From: Hayes, Miriam (Nicole) <mnhayes@blm.gov>
Sent: Thursday, March 14, 2019 8:39 AM
To: coastalplainAR; Sean Cottle
Subject: Fwd: [EXTERNAL] Comment of Coastal Plain DEIS
Attachments: Jorgenson 2019 Comments on Coastal Plain EIS Physical Resources.pdf

Follow Up Flag: Follow up
Flag Status: Completed

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From: **Torre Jorgenson** <ecoscience@alaska.net>
Date: Wed, Mar 13, 2019 at 4:58 PM
Subject: [EXTERNAL] Comment of Coastal Plain DEIS
To: <mnhayes@blm.gov>

Hi Nicole,

Attached is a file with my comments on BLM's DEIS for the Coastal Plain Oil and Gas Development Program. They mostly focus on deficiencies in the physical resources sections.

I submitted the attached file on-line but wasn't sure that I had done it successfully, so I am also sending you the comment file.

Thanks for your help.

Torre Jorgenson

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Scientific Deficiencies in the Draft EIS for the Coastal Plain Oil and Gas Leasing Program Regarding Climate, Physiography, Geology, and Permafrost Soils

Prepared for: Bureau of Land Management, Anchorage, AK
Prepared by: M. Torre Jorgenson, Alaska Ecoscience, Fairbanks, AK, ecoscience@alaska.net

12 March 2019

BACKGROUND

Based on my nearly 40 years of experience working in the Arctic and assessing environmental impacts of oil development on Alaska's North Slope, the BLM's Draft Environmental Impact Statement (DEIS) is woefully inadequate in summarizing the current state of scientific information needed to adequately assess and mitigate the impacts of oil development in the 1002 Area of the Arctic National Wildlife Refuge (ANWR). During my career conducting studies in support of oil and gas development, I have studied seismic exploration impacts (Felix and Jorgenson 1985, Jorgenson et al. 2003, Jorgenson et al. 2010, Walker et al. 2019), ice road and rolligon trail impacts (Jorgenson et al. 2003, Pullman et al. 2005), exploratory well sites (Jorgenson and Cater 1993), oilfield contaminants (Jorgenson et al. 1987, Burgess et al. 1998), oil spill remediation (Jorgenson et al. 1991, 1995, 2003; Cater and Jorgenson 1999), land rehabilitation (Jorgenson and Joyce 1994, Jorgenson et al. 2003), ecosystem and wildlife habitat mapping (Jorgenson 1984, Jorgenson et al. 1997, 2003, 2015, Jorgenson and Heiner 2003, Jorgenson and Grunblatt 2013), geomorphology and hydrology resources relevant to development (Jorgenson et al. 1996, 2003), permafrost (Jorgenson et al. 2006, 2015, Jorgenson and Shur 2007, Kanevskiy et al. 2013), and coastal dynamics (Jorgenson et al. 2002, Jorgenson and Brown 2005, Jones et al. 2009, Lantuit et al. 2012). I have been involved in the Prudhoe, Kuparuk, Endicott, Lisburne, Point McIntyre, Meltwater, Palm, Alpine, and NPRA oil development projects. Given this experience in basic and applied research, and the application of science in support of environmental management and resource development, I have many concerns regarding the inadequate scientific information and analytical approaches that were used in the DEIS to evaluate the potential impacts of the proposed alternatives. In the comments below, I provide some overarching general comments, and then focus solely on physical resources, particularly climate, physiography/topography, geology, and permafrost soils.

GENERAL COMMENTS

There are many serious issues that pertain to overall Federal policy and to the development of the DEIS that are not adequately addressed. These are listed below.

1) Given the serious consequence of climate change to ecosystem changes, national security, and economic losses documented by Federal Agencies (Reidmiller et al. 2018), and the global abundance of available oil, further oil exploration and development in the Arctic should not be pursued. The Arctic should be the last place where oil should be developed given the sensitivity of tundra ecosystems. Thus, Alternative A should be a viable alternative.

2) BLM needs to act in accordance with NEPA law by providing reasonable forecasting and scenario development to adequately assess the range of foreseeable impacts. While leasing alone may not lead to development, the expectation of the leasing program is that there will be at least seismic exploration and exploratory well drilling, with substantial likelihood of full-scale development, oil spills and indirect impacts, and eventual land rehabilitation efforts. The document lacks sufficient description of these activities and site-specific scenarios to allow adequate evaluation as required by law. Because the DEIS identifies where there is high likelihood of economically recoverable oil, the document should also provide specific development scenarios that would be needed to develop that oil.
3) The DEIS is woefully inadequate in compiling, summarizing, and evaluating scientific knowledge necessary to quantify and assess potential impacts. This must have been a politically driven imperative to rush and short-change the effort. I know many of the scientists responsible for writing the physical and biological assessments and know that they are capable of high-quality work for evaluating environmental impacts. The brief and out-of-date summaries of the science throughout the document indicates BLM does not take the NEPA mandate seriously.
4) The level of effort involved in this DEIS is totally inadequate for the level of long-term damage that is likely to the resources of ANWR. In my involvement in numerous EIS and EA efforts for oil development in the central and western coastal plain, many years of scientific studies were conducted as part of the EIS process to provide data to adequately assess environmental consequences. For the Alpine Oil Development, seven years of intensive field studies were conducted on geomorphology, soils, permafrost, hydrology, vegetation, fish, wildlife, cultural resources, and subsistence activities in preparation for the Environmental Assessment (step below an EIS)(Parametrix 1997). For potential development of ANWR, with its resources of global significance, an even more rigorous scientific process needs to be followed.
5) The limiting of potential development in the 1002 Area to 2000 acres and 19 well sites is not reasonable. In the Alpine experience, future expected expansion and cumulative impacts were downplayed in the EA/EIS process, contrary to the reasonable and easily foreseeable scenario that development would extend to the north, south, and west of the initial facilities, as is currently happening. While the Tax Cuts and Jobs Act of 2017 (Tax Act) specified a limitation of 2000 acres, this could easily be amended by future legislation to increase permitted acreage. The cumulative impacts analysis needs to address the likelihood for expansion if large oil reserves are found.
6) The DEIS does not adequately assess the impacts of seismic trails, ice roads, and ice pads, and the interacting effects of climate warming and permafrost degradation. The seismic trails and ice roads will cause disturbance and should be counted toward areas impacted by development. In particular, a rigorous evaluation of seismic exploration impacts and alternatives needs to be incorporated into the DEIS. While the Tax Act specifies that only facilities covering the surface count toward disturbed lands, this is a political decision and is not a scientifically valid limitation for assessing impacts. In addition, the location and volumes of water needed for the annual ice road construction should be specified.
7) The DEIS does not adequately assess impacts of gravel mines. The DEIS states that the surface area of the gravel mines would total approximately 300 acres for each action alternative (not included in the 2,000-acre limit on surface disturbance), but gravel mines

are not considered a “surface disturbance”. This is certainly a political statement inherent in the Tax Act and has no scientific basis.

CLIMATE

The summary of existing climate data, results of climate and sea ice modeling, and evaluation of climate warming impacts are inadequate. Some of the main deficiencies are listed below.

A more complete and graphic presentation of existing data are needed. The climate data trends for Kaktovik should be presented graphically to better support interpretation of trends. Data from the USGS weather stations at Niguanak, Marsh Creek, and Camden Bay (Urban and Clow 2018) should be summarized and used to assess climate variability from the coast to the mountains. It is insufficient to simply reference the 2018 USGS report; the data need to be analyzed and used in a meaningful way to assess the implications of the analyses for the evaluation of Alternatives. Precipitation data from the NRCS Wyoming snow gauge at Kaktovik should be analyzed. In addition, it would be useful to include to longer-term trends at Barrow where the climate data record extends to 1900. Below is a chart of mean annual air temperatures for Barrow, with smoothing to highlight trends (Figure 1). Finally, the discussion that attributes most of the recent warming to the 1977 PDO shift is misleading. While the 1977 PDO shift did indeed cause a step increase, there have been numerous PDO shifts over the last decades, there were numerous cold years in the 1980s after the PDO shift, the warming temperature trend started before the 1977 PDO shift, and the warming trend has been circumarctic unrelated to the PDO shift.

Additional weather stations should be installed and monitored for at least 5 years as part of the EIS process. There is likely a strong inland temperature gradient from the coast to the mountains. This needs to be documented because it can affect engineering design, permafrost temperatures, ground stability, winter travel requirements, and ecological patterns and processes. Data on temperature gradients are needed to adequately assess Alternatives that vary substantially in their climatic regimes.

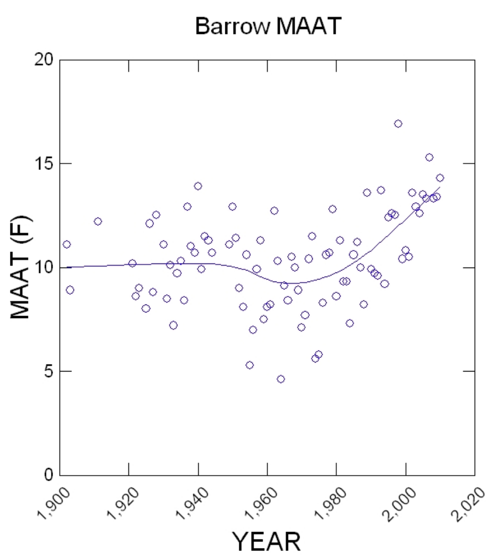

Figure 1. LOESS smoothed mean annual air temperature trends for Barrow.

