Shallow Permafrost and the Rehabilitation of Tundra on Alaska's North Slope: Lessons Learned from Case Studies

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Abstract
Alaska's North Slope oilfields, located above latitude 70o North, are underlain by permafrost with an active layer typically less than 50 cm thick. Environmental regulations require rehabilitation of disturbed tundra in the oilfields. Thawing of shallow permafrost during rehabilitation can lead to subsidence. Concerns expressed a decade ago about the importance of subsidence on rehabilitation projects appear to have been exaggerated for some types of projects but somewhat under appreciated for other types of projects. This paper underscores the importance of case studies and well documented field observations, especially when there is a paucity of data from well designed and replicated experiments.

Keywords
Active Layer; Alaska; Permafrost; Rehabilitation; Tundra.

Background: Alaska's North Slope Oilfields

Alaska's North Slope oilfields are concentrated between the Colville and Canning Rivers in the tundra biome above 70o North, an area underlain by permafrost to depths of as much as 600 m and with active layers typically less than 50 cm thick (Figure 1). Since oil production began in 1977, a complex of production facilities, pipelines, and over two thousand wells have sent more than 15 billion barrels of oil to refineries on the west coast of the United States. All of this has occurred under the scrutiny of multiple federal, state, and regional agencies tasked with overseeing environmental regulations. These regulations include requirements to rehabilitate tundra damaged by industry operations.

In general, post-excavation revegetation of sites on Alaska's North Slope is a slow process, requiring more than 20 years due to the slow growth of plants (Streever et al. 2003). While more research might improve revegetation methods and rates, this paper focuses on changes in shallow permafrost that can affect rehabilitation sites.

The two situations most commonly requiring rehabilitation efforts are (1) abandoned sites where gravel originally placed to provide a stable building foundation (i.e., a "gravel pad") has been removed, and (2) sites where cable and pipeline burial have required excavation and backfilling of trenches.

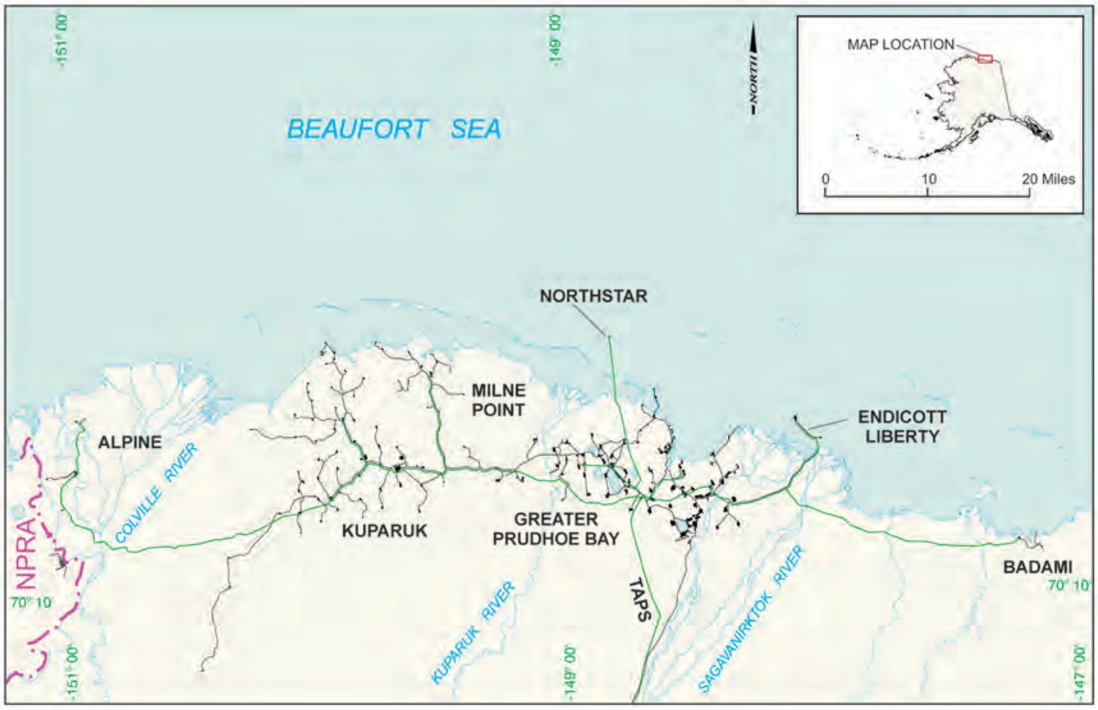

Figure 1: The North Slope oilfields of Alaska.

