# Field report AT-301

Evaluation of Rockfall and Avalanche hazard in Svea

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Jens Tveit, Samuel Foucherre, Christian Katlein, Kristoffer Hallberg

## 1. ***Introduction***

Human installations such as buildings and roads in mountainous areas are subjected to risks of rock fall and avalanches if placed in exposed areas. Historical events at Svalbard show that the risks are not negotiable and should be dealt with. Store Norske's mining facilities at Svea mine at Svalbard has experienced snow avalanches in recent years and a risk evaluation is sought for. This report addresses the risk for avalanche and rock fall in the area.

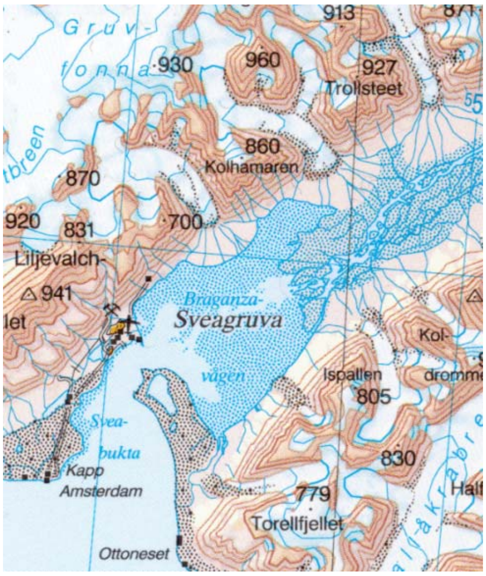


**Fig. 1:** Location of Svea (Norsk Polarinstitutt)

The ultimate driving force for mountain slope hazards is gravity even though release mechanism, flow characteristics and run-out may differ significantly between snow avalanches, rock falls and debris flows. The basic principles in mountain slope hazard mitigation are:

- Relocate objects exposed to hazard
- Retain masses at their original location by engineering structures
- Controlled removal of the mass at risk
- Protection structures at exposed objects

Rock fall potential in the Svea area is due to the highly fractured sedimentary rock and the erosion processes. Single piece rock as well as larger rock boulders may release from steep mountain sides. As a consequence of high rock density energy associated with rock fall may be high. The trajectories of a high energy boulder can be described by a bouncing pattern. Rock fall release area is widespread and distributed in several terraces.

Avalanche potential in general is due to an overloading of the snowpack followed by a mechanical failure and sudden release of snow masses. In Svalbard where annual precipitation is low, wind induced snow transport is a major factor for overloading snow packs. Avalanche potential increases with high snow accumulation rates. In leeward mountain slopes snow may accumulate hence overloading a snowpack. Gullies are natural accumulation areas and may accumulate snow effectively under many different wind directions. The primary snow avalanche release areas posing a threat for facilities at Svea are the gullies in the slope above the mine entrance where snow is deposited by the prevailing eastern winds during winter..

By use of conventional methods in mountain slope hazard evaluation for rock fall and avalanche evaluation estimations of run out length are carried out.

## 2. Methods

### *Avalanche hazard*

For the evaluation of the Avalanche hazard we used an Inclinometer to locate the point where the slope flattens out to an angle of 10 degrees. Only in the eastern and most western part of the investigation area (Profiles number 1, 2, 6) was it possible to detect the 10 degree line on not transformed natural ground. In the central part (Profiles 3, 4, 5) the impact of former earth works did not allow a proper detection of the 10 degree line. The natural surface was disturbed around the buildings due to road fillings and cuttings around the buildings. Some structures had an inclination far below 10 degrees but were not wide enough to retain an avalanche. On these profiles we took the 0° line as basis for our calculations which should be a realistic approximation. Directly above the mine entrance (Profile 5) this approximation does not seem to be realistic. Taking the 0° line in the big depression as calculation basis, we measured a far too short runout. Even though the depression will store some snow and take some of the avalanches energy, it will not stop within such a short distance. Therefore we took a manually interpolated point which seems to be reasonable compared to the adjacent profiles as calculation basis.

