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Research article

Characterization of the Kringelmomyra peatland: geotechnical, hydrogeological, and ecological aspects

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Abstract: Peats are abundant in the Northern Hemisphere and tropics, yet soil mechanics traditionally emphasize sands, clays, and silts, often overlooking peats. Despite this, engineering challenges related to peats, such as differential settlements and landslides, impact society. Understanding peat behavior is crucial for addressing modern issues like infrastructure resilience, CO_2 emissions, and climate change adaptation, and for developing less intrusive construction methods that reduce peatland degradation. Kringelmomyra is a peatland in northern Norway where the surcharging method is being used to construct a new highway. This paper presents its geotechnical, hydrogeological, and ecological characteristics, initial quantitative data on potential changes in hydrogeology, and the remaining plant biodiversity resulting from road construction. Geotechnical testing and hydrogeological monitoring reveal complex peat stratification and minimal initial hydrogeological impact. The endangered peat moss *Sphagnum venustum* was found at the site, highlighting the need to monitor the impact at the site in the coming years. Continued interdisciplinary monitoring is essential to understand long-term effects and ensure sustainable construction practices on peatlands.

Keywords: peatland; soil investigations; vegetation monitoring; groundwater measurements

1. Introduction

Peatlands are areas with moisture-demanding vegetation on soil made of partially decomposed plant material (peat). Peat forms over time due to waterlogged conditions lowering oxygen levels, which again inhibit the decomposition of organic material. As a result, organic material, along with its carbon content, is preserved below ground as long as the area remains waterlogged. Thus, the carbon stock in peatlands has become significant over the last millennia [1–3]. In addition, peatlands deliver a range of other ecosystem services such as climate mitigation, providing habitats for numerous highly specialized species, filtering water, providing recreational value, and holding a historical archive in the peat layers.

Conservation of peatlands has been identified as one of the most efficient and cost-effective actions to meet the Paris Climate Agreement (PCA) goals of limiting warming to below 1.5 °C, due to its crucial carbon stock [4,5]. Land conservation, ecological restoration, and improved land management actions of nature can provide up to 37% of the necessary CO_2 mitigation needed to meet the PCA goals [6]. Despite this, undisturbed natural areas are decreasing in Norway, even though the country is committed to ensuring that carbon emissions do not exceed removals overall for the land-using sectors [7]. Restricting the conversion of peat into other economic activities or infrastructure is a key strategy for managing net land use and land-use change. Protecting ecosystems like peatlands is crucial, as minor land-use changes can disrupt their function, transforming a natural carbon sink into a carbon source.

Norway has about 9% of its land covered by peatlands [8]. Norwegian peatlands contain an amount of carbon equivalent to Norway's total climate emissions for 66 years. Between 1992 and 2020, the destruction of peatland in Norway released over 10 million tons of CO_2 [1]. In approximately the same period (1990–2019), the construction industry degraded ca. 20 km² of peatlands, which accounts for ca. 60% of the national peatland reduction [1]. Construction on peatlands for urban development, infrastructure, renewable energy, and holiday homes has resulted in significant degradation of these ecosystems and habitat loss [7]. It is now a common understanding that using peatlands for construction should be avoided where possible. Yet, where construction appears inevitable, like for socially critical infrastructure (energy, transport, water, and sewage networks), new interdisciplinary knowledge is required to understand the impact of development on peatland and to generate currently missing competence in designing and monitoring engineering solutions. The aim of gathering new interdisciplinary knowledge is to prevent progressive peatland changes and the consequential accumulated effects on greenhouse gas emissions, ecohydrological processes, and biodiversity.

From an engineering point of view, peat is a poor foundation material with characteristics that may lead to deformations and damage to the construction that is built on it. Swedish experience [9,10] of the available construction methods on peatlands has pointed out that the ultimate choice of method will vary from site to site depending on the economic and technical demands, and the properties of the soil beneath the peat, especially if these soils are soft and compressible. Traditionally, the peat has often been replaced with materials with higher strength without accounting for the environmental effects on the area. This has been the standard practice when dealing with peat in transport infrastructure projects in Norway.

To improve sustainable practices in Norwegian construction work, research over the past five years has concentrated on the geotechnical characterization of peatlands [11–13]. This research aims to develop solutions that are less resource-intensive and preserve parts of the peatland [14–16]. However, there has been limited focus on a holistic characterization—including geotechnical, hydrogeological, and ecological aspects—along with the long-term performance of these solutions and their impact on the peatlands where they are implemented.

At Kringelmomyra, Norway, preloading has been applied for the construction of a road crossing a peatland. The solution implemented at Kringelmomyra combines the construction on the peat, without excavating the peat masses, in combination with a preload filling, i.e., the peat masses are consolidated by preloading, and the road structure is established on the consolidated peat masses. The measure was applied to keep the peat carbon stock at the site [17]. The present paper summarizes the geotechnical investigations for the construction work and the hydrogeological characteristics and ecological aspects of the remaining parts of the peatland. The novelty of this paper is the combined multi-disciplinary characterization providing input to study how preloading and construction of the road on the peat masses affect the groundwater level and vegetation in the remaining parts of the peatland.

2. Study site

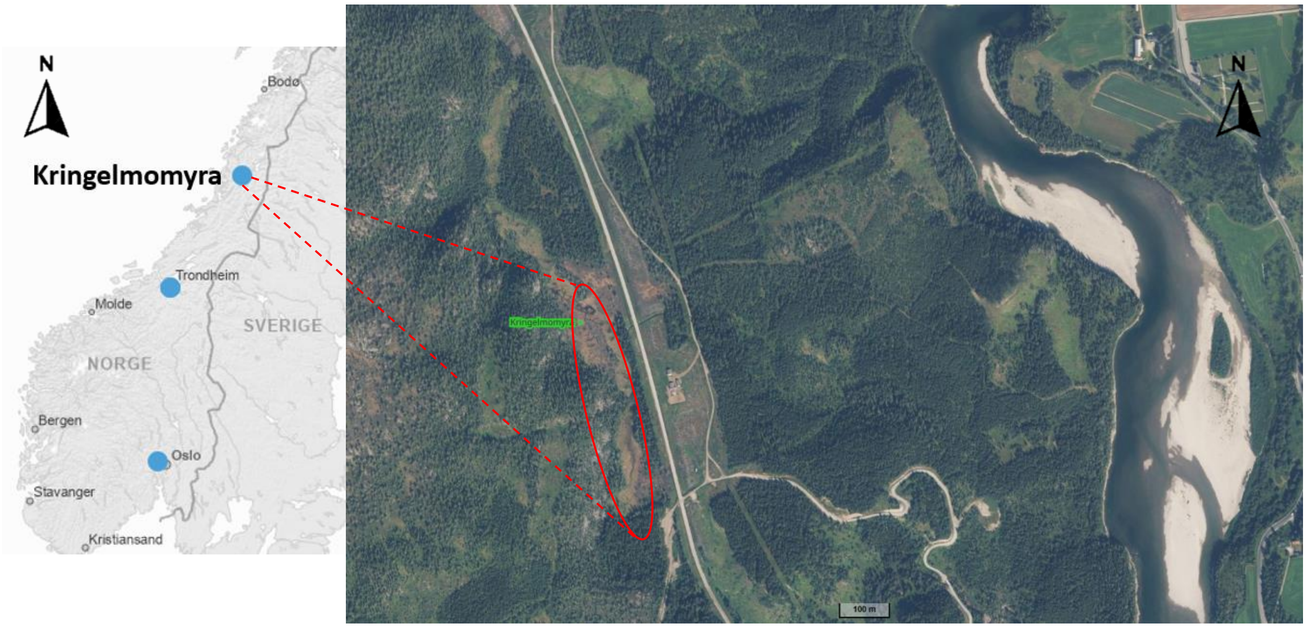

Figure 1. Overview showing the location of Kringelmomyra (marked by the red ellipse) (Source: www.norgeskart.no).

