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Risk Analysis of the Impact of Natural Hazards on Cultural Heritage

Development of a Risk Assessment Tool

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ABSTRACT

A risk assessment methodology is developed to analyse the impact of natural hazards on cultural heritage objects. The methodology involves both qualitative and quantitative risk analysis approaches. In the qualitative risk analysis, probability and consequence classes based on NS 5815 are used. Probability classes are assigned to hazard events, while consequence classes are assigned to cultural heritage objects. A risk matrix is then generated to identify objects that are most vulnerable to high-risk hazards.

The quantitative risk analysis aims to quantify the impact of natural hazards on heritage objects. It introduces the concept of Heritage Loss (HL), which provides a quantitative estimate of the expected physical loss of a cultural heritage object resulting from natural or other hazards. The quantitative risk analysis stage builds upon the findings of the qualitative risk analysis by establishing a link between risk classes and numerical probabilities, as well as estimating the potential heritage loss.

To facilitate the implementation of this risk assessment methodology, a flexible Excel tool has been developed. This tool allows for efficient and customizable risk assessment based on the inputs provided.

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Cover image: Tension station – Cable car line 1b (Strammestasjon – Taubanelinje 1b, September 2021), processed picture. Image © SINTEF, photographer: Sinitsyn, A.O.

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1 Introduction

This work focuses on the assessment of the impact of natural hazards on cultural heritage objects in Svalbard, particularly in Longyearbyen and Ny-Ålesund. It is foreseen that with certain modifications, the methodology can be extended to include archaeological sites and other types of infrastructure, beyond just technical-industrial heritage.

The risk assessment is performed on a high-level and is hence referred to as *coarse analysis*, paving the foundation for a further detailed risk assessment. The aim of coarse analysis is to provide identification of objects exposed to the most risk and hence to provide possibility for prioritization of the objects for restoration.

The motivations for the coarse risk analysis are as follows:

- Identifying cultural heritage objects subjected to the highest risks from natural hazards.
- Providing input to a sequential risk-informed decision-making process for the management and restoration of cultural heritage objects.
- Establishing a foundation for conducting further detailed risk assessment, such as GIS-based risk evaluation.

In parallel to achieving the objective implied by the above motivations, the work involved developing a highly flexible risk analysis tools that may be further used and optimized to the needs of relevant stakeholders. The risk analysis tool includes two main components, qualitative and quantitative risk analysis. Detailed explanations of these components will be provided in subsequent sections. However, before delving into the specifics, this section will briefly discuss the cultural heritage objects examined in Longyearbyen and Ny-Ålesund during the coarse analysis, as well as the natural hazards that were taken into consideration.

2 Cultural Heritage Objects

The selection of the cultural heritage objects for case study is presented in (Sinitsyn et al., 2022). The objects are selected based on several criteria. A summary of the list of objects is presented in the following subsections.

2.1 Heritage Objects in Longyearbyen

The cultural heritage objects in Longyearbyen selected for case study are presented in Table 1.

Table 1. List of cultural heritage objects in Longyearbyen selected for case study.

Heritage Object ID*	Heritage Object Name	Remark(s)
159054	Cable car line 1a (*Taubanelinje 1a*)	11 foundations
158657	Cable car line 1b (*Taubanelinje 1b*)	24 posts (*bukker*) and 1 tightening station (*Strammestasjon*). Several objects around the mine entrance were not included in the analysis, yet findings for the closest to them *Bukk 1 – Taubanelinje 1* (ID

		158657-1) would be in general applicable to those objects.
158987	Cable car line 2a (*Taubanelinje 2a*)	5 foundations (1 for machine house) at the Cable car line 2a were included in the analysis. Several objects around the mine entrance were not included in the analysis, yet findings for closest to them *Fundament maskinhus* (ID 136714-3) would be in general applicable to those objects.
158986	Cable car line 2b (*Taubanelinje 2b*)	18 posts and 1 corner station (*Vinkelstasjon*)
158619	Cable car line 3 (*Taubanelinje 3*)	41 posts and 1 tightening station
87889	Cable car line mine 5 (*Taubanelinje delstrekning gruve 5*)	23 posts and 1 tightening station (does not exist at present time)
87889	Cable car line mine 6 (*Taubanelinje delstrekning gruve 6*)	40 posts and 1 tightening station (*Strammestasjon Todalen*)
87889-6	The cable car center in Longyearbyen (*Taubanesentralen i Longyearbyen*)	-
93040-6	The cable car station in Hiorthhamn (*Taubanestasjonen i Hiorthhamn*)	-
	The Titan crane (*Titankrana*)	-
136713	Mine 1a (*Gruve 1a*)	-
136716	Mine 2b (*Gruve 2b*)	-
87889-4	Mine 5 (*Gruve 5*)	-
87889-3	Mine 6, the pit top North building (*Gruve 6, Daganlegget Bygning Nord*)	-
87889-8	Mine 6, the pit top East building (*Gruve 6, Daganlegget Bygning Aust*)	-
87889-9	Mine 6, the pit top South building (*Gruve 6, Daganlegget Bygning Sør*)	-
N/A	Mine 6, Gallery (*Gruve 6, Galleri*)	-
N/A	Mine 6, Mine entrance (*Gruve 6, Gruve inngang*)	-
87889-5	The angle station at Endalen (*Vinkelstasjon ved Endalen*)	-
146668-7	Building G in Hiorthhamn (*Boligbrakke G i Hiorthhamn*)	-
NA	Titankrana	-

* Object ID as presented in Norway's national heritage database (Riksantikvaren, n.d.)

2.2 Heritage Objects in Ny-Ålesund

The cultural heritage objects in Ny-Ålesund selected for case study are presented in Table 2.

Table 2. List of cultural heritage objects and other modern buildings in Ny-Ålesund included in the case study.

Heritage Object ID*	Heritage Object/Modern Building Name
158506-2	The airship mast (*Luftskipsmasta*)
159759-1	The Green Harbour house (*Green Harbour-Huset*)
159781	The White house (*Hvitt hus*)
159772	The Tronderheimen house (*Trønderheimen*)
159807-1	The London houses (*Londonhusene*)

159804-1 159806-1 159802-1	
159 756	The school (*Skolen*)
159 769	The telegraph (*Telegrafen*)
159793-1	The museum (*Museet*)
159761	Museum cabin, light green (*Museum/Museumshytta/hytte lysegrønn*)
159762-1	Veteran cabin, light blue (*Veteranhytta/hytte lyseblå*)
159763-1	Sysselbu
159764-1	Museum
159768	Amundsen villa (*Amundsenvillaen*)
159776-1	North Pole hotel (*Nordpolhotellet*)
159779-1	Yellow house (*Gult hus*)
159784	Blue house (*Blått hus*)
159795-1	The middle warehouse (*Mellageret*)
159796	Post office (*Posthuset*)
159801	The iron warehouse (*Jernlageret*)
159798-1	Sætra
159823-1	Boat house (*Båtnaust*), 1st operation period
159 820	Boat house (*Båtnaust*), before 1921
159 739	Boat house (*Båtnaust*), 1st operation period
159782-1	Mexico
159 785	Hospital (*Sykehuset/Skutergarasjen*)
159790-1	The community house (*Samfunnshuset*)
-	Saga
-	The old power station (*Gamle kraftstasjonen*)
-	The dog yard (*Hundegården*)
-	Doll house (*Dokkehus*)
-	Transformer house (*Transformatorhus*)

* Object ID as presented in Norway's national heritage database (Riksantikvaren, n.d.).

3 Natural Hazards

The risk analysis work carried out at this level considers the following natural hazards:

1. ***Permafrost degradation***: refers to the warming of permafrost resulting in a decrease in its thickness and areal extent coupled with an increase in the active layer thickness, the seasonally freezing and thawing surface layer above permafrost. Permafrost degradation is largely driven by climate change while local anthropogenic factors may also contribute. Permafrost degradation poses a risk to the cultural heritage objects by affecting the bearing capacity of their foundations and creating potential settlement unaccounted for in their original design.
2. ***Solifluction***: is the slow downward movement of soil on a slope where the moving mass constitutes unfrozen material. Permafrost degradation on slopes due to climate change or human activity increase the risk of solifluction. For cultural heritage objects located on a sloping ground, solifluction poses a risk to their structural and geotechnical stability.
3. ***Landslide and Debris Flow***: It is well documented that extreme weather events and climate change are increasing the frequency of natural hazards such as landslides and debris flows. Cultural heritage

objects in areas prone to landslides or debris flows will be at a risk of being damaged or destroyed if such hazards occur.

4. ***Rockfall***: Rockfalls may occur as a result of climate effects under certain geological and rock mechanical conditions, including surface water and freeze-thaw activity. Cultural heritage objects located close to steep rock slopes or cliffs may be exposed to destruction due to falling rocks.
5. ***Snow avalanche***: Induced by factors such as increased precipitation, snowpack weakening or human factors, snow avalanche is the rapid downward flow of snow on slopes. Cultural heritage objects located on slopes or close the base of hills or mountains may be exposed to the risk of snow avalanches and their destructive power.
6. ***Coastal erosion***: refers to the removal of soil and rock along coastlines due to various factors such as sediment transport, waves, currents, tides, sea ice or storms. Coastal erosion causes a retreat of the shoreline and cultural heritage objects located close to coastlines may be subjected to a risk of structural damage or loss of stability of their foundations.
7. ***Riverine flooding***: occurs when the capacity of streams or rivers is exceeded followed by an overflow of water beyond the riverbanks and into an adjacent land. Extreme weather events and climate change increase the frequency of flooding in Arctic regions due to higher temperature causing snow and permafrost melting and increased precipitation levels. Cultural heritage objects located close to rivers or streams may be subjected to destabilizing forces from the flooding and degradation.
8. ***Surface erosion and gullying.*** Surface erosion, including ravines, debris flow tracks, and snow avalanche tracks, as well as gully erosion, may affect cultural heritage sites. Surface erosion refers to the gradual wearing away of the top layer of soil by natural agents such as water, snow, wind, and animals. Gully erosion, on the other hand, occurs on relatively flat surfaces where sharp erosion creates gullies, resulting in the removal of soil or erodible materials; (Nicu et al., 2022). In Arctic regions, gully erosion is further intensified due to the unique interaction between gullies and permafrost. As the surface of the permafrost freezes and thaws, soil particles erode, exacerbating gully formation. This erosion process significantly affects the stability of cultural heritage object foundations and poses a risk to their overall existence.
9. ***Weathering***: refers to the degradation of soils, rocks, minerals and other materials where the agents include water, ice, acids, salts, atmospheric gases, plants and animals (*Weathering | National Geographic Society*, n.d.). This slow decrease on the quality of materials could be a risk to cultural heritage objects resting on or close to weathering ground. Weathering can be responsible of conditions that leads to rockfalls.
10. ***Actions from windstorms:*** wind loads and actions may cause collapse of buildings and structures. This hazard was not evaluated in version 01 of the report (this report) as the data on the rot affecting the foundations of taubanebukker (i.e. the effective dimension of cross sections not affected by fungi decay) is not known up to the date. Similar considerations apply to Luftskipsmasta in Ny-Ålesund (effective cross section area of steel elements). Furthermore, assessing windstorm-related risks is beyond the project's scope, as it primarily focuses on geohazards rather than on structural engineering and biological factors such as fungi decay.

The list of natural hazards considered is by no means exhaustive but is considered sufficient at this level of coarse analysis of the case study objects. Additional natural or anthropogenic hazards may be considered at a later stage in the assessment. As most of the hazards are site-specific, assessments at other Polar sites may require exclusion/inclusion of other natural hazards (for example surface overland flow) and other types of hazards (for example impacts for vegetation, etc.).

4 Risk Analysis Methodologies

There are two primary methodologies employed in risk analysis: qualitative and quantitative.

Qualitative risk analysis focuses on evaluating the likelihood and impact of risks based on their potential severity and probability of occurrence. It relies on expert judgment and is subjective to some extent, as it involves assessing risks using a qualitative scale. This approach is often utilized when data is limited or when conducting a more intricate analysis is impractical. The outcome of qualitative risk analysis is typically a risk register or risk matrix that ranks risks based on their likelihood and potential impact.

On the other hand, quantitative risk analysis involves a more comprehensive examination that employs numerical estimations to assess the probability and impact of risks. It relies on numerical data and is generally more objective than qualitative analysis. Quantitative risk analysis encompasses the identification and modelling of risks, simulation of scenarios to estimate the likelihood and impact of risks, and assessment of the overall risk exposure of a project. This approach provides a more accurate assessment of risks and aids in prioritizing risk mitigation strategies.

A combination of qualitative and quantitative risk analysis approaches is often used to provide a more comprehensive assessment of risks. Qualitative risk analysis can help identify and prioritize risks that require further analysis, while quantitative analysis can provide a more detailed assessment of those risks. By combining the two approaches, project managers can develop effective risk mitigation strategies that address both the likelihood and potential impact of risks. Ultimately, the choice of risk analysis methodology depends on the specific needs and constraints of the project, as well as the availability of data and resources.

Four the purpose of the project, the qualitative risk analysis step is based on risk identification, assignment of probability and consequence classes (based on NS 5815) and generation of a risk matrix. The quantitative risk analysis step builds on the qualitative risk analysis by defining numerical values for the probabilities and consequences. Figure 1 shows an illustration of these two steps. Each step is presented in detail in the following sections.

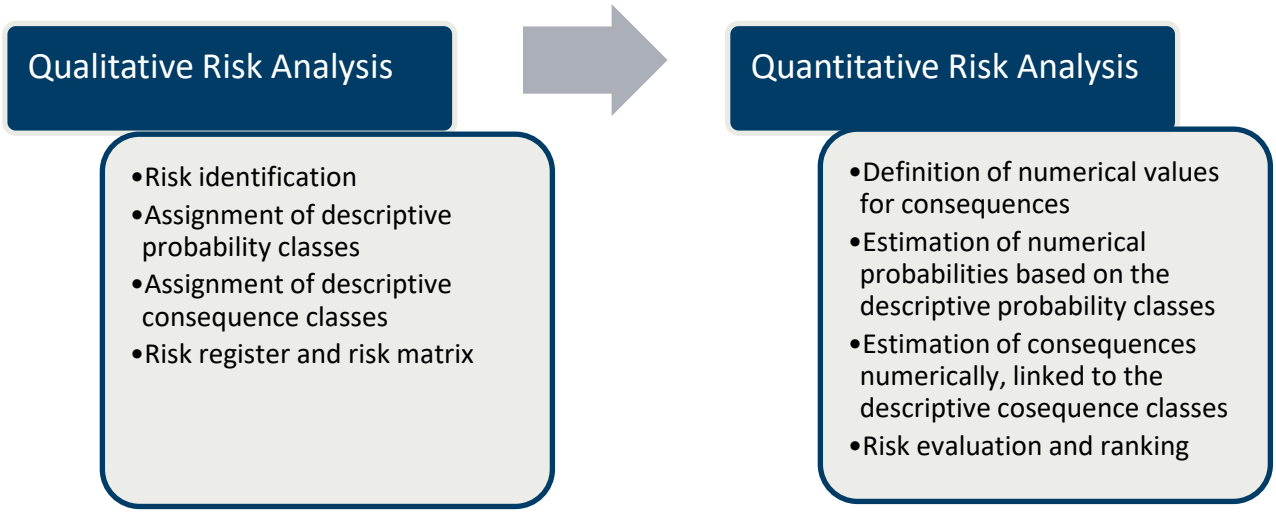


Figure 1. Qualitative and quantitative risk analysis steps and a link between the two.

5 Qualitative Risk Analysis

During the qualitative risk analysis stage, the risks for each cultural heritage object with respect to different natural hazards are described using the risk classes based on NS 5815 (Risikovurdering Av Anleggsarbeid - NS 5815 | Standard.No, n.d.). The qualitative risk analysis process involves the following main steps:

- Definition of the probability classes for the different natural hazards with respect to a given cultural heritage object of interest and its geographic location.
- Assessment of the consequence of a natural hazard on a given cultural heritage object if it were to occur and assignment of a corresponding consequence class.
- Visualization of the results in a risk matrix which can then be used to identify which objects are exposed to the highest risk and from which natural hazard(s).

The details are presented in the subsections below.

5.1 Risk Classes

Risk classes, in particular probability and consequence classes, are defined according to NS5815. Classes for both the probability of a natural or anthropogenic hazard and its consequence on a cultural heritage object are defined on a scale from 1 to 5, where 1 represents the lowest class (a very unlikely hazard event/a negligible consequence) and 5 represents the highest class (a very likely hazard event/a severe consequence). The probability classes and their descriptions are given in Table 3. Similarly, consequence classes and their descriptions are presented in Table 4.

Table 3. Probability classes and their descriptions according to NS 5815.

Probability Class	Description
1	Very unlikely
2	Unlikely
3	Possible
4	Likely
5	Very likely

Table 4. Consequence classes and their descriptions according to NS 5815.

Consequence Class	Description
1	Negligible
2	Minor
3	Moderate
4	Significant
5	Severe

These probability and consequence classes are used to generate a risk matrix for a list of cultural heritage objects and natural/anthropogenic hazards.

5.2 Risk Identification

During the risk identification stage, probability and consequence classes are assigned for each combination of cultural heritage object and natural hazard. The assignment of the probability and consequence is based on the geographic location of the cultural heritage object and the potential natural hazards that may/could occur at that location.

5.2.1 Assigning Probability Classes (PC)

Various previous studies on natural hazards on Svalbard and hazard maps provide a basis for assessment of the potential occurrence of a specific natural hazard at a given location. This is in addition to data collected during the field survey work in the PCCH-Arctic project. Whenever such data is not available, the probability classes are assigned based on reasonable assumptions considering the location of the object. Resources used to estimate the probability classes for qualitative risk analysis are presented in Table 5.

Table 5. Resources used to estimate the probability classes for qualitative risk analysis.

Natural hazard	Resources used for estimating probability classes in addition to PCCH field survey 2021
Permafrost degradation	(Boike et al., 2018) (Adakudlu et al., 2019) (Rongved & Instanes, n.d.) (Instanes, 2016) (Westermann et al., 2011) (Etzelmüller et al., 2011) (Rouyet et al., 2019) (Schmidt et al., 2021)
Slope hazards (Solifluction, Landslide and Debris flow, Rockfall, Snow avalanche)	(Eckerstorfer et al., 2013) (Eckerstorfer, 2013) (Christiansen et al., 2016) (Hannus, 2016) (Gundersen et al., 2018) (Bekele & Sinitsyn, n.d.) (Nicu et al., 2021) (*Research Project - Risk Governance in the Arctic - Industrial Economics and Technology Management (IØT) - NTNU - NTNU*, n.d.) The Arctic Safety Center, UNIS

Coastal erosion	(Guégan, 2015) (Nicu et al., 2020) (*SVALCOAST*, n.d.) (Jaskólski et al., 2018)
Riverine flooding	(Adakudlu et al., 2019) (*Longyeardalen Monitoring*, n.d.) (*SvalDEM | Glacier Observatory*, n.d.) (Ottem, 2022) (Pallesen, 2022)
Surface erosion and gullying	Evaluations based on field observations performed withing PCCH-Arctic
Weathering	Evaluations based on field observations performed withing PCCH-Arctic

5.2.2 Assigning Consequence Classes (CC)

The expected consequence classes are assigned depending on the type of natural hazard (i.e. magnitude of impact), the geographic location of the cultural heritage object and the current condition of the object. The present state of a cultural heritage object is crucial in determining its ability to withstand natural hazards. Special attention is given to the current condition of the object, particularly regarding permafrost degradation, considering the anticipated consequences. In addition to data collected during the PCCH-Arctic field survey work in 2021, recent and existing resources are utilized to assess the current condition of the objects. For the cable way posts (*Taubanebukker*), the decision letter (*Longyearbyen - Svalbard - Vedtak Om Dispensajon for Stabiliserende Tiltak På Automatisk Fredete Taubanebukker, ID 158957, 158986, 158619 Og Vedtaksfredete Taubanebukker, ID 87889, n.d.*) for stabilization measures of the cable way posts is used as a reference to assess their conditions. The conditions of the cable way posts are reported in terms of *Tilstandsgrad* (TG) – condition grade. The assumed link between TG and consequence class is presented in Table 6. The reasoning behind this link is that structures which are in a relatively good condition are able to withstand the impact of permafrost degradation compared to those that are in a relatively deteriorated condition. The consequence class of permafrost degradation is judged to be directly related to the condition grading. For other natural hazards, the consequence class is determined based on engineering judgement.

