		170	**354**	80	**37**	60	111	1526	1356	180,2	21.05.1999	389	05.1999
105	⊖	Tannheim-Untergschw.		Vils	153	107	78	104	202	146		93	136,8	22.08.		
		101261	1090		203	**354**	90	52	**49**	94	1632	1753	158,5	21.05.1999	479	05.1999
106	=	Jungholz		Vils	157	132	99	120	193	115			140,8	22.08.		
		101493	1060		229	**380**	100	71	**56**	123	1775		190,6	21.05.1999	457	05.1999
107	=	Vils		Vils	85	81	86	97	164	88		105	144,7	22.08.		
		101279	810		180	**344**	133	58	**46**	86	1448	1376	121,6	09.08.1970	449	08.2002
110	⊖	Scharnitz		Isar	87	79	51	62	125	99		99	102,0	22.08.		
		101287	970		267	**292**	57	**23**	50	99	1291	1306	162,0	21.05.1999	402	08.1970
111	=	Seefeld in Tirol		Isar	106	90	47	56	117	85		103	88,4	22.08.		
		101295	1200		201	**246**	65	**25**	59	116	1213	1172	116,6	21.05.1999	303	02.1935
113	E	Leutasch-Kirchplatzl		Leutascher Ache	112	95	73	67	137	116		117	129,8	22.08.		
		101303	1135		240	**338**	75	**22**	59	130	1464	1256	141,5	21.05.1999	333	08.1970
116	=	Hinterriß		Rißbach	112	112	90	106	180	129		108	121,4	22.08.		
		101311	930		273	**364**	83	**37**	82	123	1691	1572	150,0	19.07.1981	409	07.1955
124	⊖	Pertisau ←		Achensee	109	122	76	101	153	96		105	110,5	22.08.		
		101337	935		275	**350**	77	**29**	64	149	1601	1526	130,8	30.05.1940	446	07.1981
126	⊖	Achenkirch		Ache	104	112	71	108	149	82		103	84,4	22.08.		
		101345	905		240	**293**	75	**29**	62	137	1462	1420	134,9	08.05.1912	396	07.1954
129		Ehrwald		Loisach	89	90	79	67	123	86		104	121,6	22.08.		
		101485	960		205	**324**	75	**35**	45	79	1297	1249	142,5	09.01.1914	361	08.1937
130	⊖	Hall in Tirol		Inn	37	42	**22**	60	83	110			76,2	04.07.		
		120022	585		**214**	166	75	28	46	71	954		40,0	03.10.2003	147	10.2003
		INNGEBIET OBERHALB DER SALZACH														
131	=	Nauders		Inn	45	21	**16**	44	61	33		96	62,8	22.08.		
		101709	1360		87	**147**	46	60	22	61	643	670	91,0	13.08.1948	234	05.1983

APPENDIX E: MEAN ANNUAL PRECIPITATION VALUES FOR STATIONS (CONTINUED)

NL 2

2004

Hydrographisches Verzeichnis der Niederschlags- und Lufttemperaturmessstellen mit Evidenzdaten

