MPU DIESEL SPILL VEGETATION MONITORING: 2001
A REPORT

Relating to:
Milne Point Unit Spill No. 97-027M
Post-burn Sampling and Revegetation Plan, 22 August 1997

TO: BP EXPLORATION (ALASKA), INC.
ANCHORAGE, ALASKA

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JANUARY 2002

FRONT COVER:

Aerial oblique of the Milne Point Diesel Spill site, 4 July 2001. This view shows the road with the spill site on the east side. Polygon troughs have deepened and widened from thermokarst since the spill and cleanup occurred. The light-colored box just beyond the spill is a data recorder for measuring soil and air temperatures at this location. Notice the vegetation has not become green by this date. The green surface next to the road is moss growing in the unseeded strip. Seeding strips are left to right in this image. Fertilizer strips are arranged perpendicular to the seed applications and extend foreground to background. The light colored grass within the spill area is Puccinellia borealis*, northern alkaligrass, which was included in experimental seeding on the site. Even though much of the spill site appears barren in this image, by the end of the growing season, it was relatively well covered with vascular plants. The most prominent seeded grass was the Umiat collection of northern alkaligrass. The seed source developed from a collection at ERA Helicopters, Deadhorse, was slower to develop than the Umiat collection, but the ERA source produced an acceptable stand of plants, whose heights were shorter than those of the Umiat seed source. The poorest seeded grass was* Puccinellia augustata*, which was hand collected in WOA and coated with phosphorus fertilizer, clay and talc to facilitate handling and distributing the seed.*

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INTRODUCTION

This report contains information on the vegetation development on a site affected by spilled diesel fuel on near coastal wet-sedge tundra, four growing seasons after cleanup and rehabilitation treatments were imposed on the site. This documentation has been requested by the Alaska Department of Environmental Conservation in the Milne Point Unit Spill No. 97-027M Post-burn Sampling and Revegetation Plan.

BACKGROUND

On 22 June 1997 a truck overturned on the gravel road approaching F Pad in the Milne Point Oil Field, spilling diesel fuel onto the adjacent tundra on the east side of the road (N70E30'08"; W149E39'52"). The Alaska Department of Environmental Conservation authorized burning as a cleanup procedure. Questions regarding impacts of the spill and cleanup on tundra vegetation required a monitoring project to document vegetation recovery. Fertilizer and native grass seed applications were imposed on the affected area, and a monitoring report was produced (McKendrick, 2000) with data and photos of the site through September 1999.

Names of the seeded grass species in the 2000 report were *Puccinellia arctica* (northern alkaligrass) and *Puccinellia langeana.* Since then, we have been informed by a grass taxonomist from the Smithsonian Institute that these names were incorrect. *Puccinellia arctica* should have been *Puccinellia borealis* (northern alkaligrass), and *Puccinellia langeana* should have been *Puccinellia augustata* (arctic alkaligrass). Sources of the original *Puccinellia borealis* seed were from an exploration site east of Umiat, Alaska, and from a collection at ERA Helicopters hangar, Deadhorse, Alaska. These collections were increased in seed production fields near Palmer, Alaska by Northern Native Seeds. *Puccinellia augustata* seed originated from hand collections by summer field crews in WOA Prudhoe Bay Oil Field on 23 August 1994 and 31 August 1995. These collections were taken to Precision Seed Coaters (Yuma, AZ) and coated with a mixture of clay, talc, and phosphorus fertilizer. Seeds from these collections were applied on the north side of the Point McIntyre No. 1 drilling site (PM-1). Seedlings emerged well on the PM-1 site, particularly in surface cracks within the drilling mud portion of the area. These same seed collections were used on flare pit removal sites in WOA, drilling sites R, S, D, and F. Results were mixed at the flare pit sites. The performance of this seed at the Milne Point Diesel spill site in 1999 was poor, and we attributed that to seed quality. Seed applied to a berm near the Milne Point gravel mine resulted in very few plants. Germination was depressed perhaps because of the seed coating treatment. *Puccinellia borealis* applications at the Milne Point diesel spill site and on the gravel pit berm at Milne were successful in 1999, with the Umiat collection appearing to be the more vigorous ecotype. New seedlings were being grazed in 1999. Geese and caribou were the primary grazers at the diesel spill location.

Nitrogen appeared to be the most effective fertilizer application at the site in 1999. Phosphorus ranked second, and potassium was not particularly beneficial to promoting plant growth at this location in 1999.

The soil was sampled and tested in 1997 for DRO (diesel range organics), but we were not informed of the results; consequently, the relationship of DRO to various treatments remains unknown. Sampling for hydrocarbon contents was performed only in 1997, as far as we know. The locations from which these samples were obtained are still marked with allthread shafts at the site. Burning with a weed burner was included in cleanup, but we could not separate diesel spill locations from burning to accommodate both effects in field tests.

METHODS

Two objectives in the revegetation and sampling plan related to vegetation:

1. Establish baseline for evaluating revegetation as a function of diesel remaining in the tundra.

2. Establish baseline for evaluating revegetation as a function of the degree of tundra impact from the burning operation.

Fertilizer and seeding test plots and photoplots were established to evaluate and record tundra revegetation progress over time on this site. Figure 1 is a diagram of the fertilizer and seeding plots. An area 40' x 50' was subdivided into plots 5' x 10' in size. Nitrogen, phosphorus, and potassium fertilizers were used. One fourth of the area was left unseeded, two ecotypes of *Puccinellia borealis* and one collection of *Puccinellia augustata* were seeded into the other three quarters of the test plot area. These applications were detailed in a previous report (McKendrick, 2000).

Various fertilizers were applied in a series of 10 east-to-west strips across the spill. Nitrogen varied from nil to 400 lb/a. Phosphorus varied from nil to 240 lb/a. Potassium varied from nil to 240 lb/a. Area limitations prevented a complete factorial fertilizer design. There are nine fertilized strips and one nil treatment. Three strips were seeded north to south across the fertilizer treatments. Beginning at the eastern margin, these seedings were: *Puccinellia borealis* (ERA Helicopter source), *Puccinellia augustata* (WOA hand collections), *Puccinellia borealis* (Umiat collection), and no seed in the strip next to the road. This resulted in a total of 40 plots, 5' x 10' in size. Each plot was photographed and evaluated for plant cover and species present. Vegetation cover was estimated within each plot for the portion not flooded. Cover was not measured, just visually estimated by two observers. Plant heights were measured for *Poa arctica* (naturally persisting), *Puccinellia borealis* (seeded), *Puccinellia augustata* (seeded) and *Dupontia fisheri* (naturally occurring). Portions of the plots were in polygon troughs which were seasonally flooded. The flooded portions of these plots were excluded from cover estimates, because plants were largely absent in those habitats.

In prior years, we measured thaw depths with a probe and meter stick. These measurements did not yield useful data (McKendrick, 2000) and the procedure was discontinued. Soils were sampled and tested for available nitrogen, phosphorus, potassium and pH prior to imposing fertilizer and seed applications. Soils have not been tested since the initial sampling in 1997.

Notes were taken to record general observations at the time the site was evaluated on 23 September 2001.

RESULTS

Data

Seed applications

The most obvious effect of applying seed was the establishment of *Puccinellia borealis* on the spill site (Figure 2). The species was absent from the site prior to seeding. *Puccinellia augustata* seed did not produce a significant stand of grass. *P. borealis* plants occurred in all seeded strips. *P.* borealis seedlings in plots not intentionally seeded were products of accidental scattering of seed. The Umiat seed source resulted in the most prominent and robust stand (Figure 2) and was most likely the dominant ecotype that occurred throughout the test area. In plots where *P. borealis* was seeded the total number of graminoid species was reduced below that found in either the unseeded or the *P. augustata*-seeded plots (Figure 3). Seeding *P. borealis* (ERA ecotype) seemed to reduce moss cover (Figure 4).

Seeding *P. augustata* increased cover of that species also (Figure 5). However, the cover averaged less than five percent, only slightly more than cover for that grass in the unseeded treatment. *P. augustata* occurs naturally in the vicinity. Some plants within the spill area may have originated from seed produced locally.

Others in the unseeded plots may have been from seed accidentally drifting onto the unseeded area.

Nitrogen fertilizer applications

The most obvious effects from nitrogen fertilizer applications were to increase plant heights and palatability of grasses, as indicated by grazing. *Dupontia fisheri* heights were notably greater at the higher nitrogen applications (Figure 6). *P. augustata* heights increased at the 400 lb/a nitrogen application, but not at lower applications (Figure 7). There was a positive trend for *P. borealis* heights to increase with nitrogen fertilization (Figure 8). Grazing percentages were greater in treatments receiving 200 or more lb/a nitrogen (Figure 9).

Phosphorus fertilizer applications

Phosphorus fertilizer increased grass heights and grazing, but decreased species diversity on these plots. *Poa arctica* heights were increasingly greater as phosphorus fertilizer applications increased (Figure 10). *Dupontia fisheri, Puccinellia augustata* and *Puccinellia borealis* heights all responded positively to phosphorus (Figures 11 through 13). Grazing intensity generally increased with phosphorus fertilization through the 120 lb/a treatment, but not with the 240 lb/a application (Figure 14). The total plant species number declined as phosphorus application levels increased (Figure 15). The occurrence of mushrooms increased at the lowest phosphorus fertilizer application (60 lb/a) and then declined at the 120 lb/a application (Figure 16).

Potassium fertilizer applications

The most consistent response observed from potassium fertilization was plant height increases in *Dupontia fisheri* and *Poa arctica* (Figures 17 and 18). Heights of *Puccinellia augustata* and *Puccinellia borealis* also exhibited a positive response to potassium (Figures 19 and 20). There appeared to be a general decline in species diversity with increasing levels of potassium fertilization (Figure 21).

