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Master Thesis

AVALANCHE MITIGATION MEASURES IN TURKEY
CASE STUDY OF AYDER

presented by
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THESIS DECLARATION

I affirm that I have written my master thesis and have not used any sources or aids other than those indicated. I certify that the master thesis was not submitted either nationally or internationally in any form.

Date:

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LIST OF SYMBOLS

CBR	: Cost and Benefit Ratio
CBA	: Cost and Benefit Analysis
B-C	: Benefit-cost
DTM	: Digital Terrain Model
DSM	: Digital Surface Model
DFA	: Dense Flow Avalanche
DFL	: Dense Flow Layer
H	: Snow Height
RAMMS	: Rapid Mass Movements Simulation
SAMOS AT	: Snow Avalanche Modelling and Simulation Austria
NE	: North - East
SW	: South - West
AFAD	: Disaster and Emergency Management Presidency in Turkey
%	: Percentage
Hk	: Structure Height
ONR 24806	: Design of structure, Austrian Standards Institute.

ABSTRACT

Snow avalanches threaten human life, settlements, infrastructure facilities, and other important structures in high mountainous areas. For many years various studies have been carried in order to develop preventive measures aiming to minimize the avalanche hazard.

The current study represents the starting point for developing avalanche mitigation measures in the Ayder Plateau area, which is located in the north east of Turkey. This is important because ….

Avalanche starting zones (or release areas) were found by performing an ArcGIS analysis using a 1.4 m resolution digital elevation model (DTM) obtained from drone images. The avalanche starting zones from the ArcGIS analysis were fed into the avalanche simulation models Ramms and SamosAT. The simulations performed with the avalanche simulation models allowed calculating avalanche runout lengths and avalanche impact pressures, the latter defining the avalanche hazard zones. As there are no systematic historical avalanche records available, I verified the model results by considering silent witnesses and by interviewing inhabitants.

According to the results of the avalanche simulation models, avalanche mitigation measures for the Ayder Plateau area were developed. In particular, I suggest to generate a hazard map defining yellow and red zones with respect to avalanche hazard. Moreover, I planned snow bridges as well as wind fences in the avalanche release areas. For the case of an extraordinary hazardous avalanche situation, a plan for evacuating the people from the building in the endangered areas should be prepared. However, the evacuation plan should only be used as an adjunct to permanent protection because evacuation of people from the dangerous areas is a very difficult and time-consuming process.

Finally, I performed a benefit and cost analysis (B-C analysis) of the planned protection measures. The B-C analysis shows that the planned protection measures are suitable. The hazard mapping and protection measures should be implemented within a short time because the number of buildings in the danger zone increases day by day due to the lack of hazard maps so the amount of loss will increase in any possible future avalanche events.

GERMAN ABSTRACT

In Hochgebirgsregionen bedrohen Schneelawinen Menschenleben, Siedlungen, Infrastruktureinrichtungen und andere wichtige Strukturen. Seit vielen Jahren werden daher verschiedene Studien durchgeführt, um präventive Maßnahmen zur Minimierung der Lawinengefahr zu entwickeln.

Die aktuelle Studie stellt den Ausgangspunkt für die Entwicklung von Lawinenabbaumaßnahmen im Ayder Plateau im Nordosten der Türkei dar. Dies ist wichtig, weil:

Mit Drohnenbildern, zu deren Gewinnung ein digitales Höhenmodell (DTM) mit einer Auflösung von 1,4 verwendet wurde, wurde eine ArcGIS-Analyse durchgeführt bei der Avalanche Startzonen (oder Freisetzungsbereiche) gefunden wurden. Die Lawinenstartzonen aus der ArcGIS-Analyse wurden in die Lawinen-Simulationsmodelle Ramms und SamosAT eingespeist. Die mit den Lawinen-Simulationsmodellen durchgeführten Simulationen erlaubten die Berechnung von Lawinenauslauflängen und Lawinenaufpralldruck, wobei letzterer die Lawinenwarnzonen definiert. Da keine systematischen historischen Lawinenverläufe zur Verfügung stehen, habe ich die Modellergebnisse überprüft, indem ich Zeugen berücksichtigt und Bewohner interviewt habe.

Auf Basis der Ergebnisse der Lawinen-Simulationsmodelle, wurden Lawinenabbaumaßnahmen für das Ayder-Plateau-Gebiet entwickelt. Insbesondere schlage ich vor, eine Gefahrenkarte zu erstellen, die gelbe und rote Zonen in Bezug auf die Lawinengefahr definiert. Außerdem habe ich Schneebrücken sowie Windzäune in den Lawinenabwurfgebieten geplant. Für den Fall einer außergewöhnlichen Lawinenlage sollte ein Plan für die Evakuierung der Menschen aus Gebäuden in den gefährdeten Gebieten erstellt werden. Der Evakuierungsplan sollte jedoch nur als Ergänzung zu einem dauerhaften Schutz verwendet werden, da die Evakuierung von Personen aus den gefährlichen Gebieten ein sehr schwieriger und zeitaufwändiger Prozess ist.

Zum Abschluss habe ich eine Nutzen-Kosten-Analyse (B-C-Analyse) der geplanten Schutzmaßnahmen durchgeführt. Die B-C-Analyse zeigt, dass die geplanten Schutzmaßnahmen geeignet sind. Die Maßnahmen zur Gefahrenkartierung und -sicherung sollten schnellstmöglich umgesetzt werden, da die Zahl der Gebäude in der Gefahrenzone aufgrund fehlender Gefahrenkarten Tag für Tag steigt, so dass sich die Schadenhöhe bei möglichen Lawinenereignissen in Zukunft erhöhen wird.

1. INTRODUCTION

1.1. Snow Avalanches

One of the natural disasters is snow avalanche, which can be described as high amount of snow moving down on the sloping surface of a mountain under gravity force. It causes human, economic and environmental losses. *[Sauermoser, Rudolf-Miklau, Mears, 2015]*. It is necessary for various conditions to co-exist in order for the avalanche event to take place. These three conditions are an instability in the snow cover layer, suitability of the terrain for avalanche initiation and weather conditions, as shown Figure 1.

In recent years, the importance of this natural hazard has increased because of the increase in winter tourism and sports and the necessity of reaching these tourist attractions as well as the increasing importance of transportation in the globalizing world and the influence of the avalanches on the people.

Figure 1: The avalanche triangle

1.1.1. Classification

There are two types of avalanches called loose snow avalanches and slab avalanches. Starting point of loose snow avalanches is on snow surface. They are also called as point release avalanches. Between 30-60 slope angle is needed for loose snow avalanche initiation. It is generally not a dangerous type of avalanche *[McClung and Schaerer, 2006]*.

Second type is slab avalanches which are more dangerous than loose snow avalanches. Slab avalanches are initiated by failure of weak layer into the snow cover over the large area. Starting place of slab avalanches are delimited by crown surface, flank surface, stauchwall. *[McClung and Schaerer, 2006]*. Slab avalanches are extremely threatening for the backcountry skiers. It is called human triggered avalanches in Europe and North America.

1.2. Avalanche Control Measures

There is a need for mitigation measures to reduce human losses and protect their goods. While temporary avalanche protection measures are used to mitigate current avalanche danger for a specific duration of time, permanent ones enable long-term protection. They are also divided into active and passive classes within themselves. While active measures act directly on the flow process, passive measures mitigate the consequences of avalanche hazards, as shown Figure 2.

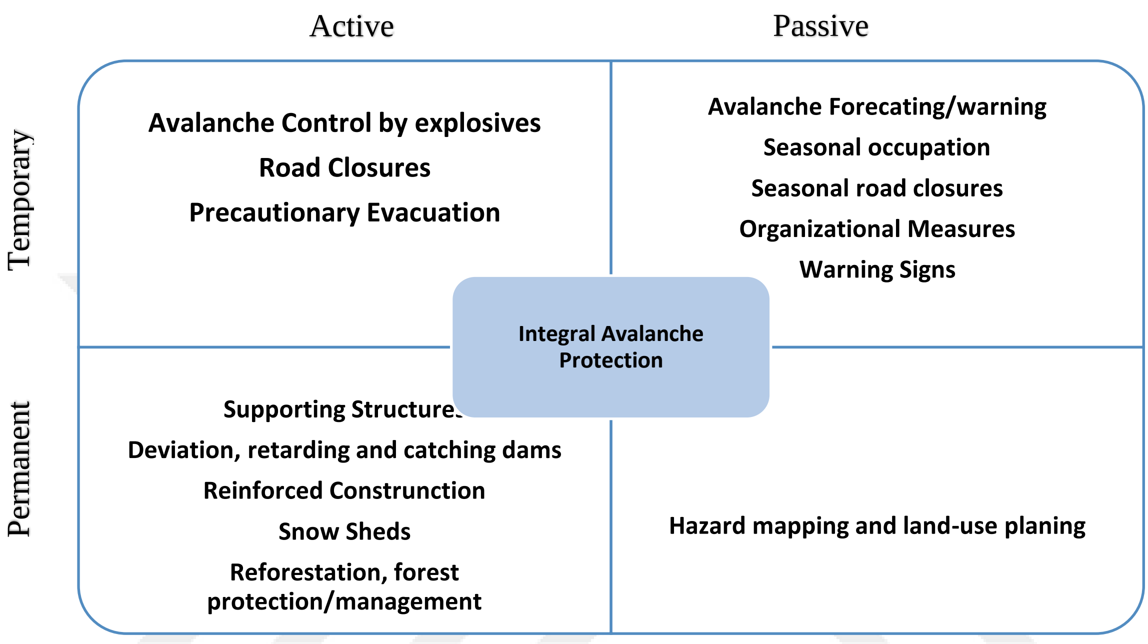


Figure 2: Classification of Avalanche Mitigation Measures *(McClung And Schaere, 2006)*

1.3. Hazard Mapping

Avalanche is a natural event. Thus, this phenomenon causes the natural disasters because of the unplanned land-use in which settlements are influenced and the inadequate knowledge of people about avalanches. Hazard maps can be used to identify areas of potential avalanche path, run-out zones and identify important facilities such as structures on the avalanche track, residential areas, transportation routes, energy transmission lines. If the areas under the threat of avalanches, hazard mapping is a necessary measurement for these areas.

There are 3 steps for making hazard zoning:

- Drawing avalanche path
- Identify run-out areas
- Restriction of certain areas

Austrian standards for Avalanche hazard mapping is used in this thesis, as shown Table 1.

1.3.1 Red Hazard zone: Red zone shows that the area is at risk by avalanche so permanent use of the place should not be allowed for new settlement, infrastructure, entrainment (ski areas) and transportation purposes. Existing building and structures must be protected by control mitigations (snow bridge, snow nets, afforestation etc.) or evacuation plans must be implemented.

1.3.2. Yellow Hazard Zone: the use of these areas is feasible but it is necessary to protect structures which are made in these areas with various measures.

Zone	Return Period	Avalanche Pressure
Red Zone	1-150 Years	≥ 10kN/m²
Yellow Zone	1-150 Years	1 - 10 kN/m²

Table 1: Austrian Hazard Mapping *(F.Rudolf-Miklau, S.Sauermoser, A.I. Mears, 2015)*

To interpret the hazards zones (red and yellow zones), typical damage levels below of avalanche impact pressure are expected, as shown Table 2.

IMPACT PRESSURE (KPA)	POTENTIAL DAMAGE
1	Break Windows
5	Push in doors
30	Destroy wood-framed structures
100	Uproot mature spruce
1000	Move reinforced – Concrete Structure

Table 2: Relationship between impact pressure and potential damage of avalanche *(McClung And Schaere, 2006)*

In field analyses, rough impact pressure can be estimated from the silent witness (damaged trees, broken branch, J shape trees) or damaged building.

2. Methodology of Research

This thesis is consisting of field trips and office work. The goal of the study is to reduce the future impacts of the hazard, loss of life, property damage, and environmental damage. The concept behind the thesis is based on general assessment of avalanche control methods and risk assessment steps as follows;

- Avalanche paths were identified with interviews, field studies, remote sensing (drone images) methods.
- Using the ArcGIS program, various information about the region was obtained with the help of Digital elevation model, and an algorithm was also used in ArcGIS to identify potential avalanche starting points and areas.
- Using avalanche simulation programs, avalanche roads and avalanche run-out zones were determined and avalanche hazard maps were prepared in 1/1000 scale according to these regions.

- Based on using simulation results, the number of the people living in that area and number of buildings obtained by interviewing the residents living in the area affected by the avalanche.
- In the final part, some mitigation measures were designed and recommended and cost/benefit analysis was carried out to determine whether the project was suitable or not.

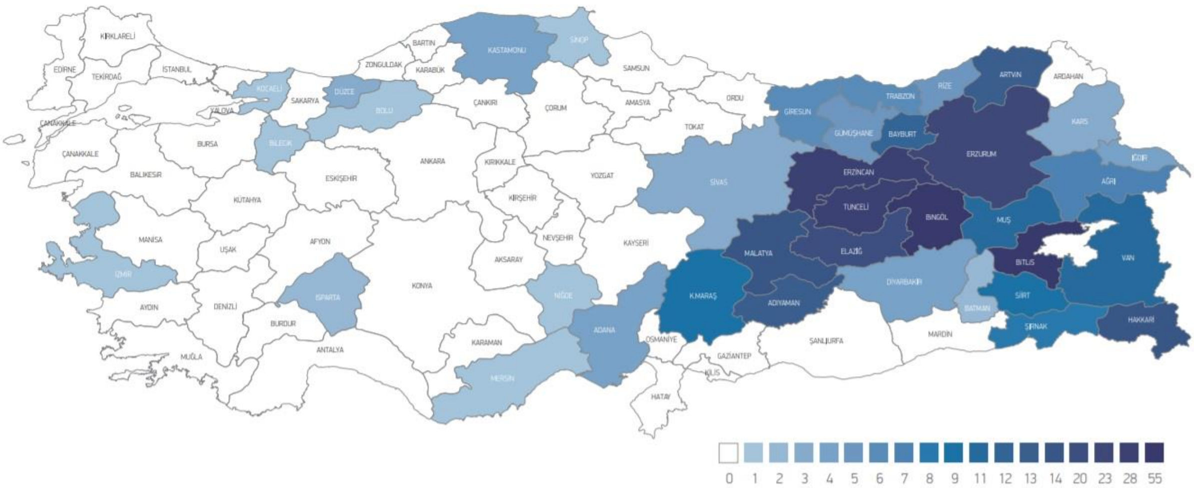


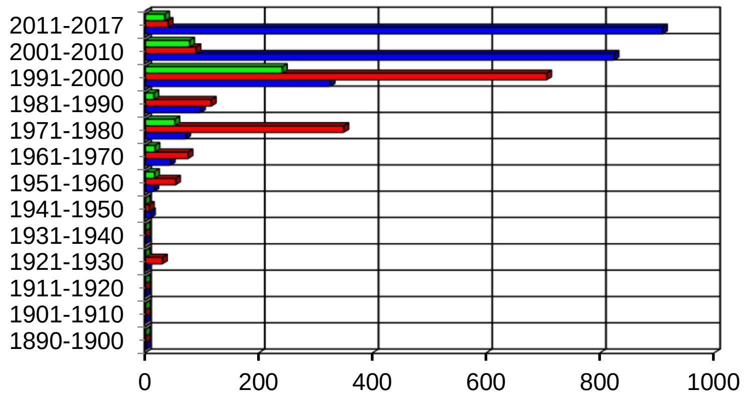
Figure 3: Number of regional avalanche events in Turkey *(AFAD)*

2.1. Description of Study Area (Turkey)

About twenty-five percent of the world's land surfaces cover mountainous areas. Approximately one-third of Turkey's land surface is mountainous areas with an average altitude of 1131 m above sea level, Turkey is one of the highest countries compared to the other world countries. The average height in Asia is 1050 m, in Europe 330 m and 1131 m in Turkey**.** ***(Ministry of environment and urbanization in Turkey)***

The mean elevation has an asymmetric distribution throughout the country and is covered with mountainous processes on the geological time scale, covering the north and south coastal mountains, and the eastern part of the country is higher than the western part of the country. As the elevated altitude brings with it the low air temperature, more frequent snowfalls and associated avalanche occurrences are encountered in these sections.

In the eastern part and the north-northeast of Turkey appropriate topographical and meteorological conditions for avalanche occurrences. The area of lands suitable for avalanche formation has a very high percentage in these regions, as shown Figure 3. Avalanches in these regions threaten settlements, roads, tourist facilities and all other state investments. The effect of the avalanche event on the settlements is as social and economic as any disaster type. In terms of giving an idea about the social effects of avalanches in Turkey; Since 1890, 2298 avalanche events have taken place and many people have died and most of them have lost their houses.



	1890-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2017
Injured	0	0	0	0	0	0	16	17	52	15	241	78	34
Dead	0	0	0	30	0	7	53	75	349	116	706	89	40
Number of Events	1	0	0	2	0	9	15	44	71	97	325	824	909

Figure 4: Number of Injured, Dead and Events in Turkey from 1890 to 2017

Annually, about 20 people are killed by snow avalanches in Turkey, as shown Figure 4. Most of the people died because of the avalanches are people in their houses in the settlement areas and second of that are soldiers, as shown Figure 5. *[Ministry Disaster and Emergency Management Authority, 2015]*

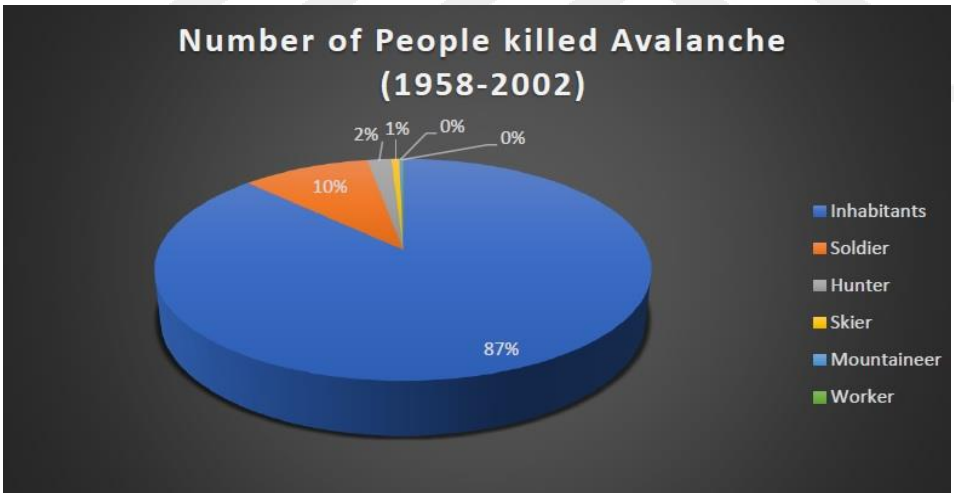


Figure 5: Categorization of people who died due to avalanche (AFAD)

2.1.1. Climate of Turkey

There are certain number of air masses located in and around Turkey. Turkey's weather and climate conditions are mainly involved in these air masses. While polar air masses in winter are influential, tropical air masses are effective over the summer months, as shown Figure 6.

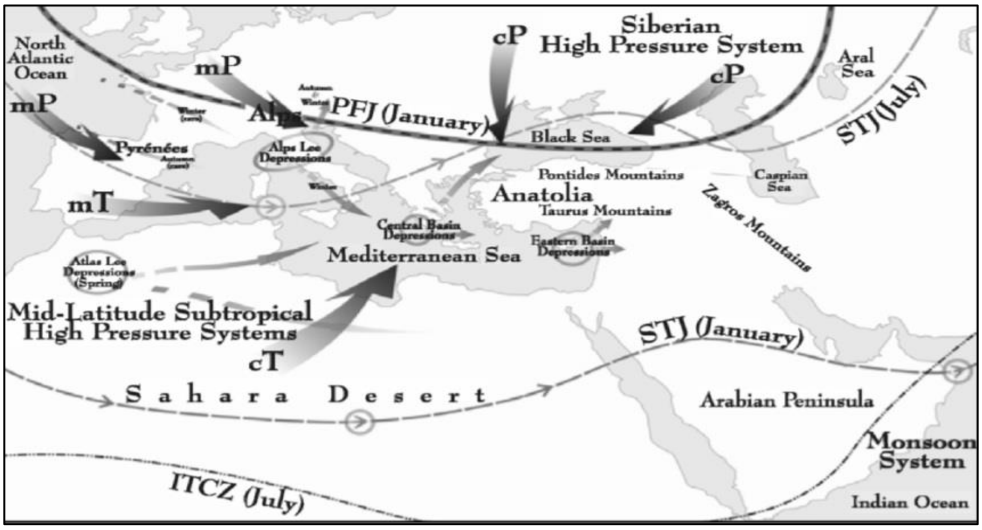


Figure 6: cP: Continental Polar Air Mass; mP: Marine Polar Air Mass ***(Akçar and Schlüchter, 2005)***

2.1.1.1. Continental polar air mass(cP): The air mass comes from Siberia, brings cold and dry air. In the winter months it caused fog and avalanches. By getting moisture while passing the Black Sea, sometimes it can make orographic precipitation on the shores of the Black Sea.

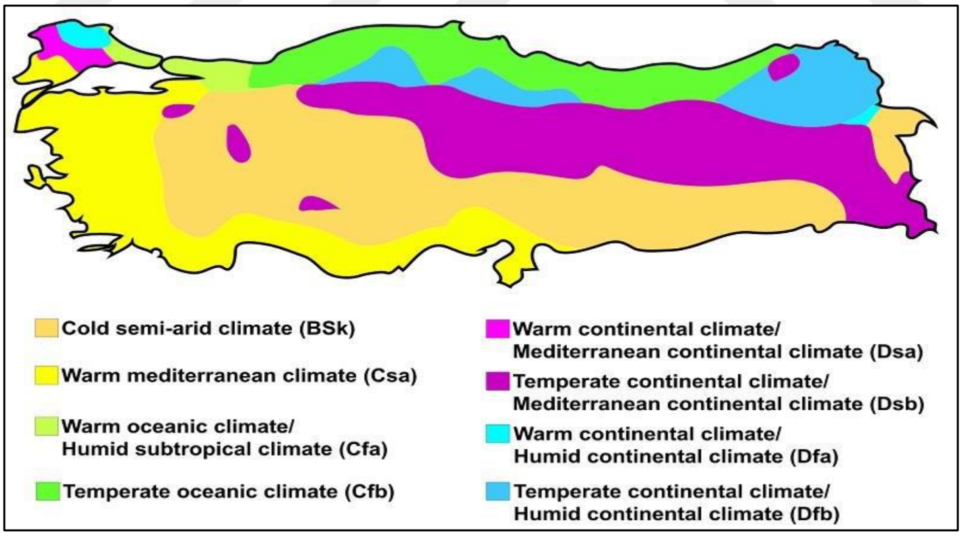


Figure 7: Climate conditions of Turkey ***(Turkish State Meteorological Service)***

2.1.1.2. Marine polar air mass (mP): It is from the North Atlantic. It affects the weather conditions in Turkey after passing through European countries and the Balkans. It can leave snow on the coast while leaving rain on the coast in Black Sea region. When it comes over the Mediterranean, it becomes more effective and releases all kinds of rainfall.

2.1.1.3. Oceanic Climate in Black Sea Region: This type of climate is influential in the coastal and mountain-facing sections of the Black Sea Region and in the Black Sea coastal belt of the Marmara Region, as shown Figure 7. The temperature difference between summer and winter is not much. The summers are relatively cool and the winters are lukewarm in the coastal area and snowy and cold in the highlands. All seasons are rainy and there is no water stress. The natural vegetation forms broad-leaved forests in the shoreline and coniferous forests in the highlands that grow in cold and humid conditions. The January average temperature of the cold month is 4.1 ° C, the July average temperature is 22.2 ° C, the annual average temperature is 13 ° C, as shown Figure 8. The average annual total precipitation is 843mm. The share of summer precipitation in annual total is 19.3%. Annual average relative humidity is 70%, relative humidity 60%.

Turkish State Meteorological Service

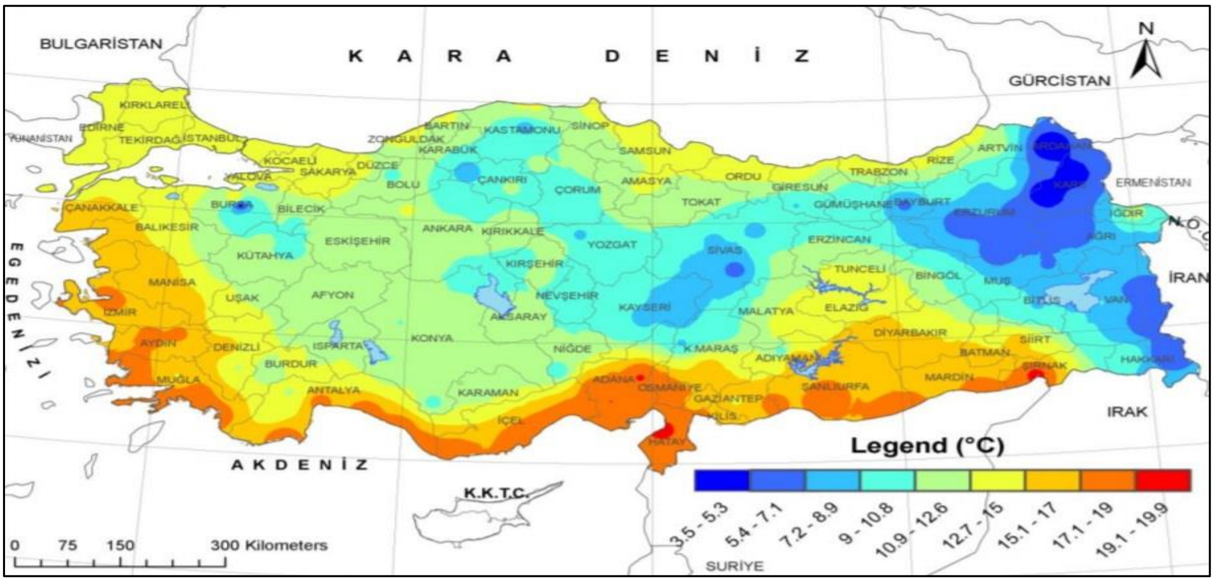


Figure 8: Annual Average Temperature ***(Turkish State Meteorological Service)***

The highest temperature in Turkey terrestrial effects of latitude and warm air currents seen in the Southeast, as shown Figure 8. Temperatures decrease from south to north with latitude and mathematical location effect. The lowest temperatures are observed in the Northeast Anatolia region. Temperatures decrease from west to east in winter due to the effect of the continentality. The temperature in the inner part is lower than the coastal areas due to the degree of saturation. The annual temperature difference in Eastern and South-eastern Anatolia is very high and the least is the Black Sea region.

2.2. Information of Study Areas (Rize Province and Ayder Pletau):

Officially the Republic of Turkey or Turkey is a Eurasian country located both in Asia and in Europe. 97% of their territory is found in Asia, while 3% remains in Europe. The capital of the Republic of Turkey is Ankara. The largest administrative units in the country are provinces and 81 provinces. There are 923 districts in total. In addition, the country has been divided into 7 regions and 21 sub-regions taking into account the geographical, demographic and economic conditions, but these regions do not represent any administrative body.

Turkey is surrounded by the sea on three sides, the variety of landforms and extent of the mountains have led to the emergence of different types of property in climate and precipitation. Most of the rain falls on the slopes of mountains facing the sea so the inner parts cannot get much rainfall. For this reason, when Rize (in the north east of Turkey) gets 2200mm of rainfall, Konya, Aksaray (located in middle of turkey) region only gets 320mm of rainfall, as shown Figure 9.

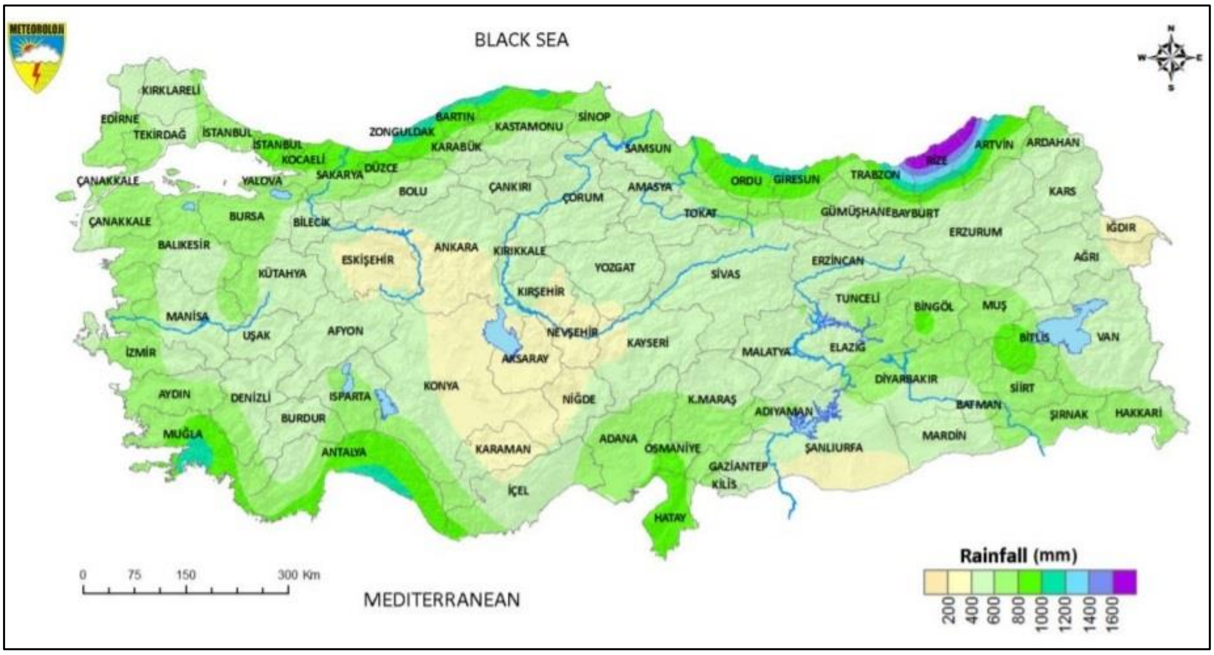


Figure 9: Annual Average Rainfall *(Turkish State Meteorological Service)*

2.2.1. Information about Rize Province

It is surrounded by Artvin in the east, Erzurum in the south, Trabzon in the west, and the Black Sea in the north. The population of the city is 143,460 by the year 2015. The climate of the Black Sea is only affected by a narrow area due to the parallel extension of the mountains to the sea on the Black Sea shores. The Black Sea climate is influential on the city. Every season is rainy. It is the wettest region and generally cool in summer, warm in winter. The vegetation is the forest. The maximum rain falls in the fall. Precipitation is regular. Annual temperature difference is small. This situation increases the frequency of floods and landslides in Rize. In winter the continental climate prevails in the interior. There is no industry because it is a mountainous region. It is economically based on agriculture. Tea, tobacco, nuts, corn, kiwi are the main products. Fishing is another main income area.

Figure 10: Location of study area

2.2.2. Ayder Plateau

Historically, the first settlements in Ayder plateau began in the 1300s by Halalılar (an ancient community). Later, it was generally used as a field of rest and livestock. Ayder is located on the border of Rize province, which is connected to Çamlıhemşin municipality, 1300 m above the sea level. The plateau is covered with spruce and beech forests. It was declared a tourism zone in 1987 and declared a natural site in 1998. Millions of tourists visit this region every year. Elevation of Ayder highland is from 1300 to 2200. From economic point of view, agriculture and livestock farming are limited. The main source of income is highland and hot spring tourism. Main forest type is broad- lead trees, coniferous. The forest cover is dominant on the slopes under 2100 m altitude. After about 2100 meters, grass land starts in that area.

2.2.3. Interview: The first snowfall in the town is usually beginning to fall in November, December, and the snow cover remains until the end of May. The dominant wind direction is south west to north-east in winter from the Black sea, south east to north-west in summer time from Kaçkar mountains. It has been expressed by the residents of the town that the thickness of the snow varies between 2-3m in Ayder plateau at about 1300 altitude. The beginning area of the avalanche that comes to the Ayder highland starts from the Huser plateau at an elevation of 2250 - 2350 m. According to Mr. Ismet who is a farmer near the study area, snow height has changed between 3-4m in recent years. However, it varies according to the wind conditions. According to the villager, the snow heights of the last 5 years were given below respectively.

5 years ago, snow height was 4.2m, 4 years ago 3.5m,3 years ago is 3.1, 2 years ago 3m and last year's 3,2 m snow. This year, 2,5m snow height was measured in end of March. Snow already starts to melt at that time.

Figure 11: Wet Avalanche

2.2.4. Chronicles:

In 1947 and 1992, two avalanches occurred. In the avalanche of 1947, the old bridges and some houses were damaged according to Mr. Ismet KANDEMIR. The details of the damage that took place in the avalanche of 1947 were not recorded. However, there are so many people who have suffered in 1947 and 1992. In 1992, a five-story hotel, two small markets, a wooden building collapsed, the old bridge was destroyed and two wooden houses damaged, as shown Figure 12. Nobody was killed because at that time there was no life in the winter periods in the region. They are shown in the picture below.

Damaged bridge in 1947 and rebuilt old bridge (In Turkish "Eski Köprü" = Old Bridge).

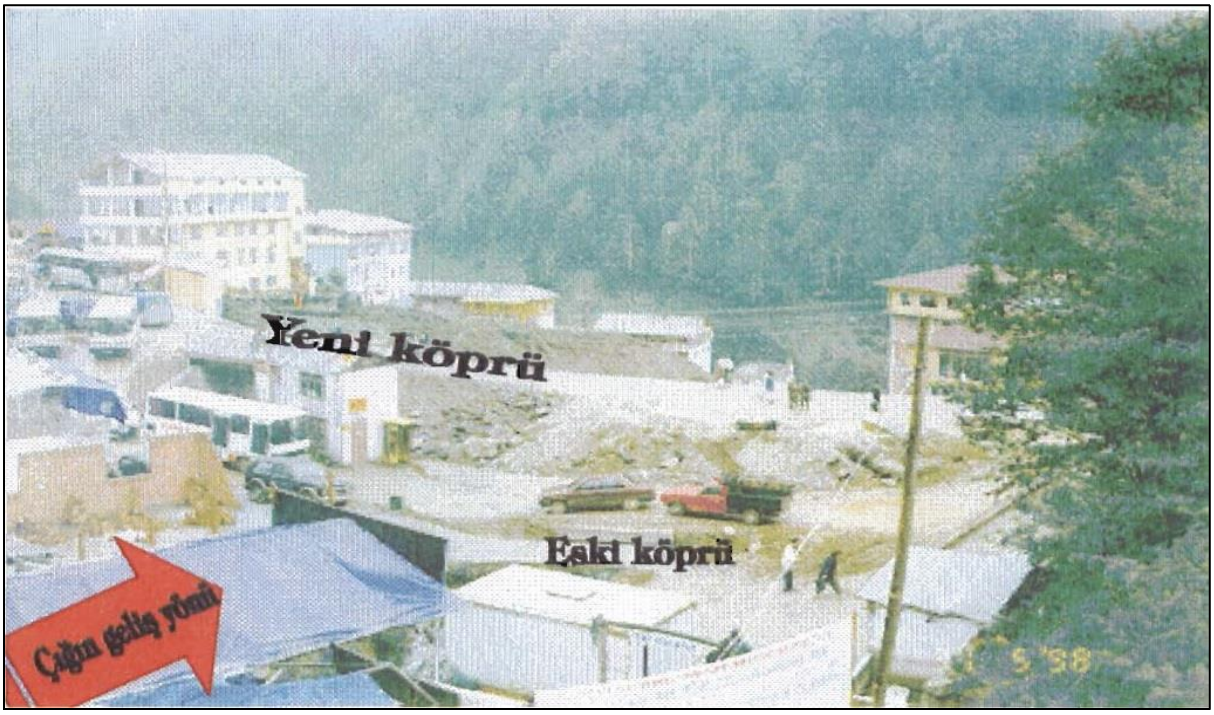


Figure 12: Field Report 2006 ***(the ministry of public works and settlement)***

Houses were damaged by snow avalanche in 1947, as shown Figure 13.

