Road Infrastructure in the Hudson Bay Lowlands: Solutions for the Northern Road Link

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Abstract
The Northern Road Link (NRL) project aims to enhance transportation infrastructure in the Hudson Bay Lowlands, connecting remote communities and improving access to resources while spanning 165 kilometers. This road will traverse the ecologically sensitive Hudson Bay Lowlands in Northern Ontario, raising concerns about impacts on Treaty 9 communities, local flora, fauna, and extensive peatlands. The road is proposed to link the Webequie Supply Road at its northern terminus and the Marten Falls Community Access Road (MFCAR) at its southern end, with MFCAR serving as the connection to the provincial road system.

The project's goals are to provide year-round accessibility, foster economic development, improve employment opportunities, and facilitate local resource access. However, significant challenges include preserving the peatland ecosystem, managing hydrological impacts, and addressing climate change considerations. Key challenges involve potential disruption of the peat ecosystem, variations in peat characteristics, and the need to safeguard groundwater quality and flow. Construction techniques such as using geogrids and geotextiles to float the road through organic terrain are proposed to address these issues.

The paper highlights an approach to road construction over peatlands that maintains groundwater flow, ensures road stability, and addresses aggregate needs as well as long-term sustainability. Proposed methods aim to elevate the road profile over peatlands without removal, prevent saturation and instability, and minimize embankment damage during overtopping events. The project also faces challenges with the limited availability of suitable aggregate, striving to minimize environmental impacts and the overall footprint.

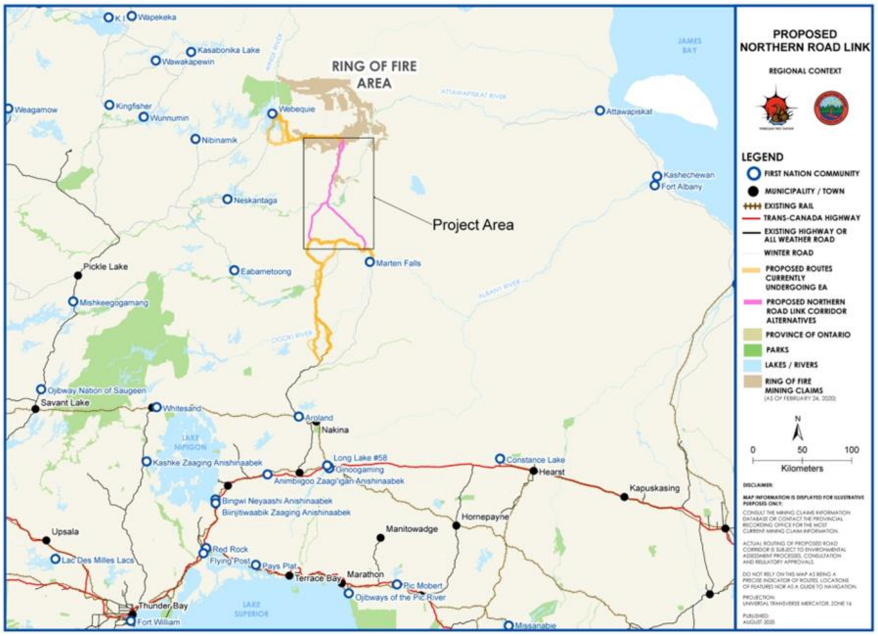
The innovative implementation of OptiHaul and Smart Pit concepts within RoadEng Software enhances efficiency and contributes to a more optimized design. The presentation outlines how the project addresses environmental issues and climate change impacts with proposed geotechnical techniques and road materials.

In conclusion, the NRL project is committed to innovative solutions that aim to address community concerns about peatland construction, minimize the ecological footprint, address environmental issues, and achieve sustainable highway design. The proposed alternative construction methodologies ensure optimal functionality, extending the road's lifespan.

Introduction
The Northern Road Link (NRL) is a transformative infrastructure project designed to connect remote communities within the Hudson Bay Lowlands to essential resources and services. Led by the Webequie and Marten Falls First Nations, the NRL aims to address the unique challenges posed by the region’s sensitive environment while minimizing ecological disruption. This project involves an environmental assessment for an all-season road that will link the 200km Marten Falls First Nation Community Access Road (MFCAR) to the south and the 110km Webequie Supply Road (WSR) to the north, reaching into the Ring of Fire area.

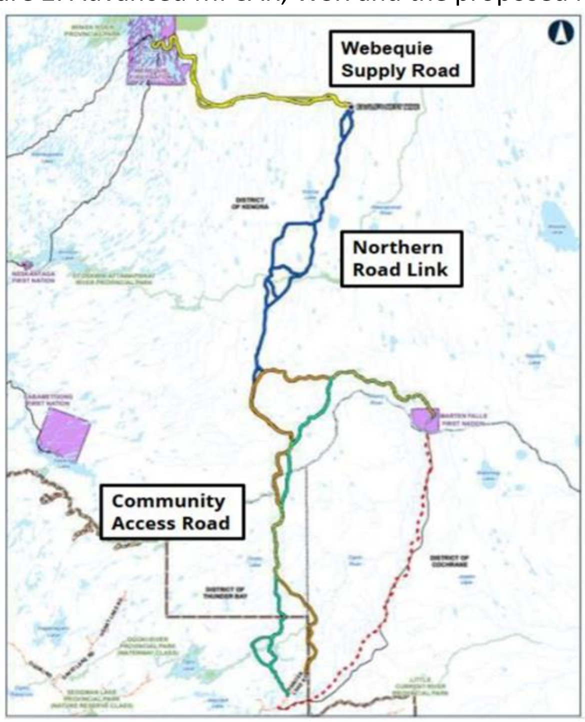
The NRL is pivotal in improving socio-economic outcomes for Indigenous communities by fostering connectivity, economic development, and sustainability in northern Ontario. The project seeks to enhance regional growth and accessibility, which are currently limited by costly winter roads and air transportation, especially given the shortened ice road seasons. Through careful planning, community engagement, and stakeholder consultation, the NRL will facilitate the movement of goods and people, improve travel efficiency, and unlock economic opportunities for Treaty 9 communities.

Figure 1. MFCAR, WSR and the proposed NRL



Source: September 2020 RFP

Figure 2. Advanced MFCAR, WSR and the proposed NRL



Source: June 2024 Presentation

A key area of potential economic growth is the Ring of Fire, known for its valuable mineral resources like chromite, nickel, copper, and cobalt, crucial to the electric vehicle industry. The lack of all-season roads or rail connections has historically restricted the region's economic potential. The construction of the NRL, along with MFCAR and WSR, will establish reliable transportation infrastructure, unlocking new opportunities and fostering long-term economic prosperity.

The NRL aims to address these transportation needs while respecting the environment, especially local flora and fauna such as the wolverine and caribou populations and the nationally significant peatland ecosystem called the Hudson Bay Lowlands. Development of the NRL must address and mitigate potential impact to these peatlands, which play a crucial role in carbon capture and thus climate change mitigation. Constructing roadways over peatlands presents various engineering and environmental challenges, including potential disruptions to the peat ecosystem; management of variations in peat characteristics; the risks of building on compressible material; and maintaining shallow groundwater and surface water.

This paper delves into the challenges facing the Northern Road Link project in evaluating, designing, and constructing over peatlands and its impact on local communities and the environment. It will focus on the proposed design and construction methods for peatland areas, including challenges such as maintaining shallow groundwater regimes, short-and long-term road stability, and sourcing suitable aggregates. Emphasizing an approach in integrating engineering, hydrogeological, and environmental considerations, this paper highlights the proposed innovative construction techniques aimed at minimizing environmental impacts and ensuring long-term sustainability. It underlines the project's commitment to Indigenous community concerns, cultural sensitivity, and climate change adaptation through responsible engineering design and the adoption of alternative methodologies.