Species of Plants

Species within the spill and outside it are listed in Table 1. These data were obtained 9 September 1997. They illustrate microhabitat preferences among these plants at this location. The greatest number of species (12) occurred on the polygon rims. Basins were next in species diversity (six species). The fewest species (four) occurred in polygon troughs. Mosses, *Carex aquatilis*, and *Eriophorum angustifolium* were the only plants occurring across all three habitats in the control. *Carex aquatilis*, *Salix planifolia* ssp *pulchra*, and mosses were the only species that survived in the spill-affected area. *Poa arctica* naturally established seedlings in favorable portions of spill troughs at this location in 1997 after the spill and burning. The following species were eliminated from the site by the spill and cleanup treatments:

Carex misandra
Eriophorum angustifolium
Eriophorum scheuchzeri
Pedicularis kanei
Vaccinium vitis-idaea
Cetraria cucullata
Cladonia rangiferina
Dactylina arctica

One species (*Saxifraga cernua*) increased in prominence on the spill site following the spill and cleanup. This species occurred in the undisturbed habitat, but not within the control area examined on 9 September 1997.

Most of the seeded plants found in the plots seeded to *Puccinellia augustata* were strays of *Puccinellia borealis* that had accidentallly fallen into this plot during seeding. There were also surviving plants of the original tundra within these plots, including sedges, mosses, *Poa arctica,* and *Dupontia fisheri*.

Within the spill area, graminoid species diversity was greatest within the plots seeded to *Puccinellia augustata (Figure 2)* and lowest in plots seeded to *Puccinellia borealis* (ERA ecotype). *Puccinellia augustata* cover was only

observed in the no-seed and *P. augustata* seeding treatments (Figure 4). Heights of *Puccinellia augustata* were affected positively with increasing levels of nitrogen (Figure 5).

Table 1. Listing of plant species within polygon features for spill area and adjacent undisturbed tundra, 11 September 1997.

Plant Species	Polygon Rims		Polygon Basins		Polygon Troughs	
	Control	*Spill*	*Control*	*Spill*	*Control*	*Spill*
Sedges and Grasses						
Carex aquatilis	●	●	●	●	●	●
Carex misandra	●					
Eriophorum angustifolium	●		●		●	
Eriophorum scheuchzeri			●		●	
Poa arctica	●	●				seedling
Forbs						
Pedicularis kanei	●					
Saxifraga cernua		●		●		
Shrubs						
Vaccinium vitis-idaea	●					
Salix planifolia ssp. *pulchra*	●	●				
Lichens						
Cetraria cucullata	●		●			
Cladonia rangiferina	●					
Dactylina arctica	●					
Thamnolia vermicularis	●		●	●		
Moss						
Moss	●	●	●	●	●	●

Photos

The photo sequences obtained at this location show a positive recovery by both natural and seeded plant species during the 1997-2001 time frame. Fertilizer effects could be seen within seeded plots and were also evident in the natural vegetation that sometimes occurred within fertilized plots. The fertilizer increased growth, delayed senescence, and encouraged grazing (Photo Series 1, 2, and 4). The northern alkaligrass ecotype from Umiat was the most vigorous of the two ecotypes seeded at this location (Photo Series 2 and 6). The ecotype from the Deadhorse ERA Helicopters location was seeded to a portion of the site that was largely flooded polygon trough (Photo Series 4). That limited the ERA ecotype's chances to establish and develop at this location. Based on seedling establishment in these seasonally flooded microhabitats, it appears that this ecotype may be better suited to wet soils than the Umiat ecotype. In an unseeded strip, *Phippsia algida* established where fertilizer was applied (Photo Series 3). This grass is indigenous to the vicinity and was a volunteer colonizer within the spill area. Native *Puccinellia augustata* did not perform well at this location (Photo Series 5). Its poor germination was attributed to the seed coating treatment, which may have reduced germination for the seedlot, which originated from hand collections in the Prudhoe Bay Western Operating Area.

DISCUSSION

Data

Seeding grass increased the vascular plant cover on the spill site. *Puccinellia borealis* (Umiat collection) was the most effective seed treatment, followed by *Puccinellia borealis* (ERA Helicopter collection). This species was found in all plots, establishing as a result of stray seeds carried by wind during planting. *Puccinellia augustata* was the poorest performer, probably because the seed germination was low. Plants of this species that established were robust and survived well on the site. These scattered individuals of *P. augustata* may have been larger because they were uncrowded. Most canopy cover in the *Puccinellia augustata* treatment consisted of *P. borealis* and native survivors, not *P. augustata*.

Grazing diminished on the seeded grasses as they matured and began developing inflorescences. This is consistent with observations elsewhere for *Puccinellia borealis*. The species is known to be short-lived and relatively unpalatable. We have observed the entire replacement of seeded *Puccinellia borealis* at other locations. Near FS-1 (EOA), a seeding of northern alkaligrass was completely replaced by sedges within seven to 10 years. The same occurred on an old road between DS-2 and the North Slope Borough Landfill. At X-Pad, *Puccinellia borealis* established and was nearly completely replaced by sedges within five growing seasons. Based on those examples, we may expect the seeding at the MPU diesel spill site to be entirely replaced by indigenous tundra graminoids sometime during the 2004 and 2007 interval.

Fertilizer influences indicated all three elements (nitrogen, phosphorus, and potassium) affected the seeded grasses. N, P, and K all appeared to increase plant heights. This differed from findings in the 1999 evaluation (McKendrick, 2000). High applications of phosphorus and potassium decreased species diversity. Nitrogen did not seem to affect species diversity, but increased palatability of grass plants. Increased grazing in response to fertilization has been observed elsewhere on the North Slope, where grass was seeded and fertilized. Fertilization increases succulence and delays senescence (McKendrick et al., 1978), resulting in a green sward that contrasts with the dead leaves of unfertilized tundra plants. These green islands of leaves are especially attractive to geese, swan, and caribou late in the growing season. As fertilizer effects diminish over time, grass palatability also declines, and that decline in palatability appeared to be occurring at this location. Grazing in 2001 was less evident than in 1998 and 1999.

Species of Plants

Very few species occurred in the polygon troughs in either the spill or control habitats. This is common in polygonized tundra terrain, because the troughs are seasonally flooded. Also the active layer in troughs is minimal, and ice masses underlie the surface mat of organic detritus. Thus, there is little soil in polygon troughs to support vegetation.

Dupontia fisheri did not appear among the species identified in the control area during the 1997 inspection. It was undoubtedly present, but overlooked within the graminoid canopy. It has become more prominent within the spill-affected area as time has passed. This species is a common increaser on disturbed habitats on the Alaska North Slope. We have observed its ability to recolonize disturbances on sites in NPRA (McKendrick, 1986) and around production pads in the Prudhoe Bay oilfield.

Salix planifolia ssp. *pulchra* was found colonizing at two reserve pit fluid leak areas at exploration wellsite in NPRA (McKendrick, 1986); however, persistence of this willow at the diesel spill site should be attributed to its having escaped spill effects, because it occurred on raised polygon rims that were least affected by the fluids released.

Saxifraga cernua is a bulbiferous forb that often colonizes on open mineral and peat soils in this region (McKendrick, 1986) and occasionally

predominates on disturbed sites, forming relatively dense stands. At this location, it appears that removal of other plants by the spill and burning eliminated competition, allowing *Saxifraga cernua* to either increase or at least become increasingly obvious in the spill area.

Graminoid species diversity was highest in the *Puccinellia augustata* plots because there was much open ground and relatively little competition. Similarly, moss cover was inversely related to the total number of graminoid species present. This may have resulted either from less competition from the higher plants or the effect of vascular plant canopy obscuring the moss cover to observers. *P. augustata* occurred only where it was seeded and in the no-seed plots. These plants probably resulted from seed applications as well as natural colonization from plants in the vicinity. Heights of *P. augustata* were relatively great because these plants occurred widely, with less competition than experienced by other species of grasses in the spill area. The grass is inherently taller than *P. borealis*. Both nitrogen and phosphorus fertilizers increased graminoid plant heights (*Dupontia fisheri*, *Puccinellia augustata*, and *Puccinellia borealis*), indicating these two nutrients were beneficial to plant growth.

All lichens except *Thamnolia vermicularis* were eliminated from the site by the spill and cleanup activities.

Field Observations
Seeded *Puccinellia borealis* plants had senesced and leaves were brown.
Caribou tracks and scat of geese and lemming were observed within the spill area.
Poa hartzii may be present at this location.
Willows were largely absent from the site.
The Umiat ecotype of *Puccinellia borealis* appeared to be starting to die out with age, as expected.
Only a few specimens of *Puccinellia augustata* established from the seed application.
Caribou were in the vicinity today, but not on the site itself.
Security warned us of a brown bear sighted on the west side of the road while we were working on the site.
A sheen was observed on the water. It broke apart when touched, and we concluded it was natural paraffin and not residue from the spill.

CONCLUSIONS

- Vegetation on the spill site is continuing to improve.
- *Puccinellia borealis* (Umiat ecotype) appeared to be the most promising seeded grass.
- Fertilizer applications were beneficial in promoting grass growth on the site. A mixture of N, P, and K is probably the most beneficial.
- P fertilizer at the higher applications limits vascular plant species diversity. Application that provides no more than 60 lbs/a P appears to prevent this species composition shift.
- Because the diesel spill and burning were confounded, it is impossible to distinguish between these effects on tundra revegetation.
- DRO and soil nutrients could be measured in soil among fertilizer applications to determine current status of these elements.

REFERENCES

McKendrick, Jay D. 2000. Seeding *Puccinellia arctica* and *P. langeana*, and applying fertilizer to a burned diesel spill on coastal wet-sedge tundra. BP Exploration (Alaska), Inc. Anchorage. 38 pp.

McKendrick, Jay D. 1986. Final cleanup at selected (1975-1981) wellsites, sampling and testing of waters and bottom muds in the reserve pits and the recording of tundra plant responses on the National Petroleum reserve in Alaska (NPRA), Volume III recording of plant responses. Nuera Reclamation Co., U.S. Geological Survey, Anchorage, Alaska. 225 pp.