Future climate projections need to be included and sufficiently discussed, such as those from the SNAP downscaled climate projections (https://www.snap.uaf.edu/). The projected climate warming in northern Alaska is projected to be large due to arctic amplification, and will likely have serious coastal, permafrost, and ecological impacts (Reidmiller et al. 2018). The projected warming also has huge implications for engineering design, facility stability, ice road seasons, and road maintenance. These need to be properly evaluated. As ice roads are an essential part of the infrastructure design, the effect of a warming climate is critical.

The information on sea ice is inadequate and misleading. Graphs should be presented for past trends and future projections. The section is misleading by highlighting a decrease in sea ice extent for July between 2005 and 2018. To dispel this misleading approach to minimizing the impacts of rapid sea ice loss, the DEIS must present the entire graphic record of sea ice changes in seasonal minimum extent since the satellite record began, as well as review recent studies on projected sea ice loss. The implications of the loss of summer sea ice are huge for nearshore wave climate, coastal erosion, inland temperatures, and effects on numerous species, particularly marine mammals. This attempt to minimize impacts through selective cherry picking of data is unconscionable.

The information of sea-level rise also is insufficient and misleading. Only past rates of sea level rise are presented, although the source is not cited. While future sea level is the subject of scientific uncertain and vigorously debated because of the complexities involved, the DEIS should use the best available projections as summarized by the National Climate Assessment program (Reidmiller et al. 2018). Sea-level rise and coastal erosion will greatly affect coastal facilities. There needs to be some analysis of how coastal engineers are going to design solutions to this problem. The airstrip at Kaktovik was just moved away from the flooding coastline at a cost of over $40 million dollars. There needs to be a summary of the huge costs that already have been incurred at Barrow, Kaktovik, DEW line stations, exploratory well sites, and oilfield facilities in attempts to mitigate the impacts of coastal erosion.

PHYSIOGRAPHY/TOPOGRAPHY

The information on physiography and topography presented in the EIS is incomplete and out of date. The physiography map of Wahrhaftig (1965), which was based on coarse resolution topography mapping, has long been superseded by higher quality mapping of physiography and ecoregions (Gallant et al. 1995, Nowacki et al. 2001, and Jorgenson and Grunblatt 2013). The higher resolution ecological landscape mapping by Jorgenson and Grunblatt (2013) delineates the western portion of the 1002 Area as upland physiography because of the higher elevations, more rugged topography, and surficial deposits typically associated with upland and not coastal plain geomorphic processes (Figure 2). The terrain-unit mapping by Walker et al. (1982) should also be considered. The DEIS notes that the Coastal Plain as mapped in the 1002 Area rises to 1000 ft at its southern boundary; this is strong evidence that the mapping is not accurate and should not be used. The more rugged upland topography in the western portion of the area has large implications for snow distribution, hillslope hydrology, and ice road construction. A rigorous analysis of effects of topography on varying impacts of facility development among the various Alternatives needs to be conducted. Trying to obfuscate the importance of topographic variation through the misleading portrayal of the entire area as coastal plain using a seriously outdated reference must have been a political decision, certainly not a scientific one. For scientific accuracy, the proposed development area should be referred to as the “1002 Area” not “Coastal Plain” because nearly half of it is not coastal plain.

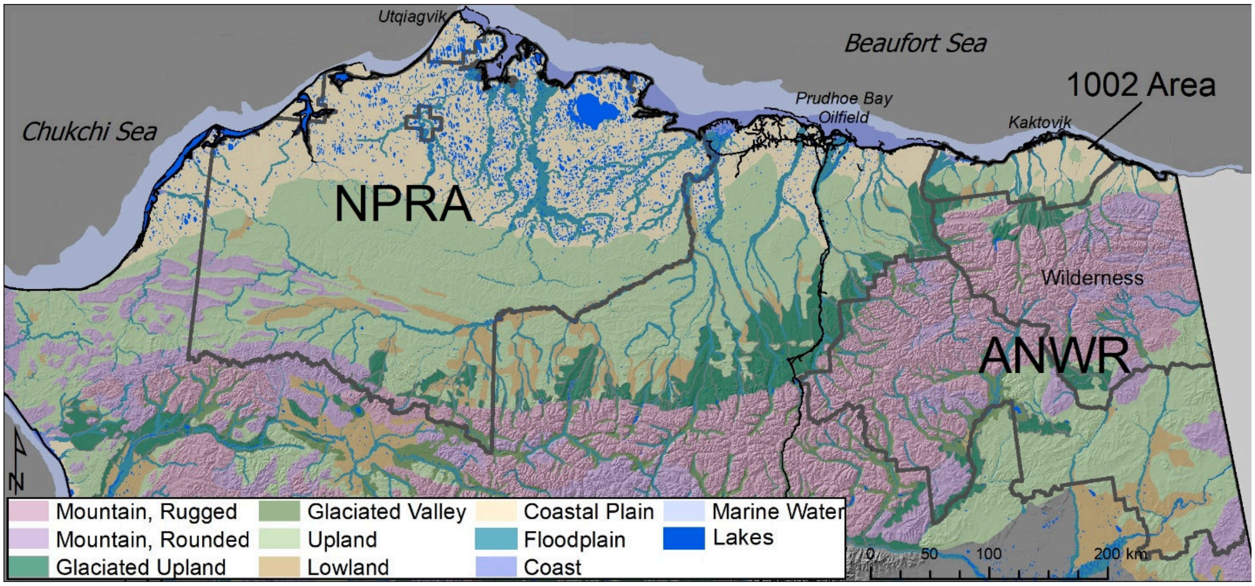

Figure 2. Physiography of northern Alaska (derived from Jorgenson and Grunblatt 2013). Note the western portion of the 1002 Area is characterized as upland terrain (foothills) instead of coastal plain.

For topography, there are NHD digital elevation models, regional IFSAR DEMs, and new Arctic DEM products that should be used to evaluate topographic conditions across the 1002 Area. An example of the IFSAR-derived DEM is provided in Figure 3. These products should be used to analyze deep drainages, exposed ridges, and steeper slopes that are important to evaluation seismic impacts, ice roads, pipeline and road alignments, and operational requirements of facilities. In addition, a new high-resolution digital elevation moderl (DEM) should be obtained for the entire 1002 area, using either LIDAR or photogrammetry (structure from motion). This can be used for detailed analysis and serve a baseline for damage assessments.

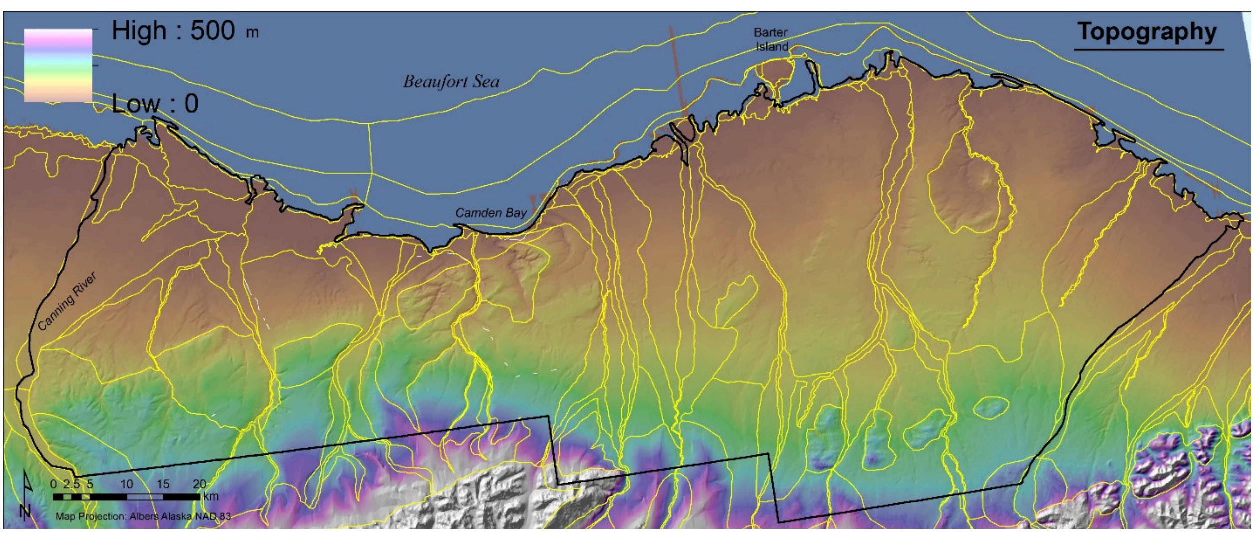

Figure 3. Topography of the 1002 based on a high-resolution digital elevation model derived from IFSAR data. Overlain are the ecological landscape units presented in

SURFICIAL GEOLOGY AND GRAVEL RESOURCES

The description and analyses of surficial geology, and how the geological resources are important to evaluating the Alternatives, are inadequate. The more detailed surficial geology mapping of Carter et al. (1986) should be used. Inclusion of map and data Rawlinson (1993) would be helpful. Also, the more recent, but generalized mapping by Jorgenson et al. (2015) should be utilized (Figure 4) because it also roughly parameterizes ground ice conditions associated with the terrain units. There are inconsistencies among these maps that have important implications for the evaluation of Alternatives that need to be resolved. In particular, the Jorgenson et al. (2015) map shows widespread distribution of eolian silt across the Foothills region. The extremely ice-rich Pleistocene deposit (yedoma) can have thaw settlement potential of up to 30 m (discussed more thoroughly in the permafrost section below). Although one section of yedoma was studied in an exposure along Camden Bay (Kanevskiy et al. 2013), the characteristics and distribution of this deposit are poorly quantified and mapped. Because of the potential for huge landscape-scale changes resulting from disturbance, this issue needs to be thoroughly investigated. As currently presented, the one paragraph on subsidence is inadequate to address permafrost issues, especially in context of evaluating alternatives (see permafrost section for a more complete discussion).

