CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Bc. Jan Černý

Landscape Planning

Thesis title

Environmental Impacts Associated with Ski Resorts: New possibilities for improved design standards

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Objectives of thesis

This Masters Thesis Project proposes to evaluate the different impacts to the environment associated with large down-hill ski resorts. Research will be supported by case studies of existing sites in the Czech Republic and in particular, assessment of published climatological data.
The main goal is set up complex guidelines for sustainable ski resorts in Krkonoše region. In this thesis, the student is proposing to establish planning guidelines and adaptable strategies, which will encourage local climatic resilience.
The thesis research results will be based on an analysis of a climatic data-set such as 1. Snow Cover, 2. Snow Cover Duration, and 3. Annual number days with solid precipitations collected within the define area and timescale. Statistical analysis will be used to generate a Snow Cover Trend for future winters. Snow Cover Trend will be used as key driver for planning an adaptable strategy or strategies. Locating and identifying each of the crucial issues of both characters (positive and negative) caused by direct or indirect (or cumulative) consequence of local ski resorts operations in Krkonoše region will be proposed. Last, but not least, the student will evaluate his results and compare these with different methods of collecting and processing data.
In conclusion, he will summarize all results, answer all unanswered questions and last of all, he will assess if this work contributes any benefits to the current topic.
From this, he will proposed solutions that will include new designs for a slope run and it's impact to flora and fauna.

Methodology

Introduction

Literature Review and Case Study assessment

Assessment of published climatological data sets

Proposed new methodology for site assessment and design

Results

Discussion

The proposed extent of the thesis

50 pages

Keywords

Ski Resort Design, Envionmental Impacts

Recommended information sources

Beniston, M., Variatons of snow depth and duration in the Swiss Alps over the last 50 years: Links to changes in large-scale climatic forcings. Climatic Change, 1997. 36: p. 281-300

Brien, K.L. (Ed.), 2000. Developing strategies for climate change: the UNEP country studies on climate change impacts and adaptations assessments. CICERO Report 2000:3. CICERO, Oslo.

MARTY C. 2013: Climate change and snow cover in the European Alps. In: RIXEN C. & ROLANDO A. (eds), The impacts of skiing and related winter recreational activities on mountain environments. Bentham Science Publishers Bussum: 30–44.

Scherrer, S.C., C. Appenzeller, and M. Laternser, Trends in Swiss Alpine snow days: The role of local- and large-scale climate variability. Geophys. Res. Lett., 2004. 31.

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The Diploma Thesis Supervisor

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CZECH AGRICULTURAL UNIVERSITY IN PRAGUE

FACULTY OF LIFE SCIENCE

DEPARTMENT OF LAND USE AND IMPROVEMENT

ČESKÁ ZEMĚDĚLSKÁ UNIVERZITA V PRAZE

Environmental Impacts Associated with Ski Resorts: New possibilities for improved design standards

DIPLOMA THESIS

Diploma thesis supervisor: doc. Peter Kumble, Ph.D.

Author: Jan Černý, BCs.

2019

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Author's declaration

I hereby declare that I wrote this diploma thesis independently, under the direction of doc. Peter Kumble, Ph.D. I have listed all literature and publications from which I have acquired information.

In Prague, the…………………………………

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I would like to genuinely thank my supervisor doc. Peter Kumble, Ph.D, for his patience, support and encouragement throughout the entirety of this project. I would also like to thank RNDr. Luboš Němec for his assistance and data providing as well as Mgr. Ilona Zusková, both from the Czech Hydrometeorological Institute.

Last but not least, I am grateful to Michal Staša for his advices and linguistic knowledge.

ABSTRACT

The purpose of the thesis is an outline of a sustainable framework for future development of ski resorts in the Giant Mountains, Czech Republic (Krkonoše in Czech). This required first a detailed study of possible alternatives in relation to the local climatic trends, focusing on the velocity and magnitude of change of snow cover in the area. Snow cover is a sine qua non for ski resorts, which is why it is the main focus of this study. Three key snow variables were defined for the ends of the study: total seasonal depth of snow cover, seasonal number of days with snow cover, and seasonal maximum depth of snow cover. The data used for processing were obtained from the digital database (CLIDATA) of the Czech Hydrometeorological Institute (ČHMÚ); additional historical data were collected from the ČHMÚ archives. The research included 23 weather stations. Missing data were interpolated from neighboring stations. The results were plotted for the period 1961-2018; a decreasing trend was found in all the three snow-cover variables. Based on the results, the author proposes in theory an adequate strategy of adaptation, and offers a comprehensive diagram explaining the need for a combination of adaptive and sustainable strategies. The other branch of the paradigm tries to map out all the stakeholders in the process, i.e. the Krkonoše National Park Authority, local community, land owners, investors, ski resorts, etc. The main ambition of the thesis is a proposal of a combination of adaptive and sustainable strategies to define a framework and guidelines for sustainable ski resorts in the Czech Republic. Last but not least, the thesis should contribute to the mapping of snow cover in the Krkonoše.

Keywords: snow, snow cover, snow depth, ski resorts, climate change, Giant Mountains, adaptable strategies, ski resorts sustainable strategies, environmental impact assessment of ski resorts, interpolation of snow records, ČHMÚ

TABLE OF CONTENT

1 INTRODUCTION

The diploma paper examines the rate of change of snow cover in the Giant Mountains (hereinafter Krkonoše) since 1961. Due to the constantly deteriorating climate situation, which is closely linked to global warming, it is now necessary to monitor the variability of snowfall in the mountains. First of all, the thesis handles with the change of snow cover in the last 60 years in Krkonoše.

Krkonoše are a mountain range located in the north of Czech Republic on the border with Poland, and it is important to mention that its significant cross-border area is designed as the strictest and highest statute of landscape conservation - the national park, which on both sides of the borders constitutes a biosphere reserve under the UNESCO Man and the Biosphere Program.

Despite the fact that Krkonoše are the highest mountain ridge in the Czech Republic, the present local situation is struggling with insufficient snow cover in Krkonoše. This fact has a direct impact on the winter industry. Furthermore, this work examines the environmental assessment of ski resorts, and therefore ski resorts are situated in the mountain environment, which is very specific environment on Earth and our activity in mountain areas has to managed. The impact of ski resorts is undisputed, but it is directly necessary to determine the size of the impact.

With regards to the themes of this diploma paper, our research shed a light on the topic of a sustainable ski resort in the Czech Republic. Those principles were adopted from the USA Chart for the ski areas with combination of knowledge about adaptation strategies of the ski resorts – they define implication framework and policy based on climate variability.

The main benefit of this work is the overall lack of publications on the topic in the Czech Republic, and therefore this work contributes to the current issue and raises awareness of sustainable ski resort.

The thesis is divided into eleven main chapters. Right after the introduction, we propose a summary of the main goals of the submitted research. In the following chapter Literature review, we will give the reader an idea about what sustainability and introduce the environmental background of ski areas. Next, a few chapters are devoted to skiing and snow in general, and are presented along with the Czech ski resort introduction, etc. The next part contains adaptation and sustainable strategies of the ski resorts. The sixth chapter is dedicated to the researched area of Krkonoše. Following, we present the study's methodology, where we explain how the data was collected, how it can be presented and a summary of results. Last but not least, we propose a broad range of charts coming of the research. Finally, we will present the thesis results and offer a discussion about the topic.

2 MAIN GOALS

The main goal is to propose a series of comprehensive guidelines to develop or transform the existing ski resort in Krkonoše region into a sustainable one. I am proposing below adaptive strategies which should encourage local climatic endurance. The research in this thesis rests on three pillars which indicate reliable on the winter season. An analysis is offered of historical climatic data, such as maximum snow cover, snow cover duration, and number of days per year with solid precipitation data collected within the study area. Using statistical tools, this thesis will aim to determine future snow cover trends in Krkonoše and set key drivers for planning adaptable strategies. Locating and identifying crucial issues of both characters (positive and negative) caused by direct or indirect (or cumulative) consequence of local ski resorts operations in Krkonoše region will be determined. Last, but not least, this thesis research will evaluate the results of the climate data and compare it with case studies, evaluate different methods of collecting and processing data, and discuss all issues, occurred during this research. In conclusion, this thesis research will summarize all results, and last of all intends to propose how this work contributes to and provides benefits to the current topic of climate change and sustainable ski resort design, planning, and management.

3 LITERATURE REVIEW

3.1 SUSTAINABLE INTR0DUCTION

Sustainability can be interpreted as achieve of prosperity in an indefinite timeframe. Current literature seems to distinguish three dimensions of sustainability: social, economic, and environmental (Kuhlman and Farrington, 2010). Moreover, healthy life, economic profit and condition of our planet must be in balance, otherwise the use of natural and man-made resources could be mismanaged and lead to an unsustainable future with neutral or rather negative (Ohmura, 2014).

Sustainability according to Robert Solow and his ilk is fully dependent on the amount of natural resources, quality of the environment and last but not least on capital. There have been statements made, that natural resources can be substituted for capital, not equally, but in a form of compensation loss of natural resources. Others, on the other hand feel that sustainability is an essential strategy or defining element for preserving natural resources, that are key for a sustainable future (Pearce, 1993). These two approaches are known as *weak and strong sustainability*[1] (Daly, 1997). For instance, the petrol industry belongs to the weak sustainability, but, "*some resources must fall under the requirement of strong sustainability, others under the*

[1]*Weak and strong sustainability* is a concept or approach to sustainability. Weak sustainability is presented as an alternative substitution of natural resources (e.g. water, minerals, fossil fuels) by human capital (knowledge, and skills). On contrary strong sustainability percept nature capital and human capital as uninterchangeable but complementary (Kuhlman and Farrington, 2010(Solow, 1993))

weak variety. Which of the two it is will depend on the degree to which they can be substituted by capital."(Solow, 1993; Kuhlman and Farrington, 2010)

Sustainable ski-resorts operate under the same or similar model. Technically, they have been practicing all aspects of sustainability, for many years, by using technological progress from energy efficiency projects to waste reduction and snowmaking. A new strategy was to define crucial issues, transform those issues into numbers of minor sustainable projects to mitigate or at least minimize negative impacts of ski-resorts towards sustainability supported by stable economy, with positive social impact as a leisure time activity center (Ayres, Bergh and Gowdy, 1998).

3.2 MOUNTAIN ENVIRONMENT

Mountains are one of the most very specific environments on Earth due to their unique micro climates. Mountains represents economic, environmental and social status. To better understand their natural background, hidden processes and variable life forms, which are part of the defining mountain environment. Growing density and rising number of settlements have created one of the very last uninhabited areas in the world (Wortman, 2014). Rich in topography, biodiversity and supply by water creates unique environment. Water is essential element for life, precipitation model for a mountain range, which creates watersheds and enables the nutrient cycle within the atmosphere (Argenti and Ferrari, 2009)(Dyurgerov and Meier, 2000). Despite all these facts, mountains remain a very fragile environment that provide a home to countless life forms, most of them are threatened, vulnerable or even endemic species (O'Brien, UNEP and CICERO, 2000). This is similar for other environments, yet mountains facing threats from various drivers starting on local up to global scale. Facing climate change has a priority and will have tremendous impact on future shape of mountain environment has the highest priority

The area which covers mountain biotope is estimated to 40 million km^2, which represents about 27% of the world, approximately 30% is cover by vegetation.

Above vegetation, a level is located Aeolian zone formed by wind-blown organic matter (pollen, fungal spores, bacteria, insect bodies) which provides a viable environment for communities of hardy insect and invertebrates. Vegetation cover expands about one-third of global mountain biotopes and consist of closed forest area.

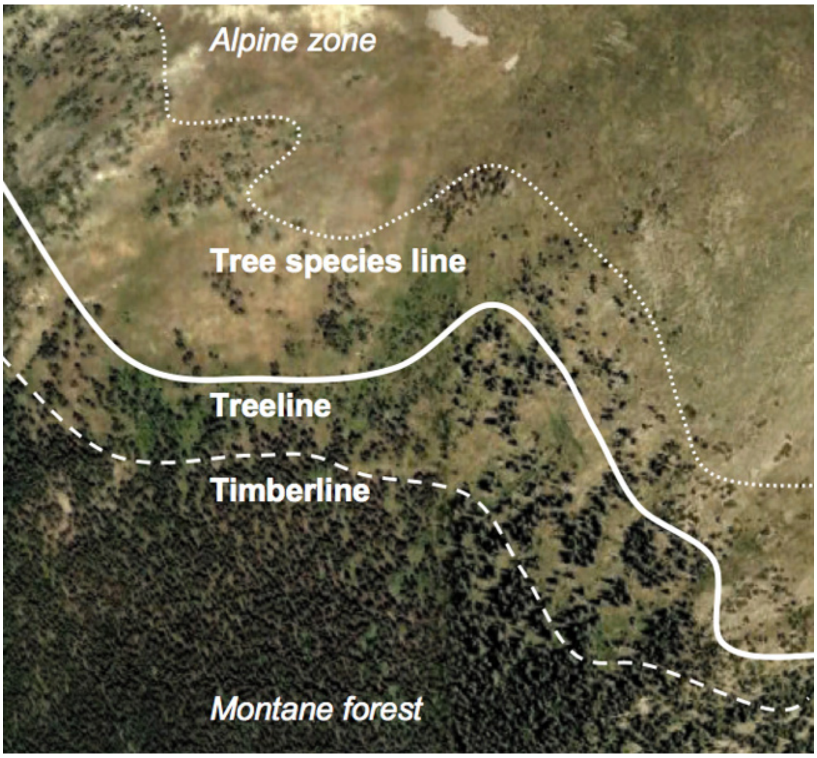

Figure 1. Conceptual representation of the tree borders. [9]
Source:
http://www.nature.com/scitable/content/ne0000/ne0000/ne0000/ne0000/15899424/f2_berdanier.jpg

Closed mountain forest represents approximately 28% of the world closed forest area (Seager, 2006; WMO, 2017). Most of the ski resorts occur in an active mountain forest ecosystem, especially in the Czech Republic, which provides significant resources of timber.

Mountains are unique for its vertical levels. A large area is afforested, which means nature reached the final stage of succession – most variable and rich ecosystem on the continent. Due to high altitude, coniferous trees are in major dominant in those hostile conditions. In the Czech Republic, the upper tree line is estimated in 1370 meters above sea level (hereinafter referred to as m), in comparison with other EU countries is relatively low, the main factor in Czech is exposure of our highest summits to wind blast wind with extreme temperatures (Berdanier, 2010). Another important function of forests is, they are capable to generate microclimate, heat capacity, improve soil attributes and water capacity, decrease surface runoff and increase local retention, anti-flood measures, creating a natural habitat for photosensitive species, timber production, food source and recreational functions (von Wissmann, 2008). The very edge of upper altitude forest is demarcated by three lines illustrated in Figure 1. (Pilli and Pase, 2018a). The main reason is heat deficiency, which causing variable timberline, fully dependent on elevation, microclimatic and climate conditions, and *mass-elevation effect*[2] on Figure 2.(Ellenberg, 1966) Based on all these factors we distinguished between various mountain environments. Last, but not least is a permanent snow line, which represents the boundary between snow-covered and

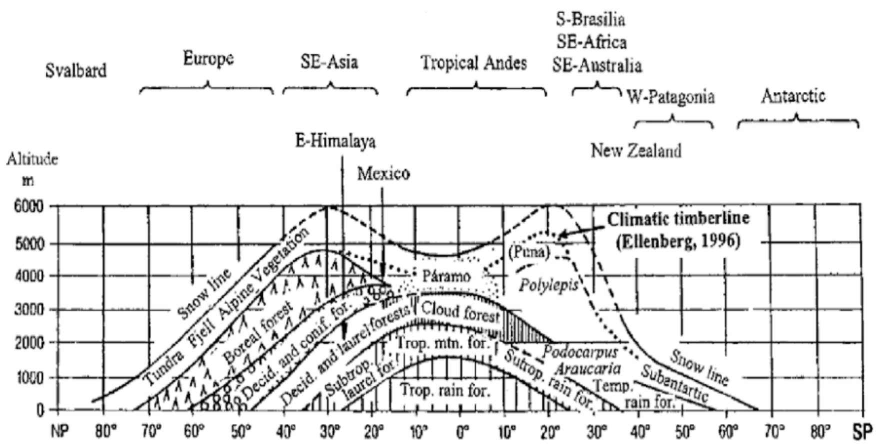

Figure 2. Mass elevation effect showing altitude position, climatic timberline, snowline on a global sc.
Source: Ellenberg, H., 1996]
https://books.google.cz/books?hl=cs&lr=&id=C8y6Vb0JO8C&oi=fnd&pg=PR7&dq=Holtmeier,+F.+Mountain+Timberlines:+Ecology,+Patchiness,+and+Dynamics.+New+York,+NY:+Springer,+2009.&ots=oyePG6pJUS&sig=TCMcsqaWU94vBgGT3OHGc3vYv2s&redir_esc=y#v=onepage&q=mass&f=f

[2] *Mass elevation effect* was discovered more than 100 years ago as a global paradox by describing recently discovered interrelation between temperature, upper tree-line, snowline and based on the distribution in same climate belt, morphology or altitude. There is no pattern on such a big scale like global, but most relevant are small scales models based on local conditions (Han et al., 2012).

snow-free surfaces. In the Alps the boundary of snow-cover moving between 2500 – 3200 meters above sea level, therefore in the Czech Republic the snow line vanished with glacier recession (O’Brien, UNEP and CICERO, 2000).

3.2.1 VERTICAL ZONING

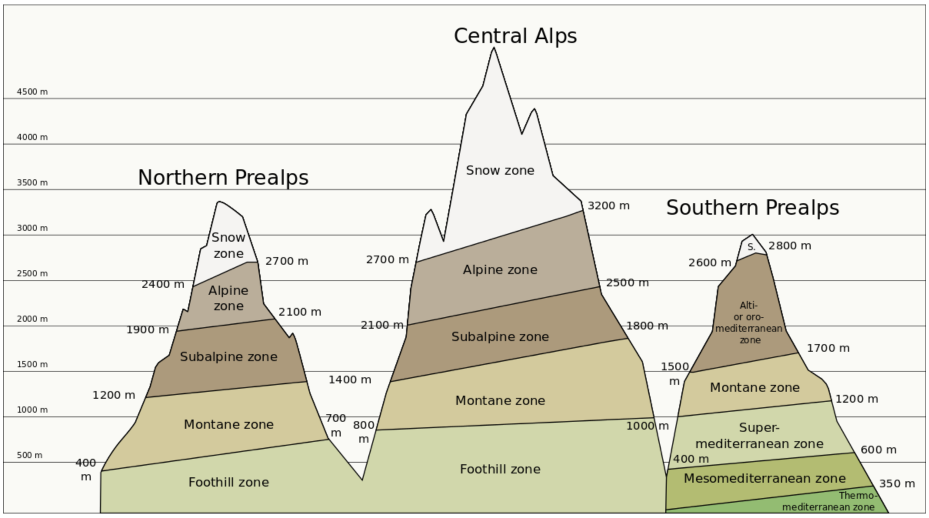

Figure 3. Alpine altitudinal zones distribution.
Source:
https://upload.wikimedia.org/wikipedia/commons/thumb/7/70/Altitudinal_zones_of_Alps_mountains-extended_diagram.svg/600px-Altitudinal_zones_of_Alps_mountains-extended_diagram.svg.png

The worldwide altitude distribution of mountain lands is shown in Figure 2. Focusing on Europe, we have to name concrete European altitudinal zones. Altitudinal zonation, firstly described by geographer Alexander von Humboldt (Frahm and Gradstein, 2006). Influenced by several factors, like temperature, humidity, soil composition, biological forces, solar radiation, *Massenerhebung effect* [3] and other factors. We have several zones in vertical order showing on Figure 4.(Han *et al.*, 2012) Zooming into a Czech Republic, according to The Krkonoše Mountains National Park agency (KRNAP) we can find 5 altitudinal zones in Czech Republic. In vertical order sub-montane zone, montane level, alpine (upper) tree line, sub-alpine (lower alpine) zone and arctic-alpine (high alpine) level (Barry *et al.*, 2007).

3.3 SNOW

Snow is an important climate element affecting the biosphere. Solid precipitations or snowfall and subsequent snow cover contain a large amount of water supply watersheds and restore groundwater level in a various climate zone. Snowflakes contain ice crystals that form under specific atmospheric conditions. The main condition determining the final shape of the snow crystals is temperature. Temperature above 0° C and suitable atmospheric conditions forms solid precipitations. Solid precipitations are divided into. Snow precipitation have a character of wet snow or even sleet (rain with snow) (Tolasz *et al.*, 2007).

Snow accumulation is concentrated at Earth's magnetic poles. Arctic and Antarctic polar areas represent approximately 1.75 - 2% of freshwater resources on our Planet. Snow has various different forms from liquid up to the solid state. Inception of snow precipitation in the atmosphere creates snow events such as snow flurry, snowstorm, snow blizzard is characterized by increase duration and intensity of solid precipitations.

3 *Massenerhebung effect* is explaining variations between tree line and mountain dimensions and terrain (Han et al., 2012).

3.3.1 SKI RESORTS IN MOUNTAIN ENVIRONMENT

Ski resorts are being constructed on all altitudinal levels, and in last four decades and for each level there must be a unique strategy developed based on local environments. Recently, we have been reporting a tremendous increase in various ecological footprints of ski resorts, especially helicopters, are nowadays affordable for private sector use (heliskiing, skiing, transport services to remote areas or inaccessible access areas for recreational use), helicopter-supported activities are used rarely, but multiples the recreational area and brings negative impacts (air pollution, sound pollution and disturbance caused by human activity) on sensitive species (EURO-CORDEX, 2017). As the popularity of winter recreation at ski resorts increased, many resorts started off-season operations with a diverse variety of options of recreation; hiking and mountain biking are now the most frequented reasons for a visit. Thus, is very important to proceed with low impact development with future monitoring, based on habitats and migrating corridors distribution to maintain functional ecosystem. Future monitoring will generate valuable complex data and set a framework for functional long-term impact assessment (Jacob *et al.*, 2014).

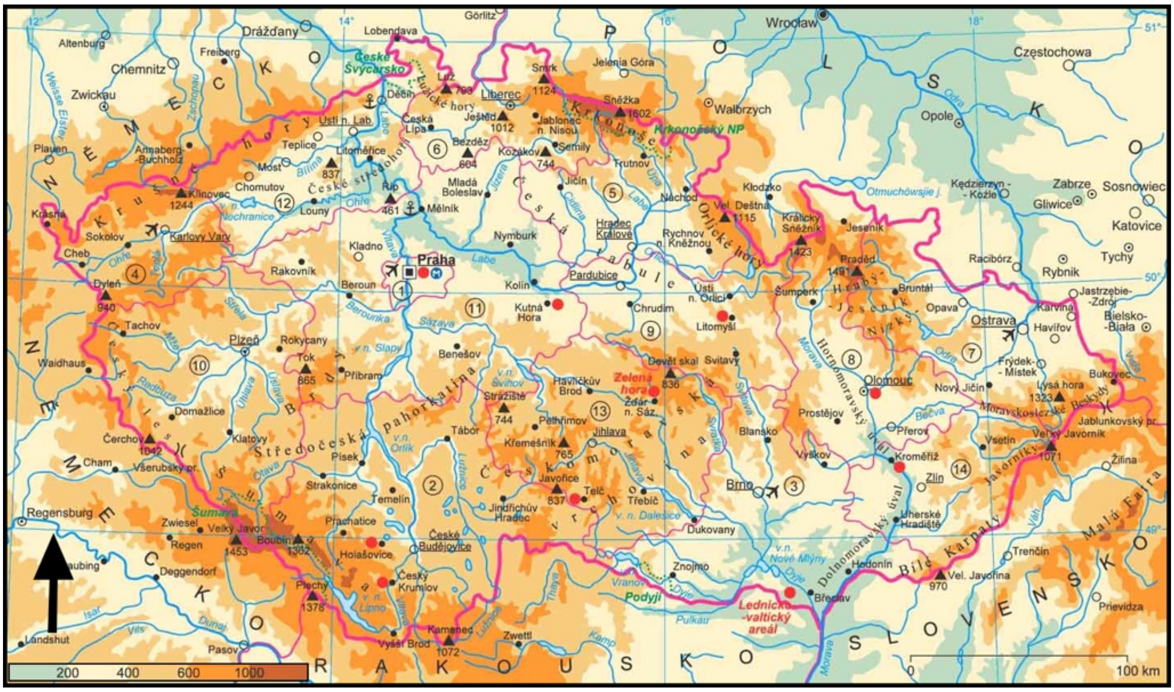

Figure 4. Geomorphology of Czech Republic
source:
https://www.google.com/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwiG_oXbj6LgAhVMbFAKHWU4AKAQjRx6BAgBEAU&url=http%3A%2F%2Fwww.primazima.cz%2Fceske-hory.html&psig=AOvVaw36VgtQyrJhUpk4ifoj4KxI&ust=1549371219801977

3.4 SKIING IN CZECH REPUBLIC

Czech Republic takes a significant place in numbers of ski resorts and lifts on worldwide level. There is no doubt that skiing in Czech Republic has become one of main financial source for winter-time recreation activities (Flousek, 2016).There are several factors that can validate ski resorts on global scale. Criteria are transport capacity and number of ski lifts. Czech Republic takes 9th place in the number of visitors and 12th place in the number of ski lifts [4] (Vanat, 2014, 2015). Vanat refers

[4] From non-alpine states takes higher places Czech Republic only USA, Japan, Canada and China (Vanat, 2015).

that Czech Republic has 176 ski resorts dates to year 2015. Base on web portal České sjezdovky, we have 289 ski resorts, but only 224 are contemporary in operation as of February 2019 (Vanat, 2014, 2015; Falk and Vanat, 2016).