McKendrick J.D., Valerie Ott, and George A. Mitchell. 1978. Effects of nitrogen and phosphorus fertilization on carbohydrate and nutrient levels in *Dupontia fisheri* and *Arctagrostis latifolia*. Chapter 22 *In:* Tieszen, L.L. (ed.) Vegetation and production ecology of an Alaskan arctic tundra. New York: Springer-Verlag. p. 509-537.

FIGURES 1 – 21

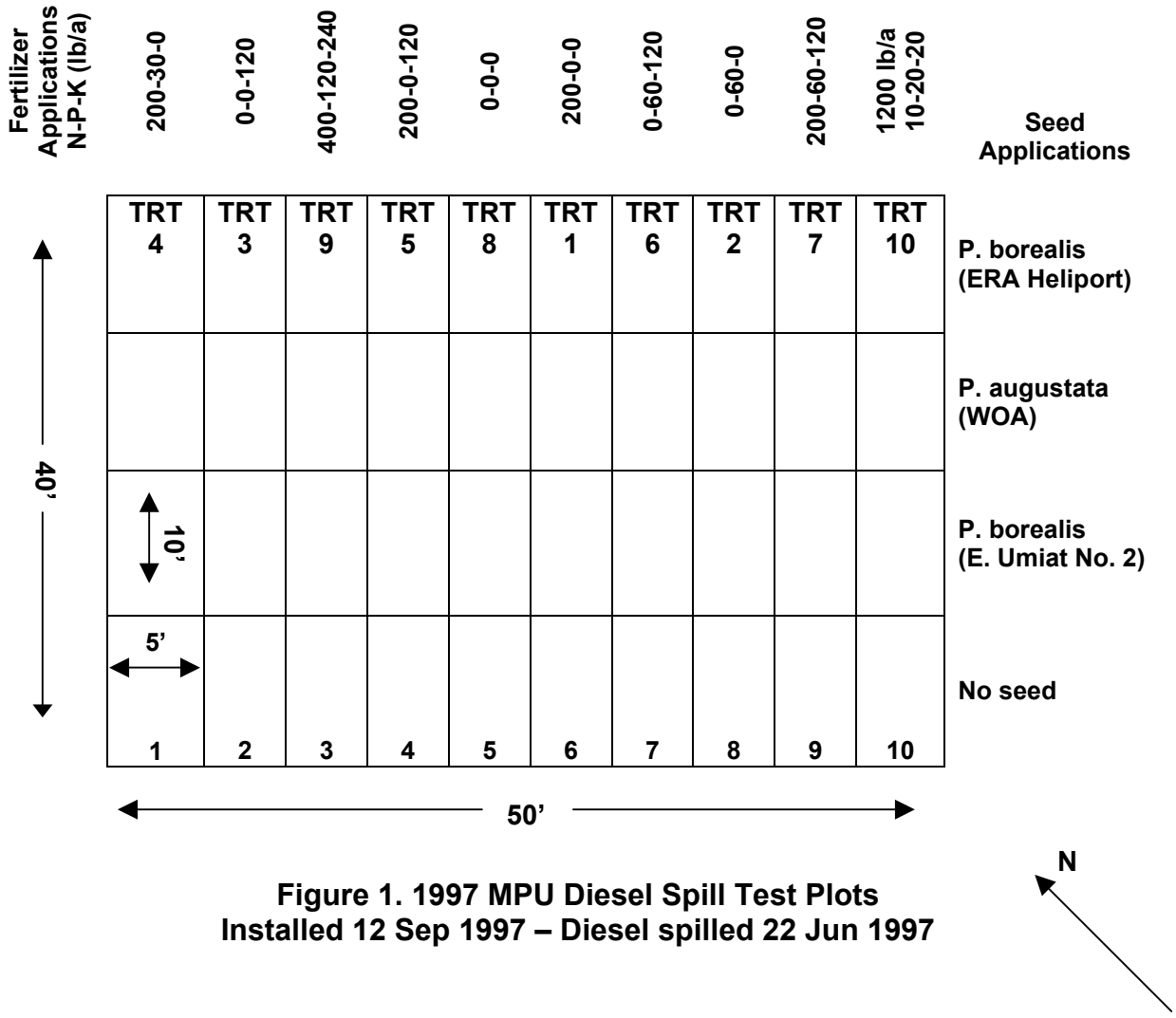

Figure 1. 1997 MPU Diesel Spill Test Plots
Installed 12 Sep 1997 – Diesel spilled 22 Jun 1997

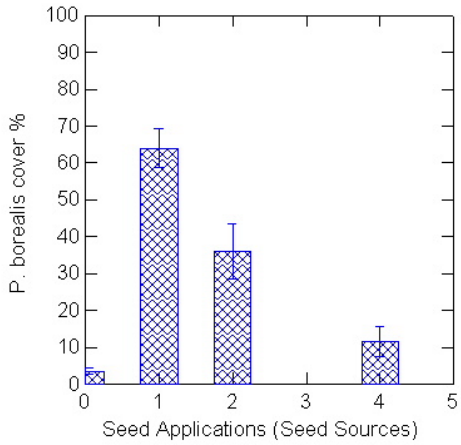

Figure 2. *P. borealis* cover by seed applications.

X axis codes:
0 = no seed
1 = P. borealis (Umiat source)
2 = P. borealis (ERA Helicopter source)
4 = P augustata (WOA).

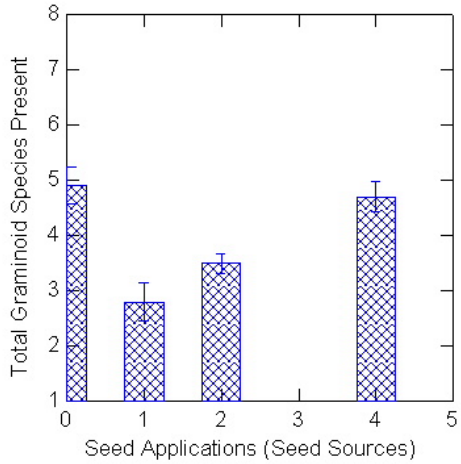

Figure 3. Total graminoid species by seed applications.

X axis codes:
0 = no seed
1 = P. borealis (Umiat source)
2 = P. borealis (ERA Helicopter source)
4 = P augustata (WOA).

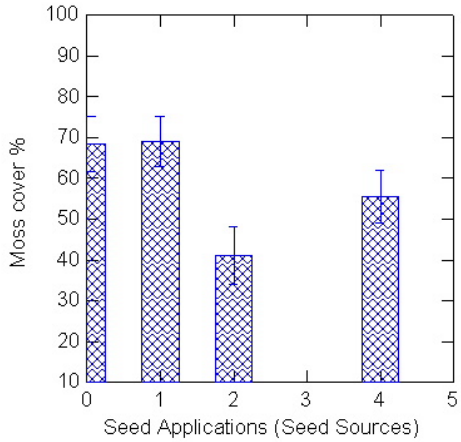

Figure 4. Moss cover by seed applications.

X axis codes:
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1 = P. borealis (Umiat source)
2 = P. borealis (ERA Helicopter source)
4 = P augustata (WOA).

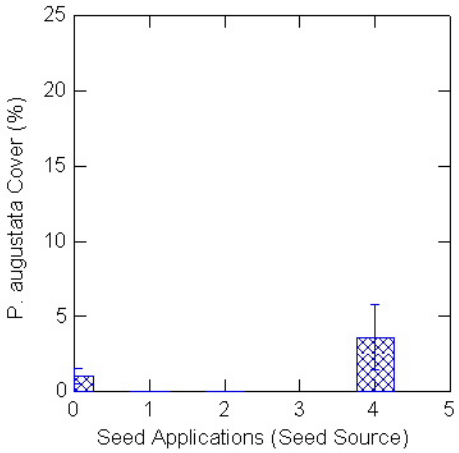


Figure 5. *P. augustata* cover by seed applications.

X axis codes:
0 = no seed
1 = P. borealis (Umiat source)
2 = P. borealis (ERA Helicopter source)
4 = P augustata (WOA).

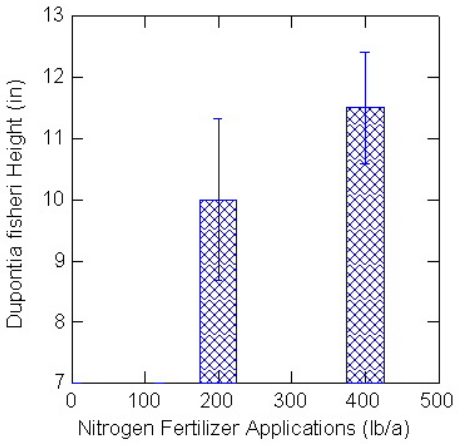


Figure 6. *Dupontia fisheri* heights and nitrogen fertilizer applications.

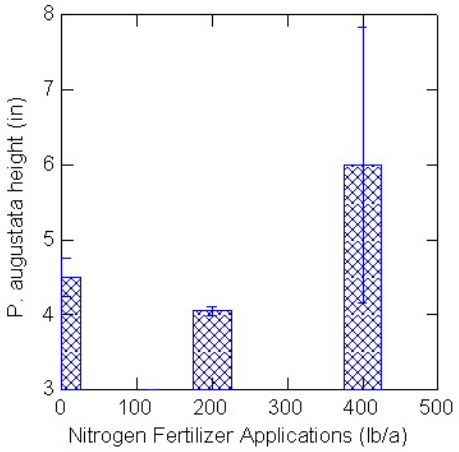


Figure 7. *P. augustata* height and nitrogen fertilizer applications.

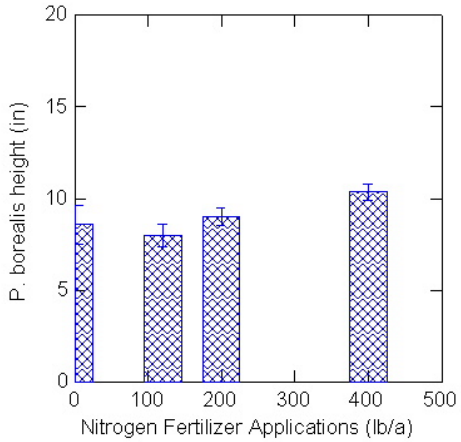


Figure 8. *P. borealis* heights and nitrogen fertilizer applications.