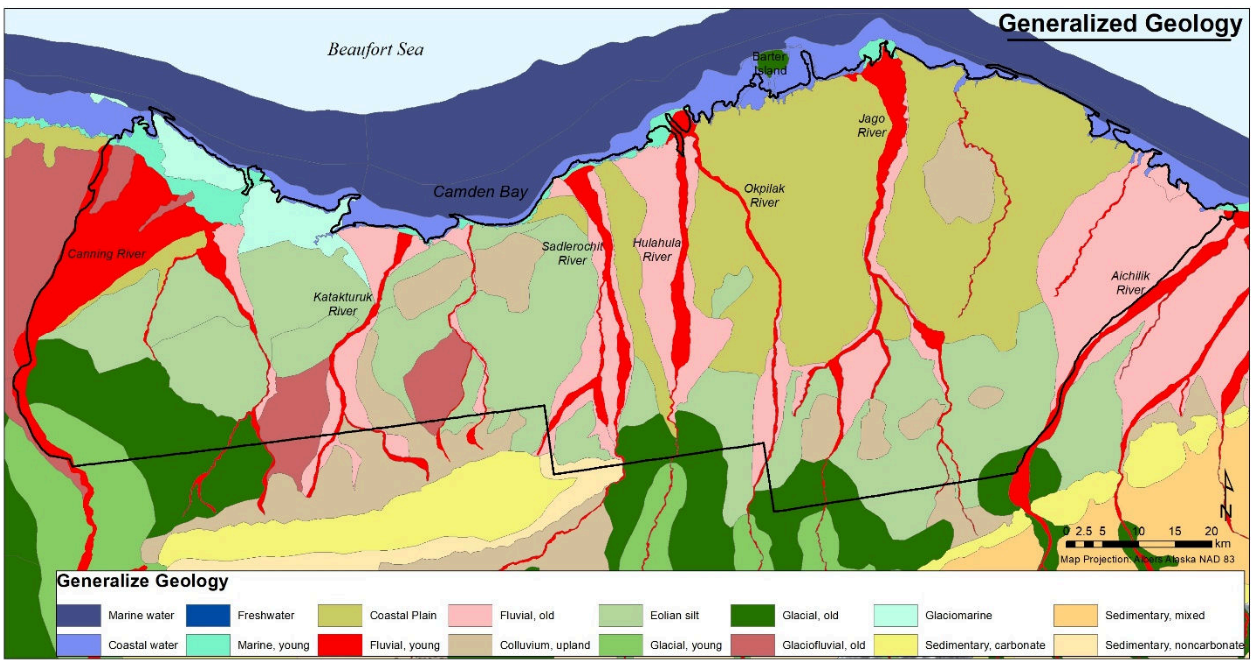

Figure 4. Topography of the 1002 derived from high-resolution digital elevation model.

The discussion on coastal erosion and storm surges, while identifying the problem is woefully inadequate. The section should provide a map of current shoreline erosion rates. It should summarize the many issues of coastal erosion and storm surges that have already affected the Kaktovik airstrip, the Kaktovik DEW line and landfill, the Beaufort Lagoon DEW line site, past storm surge flood elevations, effects of currents on nearshore sediment transport, and storm flooding of barrier islands and nesting habitat. This should be followed up through forecasting of future wave climates and coastal erosion under reduced sea ice conditions.

The section on slope failures is inadequate. While the section identifies landslides and thaw slumps as particular hazards, there is no quantification of where they occur and what specific areas might be a risk. For example, numerous large thaw slumps are present in the eolian silt deposits along Camden Bay (pers. obs.). Quantification of the abundance, historical frequency, and distribution is needed to adequately assess facility placement and the potential impacts of the Alternatives.

The section on flooding, ice jams, and aufeis is inadequate, although I recognize there is overlap with the Hydrology section. Additional, surficial geology mapping should be done to differentiate between active, inactive, and abandoned floodplains, as this mapping has utility for characterizing flooding regimes and ground ice, as was done in the EIS processes for Alpine and NPRA developments. Existing information should be better summarized, and more detailed is needed about the frequency, thickness, distribution, and duration of the large aufeis patches that develop on many of the large rivers in the 1002 Area. Aufeis has huge implications for stream avulsion, channel migration and flooding. For example, aufeis plays a critical role in the flooding of the Staines channel of the Canning delta (pers. obs.), and likely has strong affects on all the river systems. They also provide important insect relief habitat for caribou. Aufeis is strongly associated with subsurface water movement, particularly along rivers originating from carbonate-rich mountains (Yoshikawa et al. 2007, Kane et al. 2013). The recent aufeis accumulation along the Dalton Highway, that caused road closure and diversion of floodwaters should be evaluated in terms of its implication for ANWR development. A recent paper by Shur et al. (2016) concludes that the highly unusual aufeis episode most likely was caused by freezeback that blocked subsurface flow associated with the snow/ice roads used during seismic exploration in that area. This is an important topic that deserves investigation and analysis.

SOILS AND PERMAFROST

Permafrost Characteristics

Permafrost is one of the most important terrain characteristics effecting engineering design, landscape evolution, and ecosystem response to disturbance, yet there is insufficient information on permafrost characteristics specific to the 1002 Area provided in the DEIS to allow evaluation of alternatives and potential impacts. In the discussion below, I summarize some recent literature on permafrost characteristics and ground ice distribution, discuss three types of ground ice (segregated ice in upper permafrost, epigenetic ice wedges, and huge syngenetic wedges in yedoma), and identify different types of disturbance that can affect permafrost. I include recommendations for research on permafrost distribution and characteristics that will improve the analysis of potential environmental impacts of development on permafrost.

Permafrost is nearly continuous under the land in northern Alaska (except under large waterbodies) and is characterized as climate-driven, ecosystem-modified permafrost due to the important role that ecological succession has on ice aggradation in the "intermediate layer" of upper permafrost (Shur and Jorgenson 2007). Permafrost characteristics have been well documented in the central portion of the Beaufort Coastal Plain (Figure 5) by environmental and engineering studies associated with oil development (Kreig and Reger 1976, Jorgenson et al. 1996, 1998, 2003, Pullman et al. 2005), yet are inadequately studied in the 1002 Area. Ground ice most commonly occurs as segregated ice within the soil matrix in the intermediate layer, or as large ice wedges that are commonly 2–4 m across at the top and extend 3–4 m below the surface. Ground ice volume is strongly associated with terrain units (engineering geology), ranging from ice-poor conditions in eolian sands, moderately ice-rich in old alluvial-marine deposits prevalent across the coastal plain, ice-rich in abandoned floodplain deposits, and extremely ice rich eolian silt (Jorgenson et al. 1997, Pullman et al. 2007, Kanevskiy et al. 2013). Permafrost characteristics have been quantified in the 1002 Area at some locations along the coast (Jorgenson et al. 2002, Ping et al. 2011, Kanevskiy et al. 2013) and at Jago Bitty (Jorgenson in prep., Figure 6a). In addition, surficial geology and permafrost characteristics were described at hundreds of boreholes (~10 m deep) during the seismic exploration program in the 1002 Area during1984–1985, but the data collected by Geophysical Services, Inc. remain proprietary. These data should be acquired and analyzed for the EIS. Furthermore, the DEIS lacks discussion of permafrost thermal regimes and effects of a warming climate (Osterkamp and Jorgenson 2006).