Kringelmomyra is located in Grane municipality, Nordland County, Norway (Figure 1). The construction of the road at Kringelmomyra (Figure 2) is connected with the development of the 11 km new E6 parcel Svenningelv–Lien. The peat masses have been consolidated by preloading over 2 years from July 2022 to July 2024. The preloading technique involves the initial placement of geotextile and a reinforcing geogrid directly on the peatland. Subsequently, several thin layers of gravel, followed by stone, are applied. Each layer is approximately 75 cm thick, with a waiting period of 2–3 weeks before the addition of a new layer. This gradual process ensures that the substrate can withstand the load imposed by the road. The peat under the road will be compressed to approximately half of its original thickness, thereby providing sufficient stability for the road construction. Concurrently, the remains of the peatland on each side of the road should maintain its natural water level.

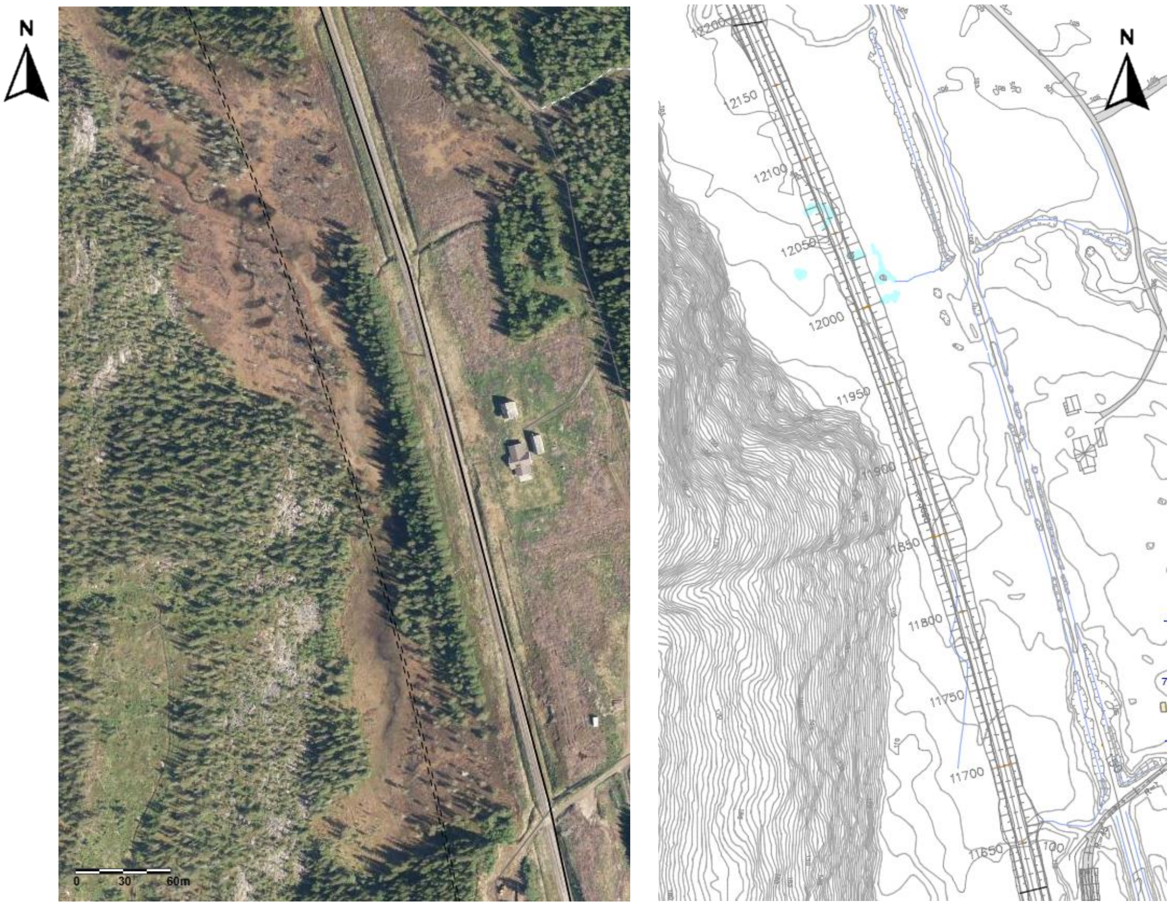

Figure 2. Kringelmomyra is shown on the left (source: www.norgeibilder.no), while the road design is depicted on the right. The road's center line is indicated by the discontinuous black line on the left photo.

3. Details of investigations on the site

Various investigation methods have been employed at Kringelmomyra; Figure 3 shows the position of these site investigations. These ground investigations were strategically conducted at multiple locations across the entire area to gain a comprehensive understanding of the site's characteristics. Geotechnical and hydrogeological characterization has been conducted using 13 total soundings [18] and 5 cone penetration tests [19] in the area, while 22 Jowsey auger probes [20] have been taken within the peatland itself before the construction started. Sampling of the soil deposits below the peat has been done using piston samplers [20].