Apparently, most significant data has been collected and analyzed by Špaček in 2015 in his summarizing of the project KPMG ČR dedicated to the identification of benefits of ski resorts in the Czech Republic for regional level development. For public budget, he found that the Czech Republic has 164 ski resorts with length 3.162 km of ski running tracks and 541 km length of ski slopes with 736 ski lifts with transport capacity 562.720 persons per hour. The major ski resorts in the Czech Republic take 17% from total number and each one has in average 10 km ski slopes and transport capacity 5.850 persons/hour (Špaček, 2015; Flousek, 2016). Border area, especially with Poland, in the Czech Republic, is situated in very suitable

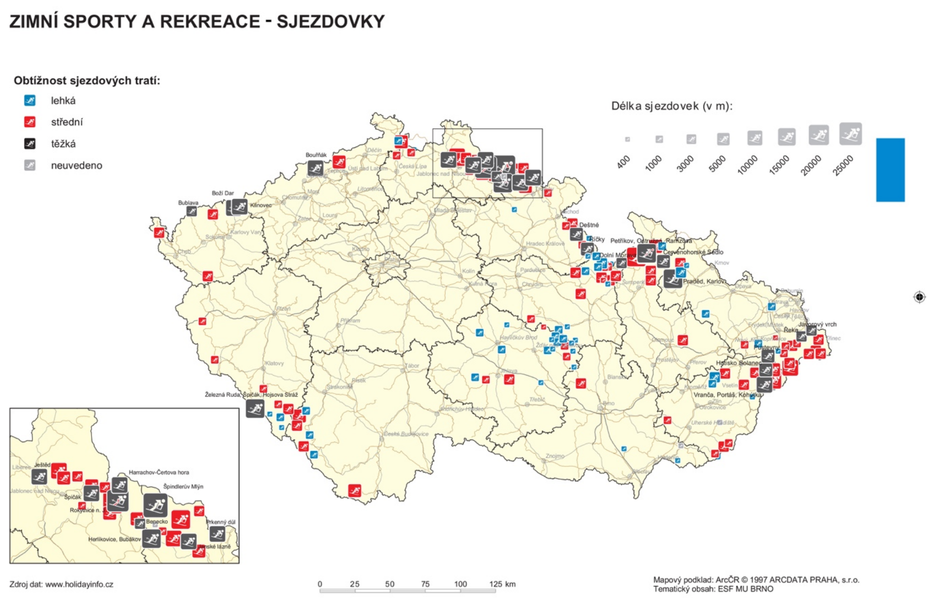

Figure 5. Winter Sports and Recreations - Ski Slopes
source: https://www.researchgate.net/profile/Josef_Kunc/publication/293823525_Atlas_cestovniho_ruchu_Ceske_republiky_The_Tourism_Atlas_of_the_Czech_Republic_in_czech/links/56bc60dc08aef81e60b15e7c/Atlas-cestovniho-ruchu-Ceske-republiky-The-Tourism-Atlas-of-the-Czech-Republic-in-czech.pdf

geomorphological and climatic conditions for skiing and other wintertime activities and therefore all large ski resorts were built within the border area (Vystoupil *et al.*, 2006).

3.5 SKIING IN NUMBERS IN KRKONOŠE

Based on research from Atlas Cestovního Ruchu (Vystoupil *et al.*, 2006) is clearly visible that Krkonoše region has the highest density of ski resorts in the Czech Republic and has the highest hotel beds capacity (Prague excluded). Since 1963 Krkonoše was declared as a National park (Vystoupil *et al.*, 2006; Flousek, 2016). Major big ski resort within the area were developed, namely: Paseky nad Jizerou, Harrachov, Rokytnice nad Jizerou, Vítkovice v Krkonoších, Špindlerův Mlýn, Herlíkovice, Černý Důl, Janské Lázně, Pec pod Sněžkou, Malá Úpa, Prkenný Důl takes account that in 1964, when area of National park was defined the area of ski slopes were calculated on bare 65 ha and till the year 1986 increased on 302 ha. To the year 2015 were recorded increased up to 553 ha of ski slopes in Krkonoše. If we add other ski slopes outside the National park area, we get the area of 672 ha, which 29% of it was defined outside of National park and rest 71% lied within Natural park (Figure 6.). Last but not least is 148 km of ski lifts (Flousek, 2016). We have to state that the numbers presented above were slightly increased due to ski resort expansion until the year 2019. Engineering and designing of new ski slopes are a part of already approved spatial plans or proposed amendments, which are approved and waiting only to discuss details. For instance, Špindlerův Mlýn in area of Medvědín, Hromovka and Přední Planiny, or Pec pod Sněžkou nearby Javor and Vlašský vrch. Another ski resorts growth is awaited due to developer pressure. From presented projects, we can highlight the connection of Harrachov with Rokytnice nad Jizerou ski resorts and the planned and expansion of Černá hora – Pec pod Sněžkou from the present 44 km of ski slopes up to 70 km, which will form “*gigantic ski resort*” (Plecháč, 2015)

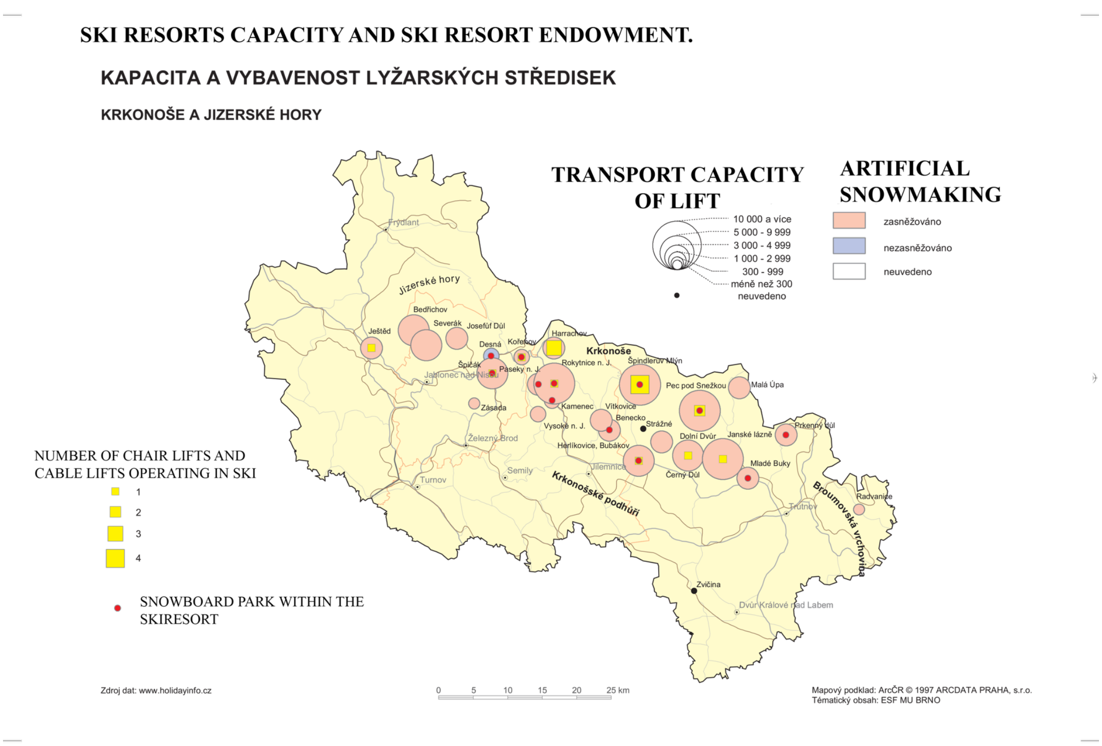

Figure 6. Ski resorts distribution in Krkonoše region and local amenity of ski areas
Source: Vystoupil 2006

3.6 ENVIRONMENTAL IMPACT ASSESSMENT FOR SKI INDUSTRY

Ski resort and its operation have a tremendous impact on the surrounding living environment and together with skiing create a complex of self-interconnected activities. Most destructive is the creation of the ski resort itself, construction of ski slopes, ski lift infrastructure and regular maintenance. This chapter is dedicated to the definition and summary of all impacts within the ecosystem generated by various activities linked with the ski industry. Last, but not least is important to identify the impact zone (Flousek, 2016).

Summary of all impacts

- Direct impact[5]
    - Impact during construction, operation, modernization and maintenance of ski resort
    - Fragmentation landscape and ecosystem
    - Impact on soil and water
    - Impact on vegetation cover
    - Impact on animal species
    - Impact related to artificial snowmaking
    - Impact caused by light and sound pollution
    - Impact linked with winter activities
- Indirect impact[6] and cumulative impact[7] of ski industry
  (Flousek, 2016)

The vast majority of the impacts listed below will be direct impacts. Those impacts can however have an indirect or cumulative effect, which can cause serious damages too.

[5] *Direct impact* is consequence of direct interaction with environmental, social or economic affect (Parr, 1999).

[6] *Indirect impact* is not a direct consequence of actions, usually occurs as a side product of combination inner interactions (Parr, 1999).

[7] *Cumulative impact* is a result of combinations various inputs interactions with final affect or affects (Parr, 1999).

3.6.1 IMPACTS DURING CONSTRUCTION, MODERNIZATION, OPERATION AND MAINTENANCE OF SKI RESORT

Most destructive is the development of the ski resort itself, construction of ski slopes, ski lift infrastructure and regular maintenance (Flousek, 2016). The construction of a new ski resort is usually accompanied by extensive landscaping while shaping and leveling the original surface. These modifications consequences interfere landscape. Ski resorts structures define new landmarks which mainly domain in new landscape (Flousek, 2016). Stripes of forest stands are being cut down for new slopes and ski lifts, afforested terrain is being modeled and prepared for service construction, access routes, parking lots, snowmaking systems and real-estate activities (Scott and McBoyle, 2007). However, the construction of a ski resort area and its subsequent maintenance does not stop the influence of the natural environment and its conditions. Often there is an increase in the supply of services and comfort of ski resorts, with other adverse impacts. Those impacts will be further developed in the upcoming chapters (Flousek, 2016).

Modernization of ski resort generates less of negative impacts compares to constructing. Generally, the amount of work is minor in time scale. Main pressure is concentrated on the environment caused by constructing works. Those modifications are mainly done off-season (same as construction), when nature activity peaks. Heavy machinery generates significant noise pollution, which affects the life of many species (Scott and McBoyle, 2007).

3.6.2 IMPACT ON SOIL AND WATERSHED

Landscaping is one of the most drastic interventions on the soil surface and vegetative patterns that can be used to make changes in soil structure above and below the upper forest line. Significantly decreases productivity and species diversity of the plants. Shrub disappearing and changing species variation in favor of *photophilic* [8] and less competitive species. (Mosimann, 1985; Delgado *et al.*, 2007; Roux-Fouillet, Wipf and Rixen, 2011) Physical degradation changes occur followed by chemical properties change of the soil. The soil horizons are superimposed and disposing of the humus layer, compressed snow on the slopes increases the thermal conductivity, which leaves soil vulnerable to deep freezing (Roux-Fouillet, Wipf and Rixen, 2011; Flousek, 2016; Rolando, Caprio and Negro, 2017). According to Gros et al. (2004) who claim ski slopes as degraded ecosystems, where the physicochemical attributes of soil have to be restored. An indicator of changes was a community of microbes, which was very unstable in the first 12 years and need a longer time period to restore soil attributes to an equilibrium state. Removing vegetation cover and terrain modifications of ski slopes drastically change the hydrological regime of soil. Retention ability of soil is decreased, and soil is exposed to often drying out. Surface runoff is increased due to deforestation in the ski resort area (Roux-Fouillet, Wipf and Rixen, 2011; Flousek, 2016).

Topsoil layer is usually flushed out which leads to vast surface erosion of area and threat of landslides connected with floods. The risk of seasonal floods is increased especially during spring rain season related to snowmelt of compressed snow. The development of a ski resort negatively influence the capacity of the local watershed, which leads to catastrophic floods (Arnaud-Fassetta, Cossart and Fort, 2004; Beniston and Stoffel, 2016). Ski resort constructing is usually connected with deforestation, building attached infrastructure and maintaining infrastructure for a ski resort and snowmaking. All those actions have a negative effect on the high ratio of clay (soft) sediments and contribute to the destabilization of riverbanks and shorelines

[8] *Photophilic* is a term for vegetation species which are dominant on direct sun light area (Weikai *et al.*, 2015)

(Pintar, Mali and Kraigher, 2009). Ski slope construction destroys vegetation and topsoil horizon, changing abiotic conditions and changing the soil specious structure. Last, but not least the soil systems are disrupted for decades (Flousek, 2016).

Figure 7. Impact on soil in Medvědín, Špindlerův Mlýn
Terrain modification and snow grooming impact on vegetation and surroundings
Source: Jan Štursa (2005)

3.6.3 IMPACT ON VEGETATION COVER

Vegetation cover is affected by the activity of the ski industry without any doubt. The ski resort is situated in the heart of wild nature. Constructing or future expanding of resort disturbs environment mainly speaking about forest sheds, meadows. More importantly ski resort forming landscape fragmentation, changing species variation overall decrease in populations of species. In the case of area deforestation, the strategic functions of forest are irreversibly disturbed such as stabilization of biocentres, watersheds, soil erosion control and many more (Flousek, 2016). The complex problems of area clear-cut and afterward fragmentation is fully described in those studies (Davies *et al.*, 2000; Ewers *et al.*, 2011; Gibson *et al.*, 2013; Haddad *et al.*, 2015).

Figure 8. Forest clear-cut process of existing ski slope in Budy Pomezí.
Source: Kamila Antošová (3. 6. 2009)

Comparison of natural alpine meadow vegetation and ski slope vegetation, which terrain was modified 26 years ago, examined that natural meadow has two times more seeds in the reproduction cycle, same as vegetation species diversity (M. Urbanska, Erdt and Fattorini, 2004).

Banaš *et al.* (2012) claim even some marginal differences in snow melting on groomed ski slopes and in a natural alpine meadow can lead to major differences in vegetation species diversity.

Large areas of the slope are being re-cultivated by commercial grass mixture which has many negative impacts, such as replacing original species diversity or even genetic erosion – high risk of expanding invasion and expansion species (Kangas et al., 2009; Flousek, 2016).

Natural snow cover and space gap between soil and snow work as a perfect insulant, keep the temperature of top soil layer around 0 C° and protect soil from deep freezing. On contrary compressed snow does not dispose/possess any of these features and abilities. In the end, everything changes the ecological processes in the soil and consequently also affects vegetation. The snow compacting process with snow groomers, as well as during skiing itself, increases snow density, its hardness, and conductivity, the balance of gases in the underwater space is disturbed, ice surface forms on the soil surface, oxygen concentration decreases, and carbon dioxide concentration increases. Movements of soil particles in freezing soil mechanically damage plant roots, changes in microbial activity in the soil are reflected in their nutrition and growth, decreasing oxygen concentration under the ice layer increases plant sensitivity to frost or pathogen action (Flousek, 2016; Fahey, Wardle and Weir, 2019).

As a result, freezing slows the growth of plants and lags their phenology, which illustrates in Davos cross-country skiing tracks in different seasons (Figure 9.) - although the growth impediment in and around the track is not distinctive, very noticeable is the shift in flowering and ripening of (*Taraxacum officinale agg*.) (Rixen, 2017)

Figure 9. Cross-country ski track, seasonal changes in Davos (Switzerland)
Influence of later snow melting on Taraxum officinale agg. Community
Source: Rixen (2017)

However, when snow is artificially added to the slopes (snowmaking) the deflated species lost competitiveness and plants with biotope on snow cover (snow bad) become dominant on slopes. The changes in vegetation on such tracks are greater compared to the surrounding meadows, the longer the ski slope is snowed. Highly fertile soil species surprisingly prefer natural snow slopes to technically snowed slopes, where we expect a higher supply of nutrients from technical snow. On the slopes with natural snow, however, its layer is mostly thinner, the soil freezes more, and the subsequent decomposition of dead microbial cells releases nitrogenous substances that increase its nutritional capacity (Flousek, 2016).

The changes in the vegetation diversity are significantly influenced by the movement of heavy technique (snow groomers) during snow adjustments. Especially at the beginning and end of the winter season, with a thin snow cover, the soil surface is damaged, and vegetation is directly affected (Fig. 12). For a long time and in the accumulation of snow and snow pressures on the slopes, the number of species, the area of vegetation and the production of above-ground biomass has been decreasing, with biochemical changes in plants (Kammer, 2002; Pielmeier *et al.*, 2007; Flousek, 2016).

Figure 10. Snow grooming impact on ski slope Černá Hora, Jánské Lázně
Soil and vegetation cover destruction
Source: Jiří Flousek (11. 4. 2016)

3.6.4 IMPACT ON ANIMAL SPECIES

The construction of ski resorts in the forest sheds frequently generates conflict zones between biotopes. Spatial fragmentation and disturbance in impact zones with absence of any environmental impact assessment could have irreversible consequences. (Rolando, 2005; Flousek, 2016; Rolando, Caprio and Negro, 2017).

Research trends for beetles (*Carabidae, Elateridae*) confirmed, that on the downhill ski track and in its edge, including the five-meter buffer from the forest, the beetle community has almost completely changed; only less than 0.5% of forest species were found on the ski slope. Although the number of species of both groups was higher on the track than on its edge and in the forest, most of them were colonizers from lower altitudes. The authors consider the ski slopes as significant barriers to the spread of forest beetles. Fragmentation of the forest with slopes creates numerous “islands” of forest vegetation (Strong, Dickert and Bell, 2002).

Despite the altitude, it has been shown that the diversity of *invertebrates* has risen with vegetation cover. Detached vegetation on the slopes is a serious obstacle to their colonization by epigeic *vertebrates*. Particularly in the forest habitats, the break-even crossings between the forest and the slope play an important role. The destruction of forests or meadows and their fragmentation by the slopes thus significantly adversely affect the communities of the examined invertebrates (Rolando, Caprio and Negro, 2017).

Bird reactions to the presence of slopes above the forest line are comparable to some invertebrate groups. A higher number of species, diversity index, and nesting density on natural grassland, a comparable number of species and comparable diversity, but significantly lower bird density on the slopes. In addition, the indirect negative impact of the slopes also affects the surrounding habitats, which are also marked by significantly lower bird habitats (Rolando, 2005; Flousek, 2016; Rolando, Caprio and Negro, 2017)

Interesting results, with an impact not only on small mammals but also other animals which use spaces in between soil and snow layer, the snow cover is compacted, and space is reduced or completely eliminated, averaging only 1,2 cm compared to an average 8 - 20 cm (depending on the type of vegetation) under the intact snow cover. The authors cited by experimental snow compaction have found that, when the space under the snow was eliminated, the occurrence of two small mammal species using this environment decreased by 75-80% (M. Sanecki *et al.*, 2006).

One of the latest researches focuses on the influence of the ski industry on sensitive alpine and subalpine communities. The authors have collected data from the past 35 years that examined the effects of winter recreation on the fauna of invertebrates and vertebrates. The results of research evaluation, suggest that negative or no effect on fauna prevailed over the positive effect (this is reported only in three works, one each devoted to mammals, reptiles, and invertebrates). Especially in Europe, where most of the studies were conducted, the most frequent negative impact of winter recreation was on animals, especially birds, less on mammals and invertebrates. Their abundance and diversity were lower in winters sports areas compared to unaffected ones. However, the authors of the study note that there are still significant gaps in our knowledge. So far, we know very little of the life strategies of mountain organisms and their responses to human activities conditioned by changes in the environment. Long-term studies missing area, as the recordable changes in subalpine and alpine communities can only manifest themselves after many decades (Sato, Wood and Lindenmayer, 2013). (Sato, Wood and Lindenmayer, 2013)

3.6.5 IMPACT RELATED TO ARTIFICIAL SNOWMAKING

Snowmaking, now a prerequisite for ski resort functionality and a major adaptation of the ski industry to climate change, is a significant intervention in soil properties and water budget. Its installation involves terrain modification for water distribution, pumping and compressor stations, etc., and thus affects the deforested areas or snow-covered grassland. In addition to water budget, technical snow also affects the species composition of plant and animal communities (Flousek, 2016).

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Figure 11. Water pipeline system excavation for water distribution for snowmaking in Medvědín, Špindlerův Mlýn
Source: Petr Flousek (27. 5. 2016)

It is generally believed that snowmaking is not harmful to nature because all the water used should return to the system and the only difference from natural snow is its return to nature a little later. However, this reasoning is erroneous because protraction of water cycle and its retention on the surface means that it is lost faster than usual by rapid runoff and evaporation. Experimental measurements from the Alps and the Atlas have shown that almost a third of the water converted into technical snow disappears from the territory: by sublimation at higher altitudes, by evaporation from snow-covered reservoirs, by the removal of ice crystals immediately after their production and the like. It is estimated that the total loss of water in the Alps, caused by the production of technical snow is equivalent to annual water consumption of a city of a population of 500,000. There are no problems with potable water supply In the alpine regions with unsuitable subsoil; January and February are the critical months. In the long run, all water use in snowmaking is very risky because it depletes water resources that serve as reservoirs of water for winter and spring (before the snow begins to thaw) and redirect the runoff to the surface at the time of thaw instead of soaking and draining underground. Such a reversal of the water cycle disconnects the classical time/space relations between surface and groundwater and can cause problems of its shortage (de Jong, Collins and Ranzi, 2006; C. de Jong, 2007; Carmen de Jong, 2007; Flousek, 2016).

Technical snowmaking uses huge amounts of water and energy. 200 – 500 liters of water and 1.5 – 9 kWh of electricity are required to make 1 m^3 of technical snow which, with a layer of about 30 cm, consumes 600,000–1,500,000 liters of water and 5,000 – 27,000 kWh of energy per hectare of downhill ski slope compared the estimated and actual water and energy consumption for snowmaking in Alpine ski centers. The actual electricity consumption at the lower end of the estimate was based on the above-mentioned literature data and ranged between 0.33 – 0.60 kWh / m^2 of slope in a small ski area (Braunwald), and 0.69 – 1.13 kWh / m^3 / m^2 in large resorts (Davos, Scuol). Water consumption was at the upper boundary of the estimates and was 0.14 – 0.2 m^3 / m^2 for downhill runs in large ski areas(Steiger, 2010, 2012; Roux-Fouillet, Wipf and Rixen, 2011; Flousek, 2016).

3.6.6 IMPACT OF LIGHT AND SONIC POLLUTION

Noise and light are important pollutants of ski resorts as well as their close and more distant surroundings (Figure 12). In addition to the day-to-day operation (including the music sound system), it is mainly the night-time movement of snow groomers and scooters for the maintenance of ski slopes and cable transport facilities. The production of artificial snow generates noise in range of 60 – 115 dB, however, the development of new snow-making facilities is aimed at reducing this noise load. Light pollution comes mainly is reflector lamps illuminating downhill ski slopes for night skiing, and the lighting of snow cannons and snow showers also contributes to light pollution (Flousek, 2016).

Figure 12. Night snowmaking in Granite Peak Ski Area, Wisconsin, USA
Sonic and light pollution illustration
Copyright: Granite Peak Ski Area
Source: https://img6.onthesnow.com/image/gg/98/98117.jpg

The influence of noise in ski areas on animals within the ski resort was not monitored in greater detail. Thus, we can only indirectly infer the level of night-time noise pollution from a study of the impact of noise on US ski resort staff. 11 – 70% of snowmaking workers were exposed to an excess of effective noise standards at 82 – 90 dB; the excess was up to 100% for night workers. No snow groomer drivers have been exposed to an excess of the standards. Thus, night noise pollution in ski resorts is a fact (Radman, 2018). In general, the negative impact of noise on animals is proven. Excessive noise, for example, complicates communication between individuals of the same species, affecting mating and reproduction, complicates orientation at prey hunting, and contributes to inferior condition of individuals or increases the risk of falling prey to predators (Francis and Barber, 2013).