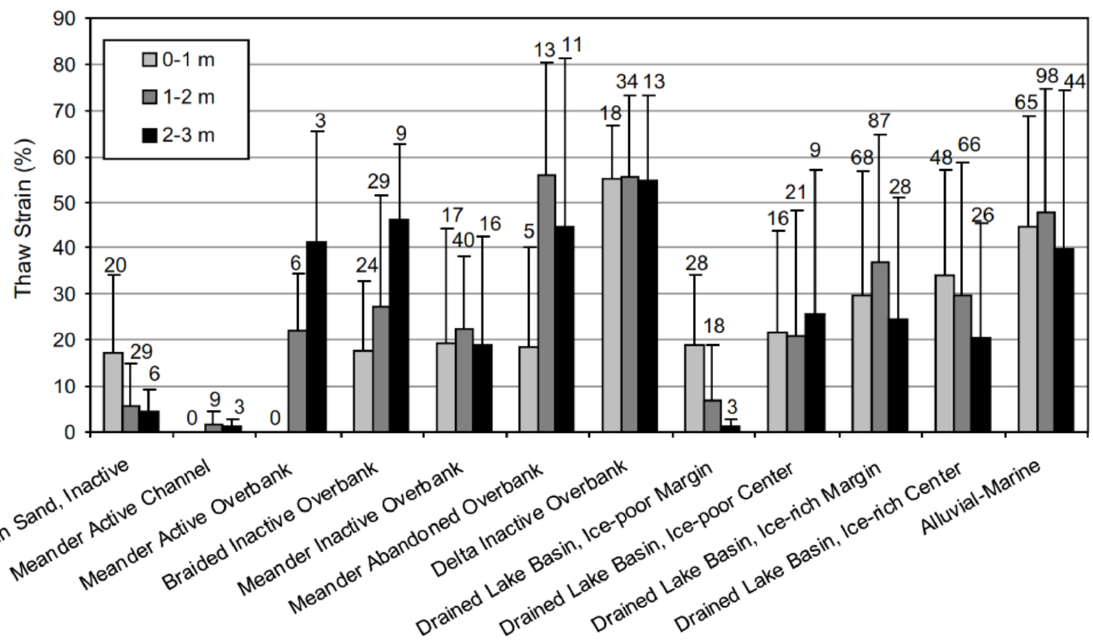

Figure 5. Variation in the amount of excess ice, as reported as thaw strain values, among common terrain units on the Beaufort central coastal plain (from Pullman et al. 2007). Note that many of the terrain units have 20–50% excess ice in the upper 1 m of permafrost.

The upper layer of permafrost just below the seasonally thawed active layer tends to be ice rich from accumulation of segregated ice and, thus, has a large thaw settlement potential (Shur 1988, Jorgenson et al. 1997, Shur and Osterkamp 2007, Pullman et al. 2007, Kanevskiy et al. 2013, Jorgenson et al. 2015a). In most terrain units, segregated ice in excess of the soil pore space occupies 30-50% of soil volume (Figure 5). In fine-grained abandoned floodplain and alluvial-marine deposits, the ice-rich "intermediate layer" often has excess ice volumes of 60–80% (Figure 6a). For moderate surface disturbance that can lead to thaw depths increasing to an equilibrium depth of 80 cm, typical thaw settlement potential is 10–40 cm depending on terrain type. Because there is little mineral soil that can be incorporated into the active layer as it adjusts to disturbance, it is sensitive to disturbance even under cold climates (Jorgenson et al. 2008). In ANWR, past seismic exploration has been shown to cause increased active-layer depths and thaw settlement resulting in permanent track depressions, and varied by vegetation type (Jorgenson et al. 2010).

Ice wedges, a common and widespread type of massive ice, typically are 2-3 m across the top and extend 2–4 m downward into fine-grained soils (Leffingwell 1919, Jorgenson and Shur 2009, Kanevskiy et al. 2017)(Figure 6b). They are formed by spring snow melt filling in the cracks caused by seasonal contraction and expansion of permafrost in cold climates. Ice wedges that form after the surficial materials have been deposite are considered “epigenetic”. The size and volume of epigenetic ice wedges, however, varies greatly by terrain type and age (Jorgenson et al. 1997, 2003; Kanevskiy et al. 2013), typically occupying 10–20% of the volume of the top 3 m of permafrost. Because ice wedges form just below the active layer (typically 35–50 cm), they are particularly sensitive to disturbance and climate change. There has been recent widespread degradation of ice wedges in response to climate warming (Jorgenson et al. 2006, 2015, Liljedahl et al. 2016, Frost et al. 2018), including the 1002 Area (Jorgenson et al. 2018)(Figure 7). Because of the large effects that ice wedges have on terrain sensitivity, the size, abundance, and distribution of ice wedges across the varying terrain types of the 1002 Area needs to be studied to better evaluate the potential impacts of oil development associated with the various Alternatives.

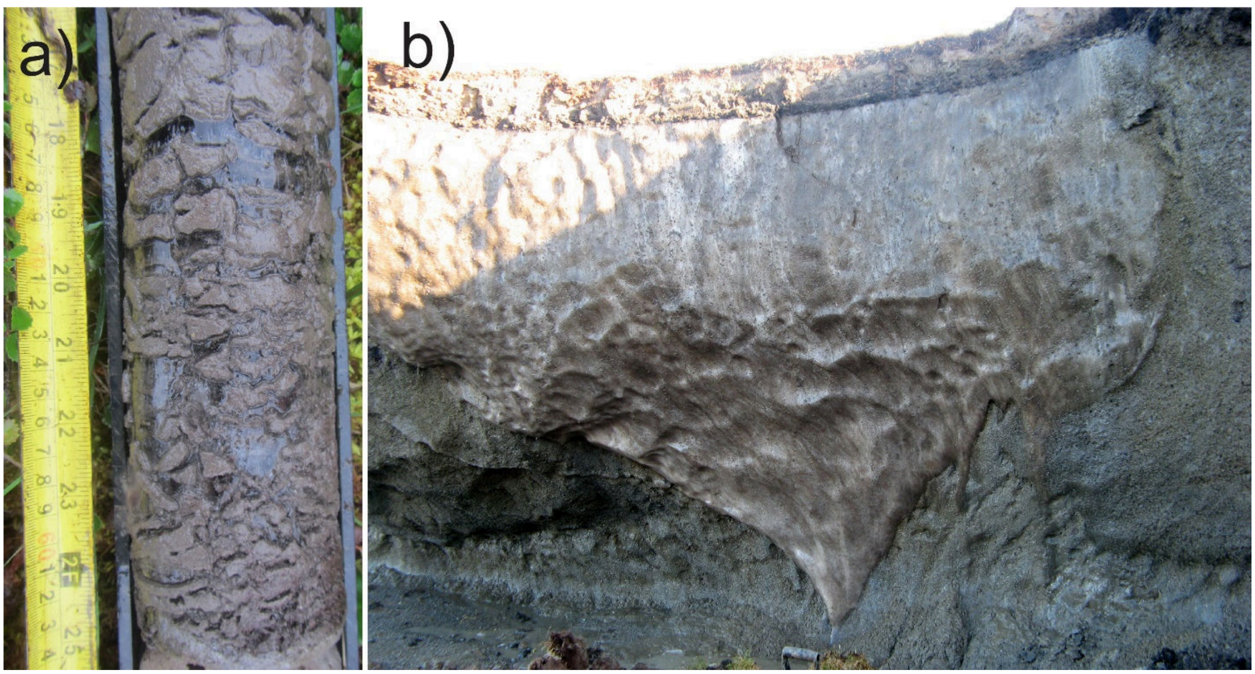

Figure 6. Common types of ground ice in northern Alaska include: (a) ataxitic cryostructure that is a form of segregated ice in the upper permafrost, and (b) ice wedges that form polygonal networks just below the seasonally thawed active layer (Photos by M.T. Jorgenson). Note the shallow depths at which high ice contents can occur (a) and the very thin protective soil layer above the ice wedge (b).

Extremely ice-rich eolian silt (yedoma), with large and deep syngenetic ice wedges of late Pleistocene age, is abundant along the lower foothills region across northern Alaska (Carter 1988, Kanevskiy et al. 2011, Jorgenson et al. 2015a)(Figure 8). Yedoma is abundant in the western portion of the 1002 Area (Jorgenson et al. 2015a), but is inadequately characterized and mapped. The potential thaw settlement is 10–30 m if the deposit were to completely thaw (Kanevskiy et al. 2011, Shur et al. 2012). While disturbance from winter seismic exploration is unlikely to lead to complete degradation of yedoma, severe disturbance such as gravel removal may have large effects. In addition, there is a potential for disturbances to cause active layer increases that can cause active-layer-detachment slides on slopes, such as those that occurred after fire in the Anaktuvuk River area. Current development in the NPRA has been limited to coastal plain deposits, so there is little experience with development on yedoma. There have been many exploratory wells drilling in the lower foothills on yedoma and in those localities deep thermokarst appears to be developing at some sites. The extremely high ice contents of this terrain make this terrain of special concern and its distribution and characteristics need to be better evaluated in the region.