As recently as ten years ago, planners repeatedly raised concerns about the possibility that thawing of shallow permafrost could cause significant problems for gravel removal rehabilitation sites. Conversely, planners were less concerned about thawing ground ice and subsidence in backfilled trenches, because it was generally accepted that simply "mounding" soil over backfilled trenches would easily address subsidence. Over the past ten years, experience has shown that assumptions made about the importance of thawing ground ice were incorrect for both gravel removal sites and backfilled trench sites.

Changes in Shallow Permafrost that Can Affect Rehabilitation Sites

For rehabilitation sites where gravel has been removed, experience has shown that thawing of shallow permafrost can lead to limited subsidence and summertime waterlogging of soils. However, the waterlogging of soils is reversed when ice wedges thaw, establishing drainage networks.

For rehabilitation of backfilled trenches, experience has shown that thawing of shallow permafrost can cause substantial subsidence over long reaches of the original trench line. This subsidence has resulted in flooding of trenches with water that is often too deep to support vegetation, even when soil was mounded to heights as great as 50 cm above backfilled trenches. Thawing of ice wedges does not promote drainage as it does on larger rehabilitation sites with shallow subsidence. Also, the thawing of ice wedges can extend laterally out from trench lines beyond the footprint of the original project.

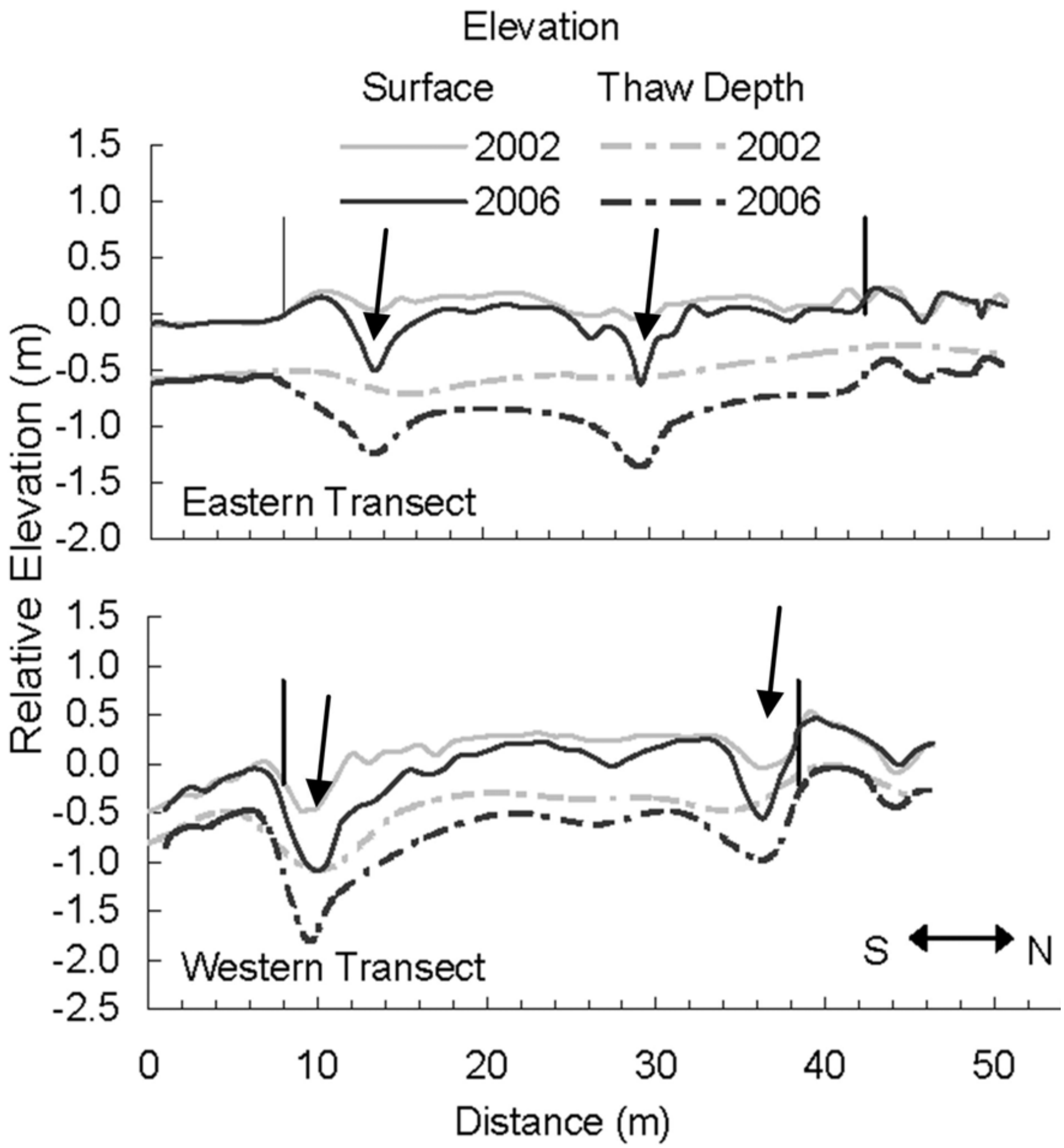

Figure 2: Thaw subsidence and change in active layer thickness at the Mobile Kuparuk Airstrip gravel removal rehabilitation site, showing both overall site subsidence from 2002 until 2006 and development of thawed ice wedge troughs (arrows) that drain saturated soils. Vertical bars mark the northern and southern edges of the site, with undisturbed tundra outside of the bars.

Thaw of Shallow Permafrost Creating Water Saturated Depressions and Ice

Wedge Thaw Creating Drainage Networks following Gravel Removal
More than 3,500 ha of gravel have been placed on the North Slope as airstrips, roads, and stable foundations for drilling and production facilities. As the oilfields mature, some of these sites are no longer needed. Over the past decade, gravel has been removed from more than fifty of these sites.