The Peatland Ecosystem

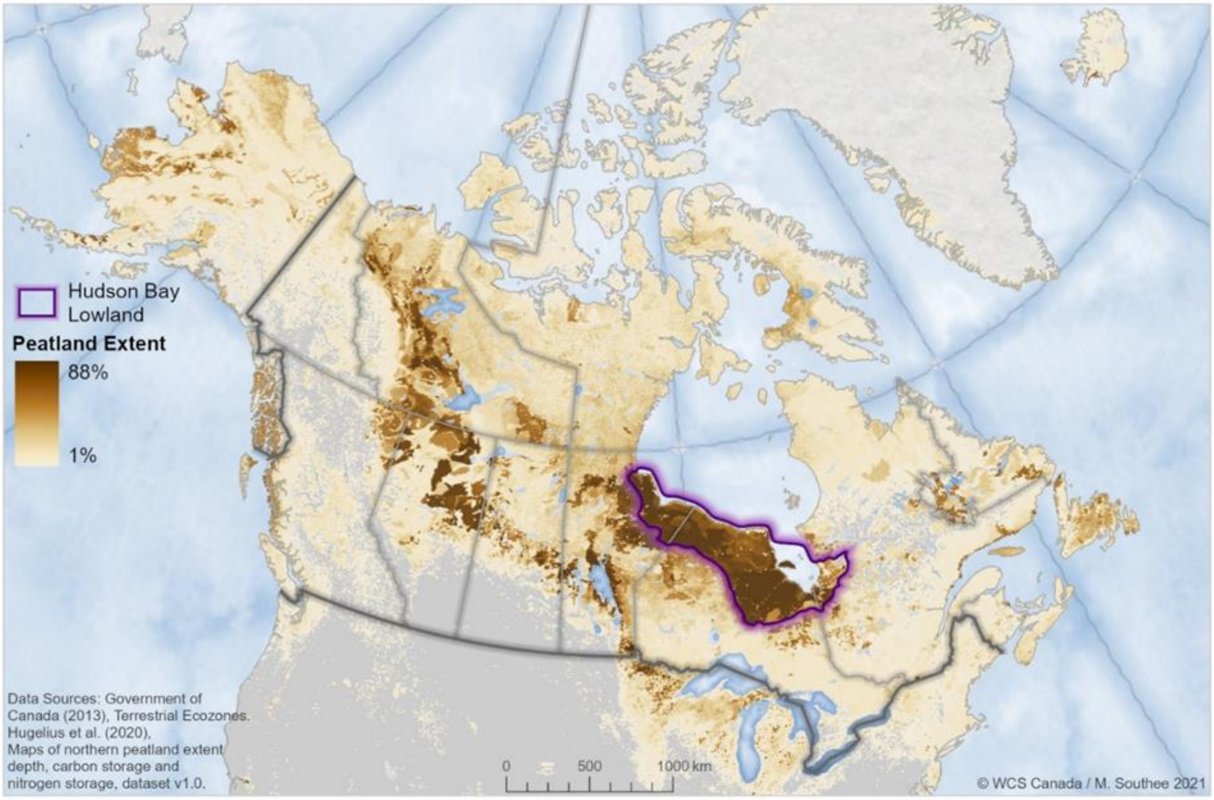
Characteristics

Peatlands are among the Earth's most vital ecosystems, serving as the largest global carbon stores on land[1]. They occupy about 3% of the Earth’s surface but hold more carbon than any other ecosystem. These unique landscapes, characterized by waterlogged conditions and the accumulation of organic matter over millennia, play a crucial role in mitigating climate change. Peatlands store vast amounts of carbon, locking it away from the atmosphere and helping regulate the global carbon cycle.

The NRL project goes through the Hudson Bay Lowland, a sprawling peatland region in Canada (See Figure 3). Covering extensive areas of northern Ontario, spanning west to Manitoba, and east to Quebec, the Hudson Bay Lowland is the second largest peatland complex in the world and is renowned for housing one of the largest remaining undeveloped boreal forests. Its sprawling bogs, fens, and marshes act as immense carbon sinks, accumulating carbon dioxide from the atmosphere and storing it in the form of peat.

This region's importance extends beyond carbon sequestration: the peatlands are rich and diverse ecosystems that support a wide array of plant and animal species. These habitats provide crucial breeding grounds, foraging areas, and refuge for wildlife species such as polar bears, caribou, and red knots. They also regulate water flow, contributing to the health of surrounding ecosystems.

Figure 3. Location and depth of peatland areas in Canada



Source: WCS Canada

Peatlands hold immense cultural, ecological, and economic significance for Indigenous peoples across Canada. These landscapes hold spiritual and traditional value, serving as important sites for ceremonies, storytelling, and cultural practices. Peatlands are deeply ingrained in Indigenous cultures, reflecting connections to ancestral lands and providing a sense of identity and belonging. Traditional harvesting of plants and materials from peatlands for food, medicine, and crafts continues to be an important aspect of Indigenous livelihoods. Additionally, peatlands may support activities such as hunting, fishing, and trapping, which are integral to Indigenous economies.

Challenges of the Hudson Bay Lowlands

The terrain in the Hudson Bay Lowlands primarily comprises poorly draining muskeg (i.e., peatlands), characterized by high-water tables and accumulations of peat often in the range of 1-4 m thick, sometimes thicker, and typically underlain by fine-grained clays and silts. Bog and fen peatlands dominate the terrain adjacent to esker ridges and exhibit characteristics such as low topographic relief, high water tables, and numerous streams and areas of standing water. The peat deposits in this area rely on maintaining consistent groundwater levels. Changes to the groundwater regime, particularly near roads, pose significant risks to both the peatland and the dependent ecosystems.

Preservation efforts are crucial to maintain the delicate balance of this peatland environment and safeguard its ecological integrity. Additionally, the region contains pockets of permafrost and frost-susceptible soil that will need to be addressed during design. The Hudson Bay Lowlands also have limited access to aggregate, borrow, and quarry materials required for highway construction, making long-distance hauling necessary for highway projects in the area.

A significant issue arises from the disparity in the significance, volume, and size of peatlands between Southern Ontario and the Hudson Bay Lowlands. In southern Ontario, peatlands are typically limited to isolated areas, whereas in the Hudson Bay Lowlands, they constitute a substantial and widespread terrain type. The current Ontario Provincial Standards and Specifications (OPSS) and Ontario Provincial Standard Drawings (OPSD) accommodate the peat terrain found in southern regions but do not adequately address the vast expanses of peatlands in the Hudson Bay Lowlands[2].

Peat Properties and Behavior

Peat, a material commonly encountered in engineering projects, is classified into three main types: coarse fibrous peats, fine fibrous peats, and amorphous-granular peats. Coarse fibrous peats are characterized by minimal decomposition and visible plant fragments, while fine fibrous peats have finer plant material and a higher degree of decomposition. Amorphous-granular peats, highly decomposed, resemble clay and lack visible plant fragments. These classifications impact how peat behaves under construction loads and environmental conditions.

A key characteristic of peat is its high-water content, which profoundly influences its engineering properties. Peat can have moisture levels as high as 95%, with typical values around 80%, and moisture content can reach up to 2000%[4]. This high-water content affects several critical properties:

- Shear Strength: As moisture content increases, the shear strength of peat decreases, making it more susceptible to deformation.
- Compressibility: Peat’s compressibility is heightened by its moisture content, leading to significant settlement over time.
- Permeability: Peat’s permeability varies with its structure and decreases when compressed under load, as the reduction in voids impedes water flow.

Understanding these properties is crucial for effective design and construction, as they determine how peat will respond to load and environmental changes.

Key Challenges in Constructing Roads Over Peatlands

Constructing roads over peatlands involves addressing several unique challenges due to peat’s properties.

- Ground Instability: Peat’s low shear strength poses significant challenges for road embankment stability. Special design and construction techniques are required to ensure that the embankments remain stable.

