REPORT

Sukkertoppen Svalbard - avalanche incidents

DOCUMENTATION OF AVALANCHES

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NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Project

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for NGI

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Summary

NGI has been contracted by NVE to collect information of previous avalanche activity influencing the houses under the Sukkertoppen Mountain in Longyearbyen. The objective of the work is to provide historical records to be used in hazard mapping and protection evaluation.

This report is divided into the following incidents or previous mapping in chronological order:

- Debris flow on road 228 in 1981.
- NGIs geomorphological 1985 mapping.
- Avalanches before 2015.
- Fatal avalanche 19th December 2015.
- Avalanche destroying houses 21st February 2017.

Chapter 7 gives facts of observed weather in avalanche situations.

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Appendix A

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1	NGIs geomorphological 1985 mapping showing deposits from debris flows.	A3	1: 3000
2	Terrain steepness and runout 2015 avalanche (blue) and 2017 avalanche (black).	A3	1: 3000

Review and reference page

1 Introduction

NGI has been contracted by NVE to collect information of previous avalanche activity influencing the houses under the Sukkertoppen Mountain in Longyearbyen. The objective of the work is to provide historical records to be used in hazard mapping and protection evaluation. The report does not consider slush flows in Vannledningsdalen.

NGI has worked with natural hazard and avalanches on Svalbard for decades. The latest field work in this project was performed by NGIs Kjetil Brattlien 30-31 October 2017.

This report is divided into the following incidents or previous mapping in chronological order:

- Debris flow on road 228 in 1981.
- NGIs geomorphological 1985 mapping.
- Avalanches before 2015.
- Fatal avalanche 19th December 2015.
- Avalanche destroying houses 21st February 2017.

Chapter 7 gives facts of observed weather in avalanche situations.

This report does not evaluate or list all the numerous reports on natural hazards prepared by NGI or others. This limitation is due to budget constraints.

Figure 1.1 shows an overview map. It has been buildings above the road 200 (Hilmar Rekstens vei) since building of the houses in road 224 in 1968-69. The buildings in road 222-228 came in 1969-1990. The buildings in road 230 (Spisshus) came 1976-77. This means that history of damage to buildings is limited to about 50 years.

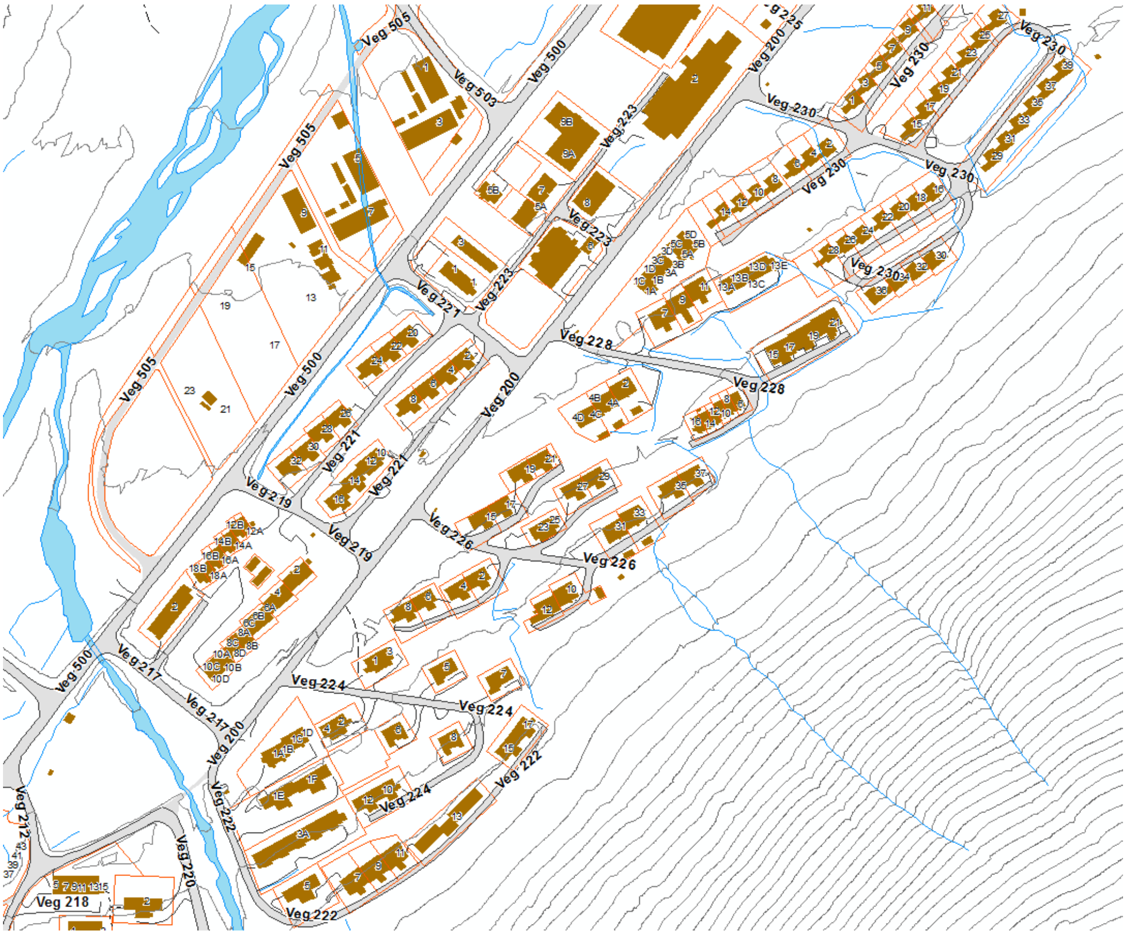


Figure 1.1: Overview map.

2 Debris flow on road 228 in 1981

The buildings in road 228 (6-16) and 228 (7-11) were hit by a debris flow 5th August 1981 in a situation where the airport got 55 mm rain in 30 hours (NGI, 1992). Photos 2.1-2.2 show the event. Parts of building 228 (6-16) was damaged, and debris filled up most of the ground floor of flat 228/12. The debris flow continued further down road 228.

It is not clear how the debris flow deposits and runout relate to the current TEK17 regulations for class S1, S2 and S3 events. Flow thickness and intensity decreases towards the longest reach of the debris, and this is especially prominent for debris flows with high water content. The maximum runout in 1981 is probably not relevant for S1-S3 events with TEK17 regulations because it had not enough destructive power. On the other hand some of the debris flow depositions are relevant for TEK17 and the design scenario.

It is interesting to notice that the avalanche in February 2017 hit the same buildings as the debris flow in 1981, and both incidents had about the same runout. But the 1981 debris flow caused less damage than the 2017 avalanche.


Photo 2.1: Debris flow in August 1981 causing damage on buildings in road 228 (6-16). Photo: Turid Telebond.