Light is one of the key factors influencing animal behavior, controlling their daily and yearly rhythms, and may cause problems of reproduction, loss of orientation, health complications, etc. There are many studies of the negative effects of night-time lighting on humans (Stevens *et al.*, 2013; Flousek, 2016). They seem to summarize existing knowledge of the effect of light on animals. Longhorns mentions, for example, the effect of night illumination on lower hunting success and, on the other hand, a higher risk of predation in small mammals, a shift in the timing of vertebrate biological clocks, or disruption of the production of the hormone melatonin, affecting physiological processes in animals and, inter alia, causing malignant tumors (Rich and Longcore, 2006).

3.6.7 IMPACTS LINKED WITH WINTER ACTIVITIES

Activities enjoyed in ski resorts such as downhill and cross-country skiing, snowboarding, and ski touring have an impact on the sites. Compacted snow affects soil or vegetation, and human activities impact directly the population of wild animals, affecting their behavior, physiological functions or reproduction (Flousek, 2016).

3.7 CLIMATE IN EUROPE

According to the World Meteorological Organization, climate can be defined as ''*the statistical description in terms of the mean and variability of relevant quantities over a period of time. This period of time has typically been defined as 30 years*'' (IPCC and IPCC5 WGII, 2014). Climate as a statistical value of weather, location, a range of states and phenomena can be described by statistical quantities: mean, standard deviation, return period and intensity-duration-frequency of extreme events (IPCC, 2000; IPCC and IPCC5 WGII, 2014; EEA, 2017). We have been witnessing on the global scale a growth of reported anomalies, which are key indicators of global warming and strongly altered climate variability. Such anomalies include volcanic eruptions, solar eruptions, or they may be the result of internal variability within the climate system. An example of the internal variability of El Niño results from interaction between the atmosphere and the ocean in the tropical Pacific (Dyurgerov and Meier, 2000; Kryzanek and Karreth, 2018). Another anomaly, directly affecting Europe, is the circulation of ocean water known as the Gulf Stream (Jacob *et al.*, 2014). The year 2017 belongs to the historic trinity of the world's three warmest years on record (together with 2016 and 2015) and was the warmest year on record with an absence of El Niño effect. Based on these trends, one can assume that the warming trend will continue (IPCC, 2000; IPCC and IPCC5 WGII, 2014; EEA, 2017; WMO, 2017; Steiger and Abegg, 2018)

Focusing on past trends of climate change in Europe, the mean annual temperature was reported to have risen by 1.61 C° to 1.71 C° from 2008 to 2017, representing a decade with the highest mean temperature ever recorded since the pre-industrial era. Temperature is rising rapidly, and we have been monitoring a linear growing trend since the 1990s. The IPCC programmed several model situations to estimate alternative projections of future climate scenarios, including data about anthropogenic driving forces, such as socio-economic, technological, demographic and environmental development. Collection of valuable information about the connection between those drivers and the level of greenhouse gas concentrations in the atmosphere is the highest priority, equal to changes in land use and land cover. between those drivers and the level of greenhouse gas (GHG) concentrations in the

Atmosphere has the highest priority equally with changes in land use and land cover

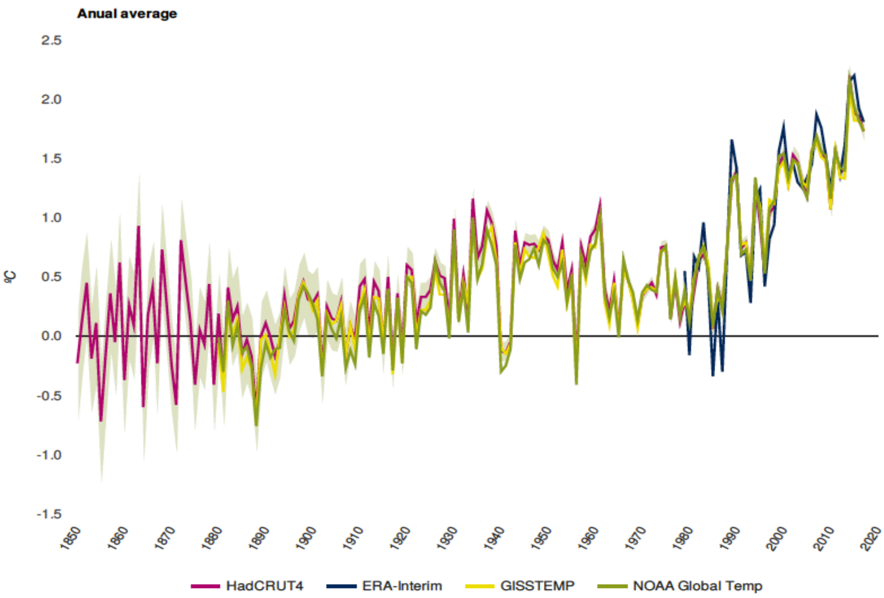

Figure 13. Annual average temperature in Europe – different records comparison

source: https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-8/assessment

(IPCC, 2000).

Since the future of anthropogenic factors is uncertain, the IPCC have to develop strategies to deal with negative prospects for the future, to explore and comprehend all causes and effects, to develop multiple scenarios with various emission pathways to cover all possible outcomes. Looking into the future, the projections of global average temperature will increase in this century as a direct result of greenhouse emission increase. Four pathways have been selected for climate modeling, known as Representative Concentration Pathways (RCP), based on greenhouse gas concentration. Climate projections suggest temperature in Europe will rise dramatically. Four different scenarios have been developed (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) by the Intergovernmental Panel on Climate Change (IPCC) for two upcoming time horizons, one for mid-century, the other for the end of 21st century.

According to the model for mid-century (2046-2065), European continent will warm in the range of 0.4 C° to 1.6 C° in the RCP2.6 scenario. The middle pathway (RCP4.5) suggests 0.9 C° to 2.0 C°, RCP6.0 0.8 C° to 1.8 C°, and the highest-emission scenario (RCP8.5) estimates mean temperature in the range 1.4 C° to 2.6 C°. The projections for the distant time at the end of the century (2081-2100) are 0.3 C° - 1.7 °C for the lowest-emission scenario (RCP2.6),, 1.1 C° - 2.6 C° for RCP4.5, 1.4 C° - 3.1 C° for RCP6.0, and 2.6 C° - 4,8 C° for the highest-emission pathway (RCP8.5). This research suggests a higher warming concentration over the land than over the ocean (NOGAMI, 2010). Graphic outputs have cell resolution of 25x25 km for the near projection and

50x50km cell *raster*[9] for the end of the 21st century. Last but not least, the IPCC admits that the two lowest RCPs (RCP1.9 and RCP2.6) presume a very strong reduction in the amount of polluting emissions in the atmosphere (IPCC, 2000).

EURO-CORDEX initiative creating climate projections is centered on the Regional Climate Model (RCM), which estimates a higher temperature escalation on the European continent than the rest of global land areas (RCM), provides projections for scenarios RCP4.5 and RCP8.5). The European landmass will face warming

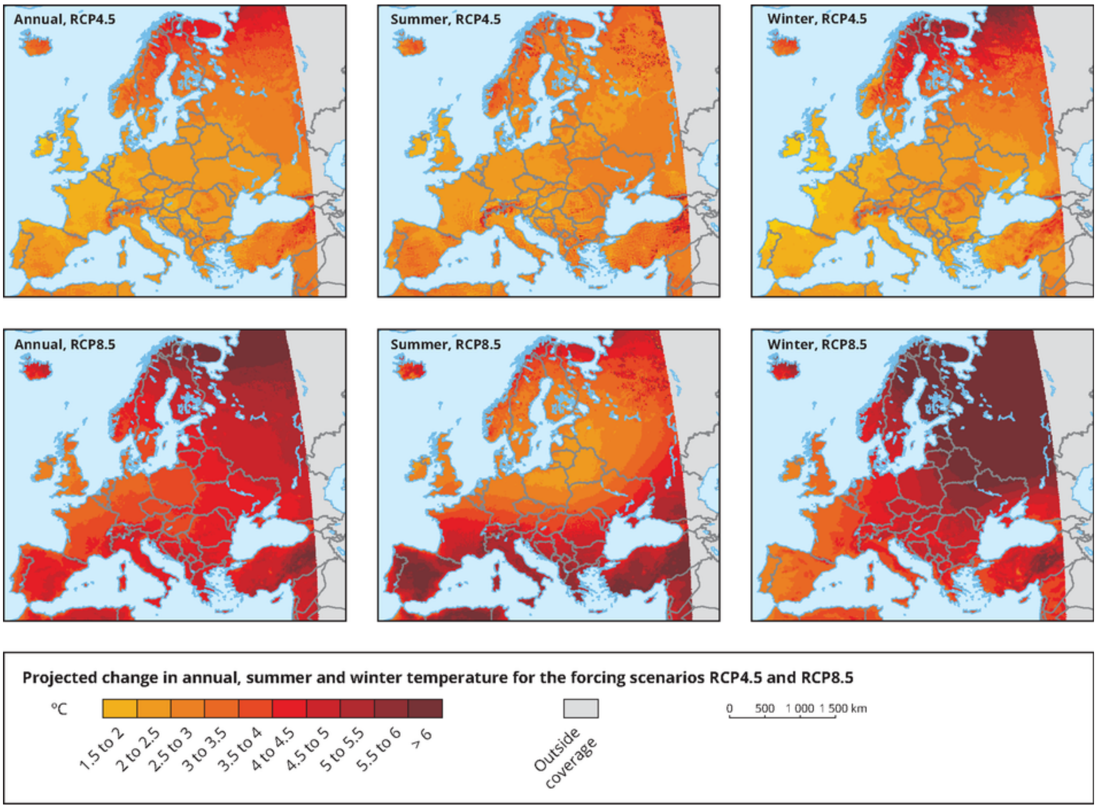

Figure 14. Projected changes in annual, summer and winter temperature
Source:

[9] *Raster* is computer graphic consists from matrix of (pixels) cells, where each cell contains a value representing information such as color or value (ESRI, 2019).

projections in the range 1.0 C° - 4.5 C° for the RCP4.5 scenario, whilst RCP8.5 suggests a stunning range of 2.5 C° - 5.5 C° for the end of 21st century (2071-2100) (Figure 4.). The significant climate fluctuation (Figure 14.) is prevails in north-eastern Europe and Scandinavia in the winter season and in southern Europe in summer [29]. Besides RCP scenarios, dedicated to man-made sources of greenhouse gases, there is the Special Report on Emission Scenarios (SRES) with four very different strategies to cover all possible alternatives. Each scenario represents an important pillar of sustainable development, i.e. demographic, social, economic, technological, and environmental (UNEP, WMO and WTO, 2008). By the year 2100, the world can change in a way we cannot even imagine. The four scenarios represent alternative futures and should not be evaluated on the short-term scale based on the current economic situation, technology or social trends (IPCC, 2000)

Scenario A1 suggests rapid economic growth, with emphasis on new technology, polycentric development favorable to competitiveness on the regional scale, a worldwide population that peaks in the mid-century and drops thereafter, avoiding large regional disparities in Europe, growing population density by promoting residential unit housing with a stronger cultural and social interaction within the community. Regional differences should be minimized, including the differences in income per capita. The A1 scenario is further distinguished into three paths, each taking an alternative direction with emphasis on specific strategies for the technology of energy systems. Each of the three A1 variants represents a technological trend opposite to the other two: fossil-intensive (A1FI), non-fossil energy sources (A1T), or a balanced mix of sources (A1B).

A2 scenario is set in a heterogeneous world, where self-reliance and independence are important to preserve local identity. Population grows; regional development supports local economy. Gaps between per capita incomes in society widen; technological sector is fragmented and less efficient than in the other scenarios.

B1 assumes population will peak in mid-century and drop thereafter, economic structure will lean towards services and transparent economy, with low demand for raw materials. A strategy is defined to move towards zero emissions with clean and resource-efficient technologies. The economy works on the global scale and builds bridges connecting a society with sustainable clean environment on the way towards equity, without heavy dependence on fossil fuels and additional climate initiatives.

The B1 storyline and family of scenarios describe a convergent world with uniform global population that peaks in mid-century and declines thereafter, the same as in the A1 storyline, but with rapid changes in economic structures toward a service and information-based economy, with reduced material intensity and introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and family of scenarios describe a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing global population at a slower rate than A2, medium rates of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. (IPCC, 2000; IPCC and IPCC5 WGII, 2014; EEA, 2017).

3.8 SNOW COVER IN EUROPE

Precipitations and temperatures below zero degrees Celsius play an important role in the snow forming process. Water vapor freezes in the atmosphere, thus creating favorable conditions for solid precipitations. Snow has a beneficial impact on all life forms, protects the ground as a thermal insulation layer, and serves as a natural reserve of fresh water. When spring snow melts, a huge amount of snow-stored water is released back to the biosphere system (rapid warming can cause devastating floods). Snow cover is obvious the essential element for a viable ski resort; it is therefore very important to plan and build ski resorts in areas with sufficient duration of snow cover in a hillside landscape. Climate change is currently pushing the snow line to higher altitudes above sea level (Ohmura, 2014)

To reveal the significant impact of climate change on ski resorts, it is therefore very important to understand natural snow reliability. Witmer (1986) established what he called the 100-day rule, which defines natural snow cover reliability as a ski resort operating more than 100 days in more than 7 seasons in a decade (Witmer, 1986; Barry *et al.*, 2007). However, it is not possible to define an applicable minimum snow depth for an operational trail due to varying characteristics of the trails. The most important characteristics are north-south exposure and rockiness(Marty, 2013). An increasing number of research articles has been published on the subject of climate change and snow cover in Europe. Several studies confirm a general decrease of snow depth and snow cover duration since the 1980s in European Alps. Reduction of snow cover at low altitudes was observed, caused by higher temperatures in winter (Marty, 2013).

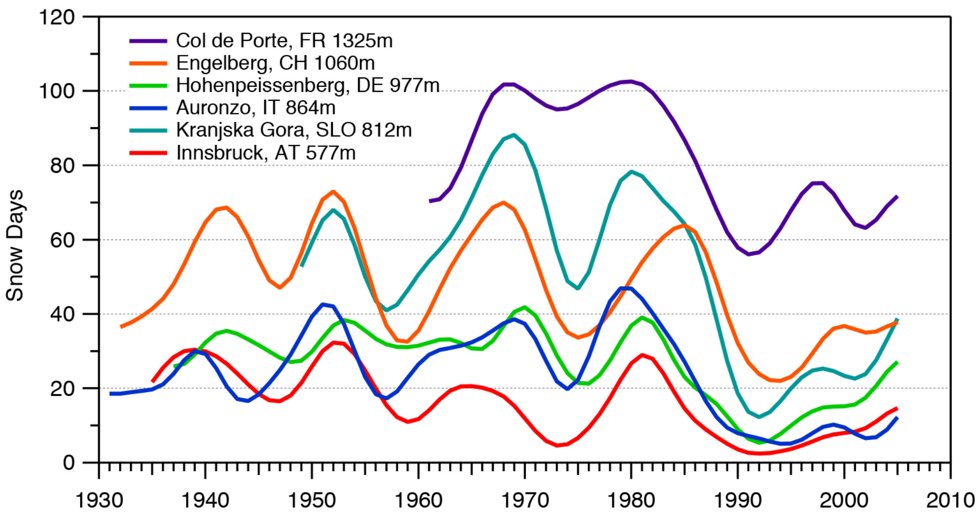

Figure 15. Number of snow days in a different European region
Figure shows numbers of snow days in Swiss Alps with depth at least 30 cm for ski resorts located in altitude between 800 – 1200 m drop about 35% after the end 1980s in comparison to long-term mean interval before change, but more important is indicator of drop, which was not caused by low precipitation, but higher temperature input
Source: (Marty, 2008; Scherrer, 2004)

Thirty centimeters of snow is generally accepted as adequate snow depth for winter sports, but with progressive warming the snow depth is decreasing and, as climatic models suggest, it will continue to decrease; the number of ski resorts with sufficient natural snow cover will drop and the resorts will have to turn to artificial snowmaking procedures to be able to compete. Alpine ski resorts will suffer most, especially those located at low altitudes, in dry valleys inside a mountain range, and on south-facing slopes. On the one hand, results from late 20th century Switzerland indicate a dramatic drop of snow depth at altitudes below 1,300 m, based on measurements from more than 100 stations; results from altitudes above 2,000 m show no significant differences of snow depth. Moreover, long-term predictions and trends in the Swiss Alps in studies from the 1980's and later show that the length of season and snow amount went down (Beniston, Keller and Goyette, 2003; Marty, 2013; Rixen, 2017). Latest studies show alternatively dataset for the last 130 years, proving that the poor-snow series of winters from 1988 to 2007 was exceptional. "In particular, it showed that the decline was caused by an abrupt change, rather than by a continuous decrease."(Marty, 2013 (Figure 16.))

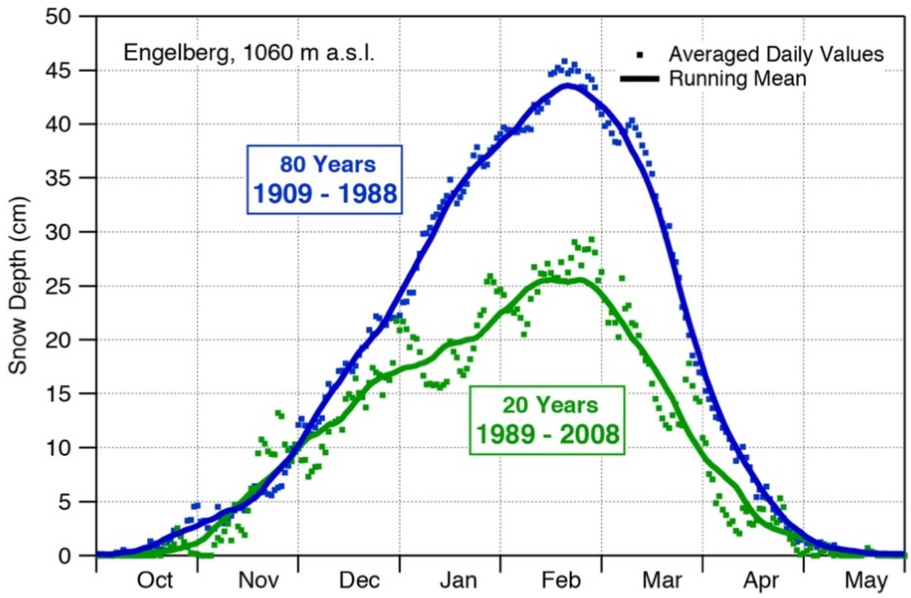

Figure 16. Number of snow days in Engelberg (Switzerland)

A study conducted in the Austrian Alps was concerned with a more diverse image. Technically speaking, data were separated in two groups: statistical analyses detected predominantly decreasing trends at the majority of stations; one significant depression in trend was captured specifically at south-Austrian stations (Jurkovic, 2008). It should be noted that the depletion of snow cover was, beside rising temperature, mainly due to a higher ratio of liquid present in precipitations, caused by warmer winters in the Alpine region with a rising temperature as described above (Serquet *et al.*, 2011). Seasonal changes in snow cover were recorded in the Italian Alps and spring snow cover depletion was not as significant as in the winter, however these results came not from one small area in northern Italy, but rather all the 20 stations located between 2000 – 3000 m a.s.l. confirmed the downward trends in snow cover (Bocchiola and Diolaiuti, 2010). Altitudinal comparison in data from the German Alps from 1952 till 1996, regarding snow cover depletion, provided outputs. Reduction detected in low-lying areas was estimated at 20-30% and high- altitude areas reported a reduction of approximately 10% (Günther *et al.*, 2005; Marty, 2013) and contributes to the conclusion that the major impact on snow cover depletion will be concentrated in low-laying mountain regions (Marty, 2013). This contributes to the conclusion that low-laying mountain regions suffer the major impact on snow cover depletion (Marty, 2013). This statement is supported by an identical trend identified in the French Alps in 1958 – 2005, with additional discovery. Besides the fact that snow depth reduction affects more low and medium altitudes, this study presents other valuable information (Durand *et al.*, 2009). *"Snow patterns in the French Alps are characterized by a marked declining gradient from the northwestern foothills to the southeastern interior regions. This applies mainly to both depths and durations, which exhibit a maximal latitudinal variation at 1500 m of about 60 days, decreasing strongly with the altitude. At present, French downhill ski resorts are economically viable from a range of about 1200 m MSL in the northern foothills to 2000 m in the south, but future prospects are uncertain. In addition, no clear and direct relationship between the North Atlantic Oscillation (NAO) or the ENSO indexes and the studied snow parameters could be established in this study." (Durand, Y., et al. 2009).* Wilke et al.

(2004) compared differences between Swiss and Austrian *snow cover duration* [10] and found that both areas show similar features in snow cover except the Swiss snow line is 150 m higher than in eastern Austria (indicated by shifting from the Atlantic maritime to the dominant continental climate).

3.9 SKI RESORTS ADAPTATION STRATEGIES

Changing climate leads to shorter winter seasons, less annual snowfall and thinner snow cover; this in turn will affect our winter seasons further in the future. Climatic studies mentioned in chapter 4:5 (Climate in Europe) generated three different scenarios and assume (bar the first scenario which is based on a decrease of carbon emissions) that many resorts are facing today a reduced natural snow cover and its duration, mainly at low altitudes (EEA, 2017). Climate and weather are the main natural elements rule touristic feedback in terms of demand provided comfort and satisfaction to visitors. Two main goals have been defined as necessary for ski resort operation. One is meeting the needs of tourists (water supply, energy cost, insurance). The other goal is related with essential environmental resources for ski industry (glaciers, biodiversity, precipitations, and sufficient water level)(Dawson and Scott, 2013). Therefore, the ski industry is one of the businesses most vulnerable to climate

[10] Snow cover duration is one of main indicators of climate change, controlled by temperature and precipitation. Duration of snow cover has a significant impact on functions within the ecosystems and climate systems. (Urban *et al.*, 2019)

change (UNEP, WMO and WTO, 2008); and this leads to the conclusion that the ski industry has to adapt to future climate change using adaptation strategies. *"Adaptation is increasingly recognized as an appropriate and necessary response option to climate change, especially since it has been established that humans are—at least in part—responsible for climate change and that some impacts can no longer be avoided."* (Klein J.T., 2011).

Technically, adaptation strategies have two main approaches. The first approach is aimed at using technological measures and represents active or direct materialistic interventions to the ski resort area and its services. The second approach focuses on business practices using financial tools to create financial models and strategies (Elsasser and Bürki, 2002; Scott and McBoyle, 2007; Klein J.T., 2011; Marty, 2013).

3.9.1 TECHNOLOGICAL MEASURES

For this thesis research, the following are the distinguishing numbers of technical measures:

- Landscape and slope development with operational practices
- Artificial snow-making
- Cloud seeding

(Elsasser and Bürki, 2002; Scott and McBoyle, 2007; Klein J.T., 2011; Marty, 2013).

3.9.2 LANDSCAPE AND SLOPE DEVELOPMENT WITH OPERATIONAL PRACTICES

The first type strategies apply to the ski resort area on a large as well as small scale. Landscaping or large-scale area transformation involves heavy machinery:

machine grading of slopes, bulldozing slope, creation of shaded areas. Small-scale landscaping consists in contouring and smoothing. In practice it means leveling run surfaces, and removal of obstacles to obtain equal snow depth on a run and thus reduce the amount of artificial snow demand on a run (Marty, 2013). Land contouring can alternatively be used to form a drainage system directing surface runoff into snowmaking reservoirs to capture molten snow. Shaded areas can be obtained by purposeful tree planting or tree cover retention (Scott and McBoyle, 2007; Marty, 2013).

Additional snow cover duration and length of ski season can be obtained by moving ski resorts into climatically reliable zones. The main indicators in this strategy are elevation and sun exposure. Moving ski resorts to higher elevations and developing runs with North exposure extend snow cover duration (Scott and McBoyle, 2007; Marty, 2013).

With increased glacier recession in the Alps, Swiss and Austrian ski resorts initiate programs to preserve glaciers by installing large white polyethylene sheets on critical spots to prevent glacier melting, (Harding, 2005; Rafi and Staff, 2018). Instead of this, the Whistler–Blackcomb ski resort in Canada has proposed a plan which involves building of snow fences and snowmaking to not just protect but grow the glacier on the summit (Efron, 2005).