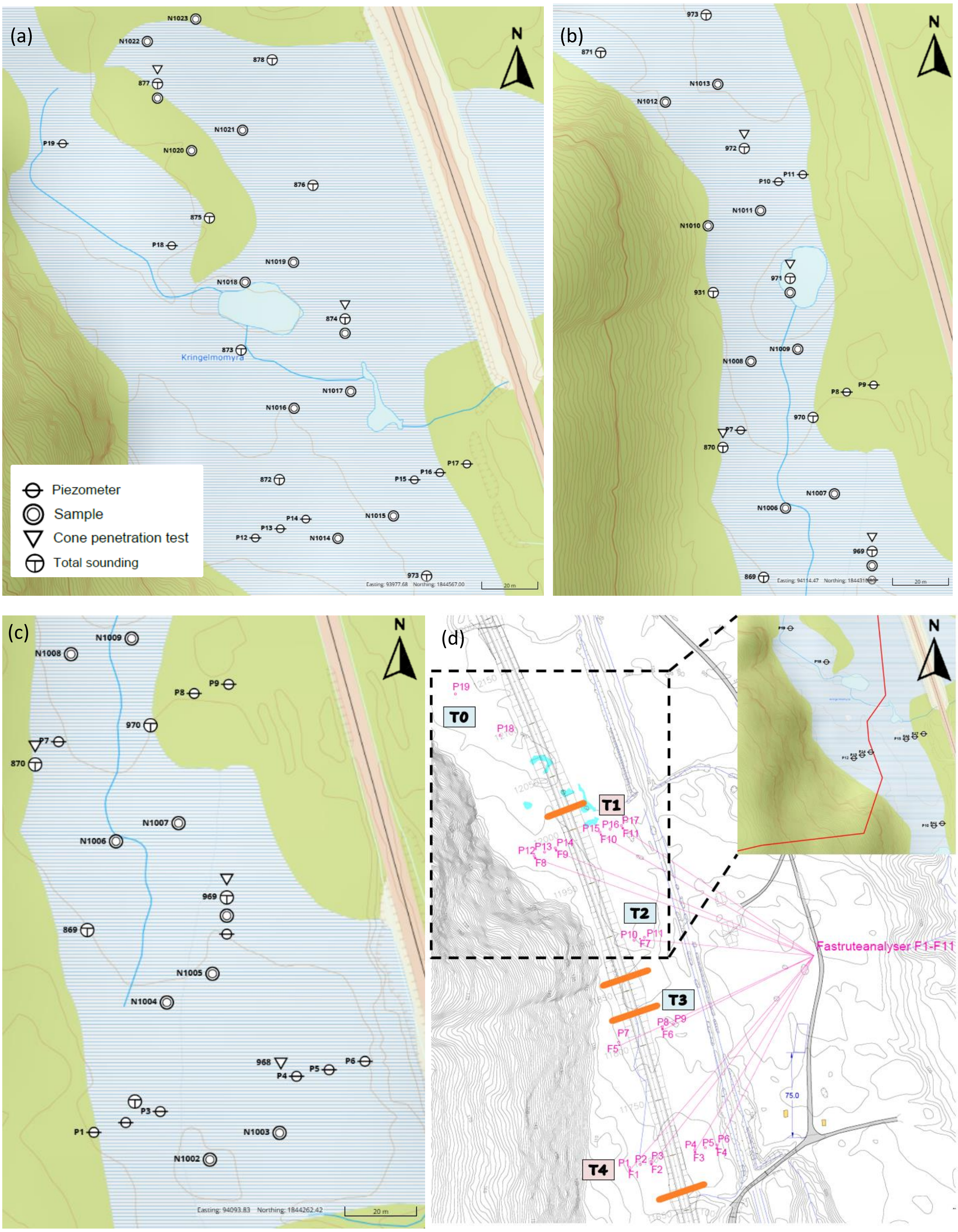

Figure 3. (a–c) Locations of soil investigations from North to South, and (d) location of pore pressure sensors (P1–P19), vegetation plots (F1–F11), and membranes (orange lines) along the road being built at Kringelmomyra. The peatland area is marked by the shaded area in light blue in (a–c).

Pore pressure sensors (see Figure 4a) have been installed since the construction of the road started (July 2022), and measurements are taken twice per day to monitor the changes in the groundwater level. These sensors were installed by pushing them manually into the peat, and they were located based on the dominant direction of water flow (see Section 5), terrain, and design of the road. The road design incorporates four 2-mm double-textured geotextile membranes installed transversely across the road body (indicated by orange lines in Figure 3d). These membranes are intended to prevent water movement within the granular road fill and to reduce drainage of the underlying peatland. The pore pressure sensors were located near these geotextile membranes and in transects (T1–T4, as in Figure 3d) perpendicular to the road alignment, allowing monitoring of the groundwater level in one dimension.

Ground penetrating radar profiles (GPR) were done after the initial preloading filling was constructed in August 2022, to map the thickness of the filling. Three profiles were investigated along the road, one along the centerline and two on each shoulder. In addition, 19 profiles were conducted across the road near profile 11750, which was an area where the greatest irregularities were expected. A GSSI SIR4000 (Geophysical Survey Systems, USA) ground-penetrating radar with a 200 MHz antenna was pulled along by a person. The measurements gave good results in terms of a sharp reflection between the road filling and the peatland masses, which provided a good picture of the thickness of the road filling.

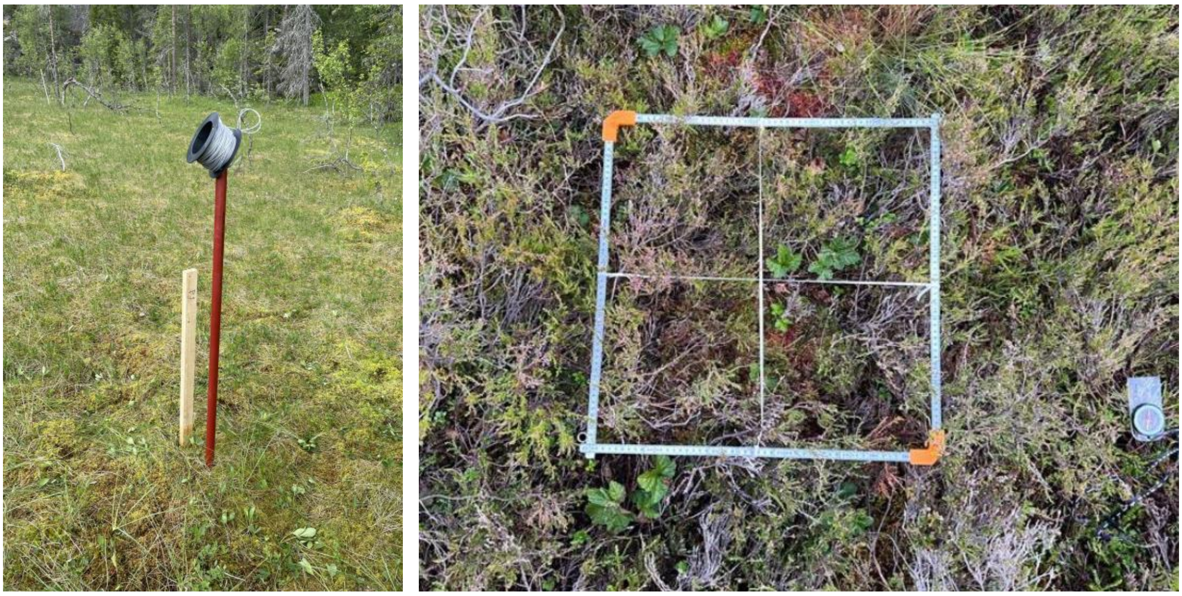

Figure 4. Examples of (a) pore pressure sensor installed at Kringelmomyra (photo: NGI) and (b) vegetation plots for vegetation monitoring (photo: Gunnar Kristiansen).

Vegetation monitoring has been established at the site to evaluate the effect of the road construction on the plant community of the remaining peatland at Kringelmomyra. Surveys have been conducted at the site in 2022 and 2024, with a third registration scheduled for 2026. At the site, all plant species, including bryophytes, were recorded within plots of 50 × 50 cm (Figure 4b). The cover of all species was estimated visually. In 2024, the frequency of all species was also recorded as present or absent within 16 subplots in each plot. In total, 11 plots were established close to the pore pressure sensors, five to the west of the road and six to the east.

Additionally, bag sampling by excavation of the top layer of the peat has been done in 2022 and 2024 at the locations where the groundwater level is being monitored. Samples were taken for carbon and nitrogen determination. These results are now under analysis and will be reported in 2025. The settlements caused by the road preloading filling were also monitored. However, these are out of the scope of the present paper and will be presented elsewhere.

4. Geotechnical ground conditions

The Quaternary geological map from the Norwegian Geological Survey (NGU) shows that the area at Kringelmomyra consists of peat and peatland surrounded by river deposits to the east and glacial river deposits and bedrock to the west (Figure 5). The rock topography in the area is steeply sloping from west to east.

