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# Solutions for draining the Åknes rockslide

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## Abstract

The Åknes rockslide area in Stranda municipality, Western Norway, is identified as a high-risk object. There are three main scenarios for activation of a rockslide, where a rockslide from the western flank, with an estimated volume of 18 million $m^3$, is considered most probable. The entire area is estimated to have a volume of approx. 54 million $m^3$. If a rockslide at Åknes occurs, it will create a displacement wave which will cause damage to populated areas along the fjord.

The rock slope has been monitored by numerous instruments for more than two decades and considerable effort has been expended to understand the rockslide area and the associated risks. Extensive investigations have demonstrated that drainage is a feasible method of stabilizing the Åknes rockslide.

Norconsult Norge AS has been engaged by the Norwegian Water Resources and Energy Directorate (NVE) to work on a preliminary project aiming to find and evaluate solutions for drainage of the Åknes rock slope area. The current drainage concept is a combination of an approx. 8 km drainage tunnel, diversion ditches above the backscarp and boreholes from the toe zone of the unstable rock slope.

A 3D groundwater flow model is under development to simulate how the different drainage measures change the groundwater pressure.

Other aspects of the project include geological engineering recommendations and design basis regarding tunnelling close to/in an unstable rock slope and technical possibilities and limitations for construction works in demanding terrain conditions with only helicopter access.

The article gives an overview of the project status with focus on the proposed design of the drainage solutions.

## Keywords

Rockslide, drainage, tunnelling, groundwater, hard rock engineering

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# 1 Introduction

## 1.1 The Åknes unstable rock slope

The Åknes rockslide area in Stranda municipality, Western Norway, is identified as a high-risk object. A rockslide from the western flank, with an estimated volume of 18 million m$^3$, is considered the most probable scenario. The entire area is estimated to have a volume of approx. 54 million m$^3$. If the whole unstable rockmass collapses, it will create a displacement wave which will cause damage to populated areas along the fjord.