- Settlement and Compression: The high compressibility of peat leads to substantial settlement over time, which can affect the road’s structural integrity. The settlement process includes instantaneous settlement, primary consolidation, secondary compression, and tertiary settlement, all of which must be managed to maintain road stability.

- Water Management: Effective groundwater management is critical in peatlands. Water primarily moves through the upper, more fibrous peat layers. Without proper management, water may pool on the upstream side of roads. This can degrade downstream vegetation and soil, affect localized permafrost, and alter the peatland's geomorphic, hydrologic, and vegetative systems.

- Overtopping Risks: In low-lying areas, overtopping occurs when headwater rises to the road's elevation, potentially causing water to flow across the road. While elevating the road profile can mitigate overtopping, it can also reduce hydraulic conductivity, trap water on one side, and impact groundwater drainage. This requires a careful balance between road elevation and maintaining effective water flow and drainage.

Addressing the challenges of constructing roads over peatlands requires a comprehensive approach that considers peat's unique properties and the potential impacts on both engineering and environmental systems. Effective management and innovative design solutions are essential to overcoming these challenges and ensuring the durability and stability of infrastructure projects.

Hydrology and Hydrogeology

Hydrological and Environmental Impacts

Constructing roads on peatland has profound and multifaceted impacts on hydrology and the environment. Road construction in peatlands significantly alters surface and groundwater flow patterns. This can lead to erosion, habitat disruption, and changes in the natural hydrology of the region. Case studies from similar projects in Norway and Canada highlight the need for careful water management to minimize environmental impact. Roads often impede groundwater flow on the upslope side, causing ponding and increased pressure that can distort or collapse sections of the roadway. Groundwater, which would normally diffuse downhill, is redirected by the road, leading to reduced waterlogging and increased drying immediately downslope, especially during extended rain-free periods[5].

Side-drains and culverts are commonly installed along roads to prevent accumulation of surface water and road damage. However, this exacerbates the drying effect by directly dehydrating the surrounding peat. Where the drains direct the water into culverts that run across the road, this produces a more focused flow at the culvert outlet, leading to further erosion downslope and drying in other areas. Even without drains, the road itself interrupts groundwater flow, leaving downslope areas dry. This leads to drainage associated consequences, including erosion gullies that threaten road stability.

Proper sediment management is crucial during construction to protect the water environment and surrounding habitats[5]. Poor-quality materials and eroding peat soils can generate large volumes of drainage water requiring treatment. The effects of compression and consolidation caused by road material not only alter adjacent hydrology, but also reduce the water content of peat downslope, exacerbating drainage effects.

Over time, the cumulative impacts of road construction result in permanent changes to peatland hydrology. This leads to reduced waterlogging and increased drying of the peat surface, which affects the peatland's overall health, stability, and ecosystem services. These long-term alterations can have cascading effects on local biodiversity, water quality, and the ecological functions of peatlands.

Hydrogeological Impacts

Understanding the hydrogeological impacts of the Northern Road Link (NRL) project is crucial for evaluating how road construction will affect the peatland environment. Hydrogeology focuses on the distribution and movement of groundwater, which is essential for assessing the environmental consequences of infrastructure projects. The construction of road embankments can alter groundwater systems in several ways, impacting both localized and broader regional areas. These effects can occur in the short term, such as during construction, and have long-term implications, influenced by factors like climate change.

To assess these impacts effectively, an integrated approach combining InSAR (Interferometric Synthetic Aperture Radar) technology and numerical groundwater flow modeling will be utilized. InSAR technology allows for the precise detection of ground deformation and surface irregularities over extensive areas, providing crucial data on how construction activities might affect ground stability. This technology helps identify potential issues before they become significant problems.

Numerical groundwater flow modeling will be employed to predict groundwater movement at the sub-watershed scale. This model is essential to ensure that the road embankment does not act as an impermeable barrier, which could disrupt natural groundwater flow. If the embankment were impermeable, it could lead to rising groundwater levels upstream and declining levels downstream, potentially harming surrounding ecosystems. The model also integrates with a hydromechanical model to forecast long-term settlements at river crossings, considering the impacts of climate change throughout the project's lifespan.

Design considerations for peatland areas include using granular materials and porous layers in road construction to minimize impacts on groundwater levels. Cross-culverts installed perpendicular to the roadway, and drainage blankets ranging from 300mm to 600mm will help preserve the peatland's hydrologic and hydrogeological characteristics by allowing natural water flow and reducing construction impacts. These measures are crucial for maintaining the ecological balance of peatlands and adjacent water bodies.

For watercourse crossings, the project will utilize either culverts or bridges to manage surface flow regimes in streams and rivers. Cross-culverts are preferred for maintaining unaltered groundwater flow across the road, complemented by a permeable roadbed to allow groundwater seepage through the embankment. This approach ensures that natural flow patterns are preserved.

Preliminary results from the integrated InSAR technology and groundwater flow modeling suggest that alternative road alignments could be explored. These alternatives would address regulatory requests for technically and economically feasible options related to the project. By considering these alternatives, the project aims to balance environmental protection with infrastructure needs, ensuring both regulatory compliance and the long-term sustainability of the peatland environment.

Floodplain Management for Highway Embankments in Peatlands

A comprehensive evaluation of design alternatives is crucial, taking into account capital costs, risks, and a wide range of economic, engineering, social, and environmental factors. This evaluation includes analyzing scenarios such as overtopping floods, base floods, and the capacity of drainage structures to handle maximum flood flows where overtopping is not feasible.

Highway embankments differ significantly from levees and other flood control structures. Unlike these structures, highway embankments typically lack internal impervious cores and adequate freeboard, making them more vulnerable to issues like piping, seepage, and infiltration due to their permeable construction materials. Therefore, the geotechnical engineering requirements for highway embankments are distinct from those for flood control structures.

Effective floodplain management involves situating embankments away from floodplains whenever possible to minimize the risk of failure due to overtopping during smaller flood events. When it is not feasible to avoid floodplains, embankments must be elevated adequately to withstand flooding with a 2% annual probability. This approach ensures compliance with regulatory standards for long-term flood resilience and safety, safeguarding against potential embankment failure.

Climate Change

Climate Change Impacts of Road Construction in Peatlands

Road construction in large peatland areas can significantly impact climate change due to disturbances in the boreal forest and the peat ecosystem, leading to the release of stored carbon. The primary environmental impacts include:

1) Carbon Dioxide Release: Peatlands store carbon accumulated over thousands of years. Excavation during road construction can release this trapped CO_2 into the atmosphere, contributing to greenhouse gas emissions. Additionally, the removal and use or disposal of trees and dead organic matter—through burning, woodchips, or lumber—further affect net CO_2 releases over time.
2) Methane Emissions: Peatlands can release methane, another potent greenhouse gas, if disturbed. Construction activities may disrupt natural water movement and drainage patterns, leading to increased methane emissions from microbial activity in waterlogged conditions. For example, similar projects in other peatland regions have shown significant methane emissions due to such disturbances.
3) Loss of Carbon Sink Function: Boreal forests and peatlands act as important carbon sinks by absorbing CO_2 from the atmosphere and storing it as organic matter. Excavating peat reduces this carbon sink function. Although it prevents CO_2 generation from the peat's aerobic decomposition over time, the net carbon exchange (NEE)—which balances CO_2 uptake and emissions—depends on the peatland ecosystem and regional temperature, including the length of the growing season.
4) Altered Hydrology: Constructing roads on peatlands can impact local hydrological processes, affecting water flow, retention, and distribution within the ecosystem. Changes in hydrology can lead to the drying of peatlands, which accelerates peat decomposition and further contributes to carbon release. Effective water management is crucial to address these changes and mitigate their impact on the peatland environment.