Photo 2.2: Debris flow in August 1981. To the left 228 (6) and below 228 (7-11). Photo: Turid Telebond.

3 NGIs geomorphological 1985 mapping

NGI had a research project on permafrost and geomorphological mapping in Longyearbyen in 1985. The project included 10 days of field work in August and September 1985 performed by NGIs Erik Hestnes and Karstein Lied. NGI report 52703-1 (NGI, 1986) contains detailed description of the work including maps showing deposition from debris flows and possibly other mass movements such as avalanches.

Map 1 in Appendix A shows deposits from debris flow and possible other types of mass movement from the 1985 mapping on a 2017 map with today's buildings. The map gives an indication previous debris flow runout, but does not consider destructive potential. Flow thickness and intensity decreases towards the longest reach of the debris. Hence, the maximum runout is probably not relevant for S1-S3 events with TEK17 regulations because it had not enough destructive power. On the other hand some of the debris flow depositions are relevant for TEK17 and the design scenario.

There were less buildings in the area in 1985 than today, and debris depositions not visible today were mapped. The 1985 NGI mapping shows that the buildings in road 220-230 are placed on deposits from debris flows and possibly other mass movements. The depositions extends also below road 200 (Hilmar Rekstens vei) and into road 221 and 223 in the city centre.

The 1985 report described some of the mapped depositions as "new" assuming it was deposited in a debris flow situations in 1972 and 1981. The 1985 report has plots of grain size distribution showing that fine grained material had the longest runouts.

Photo 3.1: Longyearbyen in 1985. Photo: NGI (1986).

4 Avalanches before 2015

NGI has no information of avalanches from the upper release area at Sukkertoppen (about 350 masl) before 2017. Avalanches from the lower release area at the shoulder about 125 masl (2015 release area) are regular and are reported to happen almost every year. The following is a list of some of the incidents in the area where the 2015 avalanche happened:

- An avalanche hit the upper row of spisshus in road 230 one time before the fatal accident in 2015. The date is uncertain but it could have been 5th April 1991. The debris piled up into the wall.
- In 1993 NGI was informed of 4 avalanches that had released in the slope in the limited period 1991-1993. The high frequency of avalanches above the houses actualized the need for protection and evacuation of the most endangered areas identified by NGI as road 226-230. Table 4.1 below from NGI report 904025-7 (NGI, 1993a) shows avalanches in situations with limited wind and very little precipitation. This indicate that precipitation alone is not necessarily a proper parameter for avalanche hazard evaluation in the area. See Chapter 7 for further discussion on avalanches and weather.
- Around 2005 an avalanche was triggered by kids playing in the area. One boy about 10 years old was caught and completely buried. He was dug out alive.
- On 19th December 2010 two persons walking on foot in the terrain triggered a large avalanche:
  - The size and the crown of the avalanche was about as the fatal avalanche 19th December 2015 with estimated fracture height of more than 2 m at the highest.
  - The two persons went up the less steep terrain at the left part of the slope (climbers left) without any problem. On the way down they took the steeper terrain on the other side (skiers left). They heard a "whomp" and was taken by a large avalanche stopping in the flat terrain above 228/21. Both persons were almost completely buried but managed to dig themselves out with their hands without shovel.
  - They described the snow as loose as sugar. The top was hard before the avalanche making it easy to walk on foot in the terrain.

Table 4.1: Observations Svalbard Airport when avalanches in Lia

Date	Precipitation mm			Wind (direction/speed) Degrees/ (m/s)			Temperature °C		
	24t	48t	120t	24t	48t	120t	24t	48t	120t
05.04.1991	0,7	0,7	0,7	160/5	150/5	140/5	-7,6	-7,6	-7,6
19.11.1991	0,5	2,6	2,7	300/3	270/4	160/5	-3,1	-2,1	-2,1
05.11.1992	3,7	4,0	7,2	150/8	150/7	160/6	-12,0	-12,0	-12,0
16.03.1993	0,1	0,2	16,6	160/5	160/5	160/5	-6,0	-5,8	-5,4
19.12.2010	0,4	0,5	2,7	120/8	120/1	120/9	-12,3	-2,9	-0.4

5 Fatal avalanche 19th December 2015

The avalanche released naturally Saturday 19th December 2015 at about 1025 in the morning in clear and calm weather with temperature a few degrees below zero. The avalanche released about two hours after the weather had cleared and calmed after a big storm with a lots of snow and heavy wind from E to SE. There was almost no snow on the ground before the storm that gave 18,1 mm at the airport during the about 18 hours with precipitation and wind that caused the avalanche. The temperature at the airport was -3ºC to -1 ºC during the precipitation.

5.1 Avalanche runout

The avalanche crown was about 175 m long situated 130-110 masl. The avalanche hit the upper row of houses in road 230 situated about 40 masl, and stopped at the third row of houses about 33 masl. The part of the avalanche with the longest runout stopping at house 230/2 had about 80 m vertical drop.

Picture 5.1.1 shows the avalanche a few days after the avalanche.

Map 2 in Appendix A shows the runout of the dense part of the debris map by NGI with hand held Garmin GPS walking around the debris. It is important to notice that runout was influenced by the buildings, and would have been longer without buildings.