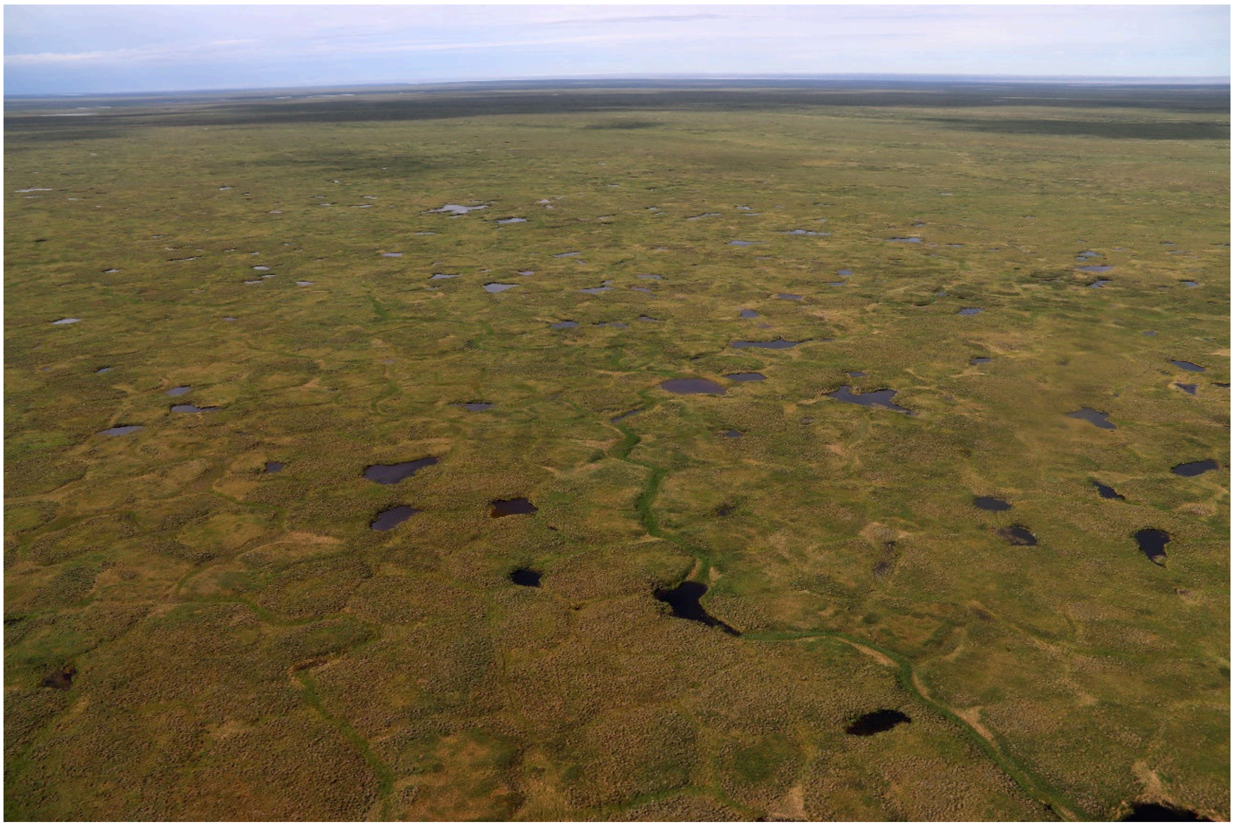

Figure 7. Aerial view of recently developed thermokarst pits resulting from degrading ice wedges at FWS's long-term monitoring site at Jago Bity (photo by M.T. Jorgenson).

Permafrost Degradation Caused by Human Disturbance

The presence of permafrost greatly increases the complexity of ecological responses to disturbance in the Arctic, due to feedbacks among soil topography, hydrology, vegetation and ground ice (Brown and Grave 1979, Lawson 1986, Jorgenson et al. 2010a, 2015b). Even initial minor thaw settlement caused by disturbance can lead to water impoundment, decreased albedo, and increased heat flux, which in turn causes more thaw settlement. Of particular concern is vegetation damage that changes the surface microclimate or track depressions from heavy vehicles that can compress vegetation and litter and thus cause slight impoundment of surface water. Both effects can lower the surface albedo and increase soil heat flux. Long-term permafrost degradation resulting from seismic exploration, ice roads, ice pads at exploratory drill sites, gravel fill for temporary pads, and gravel removal after abandonment are discussed below.

Figure 8. Photograph of exposure of extremely ice-rich loess (yedoma) along the Itkillik River showing deep syngenetic ice wedges (Photo by M.T. Jorgenson). Note person on the 30-m bluff for scale.

Seismic exploration in the 1002 Area has caused long-term damage, primarily due to subsidence related to the presence of ground ice (Jorgenson et al. 2010b). Trails with medium to high levels of disturbance typically had thaw depths 10–15 cm deeper than adjacent controls, indicating that thaw in some terrain had penetrated the ice-rich intermediate layer enough to cause some thaw settlement (Jorgenson et al. 2010b). Thaw settlement induced by the trail disturbance led to changes in surface hydrology, and caused recovery to shift away from the original site conditions toward new plant communities that make some trails remain visible for decades. Much of the persistent disturbance on seismic trails was associated with degrading ice wedges. Thermokarst troughs and pits frequently became larger after medium- and high-level disturbance, especially in sedge–Dryas tundra and sedge–willow tundra (Figure 9). These observations indicate that: thaw settlement can occur even with moderate disturbance; damage can increase gradually over long periods; stabilization may take decades; and that the surface degradation may persist for centuries. An analysis of high-resolution satellite imagery from 2005–2007 available on Google Earth found that 20 km of camp move trails, 7 km of overlapping camp and seismic trails, and 9 km of seismic trails were still visible ~20 years afterwards (Figures 10 and 11). While seismic vehicles have changed to lower pressure rubber-tracked vehicles, the equipment for camp moves has hardly changed. For a more detailed analysis of seismic trails has recently been developed by Walker et al. (2019). The effects of global climate warming complicate the evaluation of the effects of seismic trail disturbance on ice-wedge degradation because ice wedges throughout the region have been degrading in response to occasional previous years of unusually warm and wet weather (Jorgenson et al. 2006, Jorgenson et al. 2015, Lilljedahl et al. 2016). To avoid and minimize permafrost degradation, and the resulting irreversible changes in hydrology, vegetation, and trail visibility, better knowledge of permafrost distribution is needed so that sensitive terrains can be avoided, particularly for camp moves. For ice-rich terrains, snow depth requirements should be increased to an average minimum of 12", and snow depth distribution needs to be better mapped and analyzed, to minimize moderate and high-level disturbances, which can lead to increased thaw depths and thaw settlement, and permanent track depression.

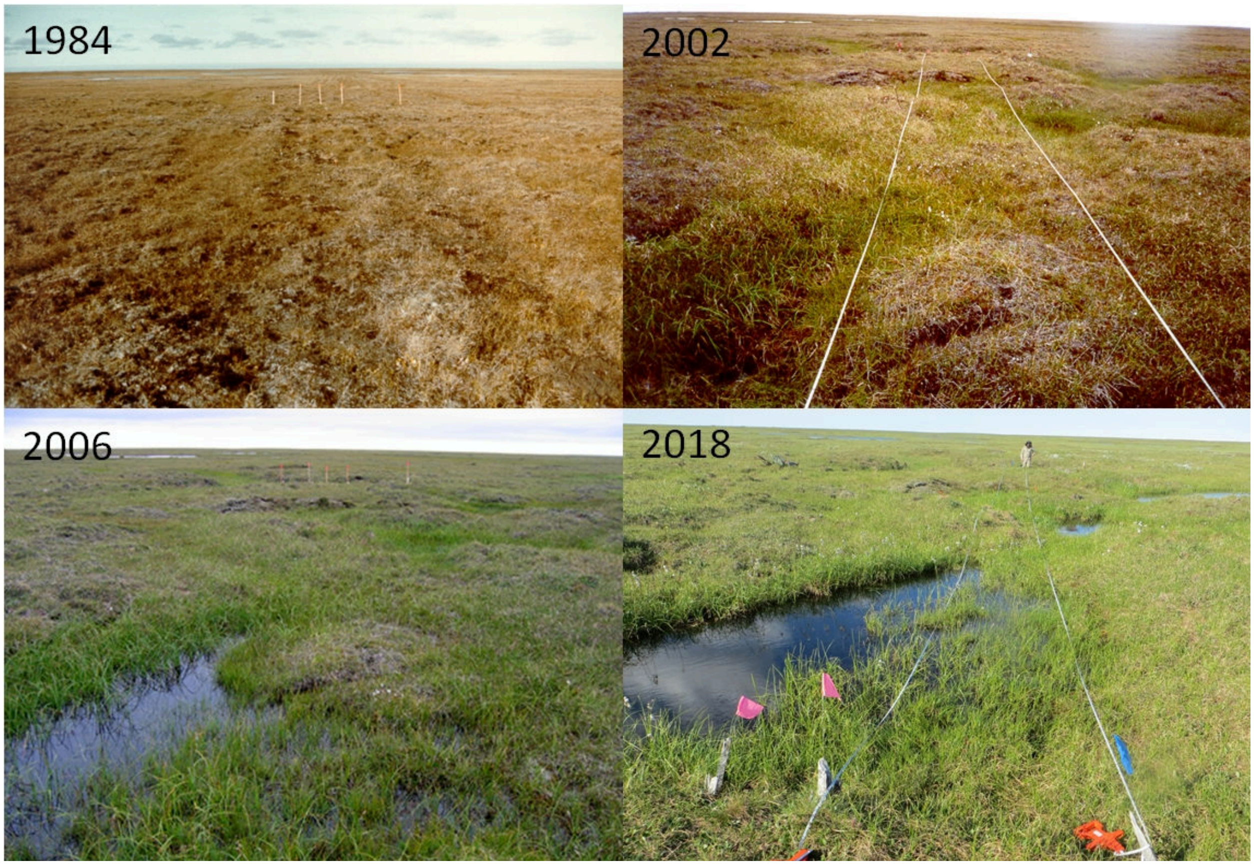

Figure 9. Repeat photographs of study plot on a camp move trail on Sedge-Dryas Tundra (Jorgenson 2018). Parallel ruts and crushed vegetation were evident in 1984, the summer following disturbance (top). By 2002, a network of sedge-filled troughs had developed where melting ice wedges caused ground subsidence, not seen in the reference plot off the trail. The thermokarst pits continued to expand and deepen through 2018.