From the 10 degrees point we measured the inclination $\beta$ to the top of the slope with Inclinometer and calculated the runout angle $\alpha$ using the following equation:

$$\alpha = 0{,}96\,\beta - 1{,}4\,^\circ$$

We located the point where the inclination of the top of the slope reaches $\alpha$ in the terrain using the inclinometer and marked it on the map. For exact measuring of the runout-point we used a Laser-distance-meter for proper location on the map. This runout point represents the probable runout of a 300-years avalanche.

### *Rockfall hazard*

To evaluate the rock fall hazard we extracted topographic profiles from maps in the Scale of 1:5 000 and 1:2 000. The profiles were used to divide the slope into several sections of equal inclination and slope properties. We ran a rock fall simulation for each profile using the Colorado rock fall simulation program (CRSP v4.0), simulating 1000 events for each profile. Investigation of the existing remnants of rock falls reveals a realistic maximum boulder diameter of not more than 1 meter. The parameters for surface roughness and coefficients of restitution were chosen according to our experience around Longyearbyen and are given in the attachments.

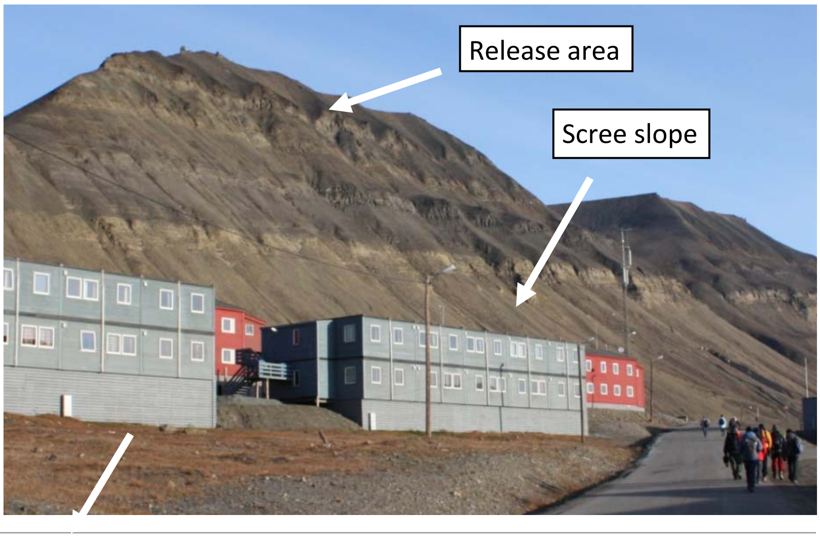


**Figure 2.** Release and run out area for rock fall and avalanches

# 2. Results

### Measures

To protect the road and buildings from rock fall mitigation measures should take place close to the exposed objects if needed. The release area is as mentioned widespread, and not realistic to stabilize. Relocation may be the best solution for buildings at risk, however not possible for the road. Some buildings can be protected by a multi purpose dam designed for both rock fall and avalanche protection.

Snow avalanches are known to reach across the road and exposed buildings call for protection measures. Stabilization or retention work in the release area is not feasible due to poor rock quality and inaccessible location. Measures should focus on the run out areas where buildings can be protected by relocation of embankments. Embankment, such as deflection or retention dams are suitable as slope inclination is below 15°. The design height of a retention dam is governed by the avalanche velocity. The embankment can be placed at an angel < 20° to the expected avalanche run out and then work as a deflection barrier. Successful design accounts for snow drift in line with prevailing winter wind direction.

### Results

The results of the field measurements are given in the attached map. The Avalanche run out zone extends all way down to the street or even further passing the buildings. Numerous buildings are built within the potentially dangerous area so there is need for a changed plan of risk management.

The rubb halls are threatened mostly by avalanche hazard as rock fall in this area is rather unprobable. The Office Building might be exposed to rock fall and the simulated bounce-height in the area well above the buildings does not exceed 5m.