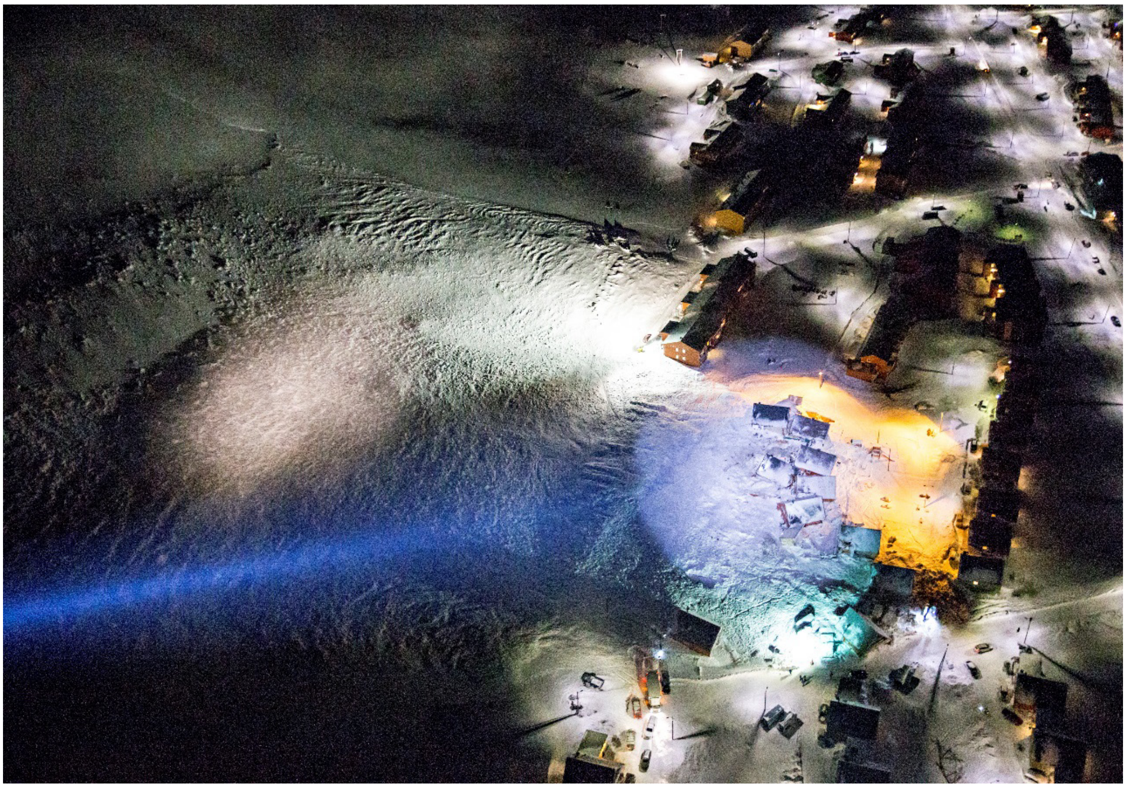


Photo 5.1.1: Picture a few days after the avalanche. Photo: Christopher Engås.

5.2 Estimation of release area and thickness

The avalanche crown was about 175 m long situated 130-110 masl. The digital terrain model shows 10-40 vertical meters of terrain steeper than 30 degrees below the crow. Further down the terrain is typically 25 degrees, but there is also some part with terrain 30-35 degrees.

There is no laser scanning before and after the avalanche, and it is not possible to know the exact release area and volume. It might be possible to run simulations with a smaller initial volume and assuming increase in avalanche volume due to entrainment of snow from the ground. It is also possible to assume a larger start volume by also including terrain less than 30 degrees steep since the initial fracture in the weak layer probably propagated also to 20-25 degrees terrain when the avalanche released. The latest approach give a release area of approximately 15.000 m^2.

The thickness of the avalanche is not known. NGI invested the crown face 1 day after the accident when it had been substantial snowdrift after the release. NGI measured crown height (vertically) from 1m to 2, 5 m. The flank on the left part (seen upwards) was 3-4 m high.

The avalanche released because of heavy snowdrift and deposition of snow in the steep terrain. The crown was at the top of a roll-over and it is assumed that the thickness of the slab was larger in the middle of the release area than at the crown. The average thickness of the area that released must be assumed to simulate avalanche runout. One assumption is that average thickness was 2 m. This gives a volume of 30.000 m^3 when assuming a release area of 15.000 m^2.

Photos 5.2.1- 5.2.6 show details of the avalanche and the crown. Figure 5.2.1 shows NGIs profile at the crown 1 day after the release. Map 2 in Appendix A shows the terrain steepness.

Photo 5.2.1: Picture just before the avalanche released. Photo: Tommy Markussen.

Photo 5.2.2: Picture just after the avalanche. Photo: Christopher Engås.

Photo 5.2.3: Photo about 13 hours after the avalanche released. Photo: Kjetil Brattlien.

Photo 5.2.4: Picture just before the avalanche released. Photo: Tommy Markussen.

Photo 5.2.5: Crown and debris 1 day after the avalanche released. Photo: Kjetil Brattlien.

Photo 5.2.6: Picture just after the avalanche. Photo: Christopher Engås.

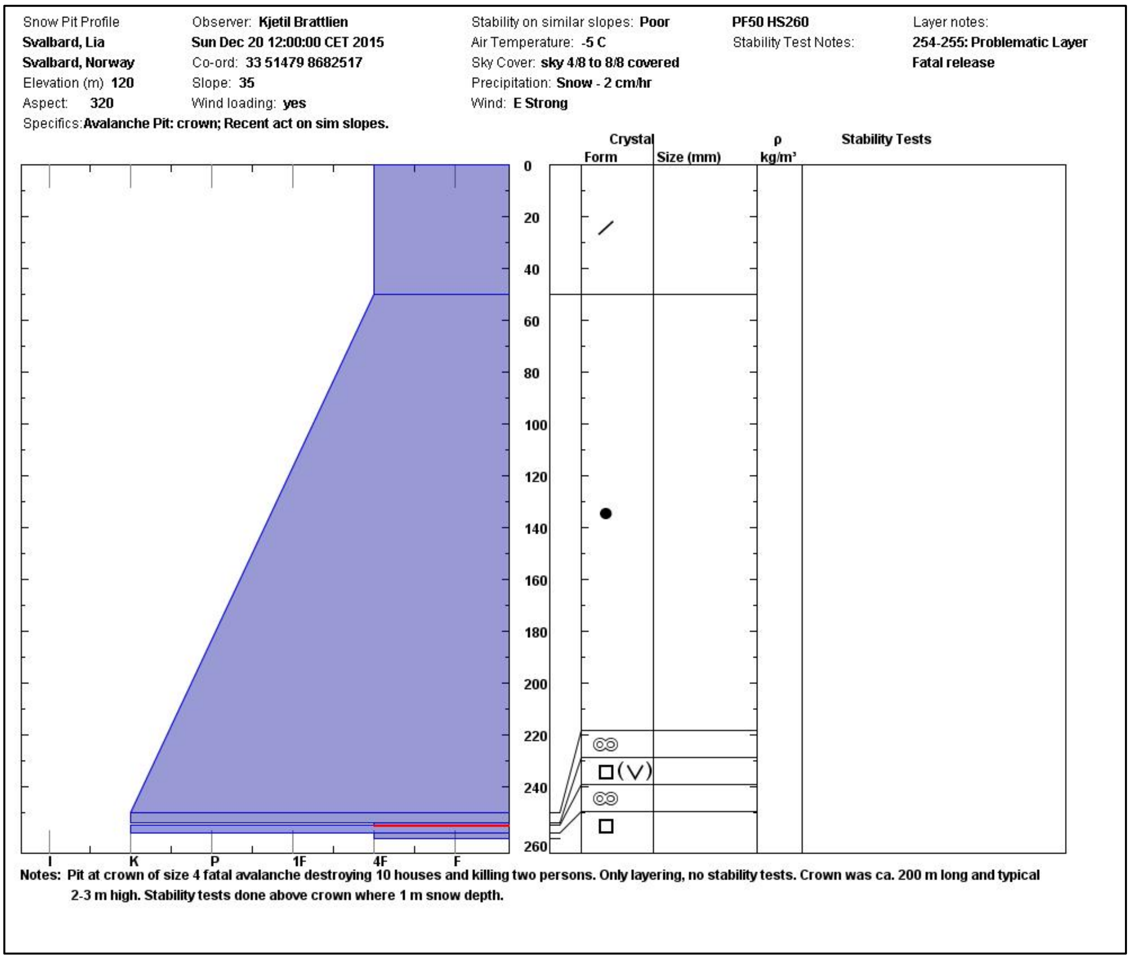


Figure 5.2.1: NGI pit at avalanche crown 25 hours after the release.