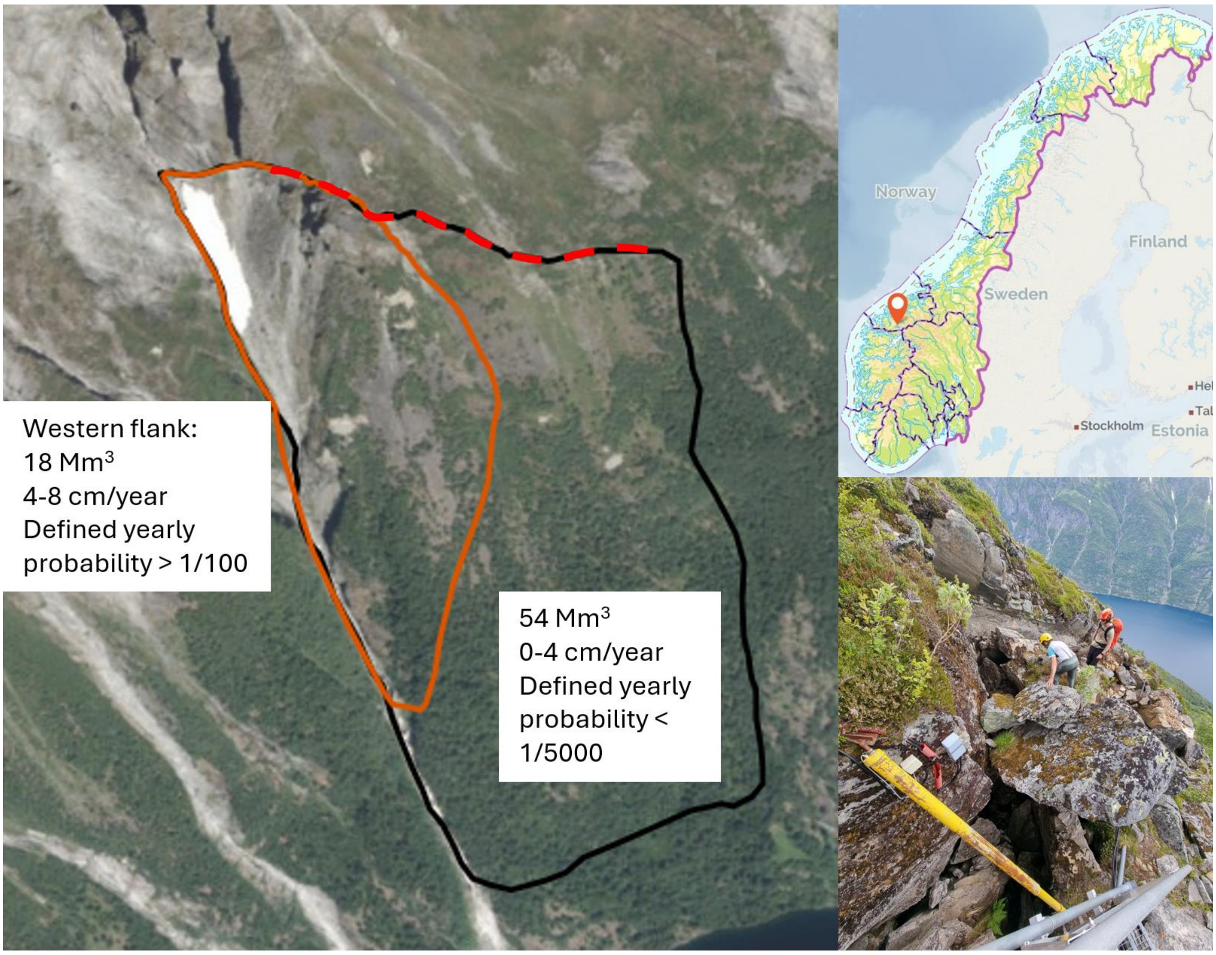


Fig. 1: Orthophoto with an overview of the Åknes rockslide area. The orange line shows the western flank and the black line marks the entire unstable area (modified after Norconsult Norge AS 2024). The map to the right gives the location in Western Norway (Kartverket 2024) and the photo shows part of the backscarp (from the project site visit in June 2024). The backscarp is also marked with the red dotted line on the orthophoto.

## 1.2 Åknes drainage project

Extensive instrumentation is installed to monitor the rockslide area (Fig. 2). The extensive monitoring program requires a lot of resources both financially and in terms of staffing. Comprehensive evacuation plans have been established for several of the municipalities affected by a possible rockslide. There is a substantial economic cost associated with an evacuation. There is also uncertainty associated with notification of danger level, resulting in repeated evacuations.

Extensive investigations and monitoring of the unstable area have been ongoing since 2005. During the years 2017-2021 the Norwegian Water Resources and Energy Directorate (NVE) carried out an extensive research project to investigate the possibility of stabilizing the mountain area. The project concluded that there is a connection between the groundwater level and displacement rates in the unstable area, and it is likely that displacement rates will be reduced if the groundwater level is reduced (NVE 2021).

In January 2024, NVE entered a contract with the engineering consulting company Norconsult Norge AS for a feasibility study and preliminary technical design for drainage measures. This article presents the project status with focus on the proposed design of the drainage solutions.

## 2 Priority areas for groundwater drainage

Fig. 2 shows recommended priority areas for groundwater drainage based on the following:

- Groundwater drainage in the upper part of the unstable rock mass, including the backscarp area, has the highest priority. This is the main inflow area for groundwater and the area with the highest registered displacement rates. Drainage in the upper part is expected to reduce both the groundwater level in the upper part of the fractured rock mass and the overpressure in deeper parts of the fractured rock mass.
- Measured displacements in the lower part of the rockslide area are very low to zero.
- The toe zone and the western gully are outflow areas for groundwater.