Table 6. Link between condition grading (tilstandsgradering) and consequence class assumed for the impact of permafrost degradation.

Condition Grade (Tilstandsgrad – TG)	Consequence Class (CC)
1	2
2	3
3	4
4	5

As a general approach, the CC values are not assigned for structures that do not exist or that are destroyed. The PC were assigned for all, existing and destroyed structures. The names of destroyed structures are included in the analysis with empty values for CC such that future evaluations can be performed if the structures are rebuilt or restored.

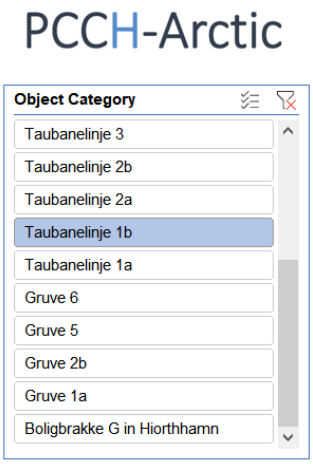
However, as an input in validating the methodology and as basis for the restoration, a separate version of the Excel tool with an extension "**_Blind_Test**" was created. This version **includes** the CC values for structures that are absent or destroyed – assuming their presence. Input in validation of the methodology is performed on a simple "blind test", i.e. by assigning the CC to all objects (i.e. to presently existing and absent objects), and comparing whether the objects under the highest risks were practically affected (i.e. destroyed) by the natural hazards. The cases of destruction/damages due to permafrost degradation are not considered as a part of the validation as observed structural damages (broken foundation members) due to degradation of permafrost (settlements of terrain) were already taken into account when assigning the consequence class

via the condition grade (see Table 6). In addition, in some cases collapse of a structure was most probably caused rod decay of timber, or a structure a absent/collapsed but the reasons for this are unknown – all such cases are taken out of considerations. Results of validation of methodology are presented in Ch. 7.

For the system of cable way posts in Longyearbyen, lists of destroyed or absent structures and restored structures are presented in Appendix 1 (Table 10 and Table 11). Overview of restored foundations in Ny-Ålesund is presented in (Sinitsyn et al., 2022; Table 6).

Stone and concrete foundations at the lines 1a and 2a are considered as "structures" in the present evaluation, while remaining in the ground parts of timber foundation of destroyed structures on other lines are not considered as the structures.

In the risk assessment tool developed in the project, the resources used for estimating the probability and consequence classes can be included in the "Explanation/Remark on Assigned PC (Probability Class)" or "Explanation/Remark on Assigned CC (Consequence Class)" columns. A screenshot of the risk identification sheets is shown in Figure 2.



Risk Identification

Heritage Object and Natural/Anthropogenic Hazard				
Heritage Object	Object ID	Natural Hazard	Hazard ID	PC
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Permafrost degradation	Per	3
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Solifluction	Sol	1
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Landslide/Debris flow	Lan	4
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Rock fall	Roc	3
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Snow avalanche	Sno	4
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Coastal erosion	Coa	1
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Riverine flooding	Riv	1
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Gully erosion	Gul	1
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	LYR81	Weathering	Wea	1
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Permafrost degradation	Per	3
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Solifluction	Sol	1
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Landslide/Debris flow	Lan	4
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Rock fall	Roc	3
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Snow avalanche	Sno	4
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Coastal erosion	Coa	1
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Riverine flooding	Riv	1
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Gully erosion	Gul	1
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	LYR82	Weathering	Wea	1
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Permafrost degradation	Per	3
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Solifluction	Sol	1
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Landslide/Debris flow	Lan	5
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Rock fall	Roc	5
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Snow avalanche	Sno	5
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Coastal erosion	Coa	1
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Riverine flooding	Riv	1
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Gully erosion	Gul	1
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	LYR83	Weathering	Wea	1
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Permafrost degradation	Per	2
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Solifluction	Sol	1
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Landslide/Debris flow	Lan	5
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Rock fall	Roc	5
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Snow avalanche	Sno	5
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Coastal erosion	Coa	1
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	LYR84	Riverine flooding	Riv	1

Figure 2. Assignment of probability and consequence classes during the risk identification stage.

5.3 Risk Matrix

Once probability and consequence classes have been assigned for all combinations of cultural heritage objects and natural hazards, the risk matrix can be generated to visualize ***which*** cultural heritage objects are the most exposed to risks from ***specific*** natural hazards. A staircase type risk matrix is used with five colour

classes: Green, Light Green, Yellow, Orange and Red with increasing levels of probability and consequence class combinations. The risk matrix visualizes which cultural heritage objects may require urgent attention for mitigation. Figure 3 shows an example of the risk matrix generated for *Taubanelinje 1b* with respect to all the natural hazards considered. The risk matrix displays the PCCH Object IDs and Hazard IDs separated by a hyphen. For example, *LYR82-Per* refers to the Object ID *LYR82* (Taubanelinje 1b, Bukk Nr. 23 as can be referred from the risk identification table) and the Hazard ID *Per* (which stands for permafrost degradation). Note that several combinations of objects and hazards may be located in a given square of the risk matrix and one may need to expand the cell to see all entries.

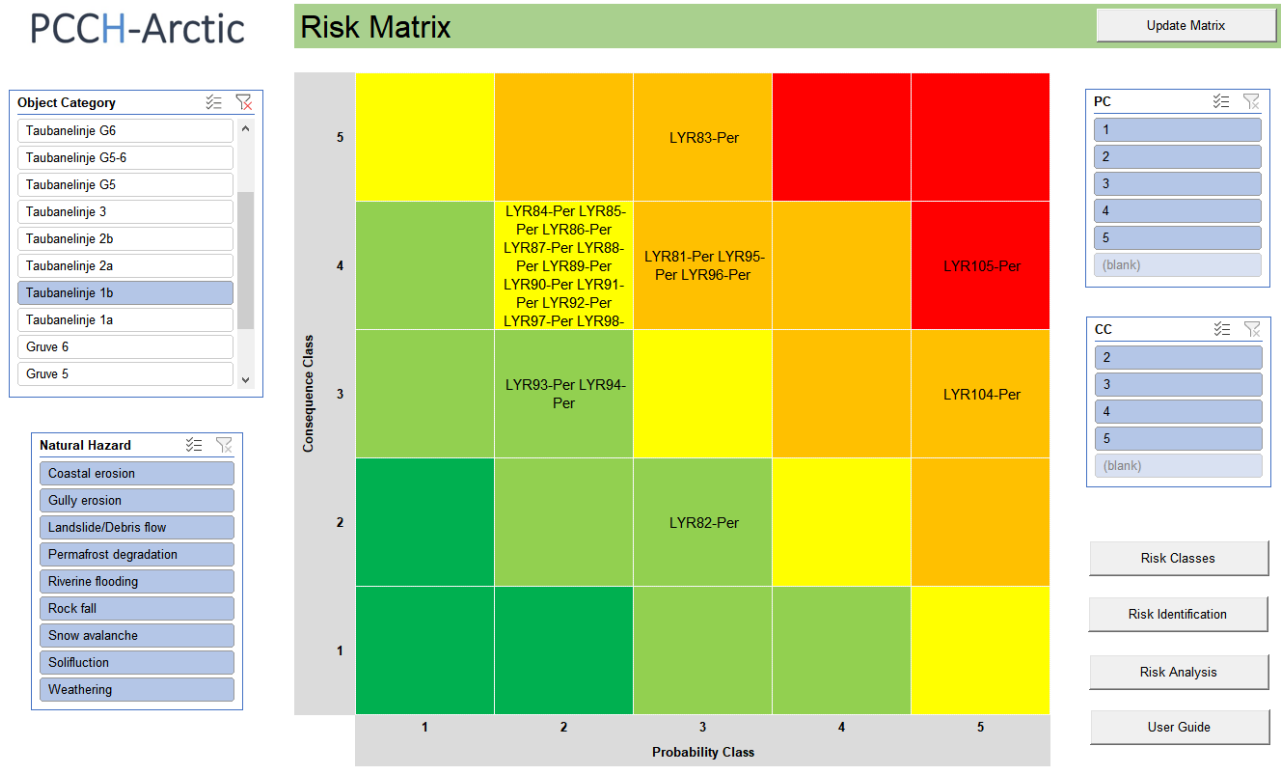


Figure 3. Risk matrix generated after assigning probability and consequence classes. The risk matrix can be generated for a selected natural hazard and cultural heritage object. Custom PCCH Object IDs are used to identify the cultural heritage objects in the risk matrix. The matrix here shows Taubanelinje 1b against all the natural hazards considered.

Risk matrices can be generated for any desired combination of cultural heritage object(s) and natural hazard(s) by using the filtering tools at the left of the risk matrix sheet. For example, Figure 4 shows the risk matrix generated for Taubanestasjonen i Hiorthhamn with respect all the natural hazards considered in the analysis here. The risk matrix provides a quick insight into which natural hazards threaten which cultural heritage objects the most. In the particular example considered for Taubanestasjonen i Hiorthhamn, it can be observed that coastal erosion and permafrost degradation are the major hazards for this particular cultural heritage object (Figure 4).

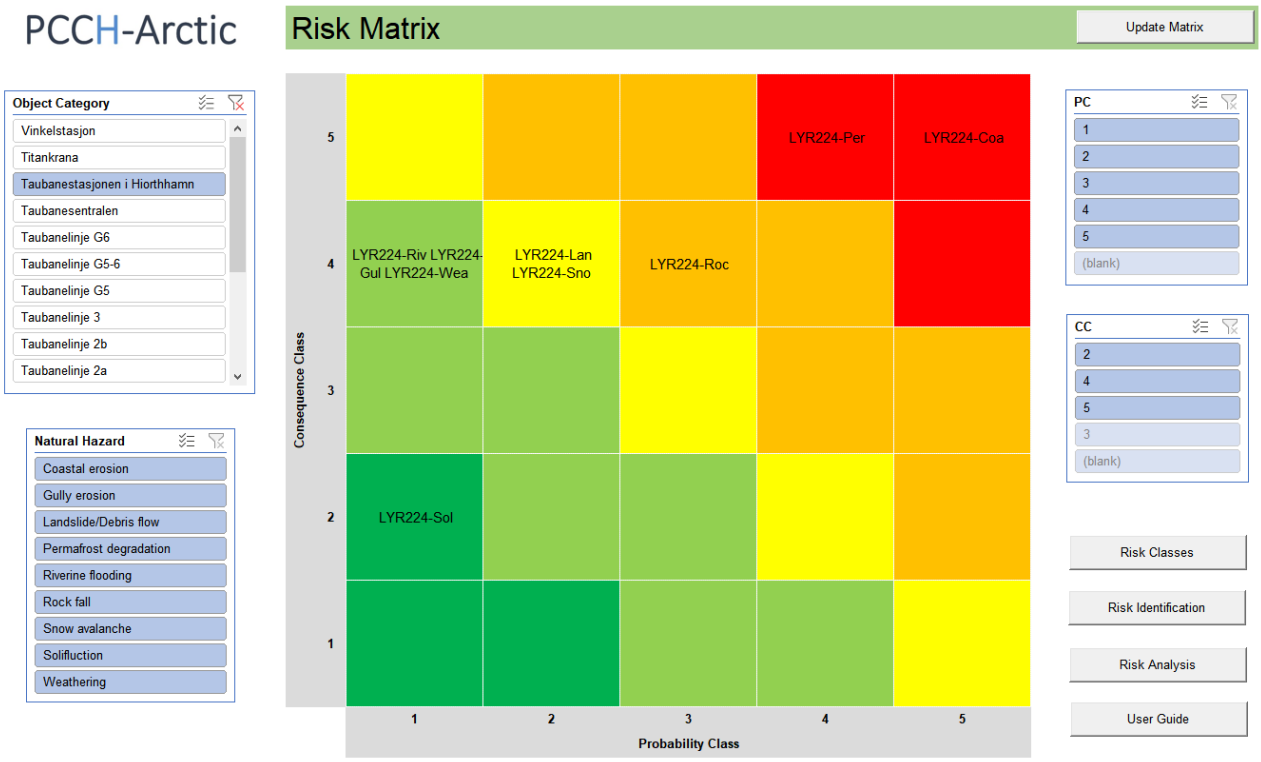


Figure 4. Risk matrix for Taubanestasjonen i Hiorthhamn against all the natural hazards considered in the analysis.

6 Quantitative Risk Analysis

Quantitative risk analysis aims to numerically quantify the level of risk that a specific cultural heritage object is exposed to. This is in contrast to qualitative risk analysis, which provides a descriptive, qualitative assessment of the risk level. Therefore, in order to quantify the risks, it is first important to define numerical estimates corresponding to the probability and consequence classes discussed earlier. The quantitative risk analysis process involves:

- Definition of lower and upper bound numerical probability estimates corresponding to the five probability classes defined during the qualitative analysis stage.
- Definition of the lower and upper bound numerical estimates (defined as Heritage Loss below) corresponding to the five consequence classes.
- Estimation of the lower and upper bound risks based on the numerical probabilities and the expected consequences.
- Visualization of the estimated risks in summary tables and charts.

Each of the steps in the process are described in detail in the following subsections.

6.1 Probability Estimates

In addition to the classes for probabilities and consequences, corresponding numerical probabilities and consequences are defined for a detailed risk analysis. The numerical probabilities required as inputs corresponding to the probability classes are:

- **Lower Bound (LB) Probability**: the lowest expected hazard likelihood corresponding to a given probability class.

- **Upper Bound (UB) Probability**: the highest expected hazard likelihood corresponding to a given probability class.

These probability estimates are defined only once at the beginning of the risk assessment work. The values are provided in the Risk Classes sheet of the risk analysis tool. Table 7 presents example upper and lower bound probability estimates corresponding to the five probability classes.

Table 7. Lower and upper bound probability estimated corresponding to the five probability classes. Note that the values provided here are only examples.

Probability Class	Description	Lower Bound (LB) Probability	Lower Bound (UB) Probability
1	Very unlikely	0.1 %	1.0 %
2	Unlikely	1.0 %	5.0 %
3	Possible	5.0 %	10.0 %
4	Likely	10.0 %	20.0 %
5	Very likely	20.0 %	50%

The risk assessment tool is designed to analyse the impact of natural hazards on cultural heritage by considering the probability and consequences of these hazards. The defined probability classes and their corresponding numerical values are not directly tied to specific return periods, as they aim to provide a general measure of the likelihood of occurrence within a given time frame. Emphasizing return periods could introduce a level of specificity that may not align with the diverse and uncertain nature of various natural hazards. In our analysis, we are focusing on the immediate understanding of risk without the complexities of the return period, as it enables a broader and more flexible analysis. This approach prioritizes the assessment of risk based on current understanding and data, rather than projecting into specific recurrence intervals, making it more applicable to the varying contexts of cultural heritage sites.

6.2 Heritage Loss (HL)

To quantify the expected consequence of a certain natural hazard on a cultural heritage, we define the concept of Heritage Loss (HL) based on inspiration from (Giuliani et al., 2021). In the context of risk assessment for cultural heritage objects, we define heritage loss as follows:

***Heritage loss**: a quantitative estimate of the expected physical loss of a cultural heritage object due to the action of natural and anthropogenic hazards or a combination of such hazards.*

As we did for the probability classes, we define HL estimates to each of the consequence classes, expressed in percentage. Lower and upper bounds are also defined the HL:

- **Lower Bound (LB) HL**: the lowest expected heritage loss corresponding to a consequence class.
- **Upper Bound (UB) HL**: the highest expected heritage loss corresponding to a consequence class.

The HL estimates as well are required to be defined only once at the beginning of the risk assessment work, in the Risk Classes sheet. Table 8 presents example upper and lower bound HL estimates corresponding to the five consequence classes. The estimates are based on a reasonable assumption of what a certain consequence means in light of the physical security of the structure. The estimates can easily be adjusted whenever desired.

Table 8. Lower and upper bound Heritage Loss (HL) estimates corresponding to the five probability classes. Note that the values provided here are only examples.

Consequence Class	Description	Lower Bound (LB) HL	Lower Bound (UB) HL
1	Negligible	0.0 %	5.0 %
2	Minor	5.0 %	10.0 %
3	Moderate	10.0 %	30.0 %
4	Significant	30.0 %	50.0 %
5	Severe	50.0 %	100.0 %

6.3 Risk of Heritage Loss (HL)

When probability and consequence classes are assigned for each combination of cultural heritage object and natural hazard during the qualitative risk analysis stage, the corresponding numerical probability and HL estimates are automatically inferred from the values provided corresponding to probability and consequence classes, respectively.

The **Risk of Heritage Loss** is defined as the product of the probability of the hazard and the corresponding HL estimate i.e.:

$$\boldsymbol{Risk\ of\ Heritage\ Loss\ =\ Probability\ of\ Hazard\ *\ Heritage\ Loss}$$

The Risk of HL is obtained in terms of lower and upper bound values corresponding to the lower and upper bound probability and HL estimates.

6.4 Risk Analysis

Once all relevant data is provided within the risk identification stage, the data can be analysed to get insight into the magnitude of risk posed by natural hazards on the cultural heritage objects. This is performed on the 'Risk Analysis' sheet of the risk assessment tool. The tool provides for a highly flexible way to visualize the Risk of HL for different combinations of cultural heritage objects and natural hazards. This is accomplished by selecting the desired cultural heritage object(s) and natural hazard(s) using the slicer tool; Figure 5.

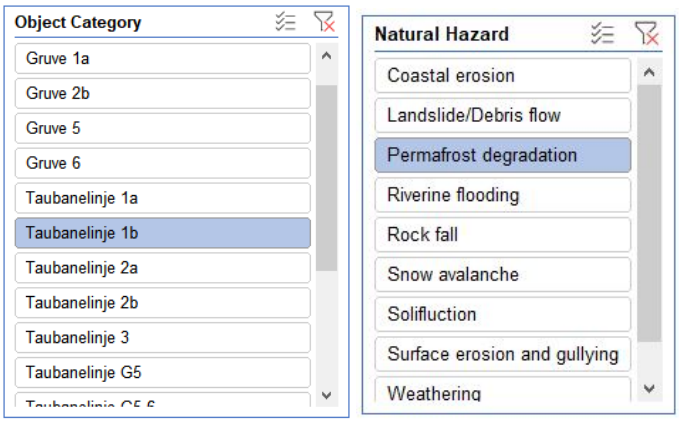


Figure 5. Slicer tools to choose a combination of cultural heritage objects and natural hazards for risk analysis visualization.