5.3 Estimates on height of avalanche powder cloud

NGIs investigation of the damage caused by the avalanche showed more damaged on the first floor in houses than higher above the ground. Photo 5.3.1 shows an example of this. Photo 5.3.2 shows the powder cloud above and in front of the avalanche just before it stops.

Photo 5.3.1: Upper row house 230/30 moved 80 m by the avalanche. Photo: Kjetil Brattlien.

Photo 5.3.2: Powder cloud above and in front of the avalanche just before it stops. Photo: Tommy Markussen.

All street lights where taken by the avalanche except the pole 15 m from house 230/16 that was intact except for one of the two solid metal lamp fixtures being broken off. Damage to the street light about 6 m above the ground (height assumed by NGI) near the side of the avalanche indicate avalanche load also high above the ground. It cannot be excluded that the poles and electrical cord where damaged by the houses when they moved past the area. The load on the electrical cord could also have caused damage to the metal lamp fixture on the street light outside house 230/16.

Photo 5.3.3. The upper row with 4 houses and street light below just before the avalanche. The two closest poles were completely destroyed by the avalanche. Photo: Tommy Markussen.

Photo 5.3.4: Picture one day after the avalanche. Blue line is ground for upper row of houses, red ring is the remaining street light pole. Photo: Kjetil Brattlien.

6 Avalanche destroying houses 21st February 2017

The avalanche released naturally Tuesday 21th February 2017 at about 1100 in the morning. The airport had -6 degrees and 18 m/s from east when the avalanche released. At 0700 the airport measured 19 cm snow depth and 4,6 mm precipitation last 24 hours. The avalanche released both from the top area about 350 masl and from the shoulder as in 2015 at about 125 masl.

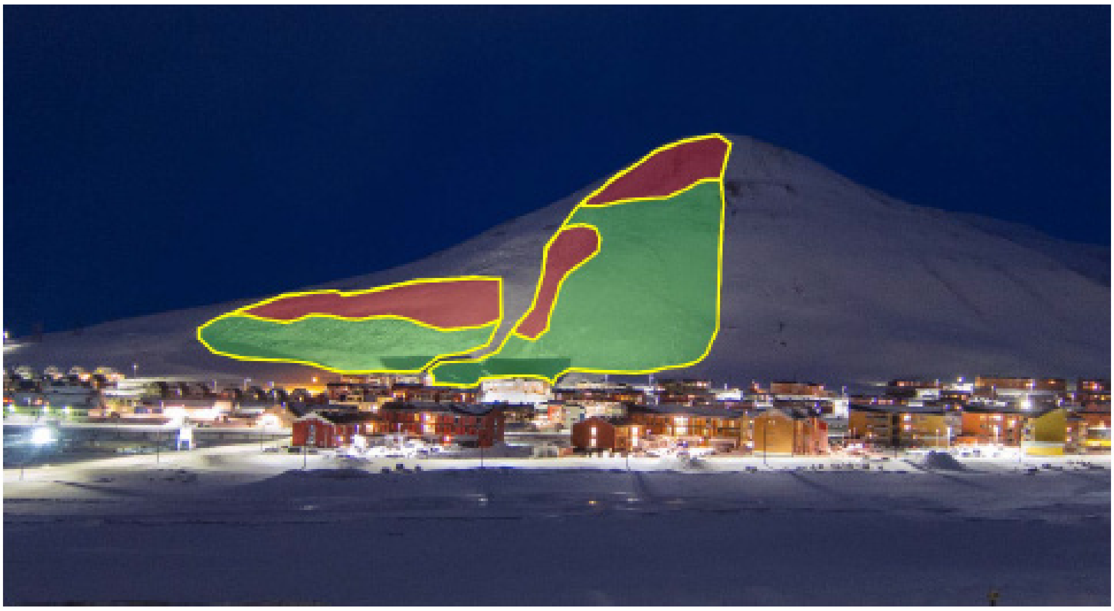


Photo 6.1: Illustration of 2017 avalanche with assumed release areas (red) and runout area (green) from NVE (2017).

6.1 Avalanche runout

The avalanche released both from the top area about 350 masl and from the shoulder as in 2015 at about 125 masl.

- The avalanche from the top stopped at houses 228/7-11 at about 35 masl giving it a vertical drop of more than 300 m. Most of the terrain is steeper than 30 degrees between elevation 350 and elevation 80, but an area 200-250 masl is about 25 degrees steep.
- The avalanche debris destroying houses and stopping in houses 228/7-11 was either from an avalanche releasing at 350 masl, or it was from the lower release area 80 to 200 masl in the same track.
- The avalanche starting from the shoulder about 125 masl as in 2015 had shorter runout in 2017 and stopped about 30 m from where the upper row of spisshus was situated before. The debris stopped 45 masl.

Map 2 in Appendix A shows the maximum runout of the dense part of the debris map by NGI by points measured by differential GPS walking around the debris. It is important to notice that runout was influenced by the buildings, and would have been longer without buildings.

Map 2 also shows best estimate of side and top limitation of the avalanches. This is mainly bases on laser scanning done by UNIS before and after the avalanche.

6.2 Estimation of release area and thickness

The release area at the top is about 18.000 m^2 between about 250-350 masl with terrain typical 30-40 degrees steep. There is also one 18.000 m^2 release area about 80-200 masl with terrain typically 30-40 degrees steep. The terrain between is typically 25 degrees steep, but fracture propagation could in extreme cases connect the release areas creating one area of about 50.000 m^2 for an avalanche width as in 2017.

The release area from the shoulder at about 125 masl released at about the same place as in 2015. The runout was shorter, and the fracture height was probably lower than in 2015.

Photos 6.2.1-6.2.3 show the 2017 avalanche.

Photo 6.2.1: Overview of 2017 avalanche. Photo: Arnt Rennan.

Photo 6.2.2: Aerial photo of 2017 avalanche. Photo: Sysselmannen.

UNIS scanned the area before and after the incident. The scan before was done 14th February and the scan after 22nd February. The weather was characterized by a combination of snow and wind almost every day in the period between 14th February and the release 21st February. Therefore the difference between scan 22 Feb and 14 Feb does not give the thickness or volume of the release directly.

Difference in snow deposition (14-22 Feb) on areas that did not avalanche gives information on deposition in general. However, this is only partly relevant as local wind is assumed to highly affect the deposition on the lee slopes that released.