Time is an adaptive measure in the event the climate brings about uneconomical snowmaking conditions in the season, which can radically reduce the length of the season. Ski resort capacity can be boosted by increasing lift transport capacity to serve more customers in time. Limiting slope availability to concentrated snow-making machines on a smaller area to increase operation time. Contemporary cost reduction by can be achieved closing selected runs, but not at the price of lower comfort and skier satisfaction (Scott and McBoyle, 2007)

3.9.3 ARTIFICIAL SNOWMAKING

The snowmaking process generates snow and therefore extends the duration of ski season (Marty, 2013). Creation of artificial snow is the key technological measure to compensate for lack of natural snow (Falk and Vanat, 2016) and attract more visitors. The first snow cannon was built in 1950 and patented in 1954 (Pierce, 1954). The process of snowmaking makes a compressed mixture of cold air and water, which is pumped through a compressor and sprayed on trails (Falk and Vanat, 2016). The earliest use of snowmaking gear dates back to 1952 in the Grossinger Resort at Fahnestock (New York, USA), and has become a typical tool to make and maintain snow cover on trails. Billions of dollars have been invested in snowmaking systems to protect and expand ski seasons all over the planet, increasing the range of climatic variability with which ski resorts could cope [11] (Scott and McBoyle, 2007). In the past, snowmaking was initially viewed as an element of luxury in so-called backup strategy of ski resorts. Nowadays it is viewed as a necessary strategy (Marty, 2013).

The large increase of application of snowmaking systems due to climate change raised a wave of questions as to the sustainability of this adaptation strategy. In ski resorts where the main source, i.e. water is secured, snowmaking is feasible by local conditions and climate. The additional costs incurred by extending the use of

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[11] *"In the US, members of the National Ski Areas Association (NSAA) had revenues of over US$3 billion in 2003 (NSAA 2004). In 2003, ski areas in Canada had annual revenues of approximately US$680 million (Statistics Canada 2005). Estimates by Lazard (2002), show the ski industry in Western Europe and Japan have annual revenues of over US$3 billion and US$1.4 billion respectively. In Australia, the ski industry was worth approximately US$94 million in 2000 (KPMG 2000). According to Lazard (2002), Western Europe represents the largest ski market with 54% of the estimated 330 million annual global skier visits, followed by North America (21%), Japan (16%) and Australia (1%)"* (Scott and McBoyle, 2007).

snowmaking technology at higher temperatures near zero Celsius seem to be an uneconomical option (Maloney, 2005) and have raised a negative feedback in public opinion by the use of chemical additives to support the formation of ice particles (Scott and McBoyle, 2007). According to a Swiss study, the average of for artificial snowmaking per kilometer of a trail is 0.6 million US dollars (Elsasser and Bürki, 2002). The potential of snowmaking systems has been raised due to the sensitivity to climatic change. With 30% of a ski resort area covered with artificial snow increased resistance up to 39% related to the number of ski resort visitors in Switzerland (Pons *et al.*, 2017)(Pons *et al.*, 2017).

3.9.4 CLOUD SEEDING

Cloud seeding or weather modification technology was primarily developed for agricultural purposes in order to generate additional precipitations (Scott and McBoyle, 2007). Experiments with cloud seeding have been conducted In the Russian in the last 6O years in an effort to generate artificial precipitations to adverse lack of local precipitation. The modern method of cloud seeding is based on the use of reagents with specific physical and chemical properties. The ice-forming reagents are a mixture of substances causing generation of ice particles in supercooled clouds. The Russian cloud seeding technology uses special aircraft with pyrotechnic generators containing cartridges and blocks; alternatively, ground-based generators are used in France, Spain, Brazil, etc. for cloud seeding. Technically speaking, a reagent is burnt into a vaporized mixture and ejected to the atmosphere by updrafts (see Figure 17) (Korneev, Potapov and Shchukin, 2017)

The experience of the work on cloud seeding in Russia does not suggest any risk of harm to the environment. Long-term works indicated no environmental

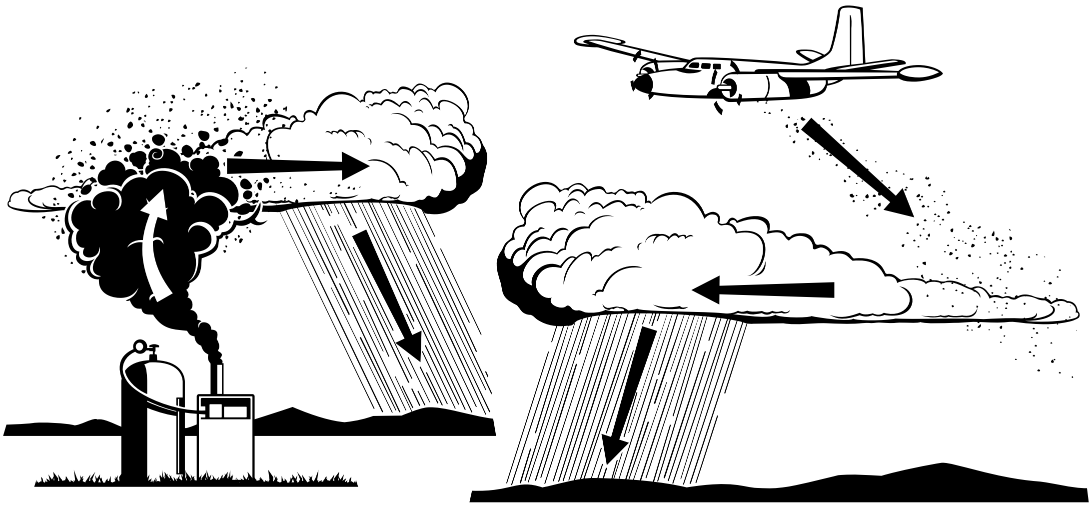

Figure 17. Cloud Seeding
The primer ways of delivery of ice forming reagents delivery to the clouds.
Source: https://upload.wikimedia.org/wikipedia/commons/thumb/4/4c/Cloud_Seeding.svg/1024px-Cloud_Seeding.svg.png

pollution caused by reagent combustion (Korneev, Potapov and Shchukin, 2017). It is assumed that the additional precipitations amount to 10% up to 30%, but, more importantly, there are significant results in diversity of precipitations in adjoining areas (Korneev, Potapov and Shchukin, 2017).

Australia invested 15 million dollars in a five-year project of cloud seeding in order to generate solid precipitation in parts of New South Wales with the result of annual snowfall declination by 1% in the last 50 years (Hennessy et al. 2003). Similar results were obtained by US government studies, which concluded that no convincing result of using cloud seeding technology was reached (National Research Council 2003). Further investigation should therefore be conducted in order to establish the real potential of the cloud seeding technology as an alternative strategy to cope with climate variability, and identify all environmental impacts(Scott and McBoyle, 2007; Korneev, Potapov and Shchukin, 2017).

3.9.5 BUSINESS MODELS

Several models of business practices using different financial strategies to face climate change have been proposed. The main approaches are the following:

- Ski resort fusions in conglomerates
- Off season diversification
- Marketing incentives
- Indoor ski resort/runs
- Visitors adaptation
- Ski industry associations
- Financial sector
- Government assistance
- Climate forecast ??? maybe can be in technological measures!!!!!!!

(Scott and McBoyle, 2007; Rixen *et al.,* 2013)

The management of ski resorts requires multidisciplinary instruments for all the parties involved, i.e. from owners, stakeholders, the general public, accommodation sector to government agencies (Elsasser and Bürki, 2002). Importance between financial viability and snow occurrences are evident due to climate change with poor-snow winters, especially for small scale ski resorts with low investment capital (Pons *et al.*, 2017).

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3.9.6 SKI CONGLOMERATES

A combination of ski resorts in order to secure and support competitiveness has been a standard approach in the last few decades (Scott and McBoyle, 2007). One common option is merging ski resorts together across the valleys with the aim of reducing operational and marketing costs (Marty, 2017). The conglomerates have proved to be one of the most efficient ways of dealing not just with climatic change, but also facing current business trends by sharing technology, equipment and labor. This type of business model provides good access to capital and other resources, and reduces vulnerability to climate change by regional diversification of business operation. Technically speaking, when winter conditions are bad, the impact can be evenly spread on the conglomerate, which has a higher financial resistance than individual ski resorts (Scott and McBoyle, 2007; Rixen *et al*, 2017). One example of conglomerate assistance is from the state of Washington, which suffered a massive decline of numbers of customers, approximately 78% in the season 2001 – 2002 due to warm weather and liquid precipitations. The shared summit of both resorts at Snoqualmie Resort sent many redundant workers to parent ski resorts in order to keep its core base of customers (Goodman, 2005)

Owners or companies operating a single remote ski resort each, mainly small-size and independent enterprises, face a greater risk of climate change and without financial reserves can face bankruptcy (Scott and McBoyle, 2007). Small ski resorts have one option of collaboration, which is more or less new and not so spread in common awareness, called nursing future customers. Basically, the main idea is to share the cost of low-altitude minor ski resorts, usually close to regional cities with high altitude major ski resorts, as a way of providing suitable ski areas for beginner riders, thus for future customers (Rixen, 2017)

Many Czech ski resorts have been entered into collaboration primary with neighboring resorts in order to secure climate resistance and lower operational costs. The largest ones are described at the end of the previous chapter Czech Ski Resorts (Plecháč, 2015).

3.9.7 DIVERSIFICATION

Common adaptation consists in diversified use beyond traditional activities connected with a sufficient depth of snow cover. References describing this trend of transformation of ski resorts into winter theme parks as *Disneyfication*[12] (The Economist, 1998). Several studies confirmed that more than 20% of visitors at some Canadian ski resorts did not engage in any ski activities during their visit; similar patterns were discovered in Switzerland and France (Scott and McBoyle, 2007; Cockerell, 1994; Wickers, 1994). These results indicate that non-skiers constitute an important segment of the market. As a consequence of this discovery, many ski resorts began to funnel their funds into alternative activities for non-skiing tourists. There is a number of alternative winter activities such as: cross-country skiing, ski touring, ice skating, snowmobiling, snow tubing, snow biking (fat bikes), snow hiking (snowshoeing), dog sledge trips, indoor pools and spa, health spa and wellness, fitness centers, indoor sports (tennis, squash and other leisure time activities), restaurants, rentals and retail stores (Elsasser and Bürki, 2002; Scott and McBoyle, 2007; Marty 2017). This is illustrated in Figure 18, done by NSAA for US ski resorts which represent total revenues of ski resorts in the season 1974 – 1975, compared to the season 2001 – 2002. Significant changes were discovered, namely in the amount of money spent in

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[12] Disneyfication or Disneyisation is a term describing commercial transformation of resort or facility based on Western style of rapid globalization of consumerist lifestyle. The name is taken from entertaining parks and resorts established by Walt Disney in the USA.
Source: https://en.wikipedia.org/wiki/Disneyfication

the past for lift tickets which were diverted to other sectors in the season 2001 - 2002 (Scott and McBoyle, 2007).

Revenue sources (%)	1974–1975	2001–2002
Lift tickets	79.4	47.4
Food and beverages	2.8	14.1
Lessons	2.8	9.8
Accommodation/lodging	1.8	9.4
Other	2.1	7.2
Retail	1.5	5.5
Rentals	4.5	5.3
Property operations	5.1	1.2

Figure 18. Total incomes of ski resort comparison
Source: Scott and McBoyle, 2007

Major ski resorts all over the planet have become even more diversified today, thus their business is not anymore just in winter, but covers all four seasons. So-called off-season use offers all kinds of activities, for instance golf, white-water rafting and boating, zorbing, biking (single tracks, mountain biking), paragliding, horseback riding, off-road motorbiking, and many other leisure activities (Elsasser and Bürki, 2002; Scott and McBoyle, 2007; Marty, 2013).

Moreover, all types of diversification can have a disturbing impact on surrounding nature because their implementation is set in previously undisturbed nature environment (Marty, 2013)

3.9.8 MARKETING INITIATIVES

Ski resorts have started a program to prevent the decrease of visitors using some marketing strategies to guarantee adequate seasonal income. One option is booking including advance booking (Scott and McBoyle, 2007). For example, US marketing approach in New England ski resorts promised a cost reduction of 25% in the next vacation season, and in case of failure to open 70% of the area of the ski resorts. The result was to be future compensation for visitors due to unusually warm weather during Christmas period in the season 1999 – 2000 (Keates L, 2000). This strategy becomes more prevalent in the marketing industry and will become the main trend towards shorter timeframes of travel planning, well-known as last-minute booking.

3.9.9 INDOOR SKI SLOPES

Indoor ski centers or domes became an equal option for skiing in regions without suitable conditions to run ski industry. Indoor complexes have been part of ski industry since 1986, when the first indoor commercial trail was opened. The Casablanca dome in Belgium was operated since its opening in 1986 and became a model to follow for more than 50 indoor ski domes, most of them still operating (Casablanca dome is no longer operating in 2019). The majority of ski domes operate in Europe, Japan and currently the largest indoor resort operates in Dubai (Thorne, 2006). The beneficial value of indoor skiing complexes is in encouraging the wide public in urban areas to ski because most of the non-skiing individuals never try to ski because of the distance to the nearest ski resort and can become future customers (Scott and McBoyle, 2007). Last but not least, it should be mentioned that indoor ski resorts are not disturbed by climate change (Thorne, 2006).

3.9.10 BEHAVIORAL PATTERNS

This chapter is devoted to the ski resort visitor and his/her adaptation to the hypothetical impact of climate. Thus, an adaptation of skiers, riders or tourists is important to dimension and has to be largely neglected (Scott and McBoyle, 2007).

Skiers and riders display a wide range of adaptvity to climate change because they can change destinations and timing of their visits. Substitution is another option (Scott and McBoyle, 2007). A survey in Switzerland examined how skiers and riders will respond to hypothetical ski conditions in the future. Five different ski areas were included in the survey whose object how skiers or riders would modify their skiing pattern. They were asked *''Where and how often would you ski if you knew the next five winters (at the survey location) would have very little natural snow? The majority (58%) indicated they would ski with the same frequency (30% at the same resort and 28% at a more snow-reliable resort). Almost one-third (32%) of the respondents indicated they would ski less often and 4% stated they would stop skiing altogether. With more than one-third of the subjects likely to skiing less or quitting, the implications of climate change for skiing demand in Switzerland are potentially significant."* (Scott and McBoyle, 2007; Bürki, 2000).

A similar survey was conducted in Australia at three different ski resorts. The scenario was the same: poor snow conditions for the upcoming five years. 25% of the participants responded they would continue skiing in Australia with the same frequency. 31% of the respondents indicated that they would still ski in Australia, but with less frequency. 38% of the participants responded that they would change their destinations to Canada or New Zealand, and the remaining 6% would stop skiing at all (König, 1998).

According to Scott and McBoyle, lack of projections on the ski industry threat its economic viability (Scott and McBoyle, 2007).

Price regulation and other incentives were applied by some ski resorts in regions affected by the decline of visitors due to climate variability to attract them back (Scott and McBoyle, 2007).

Temporal substitution of visits by skiers or riders provides another interesting explanation for the decline in numbers of visitors. This type of behavioral response can be found when poor winter season occurs and skiers/riders ski with higher frequency because of the shorter period of occasion to ski than in a season of normal length (skiing every weekend instead of every third weekend). This research is focusing on participants who usually prefer weekend skiing and the majority of them live close to ski resorts (Scott and McBoyle, 2007).

Inconclusion, further research should be conducted in order to fully understand the behavioral patterns of ski center visitors to cast some light on the behavioral adaptation of different target groups in the ski industry

3.9.11 SKI INDUSTRY ASSOCIATIONS

Climate change and global warming awareness initiate discussions, which engaged ski resorts in active participation in order to face climate variability. Those steps led to active involvement in greenhouse gases mitigation strategies (Best, 2003). A good example is the US partnership between Natural Resource Defense and NSAA initiative with a program to protect winters 'Keep Winter Cool' in 2003. The main focus is on public participation and awareness and more importantly political lobby engaged by the winter tourism industry and define conservation policy aim on greenhouse gasses mitigation(Charter and Berry, 2000; Scott and McBoyle, 2007; IPCC and IPCC5 WGII, 2014). The ski industry is a very competitive business, for instance, in North America, this cooperation is limited by government interventions, marketing on a regional level, and by competitiveness itself. Moreover, it is far more difficult to create a national adaptation program in the form of financial support of more vulnerable ski resort which plays key roles on regional levels (Scott and McBoyle, 2007).

FINANCIAL SECTORS

The banking sector started to react to climatic change risk and consider climate change in credit threat and has been providing finance assessment. There are several examples from Switzerland, where banks provide very limited loans for low altitude ski resorts (below 1500 m) (Elsasser and Bürki, 2002). The climate impact assessment was released as a bank program in the form of insurance and it has been available to ski industry in case of poor winter compensations. In 1999 – 2000 ski resort in Colorado purchase a package with snow insurance and this season the resort was compensated in the amount of 13.9 million dollars due to low snowfall. But in 2002 bank companies changed their policies and became to charge high premiums as a reaction of high-level risk insurance due to climate variability. Thus, snow insurance will be probably no more provided in a current form in the ski industry (Scott and McBoyle, 2007).

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3.9.12 GOVERNMENT ASSISTANCE

This sub-chapter is dedicated to Government and its role of assistant providing support and benefits like discounted prizes for energy, long-term public land leases, infrastructure grants as a reaction to climate variability. In the future, there might be similar programs similar to agricultural assistance, which has common water-sensitive problems. However, in the future, economic losses from the ski industry can become attract Government attention and possibly bring some state support in important regions (Scott and McBoyle, 2007). Government participation or involvement can be done in several ways. Direct interventions in the form of subsidies, insurance, and marketing initiatives. Indirect in the form of policy related to water use, land use, energy cost, exceptions in consumptions. Results can be positive or negative (in case of incorrect policy). For instance, the Government in Austria provided large subsidies for artificial snowmaking, on the other hand, provide moderate subsidies after poor winters (Wolfsegger, Gössling and Scott, 2008).

3.9.13 CLIMATE FORECAST

Climate forecast is crucial for ski resort adaptation management; improved climate forecast would lead to better risk assessment and give a head start to ski resorts in coping with climate change in terms of timing of opening and application of business strategies. Improvement accuracy of weather forecasts would be a useful tool together with cooperation government and weather forecasts agencies. In some cases, the government weather forecasts are very inaccurate and ski resorts have to use forecasts from neighboring countries or private sector weather forecasts and incur some additional costs (Scott and McBoyle, 2007; King, 2005).

Another issue which can be improved is presentation of weather forecasts in public media. Current weather conditions can be divulged on their websites using real-time cameras. Cooperation with stakeholders and the media to improve snow and weather forecasts will become more and more important in the era of climate variability whereby weather reports are needed to draw adaptation strategies (Scott and McBoyle, 2007).

3.10 ENVIRONMENTAL CHARTER FOR SKI AREAS

The environmental charter was adopted by the American ski industry in 2000 as a framework to endow winter ski industry with a sustainable and environment-friendly low-impact solution for mountain resorts in the United States of America, providing common guidelines to improve environmental performance of the industry worldwide. The National Ski Areas Association (NSAA), which was established in New York in 1962 defined a strategic plan to preserve mountain resorts for future generations (Charter and Berry, 2000).

The key element is collection, analysis and generation of statistical data to present in annual reports.

"The National Ski Areas Association is the trade association for ski area owners and operators. It represents over 300 alpine resorts that account for more than 90 percent of the skier/snowboarder visits nationwide. Additionally, it has more than 400 supplier members who provide equipment, goods and services to the mountain resort industry." (NSAA statement, http://www.nsaa.org/about-us/, 2018)

The charter distinguishes several main values which are linked with alpine or mountain environment. The values relate to the symbiosis of nature and human activities and include all the stakeholders from visitors, employees, operators of ski resorts, and accommodation providers to local people whose life is strongly interconnected with winter industry as well as the natural environment in which the ski resort is set. These values represent the most important principles, which should be adopted for the sake of sustainability are the following:

- A balance between human needs and ecosystem protection.
- Concentration of recreational areas to prevent urban sprawl and prevent dispersion impact in wild remote areas of mountains.
- Cooperation with local stakeholders in order to understand and sustain the diversity of functions and processes in the environment.
- Environment conservation with the main focus on rural areas and wild landscape to preserve scenic cultural and economic values.
- Climate change problems.
- Safety cautions for ski resort visitors.

All those values are set against a certain background which defines the framework to create guidelines for their implementation, which is to be developed further. The following chapters below will be offer a short introduction to each principle, and the way of adopting them presented in a bullet-point list (Charter and Berry, 2000).

3.10.1 PLANNING, DESIGN AND CONSTRUCTIONS

Future impacts can be explored in the basis of data collection and detail analysis . Using sensitivity analysis, we can address past disturbances found by examination of historical issues as well as potential mitigation of unavoidable future disturbances.

Principles:

- Engagement of local communities, environmental agencies, government agencies and other stakeholders in open discussions of the implications of land-use plans and development plans.
- Environmental assessment and potential restoration options on the local and regional scales.
- Regarding nature as an important element in the development of ski resorts.
- Use of smart and low-energy structures, with emphasis on efficient water management and consumption, energy efficiency and clean energy potential.
- High-density development, cluster concentration in order to reduce sprawl, providing alternative transport.
- measures to mitigate impacts caused by the ski resort.

Guidelines for the adoption of the above principles:

- Engagement of all stakeholders in the winter-recreation industry.
- Use of computer analysis and models.
- Respect for nature and review of the threshold of permissible stress on the environment.
- Preservation of tree cover by designing trails with less tree removal.
- Application of sustainable architecture (long-life and low-maintenance materials) based on green building principles.
- Inclusion of parks and open space with low-impact landscape development.
- Maximum use of alternative transport and minimum road building.
- Development storm-water controls.
- Development of sustainable guidelines.

(Charter and Berry, 2000)

3.10.2 WATER RESOURCES FOR SKI RESORT OPERATION

Water is an essential element for the ski industry, in all forms of states: solid precipitation, I,i.e. nowfall covers slope with necessary snow cover, liquid state, i.e. groundwater reserves, and the watershed – in short, what makes artificial snowmaking possible. This chapter tries to answer all the relevant questions and aims at optimization of water consumption of ski resorts. The chapter is divided into four subchapters, to describe all aspects of water resource management.

3.10.2.1 Water use for snowmaking

Principle:

- Reduce energy use or alternatively use clean energy for snowmaking.

Guidelines to adopt this principle:

- Modernization of snowmaking technology.
- Substitution of diesel engines in the snowmaking technology.
- Reduction of water loss by a monitoring system.
- Capture of water within the area to reduce input from the watershed, building of water reservoirs to store water during dry periods.
- Communication with local water suppliers and water basin management to minimize impact on the watershed.
- Installation of a water drainage system to recapture snowmelt.
- Optimization of the snowmaking process based on temperature and air humidity to achieve maximum efficiency in snowmaking and reduce loss.
- Relief modification to direct surface runoff into water bodies which supply snowmaking systems.

3.10.2.2 Water use in facilities

Principle:

- Optimization of water use in ski resorts and attached facilities based on a water conservation policy.

Guidelines to adopt this principle:

- Reduce water consumptions by way of targeted audits conducted by the management of local facilities.
- Reduce water consumption by low-flow equipment in restrooms and bathrooms.
- Education and awareness of the importance of water conservation.

3.10.2.3 Water use in landscaping and off-season activities

Principle:

- Program to minimize water consumption for landscape and off-season activities

Guidelines to adopt the principle:

- Planning and design targeted to maximize efficiency.
- Concept implementation to embrace off-season plans in ski resort planning.
- Use drought-resistant plants.
- Implement irrigation and soil erosion control with technology for recycling or reuse of water.
- Increase water retention and plant vegetation cover able to capture moisture in the soil.
- Water consumption monitoring.

- Irrigation control monitoring to improve efficiency.
- Initiatives to raise public awareness toward conservation in water use .

3.10.2.4 Water quality management

Principle:

- Water conservation policy aimed at strict watershed protection to restore natural water self-cleaning ability.

Guidelines to adopt the principle:

- Target management of erosion control, flood control, sediment control, storm-water control.
- Plant riparian vegetation and enhance formation of natural meanders.
- Filtration and separation of oil/water in facilities.
- Design using environment-friendly materials.
- Public awareness of ethical values of water quality management.

3.10.2.5 Wastewater management

Principle:

- Wastewater management.

Guidelines to adopt the principle:

- Adequate wastewater treatment plant capacity to manage seasonal peaks.
- Use modern technology in wastewater treatment plants.
- Decentralize sanitation and reuse (DASAR) program for facilities and cluster settlements.
- Join septic tanks to the municipal wastewater system.