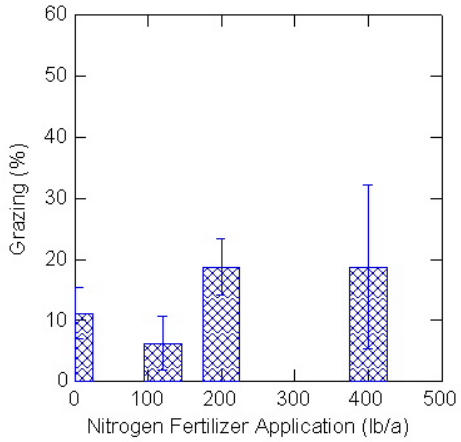


Figure 9. Grazing percentages and nitrogen fertilizer applications.

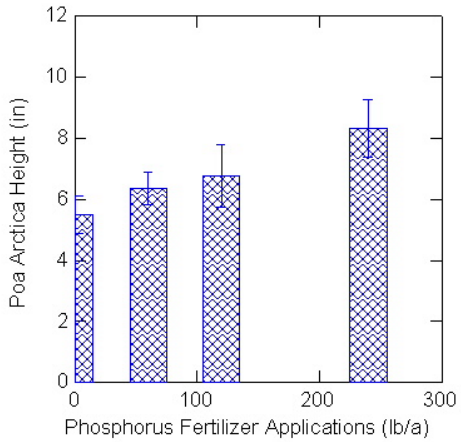


Figure 10. *Poa arctica* heights and phosphorus fertilizer applications.

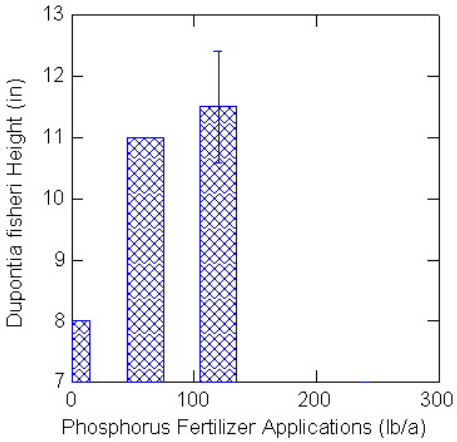


Figure 11. *Dupontia fisheri* heights and phosphorus fertilizer applications.

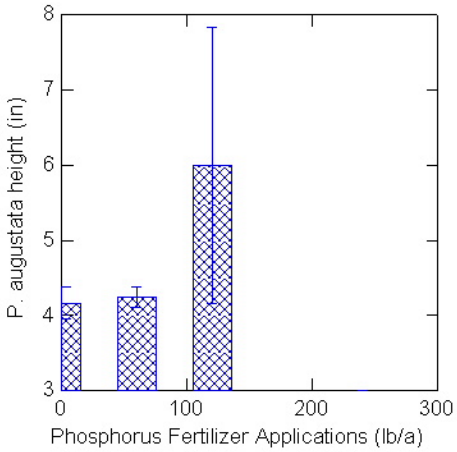


Figure 12. *P. augustata* heights and phosphorus fertilizer applications.

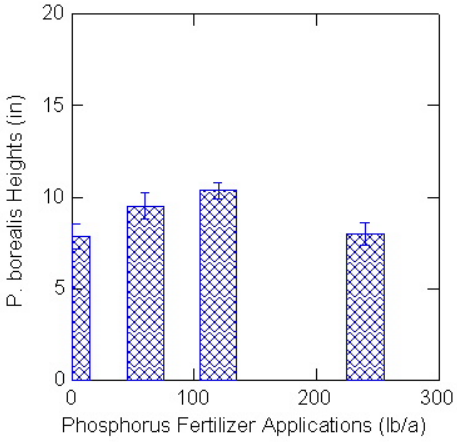


Figure 13. *P. borealis* heights and phosphorus fertilizer applications.

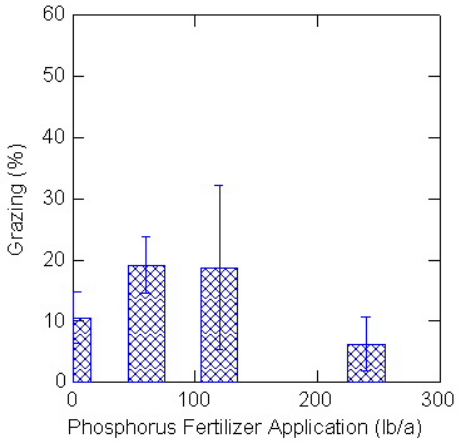


Figure 14. Grazing percentages and phosphorus fertilizer applications.

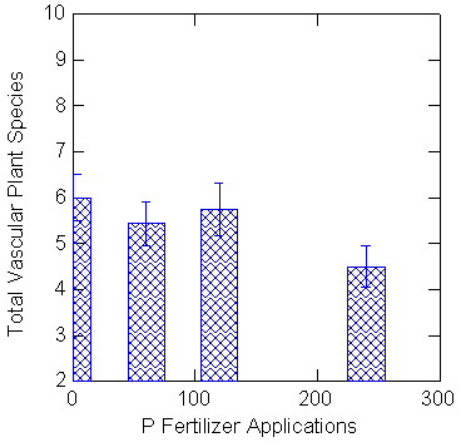


Figure 15. Total vascular plant species and phosphorus fertilizer applications.

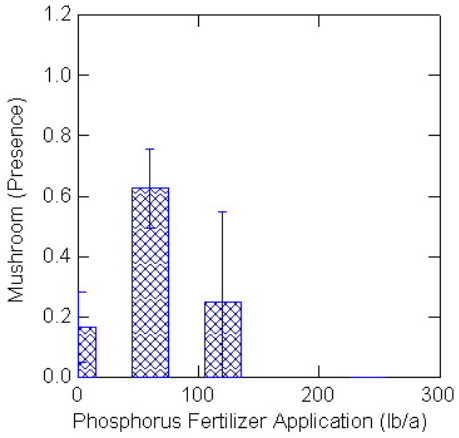


Figure 16. Occurrences of mushrooms and phosphorus fertilizer applications.

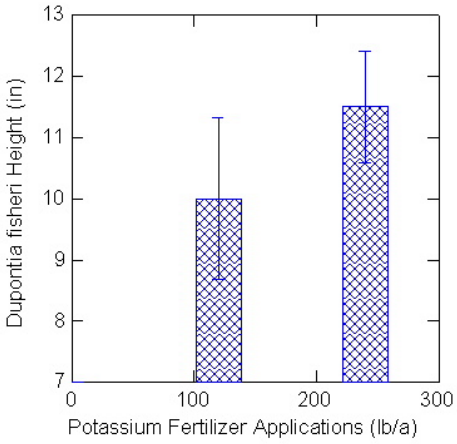


Figure 17. *Dupontia fisheri* heights and potassium fertilizer applications.

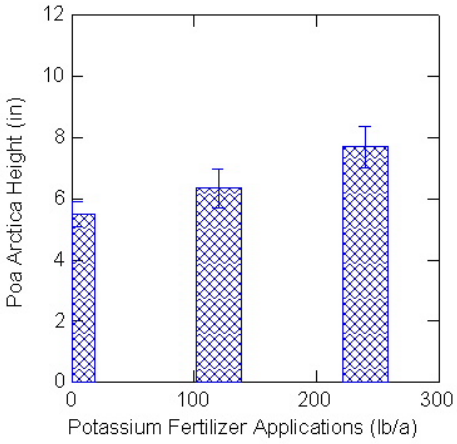


Figure 18. *Poa arctica* heights and potassium fertilizer applications.

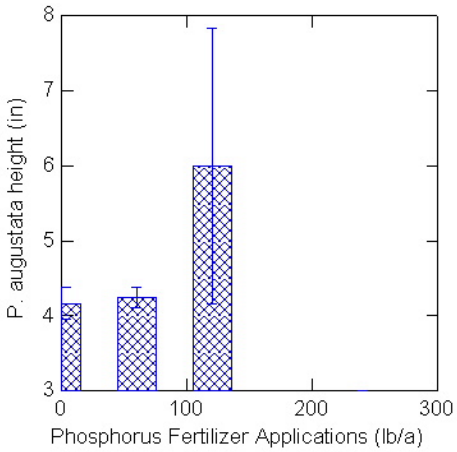


Figure 19. *Puccinellia augustata* heights and potassium fertilizer applications.

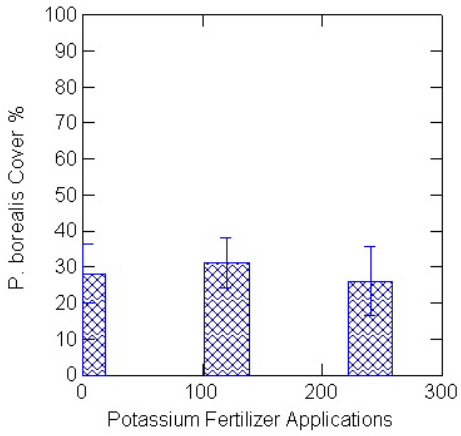


Figure 20. *Puccinellia borealis* heights and potassium fertilizer applications.