Figure 6.2.1 shows the difference between scans 22nd and 14th February. Snow deposition has increased most places from 14th to 22nd February. The exception is the top release area (around 350 masl) where green colors indicates typically 0,5 m less snow.

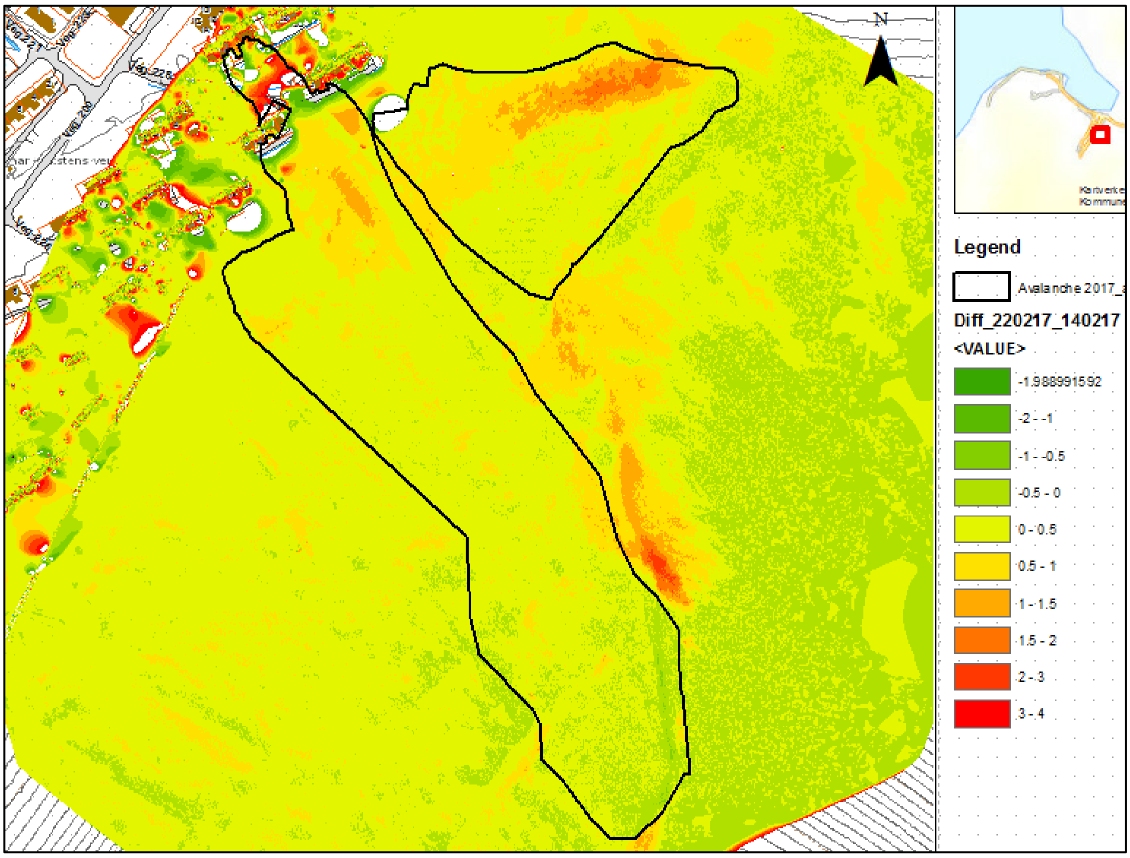


Figure 6.2.1: Difference between scans 22nd and 14th February (positive numbers is increase in snow deposition).

Figure 6.2.1 shows typically less than 0,5 m difference between scans in the upper part that released (350 masl). It is uncertain how much snow deposited in the lee slope in the 7 days with snow and wind between 14th February and the release 21st February. If 0,5 m was deposited the typical fracture height could have been around 1 m, if 1 m was deposited the fracture heights could be 1,5 m etc.

Figure 6.2.1 does not show clear results and likely fracture heights in the lower release area (80-200 masl) of the same track. The figure does not show clear results and likely fracture heights in the release area at the shoulder at 125 masl either.

NVE (2017) indicates that the fracture height at the upper release area was about 1 m.

Laser scan differences of terrain in summer (16th September 2016) and terrain in winter are given below. Figure 6.2.2 shows the 14th February difference from summer terrain, and Figure 6.2.3 shows the 22th February difference from summer terrain. The largest differences can be noted between 14 and 22 February in the deposition area. Please note that shadows from houses effect the results.

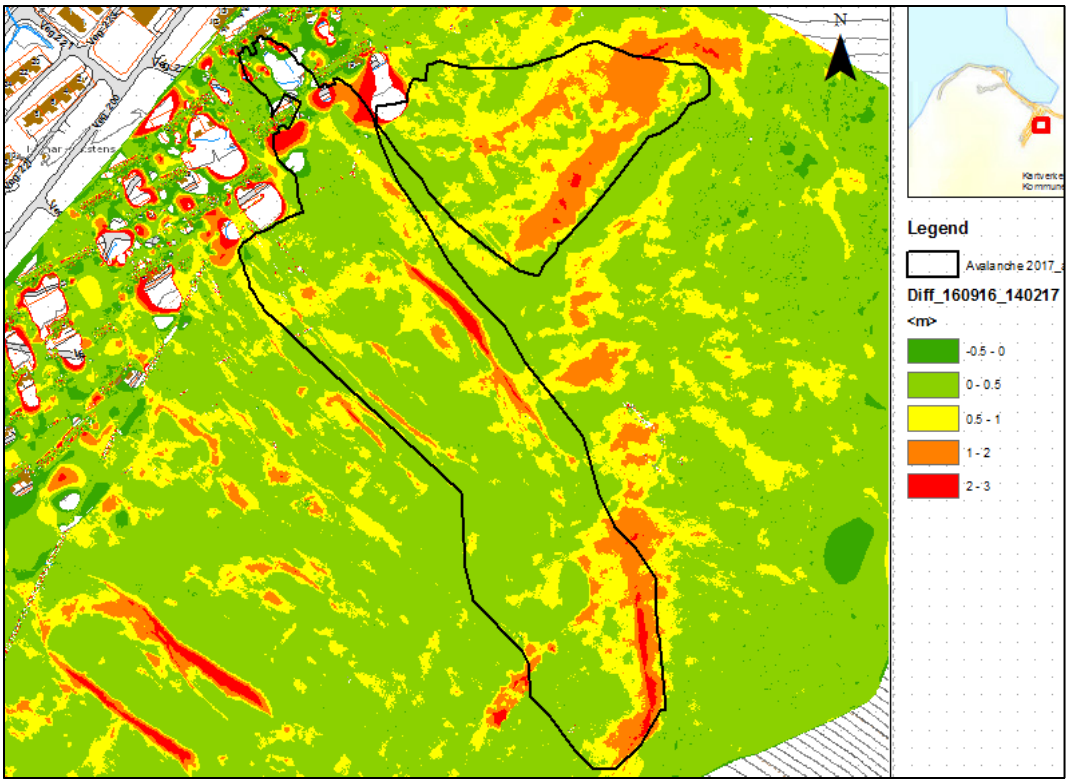


Figure 6.2.2: Difference in summer terrain and snow surface 14th February.

