Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay Oilfield, AK

Landscape & vegetation impacts


Oral talk at ASSW 2021, Lisbon, Portugal, Northern Roads and Railways: Social and Environmental Effects of Transport Infrastructure (ID 19)
Environmental impact assessments for new Arctic roads do not adequately consider the long-term cumulative impacts from infrastructure and climate change to permafrost landscapes.

This is due in part to lack of long-term historical case-studies that followed the consequences of infrastructure once it was built.
Direct impacts (footprint) of infrastructure:

As of 2011:
• 16 oilfields spread across 4000 km²
• Approximately 1000 km of roads
• 800 km of pipelines
• Hundreds of gravel pads with exploration wells and other oil field facilities


Map courtesy of BP Exploration (Alaska)
Elevated gravel roads

Source of fines for road dust

Barrier to snow and cross drainage of water
Indirect landscape effects of roads

Flooding

Thermokarst

Road dust


Infrastructure-related time series:

Difficult to evaluate complex cumulative indirect impacts adjacent to roads

Climate-related thermokarst away from infrastructure

Roadside thermokarst and flooding

Roadside dust

Combined effects of climate change, dust and flooding
Or to separate the climate-related impacts from the infrastructure-related impacts

Temperatures and thaw depth

Precipitation
Four scenarios of landscape and vegetation change*

Ground-based studies to examine climate-related and indirect impacts of roads

* Impacts to the ice wedges and protective intermediate layers are in separate papers (Jorgenson et al. 2015, Kanevskiy et al. 2017, 2021 in prep.)
Scenario A. Pre-road (1949-1968)

Aerial photos and 1970s baseline environmental studies, U.S. IBP Tundra Biome and CRREL
Scenarios B, C, D: Permafrost observatories

- Colleen Site (CS) and Jorgenson Site (JS)
- Climate and permafrost temperature data from Romanovsky Deadhorse station, Deadhorse Airport, Prudhoe (ARCO), and Kuparuk NWS data.
Scenario B. Jorgenson site, climate change, no road

Relatively isolated from infrastructure impacts, large changes in thermokarst ponds since 1968

Thermokarst pond area: 1949 (1.5%), 1988 (1.5%), 2004 (6.3%), 2012 (7.5%)

Scenarios C and D. Colleen site, climate change and road
Straddles the Spine Road with different effects on each side

Mostly thermokarst and dust impacts on the NE side of the road

Thermokarst, dust, and flooding on the SW side of the road

Time series of aerial photograph: 1949, and nearly annual 1968-2014
Transects and plots
Colleen site

- Aerial photo time series mapping
- Transect & plot surveys
  - Micro-topography
  - Permafrost cores
  - Active layer
- Environmental factors
- Vegetation
- Soil
- Snow
- Dust
- Flooding
Colleen transects for scenarios C and D

**Scenario C:** Transect T1 (Thermokarst, and heavy road dust)

Looking NE from the road

**Scenario D:** Transect T2 (thermokarst, dust, and flooding)

Looking SW from the road

**Most evident impacts:**

T1 — dust & thermokarst
T2 — flooding & thermokarst
Data: Transects T1 and T2 and 29 plots

Transects T1 and T2:
- Ground-surface elevation, thaw depth, water depth, vegetation height, patterned-ground element, vegetation type, LAI, dust-layer thickness

Vegetation plots:
- Soil, snow, vegetation properties in polygon centers and troughs, vs. distance from road along Transects T1 & T2
Mapping Colleen site changes

Water bodies (1968–2018)

Vegetation (1972 & 2013)

Jones, B. 2020.

Raynolds et al. 2014. Poster *Arctic Change 2014*
Differences between T1 (dusted) and T2 (flooded)

Key environmental and vegetation variables, 2014

Conclusion: Polygon trough-center relief, thaw depths, and productivity are greater on the flooded side of the road.
Comparison of key site factors Jorgenson (Scenario B) and Colleen transects, 2020 (Scenarios C and D)

Conclusion: Pond area, polygon morphology, thaw depths, and distribution of broad vegetation types are similar at JS and CS T1, and different at CS T2.
Comparison of disturbed Colleen plots (Walker et al. 2014) with similar undisturbed plots from 1970s (Walker 1985)

Synoptic table analysis of species distributions in veg units

Ordination: Relationship of vegetation units to environmental gradients
Scenario A: Pre-roads

- Dominantly low-centered polygons, <30 cm trough-center microrelief, dominated by wet nonacidic tundra in polygon basins and troughs.
- 1949-1968: Little change to ice-wedge thermokarst, water-bodies, or landforms... and by inference, to the vegetation.
Scenario B: Climate-change, no road

Deeper thaw depths, degrading ice wedges, trough subsidence

More, larger thermokarst ponds, conversion to transitional and high-centered polygons, with > 50 cm microrelief, changes to drainage patterns

More willows

Changes to vegetation patterns
Scenario C: Climate change + dust

Dust layer added to soils

Smothered low-growing vegetation near roads, reduced polygon microrelief

Large reductions in cover and species diversity of small forbs, mosses, lichens

Introduction of halophytic species from dust control chemicals

Dust layers in snowpack near roads, altered snow albedo, early snow melt, earlier green-up, impacts to waterfowl and wildlife

Scenario D: Climate change + dust + flooding consequences

- Very large dust impacts near road
- Extensive flooding, deep troughs, conversion of L.C. to H.C. polygons
- Water bodies interconnected to each other and to Lake Colleen

Lush growth of wet sedge vegetation on polygon centers and aquatic sedges in troughs

Largest cumulative changes to water bodies, polygon morphology, and vegetation patterns
Conclusions

• Scenario approach was useful to examine gradients of cumulative impacts.
• More work is needed to model the complex interactions of climate change and indirect infrastructure-related impacts.
• The results should be helpful for recommendations regarding future cumulative impact assessments of indirect impacts and climate change.
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2014 Colleen field team