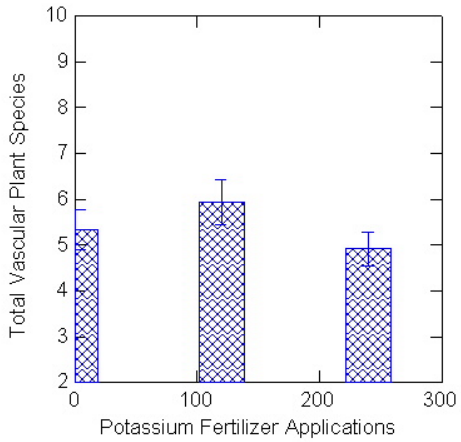
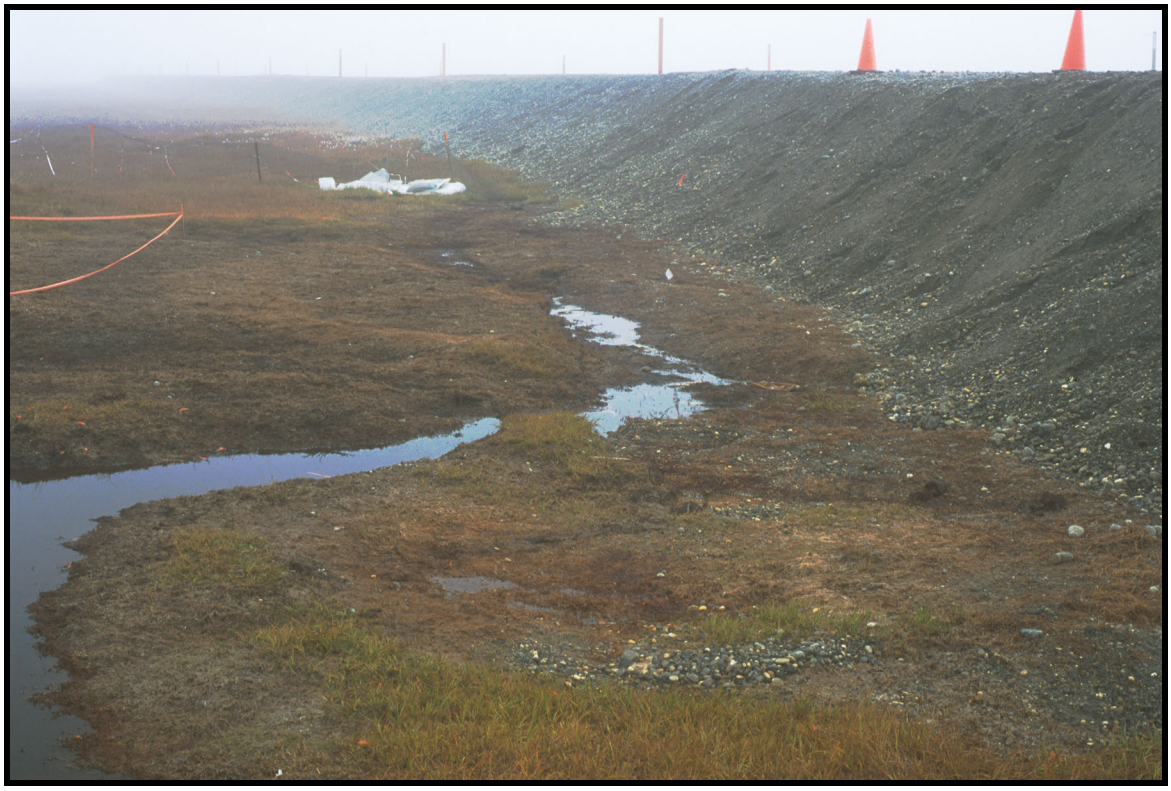


Figure 21. Total plant species and potassium fertilizer applications.

PHOTO SERIES 1

A series of images showing the vegetation recovery at the NE corner of the spill site, 1997 through 2001. Plants increasing in this portion of the spill during the interval included naturally-occurring sedges and grasses and the seeded northern alkaligrass. The green cast on the soil surface in the 2001 image is moss, which was encouraged by fertilizer applications. Notice deepening of polygon troughs occurred during the 1997-2001 interval.



