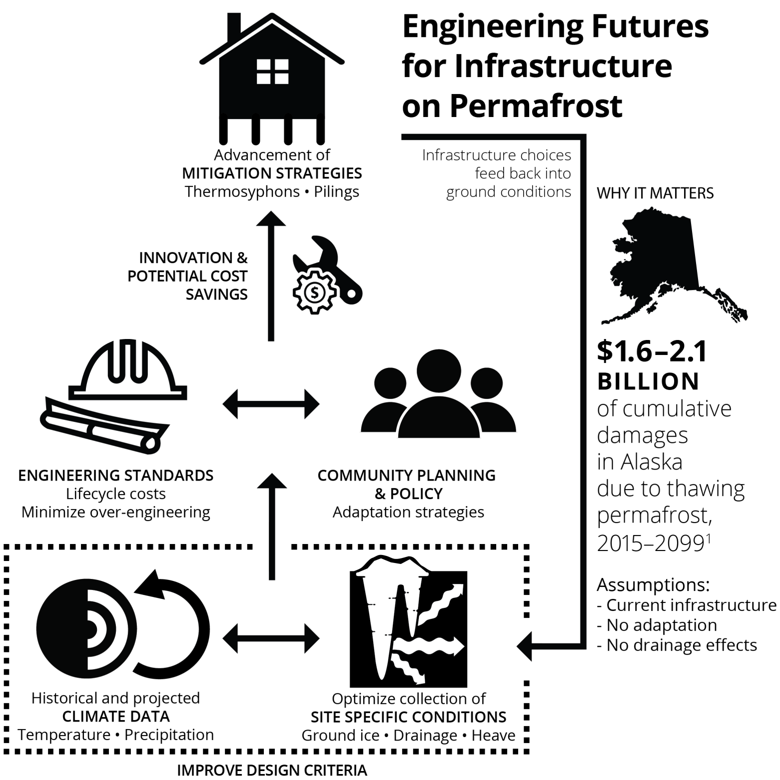
How is permafrost degradation affecting infrastructure?

THE ISSUE. Degradation of permafrost—perennially frozen ground that often contains subsurface ice—makes it difficult to build and maintain infrastructure including roads, buildings, pipelines, and airports. As ground ice melts, soils shift and collapse making the ground unstable thus jeopardizing infrastructure at the surface. Factors that contribute to permafrost thaw include thermal disruption (i.e. increase in heat) caused by both the construction of infrastructure itself as well as by a warming climate. Improved engineering methods and standards are needed to alleviate these effects.

WHY IT MATTERS. Building and maintaining infrastructure in permafrost environments is costly due to specialized design requirements that are needed to prevent or mitigate thaw caused by the presence of infrastructure. Planning infrastructure on permafrost requires knowledge about the presence of ground ice: how much there is, and where it is located. The interactions between temperature, water, and ice are the most important environmental factors for predicting how infrastructure will perform in current and future environments. In a climate that is projected to become warmer and wetter, changes in these critical factors need to be integrated in the planning and design of resilient infrastructure. Data on infrastructure, climate, permafrost temperature, ground ice distribution, and adaptive practices are currently collected by a wide variety of governmental agencies and other groups. Coordination among these groups is necessary to assess the current effects of permafrost degradation on infrastructure in a repeatable manner. This would help to develop better planning capacity and be able to predict the best approaches to provide essential community services as well as wider stakeholder needs.



STATE OF KNOWLEDGE. Construction of viable infrastructure on ice-rich permafrost can be accomplished in one of two ways, 1) protect the permafrost from thawing, and/or 2) design for flexibility with the infrastructure as the permafrost destabilizes. The main guiding principle has been to prevent permafrost thaw and settlement by keeping the ground frozen. Engineers and scientists have developed a range of adaptations to meet the challenges of building infrastructure on permafrost including: insulation, excavation of the ice-rich ground, refrigeration with *thermosyphons* (passive heat exchangers), as well as designing structures (e.g. pilings) that can be adjusted as the ground surface elevation changes over time from subsidence or heave. The biggest challenge to planning infrastructure for permafrost is creating design criteria (depicted in the **engineering futures** schematic), including identifying where ground ice is currently located, and how temperature and water will interact with ice and the infrastructure over time in a changing environment.

Currently, most engineering designs are created using 30 years of historical climate data for estimating future impacts of infrastructure with a service life of the same duration. This approach is insufficient as climate change alters the total amount of energy at the surface and ground heat movement more rapidly than is represented by the historical data. For example, the cumulative effects of both environmental change and oilfield infrastructure in northern Alaska resulted in substantial surface water ponding and abrupt permafrost degradation between 1949 and 2011. These effects have accelerated in the last 20 years likely due to increased atmospheric warming. The implications of a projected warmer and wetter environment for public infrastructure have recently been analyzed for Alaska. Permafrost thaw was projected to incur $1.6-2.1 billion dollars in cumulative damages from 2015-2099, one of the top two costliest factors, with northwest Alaska expected to be the region of greatest risk.

As permafrost thaws, ground subsidence and erosion is accelerated by water moving across the surface, as well as by loss of ground ice (photo of exposed ground ice underneath a University of Alaska parking lot). These processes add complexity to infrastructure design, especially as consequences of thawing permafrost are still being identified. For example, slowly moving landslides (*frozen debris lobes*) are advancing towards the Dalton Highway in Alaska. Rerouting the road is the cheapest viable option but one that will still add $2 million to a road alignment project. Complex interactions between permafrost and other disturbances like flooding are common for transportation infrastructure that cross large expanses of permafrost ground. Large embankments that provide the base for highways and railways substantially alter permafrost under the embankment and at the margins. Although thermosyphons can keep the ground frozen, they are more expensive than standard construction practices and may be insufficient as air and ground temperatures warm. Changes in vegetation as a result of infrastructure causes additional issues, especially along highways. Trees and tall shrubs succession advances more rapidly along disturbed road corridors, intensifying permafrost degradation due to altered soil moisture, snow, and ground insulation in the winter. A comprehensive understanding of the linkages between soil properties, hydrology, vegetation, and infrastructure will improve discussions between planners and engineers seeking updated designs.

Where the Science is Headed. Assessing risk to infrastructure from ground ice degradation and water movement requires characterization of the landscape. This includes improving geotechnical studies such as drilling and other sampling techniques used to locate ice-rich ground and identify other site conditions. Future climate scenarios must be considered in lifecycle costs of infrastructure built on permafrost to balance adaptability and resilience versus initial outlay. Scientists need to play a more effective role in producing, coordinating and translating these environmental data for engineers and communities. This dialog will help to create design criteria that offer the best alternatives for construction choices and maintenance options. Standardizing best practices for planning, designing, and constructing infrastructure for permafrost conditions, now and in the future, will help balance sustainable growth and development for local community and wider stakeholder needs.

Key References

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