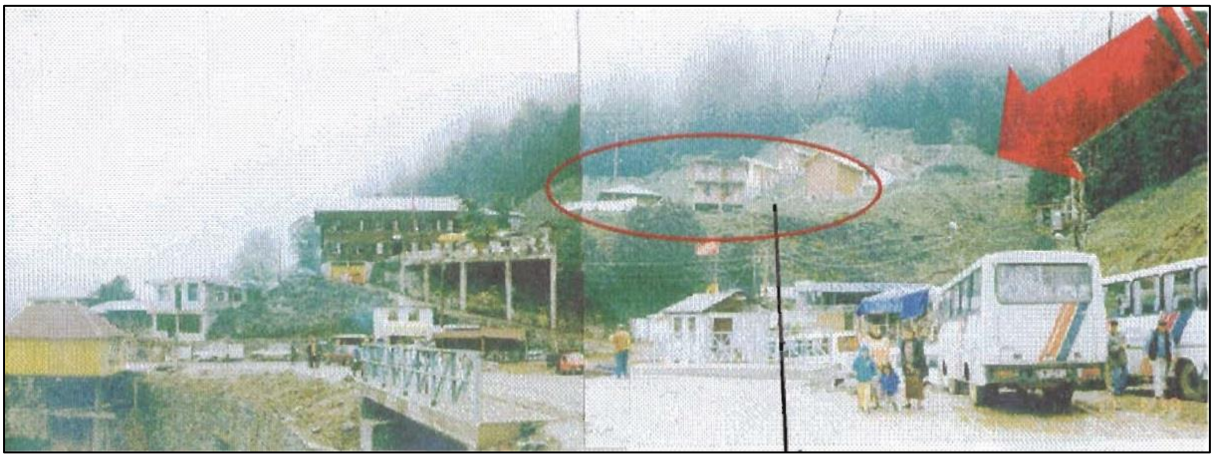


Figure 13: Field Report ***(the ministry of public works and settlement)***

3. Terrain Factors

3.1. Elevation

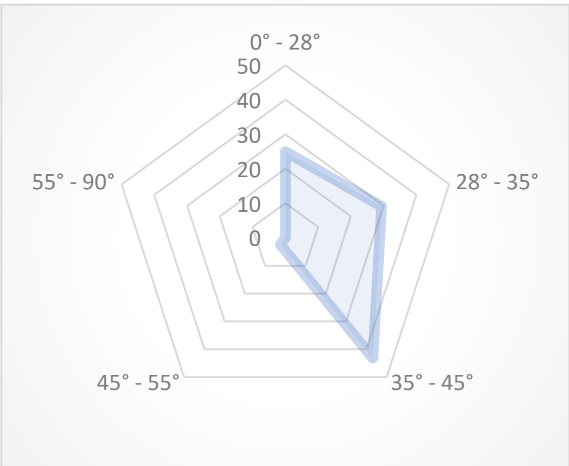
Possibility of an avalanche potential can change dramatically with altitude because change in temperature, precipitation type and intensity, direction and speed of wind, weak layers in snow cover and terrain features affect the snow layer. Frequency of avalanche is higher at above 1000 m than that of lower. *(McClung and Schaerer, 2006).* In the lower elevation protective forest decreases avalanche danger but above the timber line forests are sparse or not so the probability of an avalanche is increasing significantly.

3.2. Slope

Slope is the most important factor in assessing potential snow avalanches initiation. *Salm et al. [1990]* suggested that for defining avalanche starting area, the areas with an inclination angle between 30 ° [eventually 28 °] and 50 ° can be considered release zones.

In occasional events, the wet snow and slush avalanche starts with gentle inclines below 25, but they are infrequent because of the shear stress induced by gravity usually on gentle slopes is not big enough to start an avalanche *[Ancey et al. 2009].* An incline above 60 ° (eventually), avalanches are scarce. Sluffs snow are often observed *(McClung and Schaerer, 2006).*

These ranges may vary for specific analyses to be performed in specific application areas *(McClung and Schaerer, 2006).* In the study conducted, it was observed that the slope angle of the starting area of natural avalanches decreased by 25º. 62 avalanches that occur naturally were observed and the starting zone was defined as 25º to 55º. At slope angle range of 30º to 50º, 718 avalanches triggered by human influence (skier, climber). In addition to providing very detailed information on the minimum and maximum slope angles required to start avalanches, the most avalanche shows the range of 35º to 45º as the range of slope angle. It has also been observed that avalanches triggered by human influence begin to move from regions with an inclination of 38º at most. *(McClung, 2013).*



Slope	%
0-28°	24,90
28-35°	29,40
35-45°	43,23
45-55°	2,43
55-90°	0,04
Sum	100,00

Table 3: Percentage of slope in Ayder

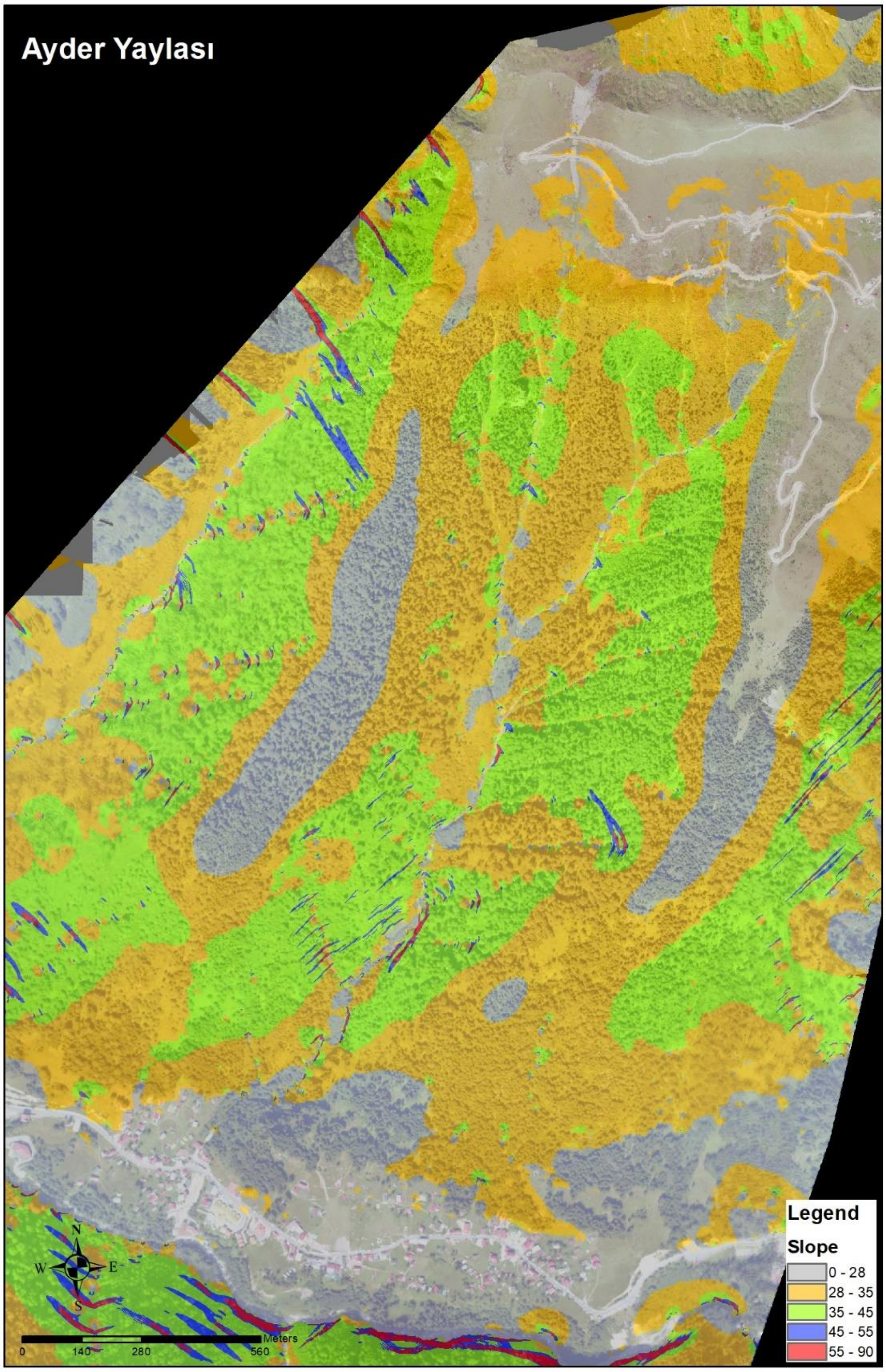


Figure 14: Slope of study Area

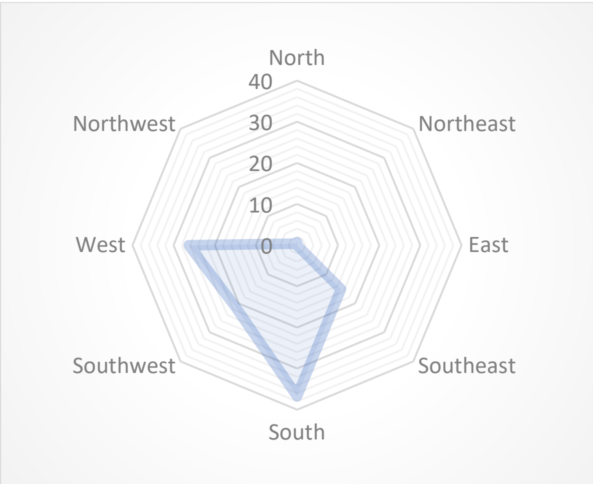
3.3. Aspect:

Aspect is one of the major parameters in evaluating potential snow avalanches starting areas. It is affected directly by incoming radiation and exposure to wind. The orientation of the sun has a significant impact on the characteristic of the snowpack. According to some research, most of avalanches event happen in the northern face slope [NW–N– NE] *[Benedikt et al., 2002]*. While in winter time northern face or shady face are exposed to very little sunlight, they lose long wave radiation so it creates temperature gradient on slope because of radiation gradient which create weak layers (facets, crust formation, depth and surface hoar) in the snow cover. In Northern hemisphere, in winter time avalanches occur N-NW-NE face slope. In end of winter and spring time wet snow avalanche occur in South face slope due to rapid warming *(McClung and Schaerer, 2006).*

In order to be used as an input to the avalanche start zone algorithm, it is necessary to be able to clearly determine the effect of the aspect in field examination. If the alteration of the aspect affects the formation of avalanches, then the link can be added as an input to the start region algorithm.

Orientation to wind is one of the most important terrain parameters contributing to the initiation of avalanches. Wind destroy and lift the snow flake and transport them above the snow cover to the lee facing slope and dense and cohesive new snow accumulation add shear stress to the snowpack. *[McClung and Schaerer, 2006]*. These accumulations might create slab avalanches when the snowpack contains a weak layer *[Delparte et al., 2008]*.

The aspect of the study area is shown on Figure 15 below.



Aspect	%
North	0,6
Northeast	0,1
East	0,2
Southeast	20,6
South	30,4
Southwest	21,2
West	24,4
Northwest	2,4
Sum	100,0

Table 4: Percentage of aspect of study area

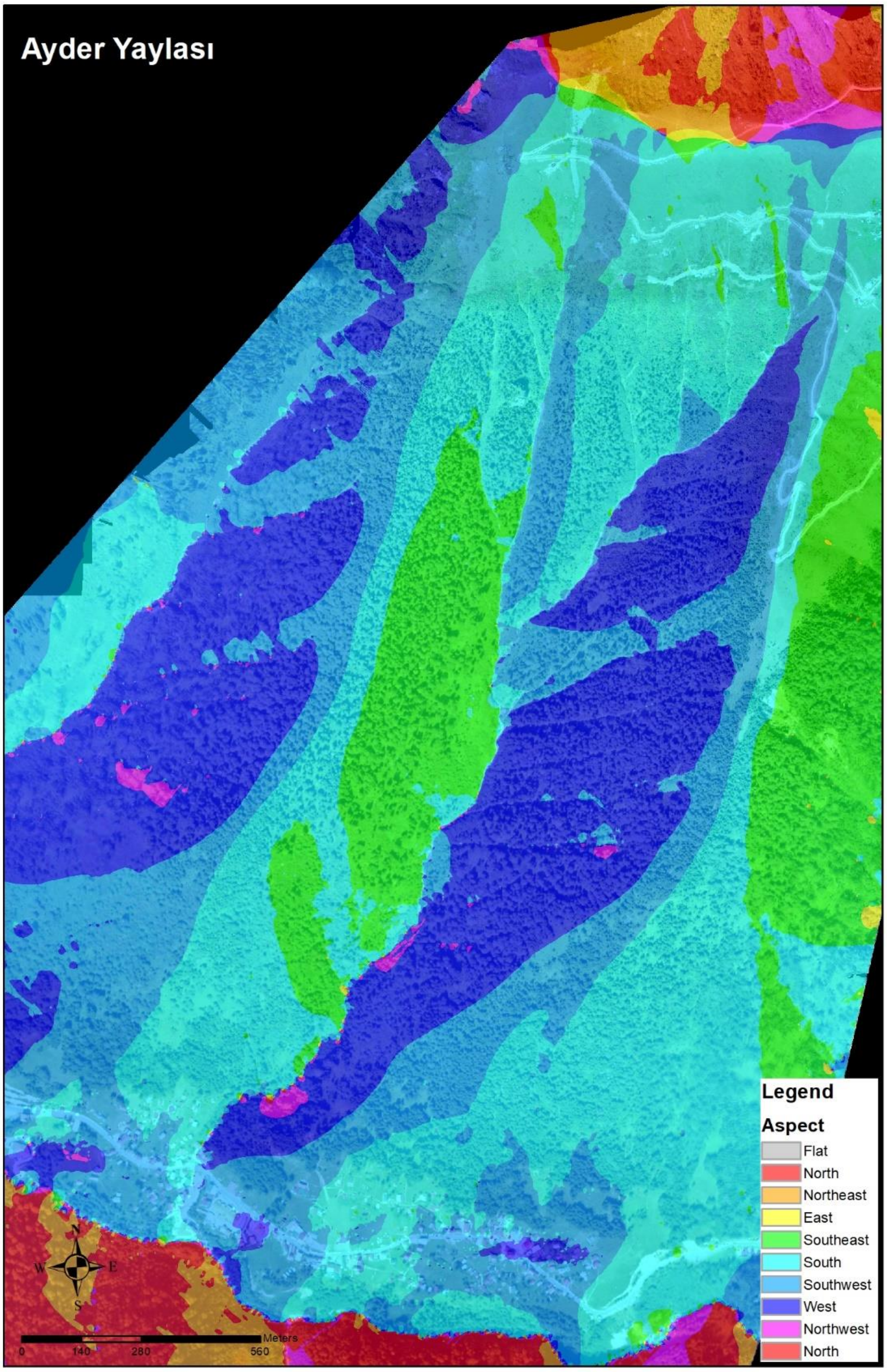


Figure 15: Aspect of study area

3.4. Curvature:

Plan curvature is the ratio of variation of aspect along a contour line. Negative value obtained after ArcGIS analysis shows that the surface is upwardly convex. The positive value represents that the plane is upwardly concave, as shown Figure 16. The acceleration or deceleration of flow are affected by shape of terrain which is profile curvature along the surface. Profile curvature is the ratio of variation of slope along a flow line. The Plan Curvature is positive value with concave plane and negative value with convex plane. Plan curvature can be used to classify between ridges and valleys. Zero value represents flat terrain in both situations. In concave plane there is a compressive support from the bottom to prevent movement of slabs but on an intermediate to steep slopes, this supporting force is not so effective. More avalanche accidents happen in convex slope than concave and flat of planes because poor compressive support at the lower part of snow layer than concave slope. Concave areas are determined lower values than -0.2 in in another study. *(Maggioni.M, Gruber U. 2003)*

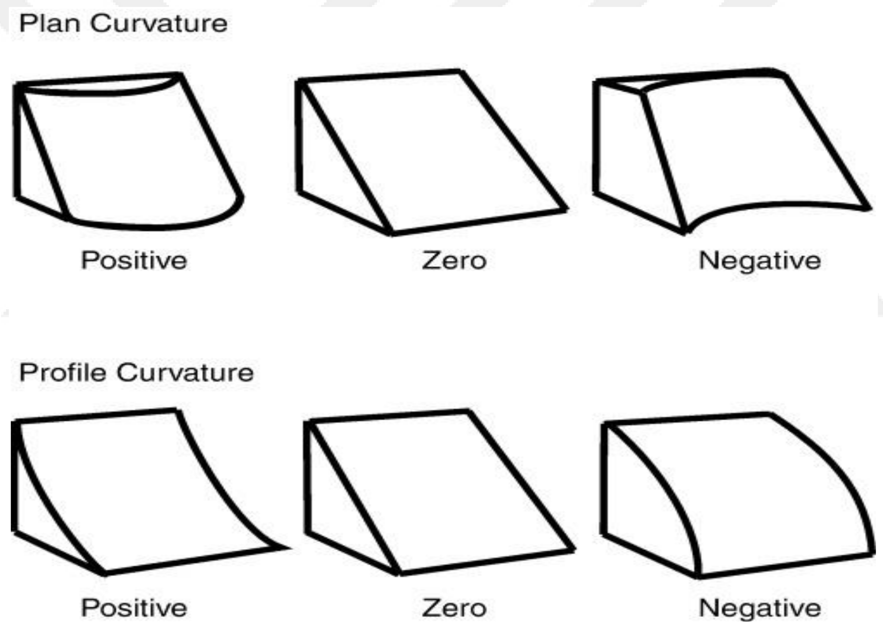


Figure 16: Plan and Profile Curvature on the area ***(Heine, Reuben and L. Lant, Christopher and Sengupta, Raja,2004)***

3.5. Vegetation:

Potential avalanche starting zones are usually above the forest line. Dense forest areas are very important to protect settlements, infrastructure facilities and people from the avalanche. However, sparse, damaged forest areas and areas above the forest line may be potential avalanche zones and avalanche can be initiated these areas. The upper limit of the forest is about 2100 m to 2400 m above sea level in Black Sea region, depending on the meteorological characteristics of the area.

While mountain forest reduces the avalanche dangers by modifying snow layer, intercept inflow radiation, wind and outgoing radiation, the forest is inefficient for high mass of avalanches. Forest only can stop small avalanches. Large avalanches often destroy trees and take them into the flow. Thus, flow mass is getting bigger and damage potential increases. *(McClung and Schaerer, 2006)*

When identifying forest areas, they stated that the height of the trees in the area should be more than 15m, otherwise the area should not be considered as a protective forest area. Key factors used when determining protected forest areas; the density of forest cover, the spacing between trees and height of trees. All models have been carried out assuming that there is no avalanche starter from the protected forest areas identified in this way.

3.6. Meteorological Conditions

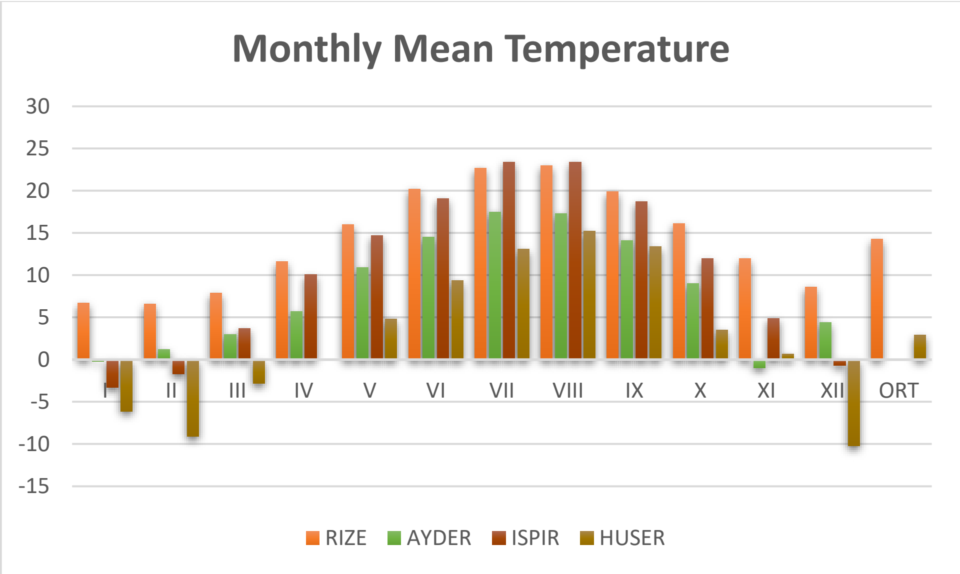


Table 5: Monthly Mean Temperature of study area

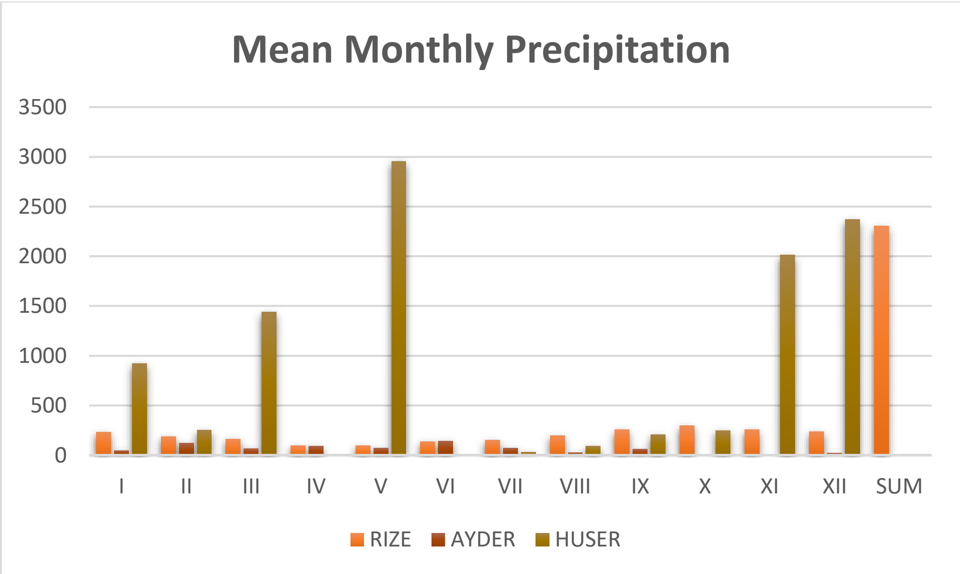


Table 6: Mean Monthly Precipitation of Study Area

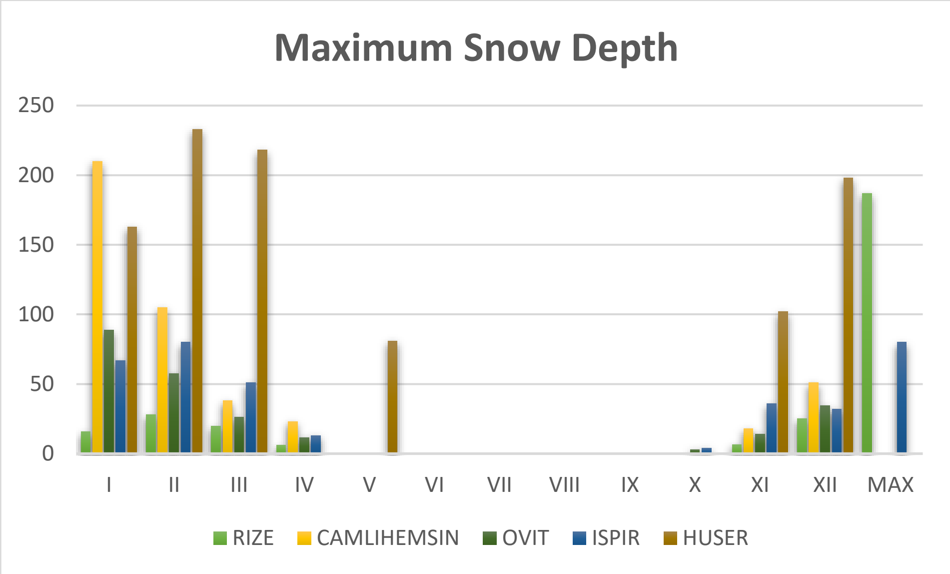


Table 7: Maximum Snow Depth of Study Area

3.6.1 Fracture Depth:

Due to the deficiencies in the data, in this study a depth of snowfall of 1.6 m is used to determine for a 150-year recurrence period, which is used especially for the mean depth of snowfall in Central Europe. In addition, field observations and information from the local community have shown that this value can be within acceptable heights, as shown Figures 17 and 18. When the observed avalanches were modelled and their results were compared with real observations, approximate values were found in terms of volume of materials collected in the accumulation zone.

Figure 17: A house at avalanche starting area

Figure 18: Some houses buried in snow

4. Starting Areas

Elevation, slope, timber line and curvature parameters are used to determine the avalanche starting areas in the study. Raster image with the pixels specified by the “Curvature”,” slope” “forest line”, application, is added as a "tool" to ArcGIS software, analysed, the regions representing the concave areas which have lower values than -0,2 in the analysis results, and 2150 m altitude was taken as the forest upper boundary line. Regions between 28 degrees and 55 degrees were determined for the slope value, as shown Figure 21. For the determination of areas that satisfy all criteria, each pixel is multiplied by the values in the "slope angle" and "curvature" and "forest line" layers. The multiplication of the cells with "2" in each case, that is, the criterion, will be 2 again, as shown Table 8. These cells are red in the resultant layer, and cells that do not provide any criterion result in a value of "1" and are shown in white. This process is known as "Overlay Analysis" in GIS, which is the overlaying of layers. If all the criteria in the starting area algorithm are applied such as the areas providing the same criteria, the areas where the avalanche is likely to occur are identified. Finally, when boundaries of these areas are drawn, potential avalanche zone boundaries will also appear. These areas have been fixed by taking information in the local people in the field examinations. The avalanche starts zones 5 and 7 where avalanche event happened during the avalanche events of 1991 are verified by the Mr. Ismet KANDEMIR who is living in the study area.