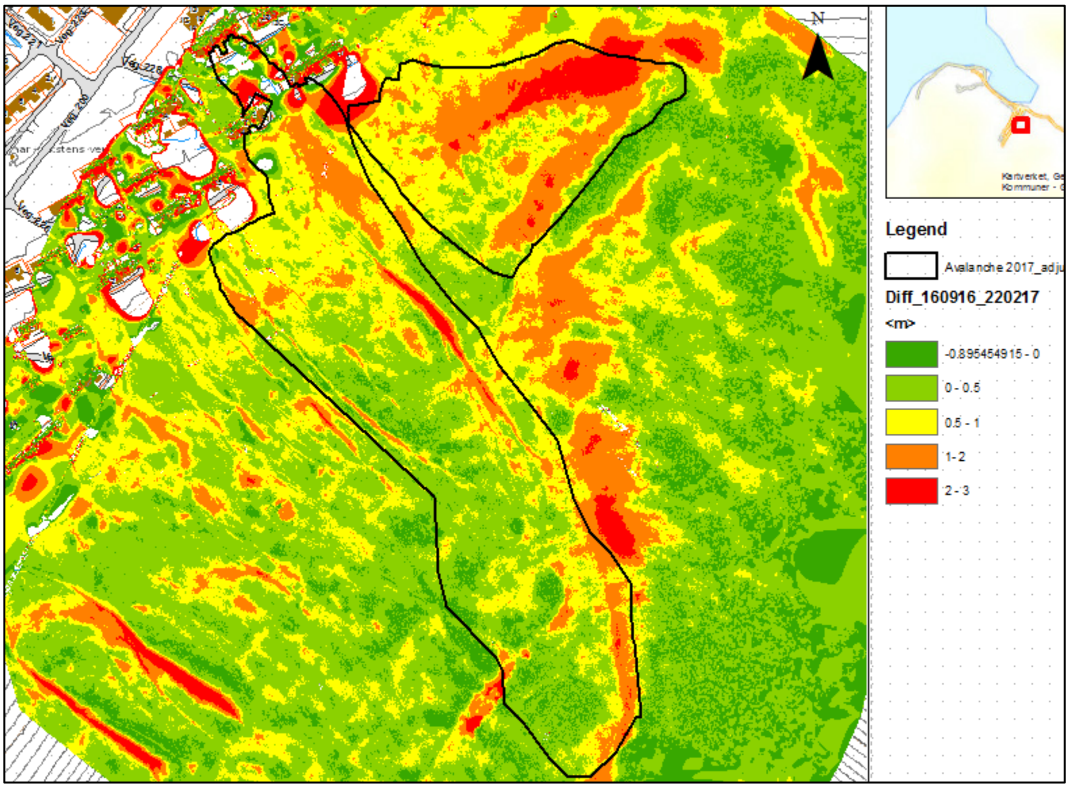


Figure 6.2.3: Difference in summer terrain and snow surface 22th February.

Despite all the information available there are large uncertainties about the release area and fracture height of 21st February avalanche. The average thickness of the areas that released must be estimated to simulate avalanche runout:

- One assumption is that average thickness was 0,5 m in the upper release area around 350 masl. This gives a release volume of 9.000 m^3 when assuming a release area of 18.000 m^2.
- One assumption is that average thickness was 1 m at the shoulder release area around 125 masl. This gives a release volume of 18.000 m^3 when assuming a release area of 18.000 m^2.

Map 2 in Appendix A shows the terrain steepness.

6.3 Estimates on height of avalanche powder cloud

The dense part of the avalanche did most damaged. Pictures below show damage from the avalanche. Note that the pictures indicate that the avalanche had a powder cloud that also did damage.

Photo 6.3.1: House 228/6-10 after the February 2017 avalanche. Photo: Christian Jaedicke.

Photo 6.3.2: Road 228 after 2017 avalanche. Photo: Christian Jaedicke.

Photo 6.3.3: Road 228 after the 2015 avalanche. Photo: Kjetil Brattlien.

Photo 6.3.4: House 228/7-11 after the 2017 avalanche. Photo: Sysselmannen.

Photo 6.3.5: Damage on vehicles outside house 228/7-9 after the 2017 avalanche. Photo: Christian Jaedicke.

7 Observed weather in avalanche situations

A weather station was established at Skjæringa in Longyearbyen in August 1911 (the area where Sysselmannen, the Governor of Svalbard, is located). The station was operated until 1977. The weather station at the airport was established in 1956 with measurement of temperature, wind and humidity, and from 1976 also measuring precipitation and snow height.

The weather station at the airport measures less precipitation than the old station at Skjæringa (NGI, 1992). This can be both because of local climatic differences, but also because the airport is more exposed to wind causing more difficulties to collect precipitation. Figure 7.1 below shows NGIs 1992 analysis of extreme precipitation in Longyearbyen (Skjæringa) and the airport. The 1992 analysis shows more precipitation in Longyearbyen than at the airport. One example of this is January-Mars 100 year 24 hour precipitation of 28 mm at the airport and 53 mm in Longyearbyen.

Please note that more data and newer analysis exists today.