Based on the selected cultural heritage object(s) and natural hazard(s), the lower and upper bound Risk of HL values are summarized in a table. Figure 6 shows an example summary table for Taubanelinje 1b as the cultural heritage object and permafrost degradation as the natural hazard. As mentioned in Ch. 5.2.2,

absent/collapsed structures are excluded from the analysis, hence the symbol "#N/A" is placed on those in Figure 6 and on others.

It is possible to select multiple cultural heritage objects and/or multiple natural hazards. The summary table will be automatically updated based on the selected object(s) and hazard(s). Figure 7 shows an example where Taubanelinje 1b is selected as the cultural heritage object and permafrost degradation and weathering are selected as the natural hazards.

	LB Risk of HL	UB Risk of HL
⊟ **Permafrost degradation**		
⊟ **Taubanelinje 1b**		
Taubanelinje 1b, Bukk Nr. 1 (158657-1)	6.00 %	25.00 %
Taubanelinje 1b, Bukk Nr. 10 (158657-10)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 11 (158657-11)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 12 (158657-12)	0.10 %	1.50 %
Taubanelinje 1b, Bukk Nr. 13 (158657-13)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 14 (158657-14)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 15 (158657-15)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 16 (158657-16)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 17 (158657-17)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 18 (158657-18)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 19 (158657-19)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 2 (158657-2)	2.00 %	15.00 %
Taubanelinje 1b, Bukk Nr. 20 (158657-20)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	0.25 %	1.00 %
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 3 (158657-3)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 4 (158657-4)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 5 (158657-5)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 6 (158657-6)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 7 (158657-7)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 8 (158657-8)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 9 (158657-9)	#N/A	#N/A
Taubanelinje 1b, Strammestasjon (158657-25)	0.10 %	1.50 %

Figure 6. Lower and upper bound Risk of HL values summarized for Taubanelinje 1b for permafrost degradation.

	LB Risk of HL	UB Risk of HL
Permafrost degradation		
Taubanelinje 1b		
Taubanelinje 1b, Bukk Nr. 1 (158657-1)	6.00 %	25.00 %
Taubanelinje 1b, Bukk Nr. 10 (158657-10)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 11 (158657-11)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 12 (158657-12)	0.10 %	1.50 %
Taubanelinje 1b, Bukk Nr. 13 (158657-13)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 14 (158657-14)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 15 (158657-15)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 16 (158657-16)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 17 (158657-17)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 18 (158657-18)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 19 (158657-19)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 2 (158657-2)	2.00 %	15.00 %
Taubanelinje 1b, Bukk Nr. 20 (158657-20)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	0.25 %	1.00 %
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	1.50 %	5.00 %
Taubanelinje 1b, Bukk Nr. 3 (158657-3)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 4 (158657-4)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 5 (158657-5)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 6 (158657-6)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 7 (158657-7)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 8 (158657-8)	0.30 %	2.50 %
Taubanelinje 1b, Bukk Nr. 9 (158657-9)	#N/A	#N/A
Taubanelinje 1b, Strammestasjon (158657-25)	0.10 %	1.50 %
Weathering		
Taubanelinje 1b		
Taubanelinje 1b, Bukk Nr. 1 (158657-1)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 10 (158657-10)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 11 (158657-11)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 12 (158657-12)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 13 (158657-13)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 14 (158657-14)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 15 (158657-15)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 16 (158657-16)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 17 (158657-17)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 18 (158657-18)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 19 (158657-19)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 2 (158657-2)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 20 (158657-20)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 23 (158657-23)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 24 (158657-24)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 3 (158657-3)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 4 (158657-4)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 5 (158657-5)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 6 (158657-6)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 7 (158657-7)	#N/A	#N/A
Taubanelinje 1b, Bukk Nr. 8 (158657-8)	0.05 %	1.00 %
Taubanelinje 1b, Bukk Nr. 9 (158657-9)	#N/A	#N/A
Taubanelinje 1b, Strammestasjon (158657-25)	0.05 %	1.00 %

Figure 7. Lower and upper bound Risk of HL values summarized for Taubanelinje 1b for permafrost degradation and weathering.

The Risk of HL results in the summary tables are visualized in a horizontal bar chart that shows which of the cultural heritage objects are exposed to the highest risk from the natural hazard(s) in consideration. An example visualization for Taubanelinje 1b due to the action of permafrost degradation is shown in Figure 8.

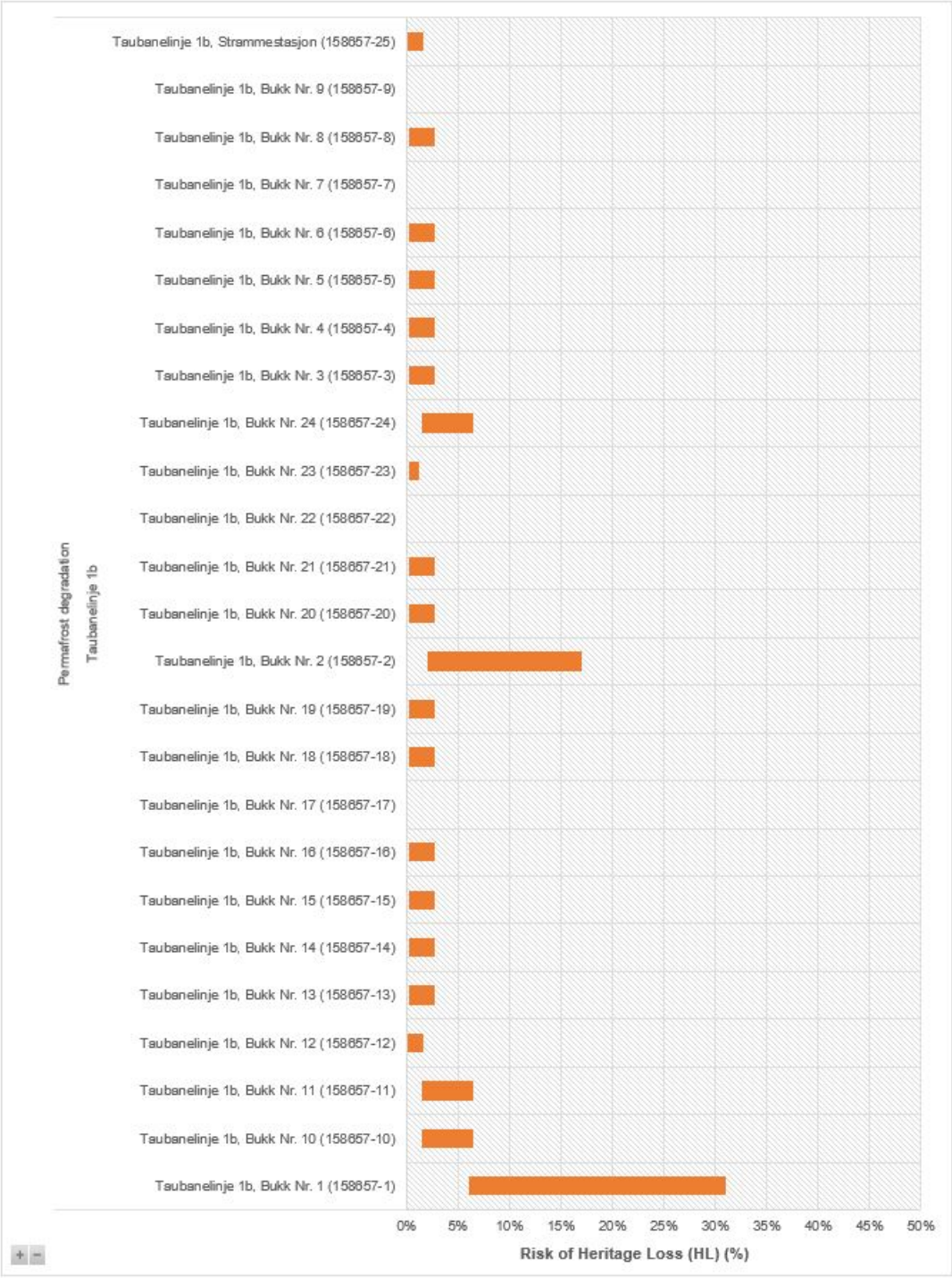


Figure 8. Visualization of lower and upper bound Risk of HL values summarized for Taubanelinje 1b for permafrost degradation.

Similar visualizations can be generated for other combinations of cultural heritage object(s) and natural hazards. For example, Figure 9 show a visualization of Risk of HL for Taubanelinje 1b due to the action of permafrost degradation, surface erosion and gullying.

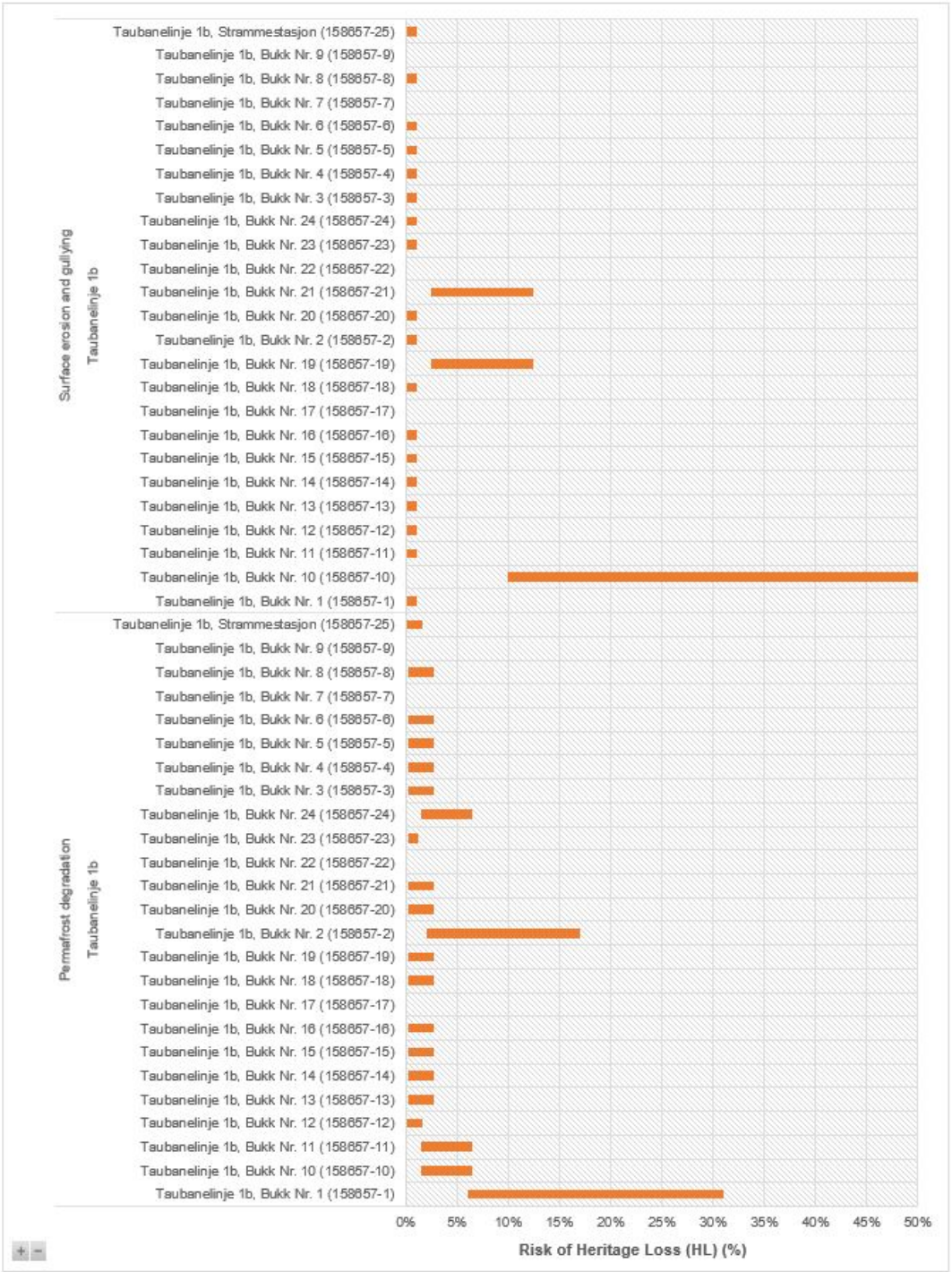


Figure 9. Visualization of lower and upper bound Risk of HL values summarized for Taubanelinje 1b for permafrost degradation, surface erosion and gullying.

6.5 Aggregated Risk Analysis

In the preceding subsection, we discussed individual risk analysis, which focuses on evaluating hazards on a per-object basis for cultural heritage objects. However, to gain a complete understanding of the potential impact of hazards on these objects, it is crucial to also consider the cumulative risks arising from multiple hazards. This is where aggregated risk analysis becomes valuable, as it offers a comprehensive perspective on the potential risks faced by cultural heritage objects.

The concept of HL defined during the quantitative risk analysis allows us to combine the risk of HL from different hazards on a single cultural heritage object. The aggregate risk of HL for a single cultural heritage object is simply defined as the sum of the risks of heritage loss corresponding to the different natural hazards i.e.:

$$\boldsymbol{Aggregate\ Risk\ of\ HL} = \sum \boldsymbol{Risk\ of\ HL\ from\ individual\ hazards}$$

We use the average risk of HL as an indicator for the aggregated risk of HL. The average risk of HL loss is estimated as the midpoint between the lower and upper bound risks of HL. It should be noted here that the aggregated risk of HL may become a number greater than 100% as it is taken as the sum of risks of HL from different natural hazards given in percentages. Our aim here is to rank the cultural heritage objects in terms of the risk of exposure to natural hazards and the aggregated risk of HL serves that purpose.

6.6 Options for visualization of risk of HL

The tool provides two options for visualization of risk of HL:

1) A bar chart presenting overview of average risk of HL from different natural hazards to a particular object (Figure 10).
2) A pie chart presenting contribution of different natural hazards to the risk of HL for a particular object. The pie utilizes normalization of the aggregated risk to 100%, that is performed within each particular case (Figure 11).

6.7 Some limitations of the methodology

In the methodology presented above, none of the numerical probabilities corresponding to the smallest PC values (PC=1) are set to zero but rather very small values are used. When evaluating the Risk of HL for a certain object exposed to a certain hazard, the choice of the numerical probabilities will define the results. For example, a certain natural hazard may be completely irrelevant for a certain object and the smallest PC value that can be assigned to it is equal to 1. If the numerical probabilities corresponding to PC = 1 are nonzero, the Risk of HL calculations will be some small values greater than zero taking the effect of the consequence class into account. For example, this can be the case when assessing the risks of coastal erosion to Taubanestasjonen while knowing that this hazard is not relevant there. The numerical probabilities can easily be adjusted by the user in the risk analysis tool.

Another particularity of the methodology is that attention needs to be paid to both the aggregated risk of HL and the combination of PC and CC. A combination where both PC and CC values have the class of "5" may occur, which represents a high-risk situation that requires attention. In the present version of the Excel tool, objects with such a PC and CC combination can be identified from the risk matrix during the qualitative analysis phase. This feature is currently not available for the quantitative analysis section of the tool focusing on the risk of HL but such objects are highly likely to be found at the top of the risk ranking.

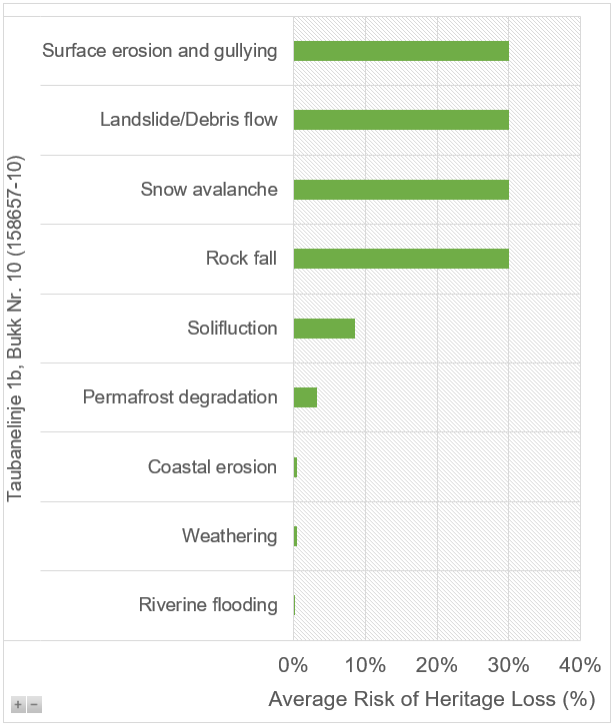


Figure 10. Contribution of different natural hazards to the risk of HL for Taubanelinje 1b, Bukk Nr. 10.

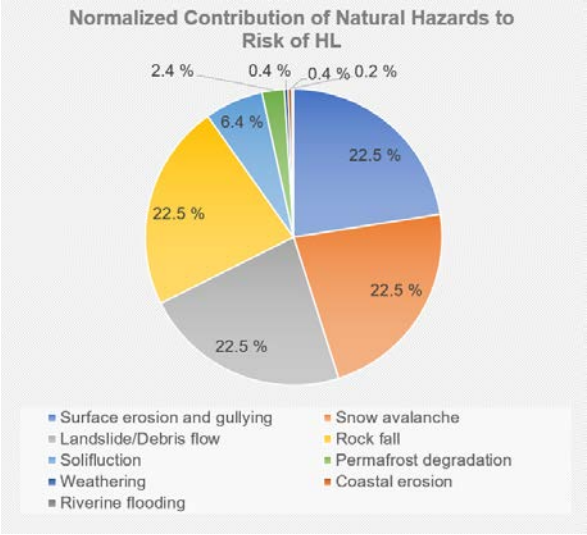


Figure 11. Pie chart presenting aggregated risk of HL from different natural hazards to Post nr. 10 at cable car line 1b.

7 Results and Discussion

A coarse risk analysis has been conducted to identify potential risks to heritage objects in the towns of Longyearbyen and Ny-Ålesund. The analysis yielded a risk ranking for all heritage objects, offering valuable insights for prioritizing risk mitigation efforts. Additionally, the cable car lines (Taubanelinjene) in the area were individually analyzed and ranked to assess their level of risk. It is important to note that risks associated with windstorms were not included in the analysis.

7.1 Heritage Objects in Longyearbyen

7.1.1 Overall Risk Ranking for Heritage Objects in Longyearbyen

Figure 12 presents the highest ranked cultural heritage objects in Longyearbyen (up the 20th place, several objects may have similar ranking) in terms of the aggregated average risk of HL. It can be seen from the results that objects within the cable car line 1b appear to be the most exposed to the combined effect of multiple natural hazards. It is also the oldest line among the remaining lines in Longyearbyen (hence a higher damage due to fungi decay may be expected). Concerning exposure to the aggregated risk, the cable car Line 1b is followed by several cable way posts on the line 2b, entrances to the Mines 6, 2b, 5 and 1a, and posts on lines 5-6, 5, and 1a.