Ten years ago, concerns were frequently raised about the possibility of gravel removal resulting in extensive thermokarst and the creation of "square ponds"—that is, ponds taking the shape of the removed gravel pad. In many cases, up to 30 cm of gravel was left in place to prevent the creation of unwanted ponds. However, experience has shown that sites subside unevenly following gravel removal, leaving behind a surface that is often slightly lower than the surrounding tundra grade but with both high and low areas and an unusually thick active layer.

While no sites on which gravel has been removed to tundra grade have collapsed to create deep ponds over the entirety of the original excavation footprint, even the relatively minor subsidence that does occur results in soils saturated with water during the first and occasionally the second summer after gravel removal. However, within two years after gravel removal, thaw collapse of ice wedges creates drainage networks that remove unwanted water.

In short, soil saturation associated with gravel removal and subsidence due to melting of shallow permafrost is alleviated by thawing of ice wedges and subsequent site drainage. Figure 2 illustrates this pattern for one of the many sites on which it has been observed.

Thaw Collapse of Trenches and Extension of Ice Wedge Thaw into Surrounding Tundra

Dozens of miles of trenches have been excavated and backfilled on the North Slope to bury cables. While most pipelines are perched above the tundra on steel support members, a few gas pipelines have been buried. In addition, pipeline burial methods were tested at two North Slope sites in anticipation of eventually burying a large diameter gas export pipeline, leaving behind about 10 km of backfilled trenches.

As is the case with excavated gravel pad sites, trenches that are excavated and backfilled tend to subside after construction and ice wedges intercepted by trenches tend to thaw. At the same time, the active layer thickens near the edges of trenches and the active layer in the backfilled trenches themselves tends to be deeper than those of surrounding undisturbed ground. However, perhaps because trenches form linear features that cross the landscape and are capable of capturing surface flows, thawing of shallow ground ice can be more extensive