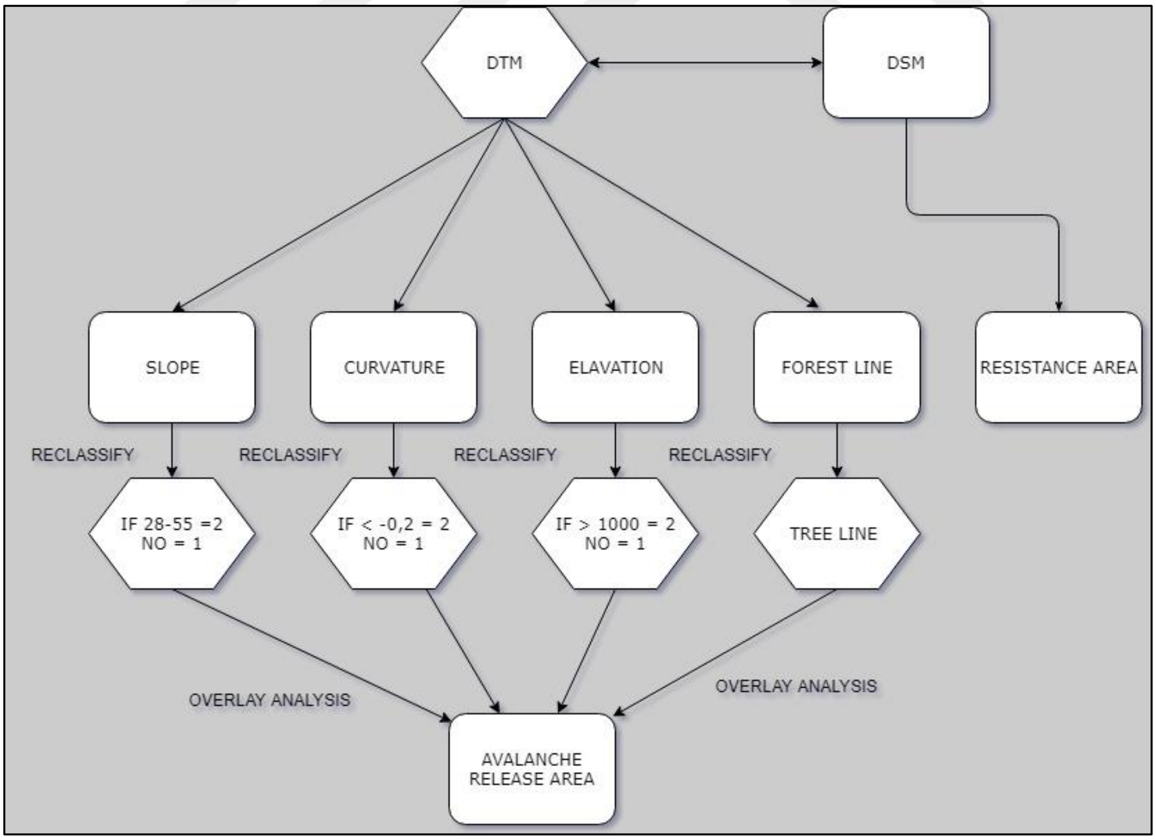


Table 8: General scheme for analysing starting area

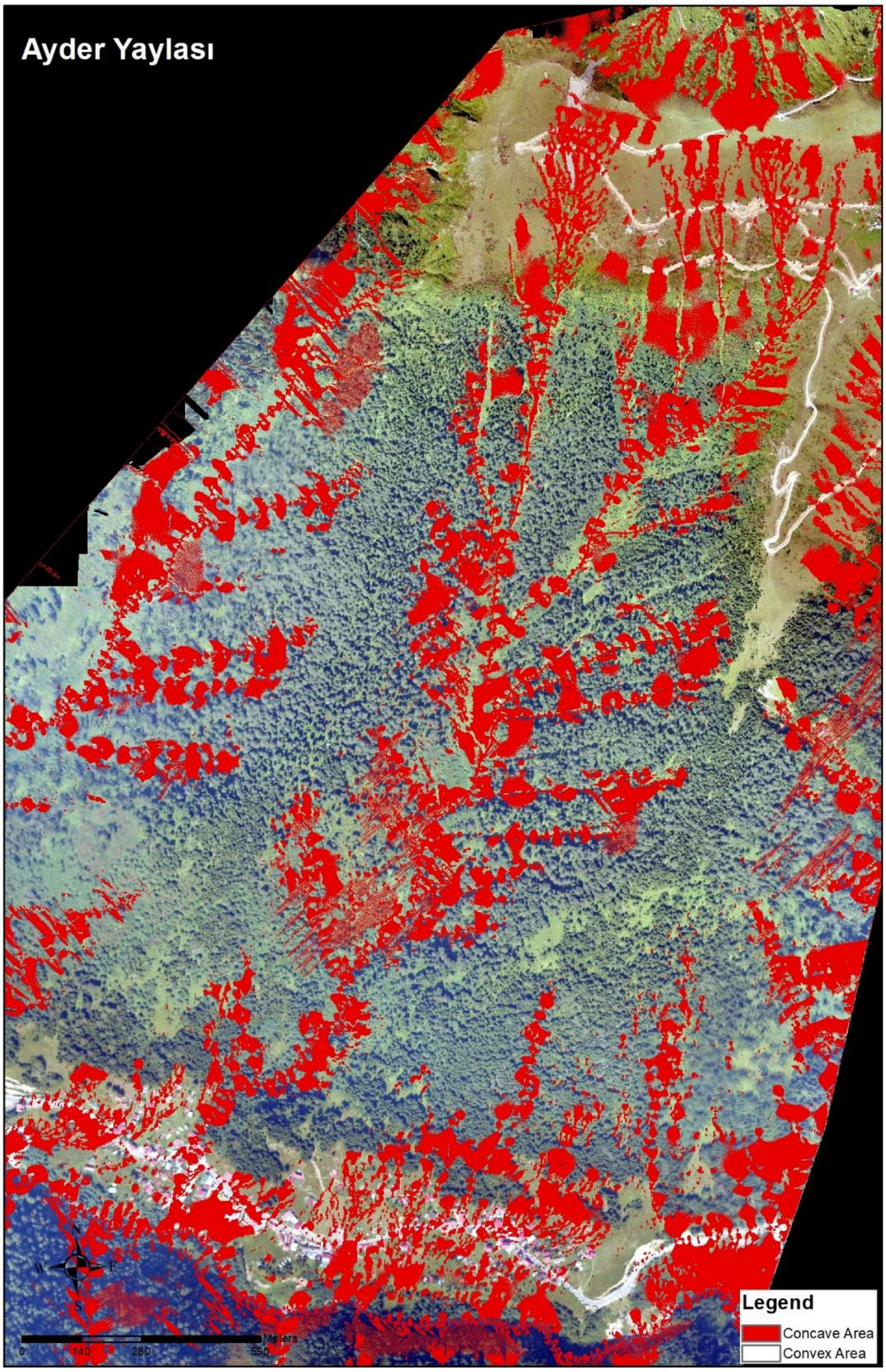


Figure 19: Plan curvature of study area

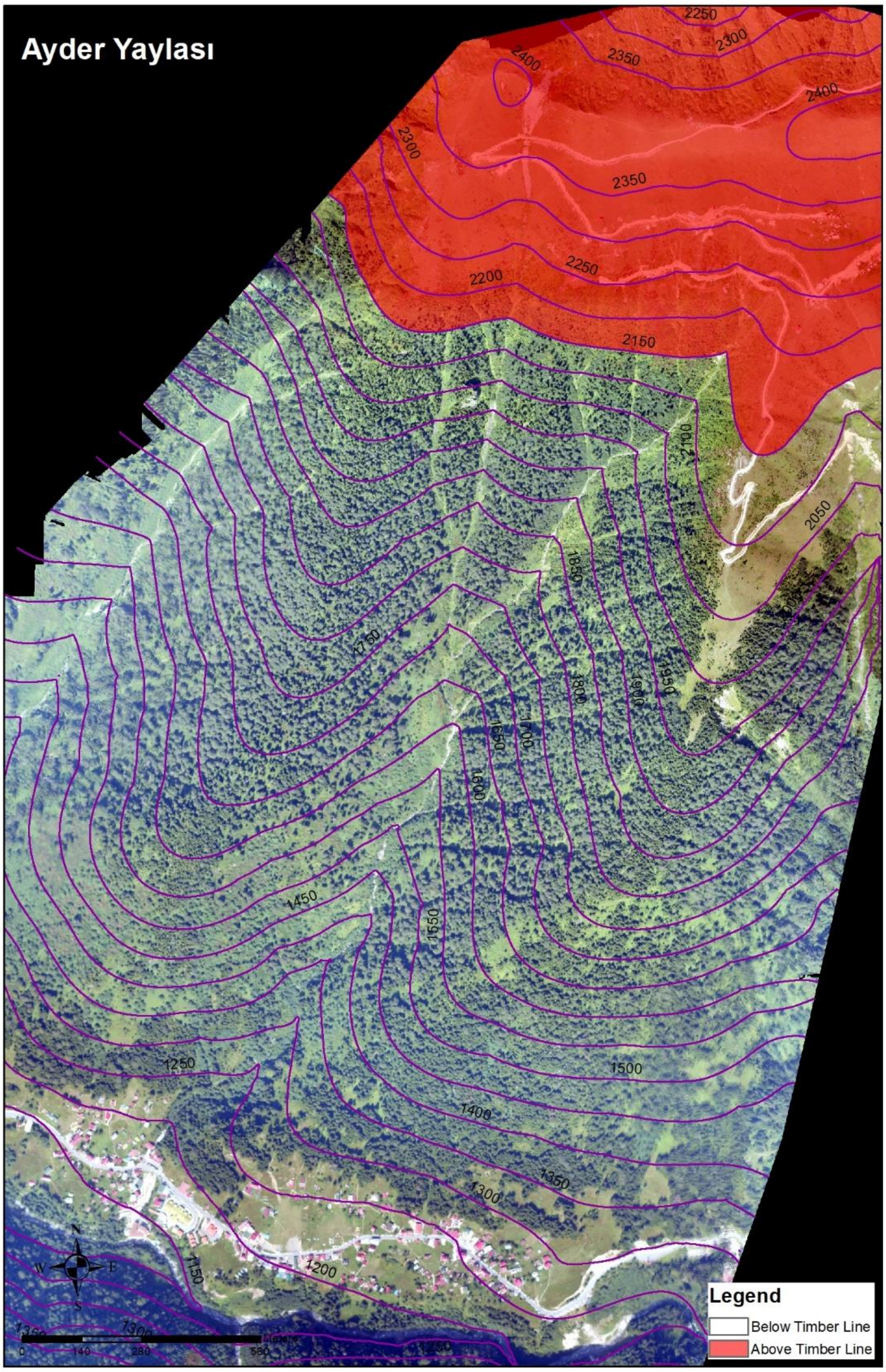


Figure 20: Forest line of study area

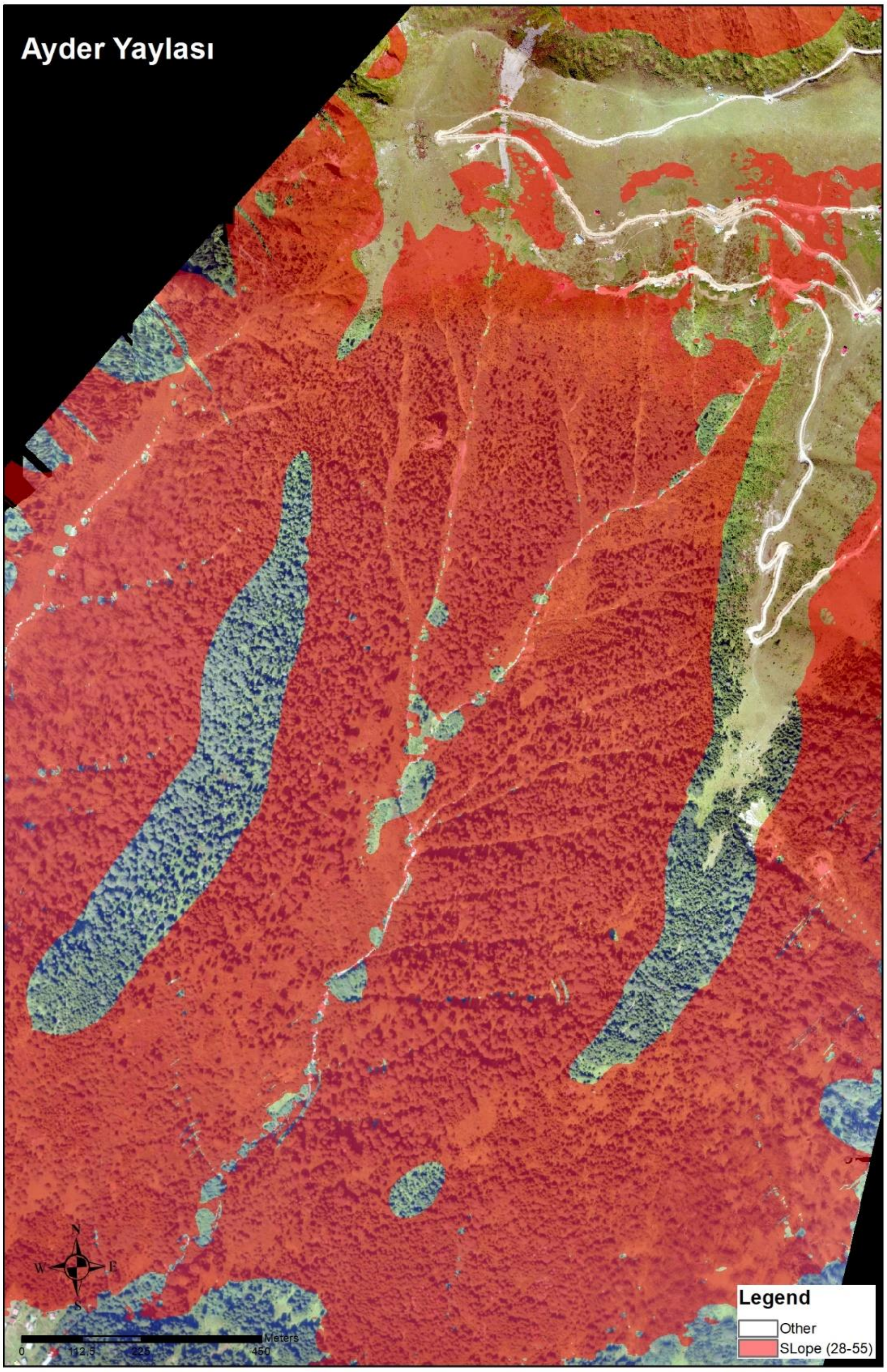


Figure 21: Slope of study area

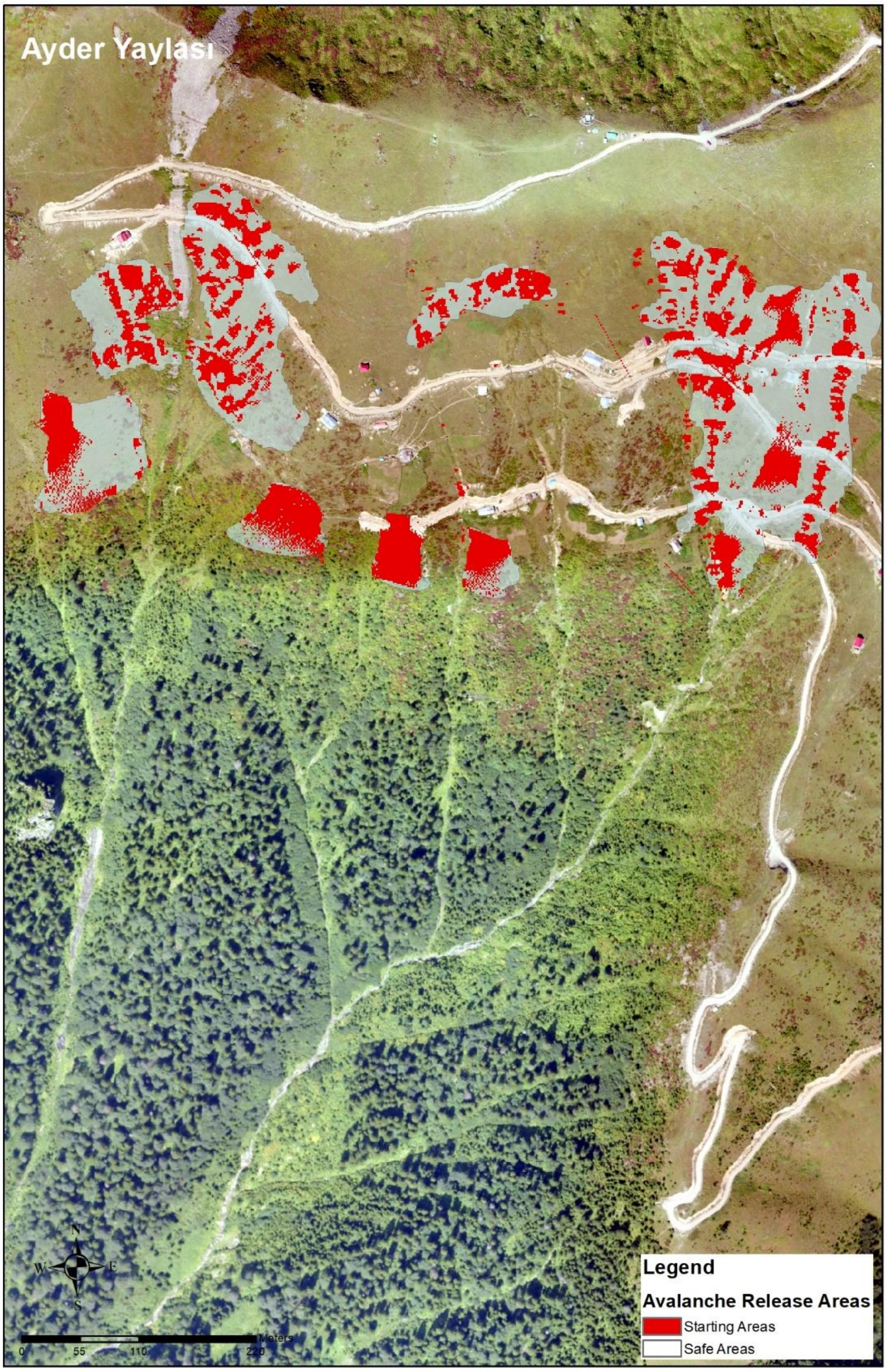


Figure 22: Analysis results in ArcGIS

5. Resistance areas

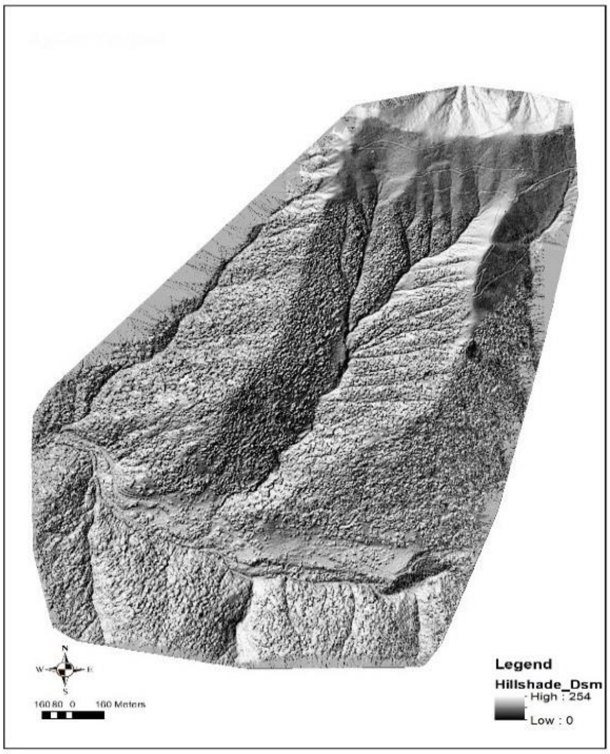


Figure 23: Dsm of Study Area

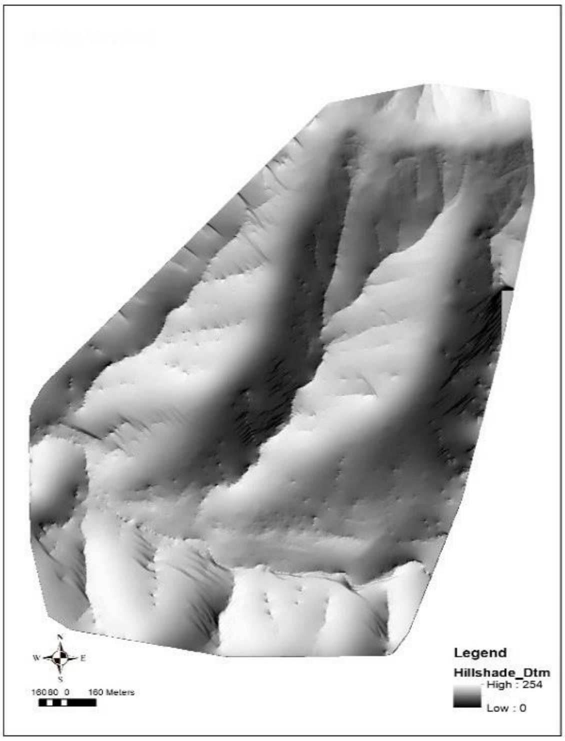


Figure 24: Dtm of Study Area

The resistances areas are calculated using the Dtm and Dsm at ArcGIS. Fifteen meters and above trees height are defined as a resistance zones in ArcGIS.

5.1. Silent Witness:

As a result of the field investigations, it was considered as a silent witness that the trees did not develop on the avalanche road and that the land was covered with the shrub and grass.

Figure 25: Silent witness

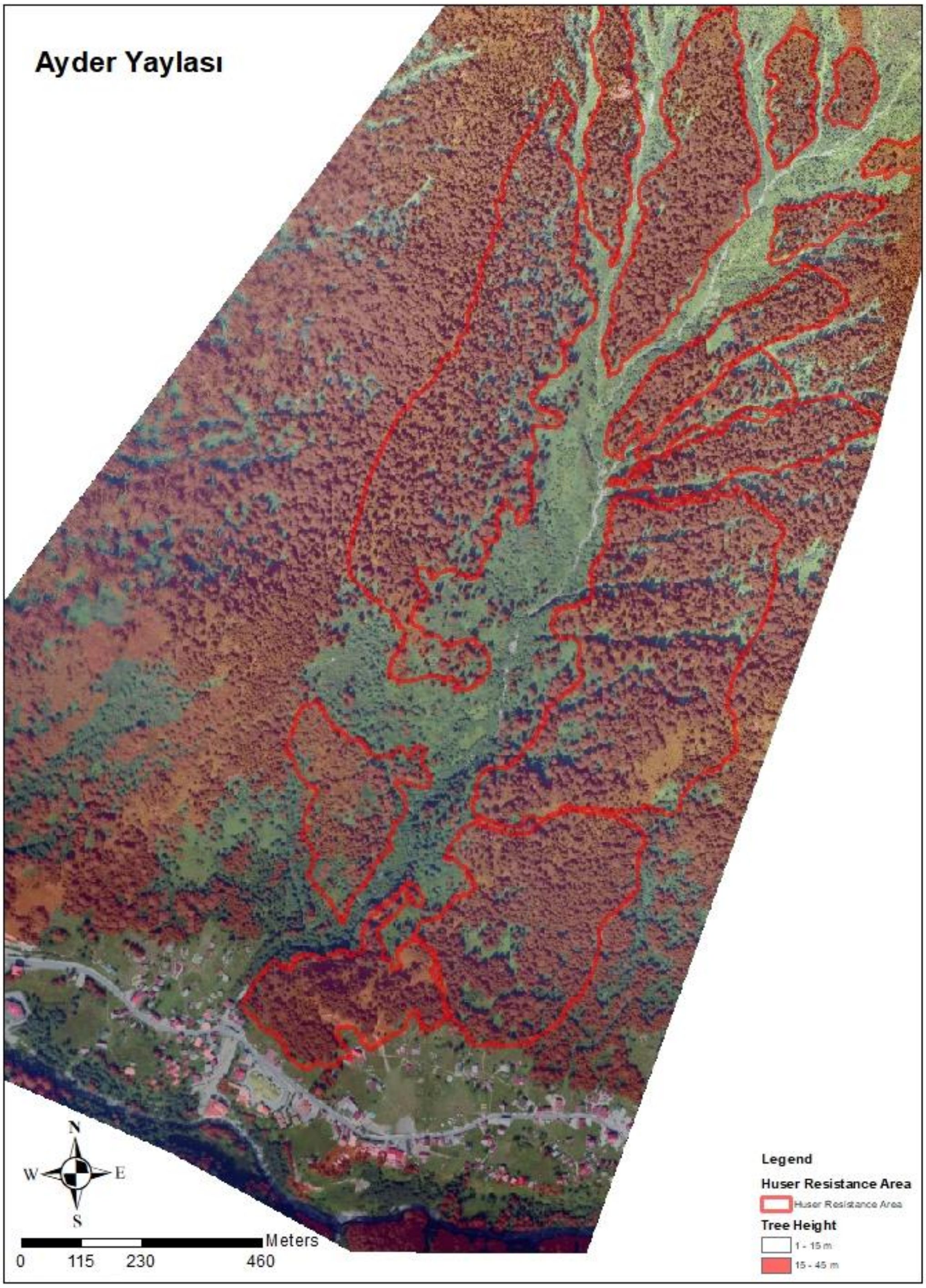


Figure 26: Resistance Area of study area

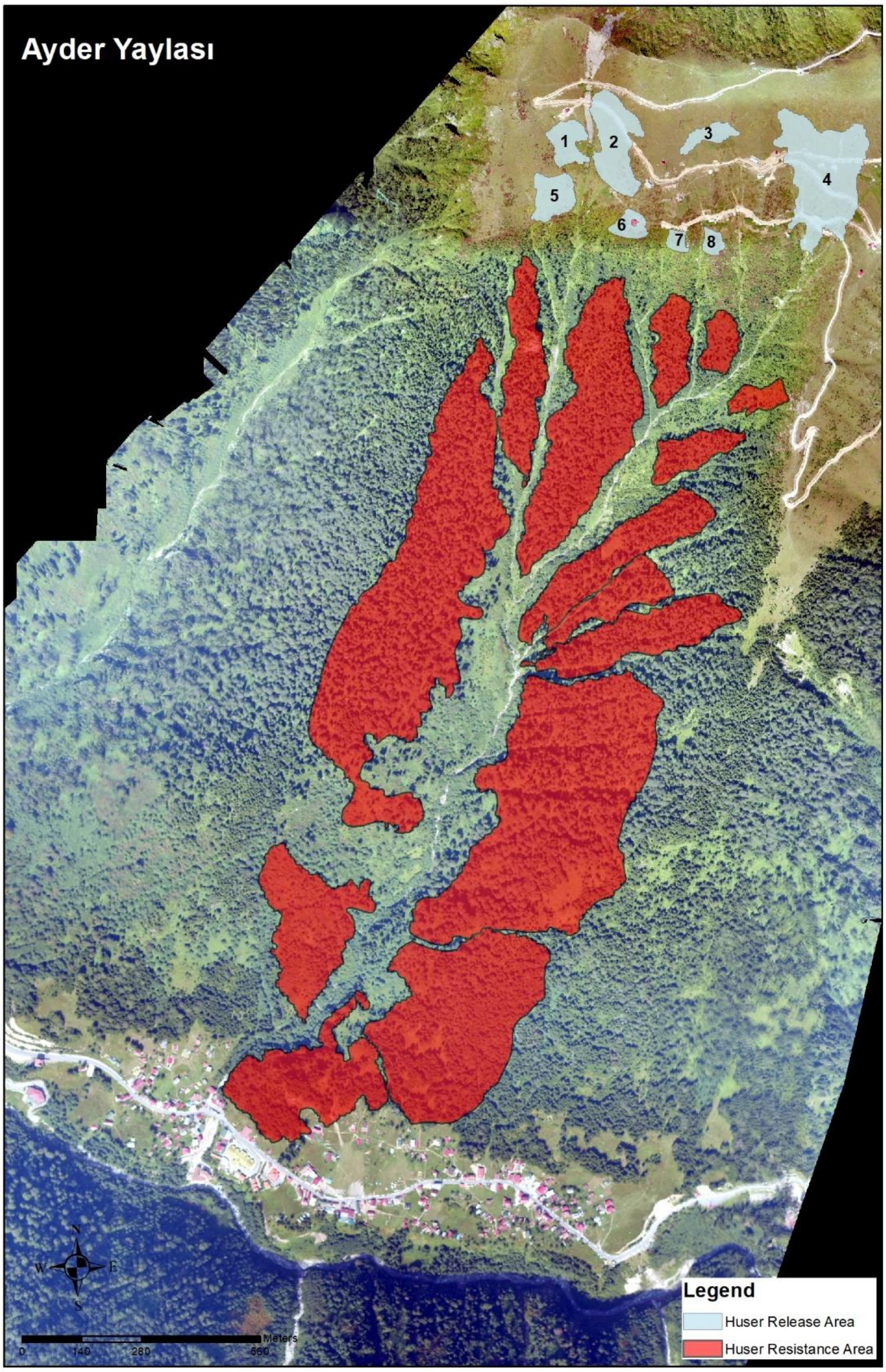


Figure 27: Resistance area and release area in Ayder plateau

RELEASE AREA	R1	R2	R3	R4	R5	R6	R7	R8
MEAN SLOPE ANGLE(°)	29.25	28.61	27.90	28.63	30.11	30.02	30.88	28.6
MEAN ALTITUDE (m)	2309.84	2324.92	2349	2306	2251	2244	2237	2230
PROJ. AREA (m²)	7252	19600	4508	43904	9408	4116	2352	2352
INCL. AREA (m²)	8343.1	22381	5141	50135	10903	4756	2739	2678
RELEASE VOLUME (m³)	13349	35809	8226	80217	17446	7610	4382	4285
RELEASE DEPTH (m)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Table 9: General information about release areas

Figure 28: Release areas

6. Simulation

In parallel with the developments in computer technology, computer software capable of performing 1, 2 and 3-dimensional analysis based on these models has been developed. One-dimensional avalanche dynamic analysis software predicts velocities in the centre of mass or in the middle of the flow of material on the avalanche route. While 2D dynamic models also determine snow depths and lateral spreading values at the same time, 3D modelling determines the volumetric progression of the avalanche flow by the finite volume method.

6.1. Ramms:

The RAMMS software is based on the Voellmy Model. 2-dimensional avalanche simulation software developed at WSL Institute for Snow and Avalanche Research (SLF). It is generally used for avalanches, debris flow, and rockfall. The software in not capable of simulating powder snow avalanches.

As input for the analysis of avalanche events; fracture depth (hu), density (ρ), ξ turbulent coefficient, obtained from the topographic data, μ friction coefficient is used at the starting point. As an output; the flow direction and length, the flow velocity, the dynamic impact pressure values and the snow depths in the flow route. The software, which has been in use since 2005, started commercial use after 2010.

Inputs parameters shown below were used to simulate avalanche scenarios with using Ramms model *(Christen et al. 2008):*

- Digital Elevation Model;
- Starting area (Prepared by using ArcGIS)
- Resistance Area (Forested Area) prepared from ArcGIS

The parameters that were used are shown below:

- Density [kg/m^3]: 300 (Default Value)
- Friction law: Voellmy Model
- Return Period: 100 years
- Avalanche size: Large
- Fracture depth :1,6 m
- Friction parameters: Automatically (Or users can be selected manually)

6.2. Samos AT

Samos AT is the avalanche simulation model which has been used in Austrian Service for Torrent and Avalanche Control in Austria since 2007. The simulation software was calibrated 22 reference avalanches. Samos At is a two-dimensional (2D) dynamic modelling software. It has a model that numerically analyses the avalanche events and performs the simulation. The solution is based on the Voellmy Model. However, the Voellmy Model is developed and uses the ξ coefficient as a changing value by observing shallow water approach. As input; Dtm of the study area, fracture depth, density values ρ (kg / m3), drift coefficient of the Voellmy type models (ξ is automatically determined for each process step from the topographic data), the Coulomb friction coefficient (modifiable and predefined as μ start = 0.25, μ flow = 0.155 and μ accumulation = 0.25), drone photographs and images are used.

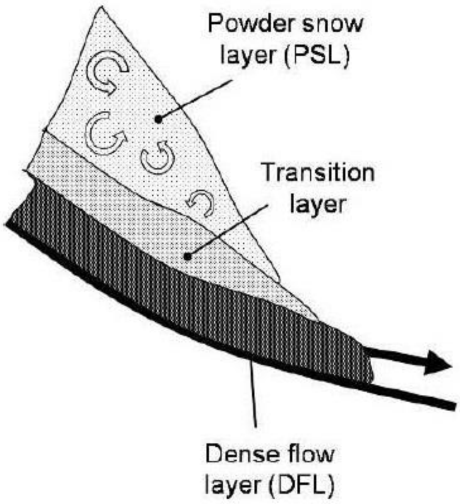


Figure 29: Layers used at Samos AT ***(Sampl and Granig, 2009)***

The following parameters were used in Samos AT simulation software:

- a digital terrain model (Recommended 5m resolution):1.4 m resolution used
- the release area: prepared in ArcGIS
- Snow depths and densities; 1.6m and 200kg/m³ respectively.
- Resistance Area: Prepared in ArcGIS
- the density of the flowing dense snow (Recommended 200 kg/m³)

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

$$\tau^{(b)} = \tau_0 + \tan\delta \cdot \left(1 + \frac{R_s^0}{R_s^0 + R_s}\right) \cdot \sigma^{(b)} + \frac{\overline{\rho}\,\overline{u}^2}{\left(\frac{1}{\kappa}\ln\frac{\overline{h}}{R}+B\right)^2}$$

Table 10: Bottom friction model ***(Sampl and Granig, 2009)***

- $\tau 0$ Minimum shear stress, in [N/m2]
- tan δ Tangent of the bed friction angle, in [°]
- ρ Flow density, in [kg/m3]
- u Flow velocity, in [m/s] ***(Sampl and Granig, 2009)***
- h Flow height, in [m]
- Rs Roughness constants
- μ is the Coulombian bed friction coefficient: 0.155.

Sparse tree and bare surface areas are defined as Entrainment areas. It is prepared in ArcGis