Nr.	Messgerät	Messstelle		Messstellennummer	Einzugsgebiet	Land	Höhe m ü.A.	Geographische Koordinaten Länge	Geographische Koordinaten Breite	Beobachtungsbeginn Niederschlag	Beobachtungsbeginn Lufttemperatur	Seite: Niederschlagssummen	Niederschlagshäufigkeiten	Niederschlags- und Trockenperioden	Schneeverhältnisse	Schneehöhenhäufigkeiten	Schneewasserwerte	Starkniederschläge	Lufttemperaturmittel	Lufttemperaturhäufigkeiten	Verdunstung
93	O	Gramais		101162	Lech	T	1320	10 32	47 16	1895		17	50	63	76	86	97	105			
94		Boden		101170	Lech	T	1355	10 36	47 17	1957		17	50	63	76	86	97				
95	O	Hinterhornbach		101188	Lech	T	1100	10 27	47 22	1900		17	50	63	76	86		105			
96	E	Vorderhornbach		101196	Lech	T	960	10 33	47 22	1896	1981	17	50	63	76	86			111	122	130
97		Namlos		101204	Lech	T	1260	10 40	47 21	1900		17	50	63	76	86					
98		Forchach		101212	Lech	T	910	10 35	47 25	1895		17	50	63	76	86					
99	=	Höfen-Oberhornberg		101220	Lech	T	870	10 41	47 28	1895	1895	17	50	63	76	86			111	122	
100	=	Hahnenkamm-Reutte		101501	Lech	T	1670	10 39	47 29	1986	1986	17	50	63	76	86			111	122	
101	⊖	Reutte	ZAMG	101238	Lech	T	870	10 44	47 30	1895	1923	17	50	63	76	86		105	111	122	
102	T	Ammerwald		119479	Archbach	T	1090	10 50	47 32	1992		101									
103	=	Berwang		101246	Lech	T	1295	10 45	47 24	1895	1895	17	50	63	76	86			111	122	
104	T	Traualpsee	EW.SCH	119347	Vils	T	1660	10 31	47 27	1990		101									
105	⊖	Tannheim-Untergschw.		101261	Vils	T	1090	10 30	47 30	1895	1895	17	50	63	76	86		105	111	122	
106	=	Jungholz		101493	Vils	T	1060	10 27	47 35	1980	1980	17	50	63	76	86			111	122	
107	=	Vils		101279	Vils	T	810	10 38	47 33	1948	1948	17	50	63	76	86			111	122	
108	T	Kastenalm		119354	Isar	T	1230	11 26	47 22	1991		101									
109	T	Bodenwald		119362	Isar	T	1280	11 21	47 20	1991		101									
110	⊖	Scharnitz		101287	Isar	T	970	11 16	47 23	1895	1963	17	50	63	76	87		105	111	122	
111	=	Seefeld in Tirol	ZAMG	101295	Isar	T	1200	11 11	47 20	1895	1896	17	50	63	76	87			111	122	
112	T	Wettersteinhütte		119644	Leutascher Ache	T	1700	11 06	47 23	1996		101									
113	E	Leutasch-Kirchplatzl		101303	Leutascher Ache	T	1135	11 09	47 22	1997	1995	17	50	63	76	87		105	111	122	130
114	T	Großer Ahornboden		119446	Rißbach	T	1170	11 34	47 25	1992		101									
115	T	Graßlegerbichl		119370	Rißbach	T	1749	11 27	47 26	1991		101									
116	⊖	Hinterriß		101311	Rißbach	T	930	11 28	47 28	1895	1957	17	50	63	76	87	97		111	122	
117	T	Ochsenhütte	TIWAG	101477	Dürrach	T	1460	11 31	47 30	1960		101									
118	T	Lochalm ML	TIWAG	101469	Dürrach	T	1430	11 36	47 31	1961		101									
119	T	Kotalm NL	TIWAG	101402	Achensee	T	1300	11 43	47 28	1951		101									
120	T	Köglalm	TIWAG	119537	Achensee	T	1487	11 44	47 30	1994		101									
121	T	Plums-Bärental	TIWAG	101386	Achensee	T	1235	11 38	47 27	1951		101									
122	T	Gramai NL	TIWAG	101360	Achensee	T	1330	11 37	47 24	1951		101									
123	T	Bärenbad	TIWAG	101394	Achensee	T	1480	11 42	47 25	1951		101									
124	⊖	Pertisau	TIWAG	101337	Achensee	T	935	11 42	47 27	1900	1986	17	50	63	76	87			111	122	
125	T	Hochstögen	TIWAG	101444	Achensee	T	1350	11 39	47 31	1951		101									
126	⊖	Achenkirch	TIWAG	101345	Ache	T	905	11 42	47 32	1895	1971	17	51	64	76	87			111	122	
127	T	Gufferthütte	TIWAG	101436	Ache	T	1415	11 48	47 35	1960		101									
128	T	Achenkirch-M.köpfl		101550	Ache	T	900	11 38	47 35	1998	2000	101									
129		Ehrwald	ZAMG	101485	Loisach	T	960	10 55	47 24	1895	1930	17	51	64	76	87	97		111	122	
130	⊖	Hall in Tirol		120022	Inn	T	585	11 30	47 17	2002	2002	17	51	64	76	87		105	111	122	