An aggregated risk analysis for all locations (including locations of absent/destroyed objects) for the top 20 places in overall ranking is presented in Figure 13. It is possible to distinguish from this figure that several objects from the top part of the list are destroyed due to the action of snow avalanches, and several – probably due to the rot decay of material.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 1b, Bukk Nr. 10 (158657-10)	133.07 %	1
Taubanelinje 1b, Bukk Nr. 1 (158657-1)	115.84 %	2
Taubanelinje 1b, Bukk Nr. 2 (158657-2)	108.84 %	3
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	99.12 %	4
Taubanelinje 1b, Bukk Nr. 19 (158657-19)	99.12 %	4
Taubanelinje 1b, Bukk Nr. 11 (158657-11)	95.25 %	5
Taubanelinje 1b, Bukk Nr. 15 (158657-15)	94.99 %	6
Taubanelinje 1b, Bukk Nr. 16 (158657-16)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 20 (158657-20)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 14 (158657-14)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 8 (158657-8)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 13 (158657-13)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 5 (158657-5)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 3 (158657-3)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 4 (158657-4)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 18 (158657-18)	93.40 %	7
Taubanelinje 1b, Bukk Nr. 6 (158657-6)	93.40 %	7
Taubanelinje 1b, Strammestasjon (158657-25)	92.80 %	8
Taubanelinje 1b, Bukk Nr. 12 (158657-12)	92.80 %	8
Taubanelinje 2b, Bukk Nr. 6 (158986-6)	73.82 %	9
Taubanelinje 2b, Bukk Nr. 5 (158986-5)	71.59 %	10
Taubanelinje 2b, Bukk Nr. 1 (158986-1)	69.05 %	11
Gruve 6, Daganlegget Bygning Sør (87889-9)	67.82 %	12
Gruve 6, Daganlegget Bygning Nord (87889-3)	67.82 %	12
Gruve 6, Daganlegget Bygning Aust (87889-8)	67.82 %	12
Gruve2b (136716)	65.68 %	13
Gruve 5 (87889-4)	65.68 %	13
Gruve 1a (136713)	65.57 %	14
Taubanelinje G5-6, Strammestasjon Vanntårnet (87889-2)	59.12 %	15
Taubanelinje G5-6, Bukk Nr. 34 (87889-43)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 30 (87889-39)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 25 (87889-33)	57.09 %	16
Taubanelinje G5, Bukk Nr. 10 (87889-69)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 38 (87889-47)	57.09 %	16
Taubanelinje G5, Bukk Nr. 7 (87889-72)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 31 (87889-40)	57.09 %	16
Taubanelinje G5, Bukk Nr. 14 (87889-65)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 29 (87889-38)	57.09 %	16
Taubanelinje G5, Bukk Nr. 12 (87889-67)	57.09 %	16
Taubanelinje G5-6, Bukk Nr. 44 (87889-53)	57.09 %	16
Taubanelinje G5, Bukk Nr. 9 (87889-70)	57.09 %	16
Taubanelinje G5, Bukk Nr. 8 (87889-71)	57.09 %	16
Taubanelinje G5, Bukk Nr. 11 (87889-68)	57.09 %	16
Taubanelinje G6, Bukk Nr. 2 (87889-117)	53.59 %	17
Taubanelinje 2b, Bukk Nr. 7 (158986-7)	52.97 %	18
Taubanelinje G5-6, Bukk Nr. 21 (87889-29)	51.37 %	19
Taubanelinje G5-6, Bukk Nr. 9 (87889-17)	51.37 %	19
Taubanelinje G5-6, Bukk Nr. 16 (87889-24)	51.37 %	19
Taubanelinje G5-6, Bukk Nr. 15 (87889-23)	51.37 %	19
Taubanelinje 1a, Foundation 8 (159054-8)	51.30 %	20
Taubanelinje 1a, Foundation 6 (159054-6)	51.30 %	20
Taubanelinje 1a, Foundation 7 (159054-7)	51.30 %	20
Taubanelinje 1a, Foundation 1 (159054-1)	51.30 %	20
Taubanelinje 1a, Foundation 5 (159054-5)	51.30 %	20
Taubanelinje 1a, Foundation 4 (159054-4)	51.30 %	20
Taubanelinje 1a, Foundation 3 (159054-3)	51.30 %	20
Taubanelinje 1a, Foundation 2 (159054-2)	51.30 %	20
Taubanelinje 1a, Foundation 11 (159054-11)	51.30 %	20
Taubanelinje 1a, Foundation 10 (159054-10)	51.30 %	20
Taubanelinje 1a, Foundation 9 (159054-9)	51.30 %	20

Figure 12. The highest ranked cultural heritage objects in Longyearbyen in terms of the aggregated average risk of HL.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 1b, Bukk Nr. 10 (158657-10)	133.07 %	1
Taubanelinje 1b, Bukk Nr. 9 (158657-9)	122.87 %	2
Taubanelinje 1b, Bukk Nr. 1 (158657-1)	115.84 %	3
Taubanelinje 1b, Bukk Nr. 2 (158657-2)	108.84 %	4
Taubanelinje 1b, Bukk Nr. 21 (158657-21)	99.12 %	5
Taubanelinje 1b, Bukk Nr. 19 (158657-19)	99.12 %	5
Taubanelinje 1b, Bukk Nr. 22 (158657-22)	98.25 %	6
Taubanelinje 1b, Bukk Nr. 11 (158657-11)	95.25 %	7
Taubanelinje 1b, Bukk Nr. 15 (158657-15)	94.99 %	8
Taubanelinje 1b, Bukk Nr. 17 (158657-17)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 5 (158657-5)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 8 (158657-8)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 16 (158657-16)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 7 (158657-7)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 14 (158657-14)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 13 (158657-13)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 4 (158657-4)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 6 (158657-6)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 18 (158657-18)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 20 (158657-20)	93.40 %	9
Taubanelinje 1b, Bukk Nr. 3 (158657-3)	93.40 %	9
Taubanelinje 1a, Foundation 5 (159054-5)	92.80 %	10
Taubanelinje 1a, Foundation 11 (159054-11)	92.80 %	10
Taubanelinje 1a, Foundation 3 (159054-3)	92.80 %	10
Taubanelinje 1b, Strammestasjon (158657-25)	92.80 %	10
Taubanelinje 1a, Foundation 6 (159054-6)	92.80 %	10
Taubanelinje 1b, Bukk Nr. 12 (158657-12)	92.80 %	10
Taubanelinje 1a, Foundation 4 (159054-4)	92.80 %	10
Taubanelinje 1a, Foundation 1 (159054-1)	92.80 %	10
Taubanelinje 1a, Foundation 2 (159054-2)	92.80 %	10
Taubanelinje 1a, Foundation 8 (159054-8)	92.80 %	10
Taubanelinje 1a, Foundation 10 (159054-10)	92.80 %	10
Taubanelinje 1a, Foundation 7 (159054-7)	92.80 %	10
Taubanelinje 1a, Foundation 9 (159054-9)	92.80 %	10
Taubanelinje 2b, Bukk Nr. 4 (158986-4)	74.50 %	11
Taubanelinje 2b, Bukk Nr. 6 (158986-6)	73.82 %	12
Taubanelinje G5-6, Bukk Nr. 28b (87889-37)	71.59 %	13
Taubanelinje 2b, Bukk Nr. 5 (158986-5)	71.59 %	13
Taubanelinje G5-6, Bukk Nr. 28c (87889-36)	71.59 %	13
Taubanelinje 2b, Bukk Nr. 2 (158986-2)	71.00 %	14
Taubanelinje 2b, Bukk Nr. 3 (158986-3)	71.00 %	14
Taubanelinje 2b, Bukk Nr. 1 (158986-1)	69.05 %	15
Gruve 6, Daganlegget Bygning Nord (87889-3)	67.82 %	16
Gruve 6, Daganlegget Bygning Sør (87889-9)	67.82 %	16
Gruve 6, Daganlegget Bygning Aust (87889-8)	67.82 %	16
Gruve2b (136716)	65.68 %	17
Gruve 5 (87889-4)	65.68 %	17
Gruve 1a (136713)	65.57 %	18
Taubanelinje G5-6, Bukk Nr. 33 (87889-42)	63.89 %	19
Taubanelinje G5-6, Strammestasjon Vanntårnet (87889-2)	59.12 %	20

Figure 13. Aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje 1b. Red rectangular presents absent objects.

Also, as an input in validation of methodology, ranking for 5 most affected objects on each line is presented in Table 9. The cases that are taken into considerations for validation are marked in red (those cases exclude permafrost degradation and rot decay as the main factors causing collapse of a structure, see description of validation in Ch. 5.2.2). In four cases (see cases in red in Table 9) the structures exposed to highest risks were destroyed by snow avalanches. This supports relevance of the hazard evaluations (on snow avalanches) that were used to determine to the Probability Class (PC), and the ability of methodology to evaluate the risk. It is interesting to note that in two other cases (market in green in Table 9) structures located on a steep terrain and exposed to the highest risks had capsized due to rot decay (combined with higher wind loads?), but not as a result of an action of snow avalanches.

Table 9. Input in validation of methodology.

Line number, ID, five objects with highest risk of HL	Sum of Avg. Risk of HL, %	Existing objects: state	Absent objects: cause of damage
Taubanelinje 1a 159054			
Foundation 2	**93**	Still exists*	–
Foundation 9	**93**	Still exists*	–
Foundation 10	**93**	Still exists*	–
Foundation 8	**93**	Still exists*	–
Foundation 3	**93**	Still exists*	–
Taubanelinje 1b 158657			
Bukk Nr. 10	**133**	Still exists, vertical	–
Bukk Nr. 9	**123**	–	Capsized, laying on a side. Most probably due to the rot decay.
Bukk Nr. 1	**116**	Still exists, vertical	–
Bukk Nr. 2	**109**	Still exists, vertical	–
Bukk Nr. 19	**99**	Still exists, vertical	–
Taubanelinje 2a 158987			
Fundament Nr.1	**20**	Still exists*	–
Fundament maskinhus	**20**	Still exists*	–
Fundament Nr.4	**8**	Still exists*	–
Fundament Nr.3	**8**	Still exists*	–
Fundament Nr.2	**8**	Still exists*	–
Taubanelinje 2b 158986			
Bukk Nr. 4	**75**	–	Crashed by an avalanche.
Bukk Nr. 6	**74**	Still exists, vertical	
Bukk Nr. 5	**72**	Still exists, vertical	
Bukk Nr. 3	**71**	–	Fallen down, most probably due to the rot decay of foundation members, laying on the top of foundation.
Bukk Nr. 2	**71**	–	Crashed by an avalanche.
Taubane 3 158619			

Bukk Nr. 38	**54**	–	Upper structure is absent
Bukk Nr. 28	**51**	Vertical	–
Bukk Nr. 14	**50**	Vertical	–
Bukk Nr. 9	**48**	Vertical	–
Bukk Nr. 10	**48**	Vertical	–
Taubane delstrekning gruve 5 87889			
Bukk Nr. 7	**57**	Heavily tilted, attempt of foundation support	–
Bukk Nr. 14	**57**	Tilted down the slope. Rotten connection is broken, which lead to tilt (second observation of such failure)	–
Bukk Nr. 11	**57**	Vertical	–
Bukk Nr. 9	**57**	Vertical	–
Bukk Nr. 12	**57**	Heavily tilted down the slope	–
Taubane delstrekning gruve 5 og 6 87889			
Bukk 28c	**72**	–	Absent, probably crashed by a snow avalanche
Bukk 28b	**72**	–	Laying on the side, fallen probably due to rupture of foundation members because of rot.
Bukk Nr. 33	**64**	–	Absent, probably crashed by a snow avalanche
Strammestasjon Vanntårnet	**59**	Still exists, seemingly vertical	–
Bukk Nr. 29	**57**	Vertical	–
Taubane delstrekning gruve 6 8788957			
Bukk Nr. 2	**54**	Vertical	–
Strammestasjon Todalen	**49**	Seemingly vertical	–
Bukk Nr. 3	**47**	Vertical	–
Bukk Nr. 1	**40**	Vertical	–
Bukk Nr. 12b	**35**	Probably vertical	–

Note: *: According to the last evaluation of the authorities (Riksantikvaren).

Post nr. 10 in cable car line 1b (Taubanelinje 1b, Bukk Nr. 10) has the highest average risk of HL from combined hazards. This can further be analysed by looking at the contributions of specific natural hazards to the aggregated risk. Figure 10 shows the contributions from the natural hazards considered to the aggregated risk of HL for Taubanelinje 1b, Bukk. Nr. 10. As can be seen in the figure, slope hazards (landslides, rock falls and snow avalanches), surface erosion and gullying pose the highest risk to this specific object, followed by relatively smaller contributions from solifluction and permafrost degradation. A pie chart of the aggregated risk of HL at Post nr. 10 is shown in Figure 11.

7.1.2 Risk Ranking for Taubanelinje 1a Posts

In addition to the overall risk ranking for objects in Longyearbyen presented above, the study looked at each one of the cable car lines separately and identified the posts (*bukker*) and/or foundations (in cases when the posts are not existing any longer, but the foundation do) which have the highest aggregate risk of HL. Figure 14 shows a risk ranking for the foundations within Taubanelinje 1a. The coarse analysis here shows an equal level of risk for the foundations. Rock fall and Landslide/Debris flow are dominating hazards at this line.

Bar and pie charts with natural hazards that provide the biggest contribution to average risk of HL at Foundation 2 are presented in Figure 15 and Figure 16.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 1a, Foundation 2 (159054-2)	51.30 %	1
Taubanelinje 1a, Foundation 9 (159054-9)	51.30 %	1
Taubanelinje 1a, Foundation 10 (159054-10)	51.30 %	1
Taubanelinje 1a, Foundation 8 (159054-8)	51.30 %	1
Taubanelinje 1a, Foundation 3 (159054-3)	51.30 %	1
Taubanelinje 1a, Foundation 7 (159054-7)	51.30 %	1
Taubanelinje 1a, Foundation 11 (159054-11)	51.30 %	1
Taubanelinje 1a, Foundation 6 (159054-6)	51.30 %	1
Taubanelinje 1a, Foundation 1 (159054-1)	51.30 %	1
Taubanelinje 1a, Foundation 5 (159054-5)	51.30 %	1
Taubanelinje 1a, Foundation 4 (159054-4)	51.30 %	1

Figure 14. Risk ranking of posts within Taubanelinje 1a.

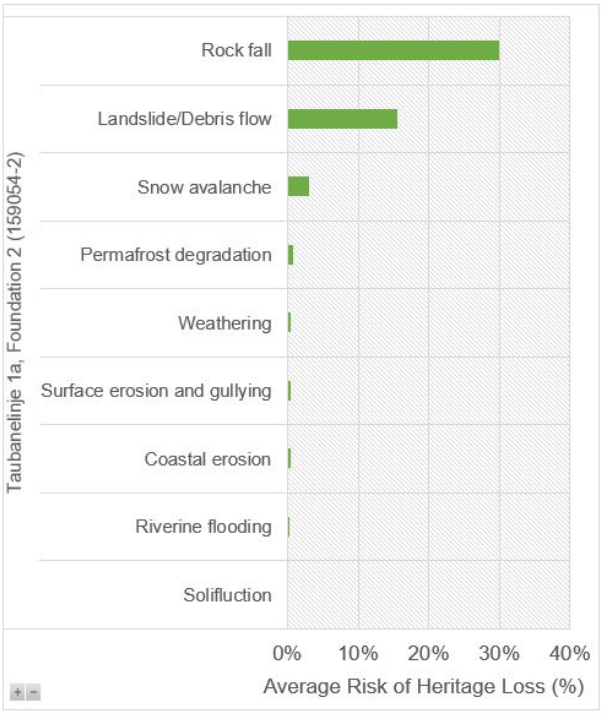


Figure 15. Contribution of different natural hazards to the risk of HL for Taubanelinje 1a, Foundation 2.

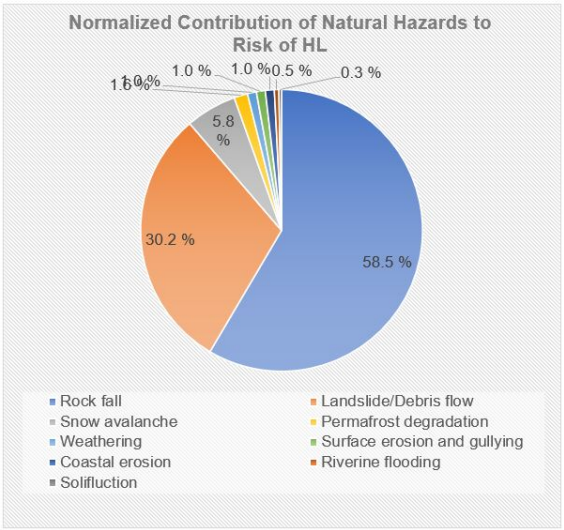


Figure 16. A pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje 1a, Foundation 2.

7.1.3 Risk Ranking for Taubanelinje 1b Posts

Figure 17 shows a ranking for posts within Taubanelinje 1b. As discussed earlier, Taubanelinje 1b was found to be the most exposed line in the overall ranking. A closer look at the contributing natural hazards has shown that slope hazards, surface erosion and gullying contribute the most to the aggregated risk of HL. Aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje 1b is presented in Figure 18.

Figure 10 and Figure 11 present bar and pie charts with natural hazards that provide biggest contribution to average risk of HL for most exposed Post Nr 10.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 1b, Bukk Nr. 10 (	133.07 %	1
Taubanelinje 1b, Bukk Nr. 1 (1	115.84 %	2
Taubanelinje 1b, Bukk Nr. 2 (1	108.84 %	3
Taubanelinje 1b, Bukk Nr. 21 (	99.12 %	4
Taubanelinje 1b, Bukk Nr. 19 (	99.12 %	4
Taubanelinje 1b, Bukk Nr. 11 (	95.25 %	5
Taubanelinje 1b, Bukk Nr. 15 (	94.99 %	6
Taubanelinje 1b, Bukk Nr. 16 (	93.40 %	7
Taubanelinje 1b, Bukk Nr. 4 (1	93.40 %	7
Taubanelinje 1b, Bukk Nr. 14 (	93.40 %	7
Taubanelinje 1b, Bukk Nr. 8 (1	93.40 %	7
Taubanelinje 1b, Bukk Nr. 13 (	93.40 %	7
Taubanelinje 1b, Bukk Nr. 6 (1	93.40 %	7
Taubanelinje 1b, Bukk Nr. 3 (1	93.40 %	7
Taubanelinje 1b, Bukk Nr. 5 (1	93.40 %	7
Taubanelinje 1b, Bukk Nr. 18 (	93.40 %	7
Taubanelinje 1b, Bukk Nr. 20 (	93.40 %	7
Taubanelinje 1b, Bukk Nr. 12 (	92.80 %	8
Taubanelinje 1b, Strammestas	92.80 %	8
Taubanelinje 1b, Bukk Nr. 24 (	36.50 %	9
Taubanelinje 1b, Bukk Nr. 23 (	33.87 %	10
Taubanelinje 1b, Bukk Nr. 9 (1	#N/A	
Taubanelinje 1b, Bukk Nr. 17 (	#N/A	
Taubanelinje 1b, Bukk Nr. 22 (	#N/A	
Taubanelinje 1b, Bukk Nr. 7 (1	#N/A	

Figure 17. Risk ranking of posts within Taubanelinje 1b.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 1b, Bukk Nr. 10 (	133.07 %	1
Taubanelinje 1b, Bukk Nr. 9 (1	122.87 %	2
Taubanelinje 1b, Bukk Nr. 1 (1	115.84 %	3
Taubanelinje 1b, Bukk Nr. 2 (1	108.84 %	4
Taubanelinje 1b, Bukk Nr. 19 (	99.12 %	5
Taubanelinje 1b, Bukk Nr. 21 (	99.12 %	5
Taubanelinje 1b, Bukk Nr. 22 (	98.25 %	6
Taubanelinje 1b, Bukk Nr. 11 (	95.25 %	7
Taubanelinje 1b, Bukk Nr. 15 (	94.99 %	8
Taubanelinje 1b, Bukk Nr. 17 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 3 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 8 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 16 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 7 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 14 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 13 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 5 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 6 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 4 (1	93.40 %	9
Taubanelinje 1b, Bukk Nr. 18 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 20 (	93.40 %	9
Taubanelinje 1b, Bukk Nr. 12 (	92.80 %	10
Taubanelinje 1b, Strammestas	92.80 %	10
Taubanelinje 1b, Bukk Nr. 24 (	36.50 %	11
Taubanelinje 1b, Bukk Nr. 23 (	33.87 %	12

Figure 18. Risk ranking for all locations (including the locations of absent/destroyed objects) at the Taubanelinje 1b.