Impact of Climate Change on Design Flows

Climate change poses significant challenges by altering temperature and precipitation, which affect water resource management and infrastructure planning. Temperatures are expected to increase by 6-10°C in the region by the end of the century, leading to increased rainfall intensity and altered flow patterns, including reduced freshet peaks and increased earlier snowmelt. These changes can significantly impact water flow dynamics, flood risks, and groundwater recharge rates.

Traditional peak flow estimations, which rely on historical data for predicting design flows to evaluate flood risks, must be updated to reflect these new climate realities.

For small catchment areas (less than 10 km^2), the Rational Method can be employed to calculate design flows, as these catchments are usually dominated by extreme rainfall events due to their short response time. This method uses Intensity Duration Frequency (IDF) curves to represent the rainfall of extreme events. Historical IDF curves have been updated by various agencies to include the potential increase in rainfall due to climate change. Table 1 presents projected increases in design flood flows, using scaling factors derived from RCP (Representative Concentration Pathways) scenarios. Each column represents different climate scenarios, with projected changes in intensity and frequency of extreme weather events.

Table 1. Projected IDF curve scaling factor for the NRL project region at the end of the century

Location	**IDF value (24-h; 100-year return period)**					
	Historical (1)	**CSA PLUS 4013:19 (2)**		**UoW IDF Tool (3)**		**CSA group recommendation (4)**
Climate change scenario	n/a	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP6.0
West of Marten Falls	113mm	+51%	+27%	+33%	+29%	+37%
West of McFaulds Lake	113mm	+53%	+27%	+32%	+28%	+38%

(1) Obtained based on precipitation data from 1971 to 2021 at Lansdowne House meteorological station located about 100 km west of the NRL.
(2) Based on Clausius-Clapeyron "temperature-to-air humidity saturation" relationship which is solely dependent on temperature increase.
(3) Extracted from the Computerized IDF CC Tool developed by a research group at Western University in Ontario for the NRL project region.
(4) CSA Group, Climate Change Provisions for CSA S6:25 Canadian Highway Bridge Desing Code, March 2022.
Source: Robertson, B. "Climate Change – Accounting for Temperature and Precipitation Increase." Presentation from AtkinsRealis. p. 5. (September 2024)

For large catchment areas (greater than 10 km^2), flow frequency analysis (FFA) of nearby hydrometric gauges can be employed to calculate design flows. These catchments are typically dominated by the spring freshet peaks, where all the snowfall accumulated over the winter months melts and contributes to the flow. FFA rely on historical measurements of flow that do not incorporate climate change.

Predictions of increased monthly temperature and modified precipitation regimes are shown in Table 2. The effect of these changes on flow were predicted through the development of a hydrological model of a local catchment (Muketei River). Known precipitation, and temperature were used to calibrate the hydrological model to reasonably re-create known Muketei River flow observations. Then, revised precipitation and temperatures were modelled to understand how climate change would affect flow. Hydrological modelling suggests that due to significant increases in temperature, snowmelt will occur sooner, effectively reducing spring freshet peak flows. Even with consideration of extreme rainfall events (e.g. +40%), the increased summer/fall peaks are still lower than historic freshet peaks. Although lower peaks were estimated from the hydrological modelling, a 15% increase in design flows is recommended due to the uncertainty and limitation of the data.

Table 2. Monthly temperature increases and modified precipitation regimes.

Month	Minimum Temperature Increase (°C)	Maximum Temperature Increase (°C)	Precipitation % Increase Predicted	Precipitation % Increase Extreme
January	11.0	8.9	38%	38%
February	10.6	7.8	38%	38%
March	8.8	5.7	36%	36%
April	6.8	6.8	35%	35%
May	5.8	6.3	32%	40%
June	5.9	6.2	6%	40%
July	5.9	6.4	-15%	40%
August	6.3	6.9	-7%	40%
September	6.0	6.6	3%	40%
October	5.7	6.3	19%	40%
November	7.2	6.4	27%	27%
December	10.5	7.9	33%	33%

Risk vs Consequences

Evaluating risks versus consequences is crucial for the Northern Road Link (NRL) project to ensure effective climate change assessments and informed policy decisions. A comprehensive approach involves integrating interdisciplinary collaboration, model-based quantifications, and qualitative assessments.

Economic models often overlook significant risks due to delays in cross-disciplinary knowledge sharing, spatial and temporal variations in climate impacts, feedback loops, and unidentified risks. Five categories of uncertainty that affect economic impact evaluations include:

1) **Future Socioeconomic Scenarios**: Variability in future social and economic conditions can significantly impact risk assessments.
2) **Process Parameters**: Uncertainties in climate process parameters can influence model accuracy.
3) **Model Structures**: Different model structures can produce varying predictions and outcomes.
4) **Trajectory Predictions**: Uncertainties in future climate trajectories affect long-term planning.
5) **Model Inadequacies**: Limitations and simplifications in models can lead to incomplete risk assessments.

Rare and extreme events, or black-swan events, are also vital for a comprehensive risk assessment. The interactions between these risks, such as cascading tipping points, disasters, and social changes, can amplify their overall impact.

For the NRL project, incorporating these uncertainties into economic evaluations requires a detailed risk vs. consequence matrix. This matrix should evaluate climate hazards such as winter conditions, freshets, rain, wind, hail, lightning, heat, drought, forest fires, and rising oceans and storm surges. Specific mitigation strategies and their implications need to be considered. For example, wind challenges might involve designing to prevent the toppling of signs and managing snow drifting, while forest fire risks could necessitate wider lanes or shoulders to act as fire breaks.

This matrix helps prioritize mitigation strategies based on the likelihood of risks and the severity of their potential impacts. By using this tool, decision-makers can allocate resources effectively to minimize project risks and enhance climate resilience.

A robust framework that integrates uncertain and qualitative information is essential for comprehensive assessments and supports effective climate policies. Collaboration between natural and social scientists is crucial for bridging gaps in models and providing actionable projections. Exploring diverse scenarios and incorporating deeply uncertain risks enable better-informed decision-making, leading to the development of climate-resilient infrastructure.

Indigenous Community Involvement

AtkinsRéalis recognizes the importance of addressing Indigenous relations in transportation projects, particularly as the industry moves towards Net Zero goals. Understanding and mitigating the impact of such projects on Indigenous lands is crucial. Integrating Indigenous Peoples' cultural ties and Traditional Knowledge into transportation planning is essential for aligning projects with environmental sustainability and Indigenous values.

Jennifer Ashawasegai-Pereira (Anishinabe, Henvey Inlet First Nation), an Indigenous Engagement Specialist at AtkinsRéalis, emphasizes three critical considerations for effective engagement:

1) Cultural Respect and Traditional Knowledge Integration: AtkinsRéalis acknowledges the diverse cultural, social, and economic contexts of the 22 Indigenous Nations and communities within Treaty 9 in Northern Ontario. The company is committed to engaging these Nations in their languages—Cree, Oji-Cree, and Ojibwe—by adapting technical information for clearer understanding. They have developed an environmental assessment glossary and utilize accessible formats to communicate effectively, fostering trust and respect with Indigenous communities.

2) Meaningful Consultation and Engagement: The company prioritizes early and ongoing engagement with Indigenous leaders, Elders, and community members. During the COVID-19 pandemic, AtkinsRéalis adopted innovative methods such as live streams and radio programs to maintain robust community engagement. They use visual aids, like miniature railway models, to clarify project details and address environmental concerns, ensuring Indigenous voices are heard and respected throughout the project lifecycle.

3) Long-Term Relationship Building: AtkinsRéalis is dedicated to creating enduring partnerships that offer mutual benefits, extending beyond mere regulatory compliance. This commitment includes fostering economic growth through Indigenous participation in project procurement and providing skills training. Guided by a comprehensive plan focused on trust, respect, and equitable benefit-sharing, the company aims to build lasting, positive relationships with Indigenous Nations.