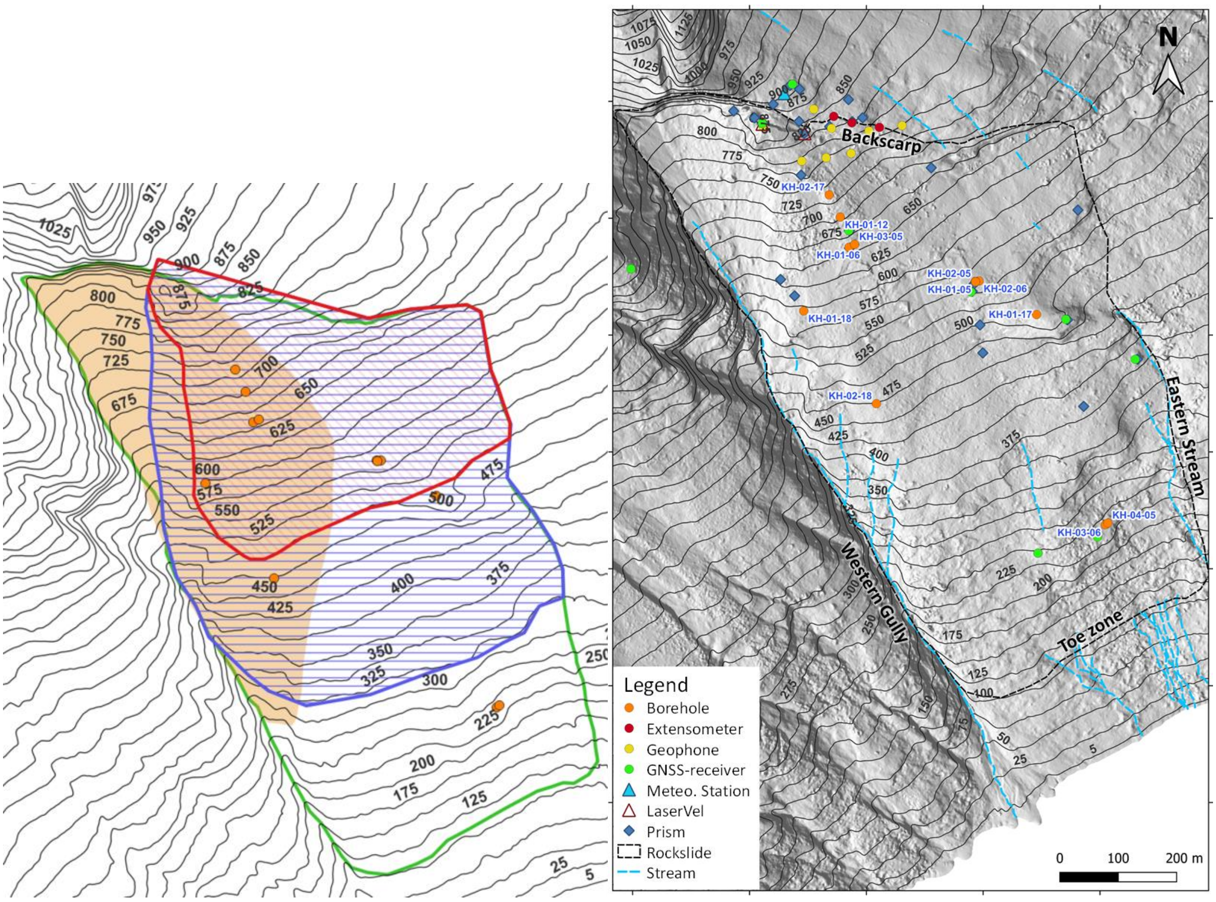


Fig. 2: Priority areas for groundwater drainage. Red line = priority area 1; blue line = priority area 2; green line = priority area 3; beige = western flank with the highest displacement rates; orange circles = boreholes. (Norconsult Norge AS 2024).

## 3 Structural geology

The terrain slope at Åknes is primarily between 30 and 40 degrees, with locally steeper parts. The rock mass consists of different types of gneiss. Details about structural geology and rock mass characterization are described in several articles and an updated summary is given in NVE (2021) and NVE (2024).

Fig. 3 shows a simplified model of the sliding planes in the rockslide area. Displacements/shear zones are identified down to +/- 100 m below the surface in three boreholes. There are several levels of sliding planes, and two main levels are interpreted: 1) a shallow level at 31-35 m depth and 2) a deep level between 63 and 115 m depth. The shallowest sliding plane lies above the groundwater level, while the deepest sliding plane is mainly below the groundwater level. The sliding planes do not seem to be continuous throughout the entire area and there is considerable uncertainty about the depth of the unstable area and how it varies. The average sliding plan depth for the design of drainage measures is assumed to be 100 m below the surface.