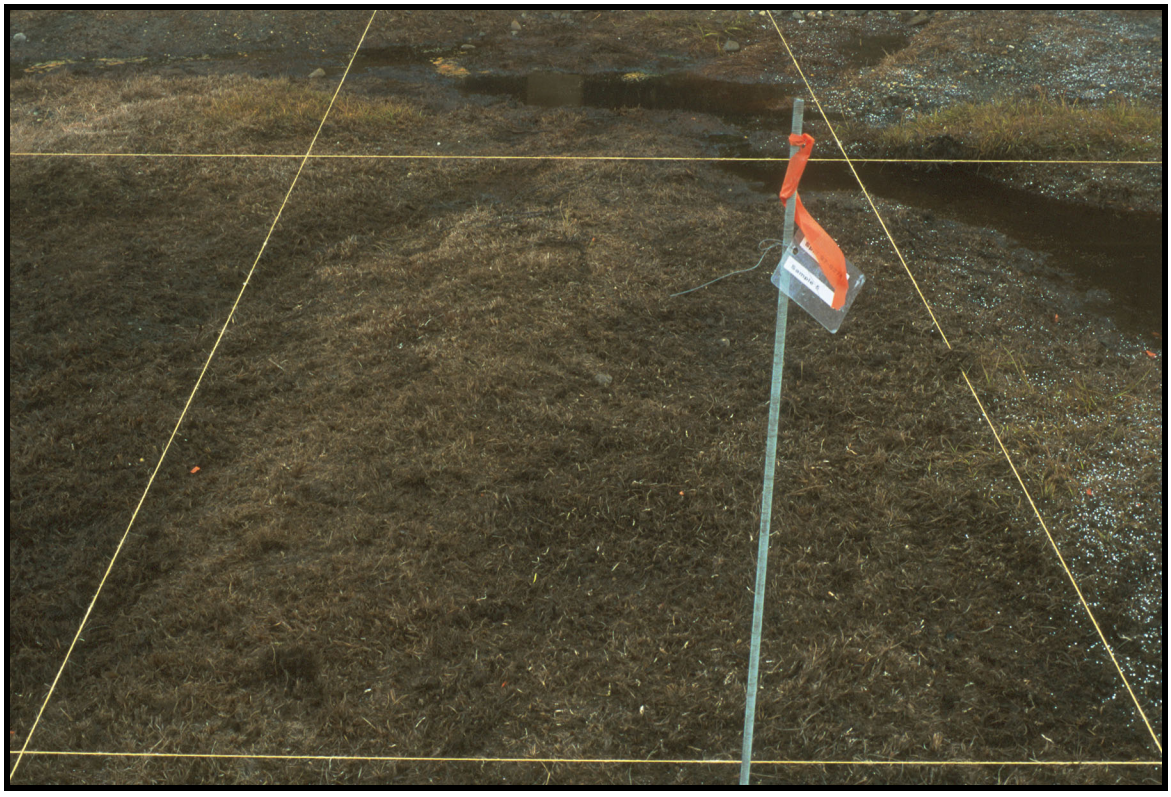
22 September 1997

30 August 1998

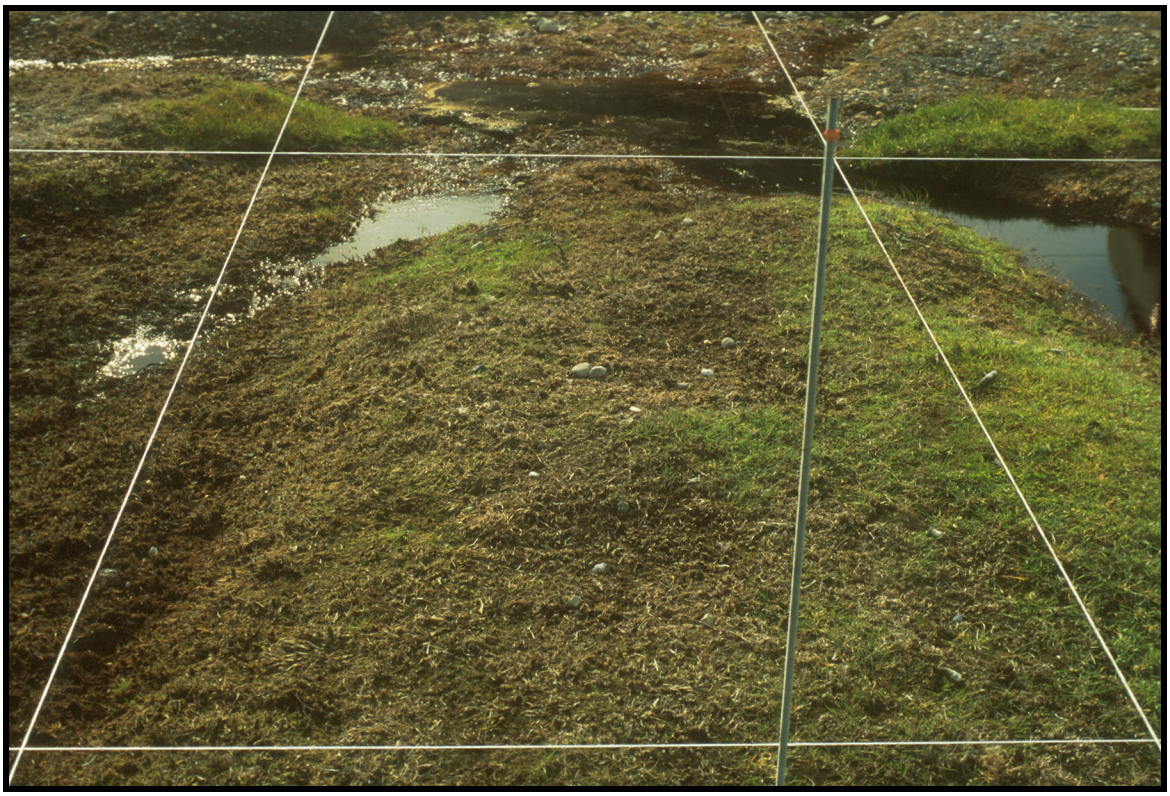
23 September 2001

PHOTO SERIES 2

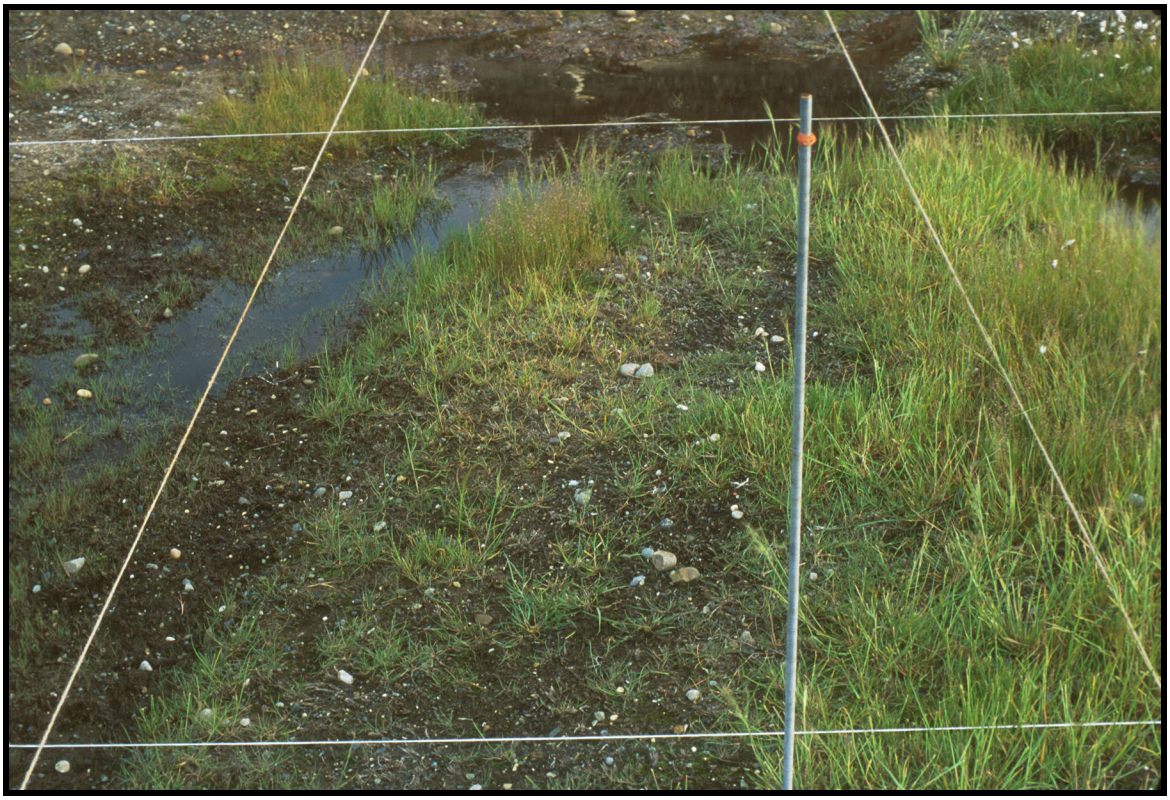
This photo sequence illustrates the establishment and maturation of *Puccinellia borealis* (Umiat ecotype). This particular plot was mostly within a polygon center, which became a raised center when the troughs subsided in response to the disturbances of the spill and cleanup operations. The fertilizer treatment in this plot was 200-0-120 (lbs/a N-P-K, respectively). In 1997, the ground surface was barren of vascular plants because of the spill and cleanup efforts. The *Puccinellia* seed was applied and germinated in 1998. These succulent seedlings were grazed intensively by geese and caribou that season and to a lesser degree the following year. By 1999, the plants were mature enough to produce inflorescences, and the grazing declined with the associated decrease in palatability, which accompanies inflorescence production, In 2000, these plants were grazed very little, and in 2001, there appeared to have been no grazing on the northern alkaligrass plants, even though they were affected by fertilizer applications.



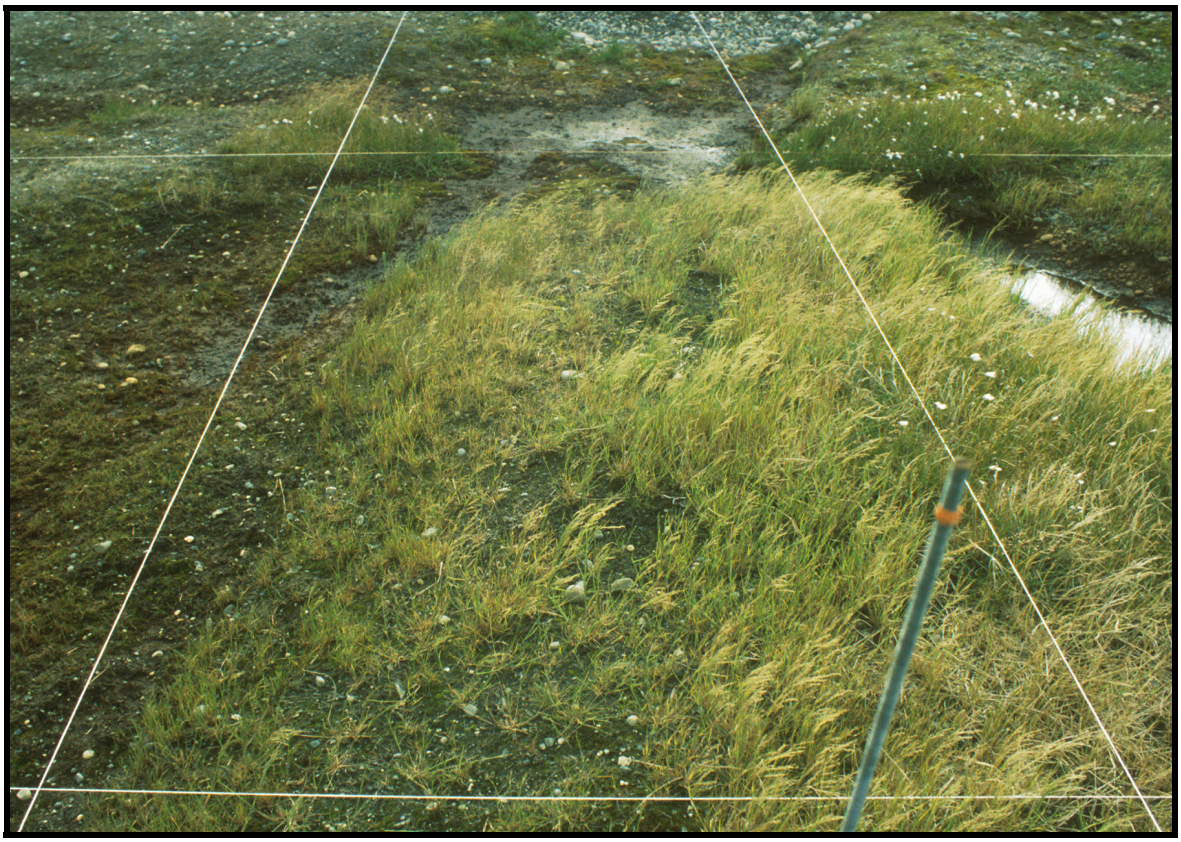
12 September 1997



30 August 1998



29 August 1999

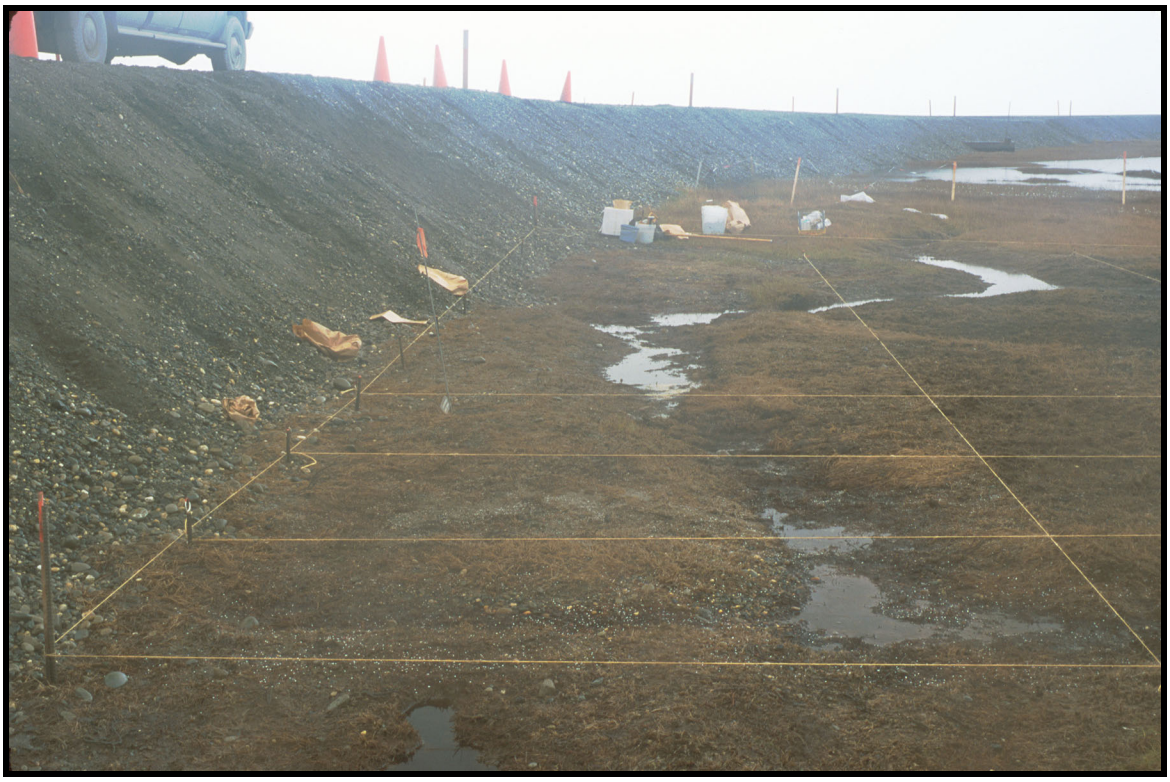


29 August 2000

23 September 2001

PHOTO SERIES 3

This sequence of photos shows the improvement of vegetation cover during a four-year interval on the unseeded strip of plots. This strip is next to the road, and affected by gravel stones that spill onto it. Snow drifts form over this area in winter, and lie late in the spring, shortening the growing season for plants in these plots. Plots are shaded in the afternoon, which possibly limits plant photosynthesis. This area was also probably more affected by the spill than locations more distant to the release point. Despite those drawbacks, there has been a gradual improvement in plant cover on these plots. *Phippsia algida* has invaded through seedling establishment (small clumps of grass in foreground of 2001 image). Mosses have established in response to fertilizer applications, and a few stray seedlings of *Puccinellia borealis* have established. These northern alkaligrass seedlings resulted mostly from seed inadvertently carried onto the site from the adjacent seeded plot.