Peatland Data and Terrain Assessment

The study area has limited data on the variability and behavior of peatlands. To address this gap, existing materials have been reviewed to identify the necessary information for the Environmental Assessment/Impact Assessment (EA/IA). These materials include high-level surficial maps from the Ontario Geological Survey, aerial photography, and relevant documents from activities within and around the proposed road corridor. Additionally, baseline studies and impact assessments from similar boreal peatland regions in northern provinces have been considered.

Previous investigations by Golder (2010) provided initial insights into the peatlands within the study area. These findings were supplemented by field investigations using peat probes to determine the thickness and composition of the organic terrain. Ongoing investigations aim to obtain peat samples for laboratory testing and conduct further in situ testing of peat properties.

Reports indicate that organic terrain, including bogs and fens, covers approximately 60% of the Northern Road Link (NRL) corridor. Peat depths measured in the area range from 0.5 meters to over 5 meters, with most observations recording depths between 2 and 3 meters. The deepest peat observed, exceeding 5 meters, was found in a string fen where the probe did not reach the underlying material.

From these investigations, 14 primary peatland types have been identified, including 8 types of fens and 6 types of bogs. Each peatland type, along with non-peatland terrain, has been mapped using aerial and satellite images, LiDAR, and available field data. These terrains have been assigned a two-letter terrain unit for identification.

Figure 4. Aerial images of areas of Treed Bog (TB), String Fen (SF), and Domed Bog (DB)

Source: J.D. Mollard and Associates (2010) Limited

Terrain types have been ranked for constructability on a scale from 1 to 4. Type 1 terrains, such as esker and mineral soil, exhibit the best constructability characteristics. Type 2 terrains, typically found in treed-bog areas with thinner peat, present moderate constructability. Types 3 and 4 terrains, which include deeper peat and water tables at or near the surface, pose greater construction challenges.

The terrain mapping also highlights critical features such as bedrock, thermokarst-affected landforms, and water bodies, essential for understanding the overall constructability and environmental impact of the proposed road project.

Addressing Challenges in Material Sourcing

A significant challenge involves the limited availability of aggregate sources complying with provincial requirements for road construction. To tackle this, the project must identify potential aggregate sources that can support construction, operations, and maintenance activities. Some potential quarry sites along the corridor have been identified but they have not yet been evaluated for suitability or quantities. Long haul distances can result in higher costs and environmental impacts. It is likely that access roads will be required to move material from its source to the roadway. Limited suitable aggregates may also lead to construction implications, potentially necessitating alternative materials or construction methods that could affect project timelines and quality.

The use of OptiHaul and Smart Pit concepts within RoadEng Software enhances efficiency and will contribute to an optimized design. The program can evaluate access distance, excavation cost, haul cost, and opening cost. With this data, the Smart Pits feature of RoadEng can analyze multiple pit options and determine the most advantageous pit for each segment of the road being constructed. By considering factors such as distance, cost, and site characteristics, RoadEng identifies the optimal pit location for extracting the required materials as well as the volume of material needed based on the project's alignment and cross-sections.

Evaluation and Selection of Preferred Alignment

The evaluation and selection process for the preferred corridor and alignment of the proposed NRL will be a multifaceted endeavour considering various critical factors. The preferred corridor has not yet been selected; however, a conceptual engineering route has been identified to support development of initial stages of preliminary design. In order to determine the preferred corridor and alignment, terrain and topography, including valleys, uneven terrain, peat lands, and soft soil areas, will be thoroughly assessed for their impact on the project. This assessment will establish a foundation for the preferred corridor and will be conducted in concert with environmental and community concerns. Minimizing ecological impact and maintaining biodiversity are paramount, requiring thorough environmental assessments and mitigation strategies to be integrated into the alignment design.

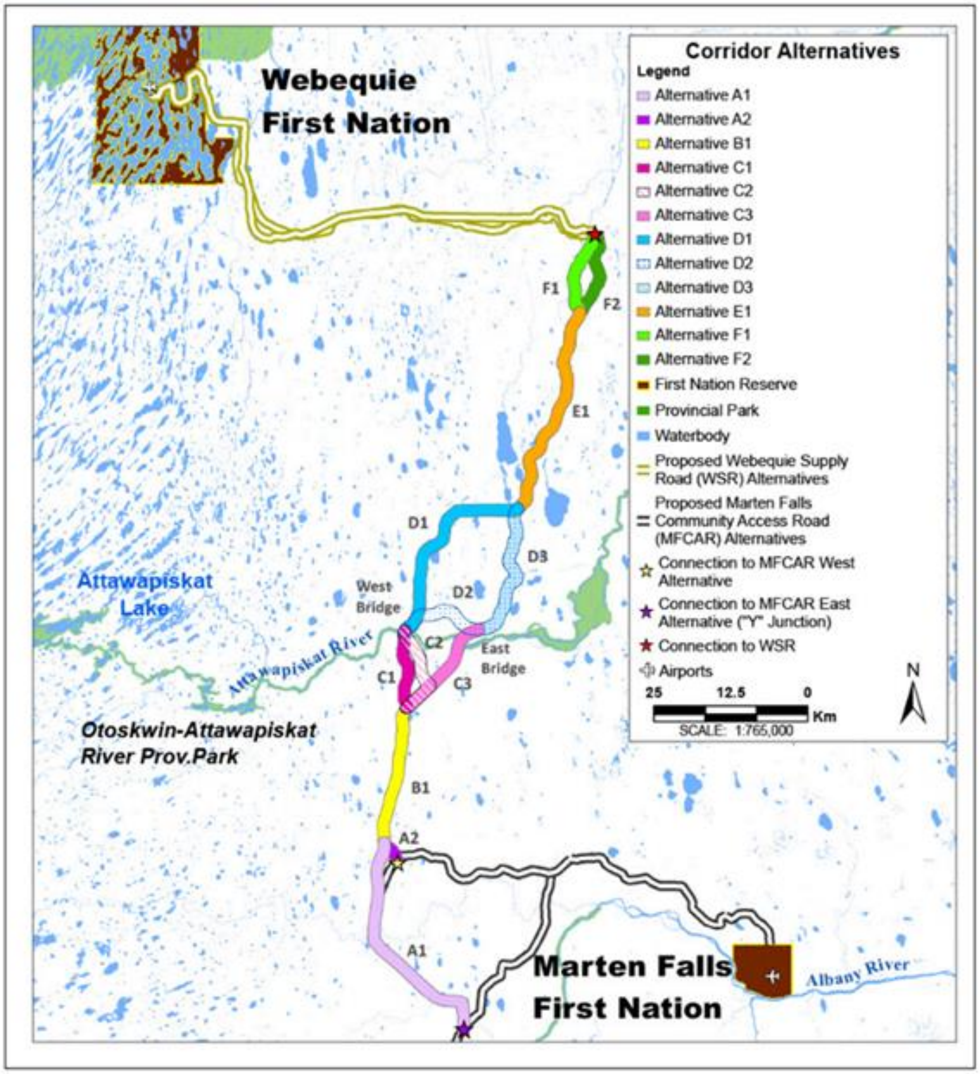
Route Optimization Criteria:

1) Maximize passage over constructible soil conditions to enhance road base stability and overall durability.
2) Optimize aggregate sourcing to reduce hauling distances, thereby minimizing transportation costs and the environmental footprint.
3) Minimize the number, span, and lengths of water crossings by aligning crossings perpendicularly to reduce construction complexity and ecological impact.
4) Integrate the route alignment with surrounding terrain features to preserve the natural landscape and enhance project sustainability.
5) Balance cut and fill quantities to reduce earthwork requirements, optimizing both construction efficiency and environmental impact.
6) Design and accommodate necessary structures along the route to ensure safety, functionality, and long-term resilience of the infrastructure.