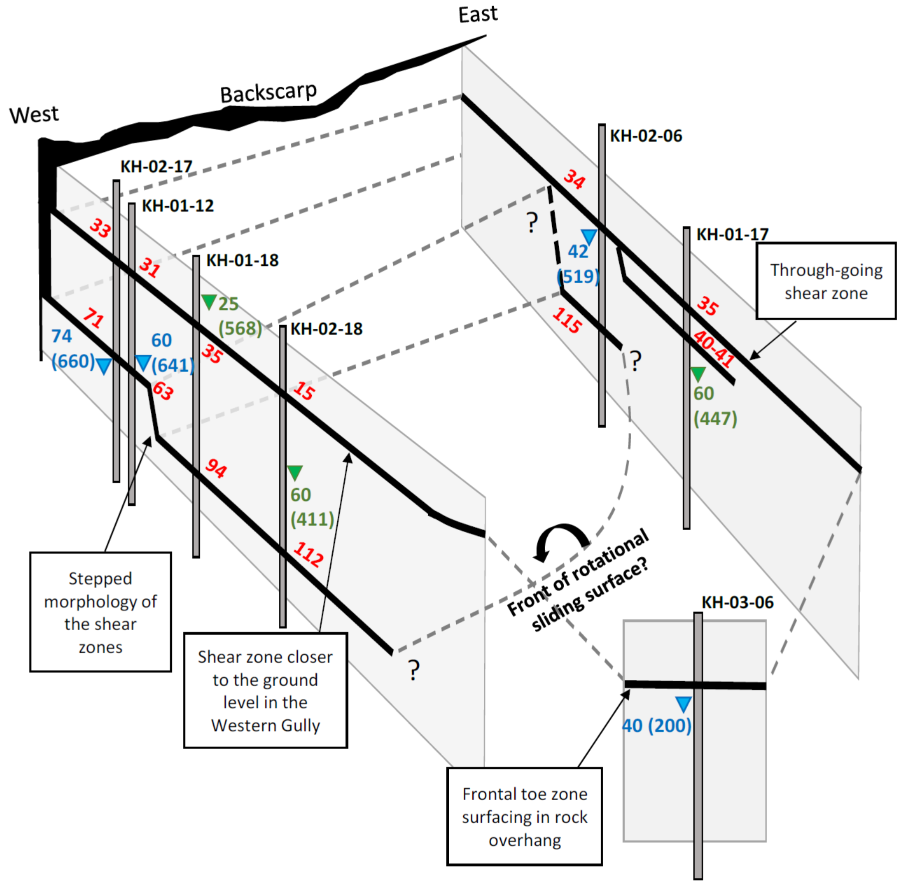


Fig. 3: Three-dimensional model of the sliding planes in the rockslide area from NVE (2024). The model is not in scale. Red text gives depth (in meters) of the sliding planes, blue text gives depth to highest measured groundwater level, green text gives groundwater depth after drilling and in parentheses the corresponding elevation (meters above sea level).

# 4 Drainage concept

## 4.1 Proposed drainage concept

The drainage solutions are developed based on the following criteria:

- The drainage tunnel shall start in the valley located on the other side of the Åknes rock slope (Strandadalen) to ensure a safe access to the tunnel entrance all year round (Fig. 5).
- A drainage solution that best meets the evaluation criterion “best possible drainage effect” is desirable.

There are three primary drainage measures that are proposed as a combined solution for drainage of the Åknes rocks slope: a drainage tunnel under the sliding plane, diversion ditches above the unstable rock mass, and drainage holes in the toe zone (Fig. 4).

The recommended main concept is a drainage tunnel. Drainage tunnels are well-proven for drainage of rockslide areas and experience shows that drainage tunnels are a robust and effective measure for decreasing groundwater pressure and lowering displacement rates (NVE 2021).

Tunnel construction will take several years, and diversion ditches above the backscarp and drainage holes in the toe zone are recommended as additional measures that can be quickly implemented. There is more uncertainty connected to the drainage effect and technical feasibility of these additional measures, but a combination of measures is considered to be a robust solution.