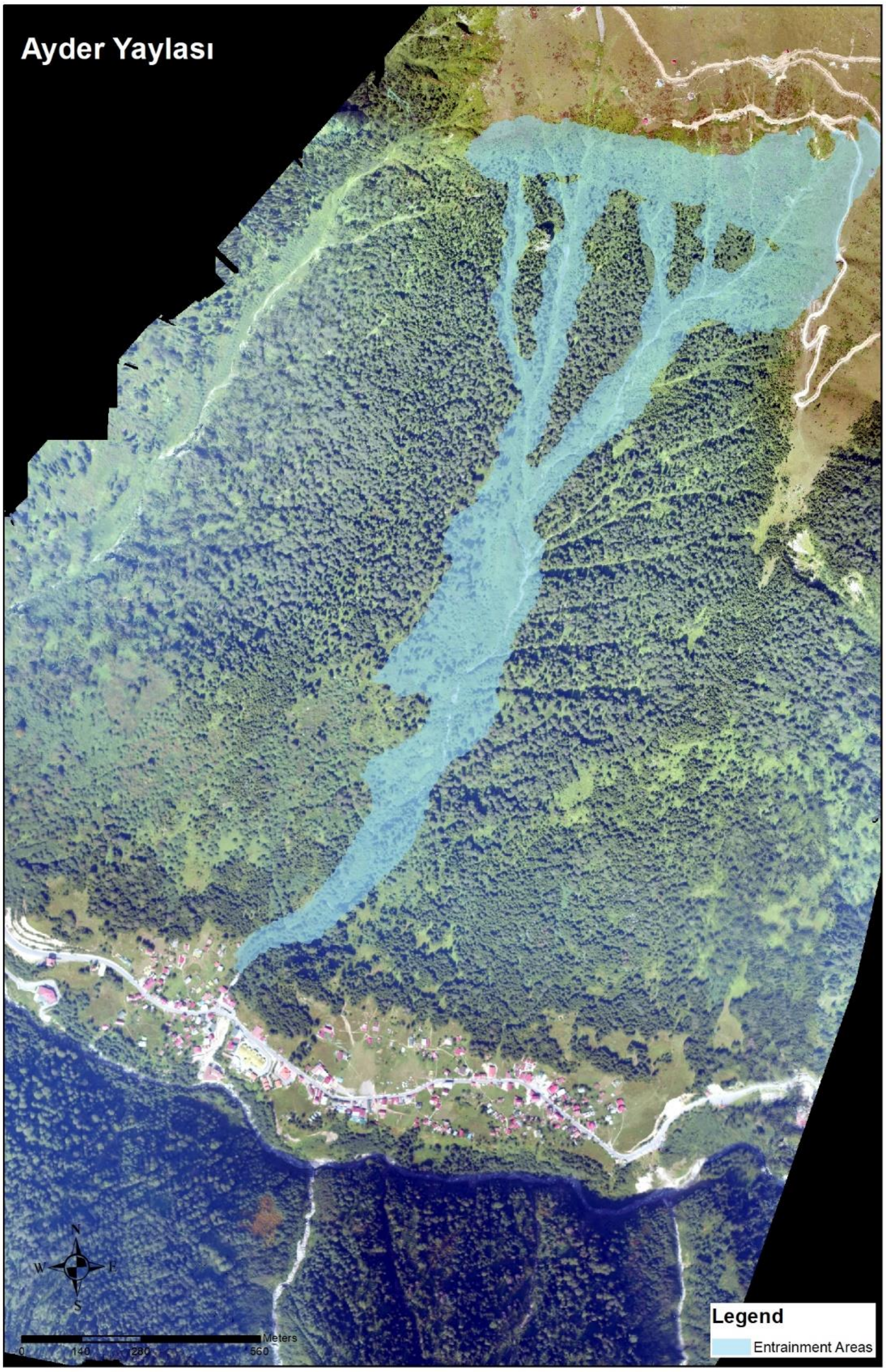


Figure 30: Entrainment areas

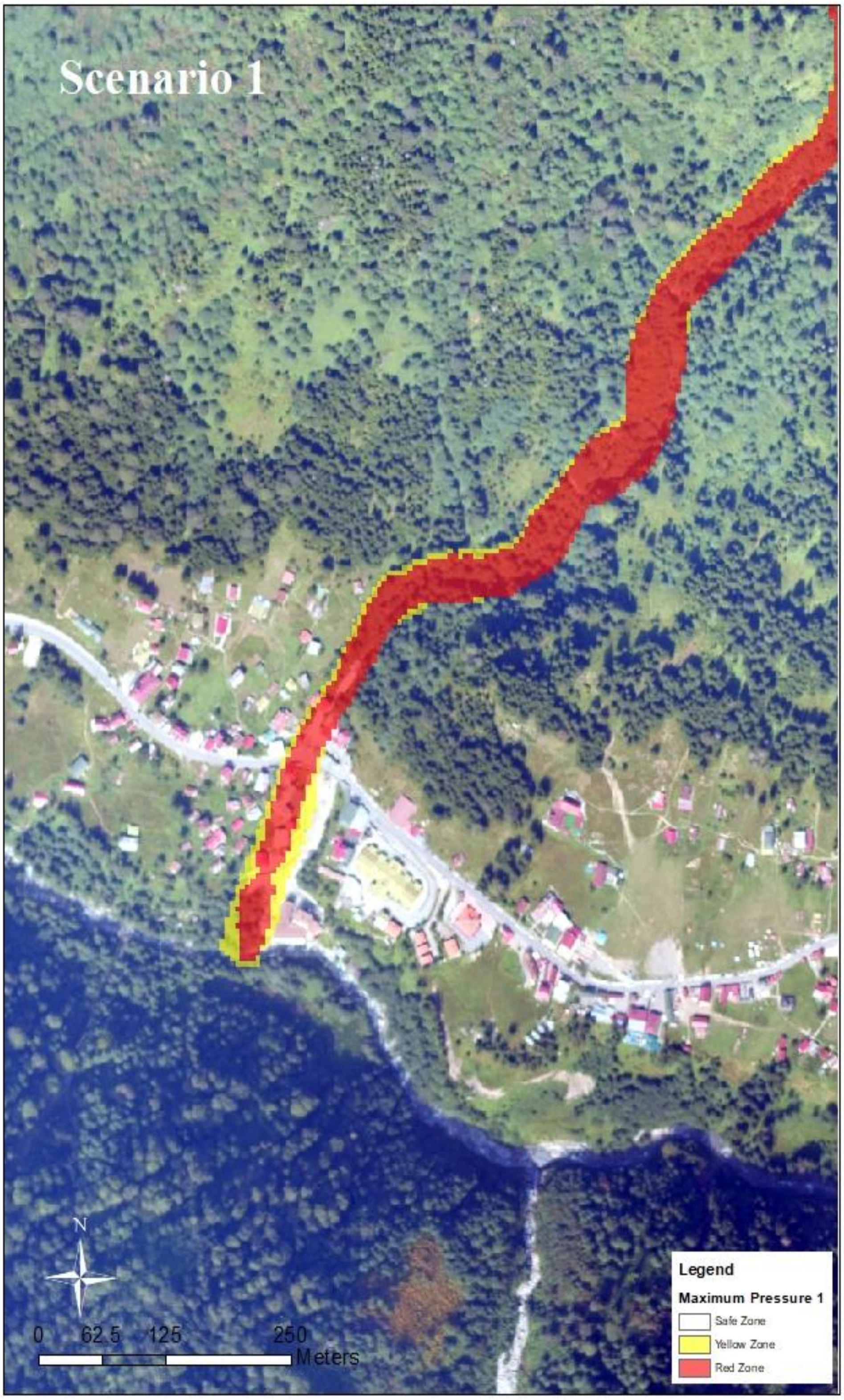


Figure 31: Scenario 1 Maximum Pressure at Samos

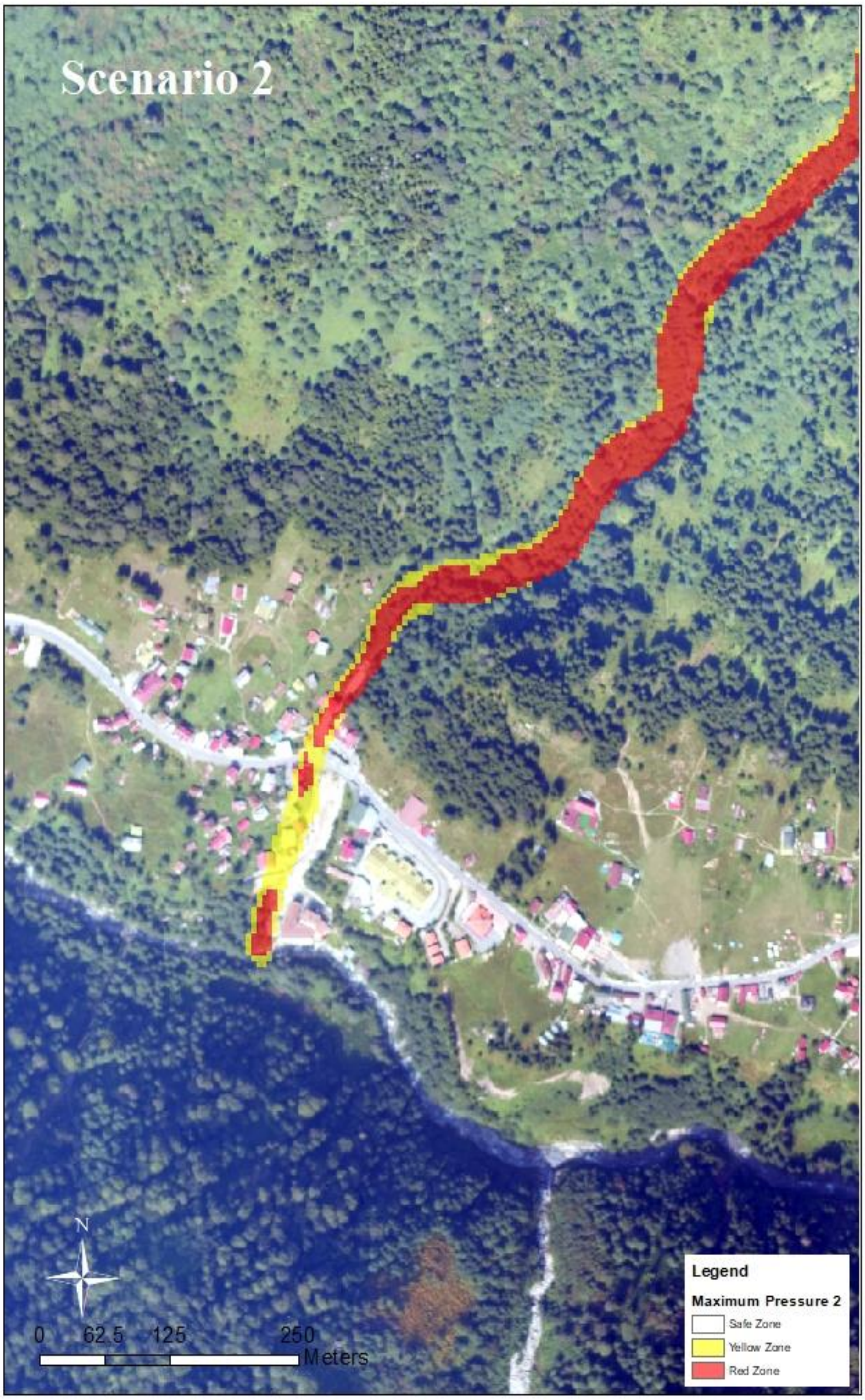


Figure 32: Scenario 2 Maximum Pressure at Samos

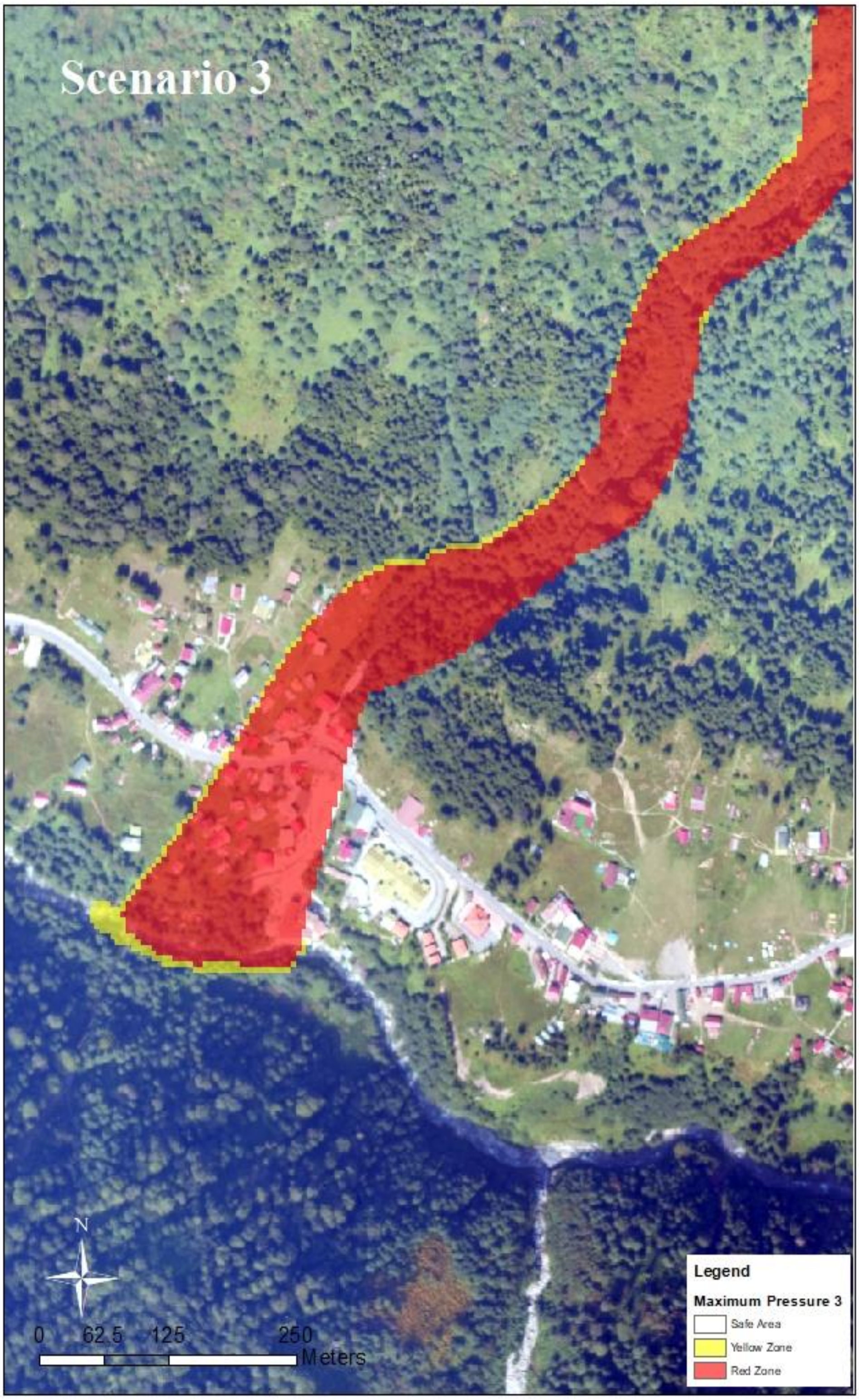


Figure 33: Scenario 3 Maximum Pressure at Samos

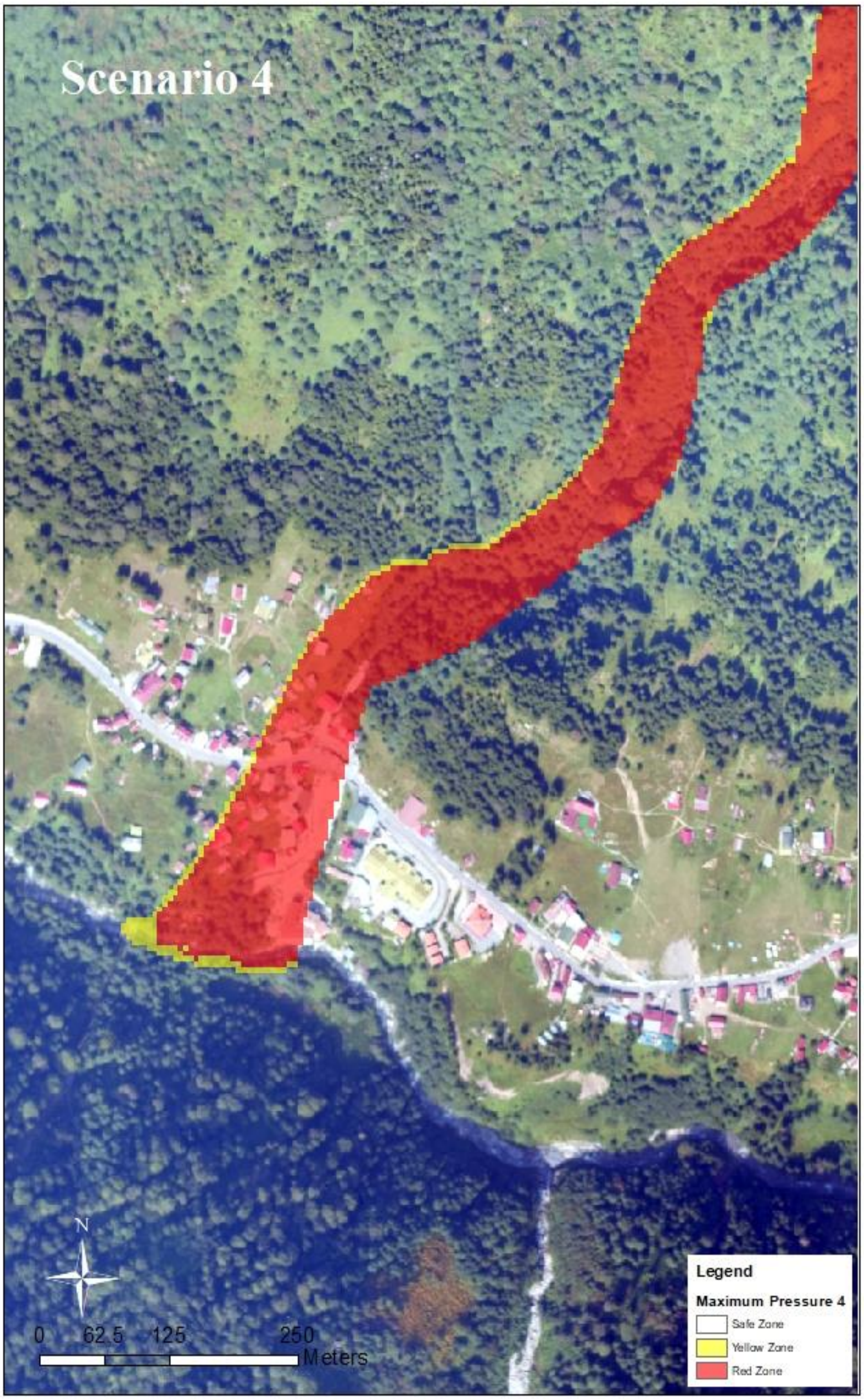


Figure 34: Scenario 4 Maximum Pressure at Samos

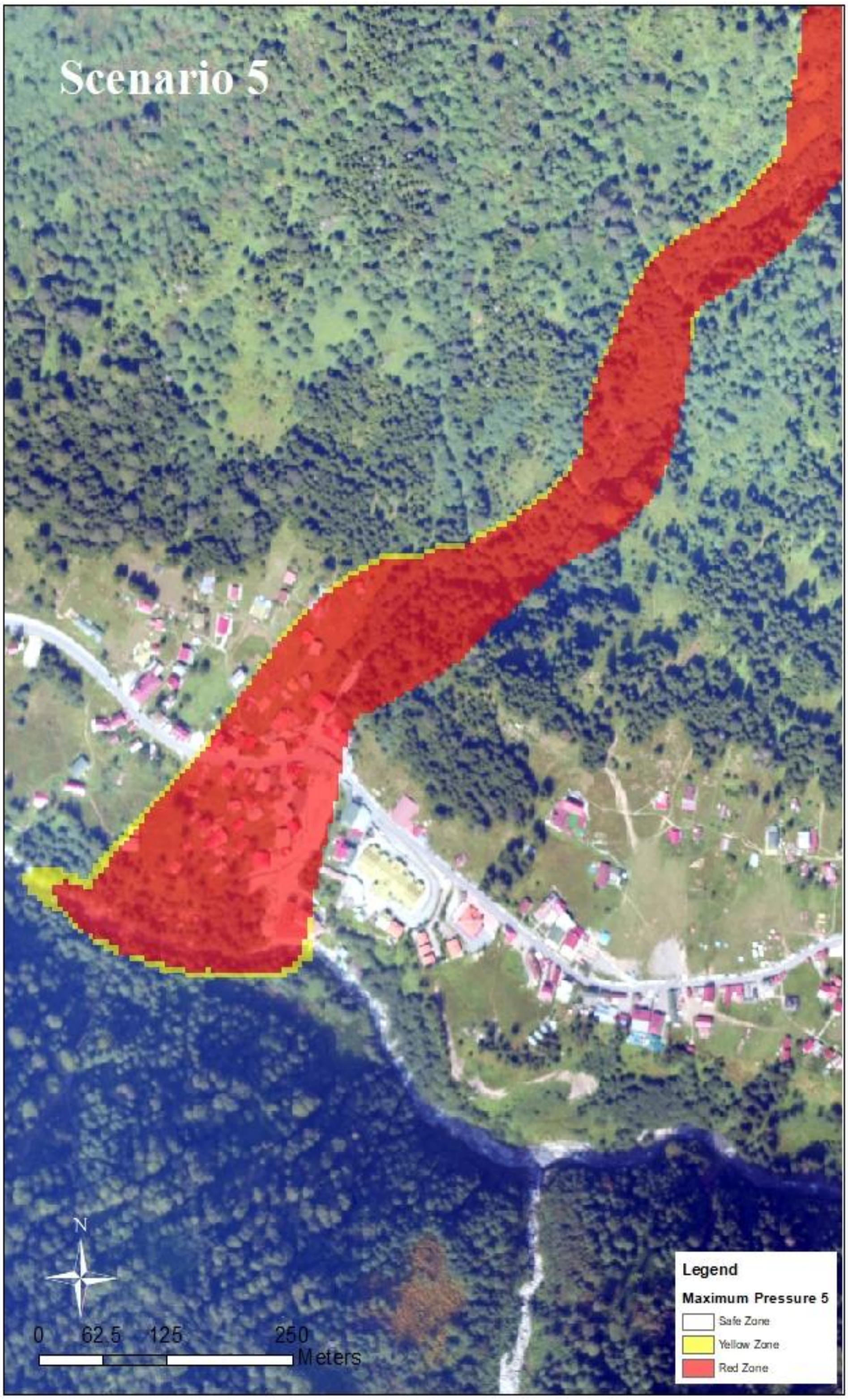


Figure 35: Scenario 5 Maximum Pressure at Samos

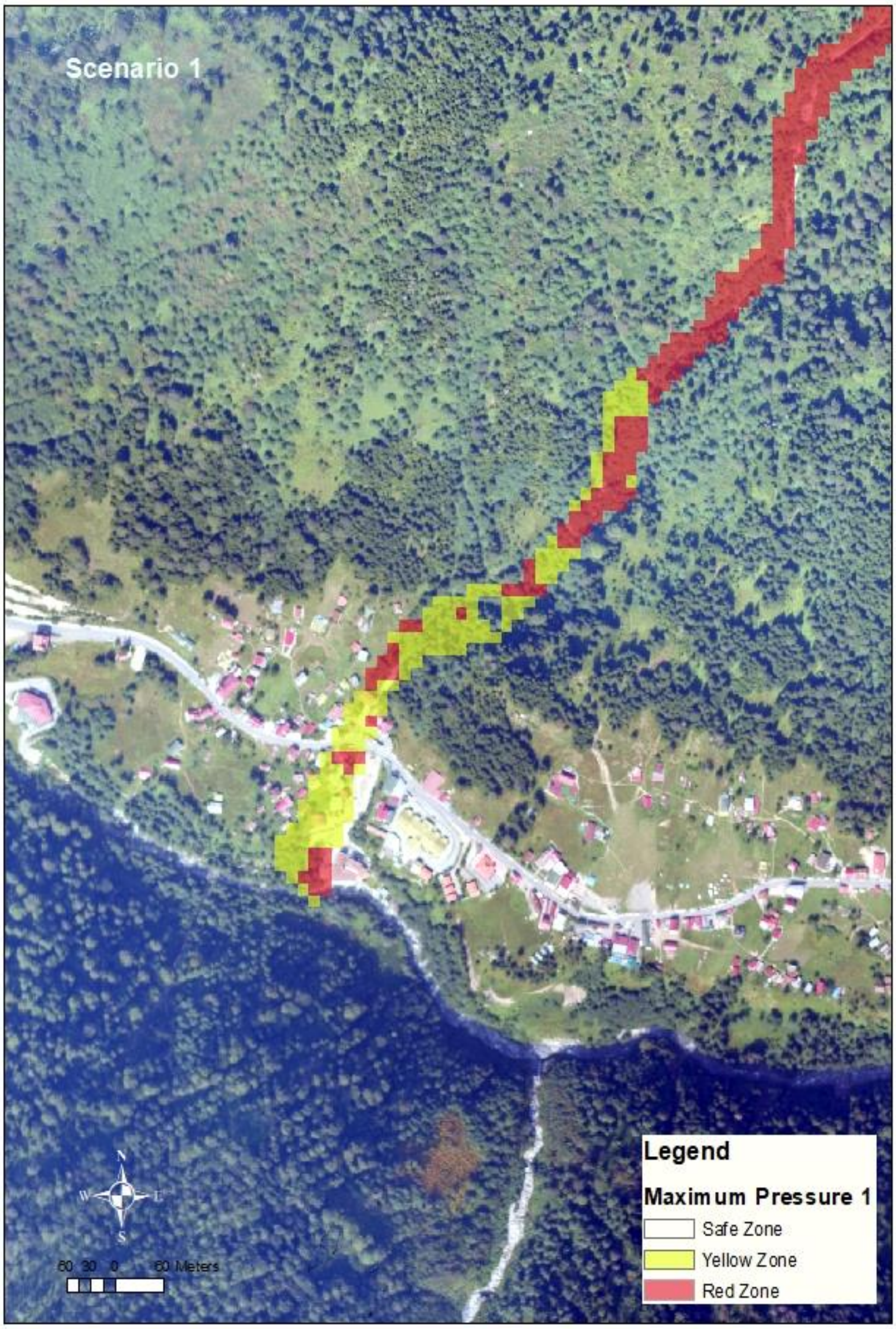


Figure 36: Scenario 1 Maximum Pressure at Ramms

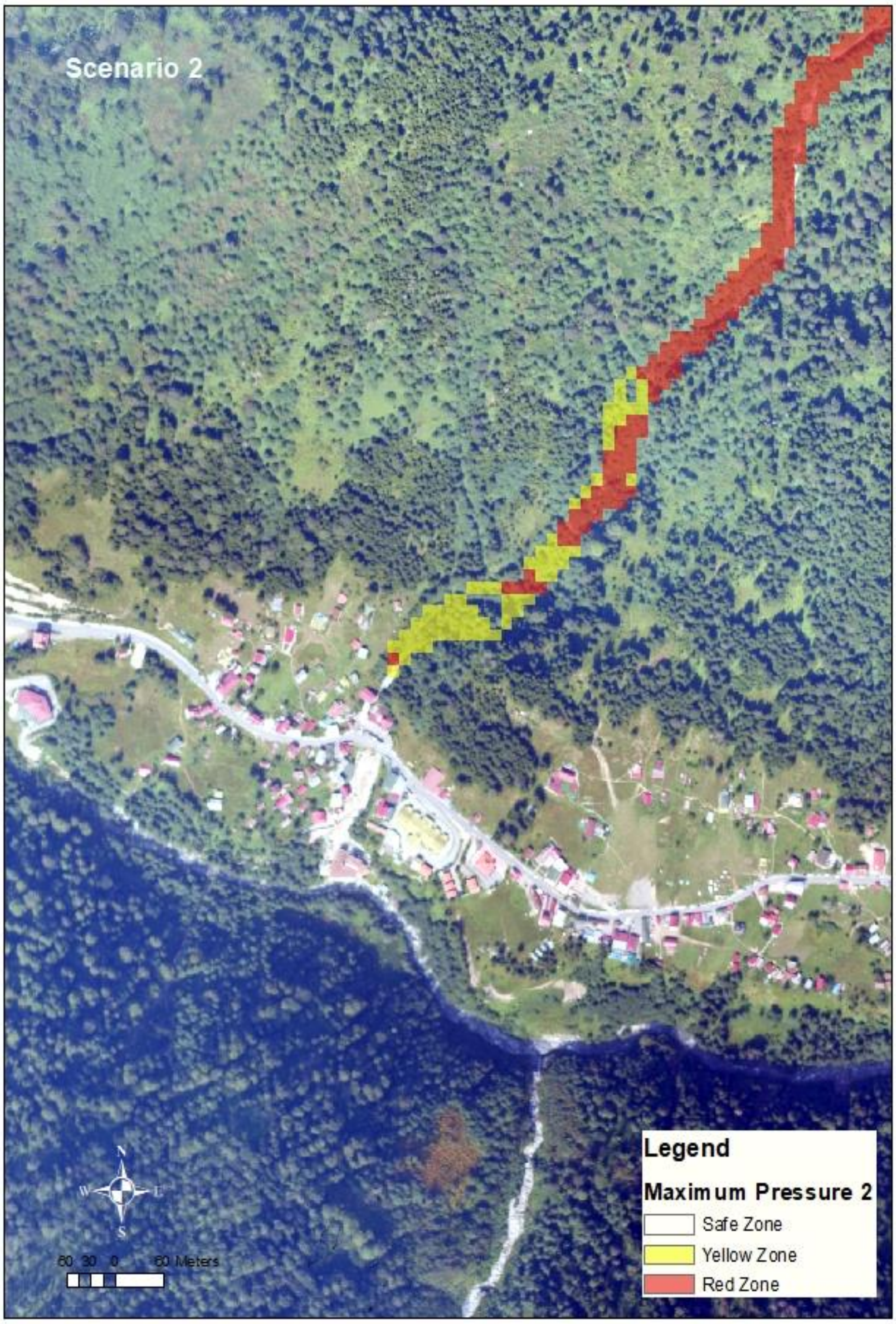


Figure 37: Scenario 2 Maximum Pressure at Ramms

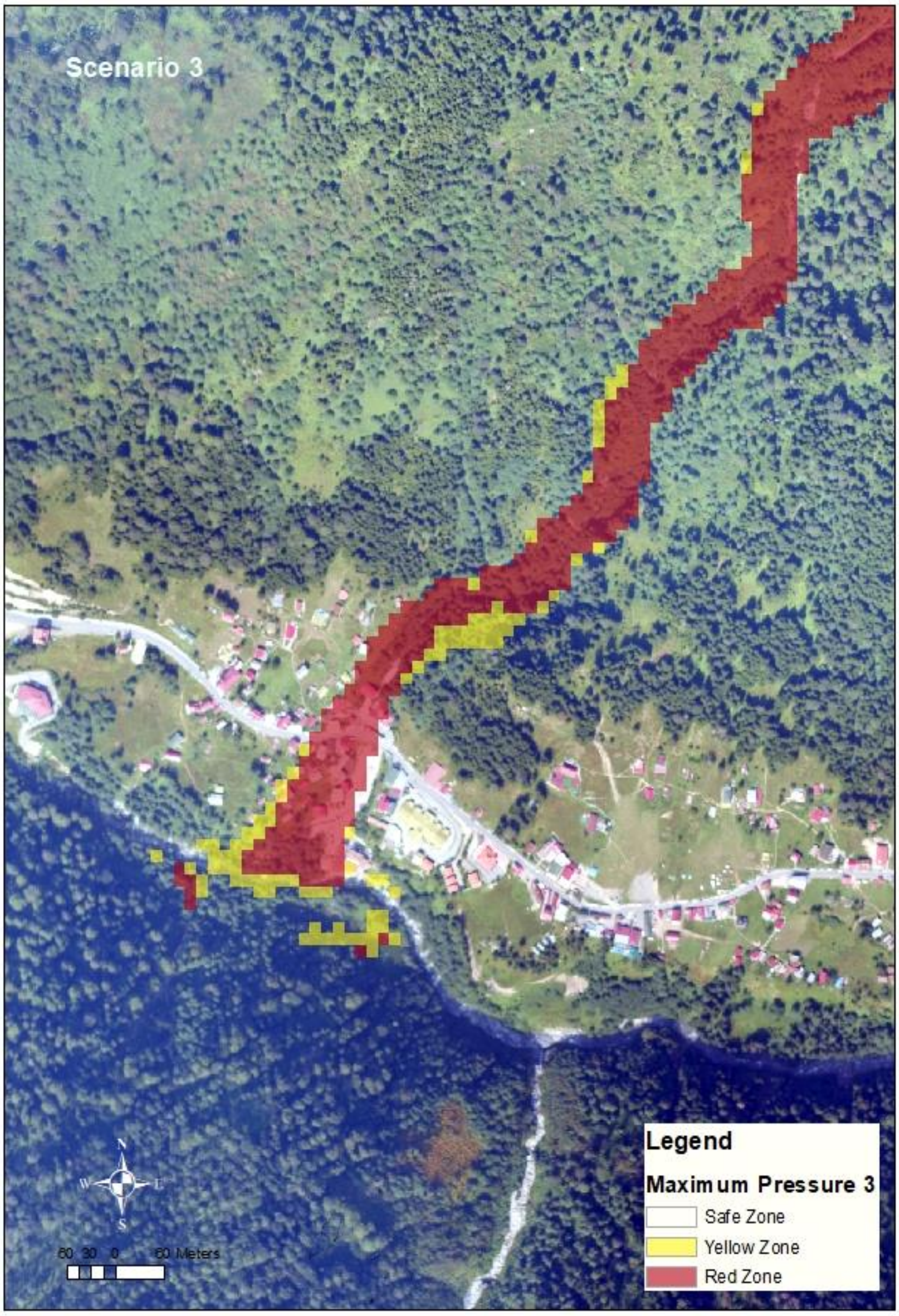


Figure 38: Scenario 3 Maximum Pressure at Ramms

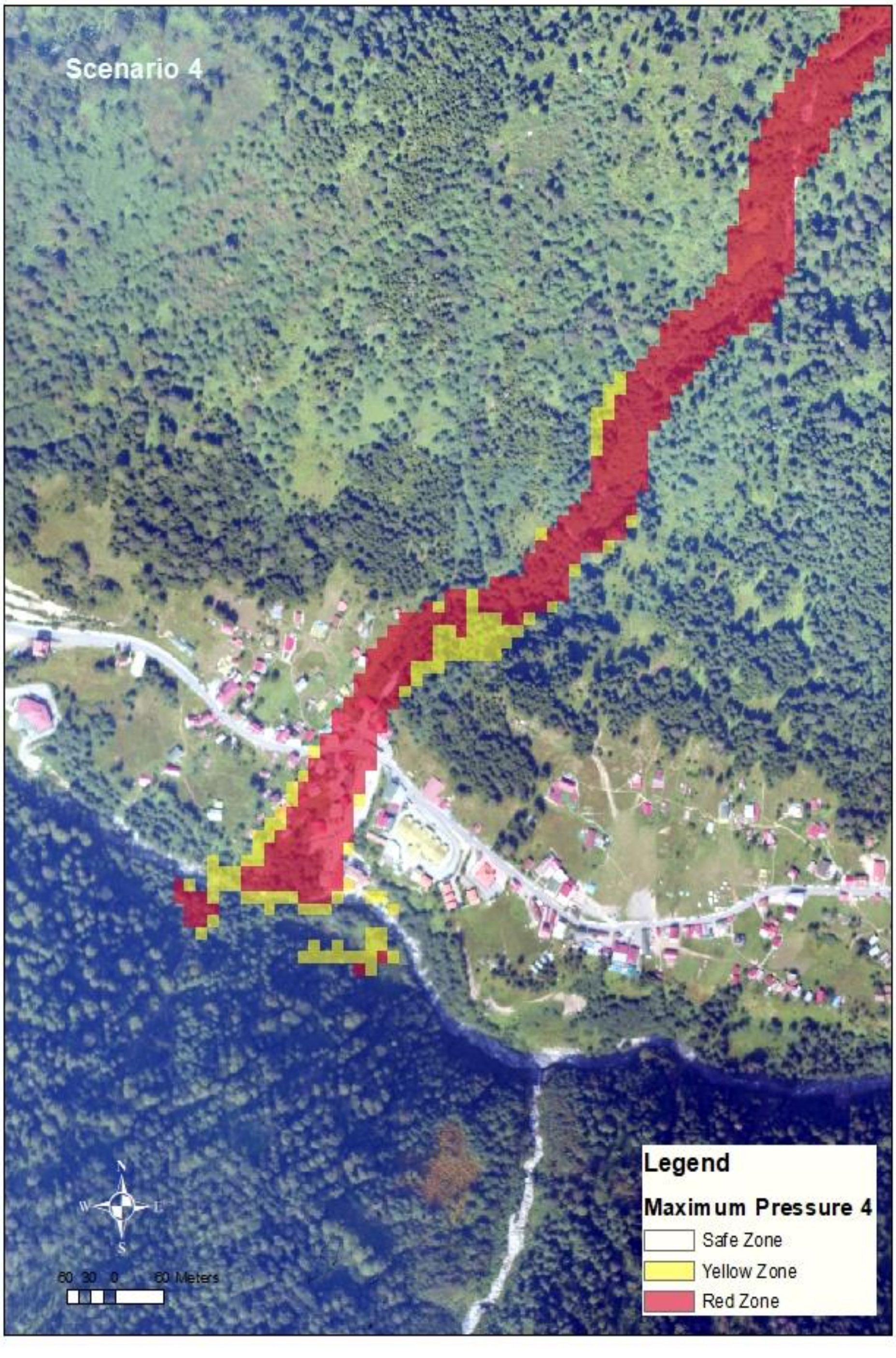


Figure 39: Scenario 4 Maximum Pressure at Ramms

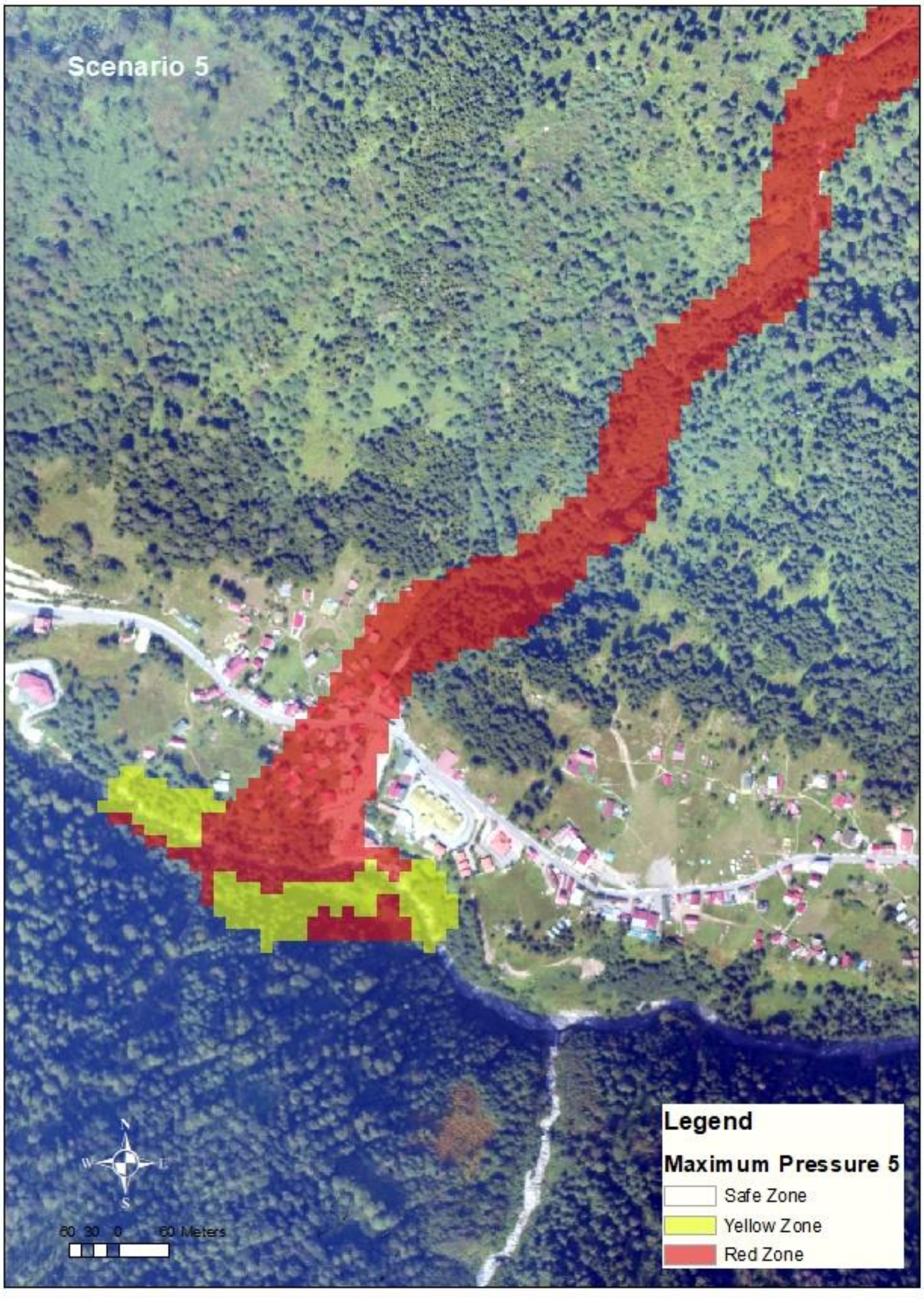


Figure 40: Scenario 5 Maximum Pressure at Ramms

- 100 years return period in swiss system equals to 150 years return period in Austria.

7. Simulation Results of Samos AT and Ramms

R1 scenario = Number **5** starting areas

R2 Scenario = Number **3,7** and **8** starting areas

R3 Scenario = Number **4** starting area

R4 Scenario = Number **1,2** and **5** starting areas

R5 Scenario **(Worst Case)** = All starting areas are used

First case scenario was made using an avalanche start zone that were related to 1991 avalanche event and the results are observed to be consistent with the information received from the local people. Verification of the values is done according to first simulation results.

7.1. Samos Results

Powder snow avalanches are not seen in the region so much. Thus, powder snow avalanche simulations were not conducted. It is also assumed that southern face slopes generally have wet snow avalanche problems.

Firstly, 5 different avalanche scenarios were used for dense avalanche using Samos avalanche simulation software. According to this scenario, it is observed that Ayder Plateau is under the avalanche threat. Despite the heavy forest area, the avalanches can reach the city. In addition, pressure maps are prepared based on Austrian standards. Thus, the red zone represents the regions with 10kpa and above. Yellow zone is between 1 to 10 kpa. The avalanche event in 1945 affected a wider area than 1991 avalanche event so the hazard zone map should be drawn considering the worst-case scenario. After the results, it can be observed that all buildings are in the red zone.

7.2. Ramms Results

As shown above, 5 different scenarios have been tested according to the same avalanche starting zones. While the results of Ramos and Samos are similar, it is seen that the results of Samos are affecting a wider area. This is due to the fact that the standard friction parameters used in the Samos are lower than Ramms. Since these values were calibrated according to the country, different results were obtained.

In conclusion, it is clearly seen that protection measures should be implemented in that area according to these results. It is also necessary to draw a hazard map to prevent the construction of new settlements in the area in the red zone.

- In addition, the maximum flow height and velocity of the scenarios are presented on the Appendix.

8. Designing Avalanche Protection Measures

The avalanche area has been determined using by field trip and simulations of RAMMS and SAMOS avalanche dynamics simulations. Structures such as deflection, catching dam have been planned but snow bridge is recommended because of lack of technical experts. Dams are also not so useful for powder snow avalanche. As a result of the interviews with the citizens who are living in the region, it was determined that there is a snow accumulation problem in the avalanche starting regions due to wind drift. In order to minimize snow accumulation in the start area, it is planned to make a wind drift fence and steel snow bridge, both of which prevent snow motion from starting to move. In the project area, 8 potential starting areas were identified with different sizes. According to a 150-year return period scenario, most of the homes and hotels on the Ayder Plateau are affected if an avalanche breaks out of these start-up areas. According to old eyewitnesses living in the village, the effects of avalanches in 1945 and 1992, which harm homes, hotels and old bridge, are seen. The measures have been determined based on a 150-year return period scenario. The simulations made have been evaluated and the following results have not been reached; There are 8 different potential start zones in the start area where the avalanche can break off. Number 1 and 5 avalanche starting zones has the most destructive effect. It has been determined that avalanche risk can be minimized in a significant part of the areas in the village if windbreak measures to be done near avalanche starting area at about 2300 altitude.

In order to prevent wind drifting, 4 meters high and 460 m long wind drift fence are planned. In three different avalanche starting zones identified to build snow bridges, the total length of snow bridge is 4 metres for all structures. Protection projects consist of 3 rows in the starting areas. First row of structure which is planned to build is 230 m and second row of steel snow bridges are projected with a total length of 540 m and last rows areas with 1235 m.

8.1. Planning of Supporting Structures

Construction area is located at 2200 altitude and it is 30 degrees inclined to surface. Mainly the avalanche path is the southern faced slope direction. According to the Swiss guidebook, the structure height is determined by the maximum snow height, the mean snow height in the area to be constructed, the extreme snow height and the average extreme snow height in the area to be built. 20 cm of snow which is transported with wind force values also add up to the structure height calculation process. In addition, Austrian zone table are used to calculate snow height but this value has been found that is not suitable the conditions in Turkey. Extreme snow height was taken 424 cm. This value is calculated according to Mr. Ismet who has a house which is located in starting area of avalanche. According to this value, the building height of 4m is calculated. The distances between the constructions are determined as 30m by using 30 ° slope value and Δh value (16).