Ice roads have been used since the 1970s and have been used extensively for the Alpine Oilfield. In the DEIS, the proposed development would use ice roads on an annual basis to transport heavy facility modules, drilling equipment, fuel, heavy equipment, and other supplies. The DEIS is deficient, however, in not specifying the amount and tonnage that would be carried over the ice roads, the total volume of water needed on an annual basis, the thickness of the ice, the proposed routes, how slopes will be effect usage, and whether they will be constructed along the same alignment. Ice roads are effective at reducing damage compared to gravel roads (Guyer and Keating 2005, Pullman et al. 2005). An examination of the ice road to the Meltwater exploratory well site south of Kuparuk the summer after use found little damage (Jorgenson 1999). Long term impacts, however, are uncertain. Guyer and Keating (2005) found negligible impacts from single season ice roads constructed in 1978 and 2001, although damage to tussock tundra was identified. Yokel et al. (2007) assessed impacts of offset and overlapping ice roads from 2001 and 2002 ice roads and found little difference between single and multi-year impacts. Their study detected slightly deeper thaw depths between trails and control, and more damage in tussock tundra than in wet tundra. Examination of these ice roads using images from 2001 and 2013, however, revealed visual persistence of ice roads and sporadic thermokarst from ice wedge degradation along some portions of the trail, particularly in tussock tundra (Figure 12). Similarly, examination of the multi-year ice road between Kuparuk and Alpine using high-resolution satellite imagery available on Google Earth revealed substantial ice-wedge degradation in upland tussock tundra, while wet sedge tundra in a drained-lake basin had less change, primarily associated with minor track depression and greening from more robust sedge growth (Figure 13). While minor damage can occur to willows at stream crossing (McKendrick 2003), willows are well adapted to disturbance and thus do not need to be avoided during ice road alignment. The potential effects in the 1002 Area, particularly the western portion, which has hillier terrain with more tussock tundra, are likely to be much worse because of the higher prevalence of tussock tundra and depressed tracks channelizing hillslope water flow. A comprehensive study of long-term impacts of ice roads is urgently needed.

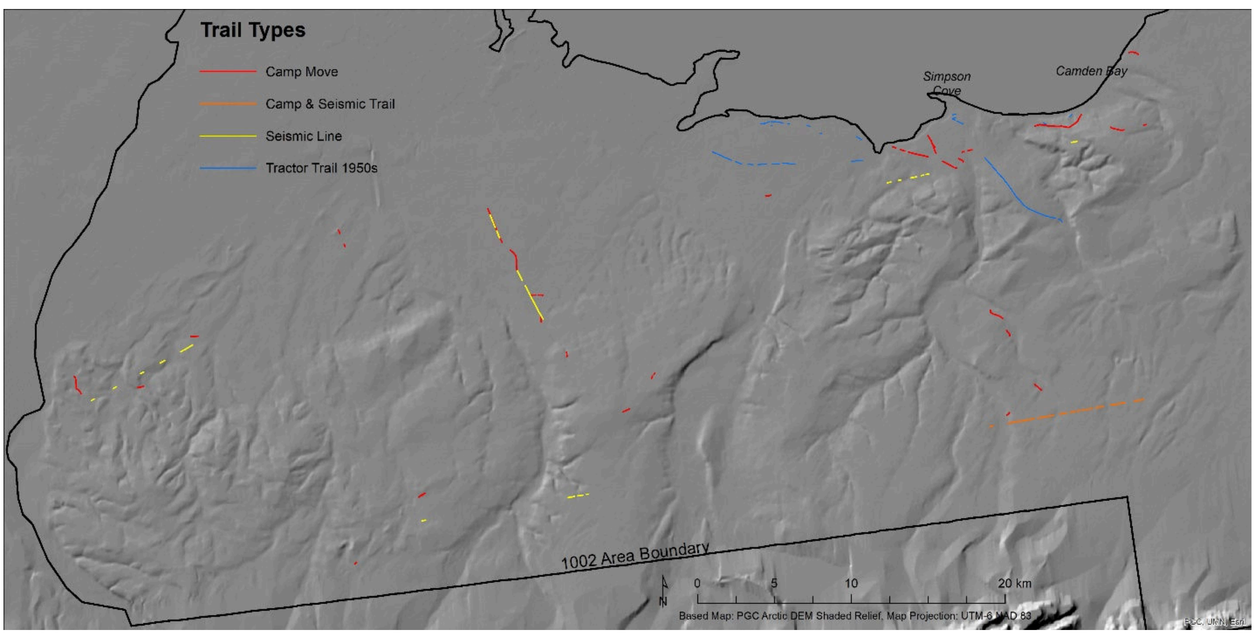

Figure 10. Map of seismic exploration trails still visible on satellite images on Google Earth due to track depression associated with permafrost degradation. The 1950s tractor trails were included to show that winter trail damage has persisted for more than 60 years.

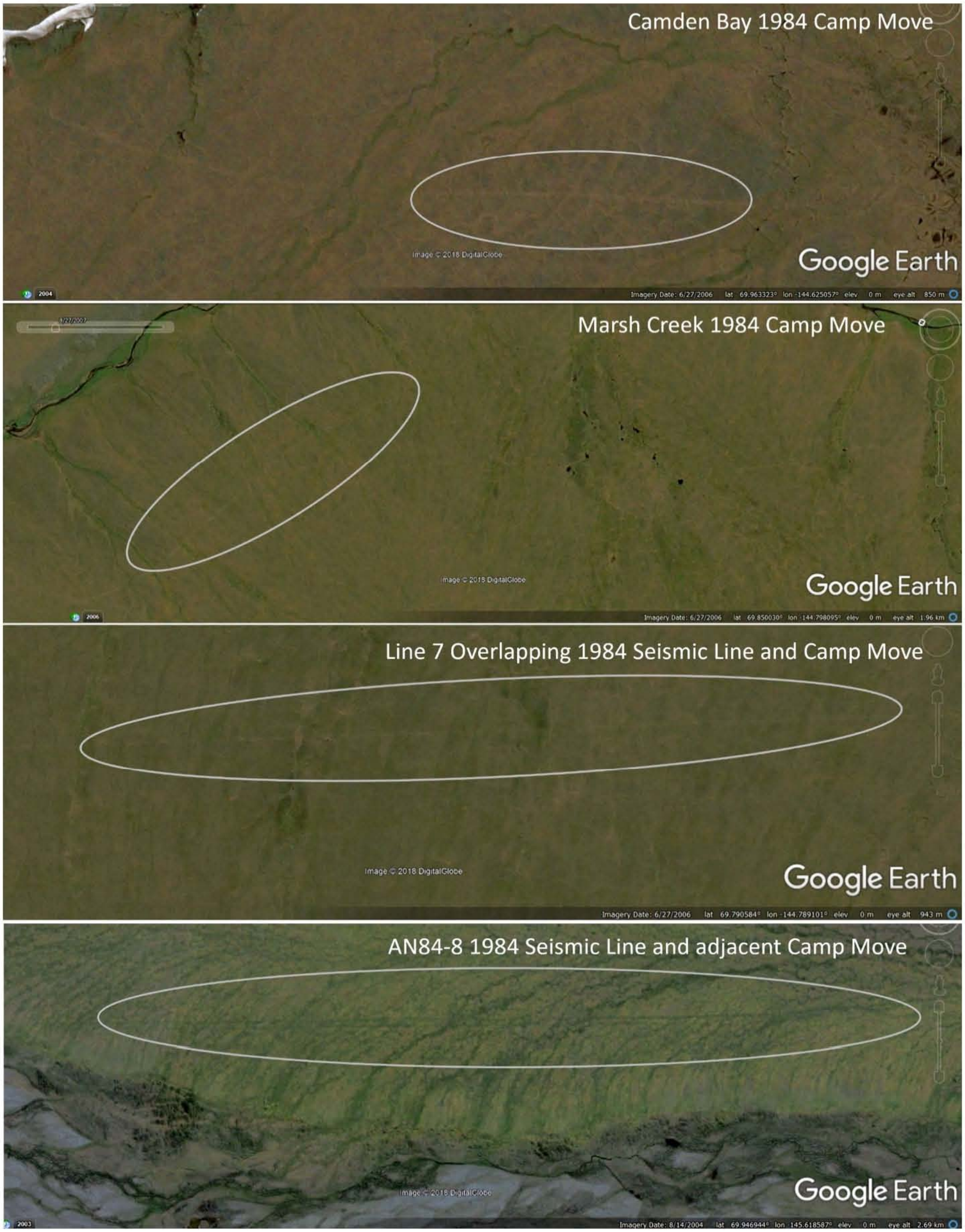

Figure 11. Examples of seismic and camp move trails from 1984 still visible on high-resolution satellite imagery from 2004-2006 due to track depression, wetting, and vegetation shifts associated with minor thawing of the upper layer of permafrost.