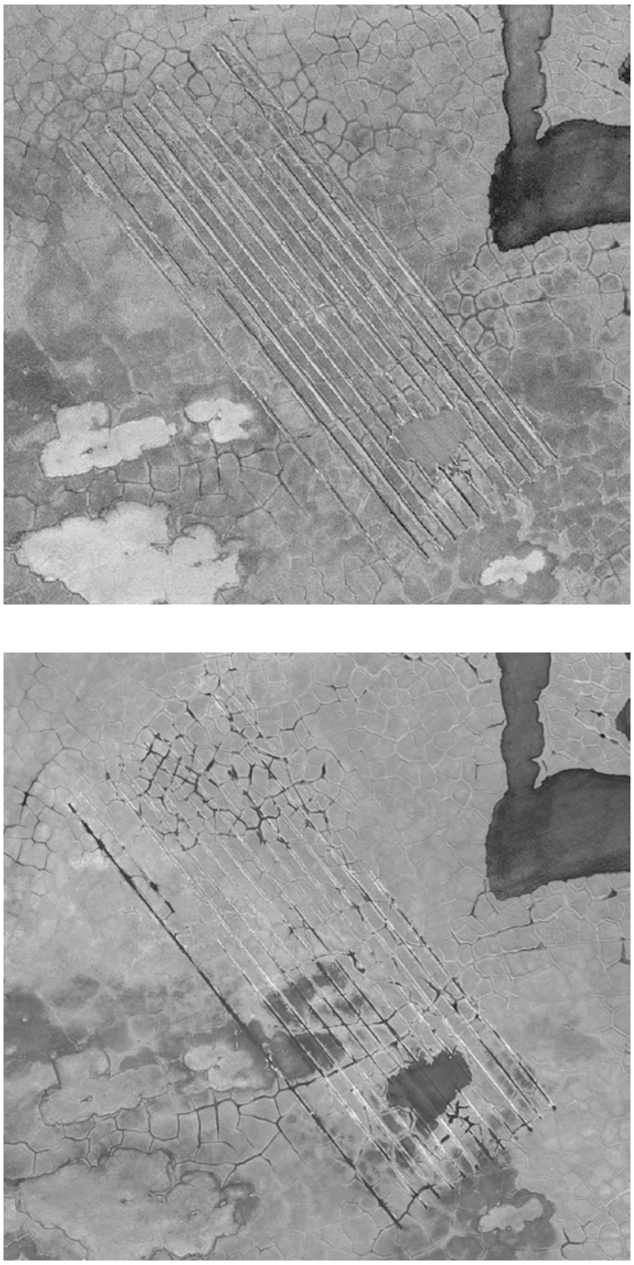

Figure 3: A site where trenching equipment and methods were tested in 2002, showing initial conditions (top) and conditions in 2011. After several attempts to backfill subsiding trenches subsidence continued, as can be seen at the trench on the left side of the bottom figure, and ice wedge troughs had thawed laterally from some of the trenches.

than that normally seen on gravel pad removal sites. More than 1 m of subsidence has been seen at some trench sites and subsidence can continue for at least a decade after construction. Thawed ice wedges do not drain subsided trenches, apparently because of the depth of subsidence. Furthermore, ice wedge thawing can extend laterally outward from trenches into the surrounding undisturbed tundra (Figure 3).

Land managers have tried different methods to control thermokarst degradation of trenches, including repeated backfilling using mineral soils trucked in during the winter season or transported in during the summer season on trucks designed for tundra travel (i.e., trucks with very low ground pressure). The only method that has worked with reasonable consistency involves placing backfill into subsided trenches to regain elevation loss followed by capping of the backfilled trenches with tundra sod (i.e., soil with intact plants harvested from nearby donor sites). The tundra sod appears to limit further ground ice degradation, probably through a combination of providing insulation, increasing albedo, and cooling through evapotranspiration during summer months.

Conclusions

On North Slope gravel removal rehabilitation sites, thawing of shallow permafrost has not presented the difficult challenges that were anticipated a decade ago. In fact, soil saturation that seems to be associated with limited thaw subsidence is often offset by drainage channels created when ice wedges thaw on gravel removal restoration sites, so, in a sense, the challenge created by thawing of shallow permafrost is solved by the thawing of ice wedges. Conversely, on trenching sites thaw subsidence appears to be a greater problem than was anticipated a decade ago, not only creating on-site subsidence but in some cases also extending beyond the trench edges into the surrounding tundra.

Well designed and replicated experiments might yield useful results and could, potentially, define relationships between the degree of thaw subsidence likely to occur in a given location, the existing pre-excavation ground ice conditions, and the planned rehabilitation activity. However, the value of case studies and well documented field observations should not be overlooked. As the North Slope oilfields continue to mature and the number of rehabilitation sites increases, an improved understanding of the dynamics of shallow ground ice on rehabilitation sites will increase in value. Because of the paucity of data from well designed and replicated experiments, improved understanding will have to come from case studies and well documented field observations. An effort to systematically understand the information available in well documented case studies is warranted.

References

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