All calculation is based on swiss starting zone structure guideline (Margreth, S., 2007)

8.1.1. Calculation of the extreme snow height Hext:

$$\boxed{H_{ext} = H_{max} \frac{\overline{H}_{ext}}{\overline{H}_{max}}} \qquad (1)$$

Hmax: Maximum height of snow in winter at the construction-site.

$\overline{\boldsymbol{H}}\boldsymbol{max}$: Averaged the maximum snow height at the construction gained from the surrounding snow measuring facilities in winter.

Hext: Maximum value of the snow heights over a long-time period at the construction site.

$\overline{\boldsymbol{H}}\boldsymbol{ext}$: Averaged extreme snow height, during the time of occurrence of extreme snow cover.

Zone Table was converted into a common recurrence interval of 150 years for Austrian region. Hext depending on altitude in the five zones is shown below;

- Zone 1:$\overline{\boldsymbol{H}}$ext. = 1.00 (0.15 · Z–20)
- Zone 2:$\overline{\boldsymbol{H}}$ext. = 1.30 (0.15 · Z–20)
- Zone 3:$\overline{\boldsymbol{H}}$ext. = 1.65 (0.15 · Z–20)
- Zone 4:$\overline{\boldsymbol{H}}$ext. = 2.00 (0.15 · Z–20)
- Zone 5:$\overline{\boldsymbol{H}}$ext. = 2.30 (0.15 · Z–20)

Table 10: Austrian Zone Table

(F.Rudolf Miklau, S. Sauermoser, 2015)

Due to lack of data extreme snow height was obtained by interviews with people living in that region. In addition, the Austrian zone table is not existent because it does not match with the value which was obtained from the people.

Hext=424 cm (Received from interview)

Snow thickness: Height of the snow layer measured at right angles

$$\boxed{D = H \cdot \cos\psi} \qquad (2)$$

D=HxCos30 = 424x0.87 = 367.2 cm

D=367,2 cm

8.1.2. Height of structure

δ:15° (δ = Grate angle [°])

Z: 2200 m (Altitude)

ρ: 0.3 t/m³

tanØ:0.55 (Friction angle)

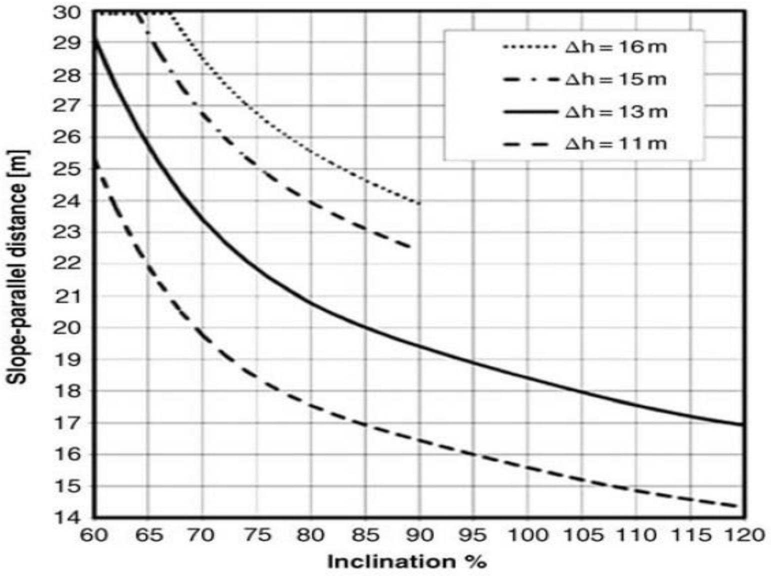
H = D/Cos δ = 367,3 /0,965 = 380cm

H + Wind Drift= 380 cm+20 cm

Recommended Hk = 400 cm

This value is a recommendation and the snow height should be measured in areas where structures will be constructed before such protection is done.

8.1.3. Calculation of distance between structures



Slope-parallel distance between rows of structures according to fixed height differences pursuant to ONR 24 806 [203]: The slope-parallel distance between rows of structures is read off with the measured slope inclination on the x-axis in Figure 6.15 from the ordinates in the slope-parallel distance between structures. Note: four lines for height differences from 11 m to 16 m are shown. For slope gradients below 75%, the curves were adjusted empirically to the practical experiences, and therefore deviate from the height differences by up to 2 m.

In order to use the diagram, the following conditions must be met:

– The max. distance between rows of structures may not exceed 30 m.
– The lines Δh 15 m and Δh 16 m may only be used at a slope inclination of max. 90% for snow thicknesses D ≥ 3 m in order to prevent the structures from being overloaded. Because of the low assessment snow pressure, smaller structures can only support a smaller snow layer.
– The lines Δh 15 m and Δh 16 m are central alpine areas, in which the new-snow increments are lower, and there are therefore better conditions for snow supporting structures than in alpine areas that lie on the rim of the Alps.
– The line Δh 13 m is indicative for positions on the rim of the Alps and may be used for all structures ≥ 3 m snow thickness. For slope inclinations ≤ 90% the line Δh 13 m can also be used for structures ≥ D = 2.7 m.
– The line Δh 11 m is meant for high safety requirements (e.g. protected objects in the avalanche path) and for smaller structures. Since small structures, because of the low assessment snow pressure only can support a small snow layer an unlimited utilization of the line Δh 11 is only possible for structures ≥ D = 2.5 m. For slope inclinations ≤ 80% Δh 11 m can also be used for structures ≥ D = 2.0 m. For smaller structures, either glide snow protection (e.g. glide snow tripods, berms) to reduce the layer pressure is required, or the structures must be assessed for a higher snow pressure

Figure 41: Calculation of distance between structures (F.Rudolf Miklau, S. Sauermoser, 2015)

Ψ:30° (Slope Inclination)

D = 367,3 cm

L:30 m (Distance between structures in the line of slope), as shown Figure 41.

Lateral Distance Between Structure: A = 2 m

L´ (Plan view) = 30 * cos 30 = 25,95 m

8.1.4. Calculation of Snow Pressure

8.1.4.1. Creep factor:

Dependent on density of snow at the area and the inclination angle of the slope

K: 0.76 * sin2 Ψ = 0,66

8.1.4.2. Glide conditions:

The glide factor N depends on the ground roughness and the slope exposure.

2.40 is selected as Glide Factor from swiss guideline.

8.1.4.3. Altitude factor

$$\boxed{f_c = 1 + 0.02(\frac{Z}{100} - 15)} \qquad (3)$$

$$fc = 1 + 0.02\left(\frac{z}{100} - 15\right) \text{ (Altitude Factor)}$$

$$fc = 1 + 0.02\left(\frac{2200}{100} - 15\right) = 1.14$$

8.1.4.4. Slope Parallel Snow Pressure component in the line of contour

$$\boxed{S'_N = \rho \cdot g \cdot \frac{H^2}{2} \cdot K \cdot N} \qquad (4)$$

$$S'N = \rho x g x \left(\frac{H^2}{2}\right) x K x N = 0.30 x 10 x \left(\frac{4.66^2}{2}\right) x 0.66 x 2.40 = 51{,}5 \text{ kN/m}$$

8.1.4.5. Pressure component normal to the slope

$$\boxed{S'_Q = S'_N \frac{a}{N \cdot \tan\psi}}$$

$$\frac{a}{N \cdot \tan\psi} = \tan\varepsilon = \frac{S'_Q}{S'_N} \qquad (5)$$

S'Q: Pressure component normal to the slope

Ψ: Slope angle

a: Vary according to the type of snow at the construction area

$$S'Q = 51.5x\left(\frac{0.5}{2.4\ x\ 0.58}\right) = 18{,}6\ kN/m$$

$$tan\varepsilon = \frac{S'Q}{S'N} = \frac{18{,}6}{51{,}5} = 0.36\ \varepsilon = 19{,}85°$$

8.1.4.6. Increment for non-normal supporting surface

Because of non-normal supporting surface, components S'N and S'Q must be increased by the weight G' occurred between the supporting surface and the plane normal to the slope. *(Margreth, S., 2007)*

$$\boxed{G' = \rho \cdot g \cdot \frac{D^2}{2} \cdot \tan\delta} \qquad \textbf{(6)}$$

D = snow thickness [m]

δ = grate angle [°]

$$G' = \rho xgx\left(\frac{D^2}{2}\right)xtan\delta = 0.30x10x\left(\frac{4{,}04^2}{2}\right)xtan15 = 6{,}56\ kN/m$$

$$tan15 = 0.27$$

8.1.4.7. Lateral Load to Support Surface: S'S = 0,1 * S'N * l [kN] **(7)**

Ss = 51,5 * 0,1 * 4 = 20,6 kN

8.1.4.8. End-effect loads: End-effect loads emerged because of the fact that the snow can move to lateral direction around the surface, so that a lateral limitation effect happens.

$$FR = (0.92 + 0.65xN)x\left(\frac{A}{2}\right) \leq (1 + 1.25xN), \qquad N = 2.40,\ \ A = 2{,}5$$

$$FR = (0.92 + 0.65x2.40)x1 \leq (1 + 1.25x2.40),$$

$$\mathbf{2{,}48 \leq 4}$$

FR=2,48

8.1.4.9. Magnitude of resultant: The magnitude of the resultant R' is obtained with the sum of forces which are parallel and normal to plane.

R'N = S'N + G'N **(8)**

R'Q = S'Q + G'Q **(9)**

$$\boxed{R' = \sqrt{R'^2_N + R'^2_Q}} \qquad (10)$$

S’R = 2,48x51,5=127,72 kN/m

$G'N = G'xsin\Psi = 6{,}6x0.5 = 3{,}3\ kN/m$

$G'Q = G'xcos\Psi = 6{,}6x0.87 = 5{,}74\ kN/m$

R’N = S’N+G’N = 51.5+3,3 = 54,8 kN/m

R’Q = S’Q+G’Q = 18,6 + 5,74= 24,34 kN/m

$\boldsymbol{R' = \sqrt{(54,8^2 + 24,34^2)} = 59,9\ kN/m}$

R'N = S'N + S'R + G'N

8.1.4.10. With End Effect Pressure

R’N = S’N+ S’R + G’N = 51.5 + 127,7 + 3,3 = 182,5 kN/m

R’Q = S’Q + G’Q = 18,6 + 5,74 = 24,34 kN/m

8.1.4.11. Direction of the Resultant Pressure

The direction of the resultant pressure in the plane normal to the contour line is calculated from equation below:

$$\boxed{\tan \varepsilon_R = \frac{R'_Q}{R'_N}} \qquad (11)$$

8.1.4.12. Resultant Pressure with End Effect Load:

$\boldsymbol{R' = \sqrt{51,5 + 127,7 + 3,3)^2 + (18,6 + 5,74)^2} = 184,1\ kN/m}$

tanεR = R’Q / R’N = 24,03 /182,5 = 0,133

εR = 7,58°

Load case 2

It is assumed that the entire structure height is covered with snow height (h) which is calculated with formula below;

$$\boxed{h = 0.77 \cdot H_K} \qquad (12)$$

h = 0.77x Hk, Hk=4 m, h = 3.08 m

Resultant Pressure load 2 as same as Load 1.

Snow pressure bigger than load 1 a factor of 1.3

Wind pressure = 3 kN/m² according to ONR 24806

8.1.4.13. Loads on the grate

Load case 2 is used. For a plane grate:

$$\boxed{P' = R' \cdot \cos(\delta - \varepsilon_R)} \qquad (13)$$

Snow pressure ph normal to the grate is showed below:

$$\boxed{p_h = \frac{P' \cdot \cos\delta}{0.77 \cdot D_k} = \frac{P'}{0.77 \cdot B_K}} \qquad (14)$$

Distributed normal load on a crossbeam implemented over total of crossbeam width and distance to the nearest supporting structure.

$$\boxed{p'_B = p_h' \cdot b} \qquad (15)$$

Load 1:

$P'h = \frac{R' x cos(\delta - \varepsilon R)}{Bk} = \frac{184{,}1x0.99}{0.77x4} = \mathbf{39{,}2\ KN/m^2}$ with end effect pressure

$P'h = \frac{R' x cos(\delta - \varepsilon R)}{Bk} = \frac{59{,}9x0.99}{0.77x4} = \mathbf{14{,}8KN/m}$ without end effect pressure

Structure width = 2m

Load 2:

$P'h = \frac{R' x cos(\delta - \varepsilon R)}{0.77xBk} = \frac{184{,}1x0.99}{0.77x4} = \mathbf{50{,}9\ KN/m^2}$ with end effect pressure

$P'h = \frac{R' x cos(\delta - \varepsilon R)}{0.77xBk} = \frac{59{,}9x0.99}{0.77x4} = \mathbf{19{,}2KN/m^2}$ without end effect pressure

P´h is rised by 25% from surface to Bk/4

Bk = Grate height

Structure width = 2m

8.1.4.14. Pressure on cross beams:

P´B=P´h x b b=37.5 cm **(16)**

P´B=50,9 x 0.375 = **19,1 kN/m**

q´b=0,20*P´B q´b=0,2*19,1 = **3,82 kN/m**

8.1.4.15. Steel Profiles

The following table shows the steel classes used in the design of the snow supporting structures.

Component	**Profile**	**Dimensions**	**Steel Elements**
Girders	IPE	140 to 270	S355JR
Supports	HEA	120 to 180	S235JR

Table 11: Steel Classes (F.Rudolf-Miklau, S.Sauermoser, A.I. Mears, 2015)

8.1.4.16. Ultimate Limit: It is necessary to verify the limit values of the constructions.

$Ed \leq Rd$

$Ed = \gamma Q \cdot Qk$: Design effect of actions and

$\gamma Q = 1.5$ load coefficient

$Rd = Rk/\gamma M$: Design resistance and **(Margreth, S., 2007)**

$\gamma M1 = 1.05$ for strength and stability approval purposes

$\gamma M2 = 1.25$ for connections and verification in net section.

CALCULATION OF SNOW AVALANCHE PROTECTION STRUCTURE			
NR	FACTOR	INPUT	SELECTION
1	ZONE	4,00	[1 TO 5]
2	ELEVATION	2200	[M]
3	WIND	20	
4	EXPOSITION	SOUTHWEST	[1 TO 8]
5	DENSITY	0,3	[0,2 TO 0,6]
6	SLOPE	30	[DEGREE]
7	Hmax	500	[cm]
8	Hext	424	[cm]
9	Hmax	500	[cm]
10	CREEP FACTOR=K	0,66	DO NOT CHANGE
11	GLIDE FACTOR=N	2,4	DO NOT CHANGE
12	ALTITUDE FACTOR	1,14	DO NOT CHANGE
13	(a) COEEFCIENT	0,5	DO NOT CHANGE
14	SOIL CLASS	3	[1 TO 4]
	RESULTS	AUSTRIA (ZONE TABLE)	USE GENERAL FORMULA
	EXTREME SNOW HEIGHT	620,0	424,0
	SNOW DEPTH	536,9	367,2
	STRUCTURE HEIGHT	575,9	400
	NEW SNOW HEIGHT	671,0	466,2
	NEW SNOW DEPTH	581,1	403,8
	SNOW PRESSURE (Sn)	106,7	51,5
	SNOW PRESSURE (SQ)	38,5	18,6
	G (NON-NORMAL)	13,6	6,6
	LATERAL LOAD TO SUPPORT (Ss)	42,7	20,6
	END EFFECT LOAD	330,7	127,7
	Єr (With End Effect)	6,45	7,57
	Єr (Without End Effect)	23,89	23,89
	RESULTING SNOW PRESSURE	124,1	59,9
	RESULTING SNOW PRESSURE WITH END-EFFECT	447,0	184,1
	Snow Pressure On Grate Load 1	39,8	14,8
	Snow Pressure On Grate With End Effect Load 1	123,2	39,2
	Snow Pressure On Grate Load 2	51,7	19,2
	Snow Pressure On Grate With End Effect Load 2	160,1	50,9

Figure 42: Calculator of Snow bridge

8.1.5. Design of Structures

8.1.5.1. SAP2000

SAP2000 is a civil engineering software which is used for the design and analysis of all types of structure systems. Structural Analysis Program is called as "Sap"2000 which is a general-purpose software used for the development, analysis and dimensioning of structure system models.

A detailed analysis of the finite element can be done by the module called SAPFire Analysis Engine which comes with the SAP2000 program. With this method called Finite Element Analysis, complicated geometries are divided into finite number of elements and each one is subjected to stress analysis separately, then the results are combined so that stress analysis in one time is not possible; it is ensured that the analysis of the parts is done correctly.

8.1.5.2. AutoCAD

AutoCAD program, which is one of the world's most preferred computer-aided design programs and is produced by Autodesk, has a very simple and practical interface. In AutoCAD, two or three-dimensional machine parts, electrical circuits and even building drawings can be made.

In the thesis:

The avalanche bridges plotted using AutoCAD software and static loads were calculated using Sap2000 software.

- Dead Loads: The dead weights of the elements are automatically calculated by the software.
- Snow Loads: Loads calculated by using excel calculator and then it is used in sap2000.
- Wind loads: According to the first load, the wind load is not used because the structure will completely cover the snow. In the second situation, it is assumed that the upper part of the structure is affected by snow, as can be understood from the formula “0.77 * Hk”. For this reason, the wind effect was used for this installation. Wind load is assumed to be 3 kN/m² according to ONR 806.

Component Design Loads: The steel element design results are below 1 in all ratios. Since the capacity ratios observed on the elements are less than 1 degree, the elements safely carry the loads on them.

➢ Designed system was tested according to ultimate limit. It can be seen from Figure 45,46,47,48.

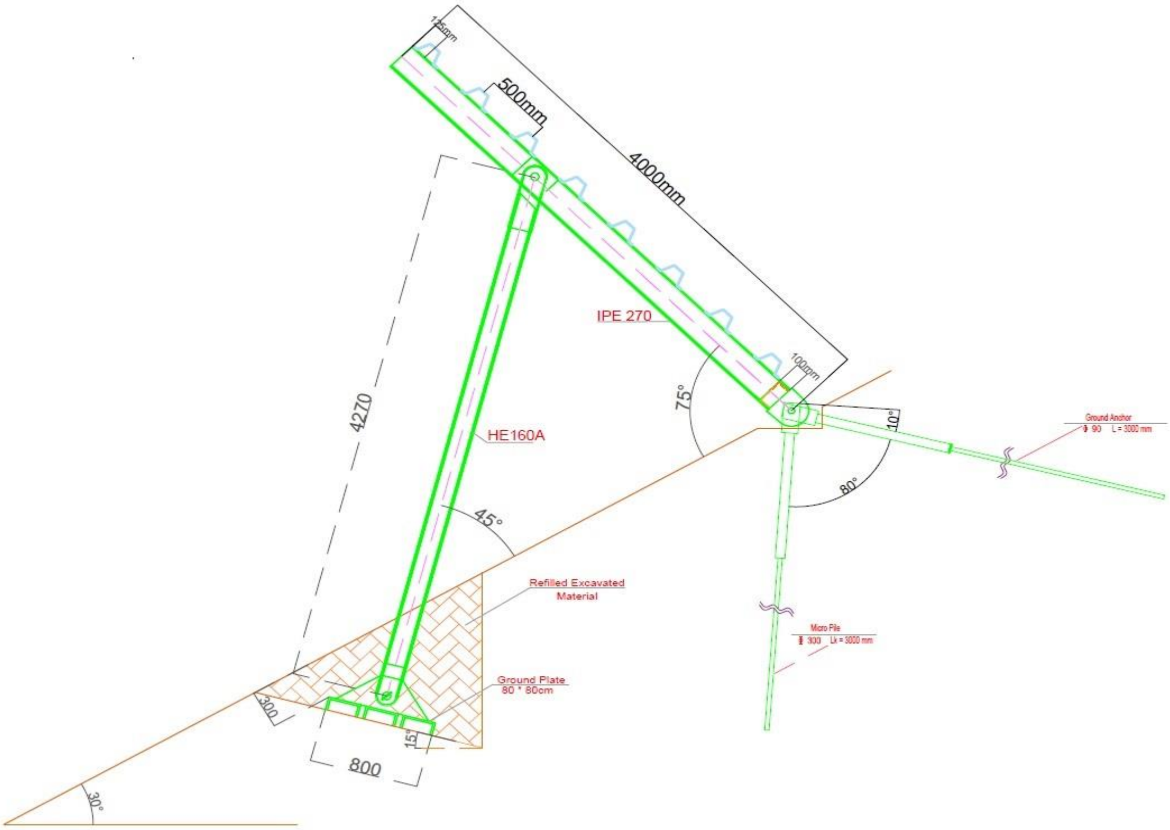


Figure 43: Designed snow bridge of study area

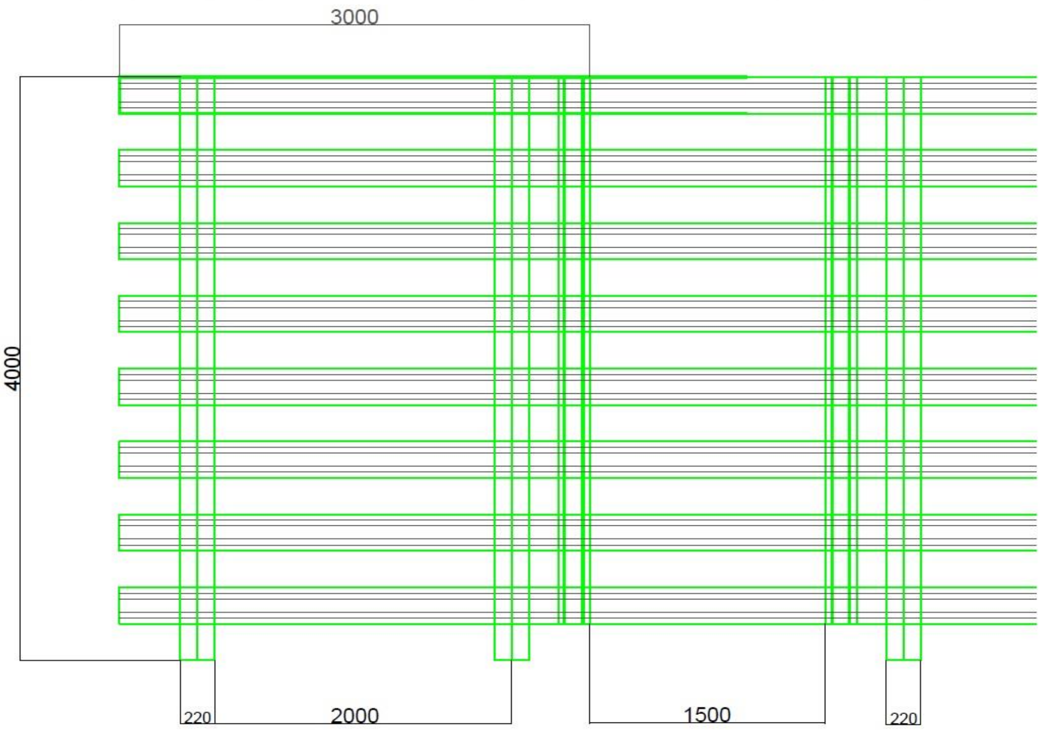


Figure 44: Designed snow bridge of study area

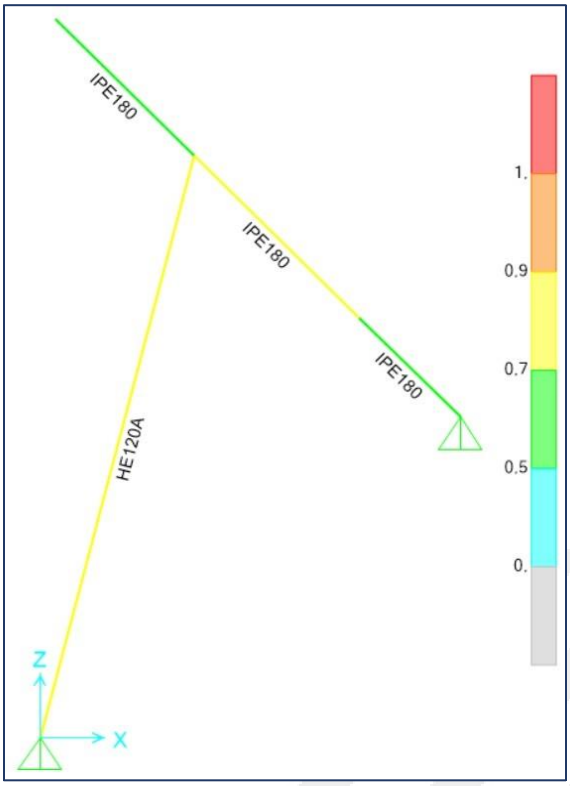


Figure 45: Load 1 Without end effect

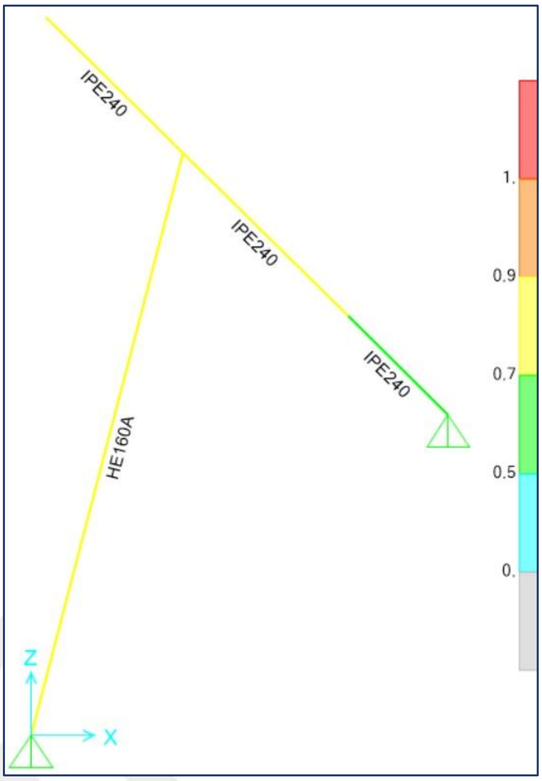


Figure 46: Load 1 With end effect

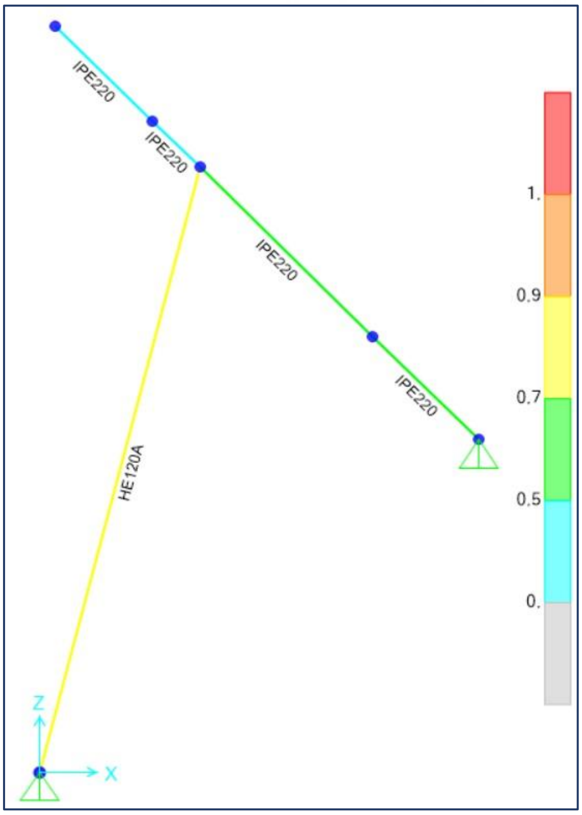


Figure 47: Load 2 without End Effect

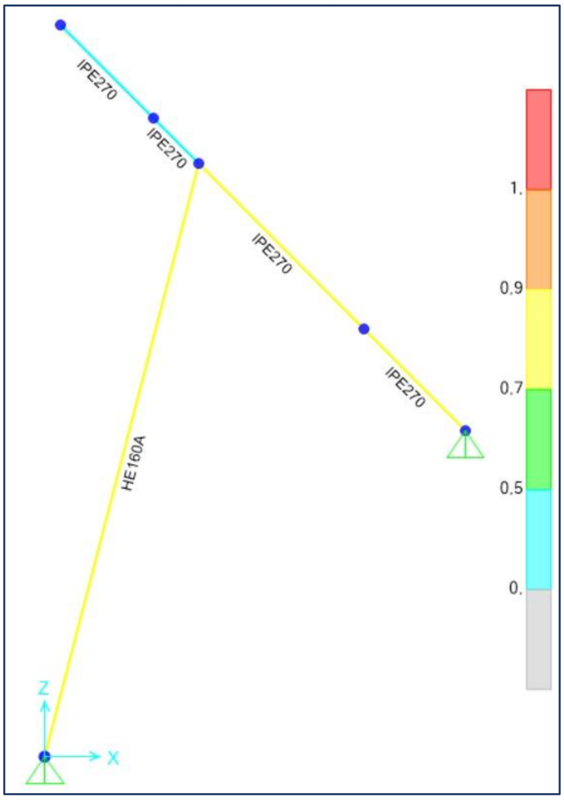


Figure 48: Load 2 With End Effect

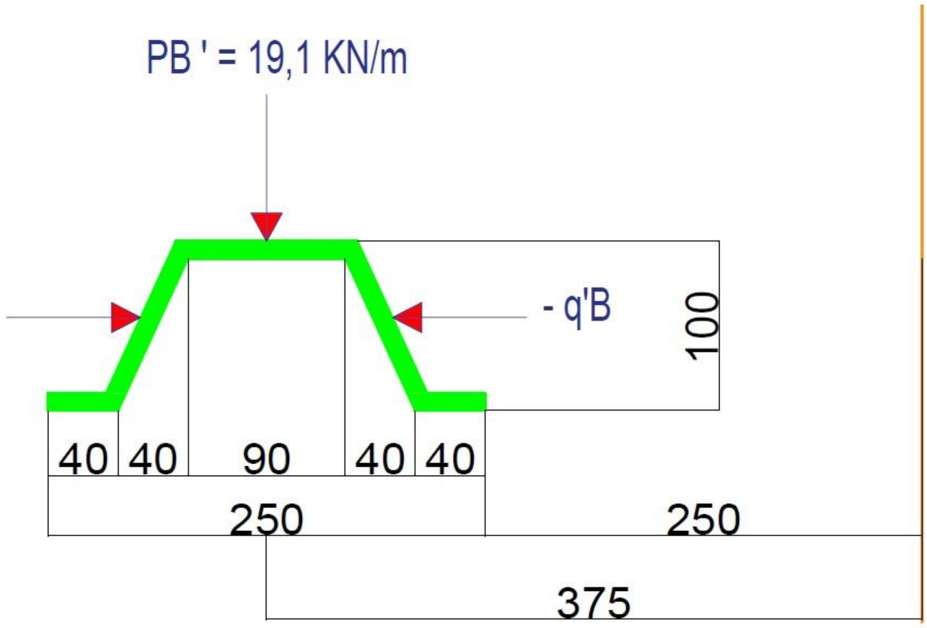


Figure 49: Designed cross beam of snow bridge

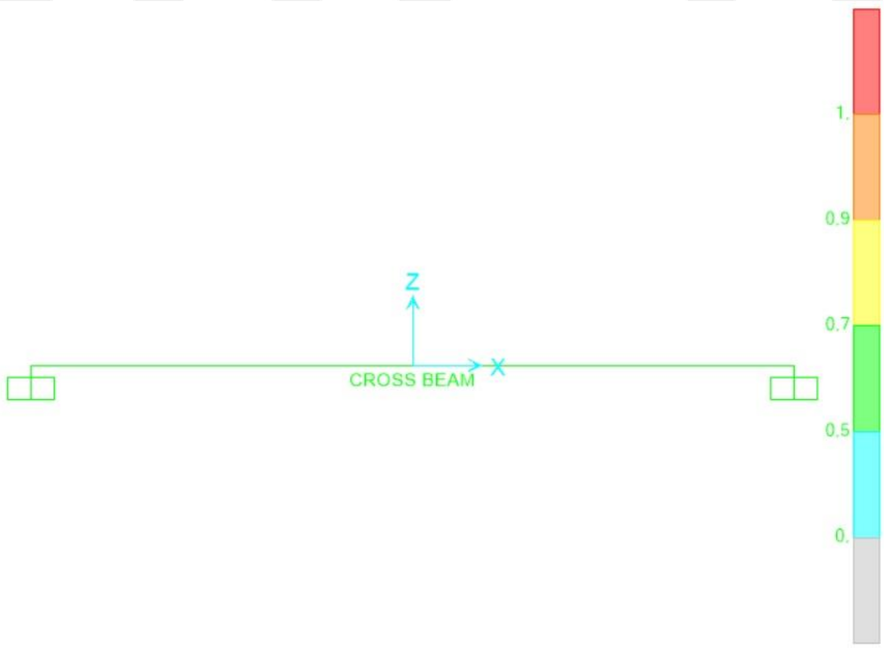


Figure 50: Designed cross beam of snow bridge

8.1.6. Design of Foundation of Snow Bridge

The most general type of foundation for snow bridges in Austria is the base plate. The ground plates vary in size related to the quality of the soil. **40 * 40** cm is used in rocky soil, **60 * 60 cm** for weak soil and **80*80 cm** for very weak soil.

Prefabricated foundation must be buried under 300 cm below from surface level and should be at 15 degrees to the surface. When the foundation is made, the removed soil should be repressed in the same way and replaced. The floor was determined to be very weak and **80 * 80 cm** prefabricated foundation was chosen according to the Austrian standards.

The pile length in the upper part is determined according to the Swiss guidebook based on the forces obtained from the calculations made with the aid of the SAP2000 program. The angle between the piles is 80 degrees. Cross Beams are chosen to be 250 mm, which is the most appropriate value, according to the guideline.

Steel types used in support and beam are selected according to SAP2000 program with the values given in technical book. These values are chosen according to the load 1 and load 2 and also taking the end effect load into consideration. These loads tested normal and ultimate loads. The normal load is the load under normal conditions. In the case of ultimate load, the calculated load is multiplied by a coefficient of 1.6. This value is taken from the Austrian standard book. All calculation is made based on Eurocode 2005-8 in Sap2000.