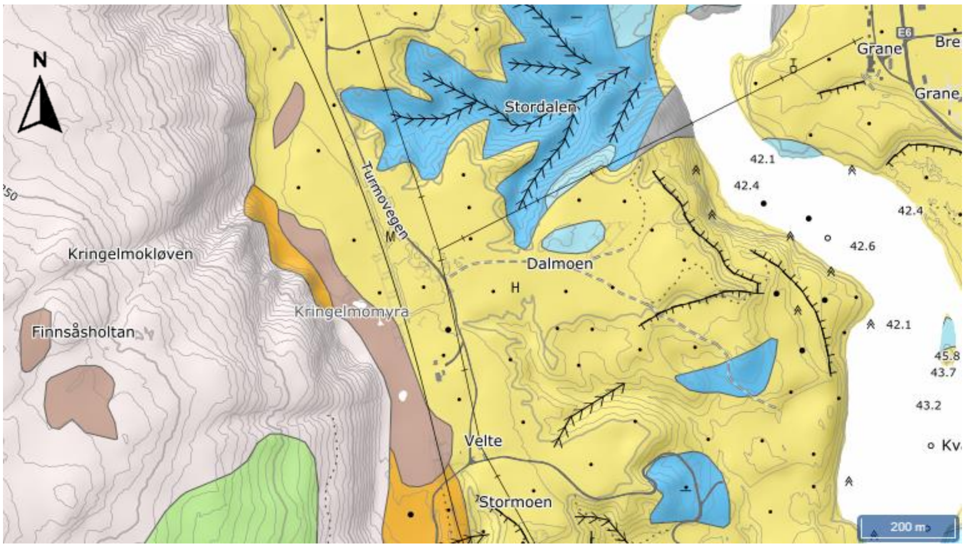

Figure 5. Quaternary geological map from the Kringelmomyra area (source: Norwegian Geological Survey). Brown: peat and peatlands; yellow: river sediments; blue: marine deposits; orange: glacial deposits; light pink: bedrock; green: thin moraine deposits.

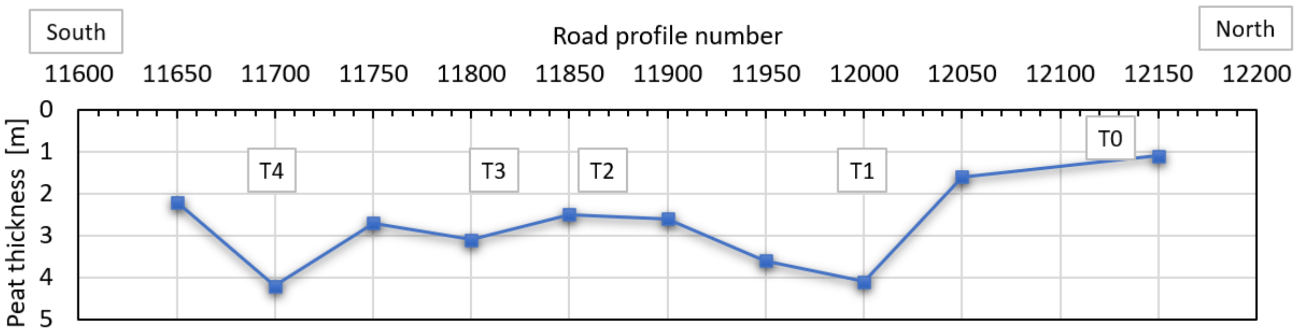

Figure 6. Peatland thickness at Kringelmomyra before road construction, interpreted from ground investigations. Transects (T0–T4) for pore pressure sensors are also indicated. The location of the transects is shown in Figure 3.

Sampling and ground investigations in the area [21] showed that the peat has a thickness between 3 and 5 m before road construction. Figure 6 shows the original peat thickness along the centerline of the road, from south (left) to north (right).

The total soundings and piezocone investigations (Figure 7) reveal that beneath the peat lies a coarser sand layer, approximately 1 m thick, situated above a thick marine clay deposit. In some areas, the clay exceeds 50 m in thickness and contains several layers of silt and fine sand. This clay is normally consolidated and prone to settlements under loading. Samples from the southern part of the peatland indicate that the clay is particularly sensitive[1] in a 1–2 m layer at the sand–clay transition. In this area, there is a quick clay hazard zone. In the middle of the peatland, peat thickness is limited to a small layer of vegetation, and the sand thickness is greater. Under the sand, there is a thick clay deposit, as described above. In the northern part of Kringelmomyra, the stratigraphy is similar to that in the southern part (peat over sand above a thick clay unit). Here, however, the peat thickness is lower, at approximately 2 m, over a thin layer of sand. Toward the north, there is another quick clay hazard zone.

The peat layer can be divided into two main layers:

- **Upper peat layer**: the top 1–2 m of the peatland. The upper peat layer has limited peat decomposition (von Post values H [22] ranging between 2 and 4), which means that it has a high fiber content and relatively high strength, as the fiber and roots bind the material together. The geotechnical water content is high and typically varies between 700 and > 2000% (ratio of the weight of water divided by the weight of solids). See Figure 8.
- **Lower peat layer**: This peat is between 2 and 5 m below the surface. The lower peat layer is more decomposed (H = 6–9), and roots and fibers have broken down. This means that the peat material varies from having a very indistinct plan structure to a material where it is hard to recognize plant structures. This results in the strength of the peat being lower. The water content in the lower part is less than in the upper part, with typical values ranging between 400 and 700%. See Figure 8.

Figure 8 shows the water content and degree of decomposition following von Post classification of peat samples taken along the centerline of the road, before construction. The high variability in the water content makes it difficult to establish correlations between water content and the degree of decomposition. However, one can expect that peat with a higher degree of decomposition (higher H value) generally has higher water content. This is because the amorphous and colloidal nature of more decomposed peat allows it to hold more water. The water content values, degree of decomposition, and peat thickness for Kringelmomyra agree with typical values for peatlands in Norway, according to a database published by [11].

[1] Sensitive clay behaves as a brittle material due to its strain-softening response under undrained shear conditions.