# 3. Suggestions

There are several possibilities to increase personal safety in and around buildings as well as operation of the road by means of earthworks in the run out area. The base materials for this kind of protection are readily available as well as suitable machinery. Following measures are suggested to increase the overall safety in avalanche and rock fall events:

### Rubb halls

Actions addressing the overall safety in the rubb halls should focus on the risks associated with avalanches. From a rock fall perspective there is no urgent need of actions to be taken. The most realistic and economical protection is relocation outside the avalanche run out zone for example further south at the today's container storage. Retaining fences and retaining dams are rejected due to the vast area to stabilize and large volumes to retain.

### Mine entrance and office building

Measure to protect the mine entrance and the office building should handle the combined risk associated with rock fall and avalanches. The main risk is due to avalanches, however rock fall should not be negotiated, especially as the office building is occupied all day round. The probability for fatalities in case of an avalanche or rock fall event is high. Relocation of the mine entrance is not possible hence we suggest protecting the building with deflecting dams which will deflect avalanches and stop rock falls. The deflecting dam should not be constructed too close to the building to avoid problems with drifting snow accumulation in winter. The suggested location of the deflecting dam is shown on the attached map.

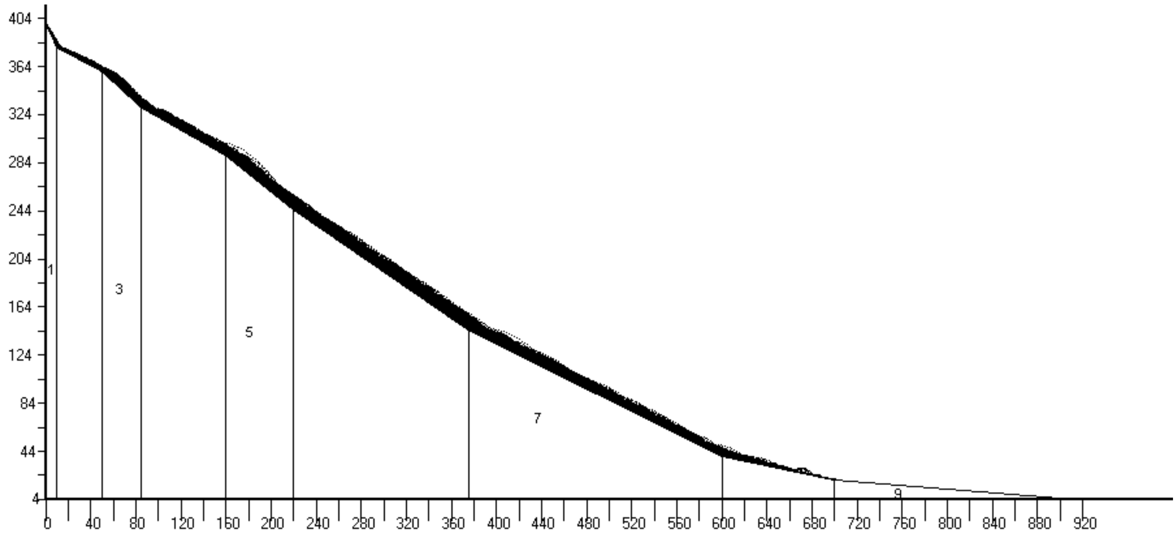
The dam has to reach a certain height to be able to deflect the avalanche without the avalanche passing over it. This height is given by $H = H_{snow} + \frac{(V\ sin\phi)^2}{2g}$

To achieve a good deflecting effect the angle $\phi$ between the dam and the avalanche path should not exceed 20°. The velocity of the avalanche is given by $v_{max} = \sqrt{\xi \cdot h(\sin\theta - \mu\cos\theta)}$ , where $\xi$ is given to $500\frac{m}{s^2}$. Field measurements revealed that the terrain above the suggested deflecting dam has an inclination of $\theta = 20°$. This results in a relevant velocity around 10 to 15 m/s and a height of approximately 5 meters for the deflecting structures. A dam with the height of 5 meters will also be able to catch the probable rock fall.