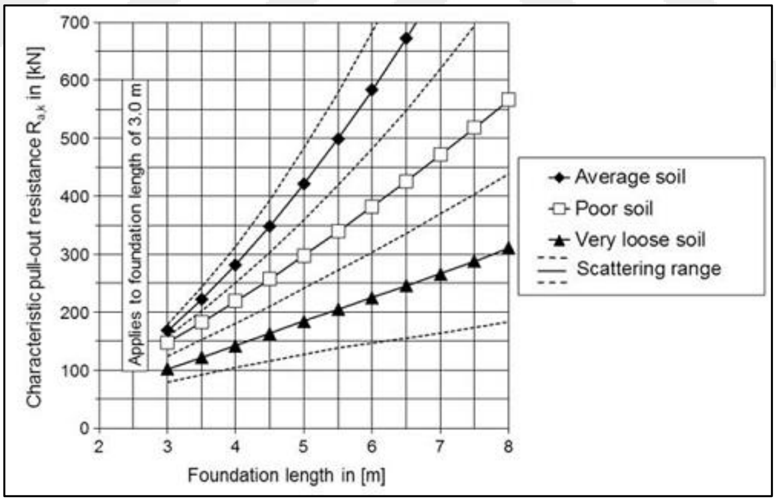


Figure 51: Relationship between pull-out resistance and foundation lenght ***(Margreth, S., 2007)***

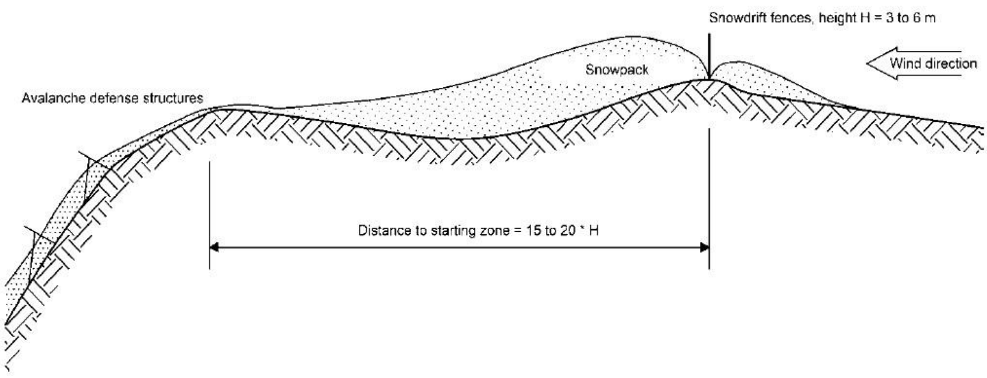
PRESSURE Normal Situation	Tensile Pressure (kN)	Compressive Pressure (kN)	FOUNDATION LENGTH (m)
Load 1	101,24	22,81	3
Load 2	110,21	23,3	3
With End Effect			
Load 1	261,31	53,91	6,5
Load 2	293,99	52,34	7,5

Table 12: Calculation of upper part of structure foundation

Figure 52: Position of snow bridge in study area

8.2. Snow Drift Fence

Snowdrift fences are built on high ridges above snow bridge, in order to reduce snow drifting accumulation into the avalanche starting zone. The structures should be constructed normal to the main wind directions. The fences can be consisting of both horizontal beams (grate) and vertical beams (grate). Snowdrift fences can be made with space from the ground surface. Depending on the quality of the foundation, the base is carried out with anchors in combination with ground plates or concrete pillars. *(Rudolf-Miklau, Sauermoser,2015)*



Placement of a snowdrift fence (© Margreth, illustrated by Herbert)

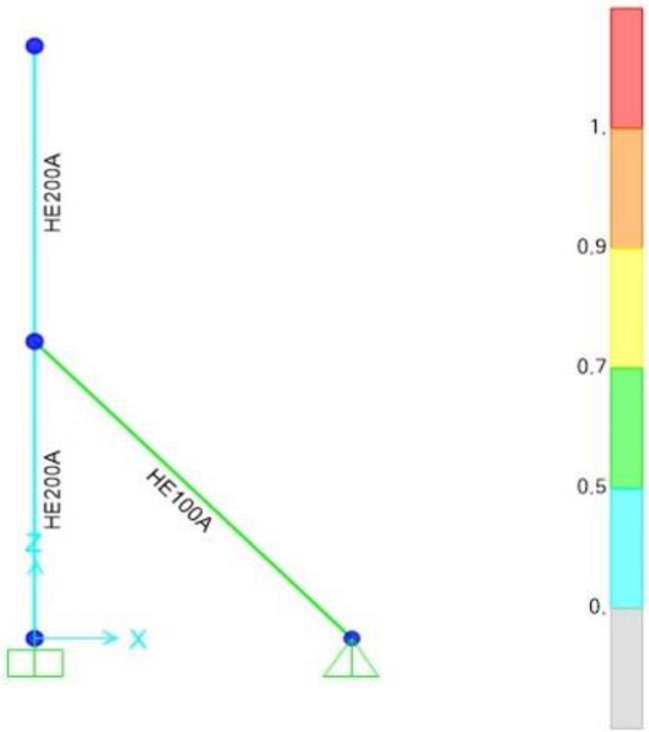
Figure 53: Placement of snowdrift fence *(F.Rudolf-Miklau, S.Sauermoser, A.I. Mears, 2015)*

The most suitable places where these structures can be made are places positioned perpendicular to the direction of the wind at a length between 15 to 20 times the level of the framework from the starting area of avalanche, as shown Figure 51. The storage capacity of these structures varies in proportion to its vertical position in the wind direction. The wind speed reaches maximum storage capacity if the wind is positioned upright. *(Rudolf-Miklau, Sauermoser, 2015)*

According to Austrian Standards,

- Recommended horizontal wind pressure 3.1 kN/m² according to ONR 806.
- Fence height is chosen as 4m because of the maximum snow height at the starting zone, as shown Figure 54.
- Distance between the fence and starting zone from 60 to 80m
- Space from the fence to the ground 400 cm is selected.
- Wind pressure = 3,1 kN/m², as shown Figure 55.
- Total length of structures in the study area is 500 m.

Figure 54: Designed Snow Drift Fence



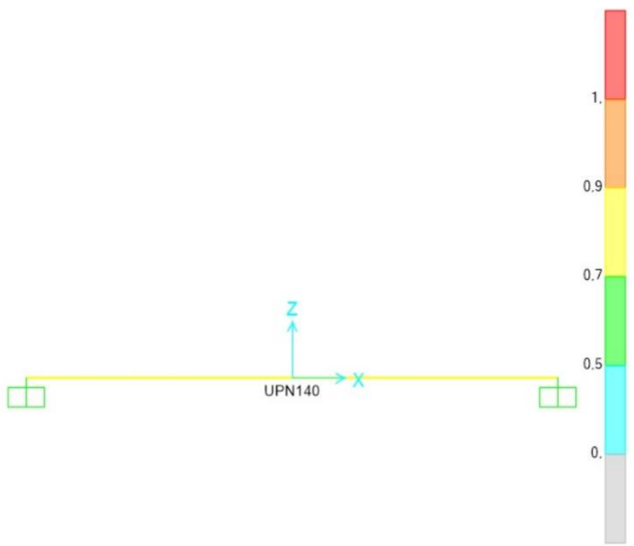


Figure 55: Designed Wind Fence

Figure 56: Designed of UNP 140

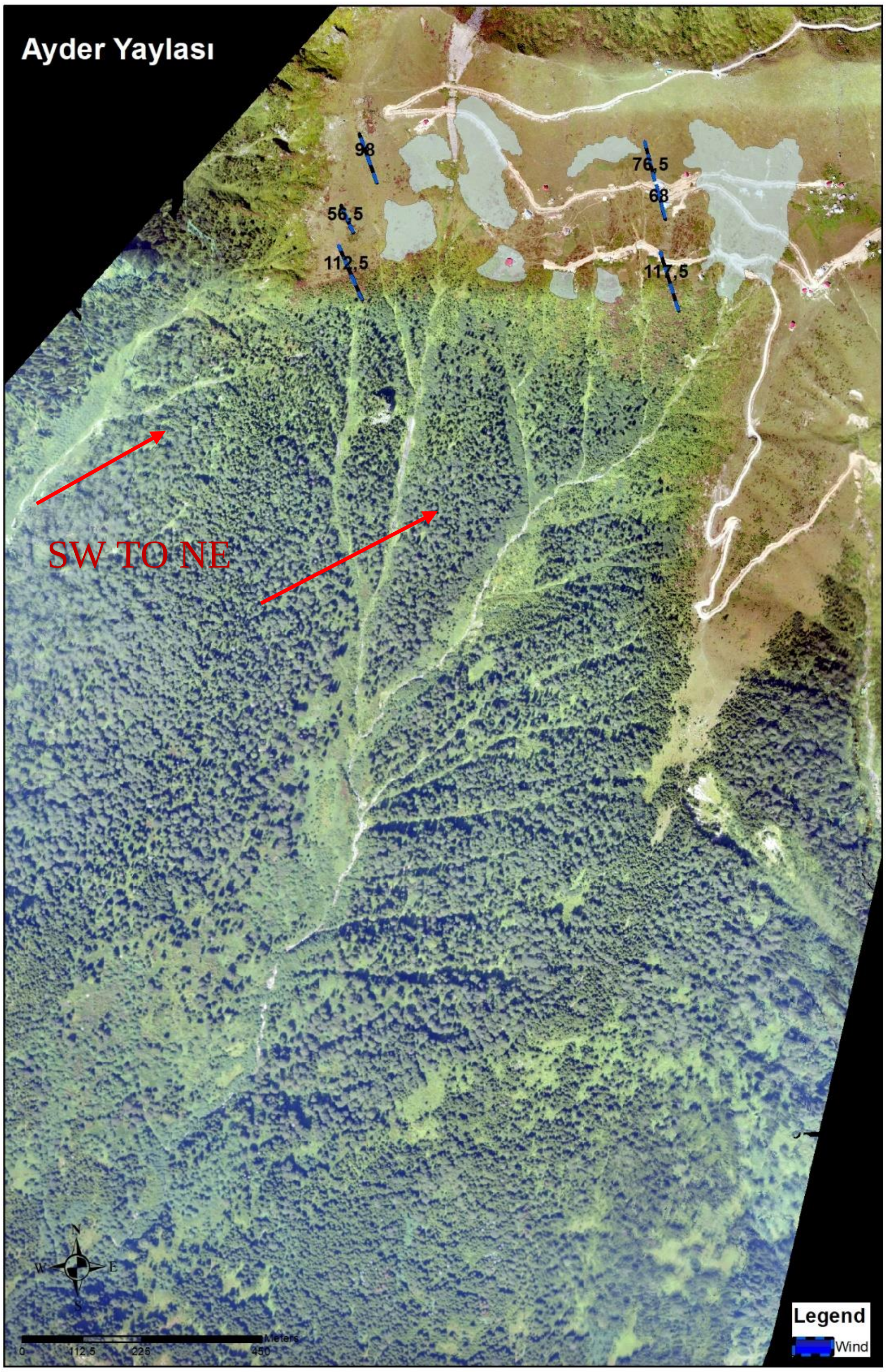


Figure 57: Position of Wind Fence

8.3. Deflecting Dam and Catching Dam

8.3.1. Catching Dam

Catching walls are often used to stop the dense avalanches and/or mixed type avalanches before reaching settlements but for powder part of mixed avalanches dams are not so useful.

Design and calculation of catching dam are shown below *(Jóhannesson, 2009):*

HDE = hu + hf + hs,

HDE = Height of the catching dam

hu = Energy height dependent on velocity of avalanche which are taken from Ramms simulations and deflection angle of the dam.

$$hu = \frac{U^2}{2*g*\lambda}$$

u: Avalanche velocity which obtained from Ramms	=	11 [m/s]
g: Gravitational acceleration [m/s]	=	9, 81 [m/s]
λ: Empirical Value	=	1

Empirical Value (Momentum loss value) ´1´ means flowing avalanche is dry and large size.

Φ: Deflecting angle [°]	=	90 [°]
hu:	=	6,2 m
hf: Flow Height which are taken from Ramms	=	2,5 m

hs: Thickness of snow (1,58 m) and previous avalanche ground deposits on the upper side of the dam (2 m).

HDE: Recommended dam height	=	**12,3 m**
Length of Dam:	=	**255 m**

Location of Catching dam should be made as close as possible to the settlement area. Because the settlement areas are usually located in the avalanche run-out zone and the areas where the speed of the avalanche is reduced so it will be avoided abnormal height of the structure, as shown Figure 56.

The length of structure determined to secure the settlement area is selected as the result of simulations using the Ramms simulation software.

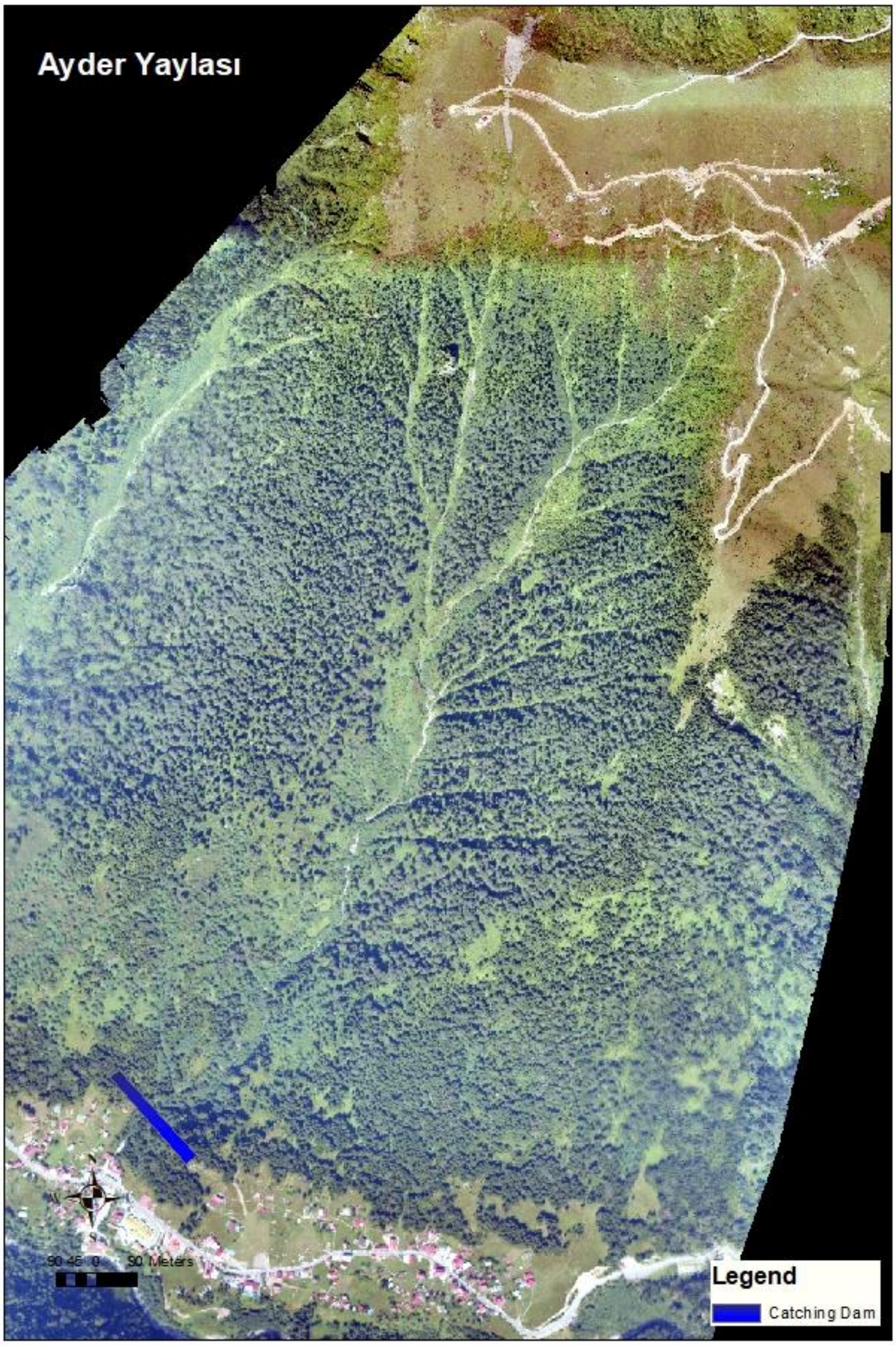


Figure 58: Position of Catching Dam

8.3.2. Deflecting Dam

If there is enough space in the avalanche deposition area and there is an empty place to send avalanche out of settlement area, the deflecting wall can be used to change the avalanche direction. The walls are often one of the most cost-effective solutions.

Design and calculation of catching dam are shown below *(Jóhannesson, 2009):*

HDE = hu + hf + hs,

HDE = Dam height

hu = Energy height dependent on velocity of avalanche which are taken from Ramms simulations and deflection angle (20° are recommended) of the dam.

$$\text{hu} = \frac{(U * sin\varphi)^2}{2 * g * \lambda}$$

u: Avalanche velocity are obtained from Ramms	=	25 [m/s]
g: Gravitational acceleration [m/s]	=	9, 81 [m/s]
λ: Empirical Value	=	1

Empirical Value (Momentum loss value) ´1´ means flowing avalanche is dry and large size.

Φ: Deflecting angle [°]	=	20 [°]
hu	=	3,7 m.
hf: Flow Height which are taken from Ramms	=	3,5 m

hs: Thickness of snow (1,58 m) and previous avalanche deposits on the upper side of the dam (2 m).

HDE: Recommended dam height	=	**10,8 m**
Length of dam	=	**610 m**

The velocity value which is used at deflecting dam is greater than at the catching wall. The reason is that the structure is planned to be constructed at a higher altitude than the catching wall, as shown Figure 57. The position of the building is determined by simulation results using the Ramms program.

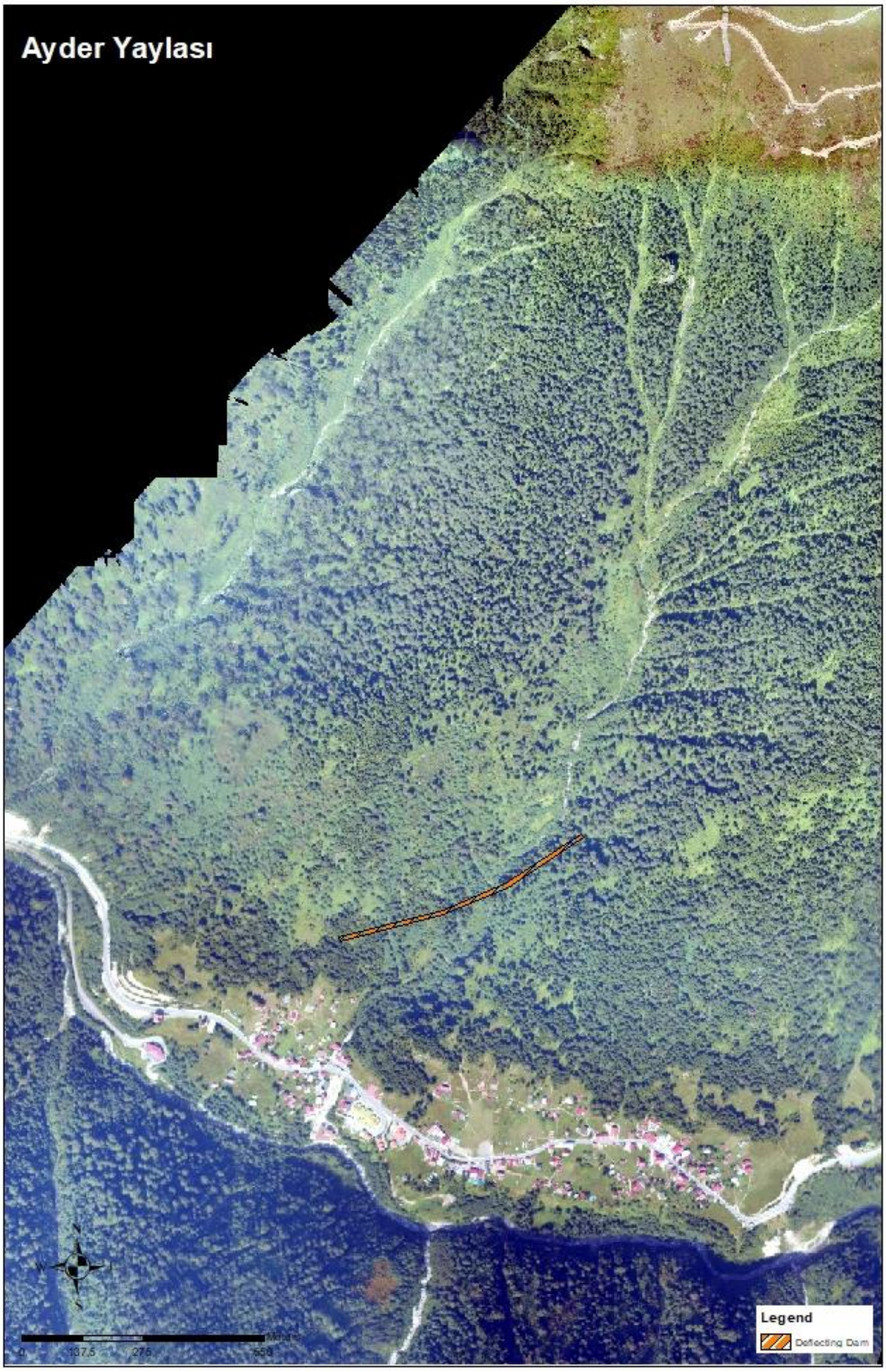


Figure 59: Position of Deflecting Dam

9. Cost Benefit Analysis

Benefit-cost analysis (B-C) is a technique that is used to evaluate investment projects in the public economy in terms of efficiency, in the selection or prioritization of projects that will provide the utmost benefit. Equally important is the application of benefit-cost analysis in the elimination of waste and wastefulness in public investments. Nowadays, Benefit-cost analysis is mainly applied to private investment projects, and it has started to be widely applied in public investment projects over time.

We can briefly summarize the nature of the B-C analysis as follows: The benefits and costs that a given investment project will provide over its entire life cycle are monetarily determined. After the benefits and costs are expressed in monetary terms, the current value of the benefits and costs are discounted with an appropriate discount rate and the feasibility of the investment project is decided. If the present value of the utility (B) is greater than the present value of the cost (C), it is considered appropriate to invest in.

The following unit price parameters as shown were taken from Ministry of Forest, Energy and Natural Resources, Environment and urbanization in Turkey. They were used to calculate the cost of avalanche protection, as Table Figure 13.

Name	Feature	Unit Price	
Hotel	4 Star	₺1.764	Tl/m2
Hotel	3 Star	₺1.135	Tl/m2
House	30-50m	₺1.135	Tl/m2
Cafe	Cafe	₺1.021	Tl/m2
Otel	1 and 2 star	₺882	Tl/m2
House	Lower 30m	₺882	Tl/m2
Restaurant	Restaurant	₺838	Tl/m2
Hostel	Pansiyon	₺838	Tl/m2
House	3 Floor	₺694	Tl/m2
Afforestation	1 ha	₺17.420	Tl
Maintenance of Afforestation	1 ha	₺1.200	Tl
Excavation And Clearance	1 m3	₺9	Tl
Planting	1 Peace	₺4,5	Tl

Table 13: List of Unit Price (5 $TL \cong 1$ $EURO$)

The discount rate is used in the analysis of project costs and incomes in different years and in evaluating the success of financial or economic efficiency of the project according to the calculation of present values of these assets. It can be seen clearly from table 15.

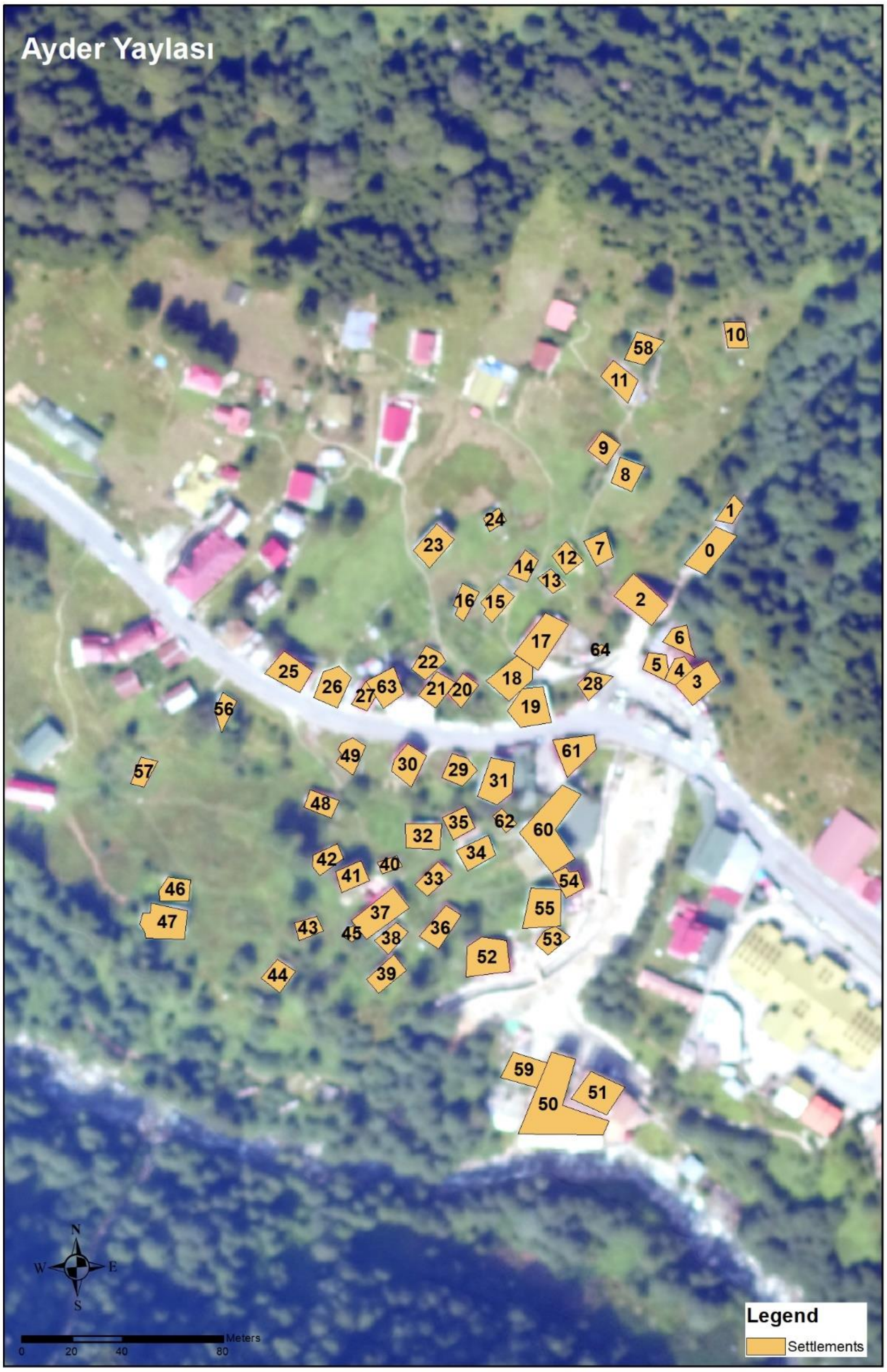


Figure 60: Position of Settlements of study area

FID	Name	Floor	Capacity
0	Hotel	3	35
1	Hotel	3	15
2	Hotel	3	25
3	Supermarket	1	5
4	Cafe	1	20
5	Restaurant	1	50
6	Hotel	2	25
7	House	2	5
8	House	2	5
9	House	2	5
10	House	2	2
11	House	2	6
12	Hotel	2	30
13	House	2	6
14	Motel	2	35
15	Hotel	3	35
16	House	1	4
17	Hotel	3	80
18	Hotel	2	15
19	Restaurant	1	30
20	House	2	7
21	Hotel	3	40
22	Hotel	3	50
23	Hotel	3	50
24	House	2	5
25	Hotel	3	45
26	Hotel	3	35
27	Restaurant	1	30
28	Restaurant	1	15
29	Hotel	2	15
30	Hotel	2	35
31	Hotel	3	65
32	Hotel	3	55
33	Hotel	3	55
34	Hotel	3	50
35	House	2	5
36	Hotel	3	25
37	Hotel	3	25
38	Hotel	2	20
39	Hotel	3	55
40	House	2	6
41	Hotel	3	45
42	Hotel	3	25
43	Hotel	2	10
44	Hotel	2	30
45	Hostel	2	10
46	Hotel	2	15
47	Hotel	3	70
48	Hotel	3	45
49	Hotel	3	45
50	Hotel	3	20
51	Hotel	3	15
52	Hotel	3	45
53	Hotel	2	20
54	Hotel	3	15
55	Hotel	3	50
56	Hotel	2	25
57	Hotel	2	25
58	House	2	0
59	Hotel	3	20
60	Hotel	3	130
61	Hotel	2	110
62	House	2	5
63	Hotel	2	35
64	C. Machine	0	0

Table 14: Description of structures which is located in endangered area

To find the actual interest rate (discount rate) **i** real was calculated on nominal interest rate **i** nom and inflation **inf**. Nominal interest rate is procured by the median rate of government bonds, as shown Table 15. Inflation rate is acquired from the central bank website of Turkey.

$$\boldsymbol{i\,real = \frac{(1 + i_{nom})}{(1 + inf)} - 1}$$

Government Bond Interest Rate	13,58
Inflation Rate	10,26
Real Interest Rate	3%

Table 15: Calculation of real interest rate (Discount rate)

9.1. Determination of Costs

Annual evacuation cost calculated by using;

$$\boldsymbol{C_e = \frac{(C_h * t_e * N_{Ae} * N_b) + (N_p * C_{acc} * N_t)}{n}}$$

$C_e = Annual\ cost\ of\ evacuation$

$C_h = hourly\ salary\ of\ workers$

$t_e = average\ time\ required\ for\ one\ evacuation$

$N_{Ae} = number\ of\ person\ for\ helping\ and\ lodging$

$N_b = total\ number\ of\ building\ in$ avalanche $endangered\ area$

$C_{acc} = total\ cost\ for\ aid\ and\ lodging\ per\ day$

$N_t = number\ of\ days$

$n = reoccurence\ interval$

(Fuchs S. Thöni M. Christina M. Gruber U. Bründl M. (2006))

Hourly Salary Of Workers	10	TL
Average Time needed	5	Hour
Number Of Persons	2	Number
Number Of Buildings	70	Number
Costs for aid and lodging	100	TL
Number of days	2	Day
Reoccurrence interval	1	Number
Number Of Household	534,9	Number
Annual Cost of Evacuation	₺113.980	TL

Table 16: Calculation of evacuation cost

9.1.1. Discounted present value of PV calculated;

$$PV = \frac{1 - (1 + r/n)^{-t}}{r/n} * C$$

The costs associated with snow bridges and wind drift fences were evaluated in terms of market prices. Annual maintenance costs for the structures were assumed to be one percent of the investment cost. These amounts have been estimated on the basis of assumption that the structures are renewed every eighty years, as shown Table 17.

COST ANALYSIS			
Snow Bridge and Snow Drift Fence	Length (M)	Unit Price (TL)	Total (TL)
Area 1	230	₺3.295	₺757.850
Area 2	548	₺3.295	₺1.805.660
Area 4	1235	₺3.295	4069325
Fence 1	267	₺1.296	₺346.032
Fence 2	262	₺1.296	₺339.552
Total			₺7.318.419
Expected Life Of Structure (Years)	80		
Interest Rate %	3		
Required Time of Project (Years)	2		
Total cost of project Calculation	₺7.318.419		
Annual cost of project	₺3.659.210		
Total cost of project	₺7.318.419		
Total annual maintenance cost	₺36.592		
Restoration cost for first 80 years	₺2.927.368		
Total cost	₺10.245.787		
Discounted annual cost for new construction	₺7.001.786		
Discounted maintenance cost within 80 years	₺1.105.109		
Sum of discounted total (Costs)	₺8.106.896		

Table 17: Calculation of discounted total costs

Figure 61: Avalanche run-out zone in study area

9.2. Determination of Benefits

The main aim of the mitigation measures is to reduce the damage of the avalanches to people, buildings and environment. These positive effects can be considered as benefits. The number of buildings, infrastructure and the residents in these buildings were obtained by communicating with mayor, residents of the region and hotel owners, as shown Figure 58. Because of the winter season, some of building and hotels was empty so information about them was taken from the other people living in that area. With the help of the GIS program, the buildings and their locations in the red zone, which are obtained by using the RAMMS and Samos programs, have been identified. The red zone has been determined according to the return period of 150 years in SAMOS and 100 years in RAMMS.

Name Of Building	Number	Capacity	Floor	M2	Value Of Building	Room Price D.	D. Closed	Total	Sum
Restaurant	4	100	1	422	353.636	30	180	₺540.000	₺893.636
Cafe	1	0	1	73	74.533	0	0		₺74.533
Market	3	5	1	165	168.465	0	0		₺168.465
C. Machine	1	0	1	14	14.294	0	0		₺14.294
Hotel 2 Star	16	450	3	1441	3.812.886	60	180	₺4.860.000	₺8.672.886
Hotel 3 Star	19	795	3	2784	9.479.520	100	180	₺14.310.000	₺23.789.520
Hotel 4 Star	11	344	3	2211	11.700.612	200	180	₺12.384.000	₺24.084.612
Hostel	1	10	2	65	108.940	60	180	₺108.000	₺216.940
House	14	79	2	1165	2.055.060	0	0	₺0	₺2.055.060
Total	70	1783			27.767.946				₺87.737.892

Table18: Calculation of total price of buildings which are in endangered area

Name of Infrastucture	Number	Capacity	Lenght(m)	Unit Price	Total
Electrical power transmission	7	220	170	₺2.000	₺272.000

Name Of Land	Area	alue Of Lar	Unit	Total
Forest	14	₺17.420	ha	₺243.880
Clearence	10000	₺9	m3	₺90.000
Maintenance of Forest (5 year)	14	₺6.000	ha	₺84.000
				₺334.304

Table 19: Calculation of total price of infrastructure and planting

$$\mathrm{ED_i} = (\mathrm{NP_{redi}} * \mathrm{PD_{redi}}) * \mathrm{VP} * \mathrm{P_f} * (1 - \mathrm{EE_i}) + (\mathrm{VB_{redi}} * \mathrm{PD_{redi}})$$

$\mathrm{ED_i}$ = Potantiel Damage

$\mathrm{NP_{redi}}$ = Total number of people in Red Zone

$\mathrm{PD_{redi}}$ = Possibility of damage to buildings in the red zone

VP = the value of people under risk of avalanches

$\mathrm{P_f}$ = the possibility of damage to people caught avalanche in an building (0,46)

$\mathrm{EE_i}$ = effectiveness of evacuation

$\mathrm{VB_{redi}}$ = monetary value of buildings in the red zone

- All structures are in the red zone, so the yellow zone created in excel is not used.

Zone	Red Zone	Yellow Zone
Average Occupancy In Winter	0,3	0,3
Probability of damage to buildings	0,8	0,8
Number Of House damaged	0,5	0,2
Number Of Person in House	534,9	
Total Value Of Buildings	₺87.737.892	
Value of Person	₺446.378	₺446.378
Evacuation effectiveness (0,90 or 0,30)	0,90	0,90
Probability of fatality (0,46)	0,46	0,46
Discount From Age Of Building	0,20	0,20
Expected Damage for scenario	₺32.469.450	₺0

Table 20: Calculation of total benefit

Reduction Factor: It has been determined that as a result of the avalanche event observed for many years; the avalanche did not harm the building in the whole deposition area. The avalanche only covers certain areas of the entire run-out area. It was also observed that the buildings in the avalanche route blocked the flow of avalanche and the avalanche was not able to reach the other buildings on the same line. *(Wilhelm 1997)*

- Reduction Factor = 0,8 for Red Zone and Yellow Zone for 100 years return period
- Building susceptibility = 0,5 for Red zone 0,2 for Yellow zone
- Forest susceptibility = 1 for Red Zone
- Infrastructure susceptibility = 1 for Red Zone

Total benefit of project calculation	₺33.075.754
Annual benefit after project is completed	₺416.047
Benefit between of the beginning and completion of project	₺592.637
Discounted benefit from comleted to end of life of structure	₺11.768.850
Sum of discounted total (Benefits)	₺12.361.487

Table 21: Calculation of total discounted benefit

Value of Human is determined by using Human Capital Approach, which is sum of the individual discounted future contribution to the social Product, as shown Table 22. In addition, the death rate of people inside the building is assumed to be forty-six percent. *(Wilhelm 1997)*

$$R_0 = r * q^{-n} * \frac{q^n - 1}{q - 1}$$

Human Value	Turkey
Annual gross earned income per working person	₺27.830
Average age of population	29,8
Average retirement age	52
Remaining average expectancy of working life	22,2
Rate of interest	0,03
Q	1,03
Value of person	₺446.378

Table 22: Calculation of value of person in Turkey

The net capital value of the project is the ratio of the sum of the present value of the income of the project to the sum of the net present values of the costs over the years. If the B / C ratio is greater than 1, then the project is financially / economically feasible. If the B / C ratio is less than 1, it is understood that the project is not attractive, as shown Table 23.