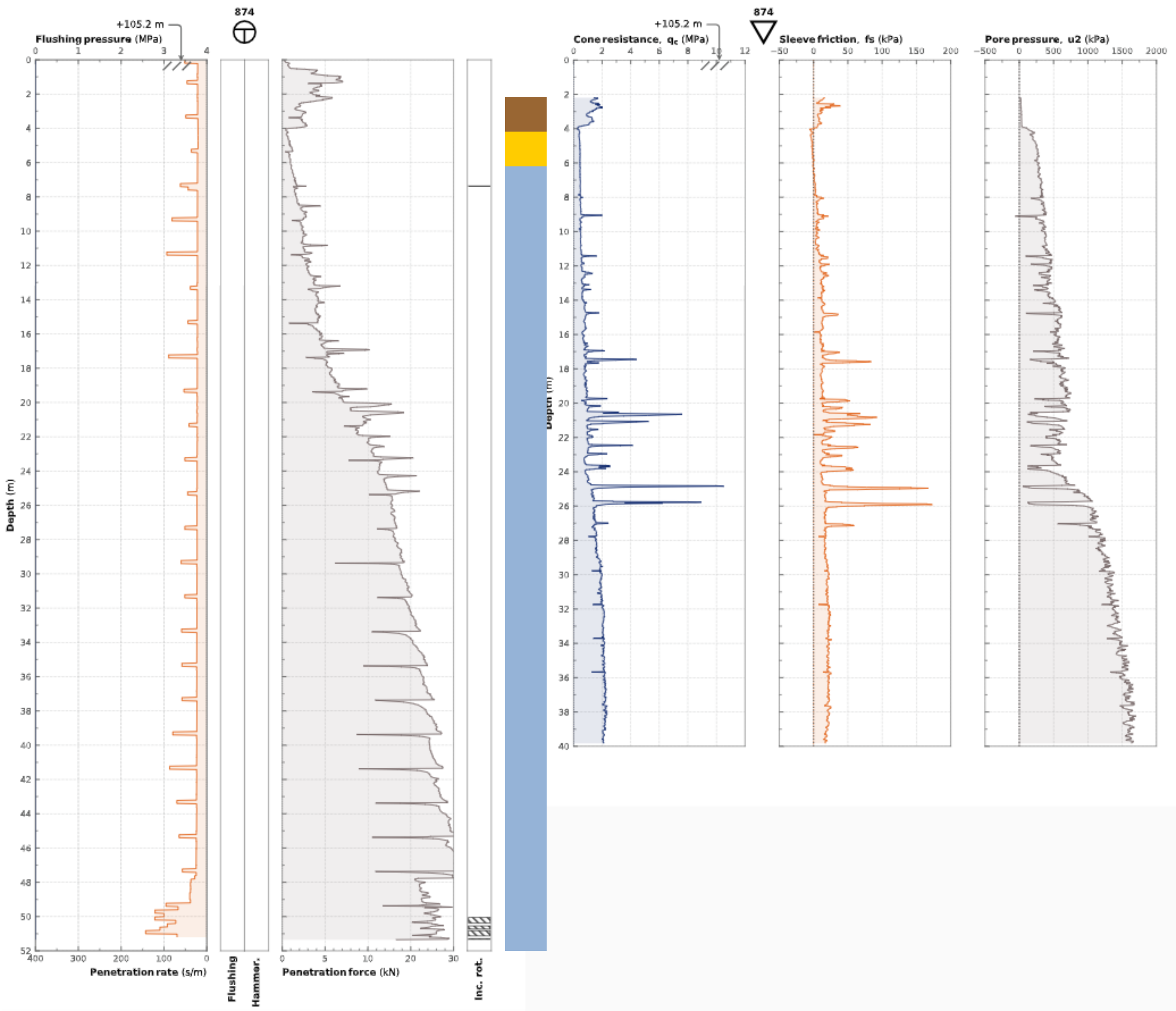

Figure 7. Typical soil profile at Kringelmomyra, consisting of peat over sand and clay. The total sounding and piezocone results are from borehole 874 (source: NADAG, National Database for Ground Investigations).

Figure 9 shows the results from GPR mapping for the peat thickness and preloading filling, after the latter was established. The GPR survey was successful in identifying the thickness of the filling. It can be seen that at locations T1, T2, and T3, the fill is approximately the same thickness (approximately 1.5 m), but the peat thickness at T2 and T3 is smaller (approximately 2.5–3 m). At T4, the fill is thinner (approximately 1 m) than in other areas, while the peatland layer reaches approximately 4 m depth. The filling and peat thickness are important aspects when monitoring the settlements in the area, since current observations [23] indicate that the greatest vertical deformations occur in the areas where the peatland is thickest (i.e., at T4 and T1), and that the settlement differences between T4 and T1 may be due to the lower thickness of the filling placed at T4. Further analysis of the settlements data is included in [23]; since this project is ongoing, it will be presented in another parallel publication.

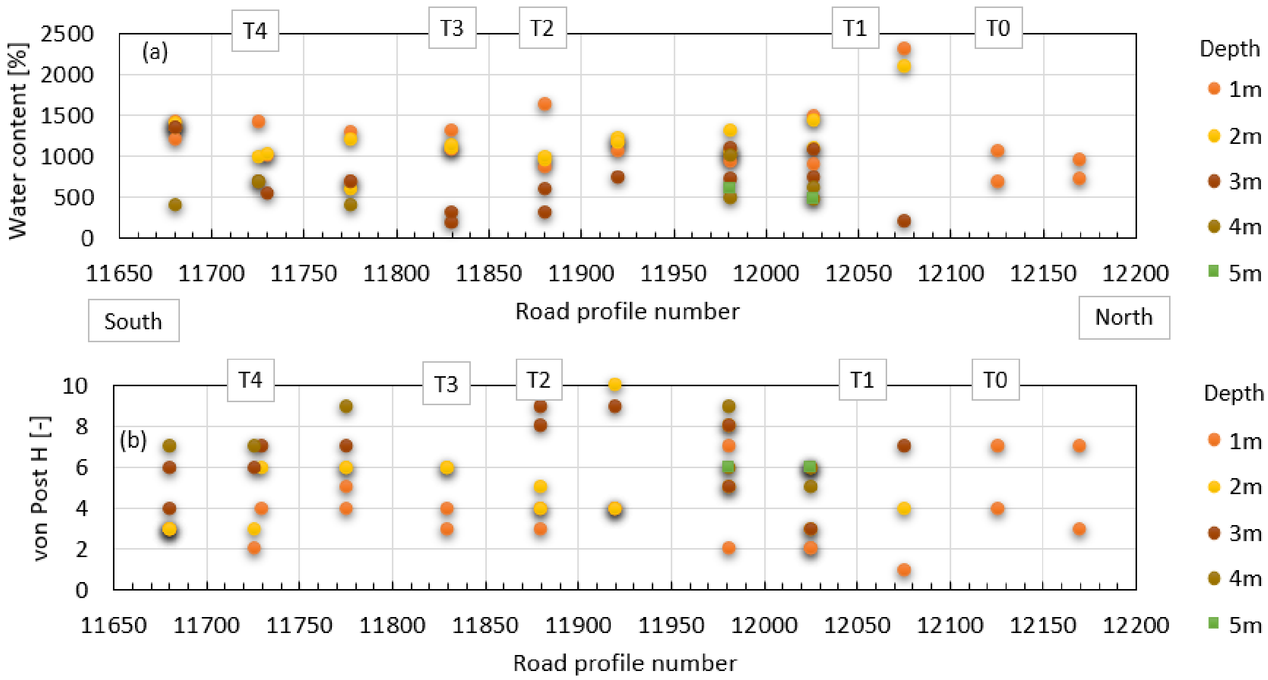

Figure 8. (a) Water content and (b) degree of decomposition (H) following von Post classification along the centerline of the road, before construction.

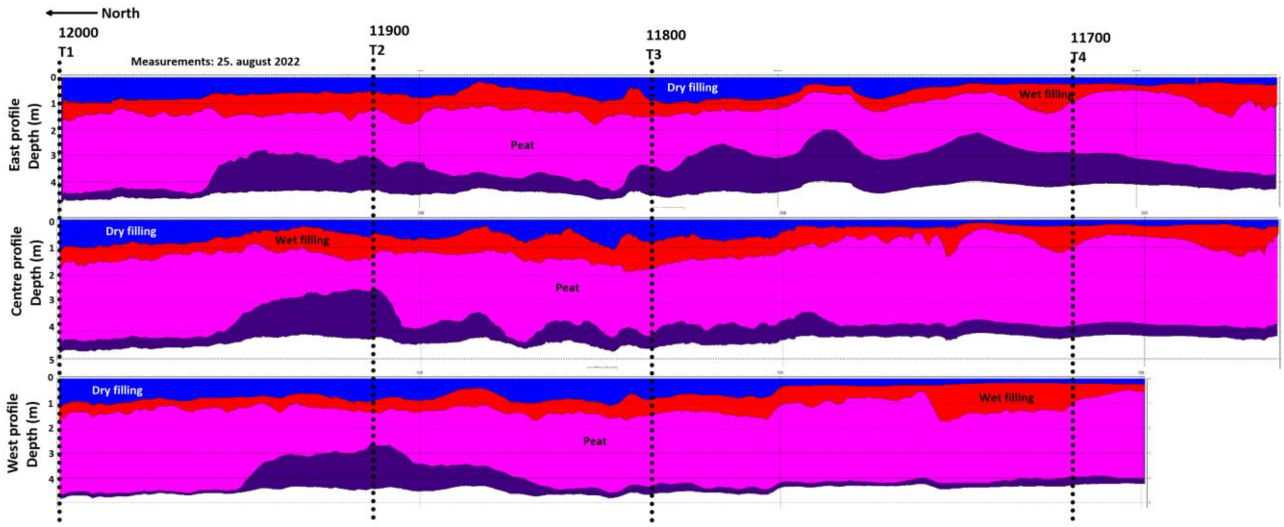

Figure 9. Fill and peatland thickness along the road line mapped in August 2022 with GPR. Transects (T1–T4) of pore pressure sensors indicated. The lowermost unit indicates the clay unit. The figure is updated from [24].