Public and stakeholder consultation and community engagement is crucial throughout the evaluation and selection process. Gathering feedback, addressing concerns, and incorporating community preferences help ensure decisions reflect the needs and interests of those affected by the project. Finally, adherence to geometric design standards ensures that the chosen alignment meets functional requirements while maintaining consistency with industry best practices and regulatory guidelines.

There are several corridor alternatives currently being considered for the NRL. The road is segmented, as shown in Figure 5, with each alternative studied individually. The route alignment, including both the vertical and horizontal alignment, will be determined after the preferred corridor is chosen from the alternatives. Multiple route alignment options will then be evaluated within the preferred corridor.

Figure 5. Corridor alternatives currently being considered for the Northern Road Link



Construction Methods for Roadways Over Peatlands[7,8]

There are three primary methods for constructing roadways over large peatland areas: excavation, displacement, and "left in place" (flotation). Each method has its own advantages and disadvantages.

1) Excavation: This involves removing the peat to create a stable base with the underlying soil. While it provides a solid foundation, it can lead to significant environmental impacts and ground settlement.
2) Displacement: Peat is sidecast and the trench is filled with locally sourced mineral soil or crushed stone. This method creates a stable surface and reduces some environmental impacts but is more costly and technically challenging.
3) Left in Place (Flotation): The roadway is built directly on the existing peat, allowing it to "float" and distribute the weight. This method preserves the peatland ecosystem but may offer less stability and be affected by water level changes. This method is the preferred method for constructing road over peatlands

Table 3. Advantages and Disadvantages of each construction method

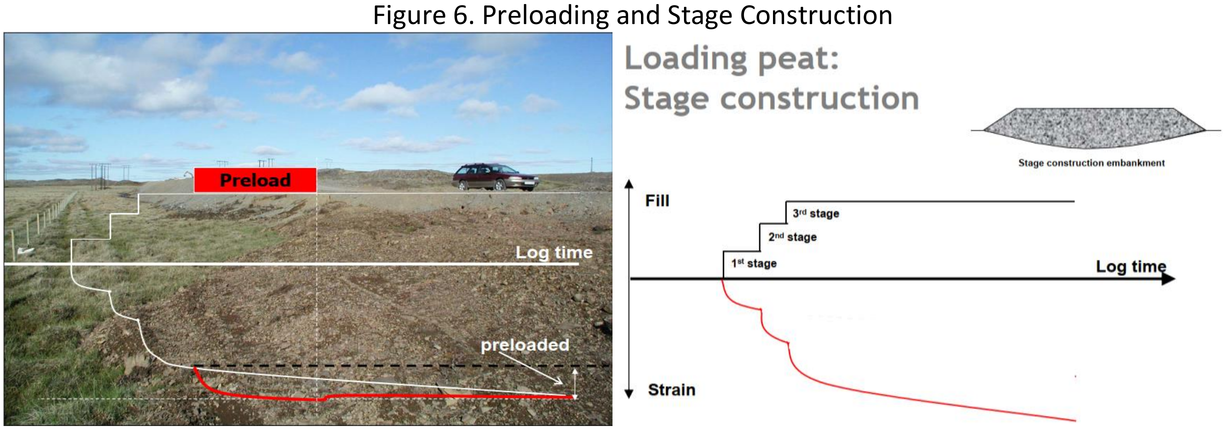
Method	Advantages	Disadvantages
Excavation	• Provides a stable base for construction by removing unstable peat. • Allows for the use of traditional construction techniques. • Can result in more predictable and manageable site conditions.	• Removal of peat can cause significant environmental impacts. • Can potentially cause significant ground settlement. • Disposal of the excavated peat can be challenging. • Causes long term changes to local ecosystem and hydrology.
Displacement	• Restores natural hydrological conditions. • Reduces environmental impact. • Less disturbance to the peatland ecosystem.	• Often is only used for shallow peat. • High cost. • Aggregate material is required to fill in the void back to the original elevation surface. • Technically challenging.
Left in Place (Flotation)	• Leaving peat largely undisturbed minimizes the environmental impact. • Preserves the natural peatland ecosystem and hydrology. • Lower cost. • Faster construction.	• May not provide the same stability as excavation or displacement. • Requires specialized construction techniques and materials. • Can be affected by changes in water levels and peatland conditions. • Limited applicability depending on project requirements and site conditions.

Construction Techniques and and Engineering Solutions for Left in Place (Flotation) Method

Strength Improvement

Enhancing the strength of peat is the key for successful road construction using the "left in place" method. Effective techniques include preloading, surcharging, and staged construction. These methods accelerate peat consolidation by leveraging its high natural permeability. Preloading is particularly suitable for peat due to its relatively quick compression under load compared to other soils. As the peat deforms, its permeability and compressibility decrease, while its shear strength increases, thus improving the stability of the construction site.

Figure 6. Preloading and Stage Construction



Source: ROADEX Implementing Accessibility, Roads on Peat

Figure 7. Surcharging

Source: ROADEX Implementing Accessibility, Roads on Peat

Vertical Drains

Vertical drains are used to shorten the paths for porewater drainage, accelerating primary consolidation and strengthening the peat more quickly. This technique helps in achieving a more stable foundation by facilitating faster drainage and consolidation.

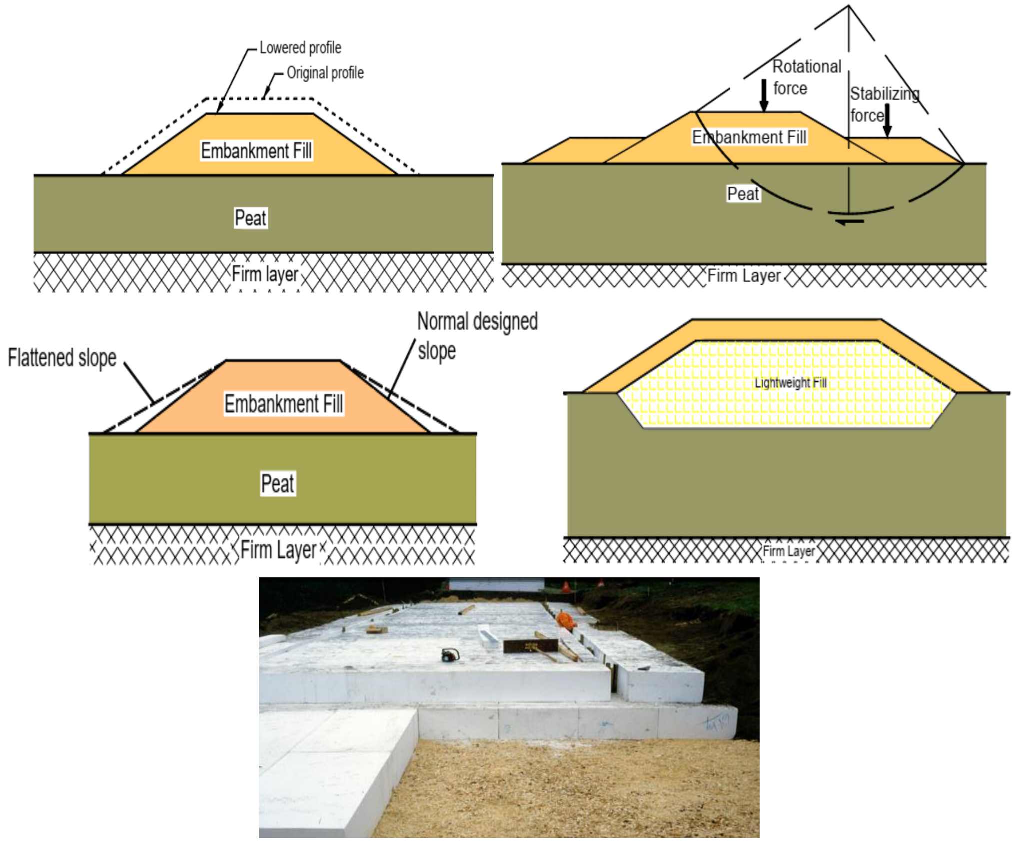
Figure 8. Vertical Drains

Source: Ground Modification Methods Reference Manual

Load Modification

Load modification techniques adjust the load distribution of a road embankment to match the peat's existing strength. Methods include profile lowering, pressure berms, slope reduction, and the use of lightweight fills and Offloading. Implemented during the design stage, load modification reduces the foundation's bearing capacity requirements and results in lighter embankment construction, which helps mitigate future settlement. Lightweight fills, such as geofoam, foam glass, lightweight cellular concrete, tire shreds, and wood fiber, are used to further reduce the load on the peat. Each material type is analyzed for its structural properties, design implications, and environmental impact. Understanding the benefits and limitations of these materials is essential for selecting the most appropriate option.