Result	Benefit / Cost Ratio	1,52
Result	Capital Value	₺4.254.591

Table 23: Results of CB

10. Conclusion

Firstly, five different avalanche scenarios were implemented using Ramms and Samos software. After Ramms and Samos simulations results, some of the hotels and houses on the Ayder Plateau were seen in avalanche dangerous areas. According to this, the worst scenario case scenario was selected to draw a hazard map because of lack of historical avalanche records and meteorological data. In addition, it can be seen that in figure 60, about 64 building are located in red zone. To protect these building some mitigation measures were planned. The dams are not recommended because of the avalanche types and lack of knowledge about the construction of them.

Secondly, it is determined that snow bridges in endangered zone are the most appropriate solutions, and the hazard map should be made in that area so that the new settlement cannot be made. Snow drift fences are recommended for certain avalanche starting areas. Afforestation is not recommended because starting area is above the forest line; instead, snow bridges and snow drift fences were designed.

Finally, cost benefit analyses are used to find project suitability. Result show that C-B ratio is higher than 1 and capital value is 4.254.591 Tl (about 5 Turkish Liras equals to 1 Euro), as shown Table 23. According to this, the project was found to be appropriate. However; the area is the one of the popular touristic areas in Turkey, it is also considered that the risk will increase when the winter tourism activities start in the future and the region will become more crowded and the new buildings may be constructed in the danger area in the future so hazard map, snow bridges, deflection walls and catching dams are proposed, but deflecting and catching walls have not been used in Turkey so in cost calculations, it is not used because of the lack of unit price.