(Charter and Berry, 2000)

3.10.3 ENERGY CONSERVATION AND CLEAN ENERGY

Ski resorts have an enormous energy demand. Electricity input powers the whole ski resort and adjoint infrastructure. That's the reason why this subchapter is divided into four parts. Technically speaking, everything in a ski resort is powered by electric current, except one department, i.e. trail maintenance and Preparation, which operates with snow groomers. Indeed, old diesel machines leave a massive carbon footprint behind and contribute to pollution released to the atmosphere in Europe. Lower carbon emissions of snow groomers using hybrid engines and renewable energy sources will be a goal for the future. In addition, compliance with the nature conservation policy has to be our priority. Carbon emissions produced by diesel engines negatively contribute to CO^2 pollution and affect climate in the mountains.

Mountains are one of the last "islands" of wild nature in Europe. The remote and hostile mountain environment provides a home for many species. They represent the last uninhabited wilderness where a man was never, and will never be dominant.

3.10.3.1 Energy use for facilities

Principles:

- Reduction of total energy consumption.
- Shift to renewable or alternative clean energy.

Guidelines to adopt the principles:

- Proposal of a new energy plan with short-term and long-term goals.
- Design facing south in order to secure exposure for photovoltaic or solar heating panels, and reduction of indispensable heating and artificial lighting.
- Implementation of geothermal heat pumps.
- Use of lightning control programs.

- On-site distribution of power generators and storage to cope with peak demand.
- Minimize heating by central heating stations.
- Build water and wind power plants and include animal impact assessment.
- Micro-hydro generators
- Educate the visitors by a simple and short campaign.

3.10.3.2 Energy use for snowmaking

Principle:

- Reduce energy or use cleaner energy for snowmaking.

Guidelines to adopt the principle:

- Invest money in new, more efficient technology.
- Snowmaking in night time. Avoid peak demands.
- Design on mountain reservoirs and water transport by gravity.

3.10.3.3 Energy use for lifts

Principles:

- Reduce energy supplying lift operation.
- Shift to renewable or clean energy.

Guidelines to adopt the principles:

- Invest in new technology.
- Adopt renewable energy principles and achieve -independence in energy in the segments of operation.
- Substitute diesel generators with generators based on cleaner energy.
- Purchase green energy to power ski resorts.

3.10.3.4 Energy Use in Transportation

Principles:

- Low emission strategy.
- Engines using biodiesel or hybrid technology.

Guidelines to adopt the principles:

- Shuttle transport for employees and visitors provided by the employer.
- Regular maintenance of the ski resort fleet.

3.10.4 WASTE MANAGEMENT

By waste, we mean used materials with no potential future use. In order to prevent environmental degradation, we need to define waste management. Reduce, reuse and recycle is fine, but far more important is a policy that can prevent or at least minimize the volume of waste generated per capita. According to global estimates as of 2014, an average person generated 2 kilograms of solid waste (Charter and Berry, 2000).

"Globally, waste volumes are increasing quickly – even faster than the rate of urbanization. Similar to rates of urbanization and increases in GDP, rates of MSW[13] *growth are fastest in China, other parts of East Asia, and parts of Eastern Europe and the Middle East. Municipal planners should manage solid waste in as holistic a manner as possible. There is a strong correlation between urban solid waste generation rates*

[13] *MSW* – Municipal Solid Waste

and GHG emissions. This link is likely similar with other urban inputs/ outputs such as waste water and total energy use." (Shawn Burke et al., 2018)

3.10.4.1 Waste Reduction

Principles:

- Reduction of waste generated by ski resort;
- Sorting of waste;
- Waste prevention measures and public awareness about waste disposal and management.

Guidelines to adopt the principles:

- Public awareness.
- Support recycling programs and initiatives.
- Prohibition or limitation of plastics used in certain industries.
- Waste reduction plan.

3.10.4.2 Product Reuse and Recycling

Principles:

- Reuse of disposed product and materials.
- Comprehensive recycling program.
- Minimize the use of potentially hazardous wastes, protect watersheds.

Guidelines to adopt the principles:

- Organic waste composting, food waste collection and composting.
- Make recycling easy.

- Smart distribution of waste containers.
- Install sediment traps into storm-water systems, especially near parking lots.

(Charter and Berry, 2000)

3.10.5 FISH AND WILDLIFE

The ski resort has to operate according to natural principles. Be familiar with nature conservation policy and directly participate in the conservation of nature and life. Include environmental impact assessment on the regional scale which improve broad relations in the ecosystem. Learn about behavioral patterns, changes in routines, migration, adaptation, resistance, threshold resilience of important elements in nature to understand environmental fluctuations. (Miklós, Diviaková and Izakovičová, 2018)

Principles:

- Reduce water pollution right at the source.
- Preserve and protect mountain wildlife.

Guidelines to adopt the principles:

- Contribute to research by active monitoring, mapping the population of endangered species.
- Reduce fragmentation by protecting selected forest patches.
- Zoning, limit access, seal key habitats areas from public access.
- Include wildlife in the planning process.
- Wildlife educational programs for employees, visitors, stakeholders, local community

(Charter and Berry, 2000)

3.10.6 FOREST AND VEGETATION MANAGEMENT

The forest stand had evolved into the most effective form plant habitat; it is the final stage of ecological succession. Plants play vital roles in ecosystems and warrant the survival of life on the planet. Important forest functions include photosynthesis, water treatment ability, stabilization of soil and prevention of all types of erosion, dust control, microclimate generation in a homogeneous forest cover, water retention, storage of moisture in the soil profile, prevention of soil degradation (loss of organic matter content) and reduce of evapotranspiration, source of timber, shelter and sunshade (canopy-cast shadow). Last but not least, forest functions include recreational use (Pilli and Pase, 2018b)

Principle:

- Forest management to improve forest health.

Guidelines to adopt the principle:

- Forest management control.
- Limit access by zoning of forest stands to minimize disturbance of important habitats, biocentres and water resources.
- Management of remove of infested or dead trees.
- Limit disturbance of vegetation mainly in summer season.
- Use different techniques of logging according to accessibility.
- Restore forest cover in disturbed areas, such as brownfields or abandoned forest roads.
- Minimize deforestation. Avoid removing whole trees, cut-off branches or parts of the canopy.
- Support the function of forest cover in the control of greenhouse gasses.
- Signage and traffic controls in sensitive areas.

(Charter and Berry, 2000)

3.10.7 WETLANDS AND RIPARIAN AREAS

Wetlands are a rare type of ecosystem on Earth. They are characterized by the greatest diversity of all ecosystems and provide habitats for many species. Formation of wetlands is strongly influenced by local climate conditions and geomorphological patterns of the area. Their main constitutive element is water and thus each wetland needs to be characterized by quantity and retention time of water in the system. In addition, wetlands are able to transport organic matter and the rest of the material sinks on the floor. The deposit is transformed into inorganic nutrients and carbon.

"Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters."

https://www.britannica.com/science/wetland

Riparian forests maintain the vitality of landscape and watersheds. The term riparian refers to communities living along rivers or streams, other water bodies and wetlands. The riparian zone is defined as the boundary of the terrestrial and aquatic zones. Environmental setting is characterized by floodplain vegetation directly adjacent to water in a watershed (Naiman *et al.*, 2011).

Principle:

- Minimize impact on wetlands and riparian forests and compensate impacts by restoration, mitigation or creation program.

Guidelines to adopt the principle:

- Monitoring program.
- Design snowmaking systems to avoid interference into wetlands and riparian forests.
- Limit access when snow cover decreases, and the risk of human disturbance is inevitable.
- Contribute to restoration, remediation and protection programs.
- Create buffer zones along wetlands and riparian forests, especially in summer.
- Cooperate with local agencies in research on wetlands and riparian forests.

(Charter and Berry, 2000)

3.10.8 AIR QUALITY

Fresh air is a valuable commodity and can be compromised by many on-site and neighborhood sources. Air pollution has a vast impact on climate change, nature, wildlife, human health, and visibility.

Principles:

- Reduce the negative impact on air quality.
- Limit operations causing air pollution and greenhouse gas emissions as much as possible.

Guidelines to adopt the principles:

- Minimize air pollutants and greenhouse gas emissions in all processes in the ski resort.
- Clean energy program.
- Prevent dust emissions from roads in summer.
- Plant support vegetation to capture dust.
- Dust control program (vacuum cleaning and sweeping of roads and parking lots).

- Limit wood and coal burning in households.

(Charter and Berry, 2000)

3.10.9 VISUAL QUALITY

Landscape character has a significant scenic value, especially in mountains. Although ski resorts are part of the visual landscape, they can be built into the landscape with no additional disturbing impact. Visual character should be a matter of protection as a part of the natural heritage.

Principles:

- Build an environmental complex which is a part of the natural surroundings.
- Support alliance with nature and land conservation agencies and local stakeholders, which can result in a protection program including open lands and viewsheds.

Guidelines to adopt the principles:

- Include landscape characteristics in planning and design.
- Reduce ridgeline development if possible.
- Protect open space areas.
- Follow local architecture pattern and set strict design guidelines for constructions.
- Locate design of lifts and buildings sensitively against the natural background and surroundings.
- Construct trails and paths in natural openings.
- Use non-reflective top cover material on constructions.
- Improve visual quality by planting trees another plants.
- Light emission control in order to reduce light pollution.

- Waste collection close to infrastructure and parking lots.
- Design underground infrastructure where feasible to minimize landscape disturbance.

(Charter and Berry, 2000)

3.10.10 TRANSPORTATION

Transportation within the ski area has a significant impact on the area. Traffic congestions and insufficient parking capacity are the main issues, which affect other aspects of the environment (energy use and air quality). Moreover, efficient transport solution can beneficially contribute to overall quality of the ski resort.

Principle:

- Ease congestions and provide transport control.

Guidelines to adopti the principle:

- Provide shuttle transportation for employees, local inhabitants, and visitors, which will improve current traffic situation.
- Promote carpooling and high-level vehicle occupancy .
- Offer discounts on Sunday night sleepovers to promote non-peak traffic.
- High-density development in the base area to reduce the need for car transport.
- Participation in community transit initiatives on the regional scale.
- Cooperation with travel agencies in order to promote car-free visits.

(Charter and Berry, 2000)

3.10.11 EDUCATION AND OUTREACH

Education and public awareness are an important pillar of sustainable development of ski resorts set to the natural environment. The unique advantage is in connection with visitor experience, providing the opportunity to take a role in the leadership of environmental education and engage public environmental awareness of all participants in the ski industry.

Principles:

- Environmental education, awareness program, and initiatives.
- Interconnection of all parties in the ski industry to the benefit of nature environment

Guidelines to adopt the principles:

- Train employees and educate the public about the environment.
- Educate stakeholders on sustainable development of ski areas.
- Engage in climate change initiatives.
- Offer active environmental education and awareness programs including school programs and guided excursions for the public.
- Partnership with local authorities, schools, business, and public initiatives.
- Design proper guidelines for signs. Display interpretive signs for important environmental resources.
- Monitoring and drafting of annual environmental reports.
- Green energy education program for the local community.
- Collect feedback from participants in order to increase the efficiency of the initiative.
- Creation of funding mechanism for sustainable projects on in-house and community scale.

(Charter and Berry, 2000)

3.10.12 CLIMATE CHANGE POLICY

The climate change policy is devised to raise awareness of all potential impacts of climate variability on the ski industry. The program aims at a reduction of greenhouse gas emissions and encouragement of the public at large and companies to contribute to the climate change policy, cooperation toward sustainable solutions for the environment, healthy economy and preservation of life quality. In order to achieve the goals, the following actions should be taken:

- Education on the dependence of winter activities on natural ecosystems. Hypothetical impacts of climate change on the ski industry. A manual for minimization of greenhouse gas release into the atmosphere.
- Raising awareness of policymakers independence of winter activities on natural ecosystems and hypothetical impacts of climate change on the ski industry.
- Legislation and regulations aiming at reduction of greenhouse gas emissions.
- Promotion of scientific solutions to climate variability, active use of renewable energy technology.
- Reduction of overall ski resort emissions and increase of energy efficiency by strategic partnerships with relevant agencies and organizations. Investment in modern machines and equipment to increase the efficiency of ski resort operation.

(Charter and Berry, 2000)

4 CHARACTERISTICS OF THE STUDY AREA

4.1 KRKONOŠE TOURISTIC REGION

Krkonoše touristic region was selected from geographical reasons. The region overlaps study area of selected metrological stations and incorporate all touristic destinations in this area.

The current form of the economy of the Krkonoše region is influenced by the industrial tradition of the region. Development of tourism since 1950 and after 1989 with market transformation significantly influences the structure of the local economy and its labor market links region traditional industry (mainly textile, woodworking, engineering, and electrical industries). A new spark for developing economy after 1989 was expanded to include tourism development (especially in the 1990s). foreign investment into regional centers (e.g. in automotive, engineering, electrical and food industries (SPF Group, 2012)

There are 65 municipalities in the area, with a total area of 1183.37 km². In 2011, 106,457 inhabitants lived in this area. Population density reaches 89.96 inhabitants / km², which is below average both in comparison with the national average of 133 inhabitants / km² and the averages of both regions (Královéhradecký 116.76 inhabitants / km², Liberecký 138.87 inhabitants / km²). The lower population density is caused by the historical development of the settlement of mountain areas of the Czech Republic and by physical-geographical conditions, as it is a territory with a very complex terrain, which limits the development of the settlement. The large area of this region is a part of National Park, with different level of protection (SPF Group, 2012)

4.2 NATURAL PARK

The Krkonoše National Park was declared on 17 May 1963. At the same time, it was decided to split the park into three zones - strict natural, controlled natural and marginal. In the first zone of the national park there is no entry outside the marked paths. In the second and third zones, visitors can walk freely in the meadows and forests. The original territory of the National Park was reduced in 1991 from 385 km^2 to the current 363.27 km^2. The borders of KRNAP have moved further into the mountains and the built-up areas of most municipalities have been removed from the National Park of Krkonoše. The buildup area has been transferred under protection zone where protection is similar to the protection of Protected Landscape Area. In 1992, both national parks on the Czech and Polish sides were included in the UNESCO Biosphere Reserve Network. In the area of the National Park of Krkonoše there are peat bogs, which are included in the list of world important wetlands according to the Ramsar Convention.

4.3 CLIMATE CHARACTERISTICS

4.3.1 CLIMATE IN CZECH REPUBLIC

The current trend of climate change is the most important factor influencing the environment. Snow cover is very important in mountain areas, where the ski industry is mainly located. All fluctuations in the depth and duration of snow cover can cause long-term impacts on the environment and economy (Urban *et al.*, 2019). Global air temperature increased in the 20th century and the beginning of the 21st century as a consequence of the global reduction of the cryosphere in lowlands and mountain regions (IPCC and IPCC5 WGII, 2014).

Forecast for the Czech Republic till 2030. Simulations till 2030 are show a rising trend in average temperature. The average annual temperature will increase by

1°C according to Aladin-Climate/CZ model. In summer, a moderate increase is expected in the occurrence of tropical days and tropical nights. in winter, on the contrary, we can expect a decrease in the occurrence of frost, ice and arctic days. Precipitation model is somewhat difficult to interpret, but it shows more or less a decrease in future winter precipitations (up to 20% in some areas). Spring precipitation will moderately increase in an interval of approximately 2% to 16% in some areas. Autumn and summer offer various precipitation forecasts and differ across the Czech territory. In autumn, some zones will witness a moderate decrease by a few percentage points, whilst other areas will record an increase by up to 26%. Summer trend will be moderately downward. However, some areas will register an increase by up to 10%. The variety should be attributed to the geomorphological diversity of the Czech territory (EU, 2012) forecast till 2050 suggests more negative trends. The major upward trend will be in air temperature, showing high values especially in summer. Summer temperature rise is estimated to be 2.7°C on average, whilst winter temperature should increase by 1.8°C on average. Crucial differences in the Czech Republic will be registered in summer period: for example, average temperature in August will increase in by up to 3,9°C. Changes of average temperatures will range from 2.3°C to 3.2°C in summer and spring, 1.7°C to 2.1°C in autumn, and 1.5°C to 2.0°C in winter. A decline of precipitations namely in winter is already noticeable in Krkonoše, Českomoravská Vrchovina, and Beskydy, where it is calculated in some mountainous parts to be up to 20%. Total future winter precipitations will decrease, but in comparison with the 2030 model, the decrease will be smaller and less significant. Summer decline will be dominant and bring a lot of heat waves and negatively influence the nature and human health. Autumn precipitations will moderately increase. All the findings expect future air temperature increase and an overall drop of annual precipitation (EU, 2012).

The findings more or less predict future climate change, an outline of climate variation for ski resorts would need more specific data about future snow cover in the Czech Republic. In addition, we need to contemplate annual temperature in the Czech Republic. Average annual temperature for the year 2018 was calculated to be 9.6°C; for more detail for each month, see Figure 22 (source: ČHMÚ).

Kraj		Měsíc												Rok
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
Česká republika	T	1,8	-3,5	0,8	12,7	16,2	17,5	19,7	20,6	14,5	10,0	4,3	1,2	9,6
	N	-2,8	-1,1	2,5	7,3	12,3	15,5	16,9	16,4	12,8	8,0	2,7	-1,0	7,5
	O	4,6	-2,4	-1,7	5,4	3,9	2,0	2,8	4,2	1,7	2,0	1,6	2,2	2,1

Figure 19. Annual average temperature for Czech Republic in 2018
T – temperature, N - long-term normal air temperature 1961-1990 [° C], O - deviation from normal [° C]
Source: ***http://portal.chmi.cz/historicka-data/pocasi/uzemni-teploty#***

Snow cover trend in the Czech Republic is continuously downward. Research conducted in 2008 shows a decreasing trend based on collected data for the period 1961 – 2005, especially in December, January and March. The total decrease of days with snow cover is mainly due to the increase of air temperature and the amount of liquid precipitations in winter periods. Analyzing the data, we identified four extraordinary winters. Central Europe recorded a large quantity of snowfall in winter 2005 – 2006, mainly at medium altitudes. The 1969 – 1970 and 1962 – 1963 winters were remarkable by for the number of days with snow cover. On the contrary, winter 2006 – 2007 brought an extremely warm weather, which was lower than any winter recorded from 1961 (Brázdil *et al.*, 2008)

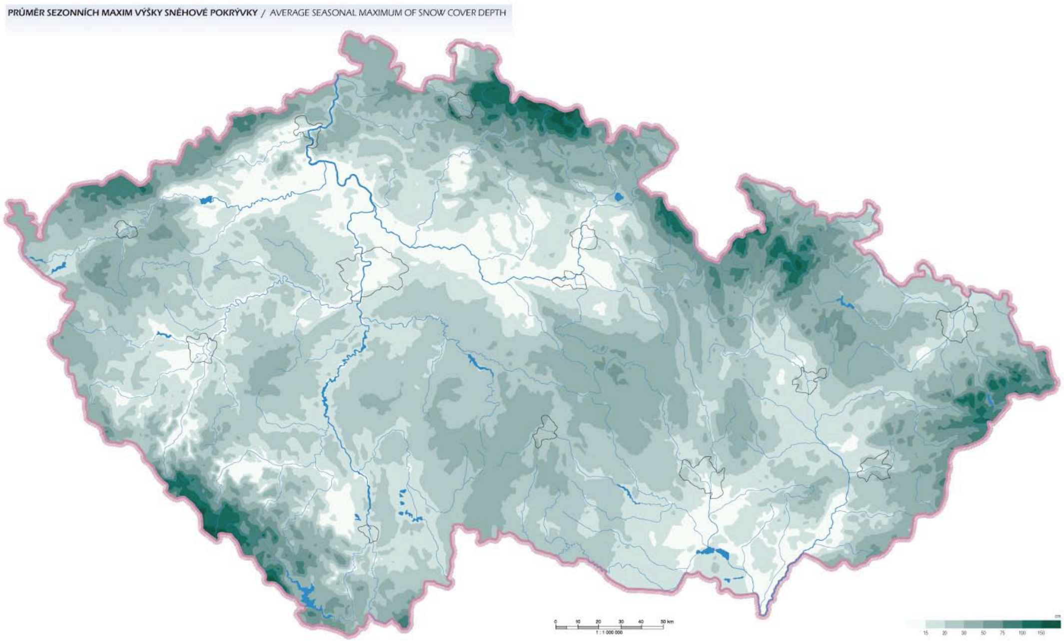

Figure 20. Average Seasonal maximum of snow cover depth
Source: Vystoupil et al., 2006)

4.3.2 CLIMATE IN KRKONOŠE

The Krkonoše Mountains are the highest Hercynian mountain range in central Europe, this results in high rain and snowfall and low temperatures. Therefore, the climate of the Krkonoše Mountains is damper, cooler and rougher than in the Tatra Mountains or in the Šumava and has a distinctly oceanic character. In addition to the significant change of seasons, the weather in the Krkonoše is characterized by its strong variability in short periods of time (KRNAP, 2019).

The description of climate in the Krkonoše is a challenging task. On the one hand, there is lack of research publications on the subject, on the other hand, there are many types of research studies, but rather dedicated to climate variability. The main focus of modern elementary research in climatology is on trend forecasting. The forecasted trend is based on climatic variability and analysis of historical data on winter severity, snowiness and snow cover duration (Foster, Owe and Rango, 2002; Urban *et al.*, 2017, 2019). Any projected fluctuations in snow cover depth and duration can have long-term impacts on the environment and economy (Beniston, Keller and Goyette, 2003).

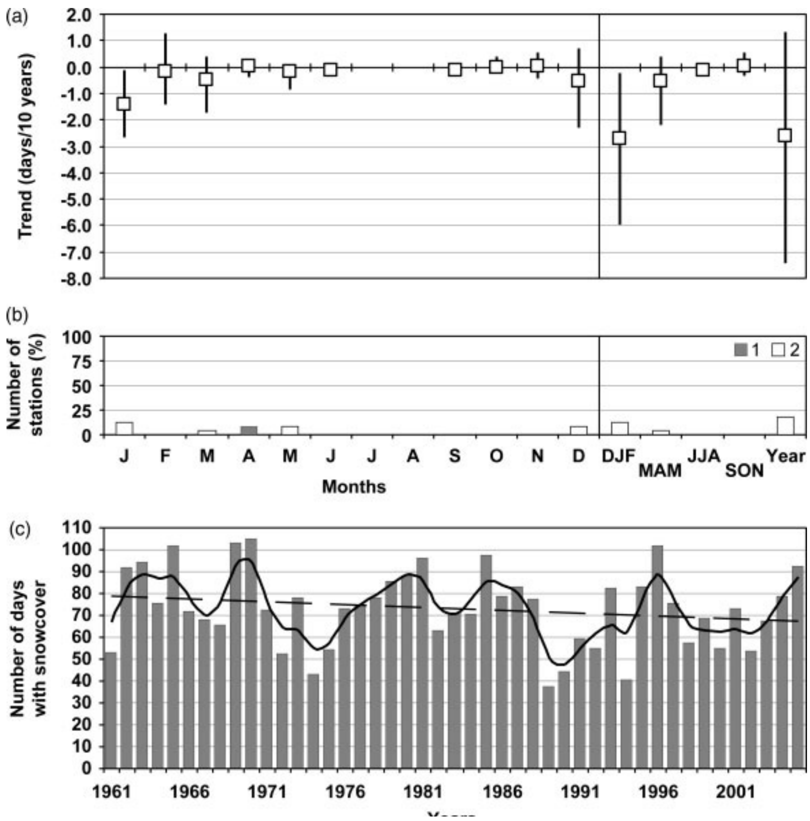

Figure 21. (a) Mean and extreme values of linear trends in number of days with snow cover (days/10 years) at 23 climatological stations in the Czech Republic over the period 1961–2005 for months, seasons, and the year; (b) percentage shares of the number of stations at which the corresponding trend (1 – positive, 2 – negative) was statistically significant; (c) fluctuation of the mean annual number of days with snow cover in the Czech Republic over the period 1961–2005. Smoothed by Gaussian filter over 5 years; dashes indicate linear trend Source: Brázdil et al., 2008

4.4 DAYS WITH SNOW PRECIPITATIONS

The number of days with a new snow height of at least 5 cm occurs 20 times more often in mountainous locations than in the lowlands, the same applies to snowfall of at least 10 cm. A depth of new snow of at least 20 cm occurs exceptionally in the lowlands and became to be considered an extreme event. On contrary maps of mountain areas illustrates the influence of elevation on snowfall occurrence. Climate of mountains plays a vital role for snow cover durability, snow cover depth and total depths of new snow. On contrary lower altitudes are presently covered with snow cover depth higher than 10 cm in rare occasions. In addition, the frequency of extreme snow cases is higher at the beginning and end of the season than in January (Němec and Zusková, 2005; Tolasz *et al.*, 2007)

The seasonal sum of the new snow is a characteristic that has not yet been given more attention While in lowland snow-poor conditions, does not exceed depth of 30 cm, in mountainous areas it exceeds 300 cm and in the highest positions even 550 cm of total sum of annual snowfall. In the lowest positions, the highest monthly sum in January, 10 cm, the mountains are again all four winter months, December to March is moreover in balanced with monthly sums over 50 cm, total in December, January and February is reaching to 100cm. The average of the first and last snowfall in the season was adjusted to observations at the stations without modification. Especially the first snowfall in the season is not only an important event for observers (HMÚ, 1958; Němec and Zusková, 2005; Tolasz *et al.*, 2007).