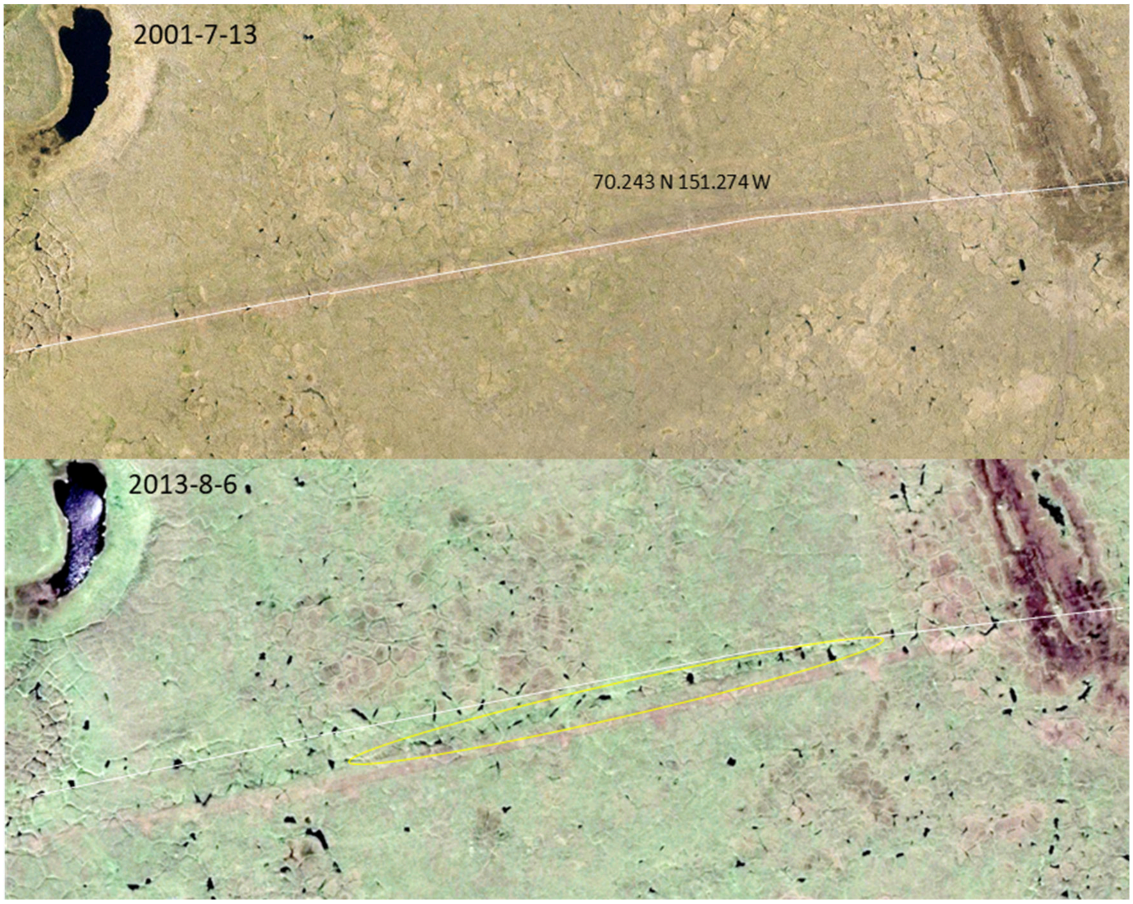

Figure 12. During exploratory well drilling in eastern NPRA ice roads were used multiple years and offset. The winter 2001 ice road evident as a brown trail in tussock tundra (with white line) in 2001 (airphoto) was not distinctly evident on satellite imagery (Google Earth) in 2013. However, a later ice road (unknown year) caused substantial thermokarst evident in 2013 (yellow ellipse).

Ice and timber pads have been used at exploratory well sites to reduce surface disturbance since the 1980s. While these pads are much less damaging that using gravel fill, they still can lead to dead vegetation because of the delayed ice melt the following summer and can lead to eventual thermokarst and surface water impoundments. At the KIC exploratory well site drilled in winters 1985 and 1986 near the 1002 Area, extensive grass seeding was undertaken to revegetated the dead tundra for five years after abandonment and the reserve pit. The reserve pit, which leached salts from the drilling waste, had extensive thermokarst with impounded surface water, and later necessitated backfilling (Figure 14). An airphoto from 2018 showed that ice-wedge degradation was well advanced across most of the site and again the backfilled reserve pit had partially collapsed and impounded surface water. At Chandlar 1 southwest of Umiat in the NPRA, the exploratory well was drilled using an ice pad in winters 2008 and 2009. Satellite imagery showed that vegetation was dead in 2010, but had recovered substantially by 2016. By 2016, shallow ice-wedge degradation had occurred throughout the pad area. Because there is almost no available information about the eventual fate of sites covered by ice or insulated timber pads, there is an urgent need to conduct a comprehensive study of the long-term effects of these pads on vegetation, permafrost, and hydrology.

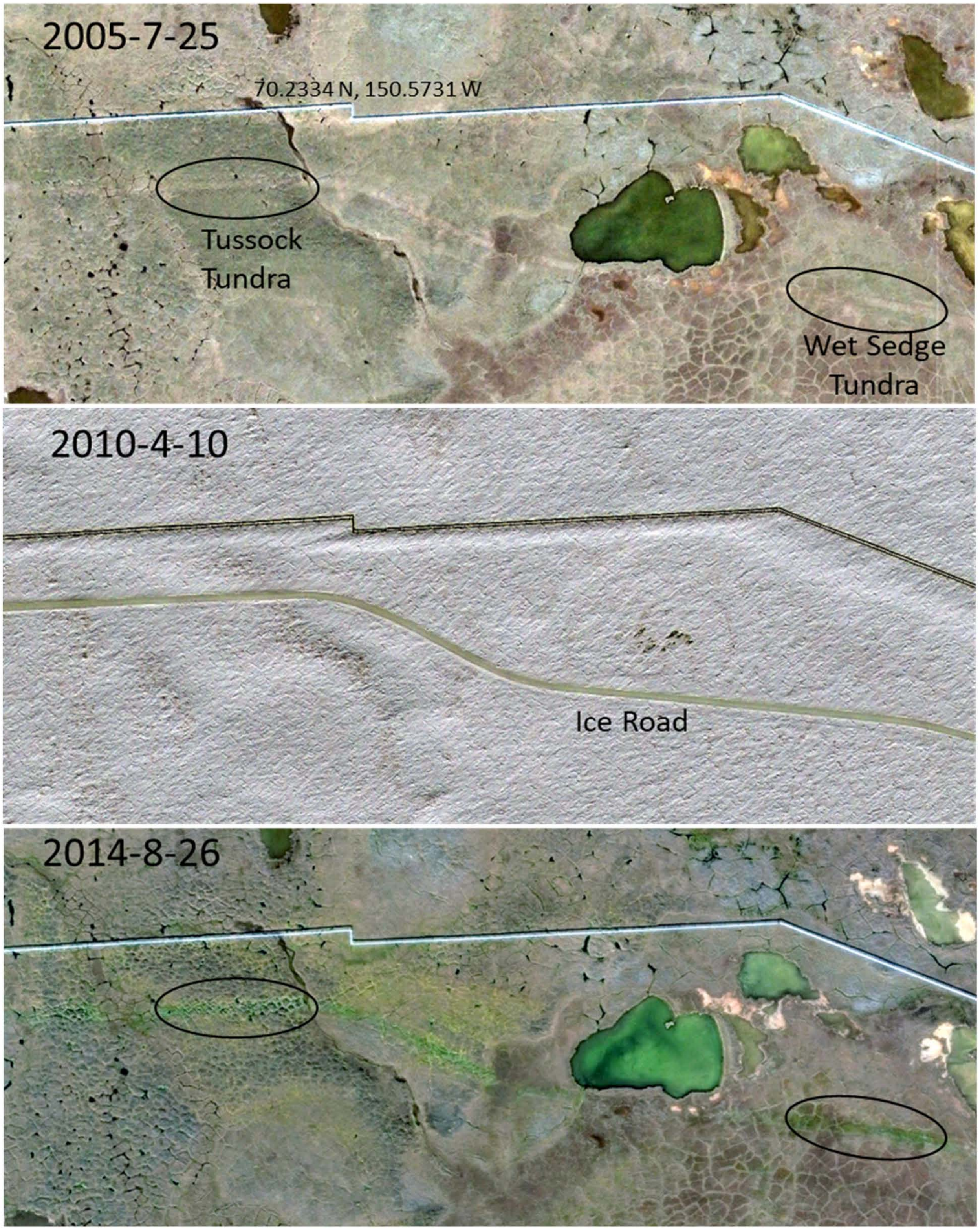

Figure 13. Satellite images from Google Earth of a multi-year ice road from the Kuparuk Oilfield to the Alpine Oilfield, illustrating the long-term impacts of ice road use. Note substantial ice-wedge degradation in Tussock Tundra on a gentle upland versus minor compaction and greening in the Wet Sedge Tundra within a drained-lake basin.