INNGEBIET OBERHALB DER SALZACH

Nr.	Messgerät	Messstelle		Messstellennummer	Einzugsgebiet	Land	Höhe m ü.A.	Länge	Breite	Niederschlag	Lufttemperatur	Niederschlagssummen	Niederschlagshäufigkeiten	Niederschlags- und Trockenperioden	Schneeverhältnisse	Schneehöhenhäufigkeiten	Schneewasserwerte	Starkniederschläge	Lufttemperaturmittel	Lufttemperaturhäufigkeiten	Verdunstung
131	=	Nauders	TIWAG	101709	Inn	T	1360	10 30	46 53	1895	1995	17	51	64	77	87			111	122	
132	=	Spiss		101717	Schalklbach	T	1540	10 27	46 57	1911	1992	18	51	64	77	87			111	122	
133	W	Pfunds	TIWAG	103275	Inn	T	995	10 31	46 57	1982	1982	18	51	64					111	122	
134	T	Hohenzollernhaus	TIWAG	101741	Radurschlbach	T	2200	10 39	46 54	1957		101									
135	T	Nauderer-Tschey	TIWAG	119099	Radurschlbach	T	1920	10 35	46 54	1980		101									
136	T	Furgglersee	TIWAG	101766	Inn	T	2330	10 32	47 03	1955		101									
137		Ried im Oberinntal		101790	Inn	T	880	10 40	47 03	1886		18	51	64	77	87					
138	⊖	Fendels	TIWAG	101808	Inn	T	1356	10 41	47 03	1957	1966	18	51	64	77	87			111	122	
139	T	Zirmesköpfl	TIWAG	101758	Inn	T	2050	10 41	47 02	1957		101									
140	⊖	Prutz	TIWAG	102947	Inn	T	870	10 40	47 04	1972	1972	18	51	64	77	87			111	122	
141	T	Rauher Kopf	TIWAG	101774	Fagge	T	2670	10 46	46 52	1957		101									
142	T	Glockturm	TIWAG	101782	Fagge	T	2800	10 42	46 54	1969		101									
143	T	Weisssee	TIWAG	101824	Fagge	T	2540	10 43	46 52	1957		101									
144	T	Oberbirg-s'Gliger	TIWAG	119107	Fagge	T	2160	10 44	46 53	1980		101									
145	T	Gepatschalpe	TIWAG	101832	Fagge	T	1900	10 44	46 54	1957		101									
146	T	Wurmetal	TIWAG	101857	Fagge	T	2510	10 46	46 56	1957		101									
147	T	Kaiserbergtal	TIWAG	101840	Fagge	T	2330	10 42	46 55	1957		101									
148	T	Nassereinalpe	TIWAG	119115	Fagge	T	2050	10 44	46 56	1980		101									
149	=	Kaunertal-Feichten		101873	Fagge	T	1314	10 45	47 02	1880	1964	18	51	64	77	87			111	122	
150	T	Verpeilhütte	TIWAG	101865	Fagge	T	2045	10 47	47 01	1957		101									
151	E	Ladis-Neuegg		101816	Inn	T	1350	10 39	47 06	1911	1998	18	51	64	77	87	97		111	122	130
152	W	Runserau	TIWAG	101881	Inn	T	860	10 39	47 07	1957	1957	18	51	64					112	122	
153	T	Salzhütte	EW.STA	119289	Rosanna	T	1510	10 13	47 06	1988		101									
154	T	Kartellboden	EW.STA	119701	Rosanna	T	1980	10 16	47 04	1997		101									
155	=	St.Anton am Arlberg	ZAMG	101964	Rosanna	T	1298	10 17	47 08	1872	1978	18	51	64	77	87	97		112	122	
156		Flirsch		101519	Rosanna	T	1150	10 25	47 09	1990		18	51	64	77	87					
157	T	Bieltal	VIW	101907	Trisanna	T	2500	10 08	46 54	1951		101									
158	T	Jamtalferner-Rußkopf	VIW	101915	Trisanna	T	2690	10 10	46 52	1951		101									
159	T	Jamtalferner (Zunge)		119305	Trisanna	T	2400	10 10	46 52	1988		101									
160	T	Fluchthornferner	VIW	101923	Trisanna	T	2750	10 13	46 53	1951		101									
161	⊖	Galtür	ZAMG	101949	Trisanna	T	1587	10 11	46 58	1895	1896	18	51	64	77	87	97		112	122	