4.5 METEOROLOGICAL STATIONS DESCRIPTION

Twenty-three stations[14] contribute to our study with snow results. The list of stations with altitude:

- P2BENE01 – Benecko
- P2DESN1 – Desná
- P2HARR1 – Harrachov
- P2JDUL1 – Josefův Důl, Rudolfov
- P2JILE1 – Jílemnice
- P2KORE1 – Kořenov
- P2LOMN1 – Lomnice nad Popelkou
- P2MISE1 – Horní Mísečky, Vítkovice
- P2NPAK1 – Nová Paka
- P2ROKY1 – Rokytnice nad Jizerou, Vilémov
- P2ROPR1 – Roprochtice
- P2SMRZ1 – Smržovka
- P2VYSK1 – Vysoké nad Jizerou
- H1CDUL – Černý Důl
- H1HMAR1 – Horní Maršov
- H1HOST1 – Hostinné
- H1JANL1 – Jásnké Lázně
- H1LBOUD1 – Labská Bouda
- H1LUCB1- Luční Bouda

[14] A detailed list of all the stations is attached in the appendices.

- H1PECS1 – Pec pod Sněžkou
- H1VRCH1 – Vrchlabí

And auxiliary station Vrbatova Chata (no ID)

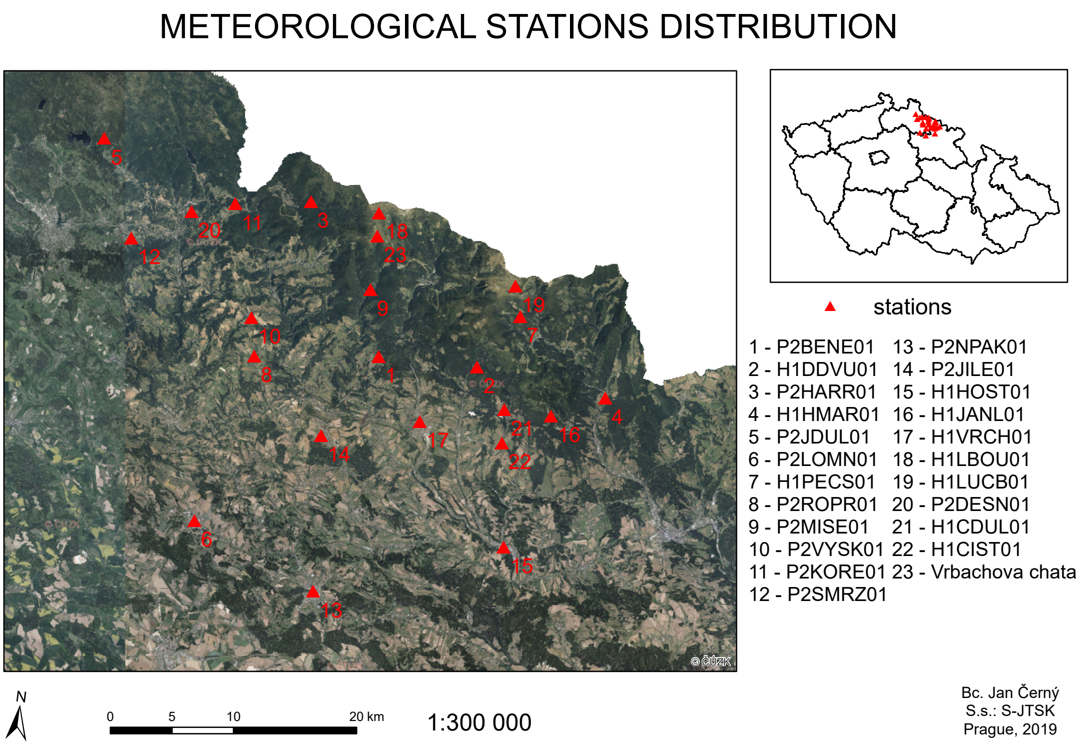

Figure 22. Meteorological stations distribution

5 METHODOLOGY

5.1 SNOW RECORDING

As a day of snowfall, we refer to the day in which there were air collisions in the form of snow precipitations (snowflakes or pellets), ice pellets, sleet, and mixed precipitations. Snow precipitation types recording examine visibility and increment of snow cover depth. Snow cover is recorded in centimeters on snow-capped battens. The main conditions for selecting a location that should be located on the site of the weather station are the natural friendly factors. A suitable place should have the characteristics of the local snow cover and should be placed in the leeward. In places with uneven, unstable or insufficient snow cover, the results are determined by means of an average of at least 3 snow stakes. Snow cover is stated as a sufficient snow layer of height more than 1 cm and covers more than half of the area defined for measuring. If these conditions are not met, this layer is referred to as a broken snow cover (HMÚ, 1958; Němec and Zusková, 2005; Tolasz *et al.*, 2007).

5.1.1 DATA COLLECTION

Twenty tree stations were selected from Krkonoše region which had an uninterrupted or almost continuous series of snow recording data (data were taken from the *CLIDATA*[15] database). The season was set for the beginning of July to the end of June of the following year. Excel sheets for three basic snow cover characteristics have been compiled for the overall assessment: seasonal total depths of new snow, seasonal number of days with snow cover, and seasonal maximum of snow cover depth. Some missing data in digital database were obtained in *ČHMÚ*[16] archives from *Ovzdušné srážky na území Československé republiky* (Atmospheric Precipitations Yearbook of Czechoslovakia Republic) (HMÚ, 1961-1978) in the time period from 1961 to 1978. Data of annual values of two characteristic were taken from yearbooks: number of days with snow cover and maximum height of snow cover. Unfortunately, data on the total depths of new snow was not included in yearbooks. The mean value of snow records was calculated for the whole Krkonoše, for stations below 649 m, for stations in altitude 650-999 m, and finally for summit stations above 1000 m.

5.1.2 DATA PROCESSING

First, the data series that recorded monthly snow records were set chronologically in order and missing time intervals were mapped carefully. For comparison of datasets, we used correlations. Station groups were determined for correlation of data series according to the several criteria. The altitude, the distance between stations, the similarity of data series. Last but not least, it is necessary to add that the data were interpolated based on measurements from neighboring stations

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[15] *CLIDATA* is digital climatic database of ČHMÚ.

[16] *ČHMÚ* - Czech Hydrometeorological Institution

(no averaging of previous years was used in interpolations). According to the criteria, we divided the stations into 5 main groups with subgroups:

- Group 1: P2BENE1, H1CDUL1, H1DDVUR1, H1HMAR1, H1JANL1
- Group 2: P2JILE1, P2NPAK1, H1CIST1, H1HOST1, H1VRCH1, H1LOMN1
- Group 3: P2VYSK1, P2ROPR1, P2SMRZ1, P2JDUL1
    - Group 3a: P2VYSK1, P2ROPR1
    - Group 3b: P2SMRZ1, P2JDUL1
- Group 4: P2DESN1, P2KORE1
- Group 5: P2HARR1, P2ROKY1, P2MISE1, H1PECS1, H1LBOU1, H1LUCB1
    - Group 5a: P2HARR1, P2ROKY1, H1PECS1
    - Group 5b: H1LBOU1, H1LUCB1, P2MISE1

5.1.2.1 GROUP 1

Missing values were determined using average values from all stations in the group. The resulting correlation coefficient between the values of P2BENE1, H1DDVUR1, H1HMAR1 stations did not exceed sufficient value (0.90), so the missing values of the mentioned stations were preferably supplemented from the averages of the measured values from the stations H1CDUL1, H1JANL0.

5.1.2.2 GROUP 2

The measured values at all stations were almost identical based on calculated correlation coefficients. Thus, missing data was supplemented by average values from all stations in this group.

5.1.2.3 GROUP 3

In group 3, we complete missing values primary from stations in subgroups. Where it was not possible to use a station in subgroup, we took data from Group 3.

5.1.2.4 GROUP 4

Missing measurements were taken from the second station in the group. Missing month records in both stations were supplemented from the auxiliary station P2ROPR1, based on data series similarity and high correlation coefficient.

5.1.2.5 GROUP 5

Firstly, we complete the values of the stations from the subgroup (5a). The values were taken from associated station in subgroup. Then we began to complete second subgroup. Values that were missing from all subgroup 5b stations were taken from maximum values of all stations in Group 5. (therefore, the subgroup 5b is summit group of meteorological station, it was assumed that the missing values would reach maximum values in range of interval).

5.1.3 ANNUAL AVERAGES OF SNOW RECORDS

To illustrate the data results, it was necessary to group the monthly snow data into annual reports, then the data taken from the ČHMÚ archive from annual reports could be used to complete missing records. Seasonal total depths of snow cover from Group 5b for stations H1LBOU1, H1LUCB1 and H1MISE1 were not included in yearbooks and were excluded from the final comparison. This was reflected in the resulting graphs, which do not show the following time interval between 1961 and 1978 for seasonal snow. Measured values from subgroup 5b. stations can be added from Group 5 stations, but the homogeneity of the resulting data series would be compromised. In the case of the length of the permanent snow cover and the maximum snow cover height, we used the data from the archive to complete the annual totals. To achieve more accurate results, we use data from temporary station Vrbatova Chata, which recorded snow data in the period 1964-1975 and significantly influenced the results in this period for subgroup 5b.

5.2 CHARTS

The results of the processed data methods are illustrated by charts. For the Krkonoše, the individual snow records and area averages were determined: seasonal total depths of new snow; seasonal days with snow cover; seasonal maximum of snow cover depth. The results were further subdivided into three altitude groups to best illustrate altitude dependence and snowfall. The first group included stations with altitudes up to 649 meters above sea level and contained 12 stations. The second group at an altitude of 650-999 m contained 8 stations. There were 3 stations in the summit station over 1000 meters above sea level.

- 356-649m: P2ROPR1, P2SMRZ1, P2JDUL1, H1CDUL1, H1DDVUR1, H1HMAR1, P2JILE1, P2NPAK1, H1HOST1, H1VRCH1, H1LOMN1, H1CIST1

- 650-999m: P2BENE1, H1CDUL1, H1JANL1, P2DESN1, P2VYSK1, P2KORE1, P2HARR1, H1PECS1,

- 1000-1413m: H1LBOU1, H1LUCB1, P2MISE1

For stations where it was not possible to interpolate data in some seasons from neighbor station or station with similar snow records, due to area long-term snow recording failure, we exclude those years from final charts. The following years could not be included in the calculated average for stations:

Seasonal New Snow Totals: (1961-1978) - H1LBOU1, H1LUCB1, P2MISE1

5.3 MISSING DATA

The discrepancy of the data series has brought many problems in the methodological part of the work. Missing records of meteorological stations were mainly due to a volatile situation and changing political situation in the territory of the present territory of the Czech Republic. Between 1939 and 1945 there was almost no measurement, due to the German occupation. The post-war period also did not bring many continuous measurements of snowfall. Since 1961 the situation has stabilized. The local belt along border used to be part of the Sudetenland. The whole history of measurements in the Sudetenland was problematic due to political changes which influenced frequent changes between Czech and German settlements (Slezák, 1978).

5.4 DESCRIPTIVE STATISTIC IN EXCEL

5.4.1 ARITHMETIC MEAN

Average or arithmetic mean is calculated by a total of numbers and then divided by the final count of group values.

$$\bar{x} = (x_1 + x_2 + \ldots \ldots x_n) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where $\bar{x}$ is arithmetic mean, x is observed value from sample, $\sum$ is sum of values, n is for final count of all values in arithmetic mean equation and $i = 1$

5.4.2 MODE

Mode is most frequent value from selected interval (MS Office, 2019).

5.4.3 MEDIAN

Median is a middle number from interval, middle can interpret as geometrical center of mass for one or two values with highest distance from center to the edge of interval. It very depends on values distribution; the median can be very often overbalanced in range of values (MS Office, 2019).

5.4.4 SUM FUNCTION

Summation function is total count of all values.

$$\sum_{i=1}^{n} i = \frac{n(n+1)}{2}$$

where $\sum$ is sum of values, x is observed value from sample, n is for final count of all values in arithmetic mean equation and $i = 1$

(MS Office, 2019)

5.4.5 MINIMUM AND MAXIMUM FUNCTION

Function max selects the largest or lowest value from the interval of values (MS Office, 2019)

5.4.6 CORRELATION AND CORRELATION COEFFICIENT

Correlation analysis deals with the rate of dependence on random data. The standard output of the correlation analysis is the coefficient describing the degree of dependence – most often the correlation coefficient. Correlation coefficients serve as a measure of the expression of “tightness of linear bond”. Correlation analysis describes linear relations between records (Milde, 2012).

Correlation equation:

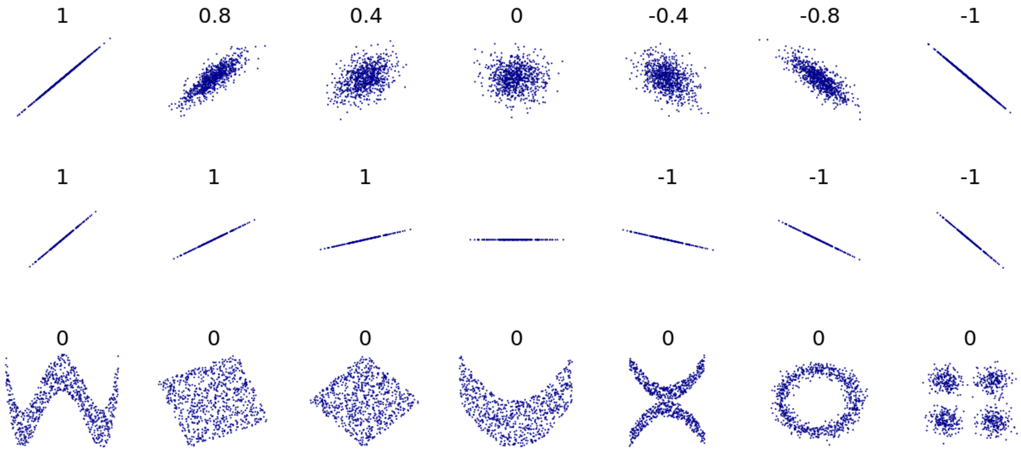

Figure 23. Correlation coefficient
There are some examples of graphical data representation and their correlation coefficients with y = x
Source: https://upload.wikimedia.org/wikipedia/commons/thumb/d/d4/Correlation_examples2.svg/460px-Correlation_examples2.svg.png

$$r = \frac{\sum(x - \bar{x}) \times (y - \bar{y})}{\sqrt{\sum(x - \bar{x}) \times (y - \bar{y})}}$$

where r is correlation coefficient, $\bar{x}$ is arithmetic mean, x_i are observed values from sample, $\sum$ is sum of values, n is for final count of all values in arithmetic mean equation and $i = 1$

(MS Office, 2019)

5.4.7 STANDARD DEVIATION

Is used to quantify the amount of variation or dispersion of a data set values. Deviation indicates that the values are spread out over an interval of values.

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N - 1}}$$

where s is standard deviation, $\bar{x}$ is arithmetic mean, x_i are observed values from sample, $\sum$ is sum of values, N is for final count of all values in arithmetic mean equation and $i = 1$

(MS Office, 2019)

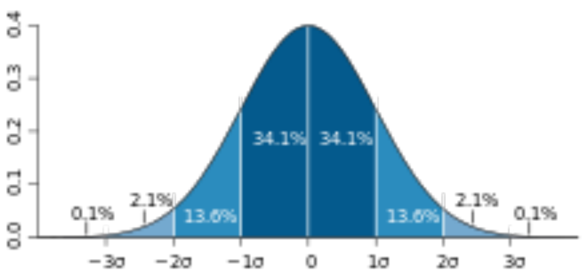

Figure 24. Normal distribution
Each belt of distribution width is equal to value of standard deviation.
Source: https://upload.wikimedia.org/wikipedia/commons/thumb/8/8c/Standard_deviation_diagram.svg/1280px-Standard_deviation_diagram.svg.png

5.4.8 VARIANCE COEFFICIENT

Estimates variance based on a sample (ignores logical values and text in the sample).

$$\frac{\sum(x-\bar{x})^2}{(n-1)}$$

where: r is correlation coefficient, $\bar{x}$ is for arithmetic mean, x_i are observed values from sample, $\sum$ is sum of values, n is for final count of all values in arithmetic mean equation and $i = 1$

(MS Office, 2019)

5.4.9 KURTOSIS AND SKEWNESS COEFFICIENT

Kurtosis and skewness coefficient describing non-normal distribution of dataset values

Kurtosis coefficient:

$$\left[\frac{n(n+1)}{(n-1)(n-2)(n-3)} \times \sum\left(\frac{x_i-\bar{x}}{s}\right)^4\right] - \frac{3(n-1)^2}{(n-2)(n-3)}$$

Skewness coefficient:

$$\frac{n}{(n-1)(n-2)} \times \sum\left(\frac{x_i-\bar{x}}{s}\right)^3$$

where: s is kurtosis and skewness coefficient, $\bar{x}$ is arithmetic mean, x_i are observed values from sample, $\sum$ is sum of values, n is for final count of all values in arithmetic mean equation and $i = 1$

(MS Office, 2019)

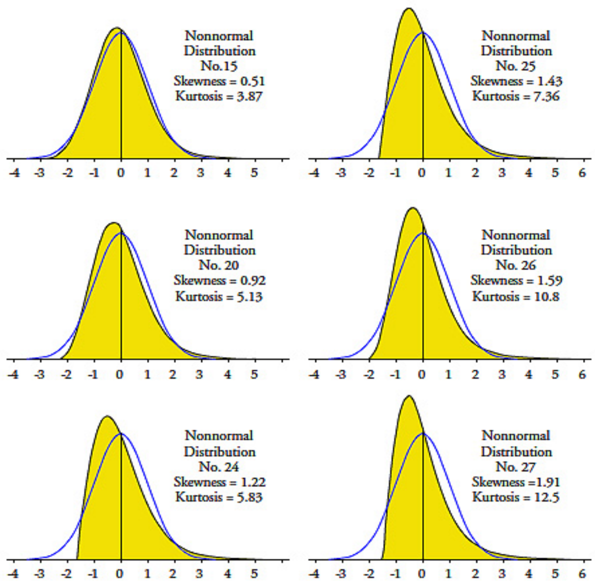

Figure 25 Kurtosis and Skewness distribution
Source: https://www.qualitydigest.com/IQedit/Images/Articles_and_Columns/2015/Feb_2015/Wheeler-Feb/fig-1.jpg

5.4.10 LINEAR TREND FUNCTION

Linear trend function returns values along a linear trend. It is fitting a straight line (using the process of least squares).

$$f_{(x)} = ax + b$$

where: a, b are calculated parameters and x is a observed value

(MS Office, 2019)

6 THESIS RESULTS

Initially, we compared the results within the groups. We discovered certain dependencies between measured snow records. First was discovered linear dependence in the measurement values and the altitude of the weather stations. This knowledge positively influenced the linear trend and has shown that snowfall increases with altitude. Most of the stations recorded depletion in the majority of the records except one – particular growth in the trend was recorded by H1LBOU01, H1LUCB01, P2MISE01 in the number of days with snow cover for altitude interval 1000-1420 m. This upward trend could be theoretically affected by interpolated values.

Another result of the analysis was the effect of snow precipitations on the maximum height and duration of snow cover. Based on the fact that snow cover is the result of snowfall, snow cover is directly dependent on local climatic conditions. The final summary of results of snow variables is:

- Descending trend in majority of snow variables
- Ascending trend in number of days with snow cover for stations in altitude 1000-1420 m
- Highest descending trend in seasonal average maximum height of snow cover
- Lowest descending trend in seasonal average of total depth of snow without summit stations
- A cycle of several seasons with average snow variables ,followed by a very poor snow season.

Last but not least, we have to state that the final results of snow records averages are affected by ununiform distribution of stations at individual altitude intervals. According to the observations and data collection, we can state that the snow precipitation could come in every month of the year.

6.1 AVERAGE RESULTS FOR SNOW RECORDS

6.1.1 SEASONAL TOTAL DEPTHS OF NEW SNOW

Seasonal total depths of new snow – slight Decrease in Linear Trend (R2 = 0.014)

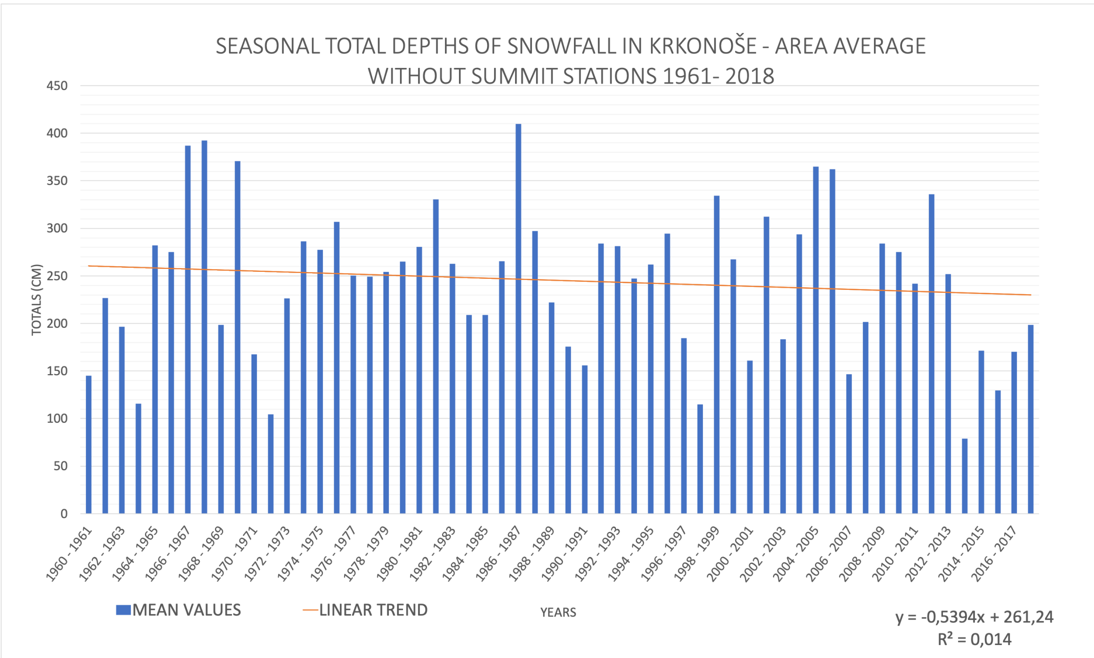

Figure 26. Seasonal total depths of new snow – area average in Krkonoše

The seasonal total depths of the new snow – area average are characters by a slight decrease in the trend (R2 = 0.014). The effect on the trend has absence of medium values, which prevailed in the second half of the time interval. Another result of observation is high concentration of extreme minimum and maximum in the second half of the time interval.