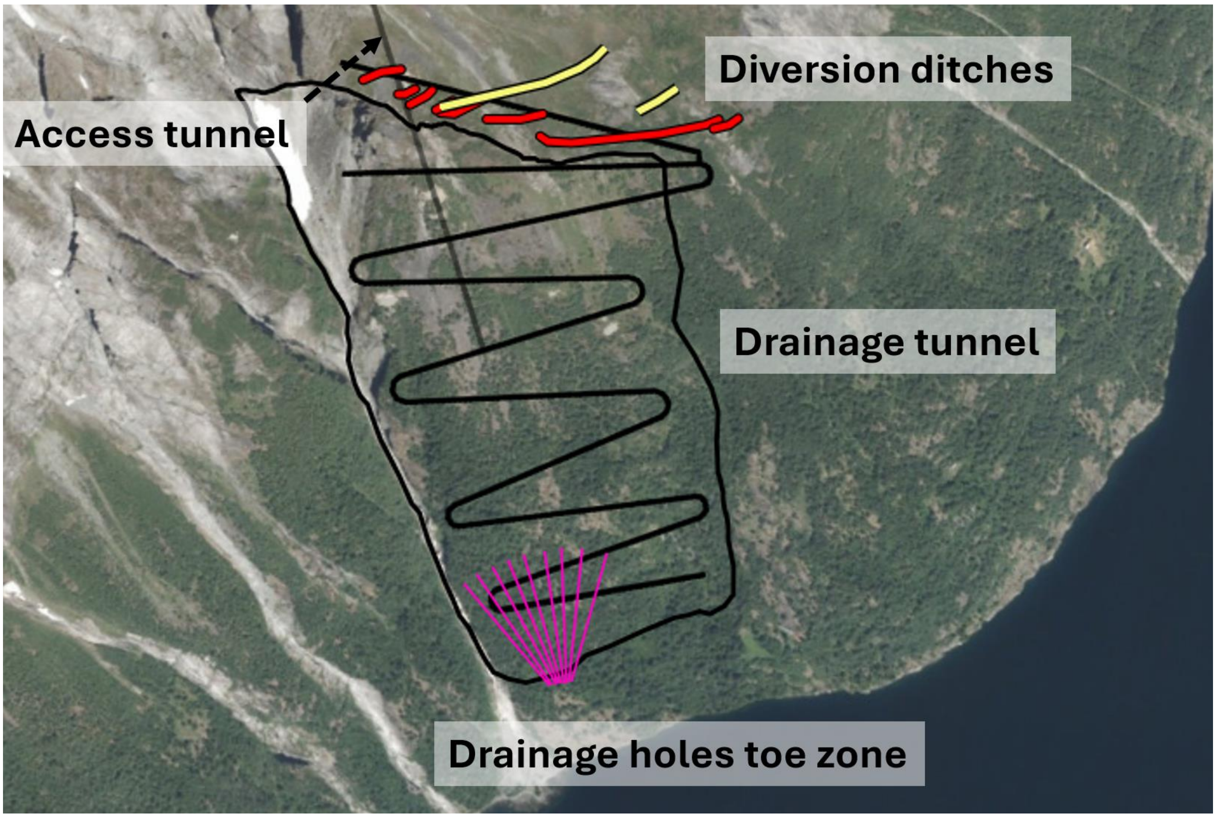


Fig. 4: Recommended concept for further development in the preliminary project.