7.1.4 Risk Ranking for Taubanelinje 2a foundations

Figure 19 shows a risk ranking for the objects in Taubanelinje 2a. Bar chart on Figure 20 and pie chart on Figure 21 show the contribution from different natural hazards for the top ranked foundation, i.e. Taubanelinje 2a, Foundament Nr. 1 (Fundament Nr. 2 is equally exposed). The plot shows that landslide/debris flow, permafrost degradation and solifluction contribute the most to the aggregated risk.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 2a, Fundament Nr.1, NS (158987-1)	14.24 %	1
Taubanelinje 2a, Fundament maskinhus, NS (136714-3)	14.24 %	1
Taubanelinje 2a, Fundament Nr.4, NS (158987-4)	7.94 %	2
Taubanelinje 2a, Fundament Nr.3, NS (158987-3)	7.94 %	2
Taubanelinje 2a, Fundament Nr.2, NS (158987-2)	7.48 %	3

Figure 19. Risk ranking of posts within Taubanelinje 2a.

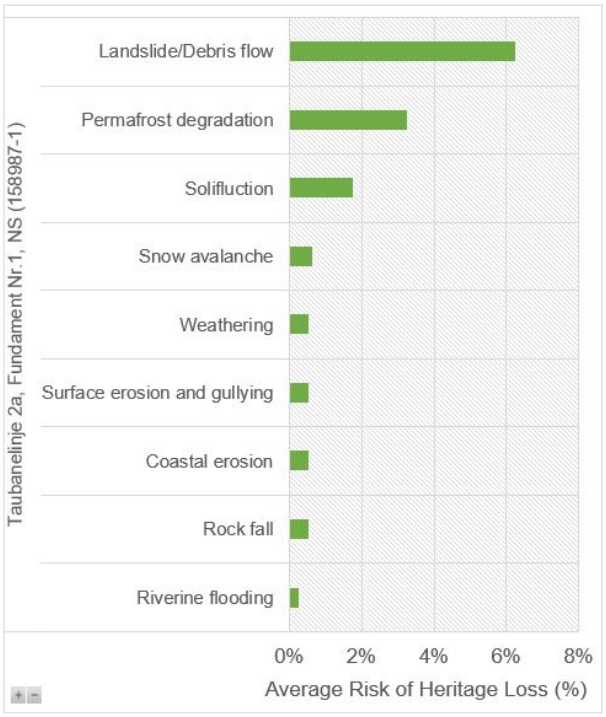


Figure 20. Contribution of different natural hazards to the risk of HL for Taubanelinje 2a, Foundation 1.

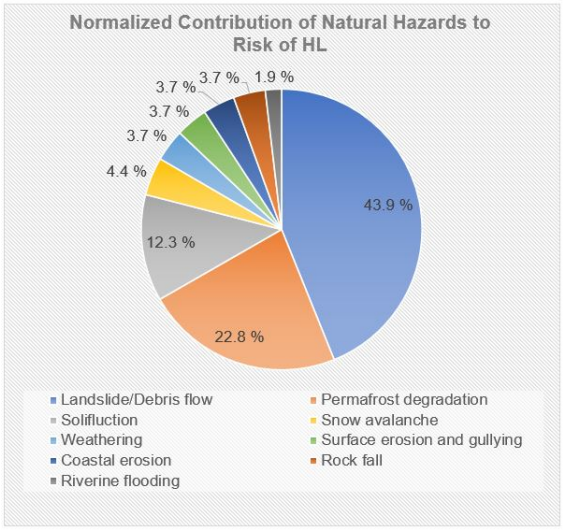


Figure 21. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje 2a, Foundation 1.

7.1.5 Risk Ranking for Taubanelinje 2b Posts

Figure 22 shows a risk ranking for the objects in Taubanelinje 2b. The aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje 1b is presented in Figure 23.

Figure 24 and Figure 25 show the contribution from different natural hazards for the top ranked post i.e. Taubanelinje 2b, Bukk Nr. 6. The overall ranking shows that the aggregated risk of HL shows a large variation for the different posts within the cable car line. It can be seen that landslide/debris flow and snow avalanche contribute the most to the aggregated risk.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 2b, Bukk Nr. 6 ('	73.82 %	1
Taubanelinje 2b, Bukk Nr. 5 ('	71.59 %	2
Taubanelinje 2b, Bukk Nr. 1 ('	69.05 %	3
Taubanelinje 2b, Bukk Nr. 7 ('	52.97 %	4
Taubanelinje 2b, Bukk Nr. 13	30.41 %	5
Taubanelinje 2b, Bukk Nr. 8 ('	23.49 %	6
Taubanelinje 2b, Bukk Nr. 16	8.05 %	7
Taubanelinje 2b, Bukk Nr. 11	6.92 %	8
Taubanelinje 2b, Bukk Nr. 17	6.92 %	8
Taubanelinje 2b, Vinkelstasjo	6.92 %	8
Taubanelinje 2b, Bukk Nr. 18	6.92 %	8
Taubanelinje 2b, Bukk Nr. 15	6.46 %	9
Taubanelinje 2b, Bukk Nr. 12	#N/A	
Taubanelinje 2b, Bukk Nr. 4 ('	#N/A	
Taubanelinje 2b, Bukk Nr. 9 ('	#N/A	
Taubanelinje 2b, Bukk Nr. 10	#N/A	
Taubanelinje 2b, Bukk Nr. 14	#N/A	
Taubanelinje 2b, Bukk Nr. 3 ('	#N/A	
Taubanelinje 2b, Bukk Nr. 2 ('	#N/A	

Figure 22. Risk ranking of posts within Taubanelinje 2b.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 2b, Bukk Nr. 4 ('	74.50 %	1
Taubanelinje 2b, Bukk Nr. 6 ('	73.82 %	2
Taubanelinje 2b, Bukk Nr. 5 ('	71.59 %	3
Taubanelinje 2b, Bukk Nr. 3 ('	71.00 %	4
Taubanelinje 2b, Bukk Nr. 2 ('	71.00 %	4
Taubanelinje 2b, Bukk Nr. 1 ('	69.05 %	5
Taubanelinje 2b, Bukk Nr. 7 ('	52.97 %	6
Taubanelinje 2b, Bukk Nr. 13	30.41 %	7
Taubanelinje 2b, Bukk Nr. 8 ('	23.49 %	8
Taubanelinje 2b, Bukk Nr. 14	12.81 %	9
Taubanelinje 2b, Bukk Nr. 9 ('	12.05 %	10
Taubanelinje 2b, Bukk Nr. 10	12.05 %	10
Taubanelinje 2b, Bukk Nr. 12	9.82 %	11
Taubanelinje 2b, Bukk Nr. 16	8.05 %	12
Taubanelinje 2b, Bukk Nr. 11	6.92 %	13
Taubanelinje 2b, Vinkelstasjo	6.92 %	13
Taubanelinje 2b, Bukk Nr. 17	6.92 %	13
Taubanelinje 2b, Bukk Nr. 18	6.92 %	13
Taubanelinje 2b, Bukk Nr. 15	6.46 %	14

Figure 23. Risk ranking for all locations (including the locations of absent/destroyed objects) at the Taubanelinje 2b.

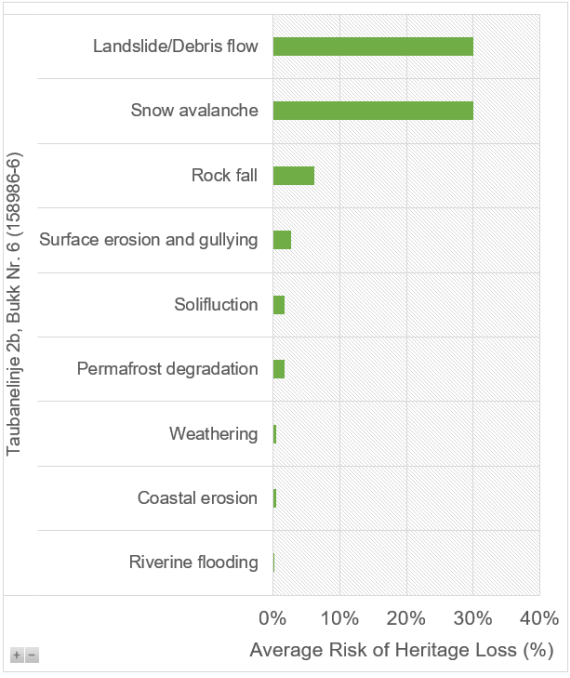


Figure 24. Contribution of different natural hazards to the risk of HL for Taubanelinje 2b, Bukk Nr. 6.

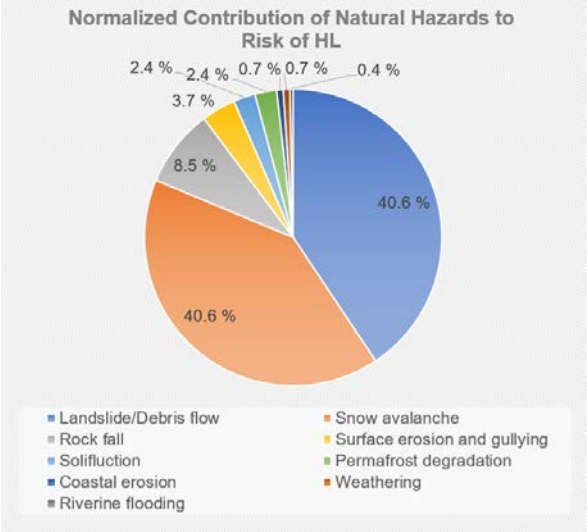


Figure 25. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje 2b, Bukk Nr. 6.

7.1.6 Risk Ranking for Taubanelinje 3 Posts

Figure 26 shows a risk ranking for the objects in Taubanelinje 3. Aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje 3 is presented in Figure 27.

Figure 28 and Figure 29 show the contribution from different natural hazards for the top ranked post i.e. Taubanelinje 3, Bukk Nr. 28. The overall ranking shows that the aggregated risk of HL shows a slight variation for the different posts within the cable car line. Permafrost degradation and landslide/debris are observed to be the natural hazards that contribute the most to the aggregated risk, followed by solifluction.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 3, Bukk Nr. 28	50.84 %	1
Taubanelinje 3, Bukk Nr. 14	49.87 %	2
Taubanelinje 3, Bukk Nr. 10	48.27 %	3
Taubanelinje 3, Bukk Nr. 9 ('	48.27 %	3
Taubanelinje 3, Bukk Nr. 3 ('	48.27 %	3
Taubanelinje 3, Bukk Nr. 27	45.12 %	4
Taubanelinje 3, Bukk Nr. 32	45.12 %	4
Taubanelinje 3, Bukk Nr. 24	45.12 %	4
Taubanelinje 3, Bukk Nr. 29	45.12 %	4
Taubanelinje 3, Bukk Nr. 36	45.12 %	5
Taubanelinje 3, Bukk Nr. 15	44.09 %	6
Taubanelinje 3, Bukk Nr. 19	42.50 %	7
Taubanelinje 3, Bukk Nr. 31	39.39 %	8
Taubanelinje 3, Bukk Nr. 30	39.39 %	8
Taubanelinje 3, Bukk Nr. 39	39.39 %	9
Taubanelinje 3, Bukk Nr. 40	39.39 %	9
Taubanelinje 3, Bukk Nr. 41 (	39.39 %	9
Taubanelinje 3, Bukk Nr. 21	38.37 %	10
Taubanelinje 3, Bukk Nr. 23	36.77 %	11
Taubanelinje 3, Bukk Nr. 35	32.87 %	12
Taubanelinje 3, Bukk Nr. 18	32.64 %	13
Taubanelinje 3, Bukk Nr. 26	32.64 %	13
Taubanelinje 3, Bukk Nr. 20	32.64 %	13
Taubanelinje 3, Bukk Nr. 11	31.05 %	14
Taubanelinje 3, Bukk Nr. 34	27.14 %	15
Taubanelinje 3, Bukk Nr. 33	27.14 %	15
Taubanelinje 3, Bukk Nr. 37	27.14 %	15
Taubanelinje 3, Strammesta:	23.39 %	16
Taubanelinje 3, Bukk Nr. 22	21.02 %	17
Taubanelinje 3, Bukk Nr. 8 ('	20.39 %	18
Taubanelinje 3, Bukk Nr. 12	20.39 %	18
Taubanelinje 3, Bukk Nr. 25	20.39 %	18
Taubanelinje 3, Bukk Nr. 13	20.39 %	18
Taubanelinje 3, Bukk Nr. 6 ('	20.39 %	18
Taubanelinje 3, Bukk Nr. 17	20.39 %	18
Taubanelinje 3, Bukk Nr. 2 ('	20.39 %	18
Taubanelinje 3, Bukk Nr. 5 ('	20.39 %	18
Taubanelinje 3, Bukk Nr. 1 ('	18.80 %	19
Taubanelinje 3, Bukk Nr. 4 ('	18.80 %	19
Taubanelinje 3, Bukk Nr. 16	18.80 %	19
Taubanelinje 3, Bukk Nr. 7 ('	18.80 %	19
Taubanelinje 3, Bukk Nr. 38	#N/A	

Figure 26. Risk ranking of posts within Taubanelinje 3.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje 3, Bukk Nr. 38	53.89 %	1
Taubanelinje 3, Bukk Nr. 28	50.84 %	2
Taubanelinje 3, Bukk Nr. 14	49.87 %	3
Taubanelinje 3, Bukk Nr. 9 (	48.27 %	4
Taubanelinje 3, Bukk Nr. 10	48.27 %	4
Taubanelinje 3, Bukk Nr. 3 (	48.27 %	4
Taubanelinje 3, Bukk Nr. 27	45.12 %	5
Taubanelinje 3, Bukk Nr. 32	45.12 %	5
Taubanelinje 3, Bukk Nr. 24	45.12 %	5
Taubanelinje 3, Bukk Nr. 29	45.12 %	5
Taubanelinje 3, Bukk Nr. 36	45.12 %	6
Taubanelinje 3, Bukk Nr. 15	44.09 %	7
Taubanelinje 3, Bukk Nr. 19	42.50 %	8
Taubanelinje 3, Bukk Nr. 31	39.39 %	9
Taubanelinje 3, Bukk Nr. 30	39.39 %	9
Taubanelinje 3, Bukk Nr. 41	39.39 %	10
Taubanelinje 3, Bukk Nr. 39	39.39 %	10
Taubanelinje 3, Bukk Nr. 40	39.39 %	10
Taubanelinje 3, Bukk Nr. 21	38.37 %	11
Taubanelinje 3, Bukk Nr. 23	36.77 %	12
Taubanelinje 3, Bukk Nr. 35	32.87 %	13
Taubanelinje 3, Bukk Nr. 18	32.64 %	14
Taubanelinje 3, Bukk Nr. 26	32.64 %	14
Taubanelinje 3, Bukk Nr. 20	32.64 %	14
Taubanelinje 3, Bukk Nr. 11	31.05 %	15
Taubanelinje 3, Bukk Nr. 37	27.14 %	16
Taubanelinje 3, Bukk Nr. 33	27.14 %	16
Taubanelinje 3, Bukk Nr. 34	27.14 %	16
Taubanelinje 3, Strammesta	23.39 %	17
Taubanelinje 3, Bukk Nr. 22	21.02 %	18
Taubanelinje 3, Bukk Nr. 17	20.39 %	19
Taubanelinje 3, Bukk Nr. 12	20.39 %	19
Taubanelinje 3, Bukk Nr. 13	20.39 %	19
Taubanelinje 3, Bukk Nr. 5 (	20.39 %	19
Taubanelinje 3, Bukk Nr. 8 (	20.39 %	19
Taubanelinje 3, Bukk Nr. 25	20.39 %	19
Taubanelinje 3, Bukk Nr. 2 (	20.39 %	19
Taubanelinje 3, Bukk Nr. 6 (	20.39 %	19
Taubanelinje 3, Bukk Nr. 1 (	18.80 %	20
Taubanelinje 3, Bukk Nr. 16	18.80 %	20
Taubanelinje 3, Bukk Nr. 7 (	18.80 %	20
Taubanelinje 3, Bukk Nr. 4 (	18.80 %	20

Figure 27. Risk ranking for all locations (including the locations of absent/destroyed objects) at the Taubanelinje 3.

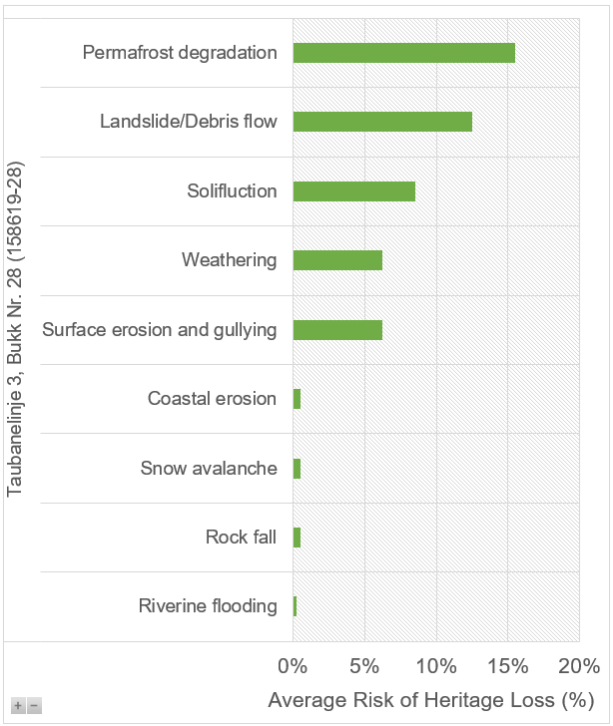


Figure 28. Contribution of different natural hazards to the risk of HL for Taubanelinje 3, Bukk Nr. 28.

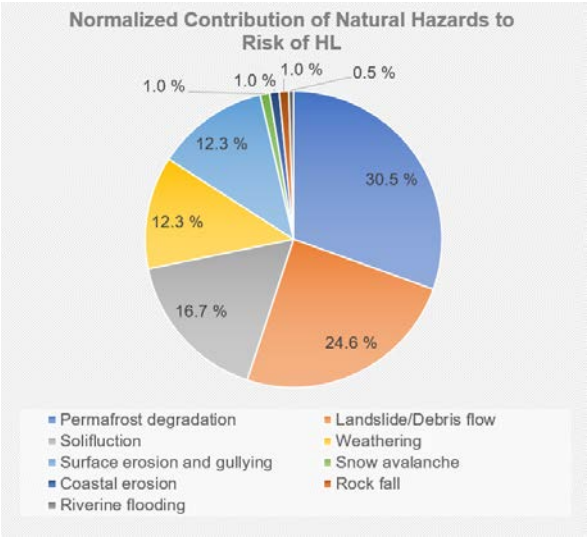


Figure 29. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje 3, Bukk Nr. 28.

7.1.7 Risk Ranking for Taubanelinje Delstrekning Gruve 5 Posts

Figure 30 shows a risk ranking for the objects in Taubanelinje G5 (Delstrekning Gruve 5). Aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje G5 is presented in Figure 31.