5. Hydrological, hydrogeological, and climatological conditions

The Grane municipality (where Kringelmomyra is located) is dominated by an inland climate. This leads to high summer temperatures and low winter temperatures. The average temperature is around 2 °C, measured over the past 40 years. The lowest temperature in this period was measured at

−44.5 °C at the measuring station in Svenningdal, located 15 km to the south of Kringelmomyra, in the winter of 1978. The highest temperature in the same period was measured at 31 °C at the same measuring station in 1980. The annual precipitation for the municipality also varies somewhat between measuring stations, but its average is 1309 mm for the period 2011–2020 at the measuring station at Majavatn, located 46 km to the south of Kringelmomyra.

The hydrology at Kringelmomyra is dominated by two catchment areas, one in the northwest and one in the southeast (see Figure 10). The theoretical division between them trends north–south as it passes through the center of Kringelmomyra. The peatland receives recharge from the mountain located to the west. For the southern area, the water drains along the stream that runs across Kringelmomyra about halfway and then west and south and out into the river Vefsna (see Figure 10). For the northern area, the water drains from south to north along the peatland and eventually into a stream that runs north and out into Vefsna.

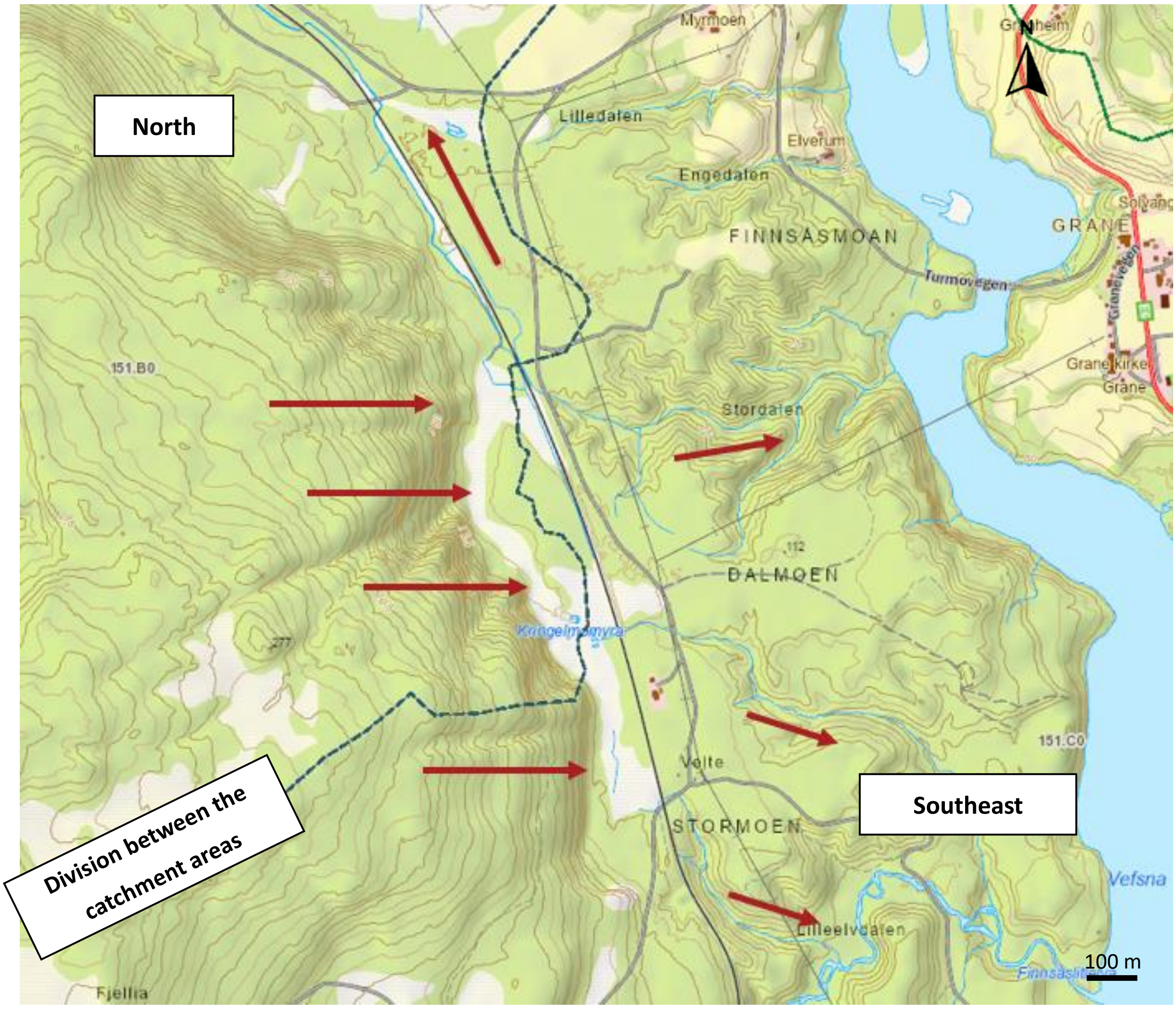

Figure 10. Delimitation between the two catchments at Kringelmomyra. The arrows show the drainage direction of the inflow water.

There is little information about pore pressure in the peat before the embankment was built. It is likely that the pore pressure was hydrostatic, with a depth below the groundwater level, which is typically at or above the terrain, depending on the season. A hydrostatic pore pressure distribution is expected in peat because of the high porosity and high water content, which allows free water drainage in the complex system structure of fibers and organic material, which mimics a hydrostatic model.

6. Ecological conditions

Kringelmomyra is an oblong poor peatland with wetter, intermediate (more nutrients) parts to the west. To the east, Kringelmomyra is forested, and part of this area is likely drained peatland. Poor peatlands are dominated by peat mosses (*Sphagnum* spp.), with graminoids in the wetter parts and ericoids on the drier hummocks. More dry-tolerant plants seem to occur in the peatland to the east of the road under construction. To the west, graminoids with *Eriophorum vaginatum* and *Trichophorum caespitosa* dominate, indicating wetter conditions [25].

The rare and critically endangered peat moss *Sphagnum venustum* [26] (see Figure 11) was recorded at the site in 2024. This was surprising, as it was previously only found in Trøndelag county (Mid-Norway) and not elsewhere in Europe. It was probably overlooked both during the vegetation surveys in 2022 and when the environmental impact assessment prior to the road construction was done, as few biologists know the species. The species occurs within several of the vegetation plots, and further monitoring will show how road construction will affect the species.

Figure 11. Picture of the peat moss *Sphagnum venustum* found at Kringelmomyra in 2024. (Photo: Magni Olsen Kyrkjeeide).

7. Building a road on a peatland from a geotechnical perspective

Kringelmomyra is a typical Norwegian peatland, in which the planned road placement is directly on the peatland surface (see Figure 12). One of the initial objectives of the monitoring program is to identify potential changes in the hydrogeology and biodiversity of the remaining peatland as a result of the compression of peat masses for the construction of the road. So far, the results show little impact on hydrogeology in Kringelmomyra from the establishment of preloading and preliminary work [23], as presented in Figure 13 for Transect T4. In that location, it is observed that the groundwater level remains above the terrain and appears to be consistent throughout the same yearly period, despite variations in the precipitation regime.