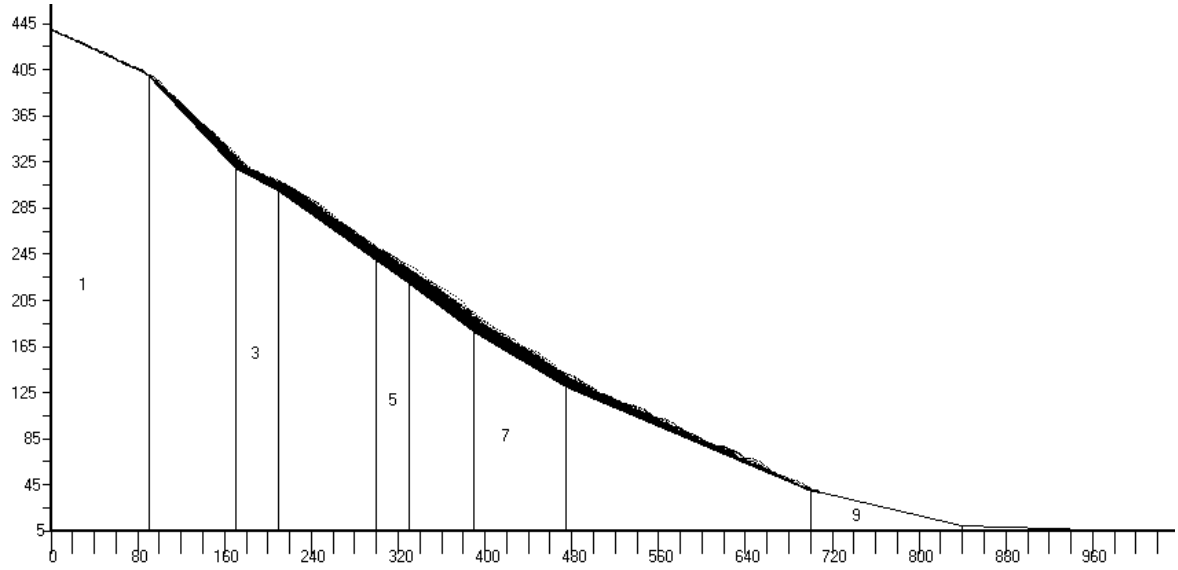
## ***4. Attachments***

Profiles with calculated paths of rock fall generated with the Colorado rock fall Simulation program v4.0:

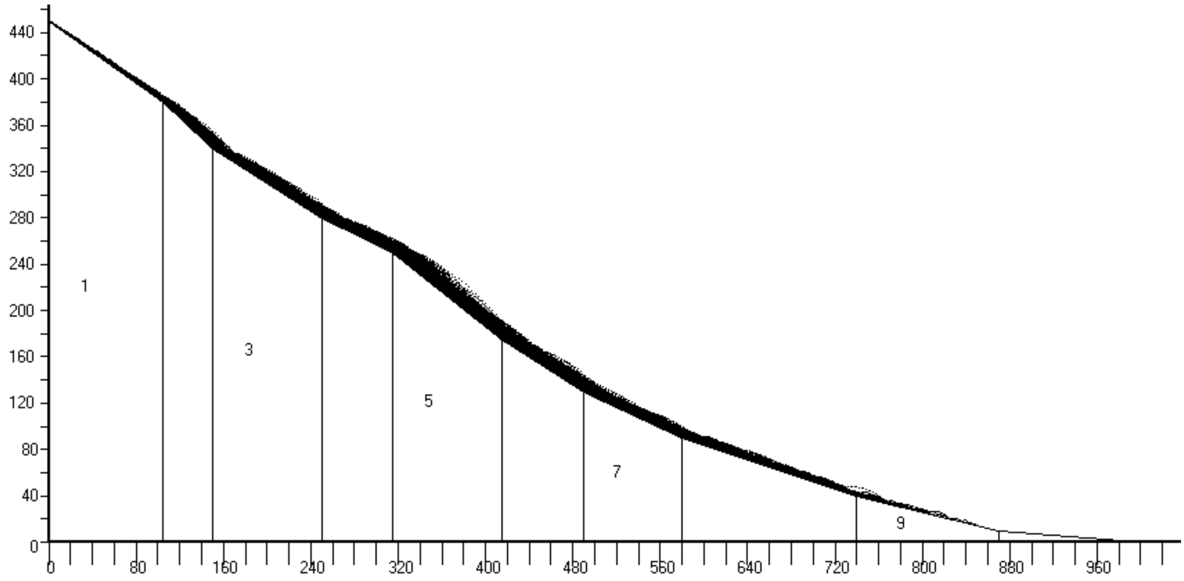
***Profile 1:***



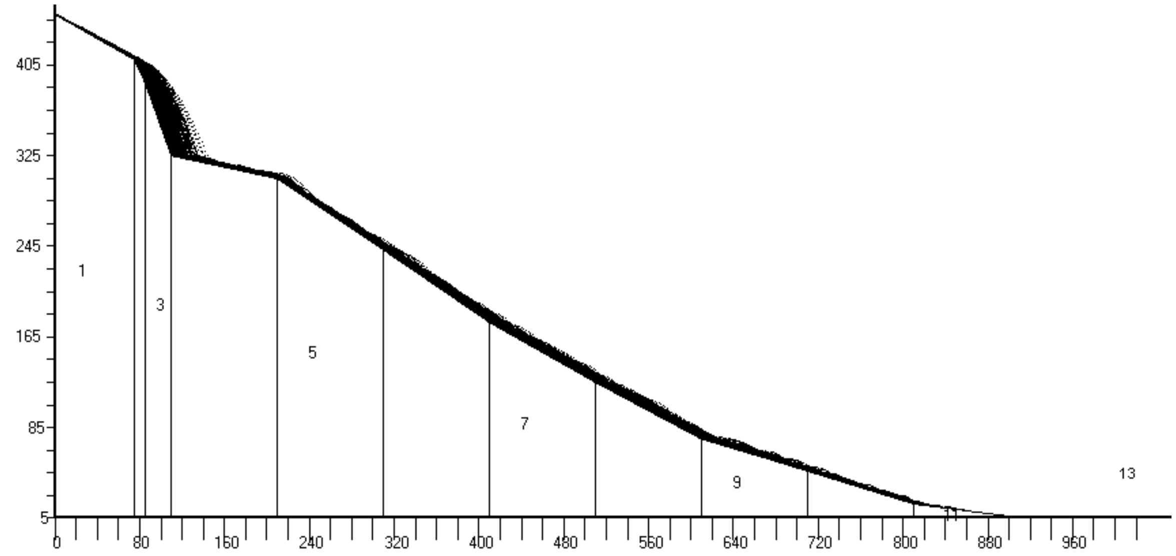
***Profile 2:***



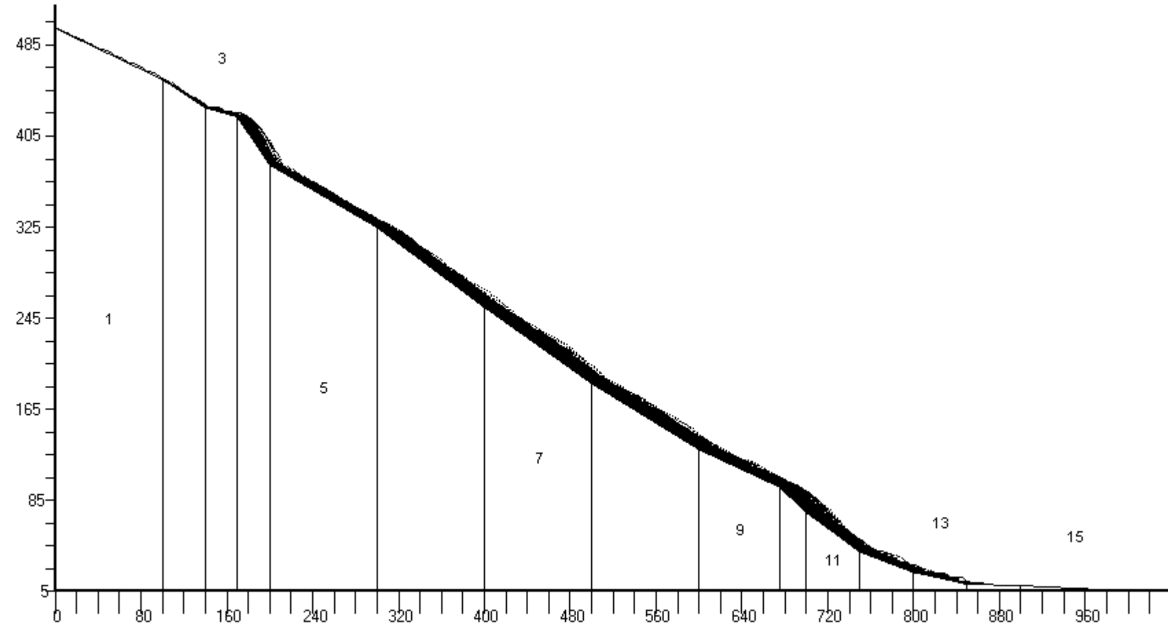
***Profile 3:***



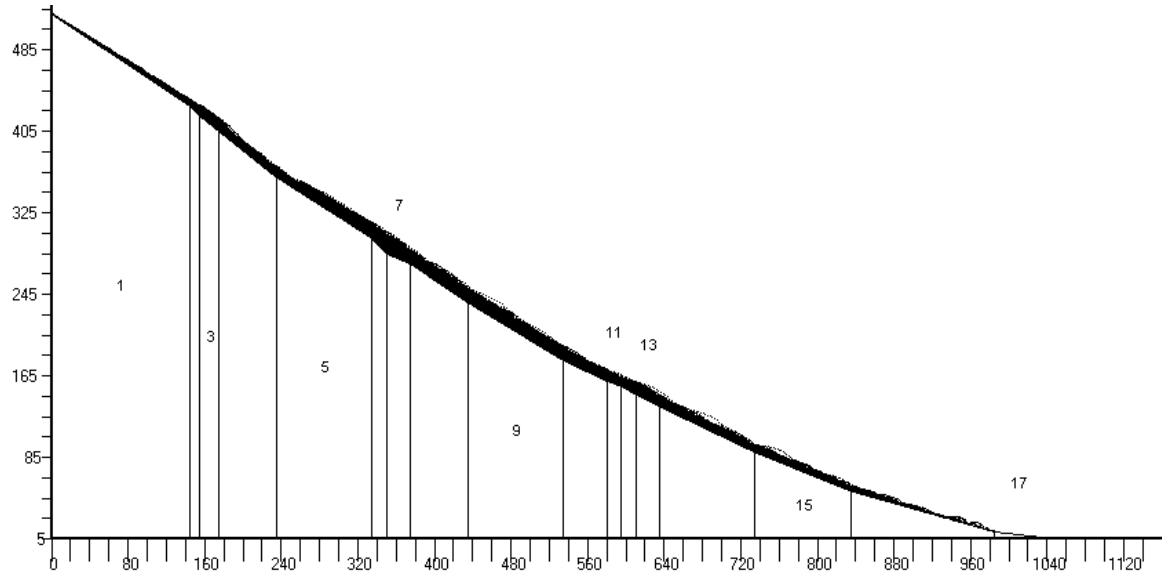
## ***Profile 4***



Profile 5:



***Profile 6:***



# ***References***

**Norwegian Public Roads Administration** Handbook: *Snow engineering for Roads, About snow avalanches and drifting snow*

**E. Sommerhalder** *Lawinenkräfte und Objektschutz* p. 5 , Winterbericht des Eidgenössischen Institutes für Schnee- und Lawinenforschung Davos Nr. 29 Winter 1964/65