Figure 32 and Figure 33 show the contribution from different natural hazards for the top ranked post i.e. Taubanelinje G5, Bukk Nr. 11. The overall ranking shows that the aggregated risk of HL shows a slight variation for the different posts within the cable car line. Permafrost degradation is observed to be the natural hazard that contributes the most to the aggregated risk. Slope hazards (landslides/debris flows, snow avalanche and rock fall) also have a high contribution to the aggregated risk.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje G5, Bukk Nr. 11	57.09 %	1
Taubanelinje G5, Bukk Nr. 14	57.09 %	1
Taubanelinje G5, Bukk Nr. 10	57.09 %	1
Taubanelinje G5, Bukk Nr. 9 (8	57.09 %	1
Taubanelinje G5, Bukk Nr. 12	57.09 %	1
Taubanelinje G5, Bukk Nr. 8 (8	57.09 %	1
Taubanelinje G5, Bukk Nr. 7 (8	57.09 %	1
Taubanelinje G5, Bukk Nr. 13	50.09 %	2
Taubanelinje G5, Bukk Nr. 15	43.34 %	3
Taubanelinje G5, Bukk Nr. 18	43.34 %	3
Taubanelinje G5, Bukk Nr. 23	42.39 %	4
Taubanelinje G5, Bukk Nr. 17	42.39 %	4
Taubanelinje G5, Bukk Nr. 22	42.39 %	4
Taubanelinje G5, Bukk Nr. 20	37.84 %	5
Taubanelinje G5, Bukk Nr. 16	37.84 %	5
Taubanelinje G5, Bukk Nr. 21	37.84 %	5
Taubanelinje G5, Bukk Nr. 1 (8	36.50 %	6
Taubanelinje G5, Bukk Nr. 2 (8	33.87 %	7
Taubanelinje G5, Strammesta:	#N/A	
Taubanelinje G5, Bukk Nr. 4 (8	#N/A	
Taubanelinje G5, Bukk Nr. 19	#N/A	
Taubanelinje G5, Bukk Nr. 3 (8	#N/A	
Taubanelinje G5, Bukk Nr. 5 (8	#N/A	

Figure 30. Risk ranking of posts within Taubanelinje G5.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje G5, Bukk Nr. 7 (	57.09 %	1
Taubanelinje G5, Bukk Nr. 14	57.09 %	1
Taubanelinje G5, Bukk Nr. 11	57.09 %	1
Taubanelinje G5, Bukk Nr. 9 (	57.09 %	1
Taubanelinje G5, Bukk Nr. 12	57.09 %	1
Taubanelinje G5, Bukk Nr. 8 (	57.09 %	1
Taubanelinje G5, Bukk Nr. 10	57.09 %	1
Taubanelinje G5, Bukk Nr. 13	50.09 %	2
Taubanelinje G5, Bukk Nr. 18	43.34 %	3
Taubanelinje G5, Bukk Nr. 15	43.34 %	3
Taubanelinje G5, Bukk Nr. 17	42.39 %	4
Taubanelinje G5, Bukk Nr. 23	42.39 %	4
Taubanelinje G5, Bukk Nr. 22	42.39 %	4
Taubanelinje G5, Bukk Nr. 4 (	39.50 %	5
Taubanelinje G5, Bukk Nr. 5 (	39.50 %	5
Taubanelinje G5, Bukk Nr. 3 (	39.50 %	5
Taubanelinje G5, Bukk Nr. 16	37.84 %	6
Taubanelinje G5, Bukk Nr. 21	37.84 %	6
Taubanelinje G5, Bukk Nr. 20	37.84 %	6
Taubanelinje G5, Bukk Nr. 1 (	36.50 %	7
Taubanelinje G5, Strammesta	36.50 %	7
Taubanelinje G5, Bukk Nr. 19	36.25 %	8
Taubanelinje G5, Bukk Nr. 2 (	33.87 %	9

Figure 31. Risk ranking for all locations (including the locations of absent/destroyed objects) at the Taubanelinje G5.

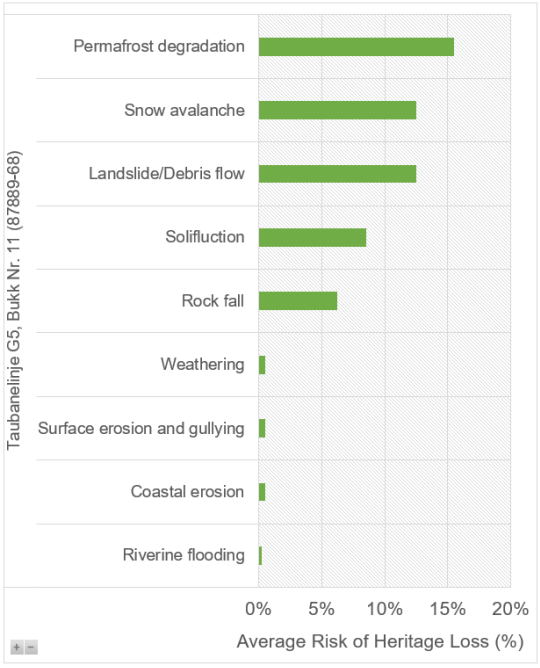


Figure 32. Contribution of different natural hazards to the risk of HL for Taubanelinje G5, Bukk Nr. 11.

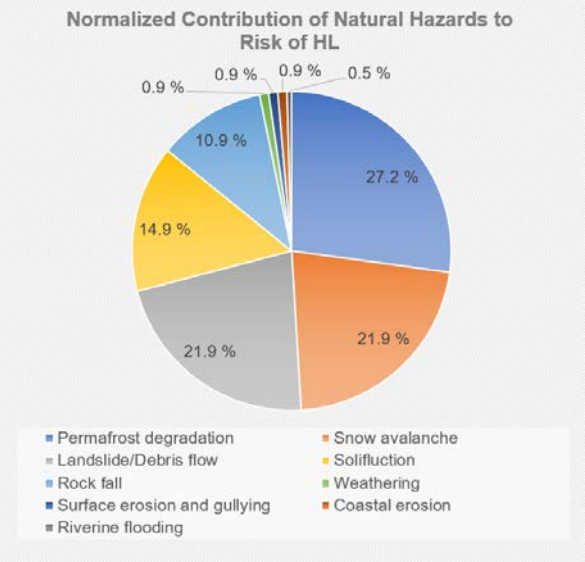


Figure 33. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje G5, Bukk Nr. 11.

7.1.8 Risk Ranking for Taubanelinje Delstrekning Gruve 5 og Gruve 6 Posts

Figure 34 shows a risk ranking for the objects in Taubanelinje G5-6 (Delstrekning Gruve 5 og Gruve 6). Aggregated risk analysis for all locations (including locations of absent/destroyed objects) at the Taubanelinje G5-6 is presented in Figure 35.

Figure 36 and Figure 37 show the contribution from different natural hazards for the top ranked object i.e. Taubanelinje G5-6, Strammestasjon Vanntårnet (87889-2). The overall ranking shows that the aggregated risk of HL shows a high variation for the different posts within the cable car line. Permafrost degradation is observed to be the natural hazard that contributes the most to the aggregated risk. Slope hazards (landslides/debris flows, snow avalanche and rock fall) also have a high contribution to the aggregated risk, followed by solifluction.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje G5-6, Strammestas	59.12 %	1
Taubanelinje G5-6, Bukk Nr. 30 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 25 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 44 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 29 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 38 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 34 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 31 (i	57.09 %	2
Taubanelinje G5-6, Bukk Nr. 21 (i	51.37 %	3
Taubanelinje G5-6, Bukk Nr. 16 (i	51.37 %	3
Taubanelinje G5-6, Bukk Nr. 9 (8	51.37 %	3
Taubanelinje G5-6, Bukk Nr. 15 (i	51.37 %	3
Taubanelinje G5-6, Bukk Nr. 27 (i	50.34 %	4
Taubanelinje G5-6, Bukk Nr. 40 (i	50.09 %	5
Taubanelinje G5-6, Bukk Nr. 39 (i	50.09 %	5
Taubanelinje G5-6, Bukk Nr. 26 (i	50.09 %	5
Taubanelinje G5-6, Bukk Nr. 32 (i	49.39 %	6
Taubanelinje G5-6, Bukk Nr. 19 (i	44.62 %	7
Taubanelinje G5-6, Bukk Nr. 20 (i	44.62 %	7
Taubanelinje G5-6, Bukk Nr. 23 (i	44.62 %	7
Taubanelinje G5-6, Bukk Nr. 36 (i	44.59 %	8
Taubanelinje G5-6, Bukk Nr. 13 (i	44.37 %	9
Taubanelinje G5-6, Bukk Nr. 37 (i	43.34 %	10
Taubanelinje G5-6, Bukk Nr. 43 (i	43.34 %	10
Taubanelinje G5-6, Bukk Nr. 35 (i	43.34 %	10
Taubanelinje G5-6, Bukk Nr. 41 (i	41.75 %	11
Taubanelinje G5-6, Bukk Nr. 46 (i	41.75 %	11
Taubanelinje G5-6, Bukk Nr. 45 (i	41.75 %	11
Taubanelinje G5-6, Strammestas	38.09 %	12
Taubanelinje G5-6, Bukk Nr. 24 (i	37.62 %	13
Taubanelinje G5-6, Bukk Nr. 22 (i	37.62 %	13
Taubanelinje G5-6, Bukk Nr. 10 (i	37.62 %	13
Taubanelinje G5-6, Bukk Nr. 11 (i	37.62 %	13
Taubanelinje G5-6, Bukk Nr. 12 (i	36.67 %	14
Taubanelinje G5-6, Bukk Nr. 42 (i	35.00 %	15
Taubanelinje G5-6, Bukk Nr. 17 (i	30.87 %	16
Taubanelinje G5-6, Bukk Nr. 8 (8	15.17 %	17
Taubanelinje G5-6, Bukk Nr. 7 (8	8.42 %	18
Taubanelinje G5-6, Bukk Nr. 6 (8	7.47 %	19
Taubanelinje G5-6, Bukk Nr. 3 (8	6.82 %	20
Taubanelinje G5-6, Bukk Nr. 5 (8	6.82 %	20
Taubanelinje G5-6, Bukk Nr. 4 (8	6.46 %	21
Taubanelinje G5-6, Bukk Nr. 15b	#N/A	
Taubanelinje G5-6, Bukk Nr. 33 (i	#N/A	
Taubanelinje G5-6, Bukk Nr. 28b	#N/A	
Taubanelinje G5-6, Bukk Nr. 18 (i	#N/A	
Taubanelinje G5-6, Bukk Nr. 28c	#N/A	

Figure 34. Risk ranking of posts within Taubanelinje G5-6.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje G5-6, Bukk Nr. 28c	71.59 %	1
Taubanelinje G5-6, Bukk Nr. 28b	71.59 %	1
Taubanelinje G5-6, Bukk Nr. 33 (	63.89 %	2
Taubanelinje G5-6, Strammestas	59.12 %	3
Taubanelinje G5-6, Bukk Nr. 29 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 25 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 44 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 38 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 34 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 30 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 31 (	57.09 %	4
Taubanelinje G5-6, Bukk Nr. 21 (	51.37 %	5
Taubanelinje G5-6, Bukk Nr. 16 (	51.37 %	5
Taubanelinje G5-6, Bukk Nr. 9 (8	51.37 %	5
Taubanelinje G5-6, Bukk Nr. 15 (	51.37 %	5
Taubanelinje G5-6, Bukk Nr. 27 (	50.34 %	6
Taubanelinje G5-6, Bukk Nr. 40 (	50.09 %	7
Taubanelinje G5-6, Bukk Nr. 39 (	50.09 %	7
Taubanelinje G5-6, Bukk Nr. 26 (	50.09 %	7
Taubanelinje G5-6, Bukk Nr. 32 (	49.39 %	8
Taubanelinje G5-6, Bukk Nr. 19 (	44.62 %	9
Taubanelinje G5-6, Bukk Nr. 20 (	44.62 %	9
Taubanelinje G5-6, Bukk Nr. 23 (	44.62 %	9
Taubanelinje G5-6, Bukk Nr. 36 (	44.59 %	10
Taubanelinje G5-6, Bukk Nr. 13 (	44.37 %	11
Taubanelinje G5-6, Bukk Nr. 37 (	43.34 %	12
Taubanelinje G5-6, Bukk Nr. 43 (	43.34 %	12
Taubanelinje G5-6, Bukk Nr. 35 (	43.34 %	12
Taubanelinje G5-6, Bukk Nr. 41 (	41.75 %	13
Taubanelinje G5-6, Bukk Nr. 45 (	41.75 %	13
Taubanelinje G5-6, Bukk Nr. 46 (	41.75 %	13
Taubanelinje G5-6, Strammestas	38.09 %	14
Taubanelinje G5-6, Bukk Nr. 24 (	37.62 %	15
Taubanelinje G5-6, Bukk Nr. 11 (	37.62 %	15
Taubanelinje G5-6, Bukk Nr. 22 (	37.62 %	15
Taubanelinje G5-6, Bukk Nr. 10 (	37.62 %	15
Taubanelinje G5-6, Bukk Nr. 12 (	36.67 %	16
Taubanelinje G5-6, Bukk Nr. 15b	35.37 %	17
Taubanelinje G5-6, Bukk Nr. 18 (	35.37 %	17
Taubanelinje G5-6, Bukk Nr. 42 (	35.00 %	18
Taubanelinje G5-6, Bukk Nr. 17 (	30.87 %	19
Taubanelinje G5-6, Bukk Nr. 8 (8	15.17 %	20
Taubanelinje G5-6, Bukk Nr. 7 (8	8.42 %	21
Taubanelinje G5-6, Bukk Nr. 6 (8	7.47 %	22
Taubanelinje G5-6, Bukk Nr. 3 (8	6.82 %	23
Taubanelinje G5-6, Bukk Nr. 5 (8	6.82 %	23
Taubanelinje G5-6, Bukk Nr. 4 (8	6.46 %	24

Figure 35. Risk ranking for all locations (including the locations of absent/destroyed objects) at the Taubanelinje G5-6.

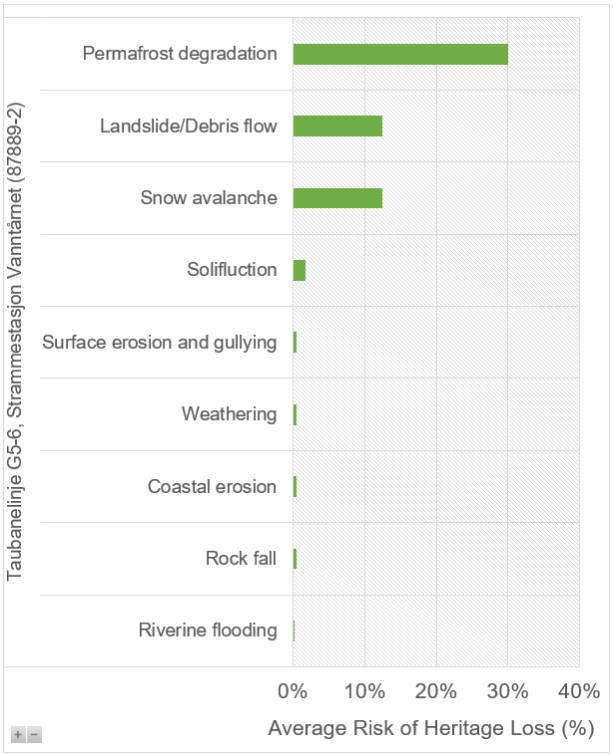


Figure 36. Contribution of different natural hazards to the risk of HL for Taubanelinje G5-6, Strammestasjon Vanntårnet (87889-2).

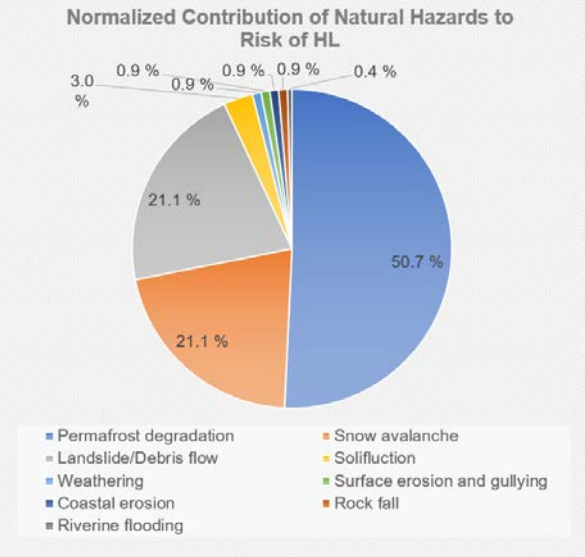


Figure 37. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje G5-6, Strammestasjon Vanntårnet (87889-2).

7.1.9 Risk Ranking for Taubanelinje Delstrekning Gruve 6 Posts

Figure 38 shows a risk ranking for the objects in Taubanelinje G6 (Delstrekning Gruve 6). Figure 39 and Figure 40 show the contribution from different natural hazards for the top ranked post i.e. Taubanelinje G6, Bukk Nr. 2. Similarly to Taubanelinje G5 and G5-6, slope hazards (landslides/debris flows, snow avalanche and rock fall) also have a high contribution to the aggregated risk for Bukk Nr. 2.

The overall ranking shows that the aggregated risk of HL shows a high variation for the different posts within the cable car line. Permafrost degradation is observed to be the natural hazard that contributes the most to the aggregated risk.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Taubanelinje G6, Bukk Nr. 2 (87889-117)	53.59 %	1
Taubanelinje G6, Strammestasjon Todalen (87889-11)	48.84 %	2
Taubanelinje G6, Bukk Nr. 3 (87889-116)	46.59 %	3
Taubanelinje G6, Bukk Nr. 1 (87889-118)	39.84 %	4
Taubanelinje G6, Bukk Nr. 12b (87889-106)	35.48 %	5
Taubanelinje G6, Bukk Nr. 19 (87889-100)	34.09 %	6
Taubanelinje G6, Bukk Nr. 17 (87889-101)	34.09 %	6
Taubanelinje G6, Bukk Nr. 16 (87889-102)	34.09 %	6
Taubanelinje G6, Bukk Nr. 21 (87889-98)	34.09 %	6
Taubanelinje G6, Bukk Nr. 22 (87889-97)	34.09 %	6
Taubanelinje G6, Bukk Nr. 32 (87889-87)	33.98 %	7
Taubanelinje G6, Bukk Nr. 34 (87889-85)	33.98 %	7
Taubanelinje G6, Bukk Nr. 14 (87889-104)	29.98 %	8
Taubanelinje G6, Bukk Nr. 13 (87889-105)	28.73 %	9
Taubanelinje G6, Bukk Nr. 15 (87889-103)	28.59 %	10
Taubanelinje G6, Bukk Nr. 10 (87889-109)	28.48 %	11
Taubanelinje G6, Bukk Nr. 25 (87889-94)	27.34 %	12
Taubanelinje G6, Bukk Nr. 24 (87889-95)	27.34 %	12
Taubanelinje G6, Bukk Nr. 23 (87889-96)	26.39 %	13
Taubanelinje G6, Bukk Nr. 33 (87889-86)	26.11 %	14
Taubanelinje G6, Bukk Nr. 29 (87889-90)	25.75 %	15
Taubanelinje G6, Bukk Nr. 31 (87889-88)	25.75 %	15
Taubanelinje G6, Bukk Nr. 28 (87889-91)	25.75 %	15
Taubanelinje G6, Bukk Nr. 36 (87889-83)	24.98 %	16
Taubanelinje G6, Bukk Nr. 35 (87889-84)	24.98 %	16
Taubanelinje G6, Bukk Nr. 12 (87889-107)	21.38 %	17
Taubanelinje G6, Bukk Nr. 4 (87889-115)	20.59 %	18
Taubanelinje G6, Bukk Nr. 27 (87889-92)	20.25 %	19
Taubanelinje G6, Bukk Nr. 37 (87889-82)	19.88 %	20
Taubanelinje G6, Bukk Nr. 26 (87889-93)	19.47 %	21
Taubanelinje G6, Bukk Nr. 20 (87889-99)	19.47 %	21
Taubanelinje G6, Bukk Nr. 30 (87889-89)	19.00 %	22
Taubanelinje G6, Bukk Nr. 5 (87889-114)	19.00 %	22
Taubanelinje G6, Bukk Nr. 38 (87889-81)	18.75 %	23
Taubanelinje G6, Bukk Nr. 8 (87889-111)	18.75 %	23
Taubanelinje G6, Bukk Nr. 6 (87889-113)	17.87 %	24
Taubanelinje G6, Bukk Nr. 11 (87889-108)	14.38 %	25
Taubanelinje G6, Bukk Nr. 40 (87889-79)	13.50 %	26
Taubanelinje G6, Bukk Nr. 9 (87889-110)	13.25 %	27
Taubanelinje G6, Bukk Nr. 39 (87889-80)	12.00 %	28
Taubanelinje G6, Bukk Nr. 7 (87889-112)	12.00 %	28

Figure 38. Risk ranking of posts within Taubanelinje G6.