With the construction of a road over the peatland surface as a floating road, the goal is to maintain the water level in the peatland to preserve the carbon stored in the soil. The carbon fluxes at the site have not been monitored, and how successful the method is in keeping the existing carbon stock is unknown. Rather, this study has focused on the technical solution and practical execution for the construction of a road at Kringelmomyra as presented in [27]. Table 1 summarizes some important learning points taken from [27]. These are aspects focusing on the geotechnical properties of the peat at the time of construction and the expected performance of the road being built. Furthermore, whether the remaining parts of Kringelmomyra will be affected by the construction work is still unknown, as it is too early to do a thorough analysis of hydrogeological and ecological aspects. A longer monitoring period will provide data on how the construction work has affected the water level table and the vegetation at the site.

Figure 12. View of Kringelmomyra from the north to the south, (left) before (2022; photo: NGI) and (right) after (2024; photo: NINA) the construction of the road embankment.

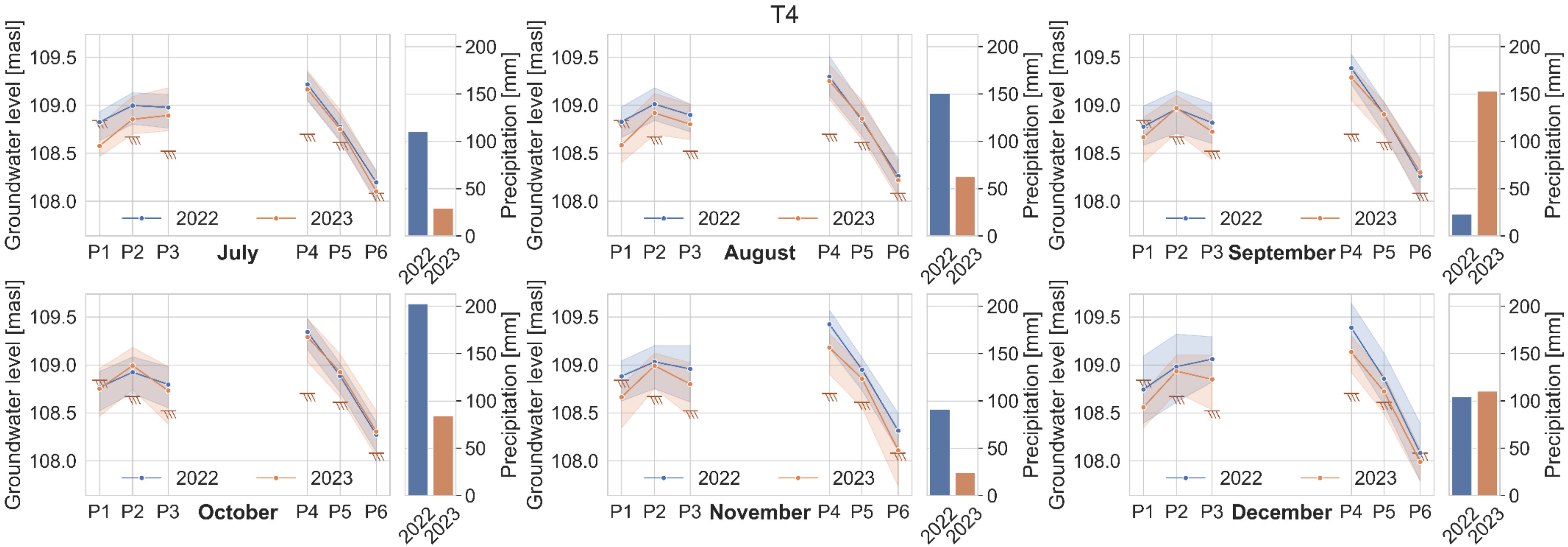

Figure 13. Comparison of water level (shown with line plots) and precipitation (shown with bar plots) in the period July–December for Transect T4 for 2022 (data in blue) vs 2023 (data in orange). Terrain level is indicated with ⩡. Taken from [23].

Table 1. Learning points for building a road on a peatland, after the 2022 work at Kringelmomyra.

Challenge	Recommendations
Long-term settlements and bearing capacity	Establishing a preload embankment: The road embankment must be built up step by step to gradually increase the strength of the clay under the peat and the peat itself.
Track formation	Using geogrids in several layers in the embankment: this binds the embankment together, so that the embankment behaves like a rigid body and local deformations, which can cause tracking, are counteracted. The geogrids must have sufficient tension capacity to carry the embankment on top and prevent shear failure of the fill material into the underlying peat.
The road structure settles into the peatland so that the road becomes a longitudinal drainage road over the peatland	Establish permanent geomembranes across the road line: these are located transversely in the road and prevent longitudinal water flow in the road structure.
Variable strength in the peatland	Construction is carried out with care. First, the peatland is leveled by scraping off the top 10-20 cm. Then, a geotextile and geogrid are installed against the filling foundation. The filling material (gravel) is placed at the outer edge of the geotextile first to tighten the geogrid, then gradually placed inward toward the center. This method allows the net to support the filling like a hammock. If there are soft areas at the outer edge of the embankment, it must be widened, and the geogrids span over these areas. Ponds and peatland holes are filled with sawdust or peat, following the same methodology.
Low strength in peat	The strength parameters of peat are determined from empirical experience and/or in situ and laboratory testing, e.g., DSS (Direct Shear Strength). The construction of the road embankment is done gradually in layers of approximately 75 cm thickness. This is done to allow the dissipation of excess pore pressure in the peat caused by the added load, thereby increasing strength and preventing local bearing capacity failure.
Poor bearing capacity for machinery	Low-weight equipment should be used.
Filling with thin layers is challenging from a purely metrological point of view, as the road embankment sinks into the peat as it fills	One solution involved placing measuring pipes on the ground and refilling them. This allowed the pipes to sink simultaneously with the road. The additional fill material was emptied onto a blasting mat placed on the already constructed embankment, enabling the excavator operator to control the use of new material when filling new areas.
Document that the construction works are as planned	Monitor groundwater levels and vegetation in sections of the peatland area for a minimum of five to six years. This period includes the period of construction work (including preloading) and at least three years aftercompletion of the construction. Install settlement anchors in the road structure after removing the preload and completing the road to monitor long-term settlements in the road structure. The groundwater levels and vegetation should be monitored for at least one full year prior to the construction phase to assess the natural seasonal changes in groundwater levels.

8. Conclusions

Kringelmomyra, a peatland in northern Norway, is the site of an innovative road construction project using preloading instead of the traditional excavate and replace method. The preloading method uses surcharge to compact the peat masses and establish the road structure on the consolidated peat. It aims to preserve the ecological and hydrogeological functions of the remaining peatland at the site, but most of all, reduce emissions by keeping the carbon stock below the road. To evaluate the soil properties and the construction's impact on eco-hydrogeological processes, geotechnical testing, hydrogeological monitoring, and ecological assessments have been and are being conducted.

Geotechnical testing involved sampling for peat depths, measuring water content, and analyzing the degree of decomposition. A hydrogeological five-year monitoring program includes pore pressure measurements in the peat surrounding the road, and it is complemented by a vegetation monitoring program. The geotechnical investigations revealed the complex stratification of peat, sand, and clay layers, which influenced the construction method. Vegetation surveys identified the critically endangered peat moss *Sphagnum venustum,* highlighting the biodiversity values at the site. A long-term monitoring program is needed to evaluate whether the conditions at Kringelmomyra following the construction work will be suitable to maintain the population of this rare species. Furthermore, monitoring the plant community will provide knowledge on how road construction impacts the remaining biodiversity at Kringelmomyra.