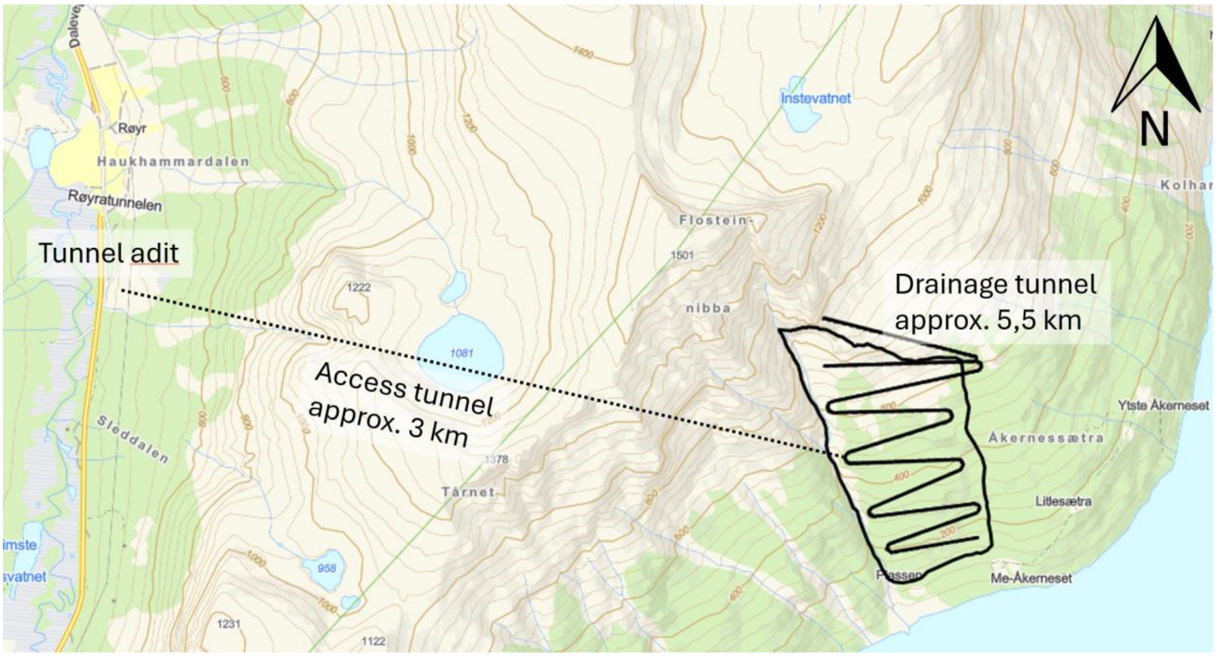


Fig. 5: The tunnel adit is planned to be in Strandadalen, the valley located on the other side of the Åknes rock slope. The access tunnel will be approximately 3 km long.

## 4.2 Drainage tunnel

Design criteria for the drainage tunnel includes the following:

- The tunnel aims to cover as much as possible of the unstable area (to meet the criterion “best possible drainage effect”)
- Maximum inclination of 1:7 for standard drill- and blast tunnelling.
- Proposed minimum cross-section 30 m$^2$ (so far), see Fig. 6.
- The location of the drainage tunnel should be below the unstable area, but still close enough to achieve drainage effect for the tunnel itself and to minimize the length of the drilling holes. A

location outside the unstable area is expected to improve the tunnel stability such that the tunnel will be less affected by deformations (see principal sketch in Fig. 6).

- It is suggested a safety distance of 20 m below the assumed deepest sliding plane to avoid tunnel deformations and regarding vibrations from tunnel blasting.
- Initially proposed vibration limit 25 mm/s based on evaluations of impact of tunnel blasting compared to earthquake vibrations. This limit is assumed to be conservative.

Based on field observations at Åknes and in Strandadalen, information from core holes at Åknes and from available background material, the rock outside the unstable rock mass is considered well-suited for tunnelling. The main geological engineering challenges are expected to be related to high rock stresses and large water inflows with high water pressure. Drilling drainage holes from the tunnel into and through the unstable area is expected to be more challenging due to increased fracturing in the unstable area.