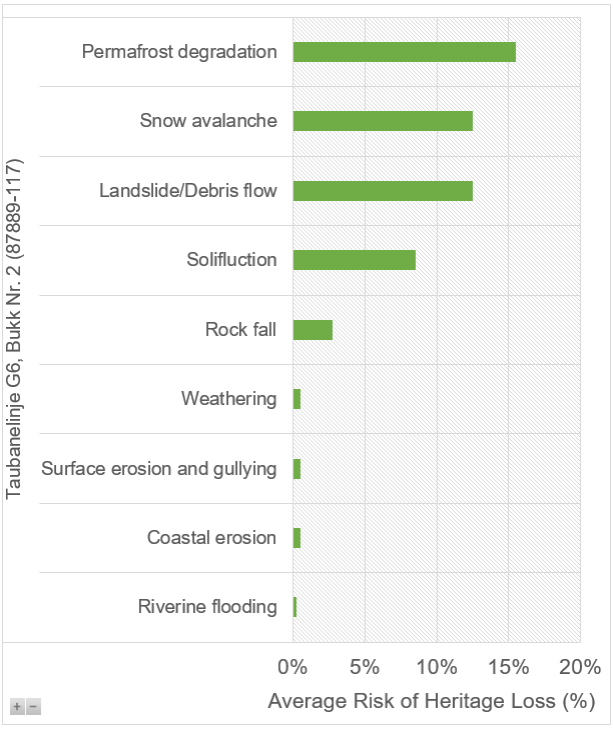


Figure 39. Contribution of different natural hazards to the risk of HL for Taubanelinje G6, Bukk Nr. 2.

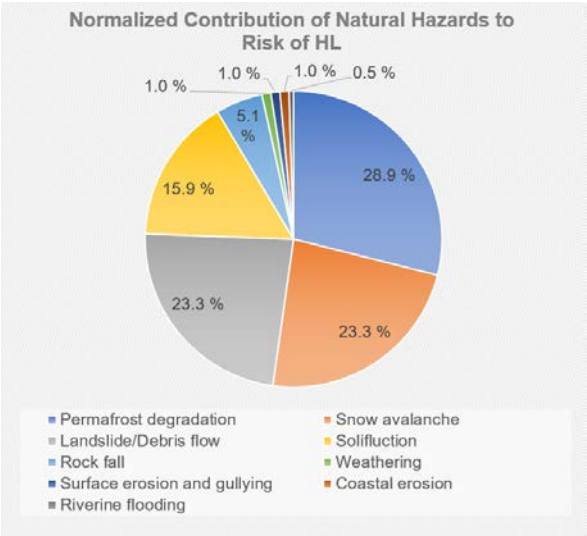


Figure 40. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanelinje G6, Bukk Nr. 2.

7.1.10 Ranking for the entrances in Mines 1a, 2b, 5 and 6

Risk ranking for the mine entrances showed the following: snow avalanches and rockfalls contribute most the aggregated risk of HL at Gruve 1a (Figure 41 and Figure 42), Gruve 2b (Figure 43 and Figure 44), and Gruve 5 (Figure 45 and Figure 46). For the several objects that are composing Gruve 6, the buildings located at the foot of the mountain are most affected by natural hazards (Daganlegget Bygning Aust (ID 87889-8), Daganlegget Bygning Nord (ID 87889-3), Daganlegget Bygning Sør (ID 87889-9) where debris flows, shallow landslides, and snow avalanches contribute most to the aggregated risk (Figure 47).

As noted in Table 1, several objects around entrances to the Mine 1b and 2a were not included in the analysis. Yet, the findings for the closest cases may be used as the first approximation for those objects.

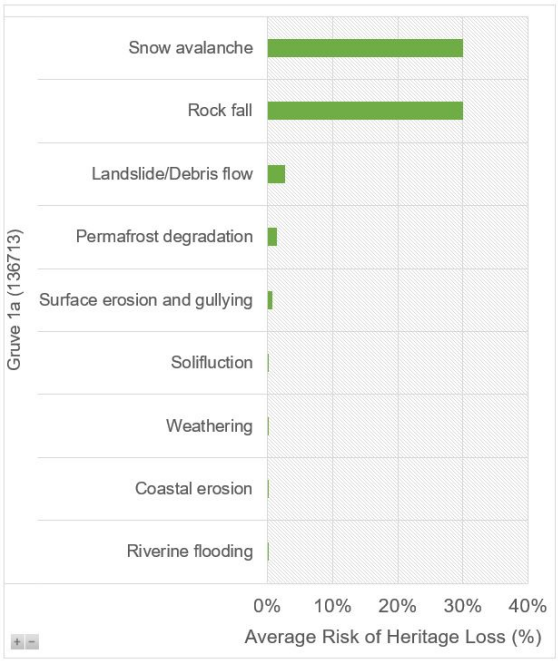


Figure 41. Contribution of different natural hazards to the risk of HL for Gruve 1a.

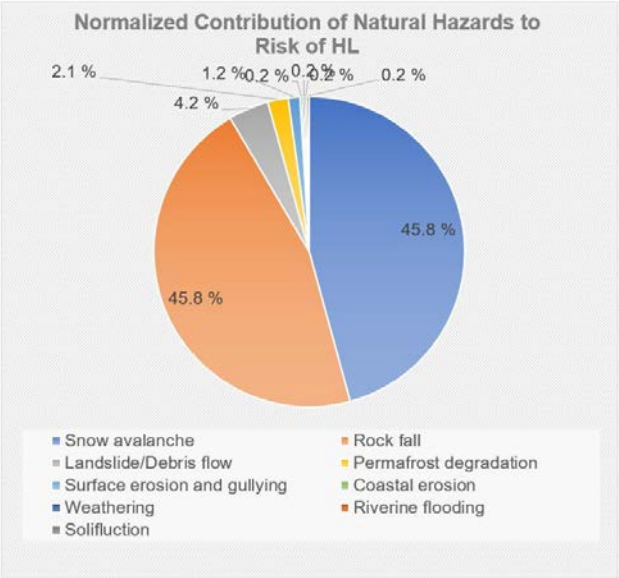


Figure 42. Pie chart presenting aggregated risk of HL from different natural hazards for Gruve 1a.

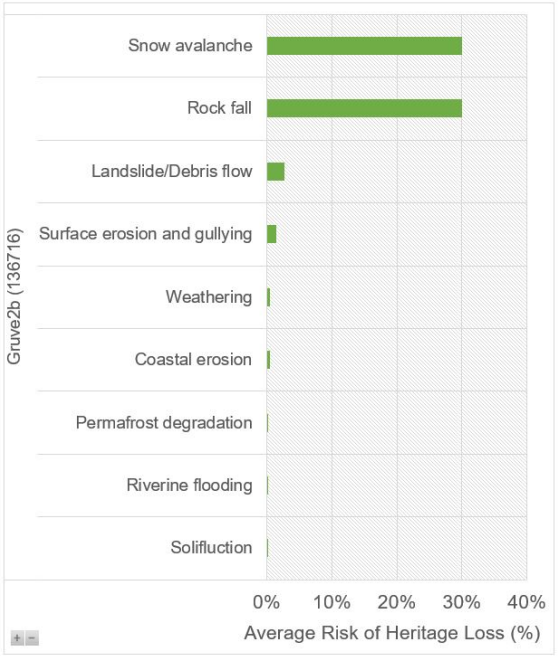


Figure 43. Contribution of different natural hazards to the risk of HL for Gruve 2b.

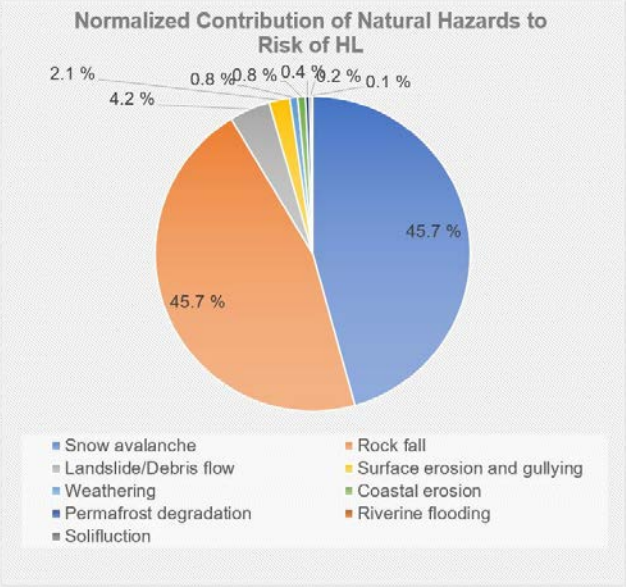


Figure 44. Pie chart presenting aggregated risk of HL from different natural hazards for Gruve 2b.

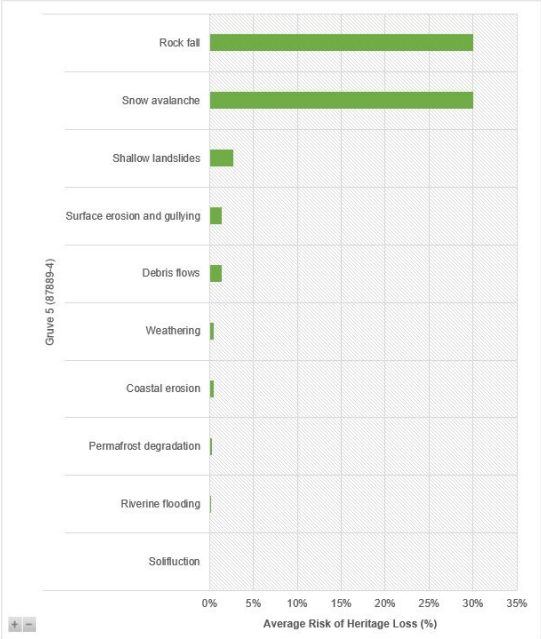


Figure 45. Contribution of different natural hazards to the risk of HL for Gruve 5.

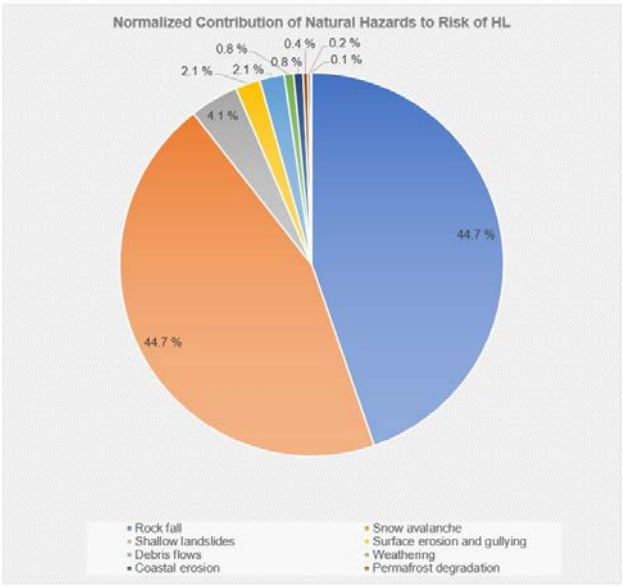


Figure 46. Pie chart presenting aggregated risk of HL from different natural hazards for Gruve 5.

Figure 47. Contribution of different natural hazards to the risk of HL to several objects comprising Gruve 6.

7.1.11 Ranking for Taubanesentralen

Permafrost degradation, surface erosion and gullying contribute most to the aggregated risk at Taubanesentralen (Figure 48 and Figure 49). Note the hazard of coastal erosion is not relevant to this object, presence of it on the figures above is due to mentioned above (Ch. 6.7) particularity of this methodology consisting in that the numerical probabilities selected are small nonzero values. Practically, coastal erosion is not relevant to this object.

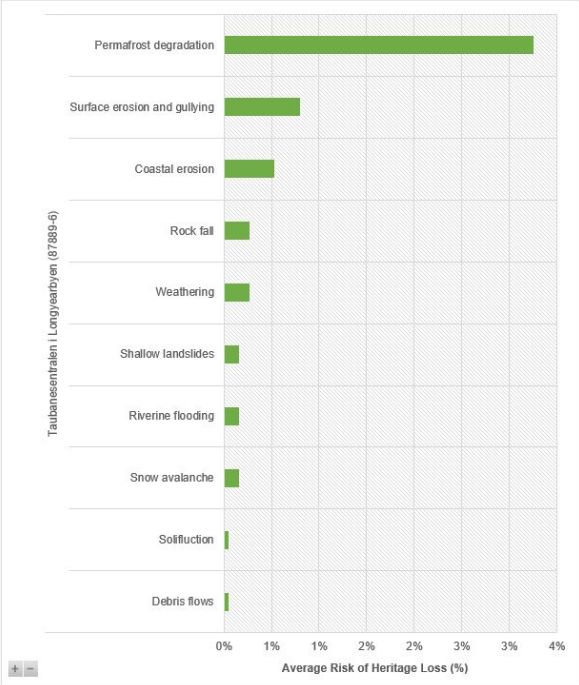


Figure 48. Contribution of different natural hazards to the risk of HL for Taubanesentralen.

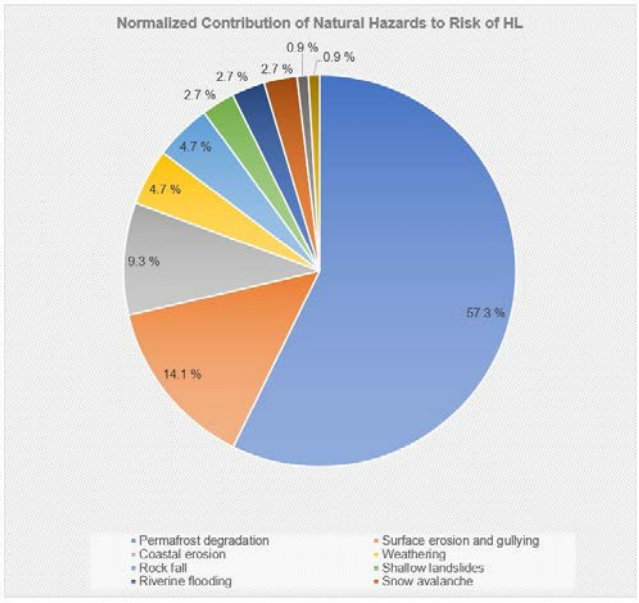


Figure 49. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanesentralen.

7.1.12 Ranking for Vinkelstasjon ved Endalen

Snow avalanches, landslides and debris flows, permafrost degradation, and rock falls contribute most to the aggregated risk at Vinkelstasjon ved Endalen (Figure 50 and Figure 51).

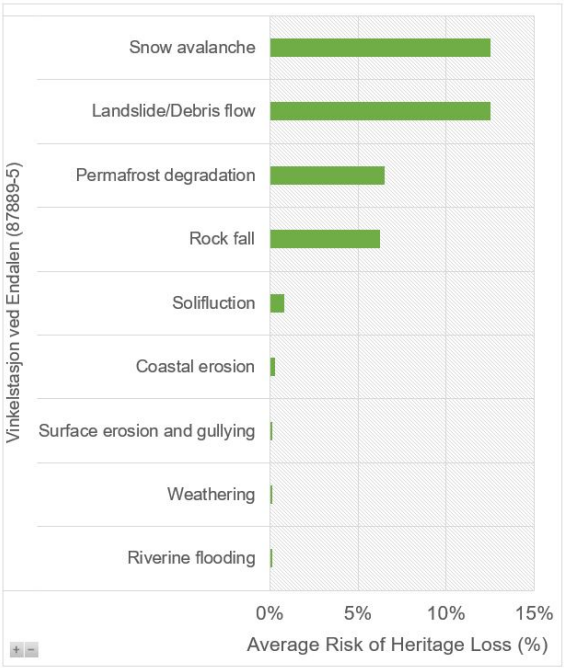


Figure 50. Contribution of different natural hazards to the risk of HL for Vinkelstasjon ved Endalen.

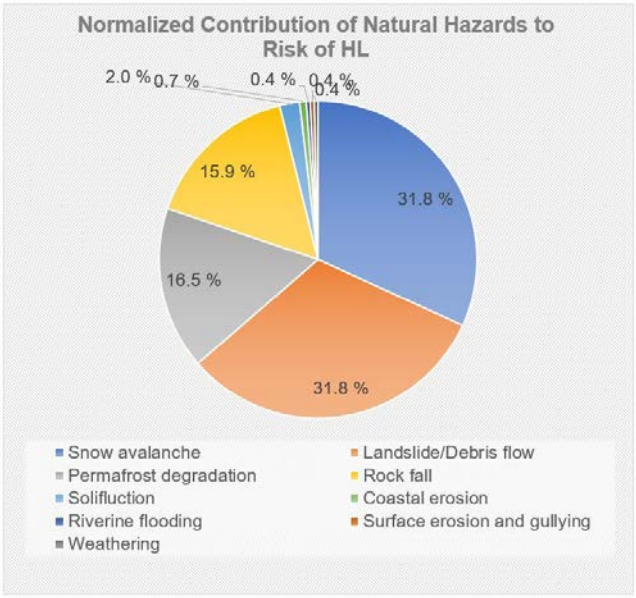


Figure 51. Pie chart presenting aggregated risk of HL from different natural hazards for Vinkelstasjon ved Endalen.

7.1.13 Ranking for Taubanestasjonen I Hiorthhamn

Coastal erosion and permafrost degradation contribute most to the aggregated risk at Taubanestasjonen in Hiorthhamn (Figure 52 and Figure 53). Note that the CP and CC values for coastal erosion equal "5" at Hiorthhamn. Such situation requires attention ("flagging") as discussed in Ch. 6.7. Indeed, the object of cultural heritage is at extreme risk are defined by (Flyen and Boro, 2021).