Although it is still early to draw definitive conclusions about the road construction's impact on the peatland, the integration of geotechnical characteristics, hydrogeology, and vegetation monitoring provides a holistic approach for understanding the mechanical behavior of the peat masses under consolidation and their influence on the surrounding ecosystem. The establishment of a comprehensive monitoring program provides valuable insights into the impact of the construction on groundwater levels, vegetation, and overall peatland health. Initial results indicate minimal impact on hydrogeology, but continued monitoring is essential to understand long-term effects.

This project highlights the importance of interdisciplinary knowledge and sustainable practices in construction on peatlands. Protecting these carbon-dense ecosystems is crucial for meeting climate goals and preserving biodiversity. Continued monitoring and adaptive management are recommended to ensure the long-term success of the project. The findings from Kringelmomyra can inform future projects and contribute to the development of best practices for construction on peatlands.

Author contributions

Priscilla Paniagua: Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing–original draft, Writing–review & editing. Bjørn Kristian Fiskvik Bache: Methodology, Resources, Writing–review & editing. Simon Ross Stenger: Conceptualization, Formal analysis, Methodology, Magni Olsen Kyrkjeeide: Conceptualization, Formal analysis, Methodology, Resources, Writing–review & editing. Elin Johanne Slettum: Conceptualization, Funding acquisition, Supervision, Writing–review & editing. Michael Long: Writing–review & editing.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

References

1. Yu ZC (2012) Northern peatland carbon stocks and dynamics: a review. *Biogeosciences* 9: 4071–4085. https://doi.org/10.5194/bg-9-4071-2012
2. Nichols JE, Peteet DM (2019) Rapid expansion of northern peatlands and doubled estimate of carbon storage. *Nat Geosci* 12: 917–921. https://doi.org/10.1038/s41561-019-0454-z
3. Girkin NT, Cooper HV, Ledger MJ, et al. (2022) Tropical peatlands in the Anthropocene: The present and the future. *Anthropocene* 40: 100354. https://doi.org/10.1016/j.ancene.2022.100354
4. Villa JA, Bernal B (2018) Carbon sequestration in wetlands, from science to practice: An overview of the biogeochemical process, measurement methods, and policy framework. *Ecol Eng* 114: 115–128. https://doi.org/10.1016/j.ecoleng.2017.06.037
5. IPCC, Summary for Policymakers of IPCC Special Report on Global Warming of 1.5ºC approved by governments, 2018. Available from: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/.
6. Bossio DA, Cook-Patton SC, Ellis PW, et al. (2020) The role of soil carbon in natural climate solutions. Nature Sustainability 3: 391–398.
7. Page SE, Baird AJ (2016) Peatlands and Global Change: Response and Resilience. *Annu Rev Env Resour* 41: 35–57. https://doi.org/10.1146/annurev-environ-110615-085520
8. Bryn A, Strand GH, Angeloff M, et al. (2018). Land cover in Norway based on an area frame survey of vegetation types. *Norsk Geogr Tidsskr* 72: 131–145. https://doi.org/10.1080/00291951.2018.1468356
9. Carlsten P (1988) Peat Geotechnical Properties and Up-to-Date Methods of Design and Construction, *State-of-the-Art-Report Preprint, Swedish Geotechnical Institute Report 215*.
10. Carlsten P (1995) Construction methods for roads in peatlands areas. *XI European Conference for Soil Mechanics and Foundation Engineering*, Danish Geotechnical Institute, Copenhagen, Denmark, 8–13.
11. Paniagua P, Long M, L'Heureux JS (2021) Geotechnical characterization of Norwegian peat: database. *IOP Conference Series: Earth and Environmental Science*, *18th Nordic Geotechnical Meeting*, Helsinki, Finland. 710: 012016. https://doi.org/10.1088/1755-1315/710/1/012016
12. Paniagua P, Long M, Trafford A, et al. (2024) The Tiller-Flotten peat site: A natural peat soil deposit aimed for geotesting, *19th Nordic Geotechnical Meeting*, Göteborg. 618–621.
13. Long M, Paniagua P, Grimstad G, et al. (2022) Engineering properties of Norwegian peat for calculation of settlements. *Eng Geol* 308: 106799. https://doi.org/10.1016/j.enggeo.2022.106799

14. Long M, von der Tann L, Ritter S, et al. (2024) Centrifuge modelling of sand and sawdust embankments on peat for sustainable infrastructure development. *Proceedings of the XVIII ECSMGE 2024—Geotechnical Engineering Challenges to Meet Current and Emerging Needs of Society*, CRC Press. https://doi.org/10.1201/9781003431749-96
15. Ritter S, von der Tann L, Dahl M, et al. (2024) Settlement behaviour of peat underneath a sand and sawdust embankment: centrifuge modelling, *5th European Conference on Physical Modelling in Geotechnics*, Delft, The Netherlands.
16. Hov S, Paniagua P, Sætre C, et al. (2023) Stabilisation of Soft Clay, Quick Clay and Peat by Industrial By-Products and Biochars. *Appl Sci* 13: 9048. https://doi.org/10.3390/app13169048
17. NPRA (2022) Bygger veg på myr med 90% mindre utslipp. Building a road on bog with 90% less emissions. Available from: https://www.vegvesen.no/vegprosjekter/europaveg/e6brattasenlien/nyhetsarkiv/bygger-veg-pa-myr-med-mindre-utslipp/.
18. NGF, Guidelines for carrying out total soundings. Rev 1. Norwegian Geotechnical Society, 2018. Available from: https://ngf.no/wp-content/uploads/2020/02/NGF-Melding-9-Totalsondering-Rev-1-2018.pdf.
19. NGF, Guidelines for carrying out piezocone tests. Rev. 3. Norwegian Geotechnical Society, 2010. Available from: https://ngf.no/wp-content/uploads/2015/03/5_NGF-Melding-5-CPTU-_revisjon-3.pdf.
20. NGF, Guidelines for sampling. Norwegian Geotechnical Society, 2013. Available from: https://ngf.no/wp-content/uploads/2015/03/NGF-Melding-11-Provetaking-2014.pdf.
21. NGI, Beslutningsnotat for bygging av veg over Kringelmomyra. Decision memorandum for the construction of a road above Kringelmomyra. E6 Svenningelv-Lien Technical Note N-GEOT-02. Rev. 0. In Norwegian. 2021. Available from: NGI Document center ngi@ngi.no.
22. von Post L, Granlund LE (1926) Södra Sveriges Torvtillgånger, I. *Sver Geo Unders C35*, 19.
23. NGI, FOU Kringelmomyra: Resultater fra overvåkning fra juli 2022 og 2023. R&D Kringelmomyra: Results of monitoring from July 2022 and 2023. Technical note 20220382-03-TN. Rev. 0, 2024. In Norwegian. Available from: NGI Document center ngi@ngi.no.
24. NGI, Georadar Kringelmomyra. E6 Svenningelv-Lien N-GEOT-16. Rev. 0, 2022. In Norwegian. Available from: NGI Document center ngi@ngi.no.
25. Halvorsen R, Skarpaas O, Bryn A, et al. (2020) Towards a Systematics of Ecodiversity: The Ecosyst Framework. *Global Ecol Biogeogr* 29: 1887–1906. https://doi.org/10.1111/geb.13164
26. Høitomt T, Blom HH, Brynjulvsrud JG, et al. (2021) Moser: Vurdering av sylfidetorvmose *Sphagnum (Acutifolia) venustum* for Norge. Rødlista for arter 2021. Artsdatabanken. Available from: https://lister.artsdatabanken.no/rodlisteforarter/2021/19679.
27. NGI, Bygging av flytende veg over myr. Building of a floating road on peat. E6 Svenningelv-Lien Technical note N-PGL-03. Rev. 0. 2023. In Norwegian. Available from: NGI Document center ngi@ngi.no.