**Norwegian Polar institute** *Map 1:100 000* Sheet C10 “Braganzavågen”

**Store Norske Kulkompani** Alexander Sebergsen: *Map of Svea 1:2000 (10.9.2009)*

## *Tables of coefficients*

The following Coefficients were used in the CRSP Rockfall Simulation:

**Profile 1**

| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .3 | .95 | .5 |
| 3 | .3 | .95 | .5 |
| 4 | .4 | .9 | .45 |
| 5 | .4 | .9 | .45 |
| 6 | .4 | .9 | .45 |
| 7 | .5 | .9 | .4 |
| 8 | .7 | .85 | .35 |
| 9 | .8 | .85 | .35 |
| 10 | .8 | .85 | .35 |

**Profile 2**

| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .3 | .95 | .5 |
| 3 | .3 | .95 | .5 |
| 4 | .4 | .9 | .45 |
| 5 | .4 | .9 | .45 |
| 6 | .4 | .9 | .45 |
| 7 | .5 | .9 | .4 |
| 8 | .7 | .85 | .35 |
| 9 | .7 | .85 | .35 |
| 10 | .8 | .85 | .35 |

**Profile 3**

| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .3 | .95 | .5 |
| 3 | .3 | .95 | .5 |
| 4 | .4 | .9 | .45 |
| 5 | .4 | .9 | .45 |
| 6 | .4 | .9 | .45 |
| 7 | .4 | .9 | .4 |
| 8 | .5 | .85 | .4 |
| 9 | .6 | .85 | .4 |
| 10 | .6 | .85 | .35 |

**Profile 4**

| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .2 | .95 | .5 |
| 3 | .3 | .95 | .5 |
| 4 | .3 | .95 | .5 |
| 5 | .4 | .9 | .45 |
| 6 | .4 | .9 | .45 |
| 7 | .4 | .9 | .45 |
| 8 | .4 | .9 | .45 |
| 9 | .4 | .9 | .45 |
| 10 | .4 | .9 | .45 |
| 11 | .5 | .9 | .4 |
| 12 | .5 | .85 | .4 |
| 13 | .6 | .85 | .4 |