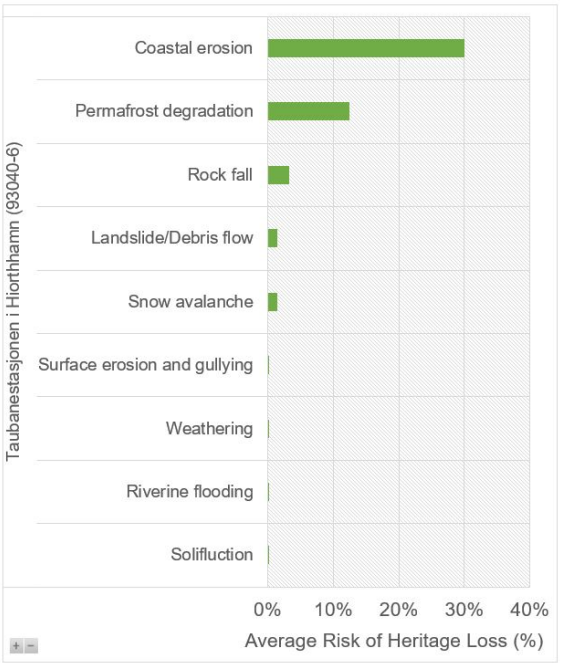


Figure 52. Contribution of different natural hazards to the risk of HL for Taubanestasjonen in Hiorthhamn.

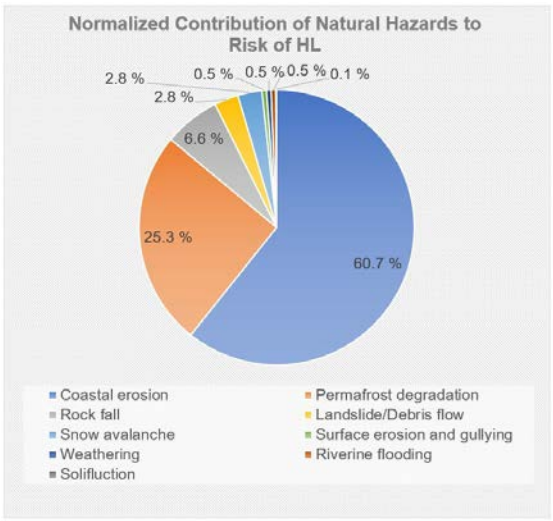


Figure 53. Pie chart presenting aggregated risk of HL from different natural hazards for Taubanestasjonen in Hiorthhamn.

7.1.14 Ranking for Boligbrakke G

All natural hazards used in this study contribute on nearly equal basis to the aggregated risk at Boligbrakke G in Hiorthhamn (Figure 54 and Figure 55).

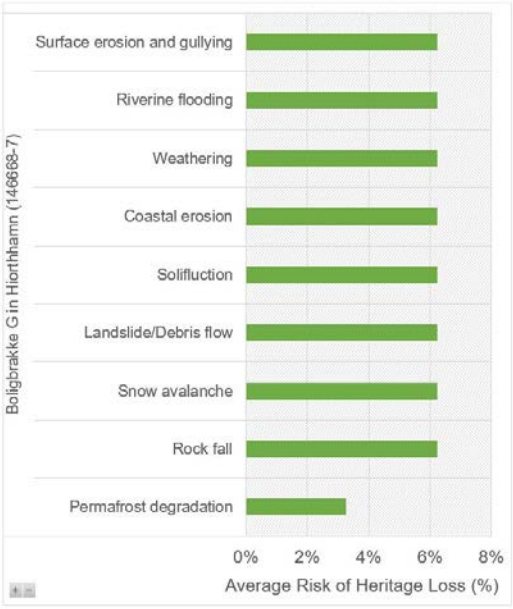


Figure 54. Contribution of different natural hazards to the risk of HL for Boligbrakke G in Hiorthhamn.

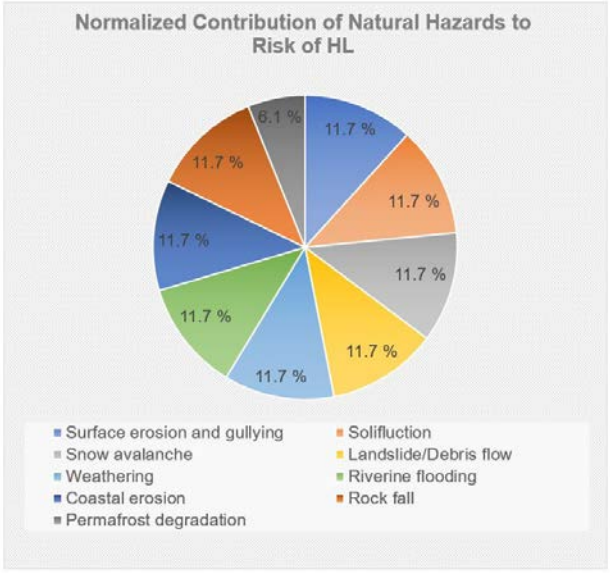


Figure 55. Pie chart presenting aggregated risk of HL from different natural hazards for Boligbrakke G in Hiorthhamn.

7.1.15 Titankrana

Coastal erosion and permafrost degradation contribute most to the aggregated risk at Titankrana (Figure 56 and Figure 57).

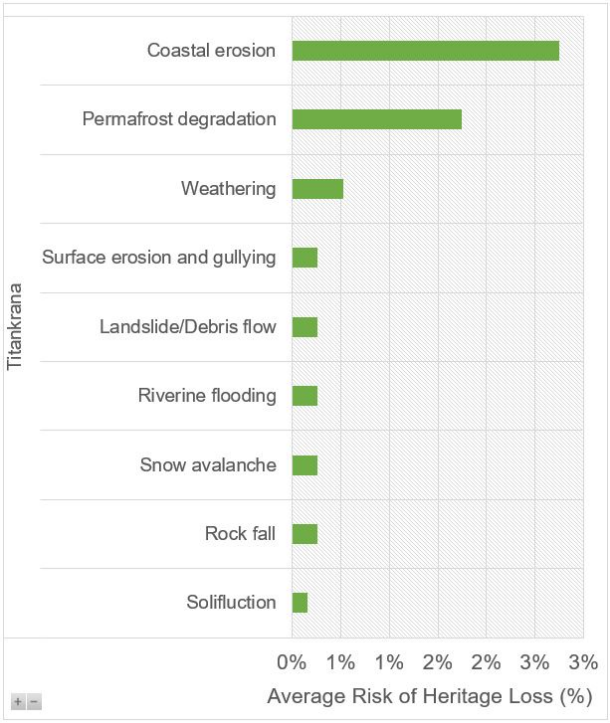


Figure 56. Contribution of different natural hazards to the risk of HL for Titankrana.

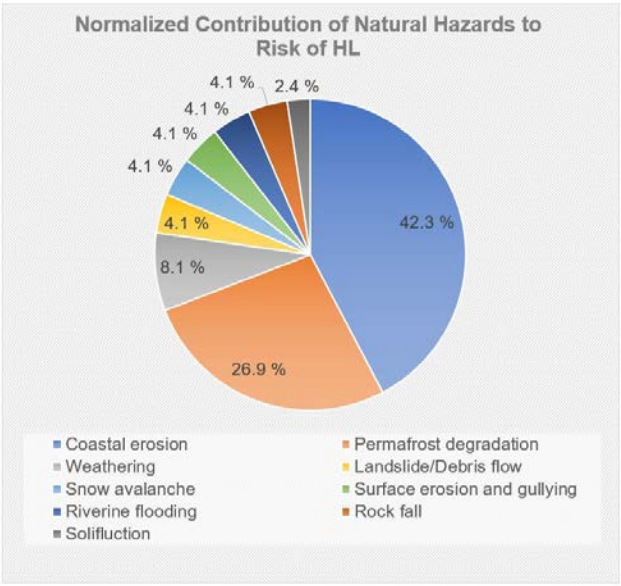


Figure 57. Pie chart presenting aggregated risk of HL from different natural hazards for Titankrana.

7.2 Heritage Objects in Ny-Ålesund

7.2.1 Overall Risk Ranking for Heritage Objects in Ny-Ålesund

An overall risk ranking for cultural heritage objects in Ny-Ålesund is performed and the results are shown in Figure 58. The air ship mast (Luftskipsmasta) was found to be the heritage object with the highest aggregated risk of HL from the coarse analysis. The aggregated risk for the objects in Ny-Ålesund is significantly lower when compared to those observed for objects in Longyearbyen and it shows a slight variation amongst the different heritage objects.

Aggregated Risk for:	Sum of Avg Risk of HL	Rank based on Avg Risk of HL
Luftskipsmasta	36.04 %	1
Båtnaust (23)	21.65 %	2
Båtnaust (24)	21.65 %	2
Båtnaust (22)	21.65 %	2
Gamle kraftstasjonen	18.91 %	3
Jernlageret	17.06 %	4
Hundegården	15.92 %	5
Samfunnsshuset	15.92 %	5
Trønderheimen	15.92 %	5
Mexico	15.92 %	5
Transformatorhus	15.92 %	5
Mellageret	15.92 %	5
Saga	15.92 %	5
Gult hus	15.92 %	5
Blått hus	15.92 %	5
Museum	15.92 %	5
Hvitt hus	15.92 %	5
London husene	9.92 %	6
Green Harbour-Huset	9.92 %	6
Veteranhytta/hytaa lyseblå	9.92 %	6
London 3	9.92 %	6
Nordpolhotellet	9.92 %	6
London 2	9.92 %	6
London 4	9.92 %	6
Posthuset	9.92 %	6
Sysselbu	9.92 %	6
London 1	9.92 %	6
Amundsenvillaen	9.92 %	6
Sætra	9.92 %	6
Dokkehus	9.92 %	6
Skolen	9.92 %	6
Telegrafen	9.92 %	6
Meseet	9.92 %	6
Sykehuset/Skutergarasjen	6.92 %	7
Museumshytta/hytte lysegrønn	4.20 %	8

Figure 58. The highest ranked cultural heritage objects in Ny-Ålesund in terms of the aggregated average risk of HL.

7.2.2 Contribution from Different Natural Hazards

A closer look at the contribution of different natural hazards to the aggregated risk for the heritage object Luftskipsmasta shows that permafrost degradation is the single most contributing natural hazard. This is visualised in

Figure **59** and Figure 60. The same is observed for the other heritage objects in Ny-Ålesund. A similar visualization for the heritage object Båtnaust (23) is shown in Figure 61 and Figure 62. Permafrost degradation is again the natural hazard that contribute the most to the aggregated risk but, in this case, coastal erosion is observed to be the next most contributor. However, one should bear in mind that coastal erosion in this case is a hypothetical hazard that would need to be verified (data on coastal erosion in Ny-Ålesund area were not found). The hypothesis was set up based on the proximity of the sea, and the general trend that most of the Arctic coastlines erode. The oldest building in Ny-Ålesund, Green Harbour Huset, are among the objects sharing the sixth rank of the aggregated risk.

Figure 59. Contribution of different natural hazards to the risk of HL for Luftskipsmasta.

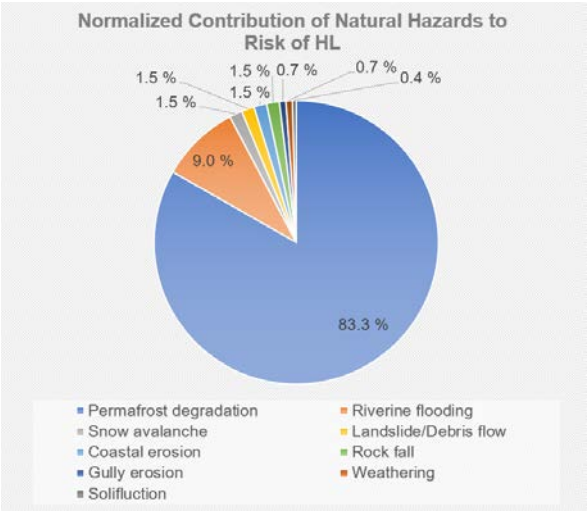


Figure 60. Pie chart presenting aggregated risk of HL from different natural hazards for Luftskipsmasta.

Figure 61. Contribution of different natural hazards to the risk of HL for Båtnaust (23).

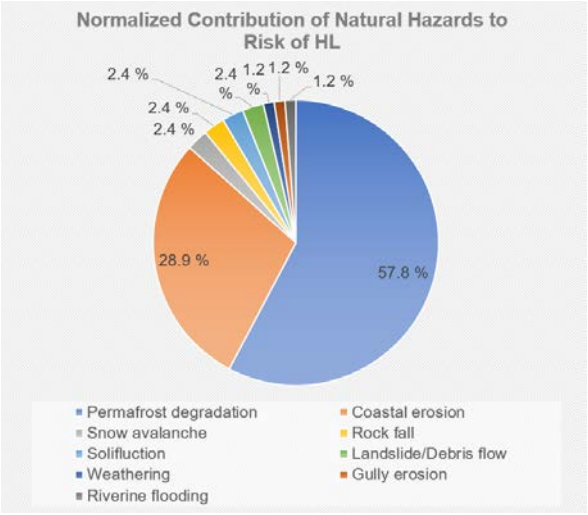


Figure 62. Pie chart presenting aggregated risk of HL from different natural hazards for Luftskipsmasta.

8 Summary and Conclusion

A risk assessment methodology is developed to analyse the impact of natural hazards on cultural heritage objects. This work is targeting particularities of natural hazards in Polar climate and permafrost. After identification of the cultural heritage objects of interest and the types of natural hazards that need to be

considered, the risk assessment methodology provides an insight into which cultural heritage objects are exposed to the highest risk from the hazards considered. This is achieved through both qualitative and quantitative risk analyses. The qualitative risk analysis is performed based on the probability and consequence classes according to NS 5815. Quantitative risk analysis is performed to quantify the impact of natural hazards on the cultural heritage objects. This requires definition of a suitable metric to quantify the risk. Thus, the concept of Heritage Loss (HL) is introduced to serve as an indicator. Heritage Loss is defined as a quantitative estimate of the expected physical loss of a cultural heritage object due to the action of natural and anthropogenic hazards or a combination of such hazards. The developed risk assessment methodology is implemented in a highly flexible risk assessment tool based on Excel and Visual Basic.

Both the qualitative and quantitative analyses provide valuable insights for the preservation, management, and restoration of cultural heritage objects. The results aid in prioritizing mitigation efforts and identifying the most vulnerable objects. It is important to note that the presented risk assessment methodology is a high level or coarse analysis based on available existing data and engineering judgement.

The main finding from the coarse risk analysis shows that Taubanelinje 1b is relatively the most threatened cultural heritage (among the case study objects in Longyearbyen and Ny-Ålesund) when considering the aggregate risk from all the examined natural hazards is considered to evaluate the risk of heritage loss. Taubanelinje 1b is followed several cable way posts on Taubanelinje 2b, entrances to the Mines Nr. 6, 2b, 5 and 1a, and the cable way posts on Taubanelinje 5-6 and Taubanelinje 6, foundations on Taubanelinje 1a. Several of the less affected object are located on Taubanelinje 6, Taubanelinje 2a and Taubanelinje 3. It is advisable to check the objects of interest specifically.

In Ny-Ålesund, the Luftskipsmasta is under the highest aggregated risk. The Luftskipsmasta followed by the objects that may be affected by coastal erosion. Majority of other objects in Ny-Ålesund has approximately the same value of aggregated risk.

Limited validation of presented methodology showed reasonable outcome that allows suggesting practical use of the results.

Input in development

Vision and identification of the need for methodology – Anatoly Sinitsyn; development of methodology – Yared Bekele and Anatoly Sinitsyn; implementation of the methodology – Yared Bekele, report writing – Yared Bekele and Anatoly Sinitsyn.

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Appendix 1. Absent and restored objects

Absent objects (as for September 1st, 2021) of the system of cable way posts in Longyearbyen are presented in Table 10. Restored objects (as for September 1st, 2022) of the system of cable way posts in Longyearbyen are presented in Table 11.

Table 10. Absent objects (as for September 1st, 2021) of the system of cable way posts in Longyearbyen

Line, ID number	Structure	Upper structure
Taubanelinje 1a		
159054		
159054-1	Foundation	–
159054-2	Foundation	–
159054-3	Foundation	–
159054-4	Foundation	–
159054-5	Foundation	–
159054-6	Foundation	–
159054-7	Foundation	–
159054-8	Foundation	–
159054-9	Foundation	–
159054-10	Foundation	–
159054-11	Foundation	–
Taubanelinje 1b		
158657		
158657-22	Bukk nr 22 - Taubanelinje 1b	Absent
158657-17	Bukk nr 17 - Taubanelinje 1b	Capsized, laying on a side
158657-9	Bukk nr 9 - Taubanelinje 1b	Capsized, laying on a side
158657-7	Bukk nr 7 - Taubanelinje 1b	Crashed by an avalanche
Taubanelinje 2a		
158987		

158987-1	Fundament Nr.1, not surveyed	Absent
158987-2	Fundament Nr.2, not surveyed	Absent
158987-3	Fundament Nr.3, not surveyed	Absent
158987-4	Fundament Nr.4, not surveyed	Absent
136714-3	Fundament maskinhus, not surveyed	Absent
Taubanelinje 2b		
158986		
158986-14	Bukk nr 14 - Taubanelinje 2b	Foundation, not found (completely gone)
158986-12	Bukk nr 12 - Taubanelinje 2b	Remains of concrete foundations
158986-10	Bukk nr 10 - Taubanelinje 2b	Not found, probably lost due to urbanization
158986-9	Bukk nr 9 - Taubanelinje 2b	Not found, probably lost due to urbanization
158986-4	Bukk nr 4 - Taubanelinje 2b	Crashed by an avalanche
158986-3	Bukk nr 3 - Taubanelinje 2b	Fallen down due to the rot of foundation members, laying on the top of foundation, was not surveyed.
158986-2	Bukk nr 2 - Taubanelinje 2b	Crashed by an avalanche
Taubane 3		
158619		
158619-38	Bukk nr 38 - Taubanelinje 3	Upper structure is absent
Taubane delstrekning gruve 5 og 6		
87889		
Not found	Bukk nr 1	Steel structure
Not found	Bukk nr 2	Steel structure

87889-22	Bukk nr 15b	Lying on the side
87889-26	Bukk nr 18	Lying on the side
87889-36	Bukk nr 28c	Absent, probably crashed by a snow avalanche
87889-37	Bukk nr 28b	Laying on the side, fallen down probably due to rupture of foundation members because of rot.
87889-42	Bukk nr 33	Absent, probably crashed by a snow avalanche
Taubane delstrekning gruve 5		
87889		
87889-60	Bukk nr 19	Absent
87889-73	Strammestasjon - Taubane delstrekning gruve 5	Probably only foundation was found
87889-74	Bukk nr 5	Only foundation was found
87889-75	Bukk nr 4	Only foundation was found
87889-76	Bukk nr 3	Only foundation was found

Table 11. Restored objects (as for September 1st, 2022) of the system of cable way posts in Longyearbyen.

Line, ID number	**Structure**	**Upper structure**
Taubanelinje 1b		
158657		
158657-23	Bukk nr 23 - Taubanelinje 1b	Vertical, Restored in 2007
Taubanelinje 2b		
158986		
158986-8	Bukk nr 8 - Taubanelinje 2b	Restored
158986-7	Bukk nr 7 - Taubanelinje 2b	Vertical, prepared for restoration
Taubane delstrekning gruve 5 og 6		
87889		

87889-11	Bukk nr 3	Vertical, prepared for restoration
87889-12	Bukk nr 4	Vertical, restored
87889-13	Bukk nr 5	Vertical, restored
87889-14	Bukk nr 6	Vertical, restored
87889-15	Bukk nr 7	Vertical, restored
87889-16	Bukk nr 8	Vertical, prepared for restoration
87889-53	Bukk nr 44	Vertical, restored in 2022

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