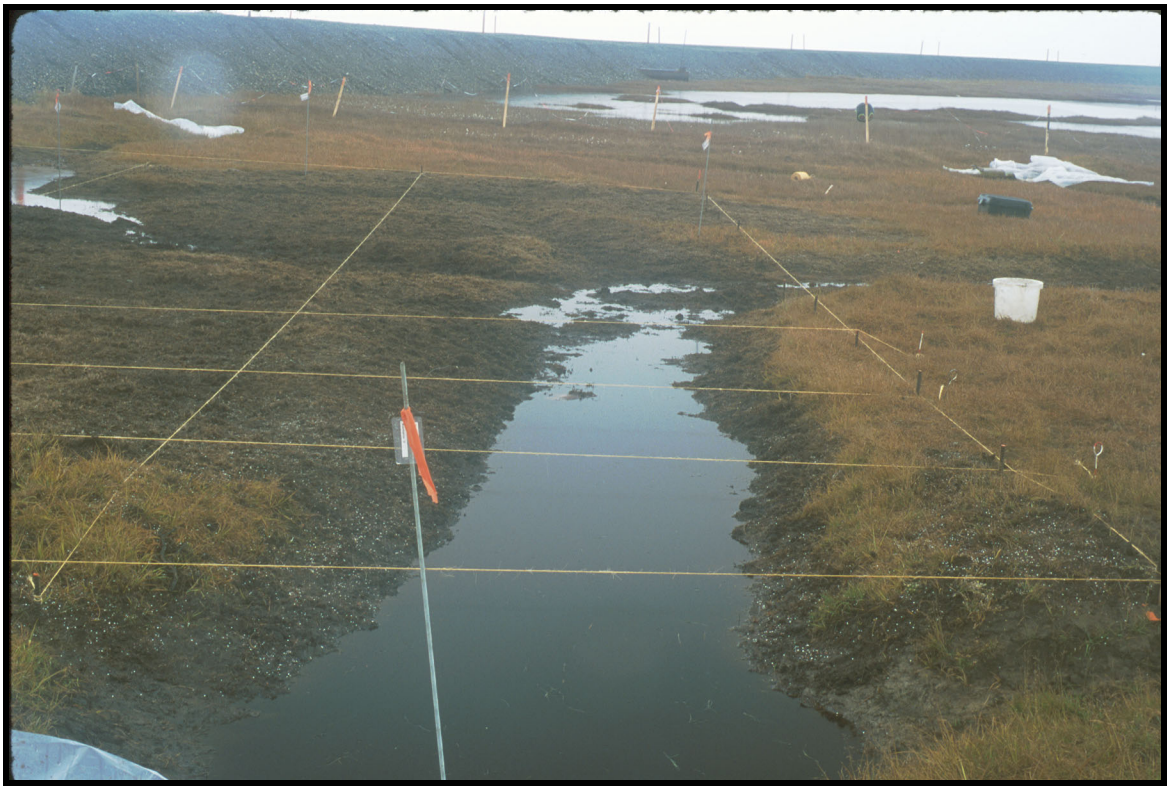
12 September 1997

30 August 1998

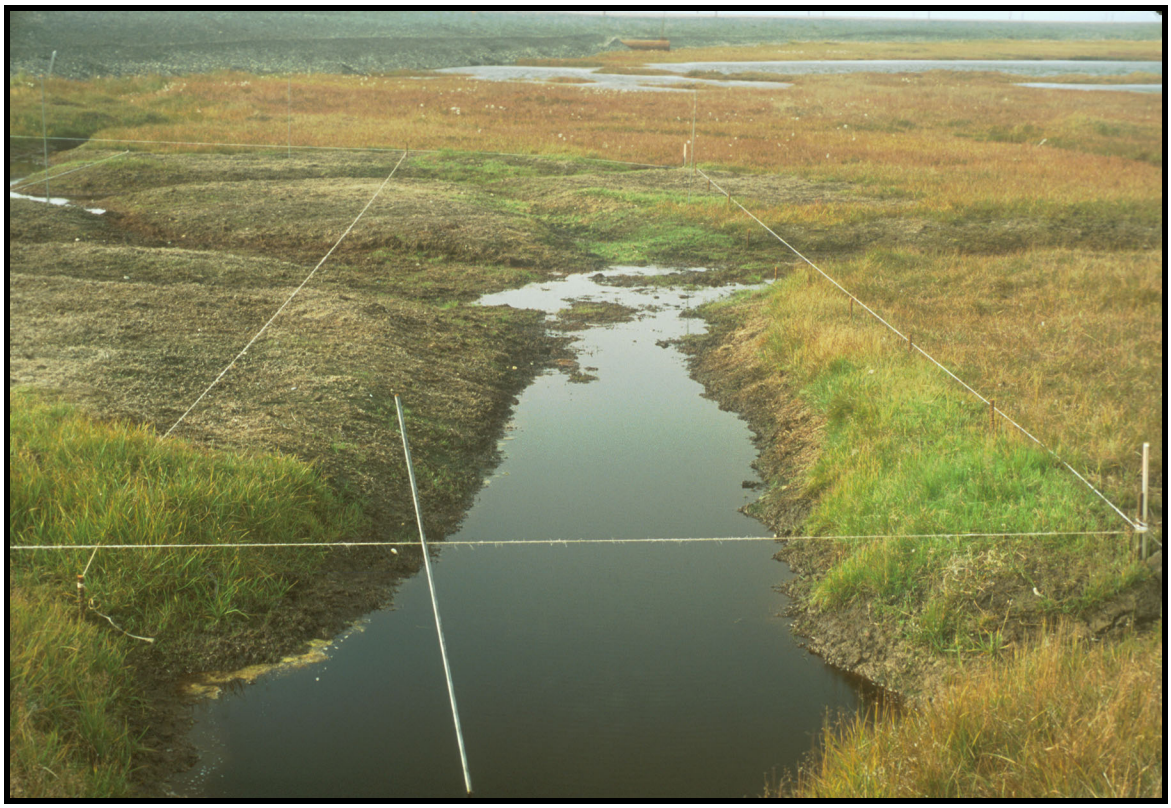
23 September 2001

PHOTO SERIES 4

This sequence of images shows the development of *Puccinellia borealis* (ERA Helicopter ecotype). Seed was applied on 12 September 1997. It germinated during the 1998 growing season. This ecotype typically establishes slowly in comparison with the ecotype from Umiat. That is evident in this sequence. The plants are shorter than those from the Umiat source. The best development of this ecotype in this plot occurred in the partially flooded polygon trough near the far end of the plot. In contrast, the Umiat ecotype developed best on the drier ground of polygon centers. The ERA Helicopter ecotype was still a better performer than *Puccinellia augustata* at this location. Notice the effect of fertilizer on the natural tundra plants at the right edge of the 30 August 1998 image. The fertilized tundra plants are still bright green, and the unfertilized cohorts outside the plot have senesced and turned brown.