6.1.2 SEASONAL NUMBER OF DAYS WITH SNOW COVER

Seasonal number of days with snow cover - slight decrease in linear trend (R2 = 0.0354)

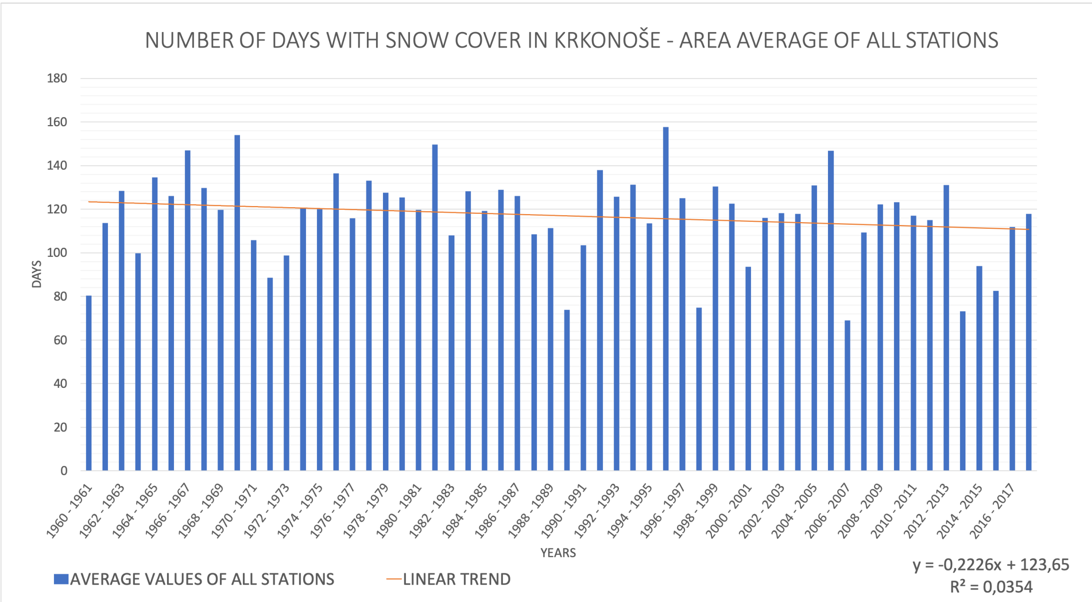

Figure 27. Seasonal days with snow cover – area average in Krkonoše

The seasonal maximums of snow cover depth – area average are characters by a slight decrease in a trend. The occurrence of minimum prevails in the second half of the time interval.

6.1.3 SEASONAL MAXIMUM OF SNOW COVER DEPTH

Seasonal maximum of snow cover depth - decrease of linear trend (R2 = 0.0402)

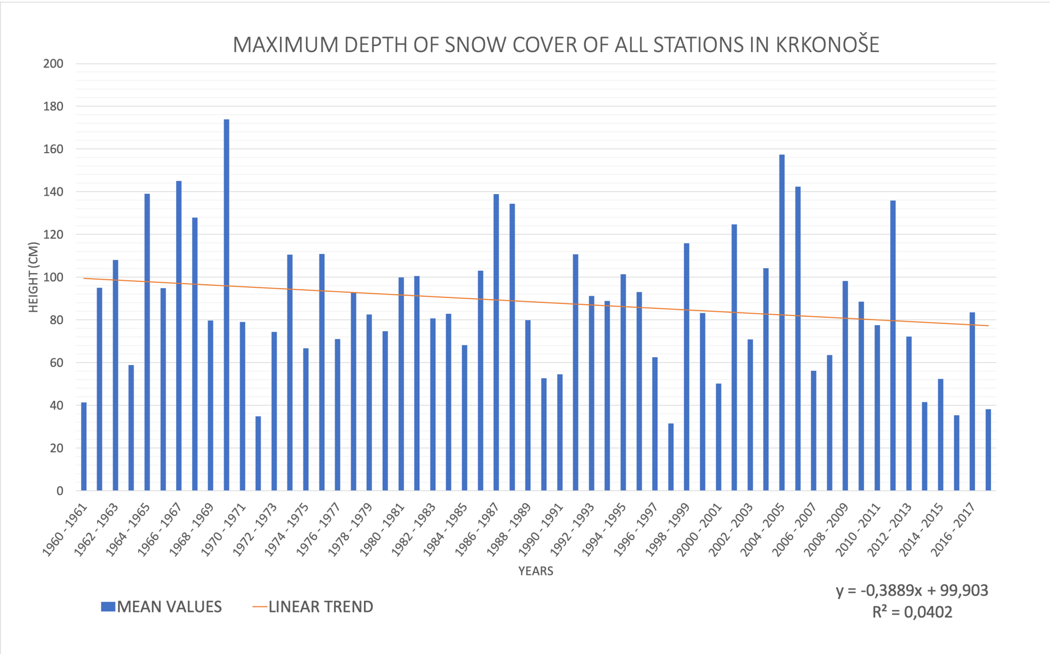

Figure 28. Seasonal maximum of snow cover depth – area average in Krkonoše

The seasonal maximum of snow cover depth – area average characters by a decrease of the trend. The main weight on trend cause concentration of minimum in the second half of the interval. The occurrence of maximum is equally spread within the time interval.

6.2 SEASONAL TOTAL DEPTHS OF NEW SNOW

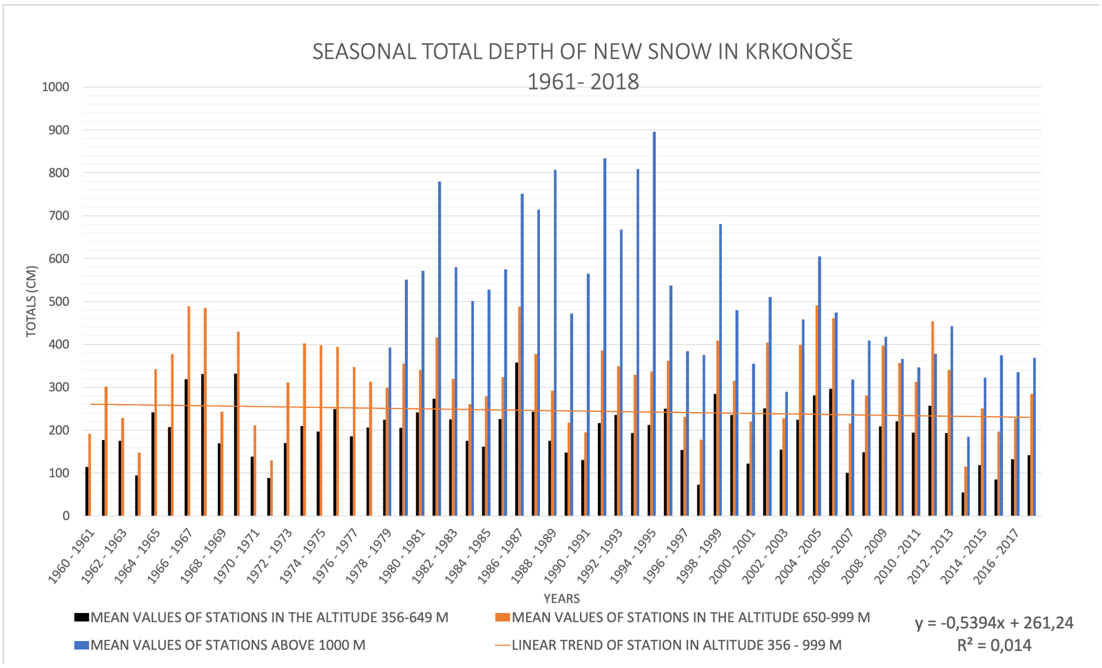

Figure 29. Total depths of new snow – comparison of altitude divisions in Krkonoše

- The seasonal totals of the new snow for the altitude of 356-649 m are characterize by a slight decrease in the trend (R2 = 0.0321). The effect on the trend was the occurrence of mean measurements, which prevailed in the first half of the time interval.
- The seasonal total of new snow for 650-999 m characterizes a constant trend, or its absence (R2 = 0.0024). The only result of the observation is absence of medium values in the second half of time interval and high concentration of extreme values in consecutive seasons is the second half of the large variance in the amount of snow in each season.

- The seasonal totals of new snow for altitudes of 1000–1420 m characters by the highest decline in the trend between 1979–2018 (R2 = 0.3629). This was a consequence of the total decrease of snowfall in the period 1997-2018.

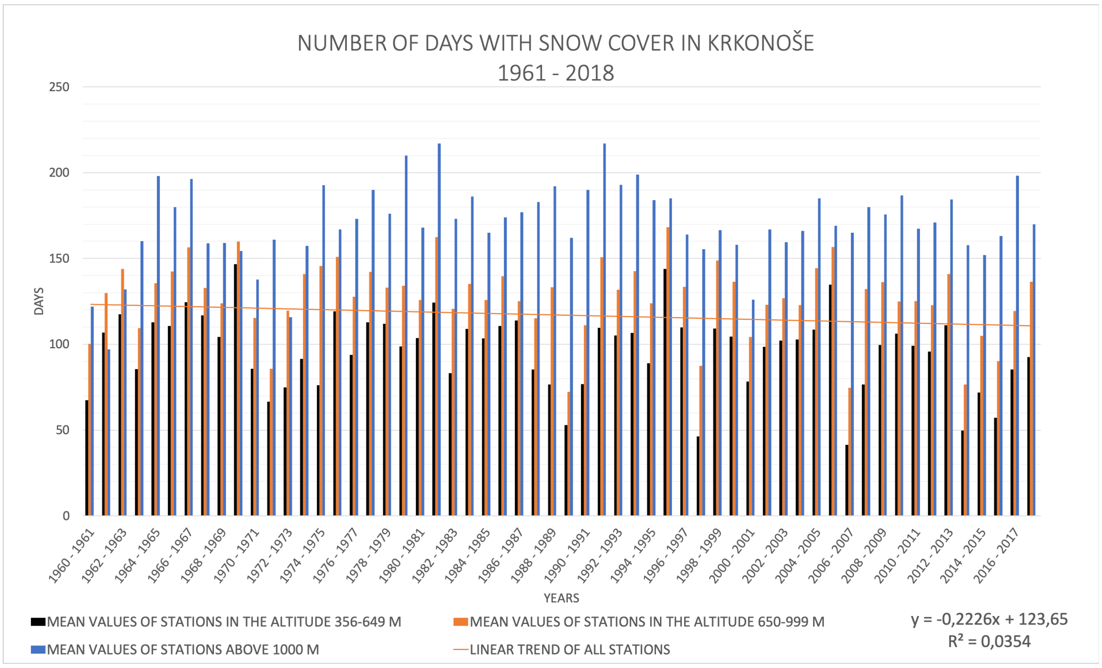

Figure 30. Seasonal number of days with snow cover - comparison of altitude divisions in Krkonoše

6.3 SEASONAL NUMBER OF DAYS WITH SNOW COVER

- The seasonal number of days with snow cover for the altitude of 356-649 m characterizes a decrease in trend (R2 = 0.0556). We may notice an overall decline, even in years where snow cover was at its peak. The occurrence of abnormal short days with snow cover occurred with the highest concentration over the last 30 years, which greatly affected the trend for snow at lower altitudes.

- Seasonal number of days with cover days for 650-999m characterizes a slight downward trend (R2 = 0.0388). The declining trend was largely influenced by the high seasonal concentration of abnormally low snow cover in the period 1990–2018.
- The seasonal number of days with snow cover for 1000-1420 m characterizes an increasing trend (R2 = 0.0432). The main factor that influenced this trend was the occurrence of short-lasting snow cover which concentrates in 1961-1974. The 1975-2018 interval did not bring any trend development. Finally, we have to add that the resulting trend was quite significantly influenced by the interval of values which were interpolated in the period 1961-1974.

6.4 SEASONAL MAXIMUM OF SNOW COVER DEPTH

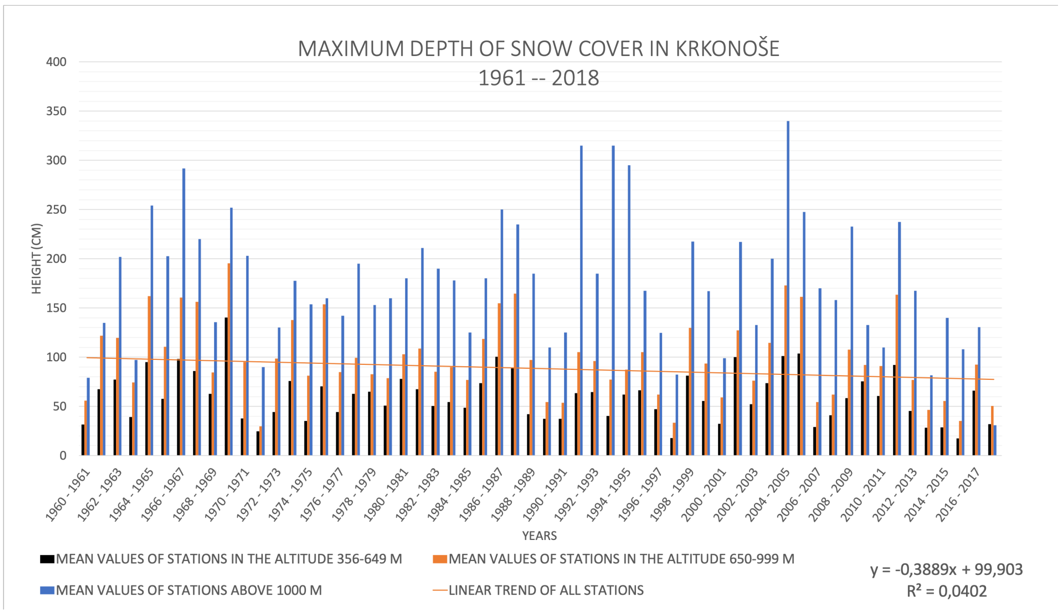

Figure 31. Seasonal maximum of snow cover depth - comparison of altitude divisions in Krkonoše

- The seasonal maximums of snow cover depth for altitude 356-649 m characterizes by a slight decrease in trend (R2 = 0.0306). Declining trend levels were most affected by a fall in the maximums snow cover in the period 1997–2018. During this period, there was a great variation in the maximum height of each season.

- The seasonal maximums of snow cover depth for 650-999m characterizes a decrease in trend (R2 = 0.0696). The trend characters an increase in seasons with a lower maximum snow cover in the period from 1989-2018.
- Seasonal peaks of snow cover depths for altitudes of 1000-1420 m characterizes by a slight decrease in trend (R2 = 0.0101). The decline in trend characterizes a large dispersion of values between seasons. Paradoxically, the maximum measurement values are in the second half of the interval, the same for the minimum.

7 DISCUSSION

The snow records analysis brings an unexpected result about snow distribution in Krkonoše area. According to researches published on the climate in Europe, we would expect a significant drop in all snow records (which was part of our research). The findings show a slight decrease in all snow variables. But in comparison with Alpine areas, which reach to higher elevations, the impact of climate change is not tremendous. Nevertheless, in case of snow occurrence, the present situation in recent years in Krkonoše is not very optimistic, except season 2018-2019 which reported summit snow cover in depth of 253 cm (Hejtmánek, 2019; Žák, 2019). This report proves the fact of incoming climate variability which carries a high frequency of extreme weather variability along with warming global climate is approaching.

Krkonoše are strongly affected by the wet and cold western winds flowing from the Atlantic. It is due to its location above the 50th parallel north. Frontal air-sea interactions manifest high volume of precipitations and snowfall in Krkonoše territory. They are well situated, because they are the first mountain ridge in the direction of the air stream and capture high amount of precipitations (Urban *et al.*, 2017, 2019; KRNAP, 2019). However, there have been many reports of the depletion of snow cover in most of the ski resorts in Krkonoše and those records lead to a question: can this type of snow recording be considered as a significant report about authentic snow conditions in Krkonoše? We have to state that our research did not take into consideration any local factors, such as exposition, slope, local climate variability, and the temperature while all those factors can drastically affect local snow occurrence. The last-mentioned temperature plays a vital role in snow cover duration. The influence of warm climate tremendously affected low altitudes values which are illustrated on charts in chapter 9.3. The highest decrease in trend was observed in a maximum depth of snow cover in altitudes 650-999 m, where the trend was significantly descending (R^2= 0.0693). Unfortunately, this area has the highest concentration of large ski resorts in Krkonoše. Another paradox that occurred in summit stations (Figure 32.), where we determined the highest ascending trend in the seasonal total of depths of new snow concerning summit stations in 1979-2018 (R^2= 0.3629). Result of this chart shows a massive diversion of snow precipitations in high altitudes. A similar decrease of seasonal depths of snow cover was reported on Lysá Hora in Moravskoslezské Beskydy (Němec and Zusková, 2005).

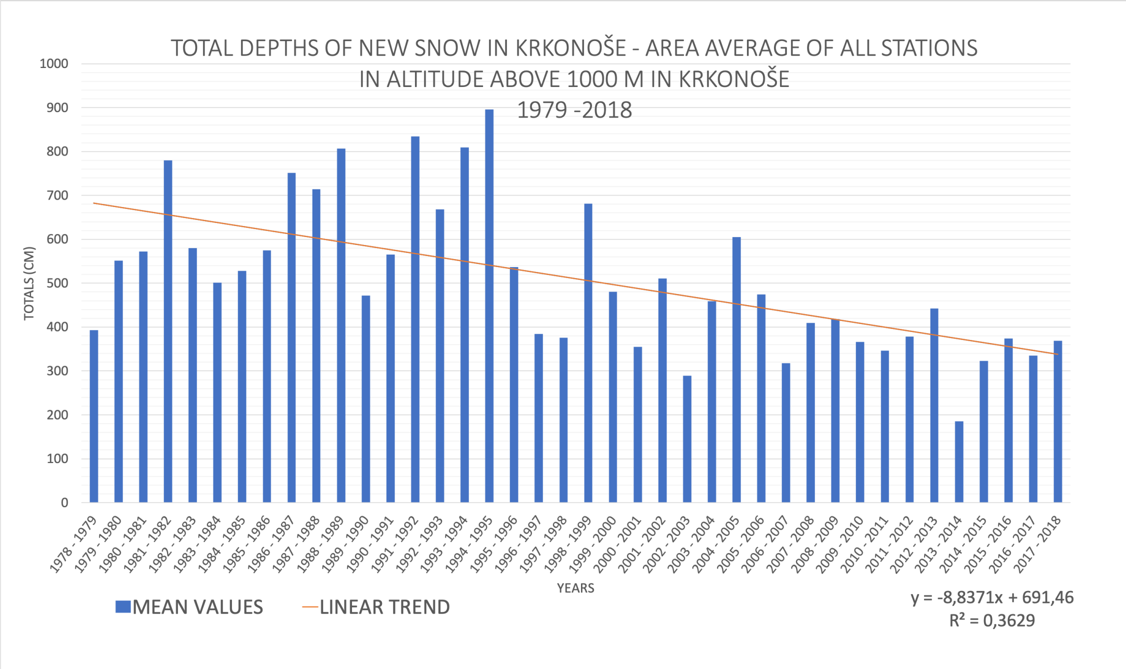

Figure 32. Seasonal total depths of new snow in 1979-2018 in Krkonoše

In addition, the chart for long-term seasonal total depths of snow cover was made. It illustrates the evolution of seasonal total depths of new snow between 1902-1939 and 1961-2018, where we can observe abnormal depths of new snow. It reaches almost to 800 cm in Pec pod Sněžkou for example. On the contrary, in Jilemnice, the maximum depths of new snow reach over 300 cm. We are facing very different results in different stations, where station H1PECS1 is in the heart of Krkonoše, and P2JILE01 is in Podkrkonoší, which is situated in lowlands. These records were taken from CLIDATA in the intervals between 1902-1939, none of these stations were affected by interpolation. It demonstrates high differentiation in snow precipitation based on spatial variability, altitude and influence of local factors in 1902-1939. It brings results about a large amount of snow precipitations, which probably stopped by the Krkonoše ridge where they brought a huge amount of snowfall. Last but not least, we have to mention that the vast majority of meteorological stations have been relocated (for unknown reasons) and this factor could have had affected the snow records and results.

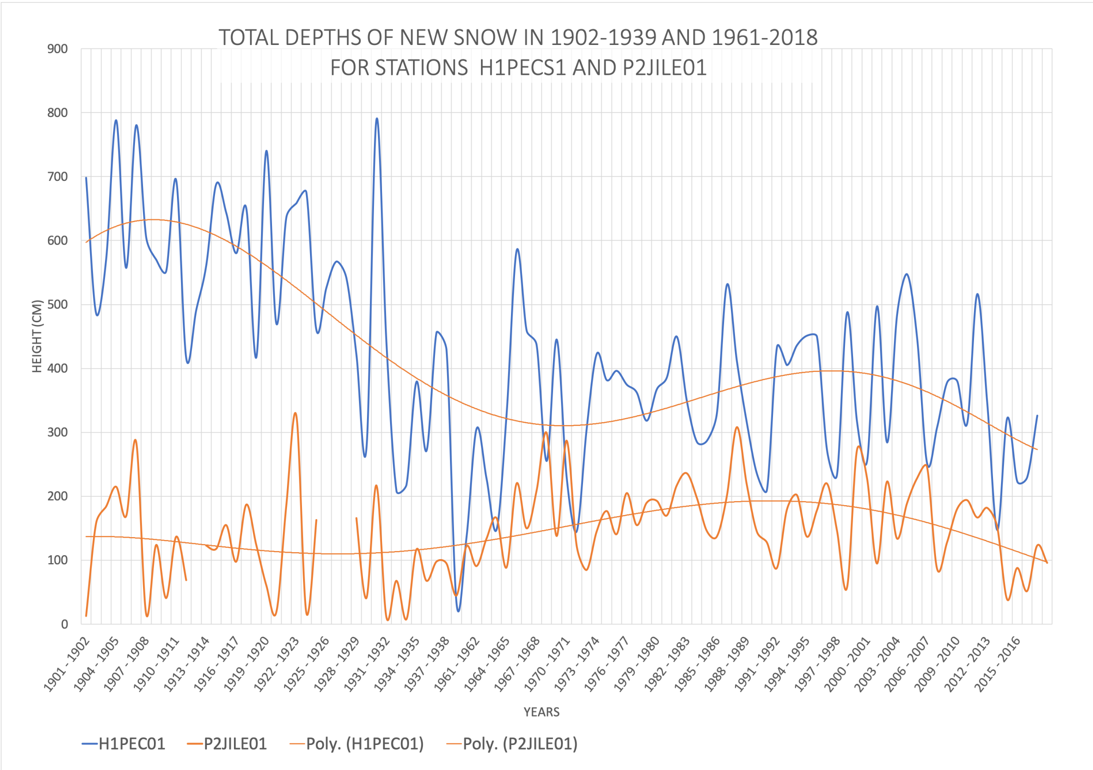

Figure 33. Seasonal total depths of new snow - H1PEC01, P2JILE01 in 1902-1939 and 1961-2018 in Krkonoše Missing records were caused by the beginning of the Second World War and the lasting post-war period.

In our literature review part, we identified many adaptable and sustainable strategies for the ski resorts, but we faced major problems with lack of researches on this topic in the Czech Republic. According to this, we could only propose certain guidelines for adopting the adaptable and sustainable framework for ski resorts. Therefore, we based our framework on many adaptable strategies which were recently published (Elsasser and Bürki, 2002; Scott and McBoyle, 2007; Klein J.T., 2011; Marty, 2013; Yang and Wan, 2015).

Based on this research, we would like to propose further steps in combinations of sustainable strategies for ski resorts in Krkonoše. What sustainable strategies can arise from our and various other researches? The sustainable strategies were adopted from the US chart and those principles and their application in Krkonoše will be further developed (Charter and Berry, 2000). Adaptable strategies are aimed at ski resort future operation, but sustainable strategies aim towards sustainable development of ski resorts and include environmental assessment, which considers environmental resources as heritage which is interchangeable for capital. Our goals were the determination of guidelines for the administrative framework and application of framework for adoption sustainable and adaptable strategies. The adaptable strategies in Krkonoše suitable for adoption are: landscaping in order to improve the drainage system and direct surface runoff into retention reservoirs; improving snowmaking systems to reduce water and energy consumption and construct water reservoirs for snowmaking; the use of cloud seeding was turned down due to different results of conducted researches. Business strategies supporting adaptation program are diversification of ski resorts, which has partly been implicated already (such as single tracks for mountain bikes, treetop rope centers (but with limits[17]), marketing strategies could be implementing a suitable measure; due to rising prices of ski tickets in the Czech Republic, many potential customers substitute Czech ski resorts with Alpine ones in order to obtain higher comfort for a similar amount of

[17] Some lifts are not authorized for summer operation due to the limitations of the number of visitors in the first zones of the national park (Horní Domky chair lift on Lysá Hora in Krkonoše). The diversification strategy or program has developed toward sustainability to avoid of mass tourism and disneyfication.

money. Relocating ski tracks into indoor facilities seems to be unpractical solution for such a scale like Krkonoše.

In order to restore groundwater reserves, we have to adopt a water policy framework which will be aimed at optimizing water use for ski resort operations (mainly focusing on snowmaking), minimizing water consumption, installing and using DESAR (in agriculture) and finally engaging water security program and water retention program.

Snowmaking and storm water management reservoirs can contribute to restoring groundwater levels by collecting the water within the area. Those reservoirs which supply snowmaking systems have to be built on strategic places in aim to reduce the power input and use mainly gravity for transportation within pipelines. Another strategy is limiting car transportation and proposing incentive parking lots (park and ride) system on a larger scale (on the local level it can improve the current traffic situation and lower the emissions generated within the area). Air quality can be improved by a different municipal policy for households, which would limit the use of low-quality coal and waste burning in aim to achieve lower air pollution. Visual quality has to be controlled by municipal regulations to preserve the local character of landscape and cityscape (Figure 34.)