**Profile 5**

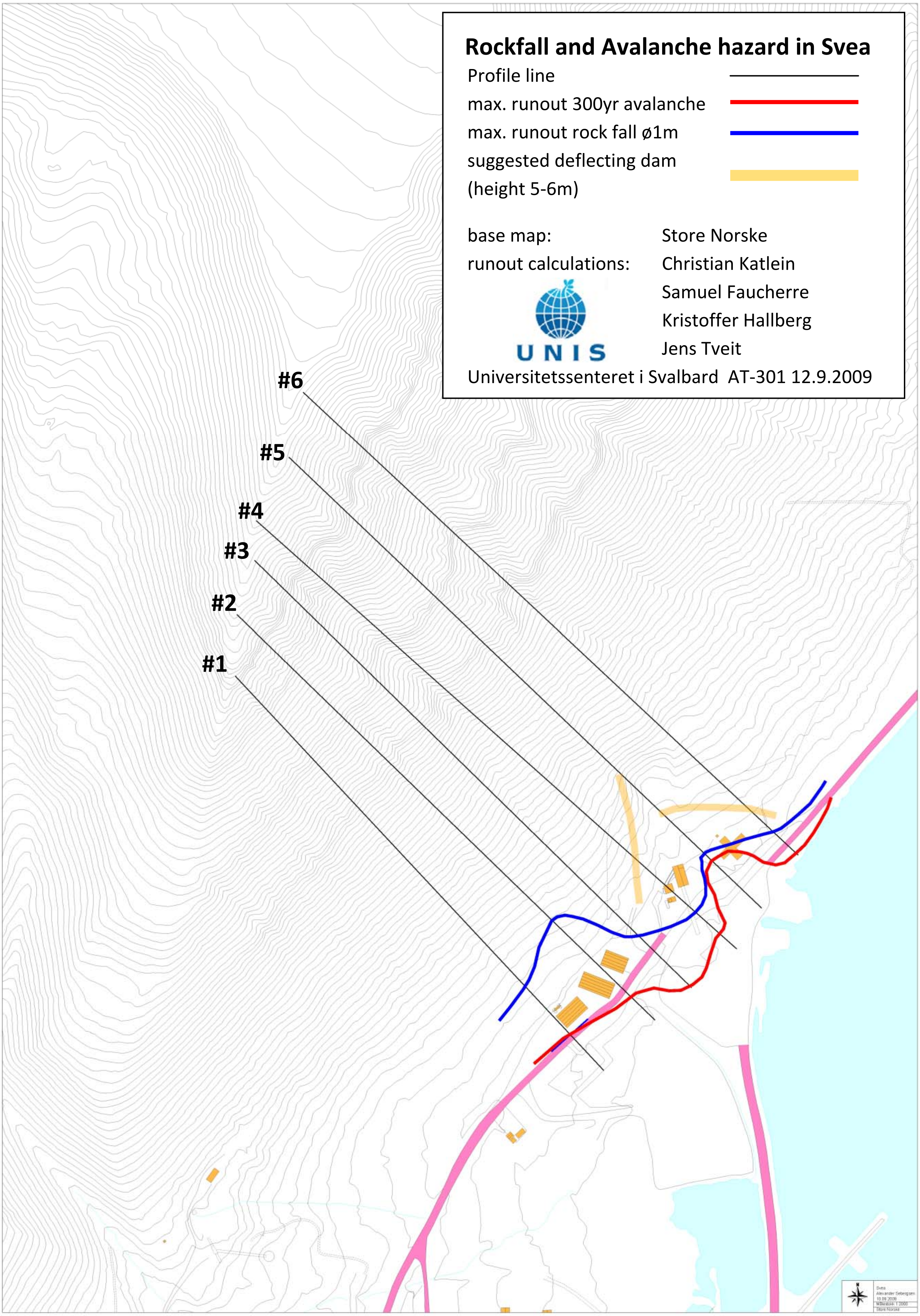
| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .2 | .95 | .5 |
| 3 | .3 | .95 | .5 |
| 4 | .3 | .95 | .5 |
| 5 | .3 | .95 | .5 |
| 6 | .4 | .9 | .45 |
| 7 | .4 | .9 | .45 |
| 8 | .4 | .9 | .45 |
| 9 | .4 | .9 | .4 |
| 10 | .4 | .9 | .4 |
| 11 | .7 | .85 | .35 |
| 12 | .7 | .85 | .35 |
| 13 | .7 | .85 | .35 |
| 14 | .7 | .85 | .35 |
| 15 | .6 | .85 | .4 |
| 16 | .6 | .85 | .4 |

**Profile 6**

| Cell # | SR | RT | RN |
|---|---|---|---|
| 1 | .2 | .95 | .5 |
| 2 | .2 | .95 | .5 |
| 3 | .2 | .95 | .5 |
| 4 | .2 | .95 | .5 |
| 5 | .3 | .95 | .5 |
| 6 | .3 | .95 | .45 |
| 7 | .3 | .95 | .45 |
| 8 | .4 | .9 | .45 |
| 9 | .4 | .9 | .45 |
| 10 | .4 | .9 | .45 |
| 11 | .4 | .9 | .45 |
| 12 | .4 | .9 | .45 |
| 13 | .4 | .9 | .4 |
| 14 | .5 | .9 | .4 |
| 15 | .5 | .9 | .4 |
| 16 | .6 | .9 | .4 |
| 17 | .7 | .85 | .35 |
| 18 | .8 | .85 | .35 |

## *Maps*

The Map showing the final Zoning Plan with the location of the deflecting structure (next page)


Rockfall and Avalanche hazard in Svea
Profile line
max. runout 300yr avalanche
max. runout rock fall ø1m
suggested deflecting dam
(height 5-6m)
base map: Store Norske
runout calculations: Christian Katlein
Samuel Faucherre
Kristoffer Hallberg
Jens Tveit
UNIS
Universitetssenteret i Svalbard AT-301 12.9.2009
#6
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Målestokk 1:2000
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