Figure 9. Diagrams of different load modification techniques



Source: ROADEX Implementing Accessibility, Roads on Peat

Reinforcement

Reinforcement techniques improve the stability of embankments using materials like geotextiles, geogrids, timber rafts, concrete mats, galvanized steel sheeting, and steel mesh reinforcement. Geotextiles and geogrids are particularly effective for road construction over soft ground and peat, serving as separators, filters, and reinforcements.

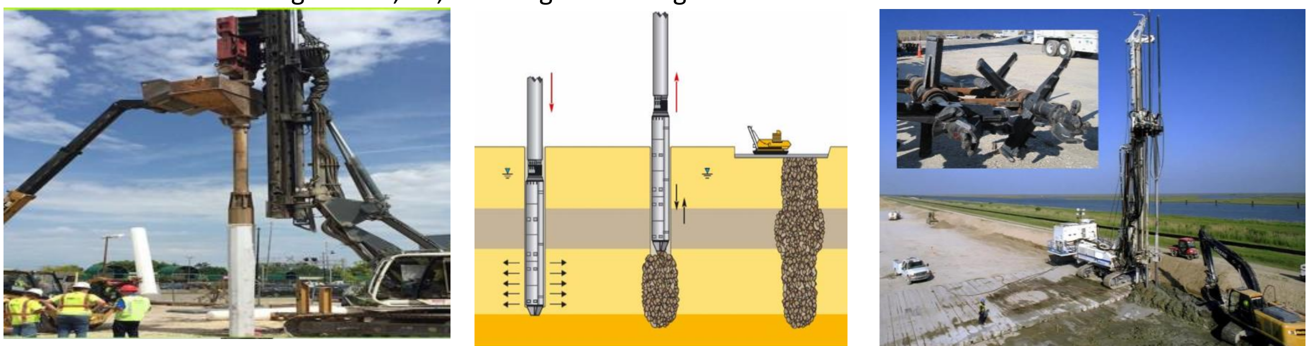
Figure 10. Geotextile reinforcement

Source: ROADEX Implementing Accessibility, Roads on Peat

Mass Stabilization

Mass stabilization combines mechanical, physical, and chemical methods to strengthen weak peat. Techniques include mass densification (compaction), reinforcement (stone columns), cementation (soil mixing and grouting), and drainage (wick drains). This approach involves mixing weak peat with a binding agent, usually cementitious, using mechanical tools to create a stronger, stiffer block. Mass stabilization can significantly enhance the strength of the underlying soil, typically achieving strengths of 50 to 150 kPa.

Figures 11, 12, 13. Images and diagram of mass stabilization

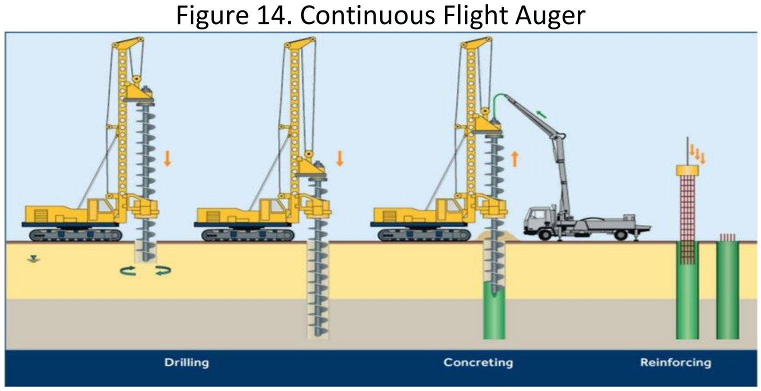


Source: ROADEX Implementing Accessibility, Roads on Peat and Ground Modification Methods Reference Manual

Piling

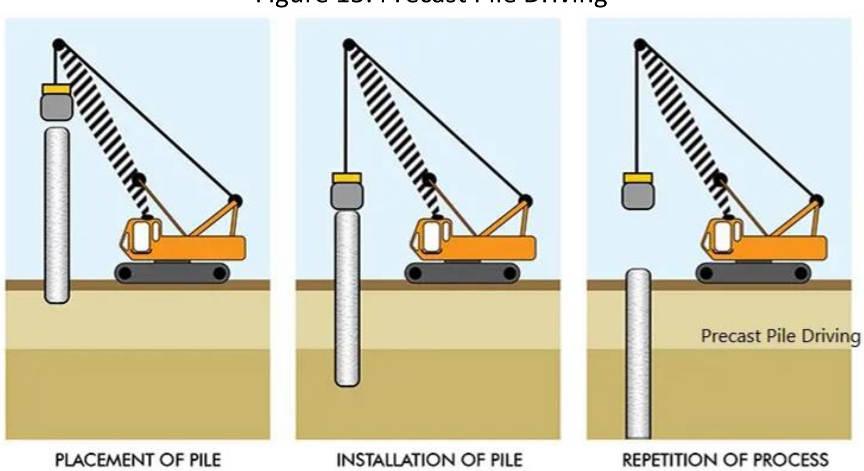
Piling is generally not favored for road construction over peat due to its high costs, including mobilization, setup, and installation. It is primarily used when precise settlement control is essential, such as for bridges and approach structures, and when no other engineering options are feasible. Piling can be executed through driven methods or drilling and casting in place.

Figure 14. Continuous Flight Auger



Source: ROADEX Implementing Accessibility, Roads on Peat

Figure 15. Precast Pile Driving



Source: ROADEX Implementing Accessibility, Roads on Peat

Two common types of piles:

- **Driven Precast Concrete Piles:** Typically, 400 to 600 mm square, these piles can support working loads of 150 to 250 tons. They can be joined for deeper depths (greater than 15 meters) and spliced as needed.
- **Continuous Flight Auger (CFA) Piles:** Increasingly popular in projects due to competitive production rates. CFA piles are formed by boring a continuous flight auger into the ground. Once the required depth is reached, sand-cement grout or concrete is pumped down through the hollow auger as it is withdrawn. Reinforcement is added immediately after the auger is removed. CFA piles range from 300 mm to 900 mm in diameter and can be installed up to 30 meters deep.

Table 3. Advantages and Disadvantages of each engineering option

Construction Method	Advantages	Disadvantages
Strength Improvement (by Consolidation)	No excavation or disposal needed, suitable for fibrous peats, increases shear strength, cost-effective for roads.	Preloading materials may require double handling and extend construction time. Limited to thin embankments.
Vertical Drain	Accelerates consolidation and pore water drainage, minimal impact on peatland hydrology, reduces construction time.	Not needed unless underlain by thick clay layers, requires specific peat type, prone to damage during construction.
Load Modification	Multiple design options available, lighter embankment means less future settlement, customizable, lowers bearing capacity requirements.	Requires larger footprint for road embankments (which restricts the maximum embankment height), lightweight fill can pose buoyancy issues in high water table areas, high cost for lightweight fill.
Reinforcement	Increases load-bearing capacity, simple construction, reduces lateral stresses, avoids excavation, minimal environmental impact.	Geotextiles may be sensitive to installation errors, prone to damage, creep affects long-term performance, does not reduce settlement, high-quality fill required.
Mass Stabilization	Reduces settlement time and horizontal displacement, strengthens weak soils, uses less fill, avoids excavation.	Specialized technique, high cost of binding agents, potential environmental concerns.
Piling (DPCP/CFA)	Minimal environmental impact, ideal for critical settlement control, highly effective for sensitive structures.	Expensive, requires detailed geotechnical investigation, requires heavy machinery and setup, typically excessive for most road projects.