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APPENDICES

APPENDIX A 1: Maximum Height simulations in Samos

APPENDIX A 2: Maximum velocity simulations in Samos

APPENDIX B 1: Maximum Height simulations in Ramms

APPENDIX B 2: Maximum Velocity simulations in Ramms

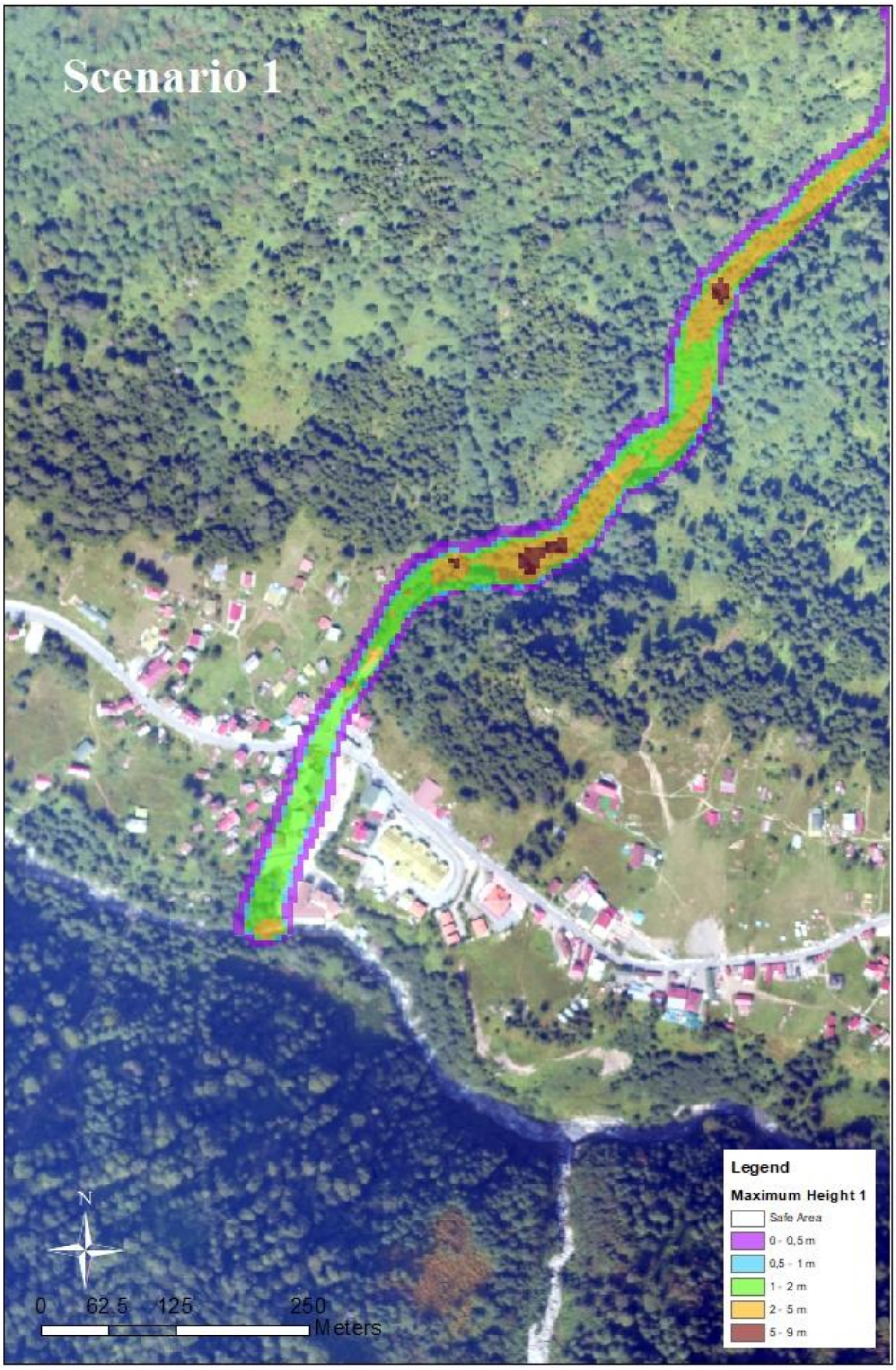

Figure 62: Scenario 1 Maximum Height in Samos

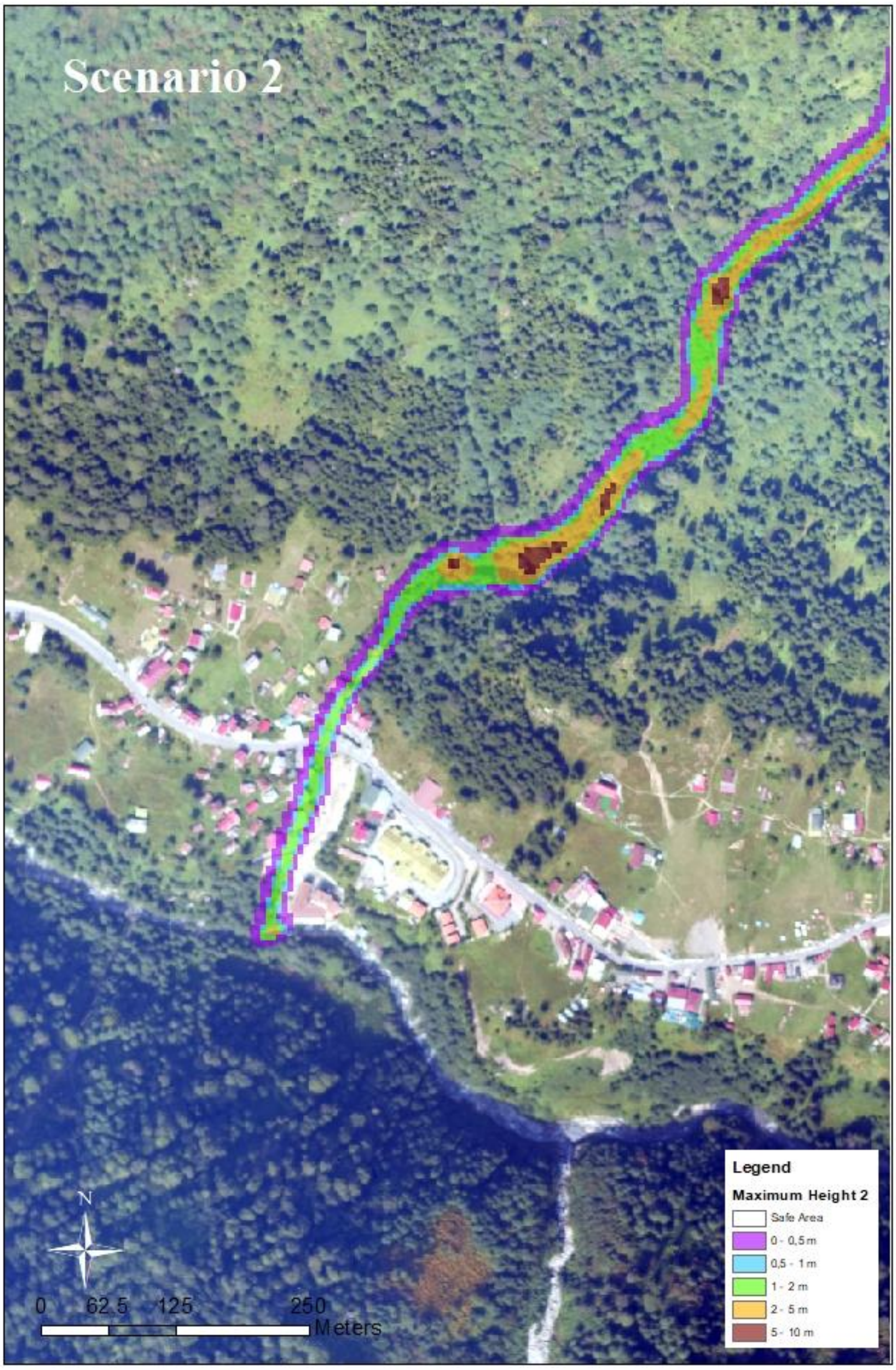

Figure 63: Scenario 2 Maximum Height in Samos

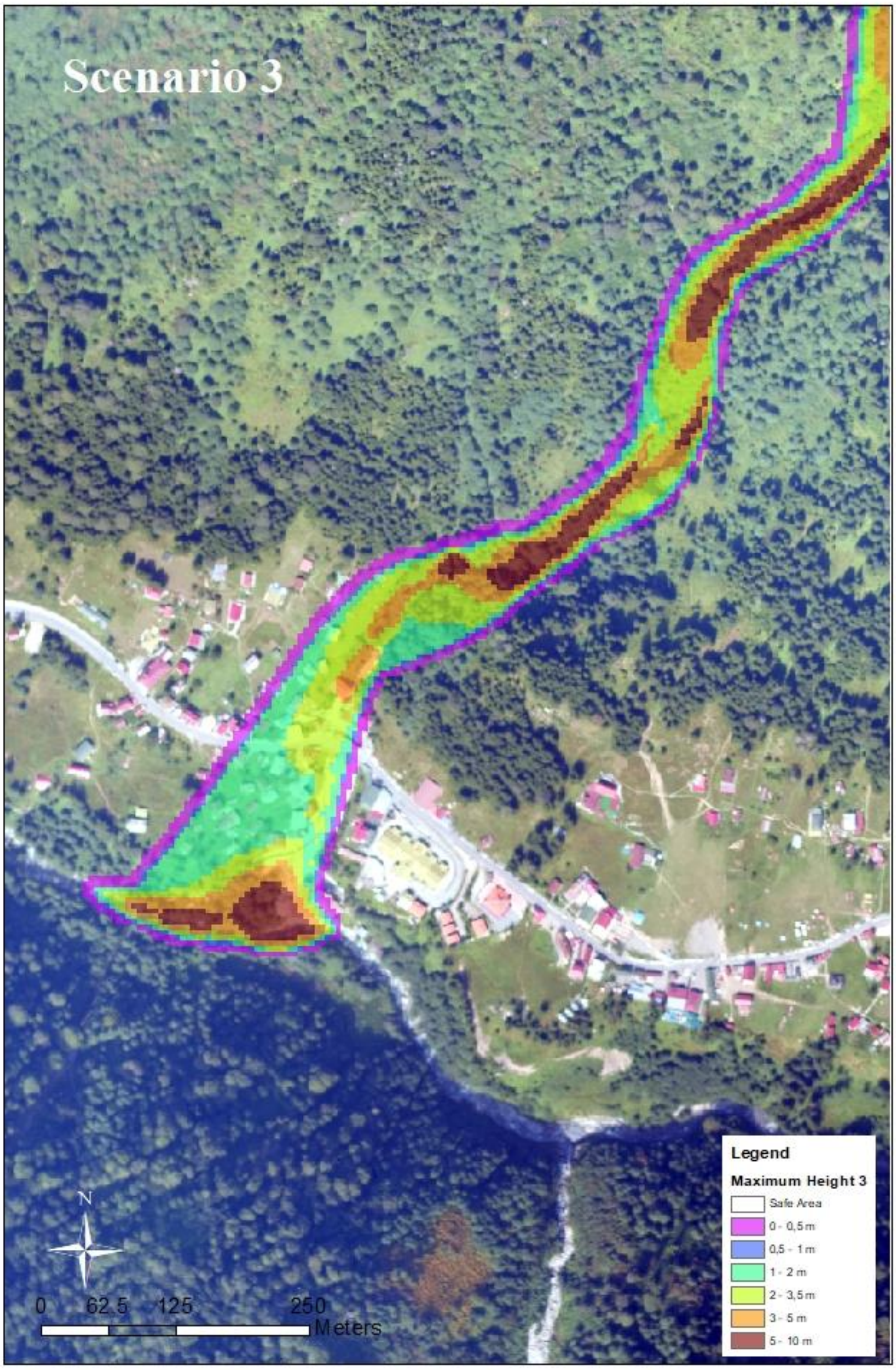

Figure 64: Scenario 3 Maximum Height in Samos

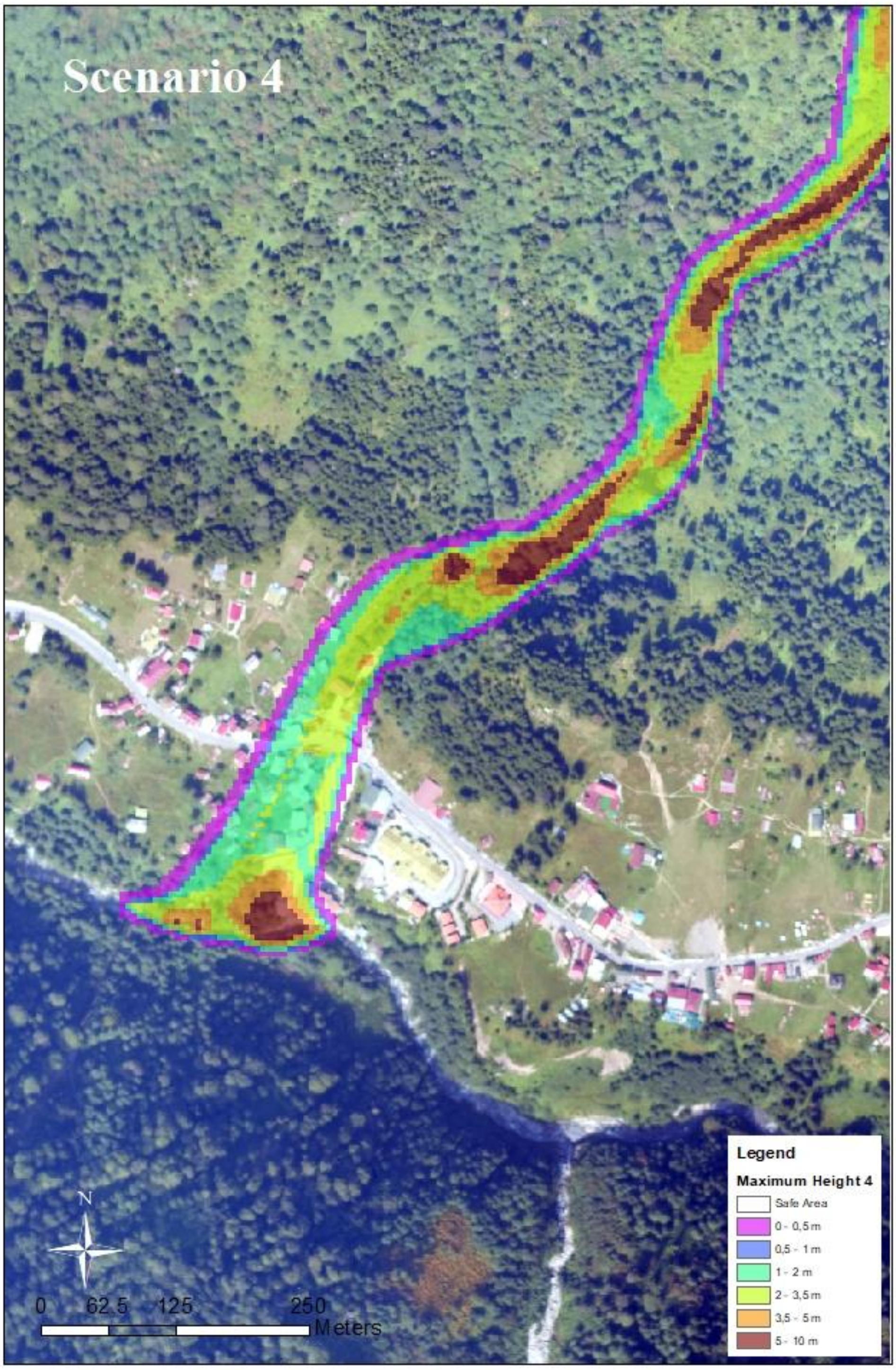

Figure 65: Scenario 4 Maximum Height in Samos

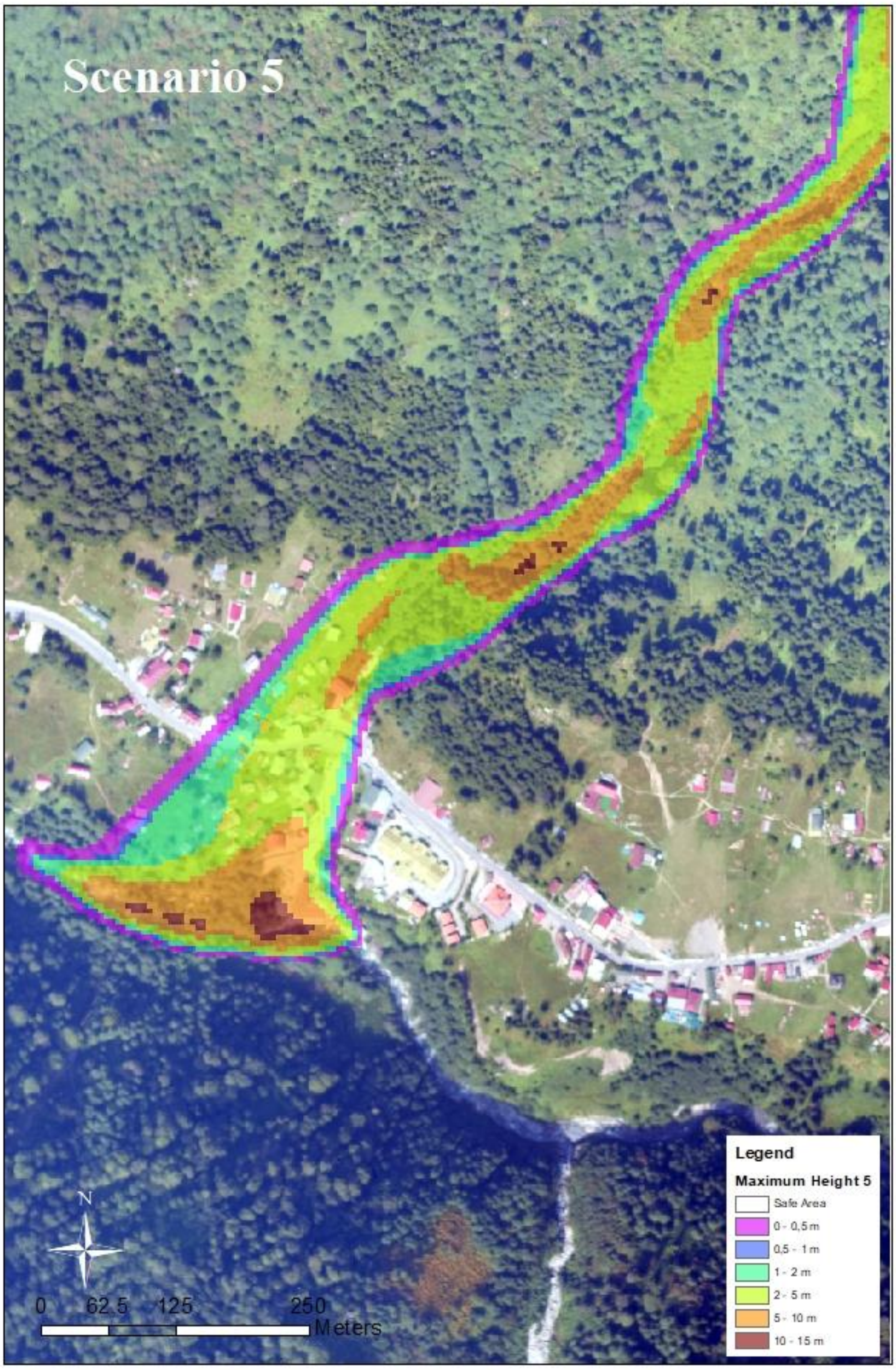

Figure 66: Scenario 5 Maximum Height in Samos

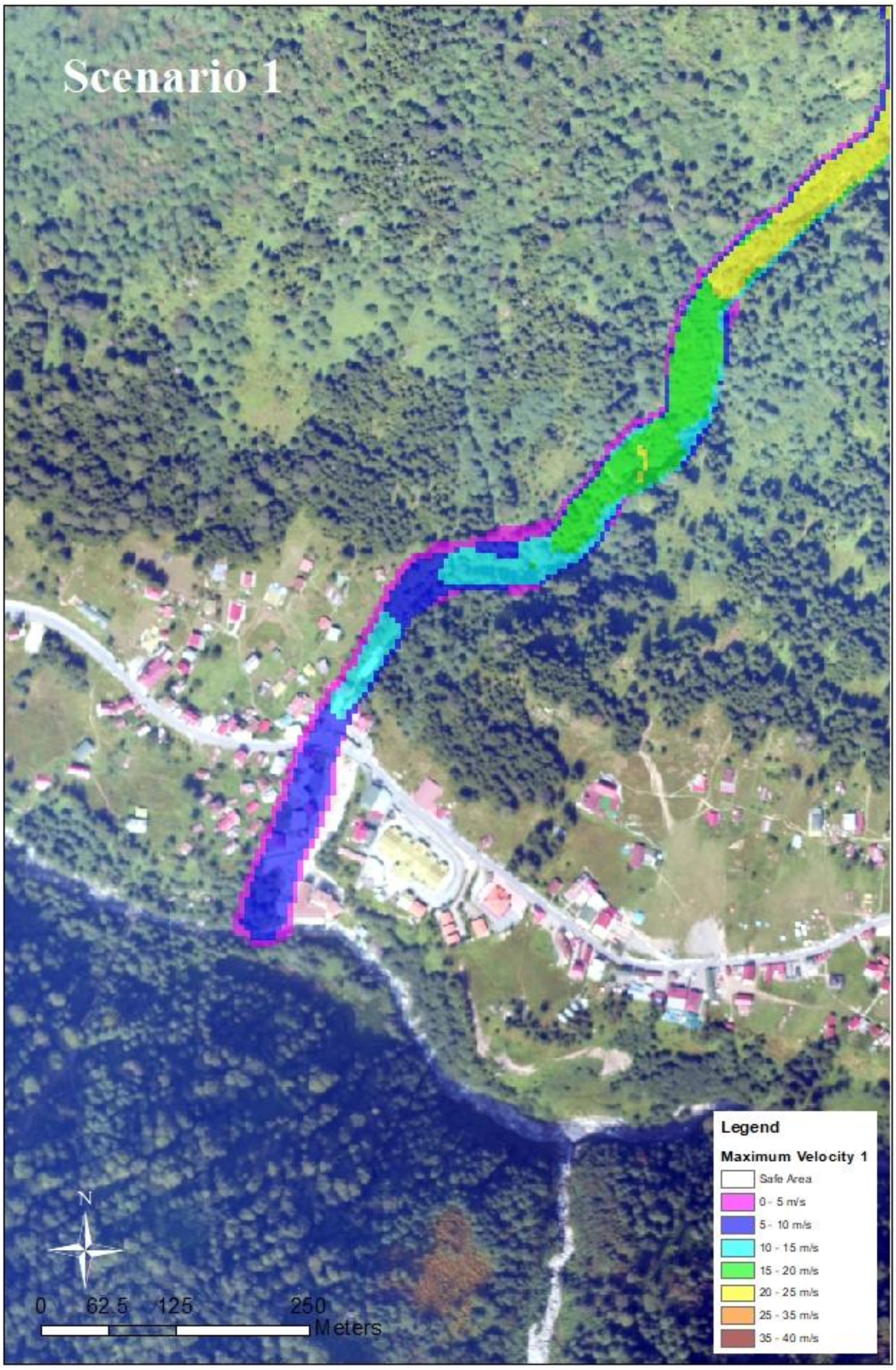

Figure 67: Scenario 1 Maximum Velocity in Samos

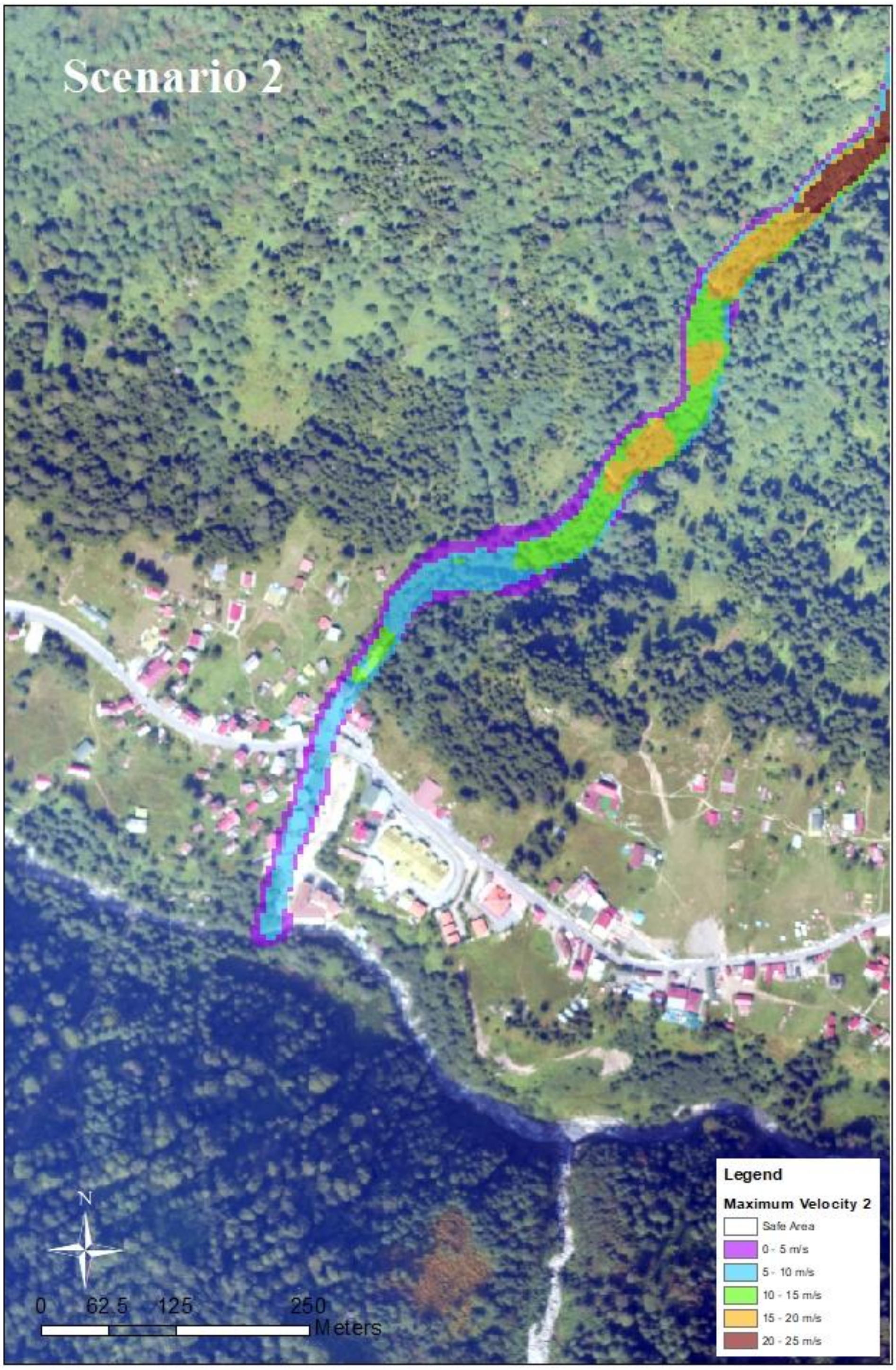

Figure 68: Scenario 2 Maximum Velocity in Samos

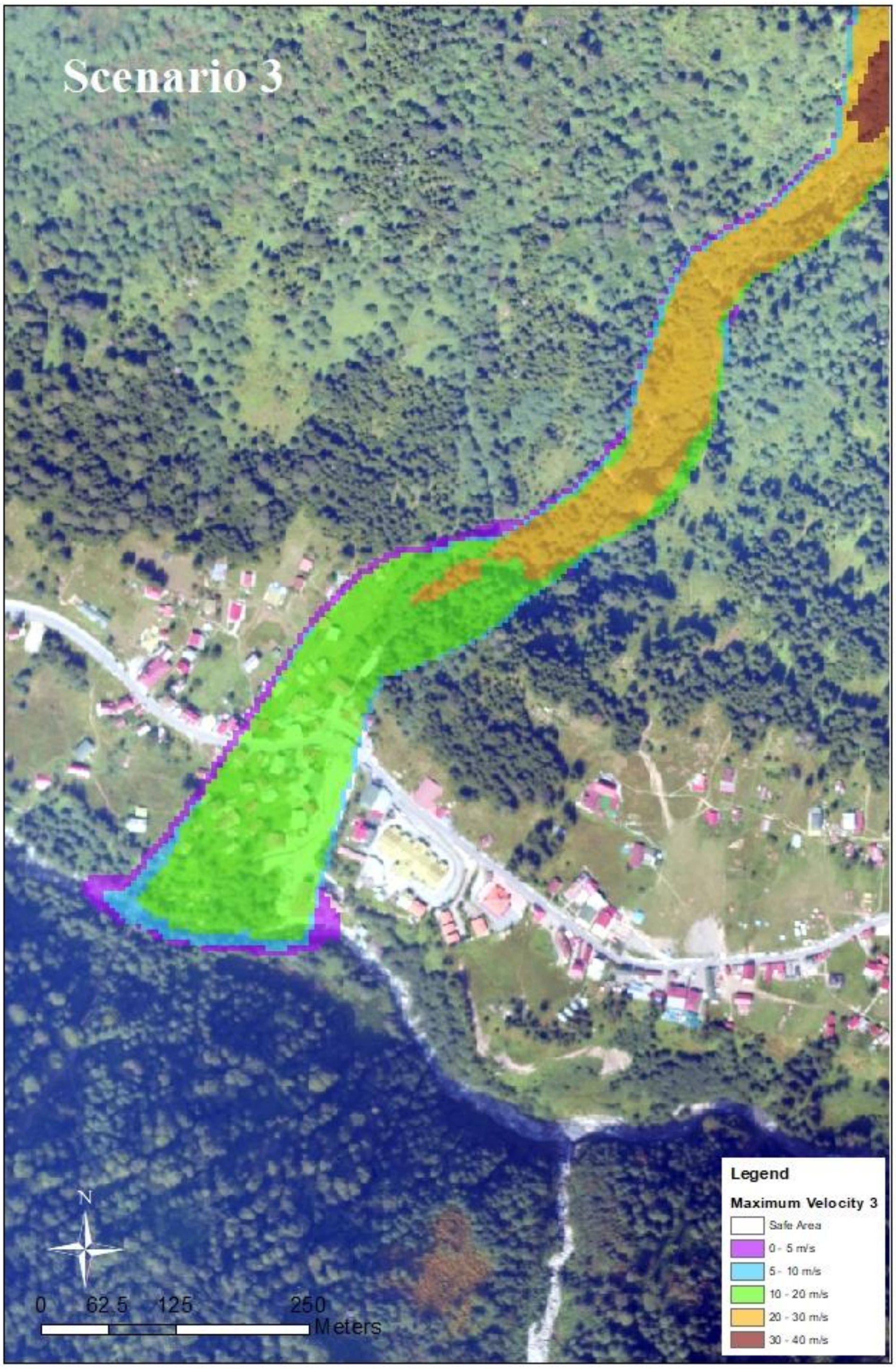

Figure 69: Scenario 3 Maximum Velocity in Samos

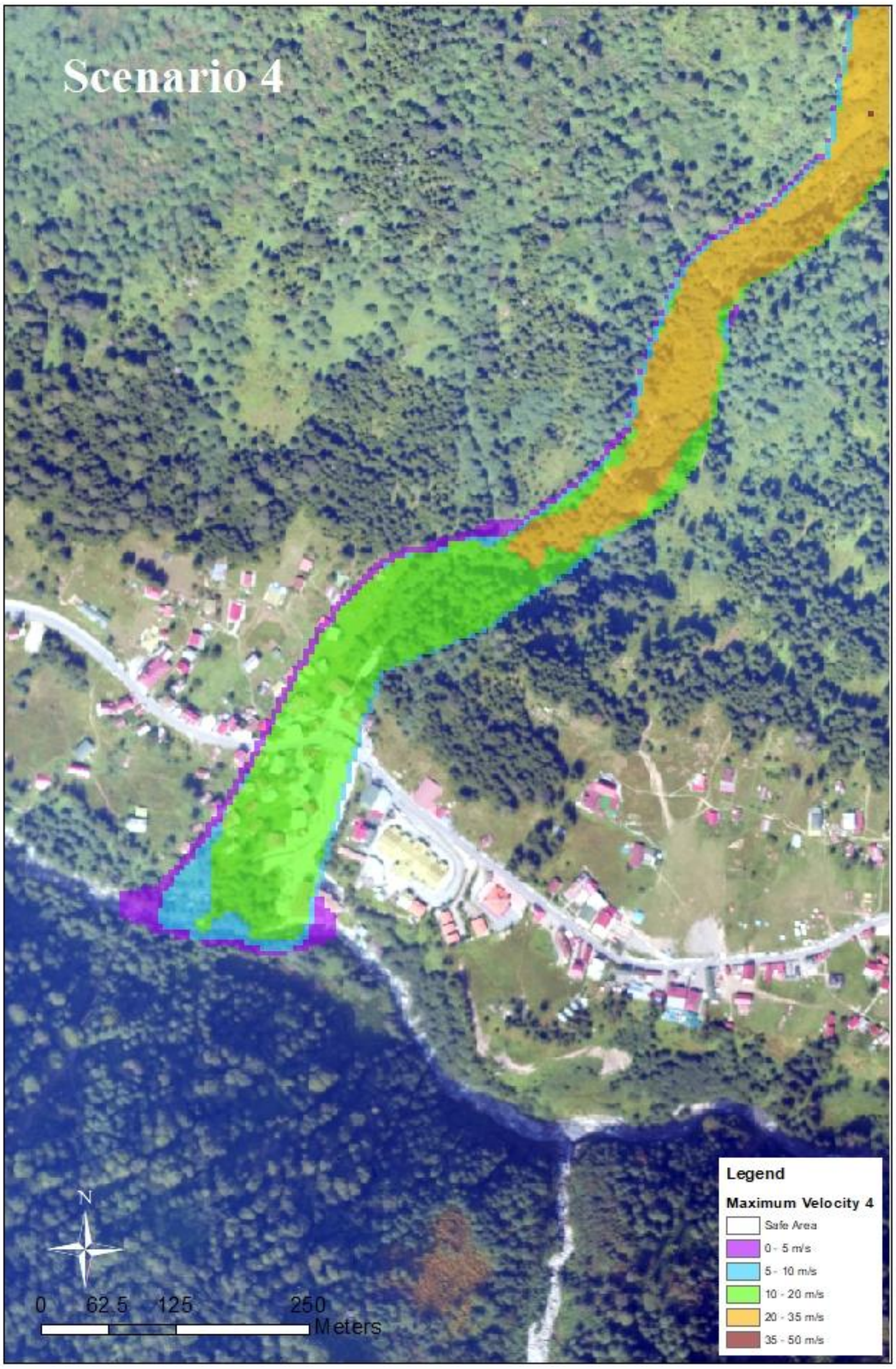

Figure 70: Scenario 4 Maximum Velocity in Samos

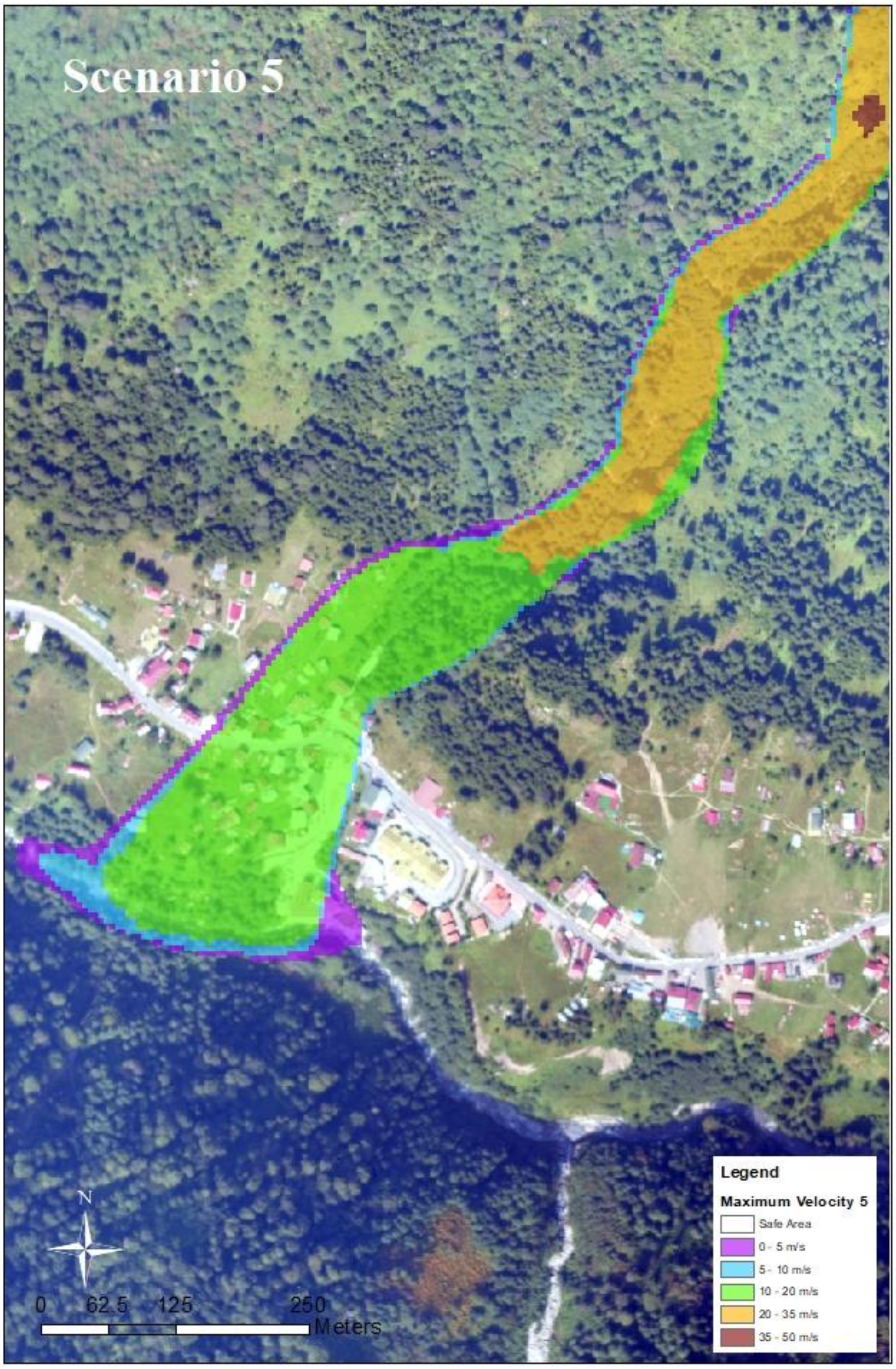

Figure 71: Scenario 5 Maximum Velocity in Samos

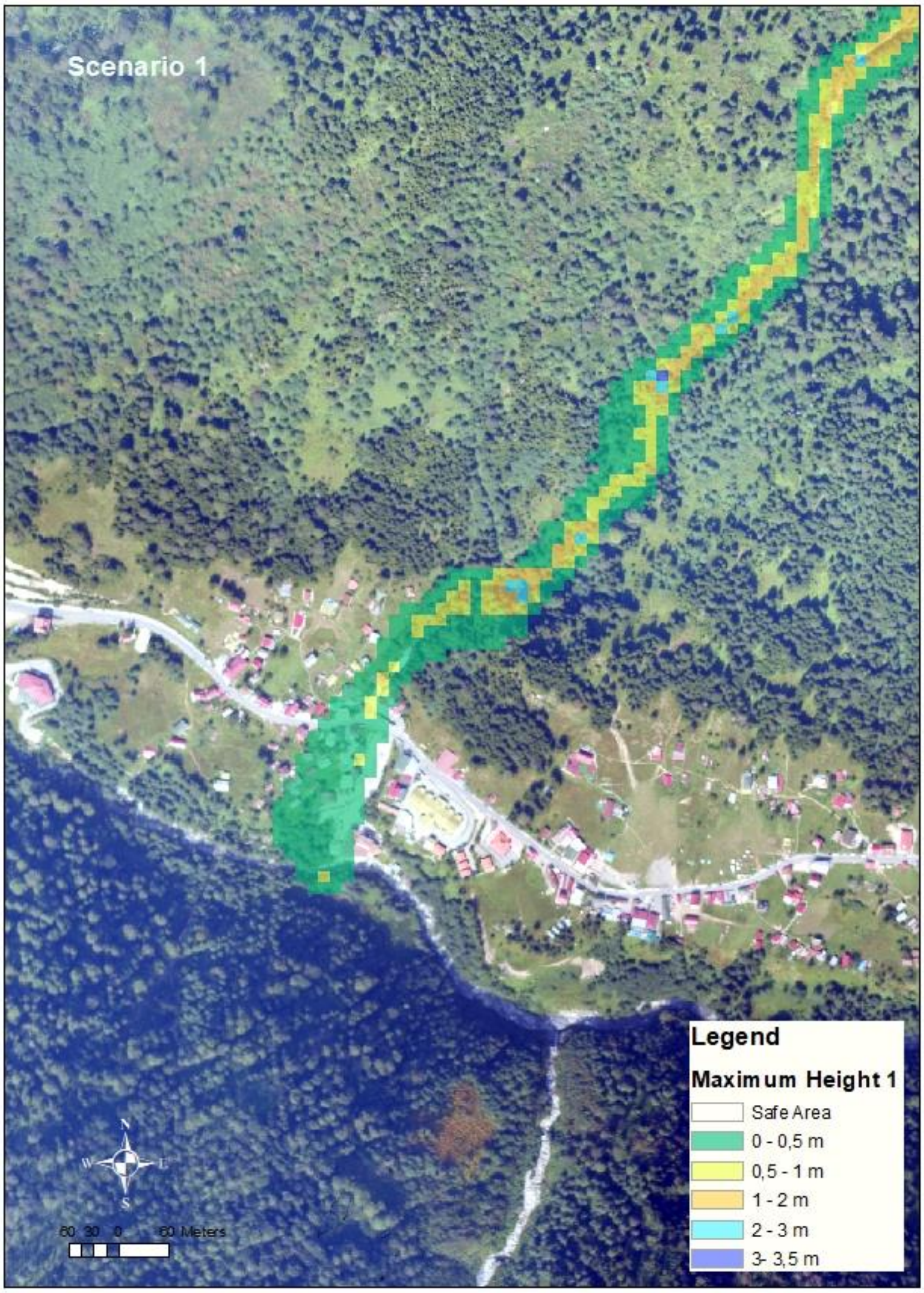

Figure 72: Scenario 1 Maximum Height in Ramms

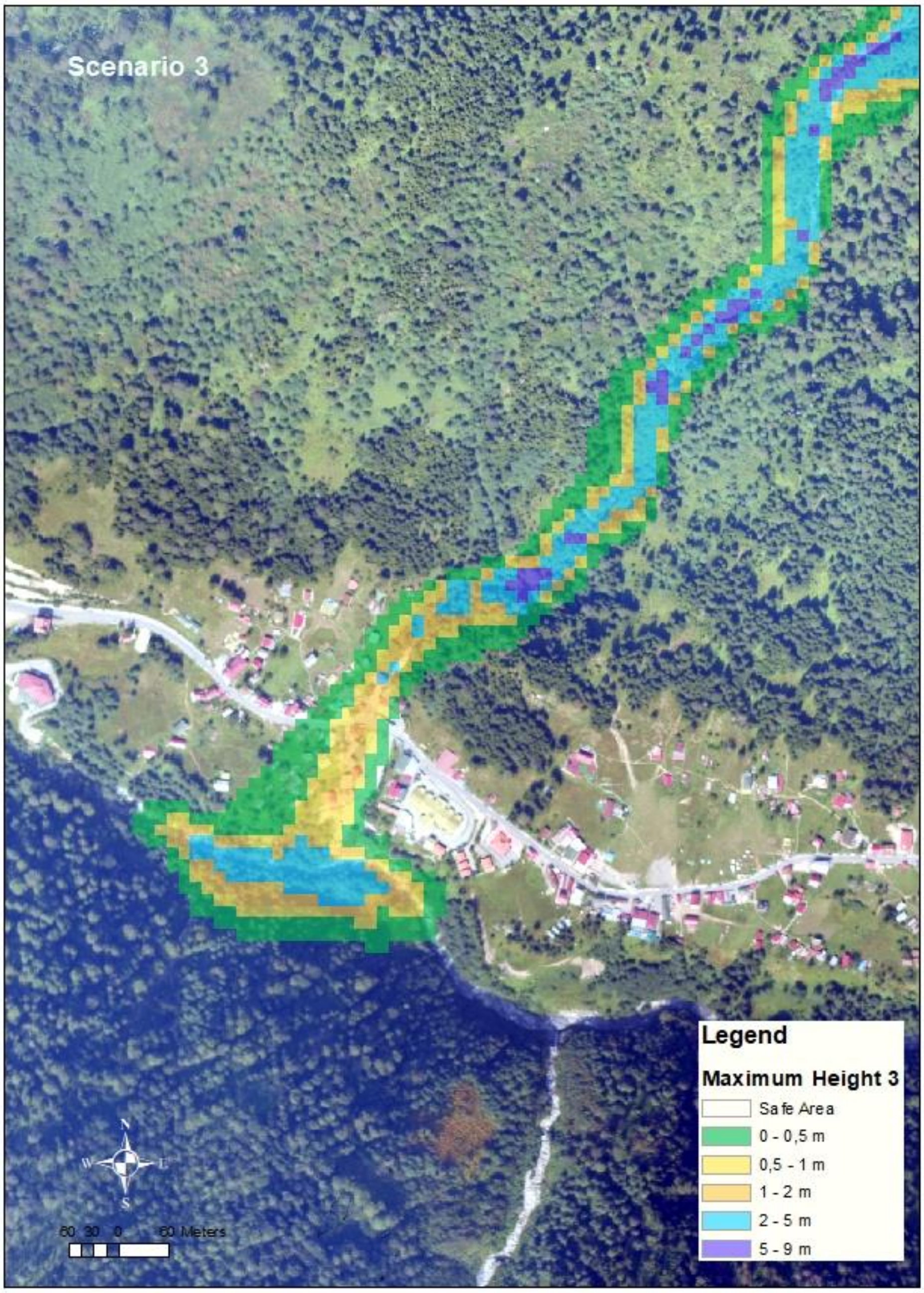

Figure 73: Scenario 3 Maximum Height in Ramms

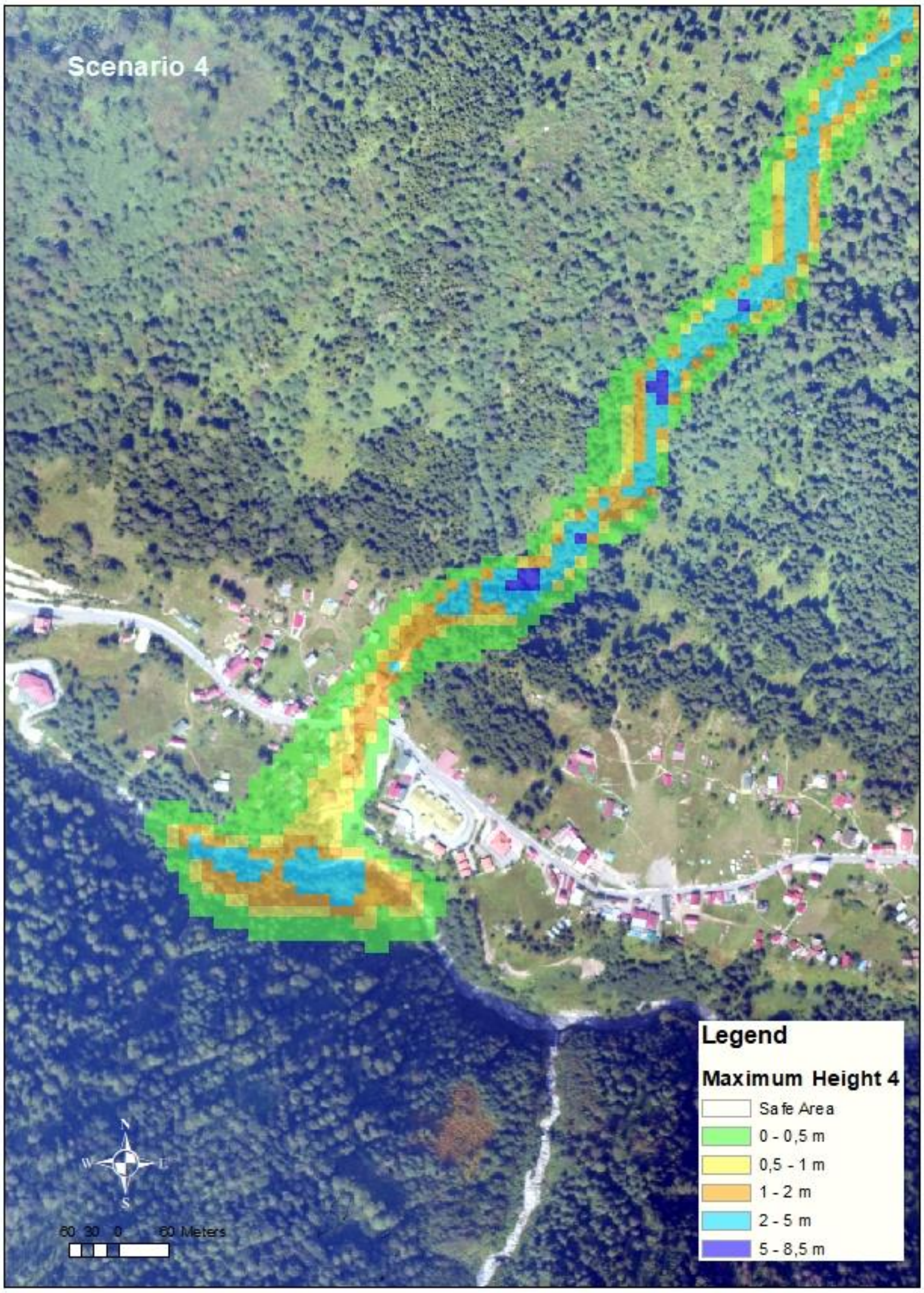

Figure 74: Scenario 4 Maximum Height in Ramms

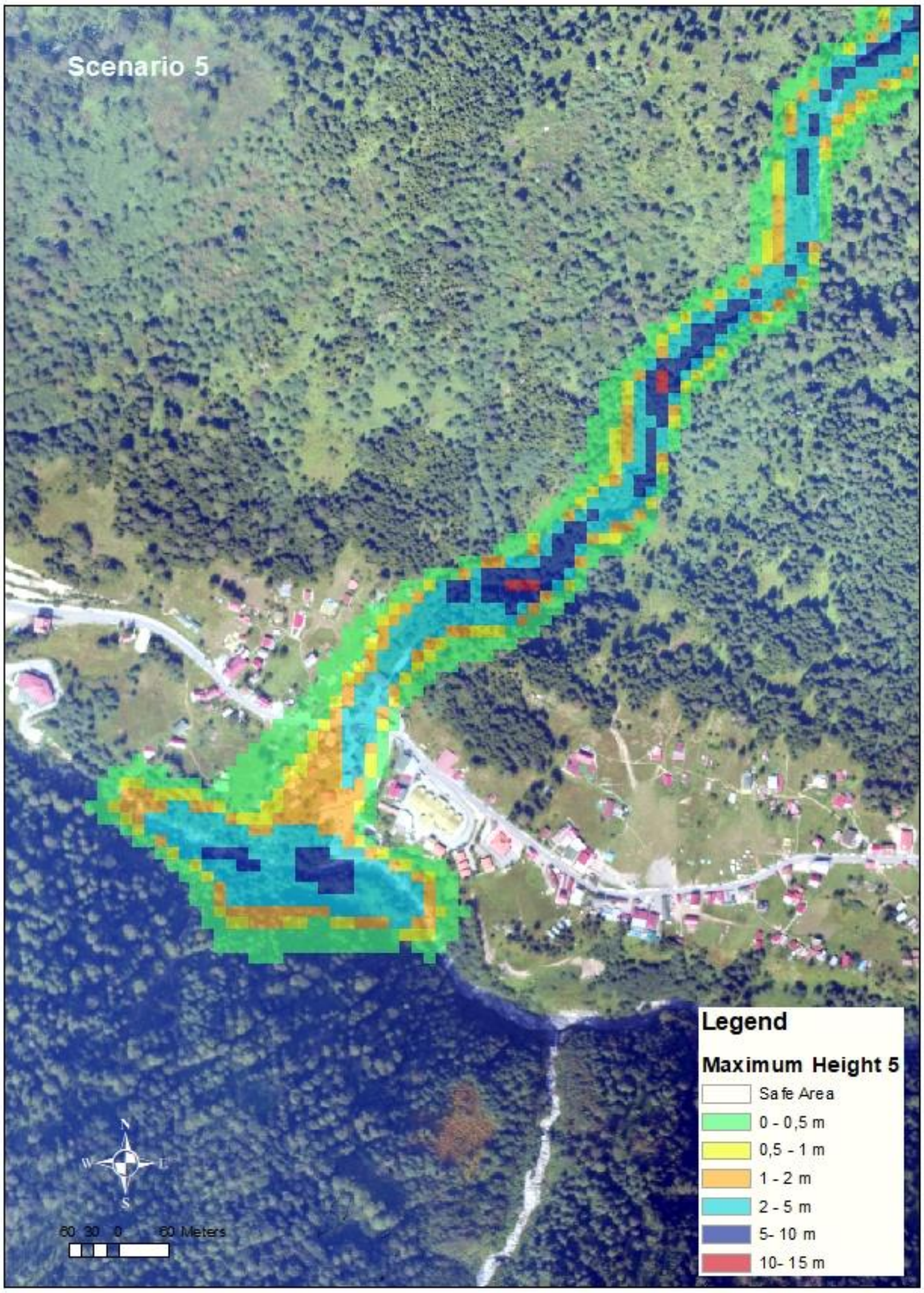

Figure 75: Scenario 5 Maximum Height in Ramms

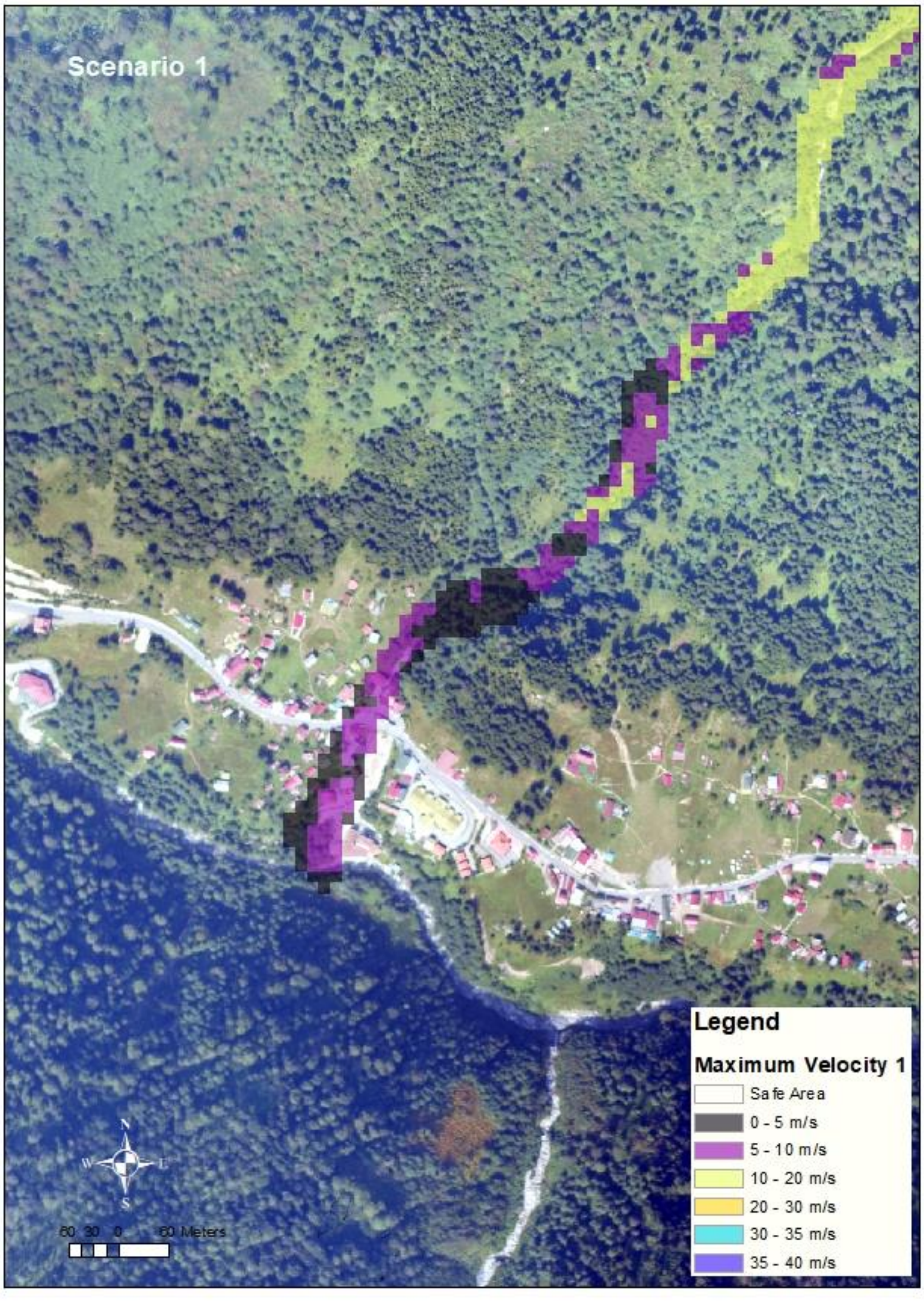

Figure 76: Scenario 1 Maximum Velocity in Ramms

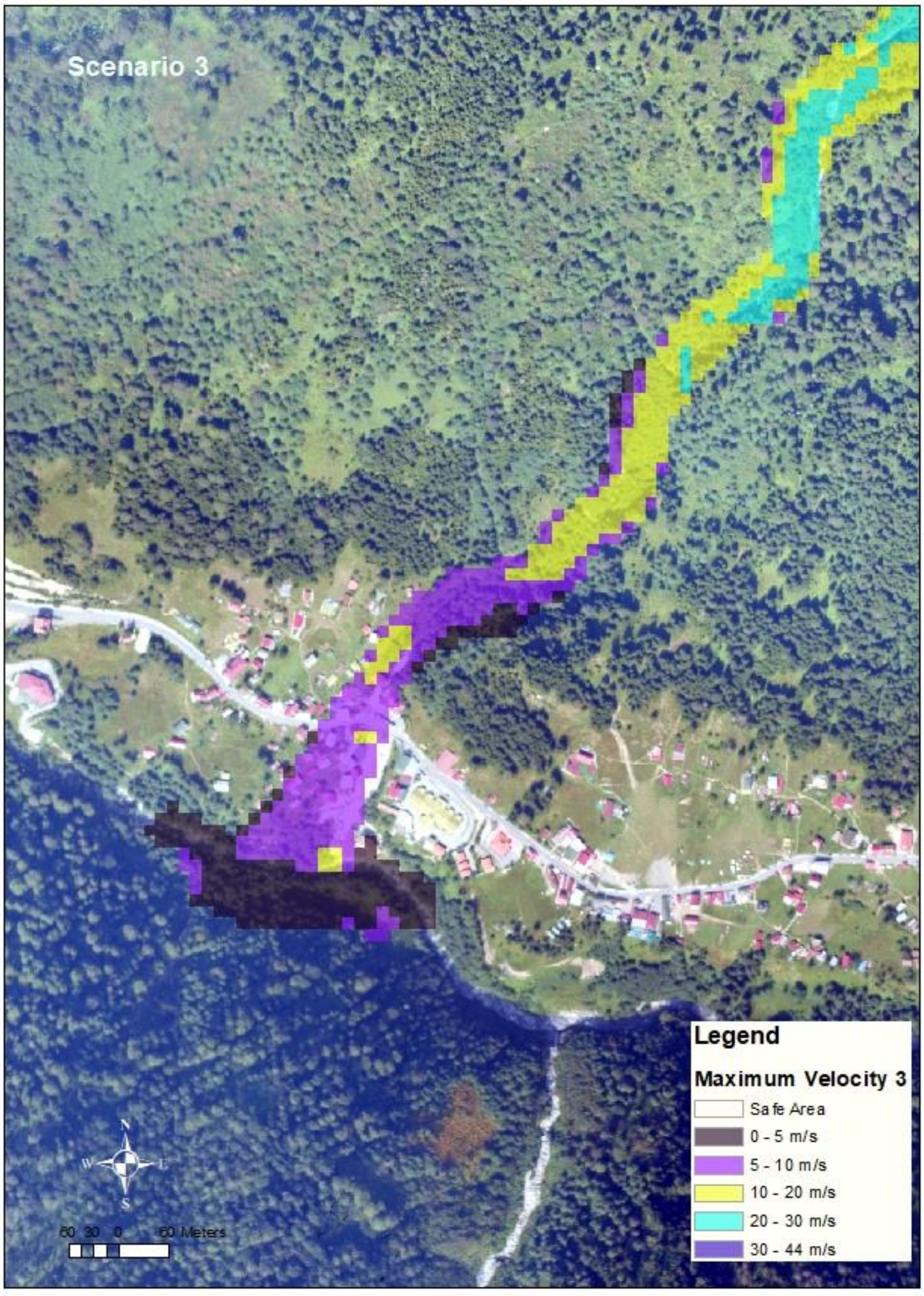

Figure 77: Scenario 3 Maximum Velocity in Ramms

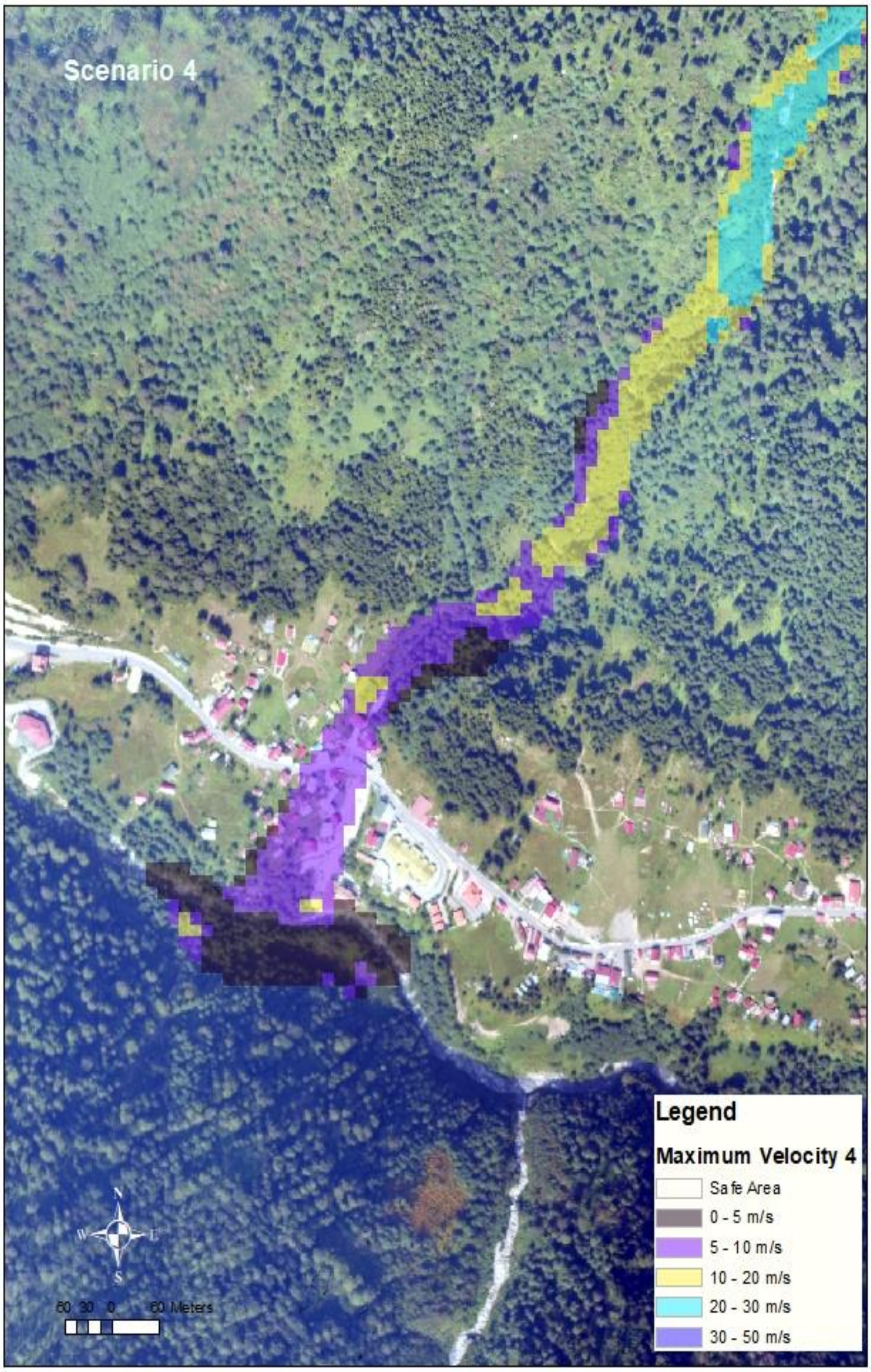

Figure 78: Scenario 4 Maximum Velocity in Ramms

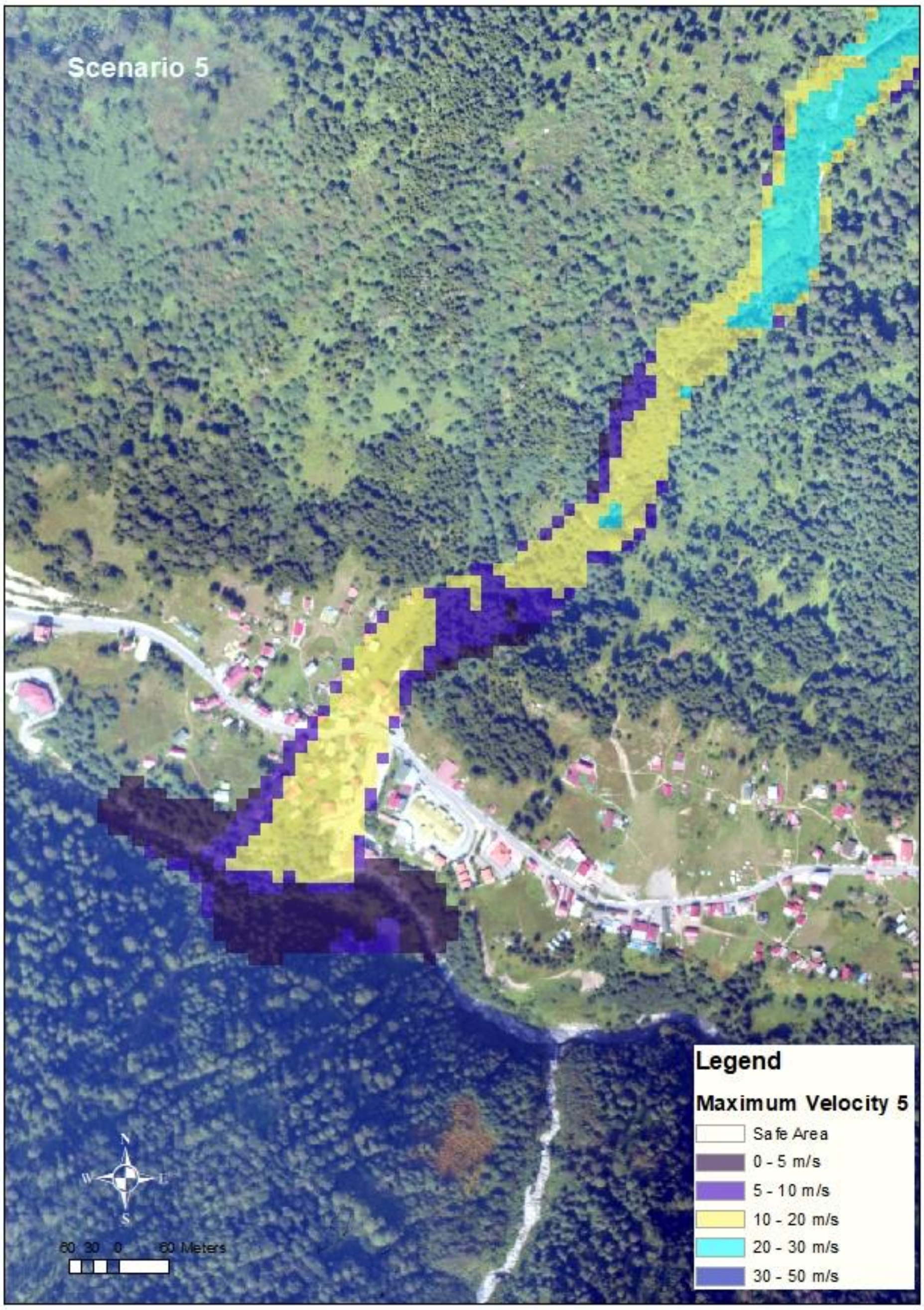

Figure 79: Scenario 5 Maximum Velocity in Ramms