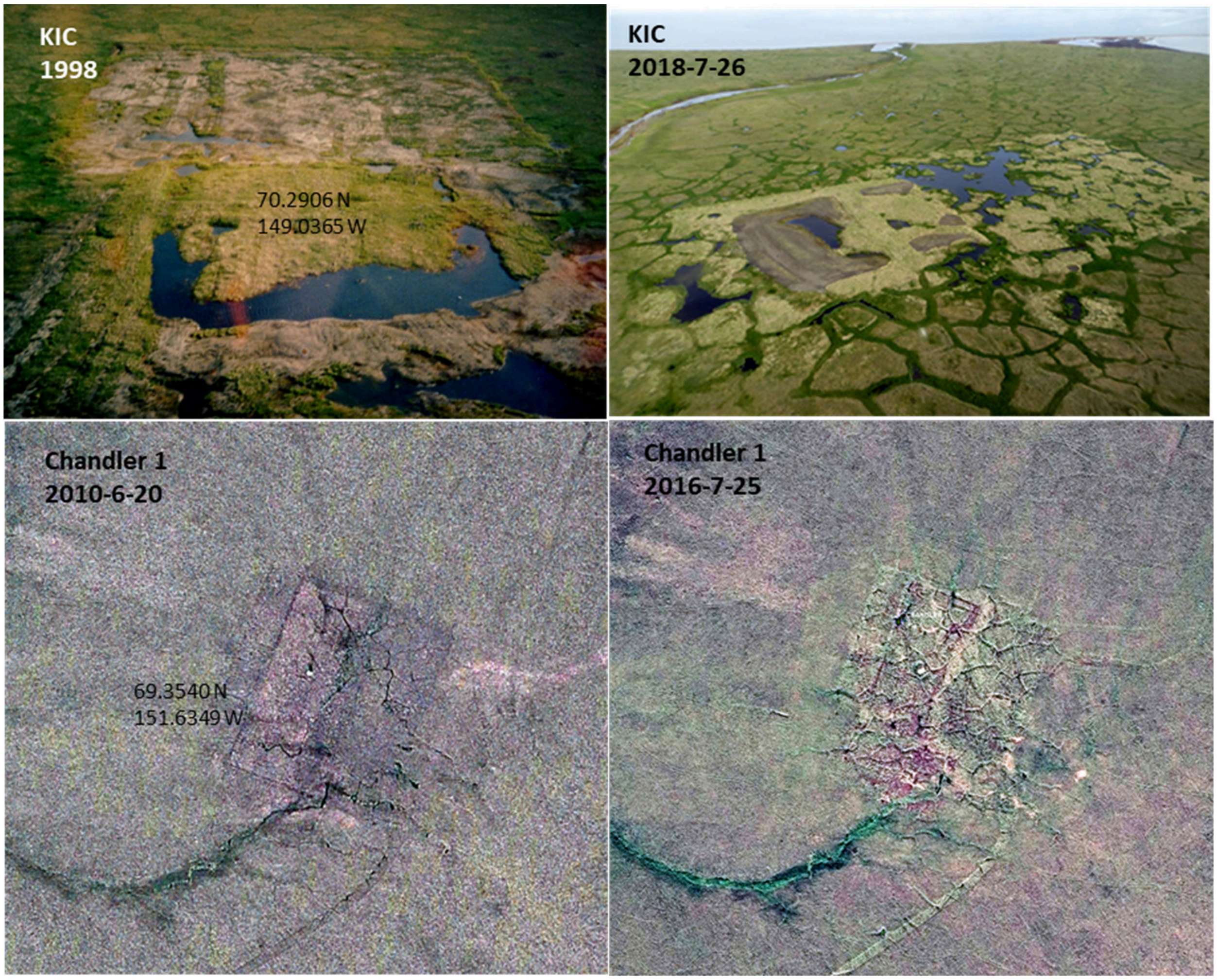

Figure 14. Aerial views of the KIC well site near Kaktovik (above, FWS photos), which was drilled in 1985 and 1986 using an insulated timber pad, and satellite imagery (Google Earth) of the Chandler 1 well site, which was drilled in winter 2008 in the foothills region in the NPRA using an ice pad to protect the tundra. Note the extensive thermokarst at both sites.

Gravel fill was used for supporting drilling activities at most exploratory well sites northern Alaska in the 1960s through the 1980s. These sites tend to develop extensive thermokarst within and around the gravel pad. For example, at the Kavik 1 site, where a thick gravel pad was used to support drilling activities from February to November 1969, the surface have partially vegetated and robust alder shrubs grew along the margins by 2018, but deep thermokarst ponds had developed within and around the pad (Figure 15). At the Colville Unit 1, a gravel pad was used during drilling in 1970. By 2010, tall shrubs had colonized the margins of the gravel pad, but nearly a third of the site has collapsed and impounded water. It is likely that climate warming has exacerbated the thermal effects of the gravel disturbance to increase the rate of thermokarst. The DEIS needs to address the effects of permafrost degradation on gravel fill that may be left in place. Gravel fill is still used for pads and roads in production phase and also causes thermokarst around the edges.

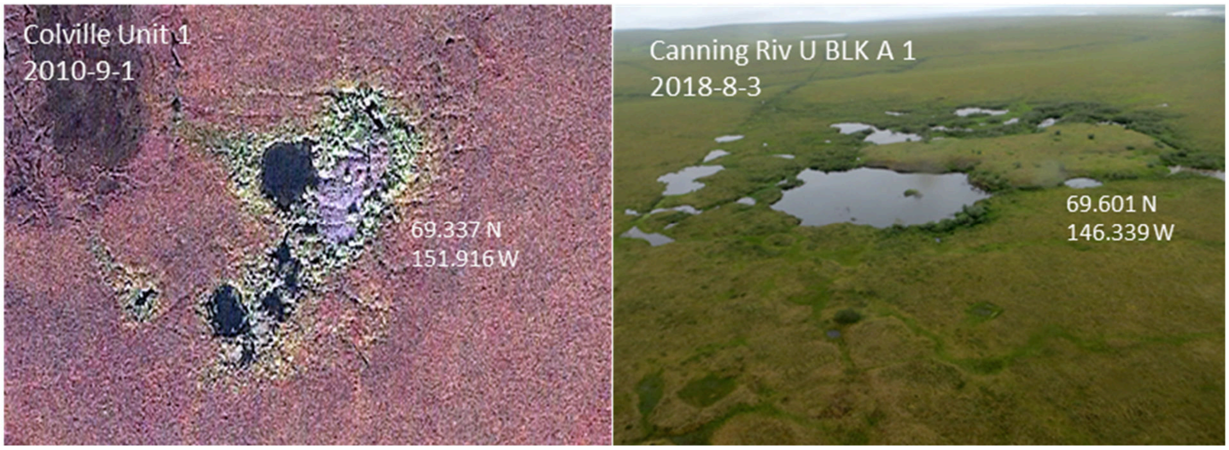

Figure 15. Satellite imagery (Google Earth) of the Colville Unit 1 exploratory well site in the NPRA drilled in 1970 (left), and aerial views of the Canning Riv U Blk A1 site (FWS photo) just west of the 1002 Area drilled in 1974 (right). Extensive thermokarst has occurred within and around the gravel pads, as well as along the bladed seismic line adjacent to the pad.

Gravel removal has been used as a rehabilitation technique at numerous abandoned gravel pads and well sites since the 1980s, and has become a common requirement associated with recent USCOE wetland permits. While rehabilitation experiments have been conducted at numerous sites (Jorgenson 1987, Jorgenson and Joyce 1990, Kidd and Jorgenson 1991), there has been little long-term monitoring of permafrost stability after gravel removal. However, satellite imagery at two exploratory well site were the gravel was removed at sites with flat terrain provides two examples of the surface changes after 8-10 years (Figure 16). While gravel removal has facilitated vegetation recovery, there has been extensive thermokarst and water impoundment after gravel removal. In some respects, the thermokarst and water impoundment has enhanced microsite diversity and waterbird habitat. But the thermokarst also has created a long-term visual scars on the tundra. Because little is known about the ecological fate at sites where gravel has been removed, there should be a comprehensive study of long-term ecological and permafrost changes at gravel removal sites. Thermokarst after gravel removal has large implications for oil development in the 1002 Area. The DEIS states that gravel fill will be removed after abandonment but does not address the issue of what effects thermokarst after gravel removal will have on long-term visual impairment from the scars, the stability of extremely ice-rich permafrost (yedoma), and on slope hydrology in areas with hilly topography.

Cumulatively, permafrost degradation that is likely to result from seismic exploration, ice roads, exploratory well sites, cross-drainage problems along roads, and where gravel fill has been left in place or removed after abandonment will create permanent scars across a wide region. While the DEIS makes brief mention of some of these issues, there is no quantification or analysis of the impacts across varying terrain associated with the various Alternatives. Nor is there any analysis of the cumulative indirect effects of road dust and water impoundments that contributes to extensive thermokarst in the Prudhoe Bay oilfields (Raynolds et al. 2014).

Figure 16. Thermokarst after gravel removal at exploratory well sites, which is much more prevalent that in the surrounding undisturbed tundra.

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