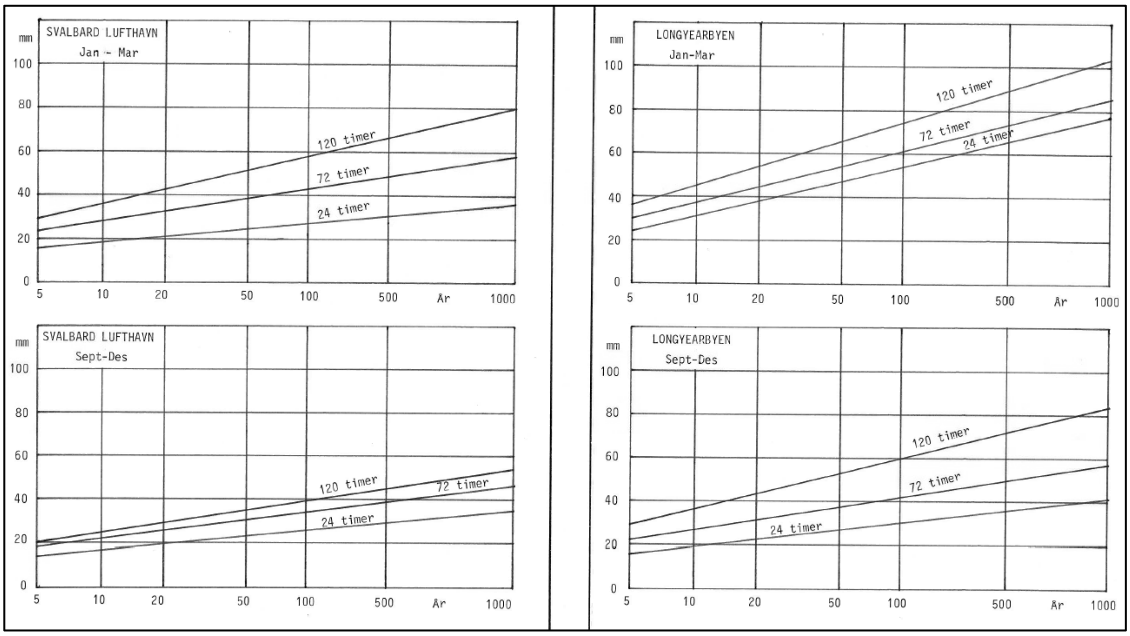


Figure 7.1: NGIs analysis of extreme precipitation done in 1992 (NGI, 1992).

Climate change is believed to increase situations with extreme precipitation. NGIs analysis of data from Isfjord Radio for the period 1934-1975 showed already then a gradual increase in precipitation with time (NGI, 1992).

Table 7.1 shows weather data from the airport in situations where avalanches have released from the Sukkertoppen Mountain (part of the table also showed in Chapter 4).

According to NGIs knowledge only the 2017 avalanche has released from the top area of the mountain. The table show that most avalanches have released in situations with very little precipitation. This indicate that precipitation alone is not necessarily a proper parameter for avalanche hazard evaluation in the area.

Table 7.1: Observations Svalbard Airport when avalanches from Sukkertoppen

Date	Precipitation mm			Wind (direction/speed) Degrees/ (m/s)			Midle Temperature °C		
	24t	48t	120t	24t	48t	120t	24t	48t	120t
05.04.1991	0,7	0,7	0,7	160/5	150/5	140/5	-7,6	-7,6	-7,6
19.11.1991	0,5	2,6	2,7	300/3	270/4	160/5	-3,1	-2,1	-2,1
05.11.1992	3,7	4,0	7,2	150/8	150/7	160/6	-12,0	-12,0	-12,0
16.03.1993	0,1	0,2	16,6	160/5	160/5	160/5	-6,0	-5,8	-5,4
19.12.2010	0,4	0,5	2,7	120/8	120/1	120/9	-12,3	-2,9	-0.4
19.12.2015	18,0	18,1	18,1	90/23	100/15	120/8	-1,6	-4,1	-12,1
21.02.2017	4,6	7,5	8,5	90/18	0/8	0/8	-7,7	-10,4	-10,3

In 1993 NGI made an analysis of local weather situations in Longyearbyen favourable for avalanches in the period 1957-1993 (NGI, 1993b). The NGI report concluded:

- 6 winters had weather situations where large avalanches where expected.
- 4 situations had 3-day precipitation of more than 40 mm (winters 1958/59, 1959/60, December 1960 and 1973/74). All these where winters with cold start of winter and likely persistent weak layers.
- 2 winters had much snow, but not large amounts in short time (winter 1965/66 and 1985/86).
- One situation is somewhat extreme for the local climate. In February 1960 it was measured 39,2 mm precipitation in 24 hours with strong E to SSE wind. Some days before 19,9 mm precipitation was measured with wind from the same direction, giving in total 60 mm in a short period. Lack of historical records makes it uncertain if avalanches released in the situation.

It should be noted that significantly more precipitation was measured in the February 1960 situation than in the 2015 fatal avalanche.

The avalanche weather situations analysed in 1993 are all related to data from the weather station at Skjæringa where observations ended in 1977. The avalanche incidents in 2015 and 2017 did not have exceptional avalanche weather conditions compared to older weather observations at Skjæringa that is located about 4 km from the airport.

8 References

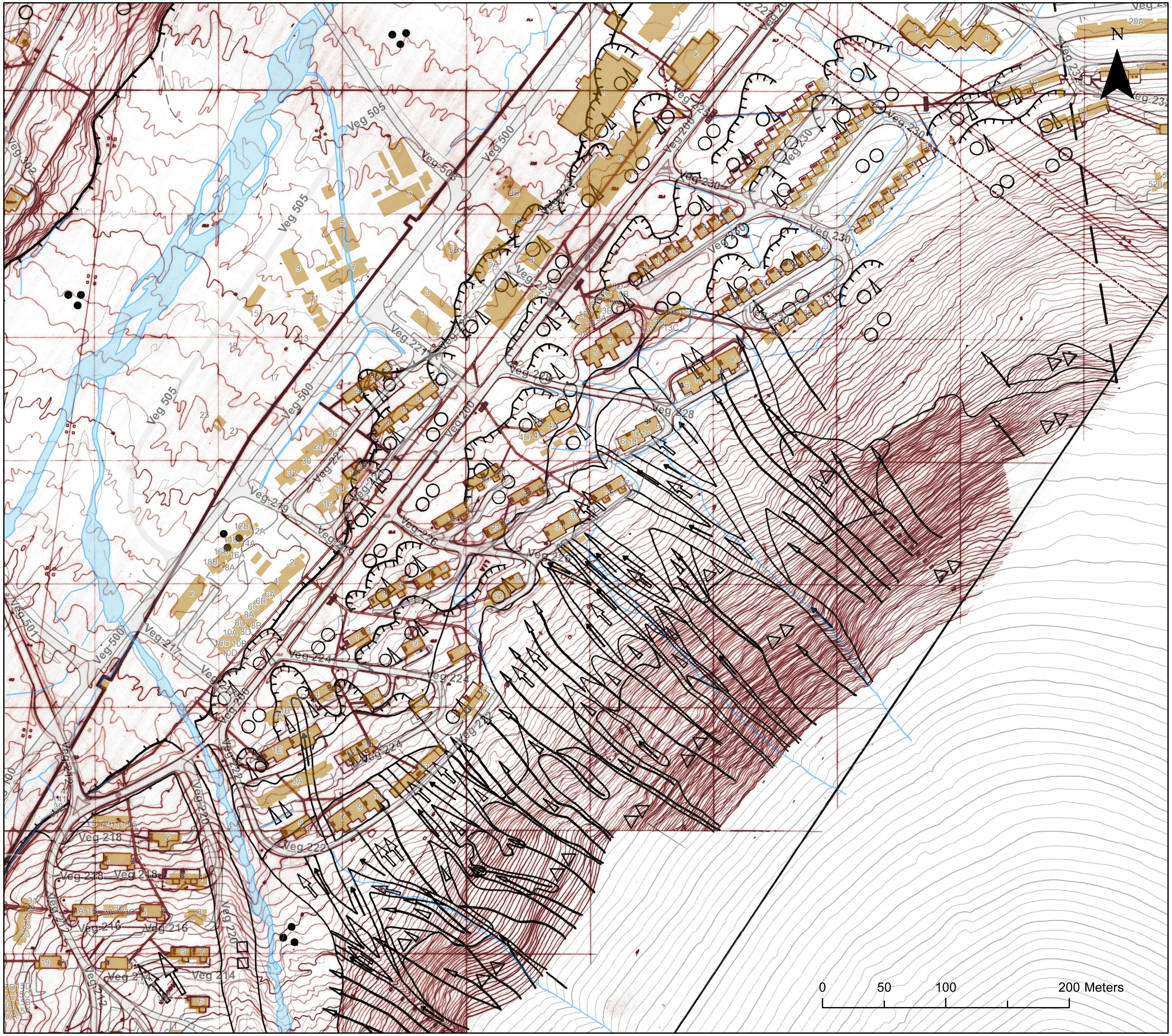
NGI, 1986: Arktisk geoteknikk og fundamentering. Geomorfologisk kartlegging av overflatestrukturer i Longyearbyen, Svalbard. Internal report 52703-1 dated 25th January 1986.