Combination of Construction Techniques and Geotechnologies

In the construction selection process, it's essential to consider combinations of construction techniques and geotechnologies to optimize outcomes. Effective combinations, such as prefabricated vertical drains used alongside fill preloading, can accelerate consolidation and streamline construction schedules. Additionally, incorporating lightweight fill materials, such as geofoam, lightweight concrete, and foam glass, is recommended for reducing the load on embankments supported by stone columns. This approach helps manage load-bearing requirements and enhances overall construction efficiency.

Evaluation of Design Options for the Project

The evaluation of design options for the project focuses on three major indicators: environmental impact reduction, aggregate source availability and shortages, and project cost. At the preliminary engineering stage, a simplified matrix is used to assess these indicators based on four key factors:

1) Peat Depth: Categorized into ranges from 0 to 4 meters.
2) Peat Property: Evaluated based on variations in peat composition, including categories such as Coarse Fibrous, Fine Fibrous, and Amorphous-Granular peats.
3) Groundwater Depth: Classified into ranges from 0 to 15 meters.
4) Terrain Type: Divided into four distinct types.

In the final stage, selecting the most suitable construction techniques and geotechnologies involves assessing site conditions, defining performance requirements, evaluating risks, developing a preliminary design, and creating a comparison matrix. This comprehensive approach ensures that all relevant factors are considered to make informed decisions.

Recommended Potential Construction Approach

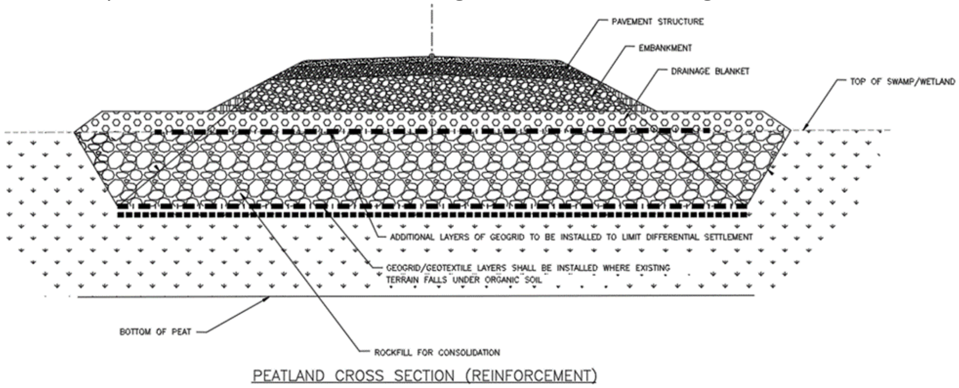
At the preliminary stage of the project, various methods and technologies should be evaluated based on terrain types. For Terrain Types 1 and 2, geosynthetics and preloading are recommended to effectively prepare the ground. In Terrain Types 3 and 4, where ground improvement is crucial, techniques such as stone columns, soil mixing and piling should be considered. For Terrain Type 4 or sensitive structures, piling is essential to ensure stability.

Along the NRL alignment in areas with peat terrain (Types 2, 3, and 4), the Flotation Method using reinforcement technique will be implemented where feasible. This approach minimizes disturbance to the subgrade, preserves the natural ecosystem, and protects the underlying peat layer. Key technical aspects of this method include leaving the peat in place, managing water flow with permeable embankment fills, addressing settlement issues, incorporating geogrids to maintain permeability, and installing equalization culverts. In areas with extreme subsidence, additional support methods such as stone columns and piling may be necessary.

The pavement structure will be composed of high-quality Granular A and B materials combined with local fill, resting on a consolidation layer made of aggregate material within the bog. Anticipated peat settlement during construction is approximately 40%, with further settlement expected post-construction. To preserve peatlands and groundwater, a consolidation layer of about 40-50% of the peat depth is recommended. This approach has been successfully demonstrated in Manitoba, where it has maintained groundwater movement and peatland health.

To enhance the foundation, a geogrid reinforcement layer will be installed between the consolidation and peat layers. This layer provides separation, improves structural integrity, promotes consistent settlement, and reduces the volume of fill material needed. It also prevents fines from migrating into the permeable layer. A detailed assessment of the pavement/subgrade profile is necessary to address seasonal freezing and thawing impacts. Frost-susceptible soils encountered during construction should be removed and replaced or treated with appropriate subgrade materials.

Figure 15. Proposed cross section of floating road structure using reinforcement technique



As the project advances to the final stage, a comprehensive assessment of site conditions is essential. Clearly defining performance requirements and evaluating potential risks are critical steps in this process. Developing a comparison matrix will aid in guiding decision-making, ensuring that the most suitable approach is selected based on the specific conditions of the project.

Pavement Design

Pavement design aims to develop a cost-effective structure tailored to meet specific performance, serviceability, and safety requirements. This complex process requires an in-depth understanding of the behavior of soils and paving materials under various traffic and climatic conditions. Key factors influencing pavement performance include traffic loading—such as traffic volume, growth rates, axle loads and distribution, tire pressures, and vehicle suspension characteristics—as well as environmental influences like precipitation, temperature variations, moisture in pavement layers, and freeze-thaw cycles. The type and properties of subgrade soil are also crucial in determining the pavement's design.

The concept of Equivalent Single Axle Loads (ESAL), developed from data from the American Association of State Highway and Transportation Officials (AASHTO) Road Test, is employed to quantify traffic load effects and establish a damage relationship for axles carrying different loads. This methodology aids in addressing the many variables that can affect pavement performance.

In practical terms, specific strategies are tailored to the conditions of different road sections. For sections located in areas with stable soil conditions, a single asphalt layer made from a tar slurry mixed with gravel will be applied as the driving surface. In contrast, sections situated in areas with soft soil, such as peatlands with less stable conditions, will initially use a gravel surface. This gravel surface will be monitored during the operational phase to assess performance, settlement, serviceability, and safety, particularly regarding dust control along the corridor. Based on these assessments, the gravel surface may be upgraded within 2 to 5 years to a more durable treatment, such as chip seal or asphalt pavement, to ensure longevity and optimal performance.

Conclusion

The Northern Road Link project exemplifies a balanced approach to infrastructure development, enhancing connectivity and economic growth in Northern Ontario while navigating the ecologically sensitive Hudson Bay Lowlands. The project integrates sustainable practices and innovative engineering solutions to minimize environmental impacts, preserve peatlands, and maintain natural hydrology. Key practices such as strength improvement, vertical drains, load modification, mass stabilization, reinforcement, and piling are employed to ensure road stability, resilience against climate change, and reduced environmental impact.

Constructing roads on peatlands presents significant risks, including the release of stored carbon dioxide and methane, which contribute to climate change, and the loss of peatlands' carbon sink function. Disruptions to local hydrology can exacerbate these issues by accelerating peat decomposition and carbon emissions. Addressing these impacts requires a comprehensive approach, including interdisciplinary collaboration, detailed risk assessments, and the development of a robust risk versus consequence matrix for climate hazards.

Meaningful engagement with Indigenous communities will be a cornerstone of the project, incorporating traditional knowledge, fostering cultural respect, and promoting economic participation. Detailed field investigations and laboratory analyses, such as exploratory boreholes, CPT, and airborne geophysics, will be critical for developing effective design options tailored to site-specific conditions. By integrating innovative engineering solutions and continuous stakeholder engagement, the NRL project sets a precedent for responsible and sustainable infrastructure development, harmonizing with environmental and cultural considerations.

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