Figure 34. Visual pollution in Pec pod Sněžkou
Source: Author

To summarize the sustainable and adaptable strategies for ski resort, we developed a diagram (Diagram 35.), which is defining guidelines for policy and implementation framework. The left branch of the ski resort diagram focuses on mapping out all the stakeholders participating in decision making process and policy framework. The right side illustrates implementation process.

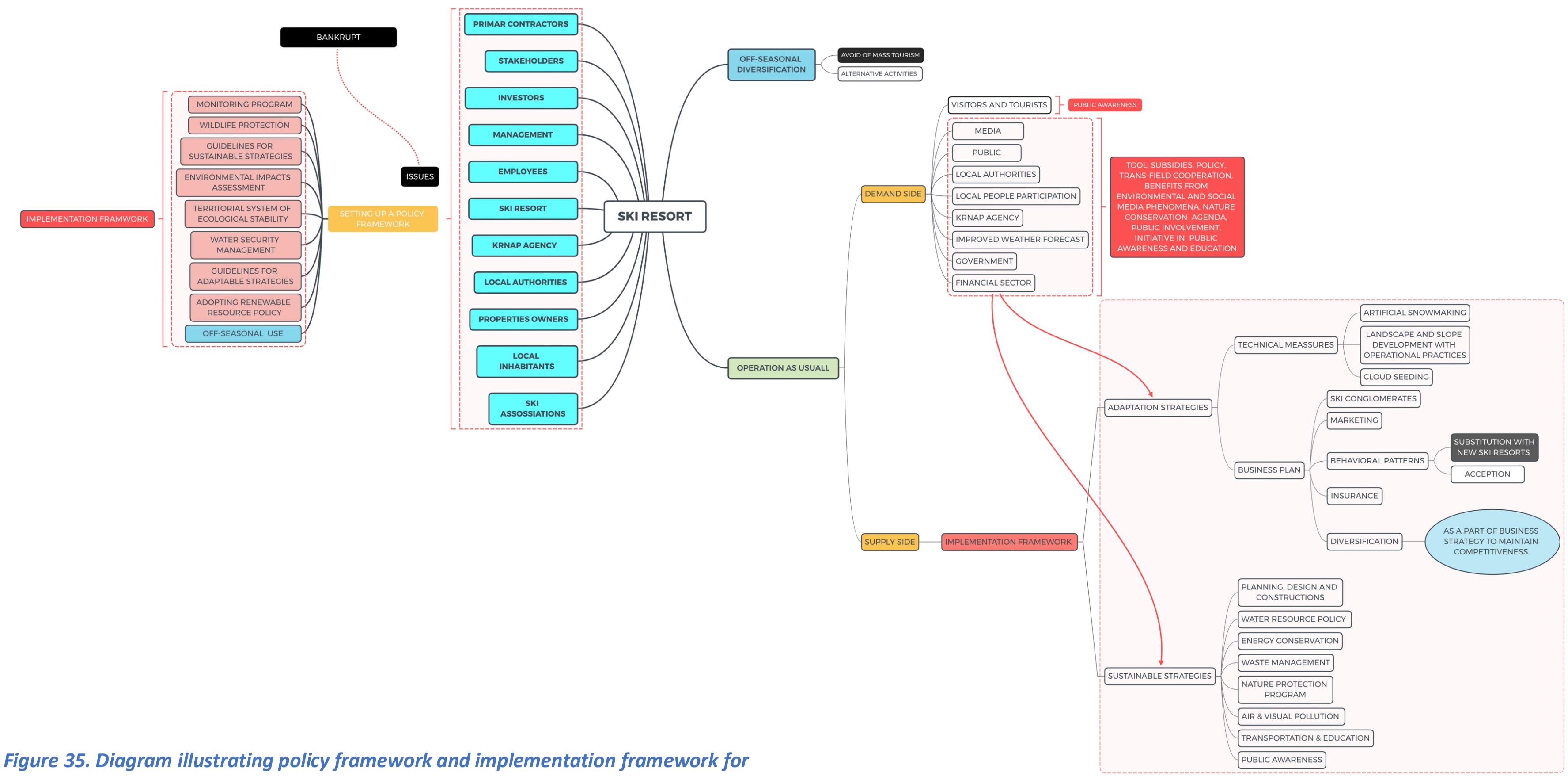

Figure 35. Diagram illustrating policy framework and implementation framework for sustainable and adaptable strategies

Another issue is that ski resorts form an artificial blockage in the territory and complicates migrating and traveling. This man-made obstacle can cause complications and problems to some species and the related fragmentation of landscape can spark a chain reaction in the ecosystem with a very complicated process of restoration.

Snow, according to temporary trend, is vanishing from low altitudes. Vast numbers of researches mention disappearing of snow cover and decrease or decline of total amount of annual snowfall on global scale (Koenig and Abegg, 1997; IPCC, 2000; Elsasser and Bürki, 2002; Němec and Zusková, 2005; Scott and McBoyle, 2007; Pielmeier *et al.*, 2007; Wolfsegger, Gössling and Scott, 2008; Jonas, Marty and Magnusson, 2009; Roux-Fouillet, Wipf and Rixen, 2011; IPCC and IPCC5 WGII, 2014; EEA, 2017; Urban *et al.*, 2017, 2019; Pons *et al.*, 2017; Rixen, 2017). Forecasts are quite skeptical about future snow trend. The EU climate study announces, in the worst-case scenario, an average warming up to 6°C, which would have a drastic impact on the entire continent (IPCC and IPCC5 WGII, 2014). In addition to the temperature rise, such warming would cause a high occurrence and frequency of extreme tropical temperatures. Alongside with the zonal decrease of rainfall in Europe.

According to a study by Svoboda and Potová, it is assumed that there is a general decrease in precipitation in the Czech Republic ((Svoboda *et al.*, 2016; Potopová *et al.*, 2018). This study aims on future projections of droughts period in Czech. Results are showing increasing trend in draught occurrence. The character of these dry periods will be periodical and with short duration. The increase in air temperature will raise the volume of evapotranspiration. In conclusion, the authors state that despite the uncertainties in model situations, it is imperative to respond to possible future climate variability, which would have a major impact on the environment. It is therefore necessary to take the necessary steps for minimizing those impacts.

In recent years, there has been observed a decrease in water precipitation. It is caused by the lack of rainfall and increase of tropical days. Despite the fact that the winter in 2019 brought heavy snowfall, the estimation of the total volume of water in the snow cover until April amounts approximately 0.323 billion m^3, which, according to experts, will not be sufficient to restore groundwater reserves (ČHMÚ, 2019). If this trend continues, we can assume that groundwater reserves will shrink and there will be problems with water scarcity. There have been many reports about groundwater disappearance such as the one by Čihák and Hájková (Čihák and Sedláčková, 2018). Therefore, the necessary steps should be taken to initiate water security in the landscape.

The Czech Republic is unique in its geographical position, because it is situated in the very center of Europe and there are located borders of three drainage basins. Main issue in our country is a missing program, insufficient network of waterbodies catching water and supply agriculture. Thereby, the problem we want to draw attention to is the absence of watercourses that would be directed to our territory. It is, therefore, necessary to respond in a timely manner to such a fact and to come up with a solution combining economic, social and environmental principles (Čihák and Sedláčková, 2018; Radman, 2018; Mahel, 2019).

At the end of this chapter, it is necessary to add that snow, in recent years, is melting in a very short time interval. In the spring periods, aggregated snow in higher altitudes begins to thaw and sometimes it takes only few days and most of the water flows away. Ideal would be a slow process thaw, which would significantly restore the amount of water absorbed in catchment area. For example, it is possible to build auxiliary retention reservoirs in the area in order to keep water within the Krkonoše region. That could simultaneously create natural habitats and biocentres. To embrace spatial distribution and integrate territorial systems of ecological stability in designed standards can be a suitable solution. The beneficial impact can be credited by re-connecting regional biotopes. Ski resorts require a lot of terrain modifications and modeling, those regular field works could carry out simultaneously with its program for revitalization local creeks and water reservoirs that supply snowmaking system by water. In other words, bring forth a diverse environment, rich for changeable water regimes. Building material would be local wooden logs and timber, which would be dredged into riverbanks to stabilize the coastline using usually heavy machinery (and possibly apply an additional soil erosion control) (Miklós, Diviaková and Izakovičová, 2018).

As an example of reclamation of dysfunctional water bodies and river flow, we can mention a project realized in Switzerland (Figure 36.). It is a river corridor restoration with an element of design which created an unique biotope (Praha 6, 2010; Descombes and Rampini, 2016).

Figure 36. Renaturation of the river Aire
Grid design contributes to variability in water regime and creates sandy aquatic environment which combines running and standing water regime biotope for many species. The self-restoration process support meanders and oxbow lakes formations scale, Restoring local aquatic biodiversity
Source: Descombes and Rampini, 2016S
http://www.landezine.com/wp-content/uploads/2016/06/09-Naturalization-river-channel-landscape-architecture-Fabio-Chironi-300x300.jpg

8 CONCLUSION

The results of this work characterize current snow variables in Krkonoše. Those results show a decreasing trend and it is based on analysis of time period between years 1961-2018.

For snow cover trend development, we used data obtained from ČHMÚ digital database (CLIDATA). The years for which the snow records are missing were primarily supplemented from annual reports and if this data were not included in annual reports, they were interpolated from related stations. Data groups of diverse stations were determined from the correlation of data series according to several criteria: the altitude, the distance between stations and the similarity of data series. The data interpolation is based on measurements from neighboring stations (no averaging of previous years was used in interpolations). According to the criteria, we divided the stations into 5 main groups with subgroups. The results are presented in the form of charts.

Concerning seasonal total depths of new snow, we identified a decreasing trend in the total of new snow; concerning seasonal number of days with snow cover, we observed decreasing too; and for a seasonal maximum of snow cover depths, we discovered decreasing trend as well. Furthermore, this work maps the climate variability, both in the Czech and European context. It elaborates in detail the issue of adaptability of ski resorts (that we investigated) and provides a solution through a combination of adaptable and sustainable strategies. The research handles with environmental impact assessment and analyzes direct, indirect and cumulative impacts of ski resorts on the natural environment. In the end, the work discusses theoretical guidelines for a sustainable framework of the ski resorts in Krkonoše.

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10 APPENDICES

10.1 TABLE OF FIGURES

10.2 METEOROLOGICAL STATIONS - METADATA

Gh id	Full name	Name	Begin date	End date	Country	Hydro id	Latitude	Ew hemisphere	Longitude	Ns hemisphere	Di district	Ba basin	Refer station	Station type	Elevation	Gauss1	Gauss2
H1HOST01	Hostinné	Hostinné	08/01/13	07/20/16	Česká republika	1010103201	503123	E	0154424	N	Trutnov	Labe		MSS	356	3551285	5601878
H1HOST01	Hostinné	Hostinné	01/01/61	08/01/13	Česká republika	1010103201	503246	E	0154325	N	Trutnov	Labe		MSS	356	3551285	5601878
H1HOST01	Hostinné	Hostinné	07/20/16	12/31/99	Česká republika	1010103201	503123	E	0154424	N	Trutnov	Labe		ASS	356	3551285	5601878
P2NPAK01	Nová Paka	Nová Paka	10/01/50	12/31/60	Česká republika	1050103601	502922	E	0153115	N	Jičín	Jizera		MSS	435	3536961	5595445
P2NPAK01	Nová Paka	Nová Paka	01/01/61	07/31/88	Česká republika	1050103601	502922	E	0153115	N	Jičín	Jizera	B2SEDC01	MSS	435	3536961	5595445
H1CIST01	Čistá	Čistá	01/01/61	12/31/12	Česká republika	1010105501	503136	E	0153503	N	Semily	Labe		MSS	445	3541432	5599617
P2NPAK01	Nová Paka	Nová Paka	10/01/05	12/31/99	Česká republika	1050103601	502924	E	0153049	N	Jičín	Jizera	B2SEDC01	MSS	450	3536450	5595508
P2NPAK01	Nová Paka	Nová Paka	01.01.1897	09/30/46	Česká republika	1050103601	502923	E	0153039	N	Jičín	Jizera		MSS	455	3536251	5595474
P2NPAK01	Nová Paka	Nová Paka	08/01/88	09/30/05	Česká republika	1050103601	502924	E	0153035	N	Jičín	Jizera	B2SEDC01	MSS	461	3536173	5595506
P2JILE01	Jilemnice	Jilemnice	01/01/02	12/31/99	Česká republika	1050102501	503605	E	0153045	N	Semily	Jizera	O2LUKA01	MSS	462	3536286	5607900
H1VRCH01	Vrchlabí	Vrchlabí	06/14/07	12/31/99	Česká republika	1010101201	503727	E	0153828	N	Trutnov	Labe		AKS1	482	3545364	5610511
H1VRCH01	Vrchlabí	Vrchlabí	01-LED-1897	06/23/05	Česká republika	1010101201	503727	E	0153827	N	Trutnov	Labe		MSS	482	3545348	5610507
H1VRCH01	Vrchlabí	Vrchlabí	06/24/05	06/13/07	Česká republika	1010101201	503727	E	0153827	N	Trutnov	Labe		ASS	482	3545348	5610507
P2LOMN01	Lomnice nad Popelkou	Lomnice nad Popelkou	09/26/06	12/31/99	Česká republika	1050103801	503218	E	0152248	N	Semily	Jizera	B2SEDC01	ASS	485	3526941	5600824
P2LOMN01	Lomnice nad Popelkou	Lomnice nad Popelkou	01/01/83	09/25/06	Česká republika	1050103801	503218	E	0152248	N	Semily	Jizera	B2SEDC01	MSS	485	3526941	5600824
P2LOMN01	Lomnice nad Popelkou	Lomnice nad Popelkou	01/01/51	12/31/60	Česká republika	1050103801	503218	E	0152248	N	Semily	Jizera	O2LUKA01	MSS	485	3526941	5600824
P2STUD01	Studenec	Studenec	01/01/61	09/09/06	Česká republika	1050103501	503248	E	0153237	N	Semily	Jizera	O2LUKA01	MSS	495	3538532	5601831
P2ROKY01	Rokytnice nad Jizerou, Vilémov	Rokytnice nad Jizerou	01/01/51	12/31/99	Česká republika	1050101101	504355	E	0152522	N	Semily	Jizera	P3PRIB01	MSS	525	3529810	5622443
P2STUD01	Studenec	Studenec	10/01/08	12/31/99	Česká republika	1050103501	503310	E	0153300	N	Semily	Jizera	P3PRIB01	ASS	532	3538981	5602512
P2ROPR01	Roprachtice	Roprachtice	03/01/04	07/19/16	Česká republika	1050103001	503905	E	0152451	N	Semily	Jizera	P3PRIB01	MSS	550	3529296	5613418
P2ROPR01	Roprachtice	Roprachtice	07/19/16	12/31/99	Česká republika	1050103001	503905	E	0152451	N	Semily	Jizera	P3PRIB01	ASS	550	3529296	5613418
P2SMRZ01	Smržovka	Smržovka	03/01/95	10/31/00	Česká republika	1050106301	504348	E	0151553	N	Jablonec nad Nisou	Jizera	P3PRIB01	MSS	550	3518692	5622114
P2SMRZ01	Smržovka	Smržovka	11/01/00	12/31/99	Česká republika	1050106301	504346	E	0151504	N	Jablonec nad Nisou	Jizera	P3PRIB01	MSS	550	3517732	5622044
H1DDVU01	Dolní Dvůr, Rudolfov	Dolní Dvůr	07/19/16	12/31/99	Česká republika	1010101901	503917	E	0153921	N	Trutnov	Labe		ASS	560	3546445	5614121
H1HMAR01	Horní Maršov	Horní Maršov	06/24/05	12/06/16	Česká republika	1010201301	503935	E	0154915	N	Trutnov	Úpa		ASS	565	3558049	5614580
H1HMAR01	Horní Maršov	Horní Maršov	01/01/61	06/23/05	Česká republika	1010201301	503945	E	0154904	N	Trutnov	Úpa		MSS	565	3557826	5614890
H1DDVU01	Dolní Dvůr, Rudolfov	Dolní Dvůr	16-KVĚ-1894	07/19/16	Česká republika	1010101901	503924	E	0153924	N	Trutnov	Labe		MSS	570	3546445	5614121
H1HMAR01	Horní Maršov	Horní Maršov	12/06/16	12/31/99	Česká republika	1010201301	503916	E	0154908	N	Trutnov	Úpa		ASS	585	3558049	5614580
P2JDUL01	Josefův Důl	Josefův Důl	01/01/25	12/31/40	Česká republika	1050106001	504659	E	0151348	N	Jablonec nad Nisou	Jizera	P3PRIB01	MSS	590	3516233	5628017
P2JDUL01	Josefův Důl	Josefův Důl	01/01/72	07/11/13	Česká republika	1050106001	504659	E	0151348	N	Jablonec nad Nisou	Jizera	L3KVAL01	MSS	590	3516233	5628017
P2JDUL01	Josefův Důl	Josefův Důl	07/11/13	12/31/99	Česká republika	1050106001	504659	E	0151348	N	Jablonec nad Nisou	Jizera	L3KVAL01	ASS	623	3516233	5628017
P2SMRZ01	Smržovka	Smržovka	01/01/51	02/28/95	Česká republika	1050106301	504421	E	0151454	N	Jablonec nad Nisou	Jizera	L3KVAL01	MSS	625	3517530	5623133

Gh id	Full name	Name	Begin date	End date	Country	Hydro id	Latitude	Ew hemisphere	Longitude	Ns hemisphere	Di district	Ba basin	Refer station	Station type	Elevation	Gauss1	Gauss2
H1JANL01	Janské Lázně	Janské Lázně	08/23/73	12/31/78	Česká republika	1010201601	503800	E	0154700	N	Trutnov	Úpa		MKS	652	3555420	5611616
P2HARR01	Harrachov	Harrachov	01/01/21	08/31/53	Česká republika	1050100801	504645	E	0152515	N	Semily	Jizera	P1PKAR01	MKS	675	3530214	5627174
P2HARR01	Harrachov	Harrachov	10/01/18	12/31/99	Česká republika	1050100802	504654	E	0152512	N	Semily	Jizera	P1PKAR01	AKS2	675	3529611	5627928
P2HARR01	Harrachov	Harrachov	05/01/12	09/30/18	Česká republika	1050100802	504654	E	0152512	N	Semily	Jizera	P1PKAR01	AKS4	675	3529611	5627928
P2HARR01	Harrachov	Harrachov	09/01/53	04/30/63	Česká republika	1050100801	504629	E	0152539	N	Semily	Jizera	P1PKAR01	MKS	690	3530214	5627174
P2HARR01	Harrachov	Harrachov	01/20/76	04/30/12	Česká republika	1050100802	504619	E	0152608	N	Semily	Jizera	P1PKAR01	MKS	706	3530730	5626865
P2HARR01	Harrachov	Harrachov	05/01/63	01/19/76	Česká republika	1050100802	504613	E	0152615	N	Semily	Jizera	P1PKAR01	MKS	707	3530922	5626688
H1CDUL01	Černý Důl	Černý Důl	06/24/05	12/31/99	Česká republika		503855	E	0154245	N	Trutnov	Labe		ASS	715	3550400	5613276
H1CDUL01	Černý Důl	Černý Důl	08/01/86	11/30/86	Česká republika		503855	E	0154245	N	Trutnov	Labe		ASS	715	3550400	5613276
H1JANL01	Janské Lázně	Janské Lázně	01/01/62	12/31/69	Česká republika	1010201601	503800	E	0154700	N	Trutnov	Úpa		MKS	740	3555420	5611616
P2DESN01	Desná, Souš	Desná	01/01/31	10/21/04	Česká republika	1050106501	504723	E	0151909	N	Jablonec nad Nisou	Jizera	P1PKAR01	MKS	772	3522511	5628770
P2DESN01	Desná, Souš	Desná	10/22/04	12/31/99	Česká republika	1050106501	504722	E	0151911	N	Jablonec nad Nisou	Jizera	P1PKAR01	AKS1	772	3522546	5628737
P2BENE01	Benecko	Benecko	09/01/94	12/31/99	Česká republika	1050102301	504018	E	0153300	N	Semily	Jizera	H1PECS01	MSS	790	3538883	5615739
H1PECS01	Pec pod Sněžkou	Pec pod Sněžkou	01/01/53	12/31/71	Česká republika	1010200201	504200	E	0154400	N	Trutnov	Úpa		MS	805	3551810	5618999
H1PECS01	Pec pod Sněžkou	Pec pod Sněžkou	01-LED-1898	02/29/32	Česká republika	1010200201	504200	E	0154400	N	Trutnov	Úpa		MS	805	3551810	5618999
H1PECS01	Pec pod Sněžkou	Pec pod Sněžkou	03/01/32	12/31/52	Česká republika	1010200201	504200	E	0154400	N	Trutnov	Úpa		MS	805	3551810	5618999
H1PECS01	Pec pod Sněžkou	Pec pod Sněžkou	01/01/04	12/31/99	Česká republika	1010200201	504131	E	0154344	N	Trutnov	Úpa		AMS1	816,3	3551507	5618100
H1PECS01	Pec pod Sněžkou	Pec pod Sněžkou	02/01/88	12/31/03	Česká republika	1010200201	504131	E	0154344	N	Trutnov	Úpa		MS	824	3551507	5618100
P2KORE01	Kořenov, Jizerka	Kořenov	10/01/09	12/31/99	Česká republika	1050100409	504912	E	0152040	N	Jablonec nad Nisou	Jizera	P1PRUZ01	AKS4	858	3524275	5632150
P2KORE01	Kořenov, Jizerka	Kořenov	01/01/02	09/30/09	Česká republika	1050100409	504915	E	0152045	N	Jablonec nad Nisou	Jizera	P1PRUZ01	MSS	858	3524371	5632238
P2KORE01	Kořenov, Jizerka	Kořenov	01.01.1898	09/30/99	Česká republika	1050100401	504903	E	0152058	N	Jablonec nad Nisou	Jizera	P1PKAR01	MSS	865	3524626	5631872
P2KORE01	Kořenov, Jizerka	Kořenov	10/14/99	12/31/01	Česká republika	1050100401	504914	E	0152048	N	Jablonec nad Nisou	Jizera	P1PKAR01	MSS	865	3524434	5632216
P2BENE01	Benecko	Benecko	10/11/31	08/31/94	Česká republika	1050102301	503951	E	0153332	N	Semily	Jizera	H1PECS01	MKS	880	3539519	5614909
P2MISE01	Vítkovice, Horní Mísečky	Vítkovice	06/01/95	05/31/06	Česká republika	1050102001	504408	E	0153416	N	Semily	Jizera	P1PRUZ01	MKS	1040	3540439	5623004
H1LBOU01	Labská bouda	Labská bouda	01/01/79	09/30/99	Česká republika	1010100101	504612	E	0153243	N	Trutnov	Labe		MKS	1300	3538470	5626672
H1LBOU01	Labská bouda	Labská bouda	10/04/02	12/31/99	Česká republika	1010100101	504612	E	0153242	N	Trutnov	Labe		AKS1	1320	3538444	5626658
H1LUCB01	Luční bouda	Luční bouda	01/20/09	12/31/99	Česká republika		504407	E	0154152	N	Trutnov	Labe		AKS1	1413	3549269	5622904
P2VYSK01	Vysoké nad Jizerou	Vysoké nad Jizerou	1767	38760,999	Česká republika	1050107801	504114	E	0152410	N	Semily				670	5617396	5617396
P2VYSK01	Vysoké nad Jizerou	Vysoké nad Jizerou	38761	41547,999	Česká republika	1050107801	504114	E	0152410	N	Semily				690	5617396	5617396
P2VYSK01	Vysoké nad Jizerou	Vysoké nad Jizerou	41548	43076,499	Česká republika	1050107801	504056	E	0152424	N	Semily				690	5617396	5617396
P2VYSK01	Vysoké nad Jizerou	Vysoké nad Jizerou	43076,5	767011	Česká republika	1050107801	504059	E	0152431	N	Semily				695	5617396	5617396
P2VYSK02	Vysoké nad Jizerou	Vysoké nad Jizerou	38961	40359,999	Česká republika	1050107801	504114	E	0152410	N	Semily				670	5617399	5617399
P2VYSO01	Vysoké nad Jizerou	Vysoké nad Jizerou	29007	34272,999	Česká republika	1050107801	504056	E	0152401	N	Semily				670	5616839	5616839
P2VYSO01	Vysoké nad Jizerou	Vysoké nad Jizerou	9572	29006,999	Česká republika	1050107801	504116	E	0152412	N	Semily				670	5617463	5617463