162	T	Piz da Val Gronda	VIW	101931	Trisanna	T	2810	10 17	46 55	1951		101									
163	⊖	Kappl-Oberhaus		119792	Trisanna	T	1500	10 23	47 04	1999	1999	18	51	64	77	87			112	122	
164		See im Paznaun		101956	Trisanna	T	1040	10 28	47 05	1895	1959	18	51	64	77	87			112	122	
165	⊖	Landeck	ZAMG	101899	Inn	T	785	10 34	47 09	1872	1896	18	51	64	77	87			112	122	
166	⊖	Nassereith		102954	Gurglbach	T	850	10 50	47 19	1974	1974	18	51	64	77	87		105	112	122	
167	T	Marienbergalm		119297	Gurglbach	T	1640	10 54	47 21	1992		101									
168		Imst (Oberstadt)		102004	Gurglbach	T	860	10 44	47 15	1885	1948	18	51	64	77	87			112	122	
169	⊖	Pitztaler Gletscher	ZAMG	101535	Pitze	T	2850	10 53	46 56	1993	1993	18	51	64	77	87		105	112	122	
170	T	Braunschweiger Hütte	TIWAG	119529	Pitze	T	2740	10 55	46 56	1994		101									
171	T	Ölgrubensee	TIWAG	119123	Pitze	T	2850	10 47	46 54	1980		101									
172	T	Taschachhaus	TIWAG	102020	Pitze	T	2470	10 49	46 55	1960		101									
173	T	Riffelferner	TIWAG	119214	Pitze	T	2740	10 49	46 57	1981		101									
174	T	Riffelseehütte	TIWAG	102038	Pitze	T	2240	10 51	46 58	1959		101									
175		Plangeroß		102046	Pitze	T	1620	10 52	46 59	1909		18	51	64	77	87					
176	T	Kaunergrathütte	TIWAG	119149	Pitze	T	2520	10 50	46 59	1980		101									
177	⊖	St.Leonhard i.P.-N.	TIWAG	103283	Pitze	T	1462	10 52	47 01	1982	1982	18	51	64	77	87			112	122	
178		St.Leonhard i.P.		102061	Pitze	T	1335	10 50	47 05	1907		18	51	64	77	87					
179	=	Jerzens-Ritzenried		102079	Pitze	T	1120	10 47	47 07	1895	2000	18	51	64	77	87			112	122	
180	⊖	Piller	TIWAG	103028	Pitze	T	1315	10 42	47 08	1956	1979	18	51	64	77	87			112	122	
181	T	Hintereisferner	IFM	102087	Rofenache	T	2970	10 46	46 48	1951		101									
182	T	Latschbloder	IFM	102178	Rofenache	T	2910	10 48	46 48	1966		101									
183	T	Rofenberg	IFM	102095	Rofenache	T	2827	10 48	46 48	1957		101									
184	T	Proviantdepot	IFM	102103	Rofenache	T	2737	10 49	46 50	1951		101									
185	T	Hochjochhospiz	IFM	102111	Rofenache	T	2360	10 50	46 49	1951		101									
186	T	Vernagtbrücke	IFM	102152	Rofenache	T	2640	10 50	46 51	1966		102									
187	T	Vent	IFM	102194	Rofenache	T	1900	10 55	46 51	1970		102									
188	⊖	Vent	IFM	102202	Venter Ache	T	1906	10 55	46 52	1867	1900	18	51	64					112	122	

CURRICULUM VITAE

Tayfun Kurt was born in district of Üsküdar in İstanbul, Republic of Turkey in 1986. He completed his primary school education in İstanbul in 2000. He then attended the life sciences high school and graduated in 2004.

He completed his undergraduate degree at Istanbul University Forest Engineering Faculty of Forestry in 2009. He has been at Mendel University in Brno, Czech Republic as Socrates Erasmus student for 2 semesters between 2006/2007 and he is still master student at the University of Natural Resources and Applied Life Sciences, Vienna.