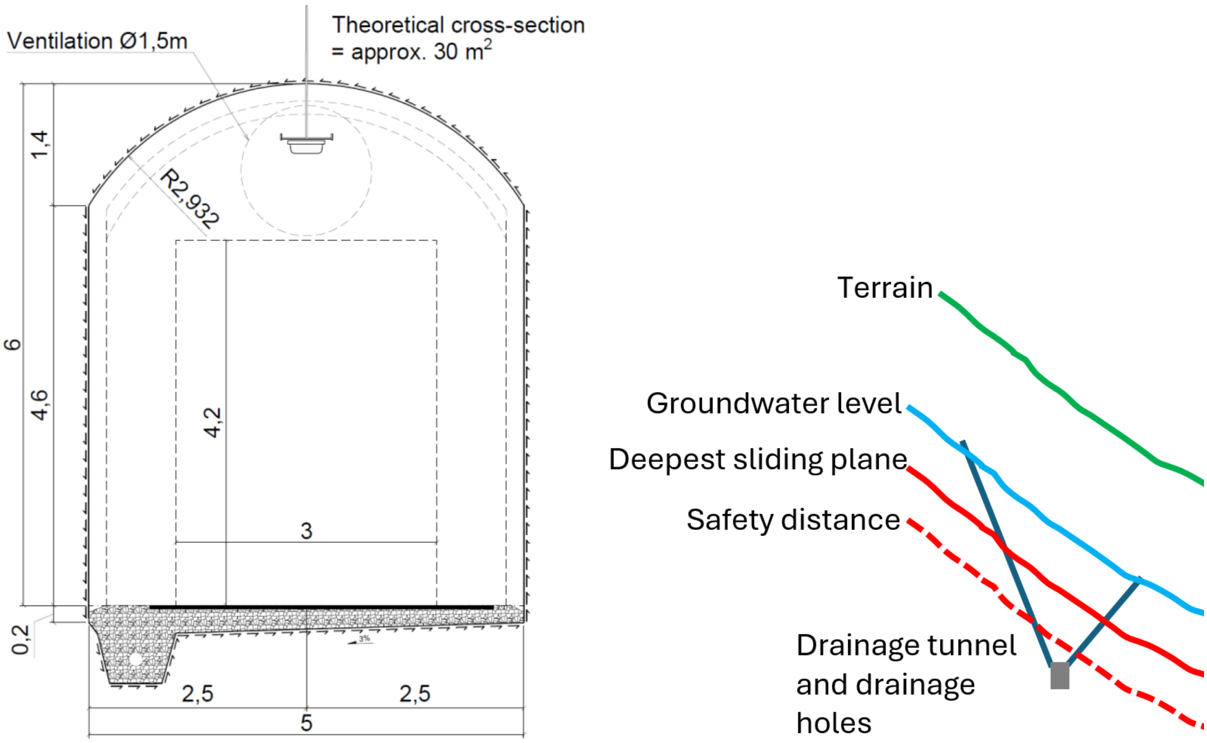


Fig. 6: Left: Preliminary proposal for minimum tunnel cross-section (Norconsult Norge AS 2024). The cross-section takes into account sufficient space for technical equipment, construction ventilation and machinery. Right: Principal sketch of the location of the drainage tunnel below the deepest sliding plane, with drainage holes into the unstable area.

## 4.3 Diversion ditches above the backscarp

The purpose of the diversion ditches is to collect and redirect surface runoff above the backscarp. Fig. 7Fig. 7 shows two alternatives for the location that define the outermost locations for ditch placement. The collected water will be led out of the catchment towards existing streams east of the unstable area. The diversion ditches will be established in bedrock, with the discharge flowing through coarse rockfill or perforated pipes primarily encased in local material from the ditch excavation to reduce helicopter transport. A bentonite membrane will prevent infiltration into the bedrock fractures. Extra erosion protection is required at stream crossings and at ditch outflow points.

The construction will be challenging due to the steep terrain, a site location which requires helicopter transport, n and the short construction (summer) season (approx. June to October). There is uncertainty particularly related to construction feasibility in the western area where the terrain is very steep and covered with rock debris.

There are three main streams disappearing down into the backscarp, feeding the backscarp with water. In addition to the ditches, there are ongoing evaluations for stream intakes with boreholes leading the water down to the tunnel.

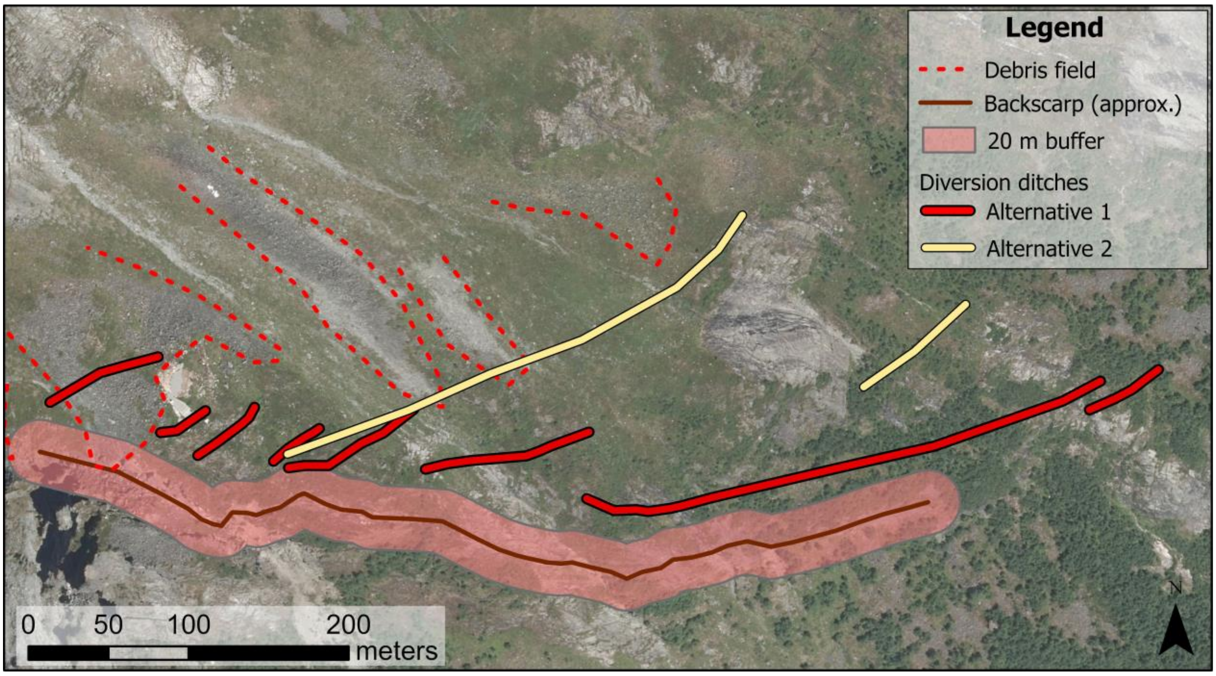


Fig. 7: Location of diversion ditches for alternatives 1 and 2 from Norconsult Norge AS (2024), delineating the outermost locations for ditch placement. There is uncertainty related to feasibility for the four ditches for alternative 1 (red) in the western part of the catchment.