NGI 1992: Longyearbyen – Gruvedalen. Skredfarevurdering utbyggingsområde. NGI Report 924004-1 dated 26th May 1992.

NGI 1993a: Lia, Longyearbyen. Rutiner for akutt skredfarevurdering. Forslag til hjelpemidler, observasjonsprogram, evaluering av innsamlede data og tiltak. NGI Report 904025-7 dated 17th December 1993.

NGI 1993b: Haugen – Nybyen, Longyearbyen. Skredfarevurdering av mulig byggeområde. NGI Report 934063-1 dated 28th May 1993.

NVE 2017: Gjennomgang og evaluering av skredhendelsen i Longyearbyen 21.02.2017. NVE rapport 31-2017.



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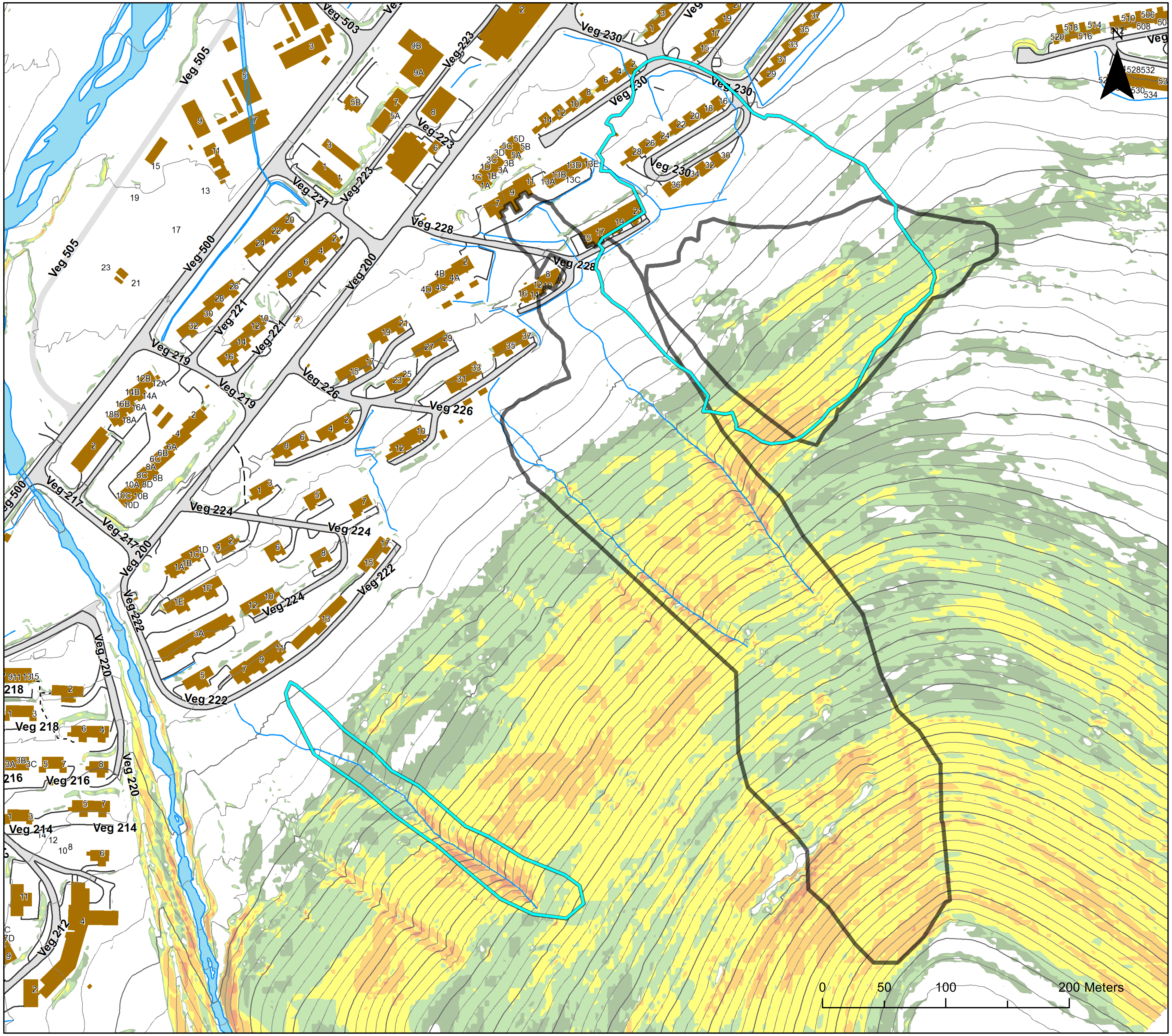
Sukkertoppen Svalbard		
Avalanche incidents	Project No. 20171006	Map No. 2
NGIs geomorphological 1985 mapping showing deposits from debris flows.	Drawn by KB	Date 2017-12-08
	Controlled by CJ	Approved by KB

NGI



Legend

Terrain steepnees

<Degrees>

- 20° - 25°
- 26° - 30°
- 31° - 35°
- 36° - 40°
- 41° - 45°
- 46° - 60°
- 61° - 90°

Scale (A3): 1:3 000 Datum: Euref89, Projection: UTM 33

Sukkertoppen Svalbard		
Avalanche incidents	Project No. 20171006	Map No. 2
Terrain steepness and runout 2015 avalanche (blue) and 2017 avalanche (black).	Drawn by KB	Date 2017-12-08
	Controlled by CJ	Approved by KB

Kontroll- og referanseside/ Review and reference page

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UTM-koordinater/*UTM-coordinates* **Zone:** 33 **East:** 514650 **North:** 8682600	**Koordinater/*Coordinates*** **Projection, datum: East: North:**

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