### 4.4 Drainage holes in the toe zone

The purpose of drainage holes in the toe zone (Fig. 4) is mainly an attempt to increase the outflow in this area. The drainage effect is considered to be limited as it only covers the lower part which is not the highest priority for drainage (ref. Fig. 2) and there is uncertainty about whether/where to find water. It is considered as an immediate measure that can be attempted until the drainage tunnel is established but it is not considered as an independent measure.

## 5 Data-driven evaluation

Fig. 8 gives an overview of elements included in the verification and evaluation of effect.

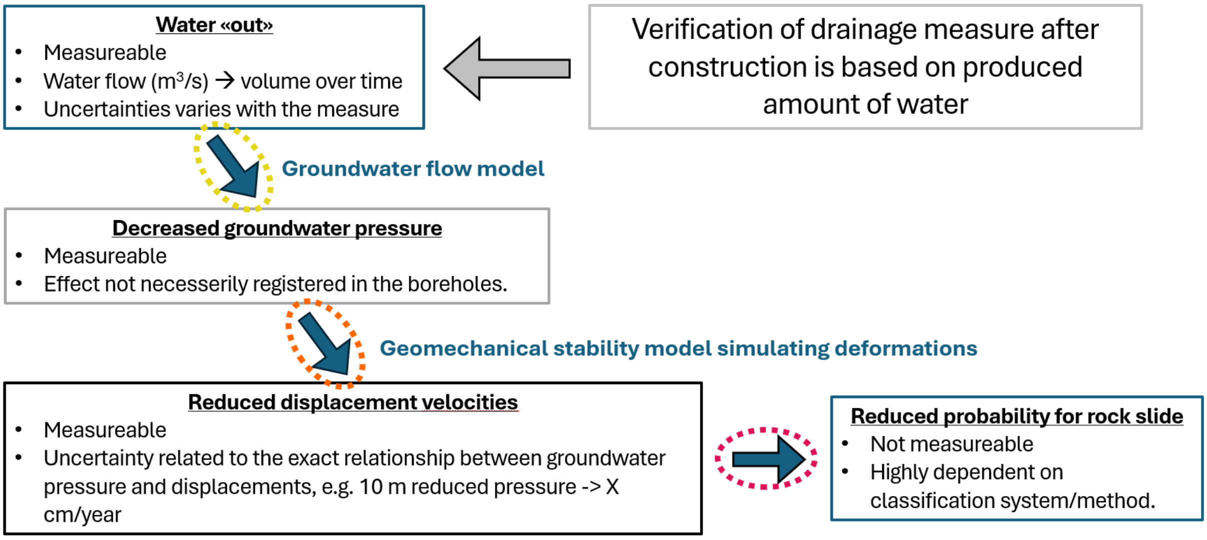


Fig. 8: Overview of elements included in the verification and evaluation of effect regarding drainage measurements. From Norconsult Norge AS (2024).

To evaluate the effect of the drainage measurements in the design phase, a groundwater flow model has been established to simulate the resulting decrease in groundwater pressure. Detailed results are currently not ready for publication.

To evaluate the relationship between reduced groundwater pressure and reduced displacement rates in the design phase, numerical stability analyses were carried out within the knowledge project, and the results indicated that a lowering of groundwater levels would significantly reduce the displacement velocities in the rock mass (NVE 2021). New numerical stability analyses are not planned to be carried out in connection with the preliminary project because they are associated with great uncertainty and are not deemed to provide sufficient benefit for the project at this phase.

# 6 Further work in the preliminary project

The preliminary project is ongoing, and the technical feasibility study is planned to be completed in May 2025. Further development and detailing of the drainage concept and simulations in the groundwater model for evaluation of effect are planned. In parallel with the technical assessments, planning and environmental impact assessments are ongoing to complete the municipality zoning plan.

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