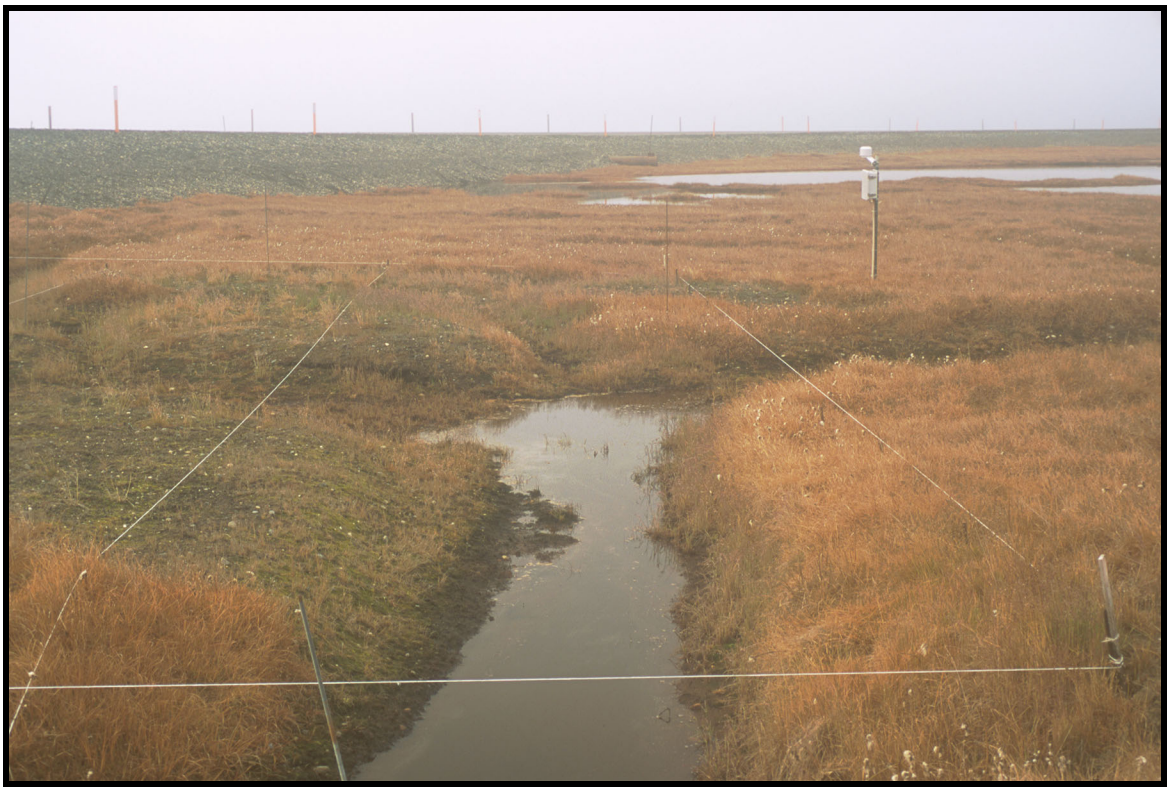


12 September 1997



30 August 1998

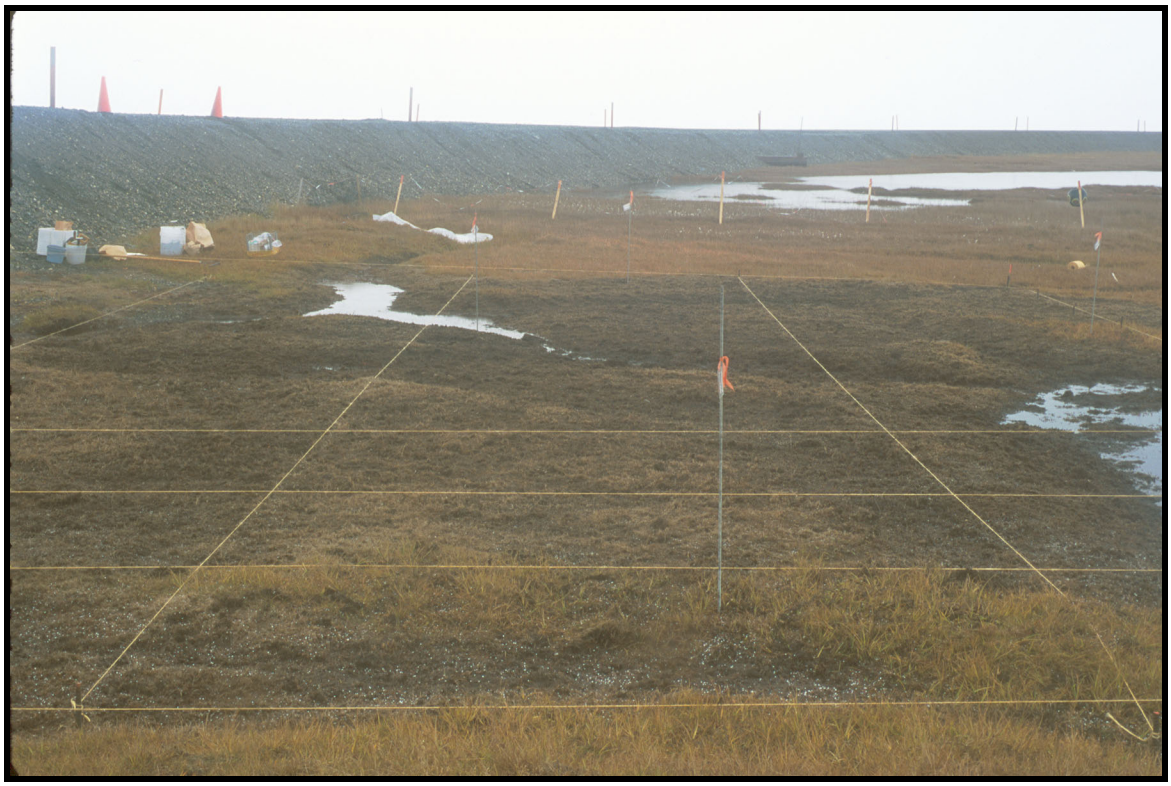
26 August 1999



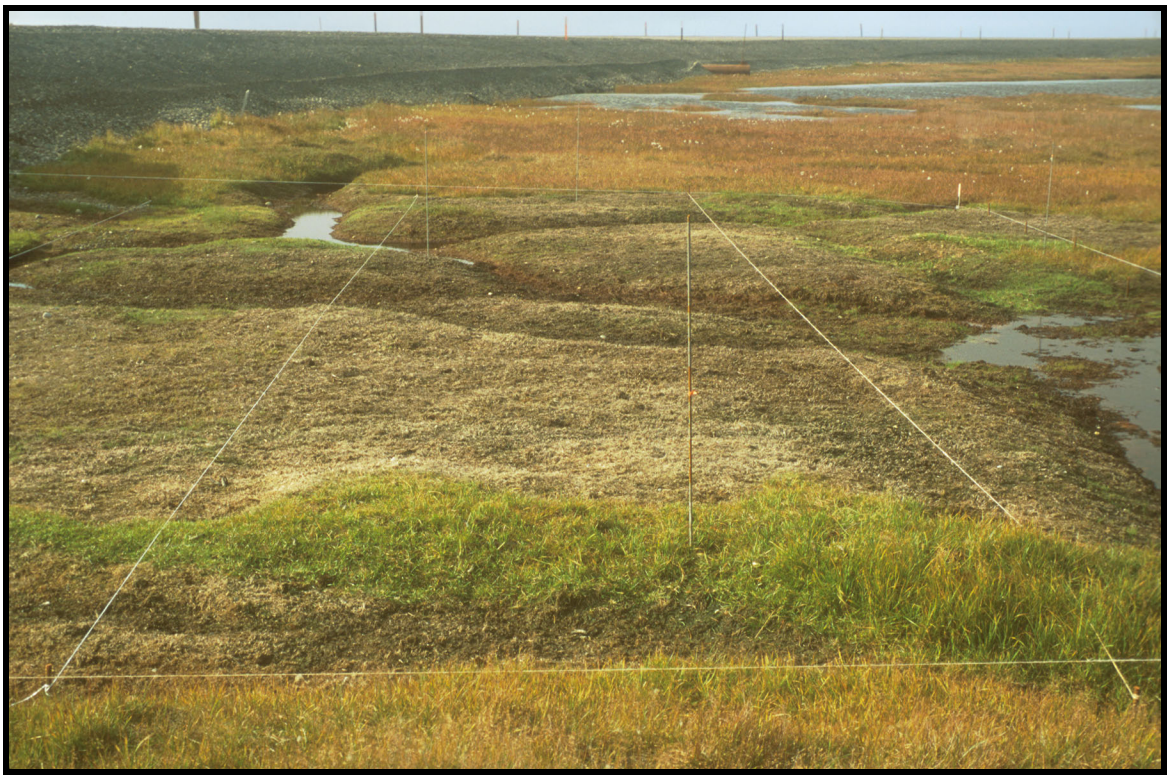
23 September 2001

PHOTO SERIES 5

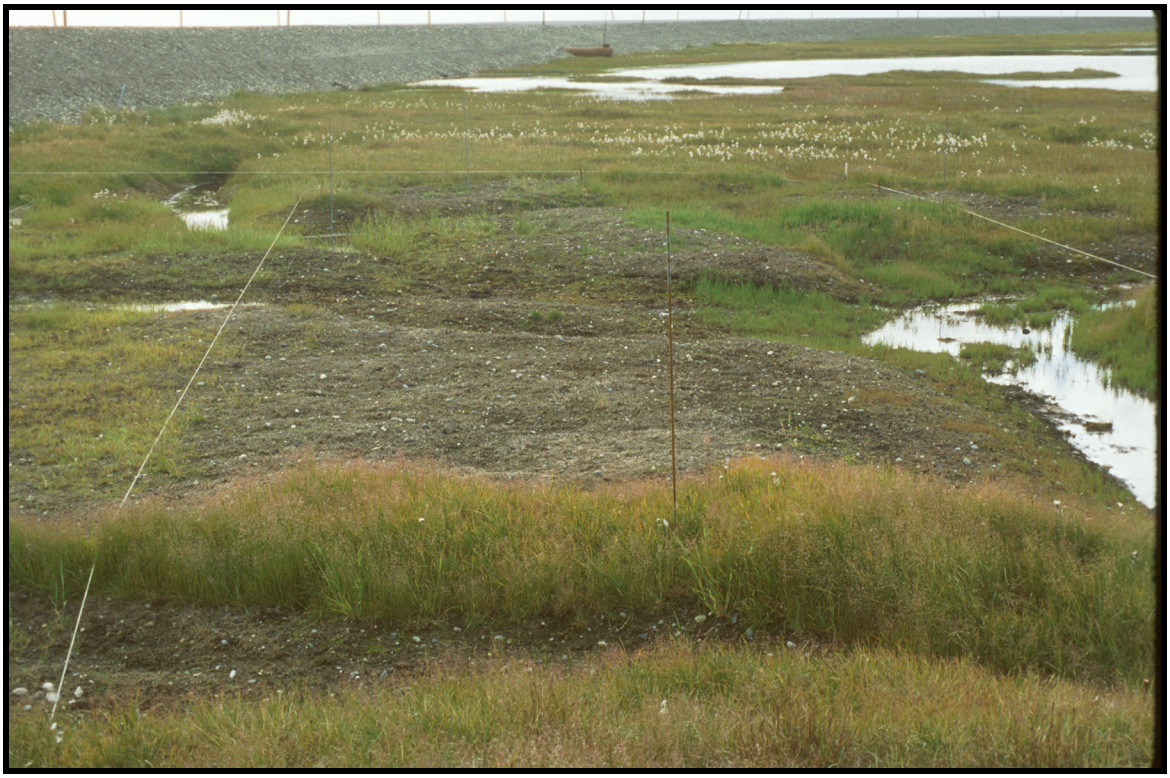
This sequence of images illustrates the poor development of *Puccinellia augustata* in the seeding at the diesel spill site. Seed was applied on 12 September 1997, and it germinated during the 1998 growing season. Plants matured during the 1999 growing season. By the end of the 2001 growing season, there were only a few scattered individuals established. The poor development was believed to have been caused by limited germination. This species' seed normally has a relatively high germination percentage (in the 90% range). However, this seed lot was given a coating to ease handling and applying the seed. Apparently the coating process substantially reduced the germination percentage. This was not the only location where poor development occurred with this seed lot. Therefore, we do not believe the performance accurately reflected the effects either of the spill or the cleanup procedures on this grass plants' establishment. Plants that did establish appeared normal, grew well and were robust.



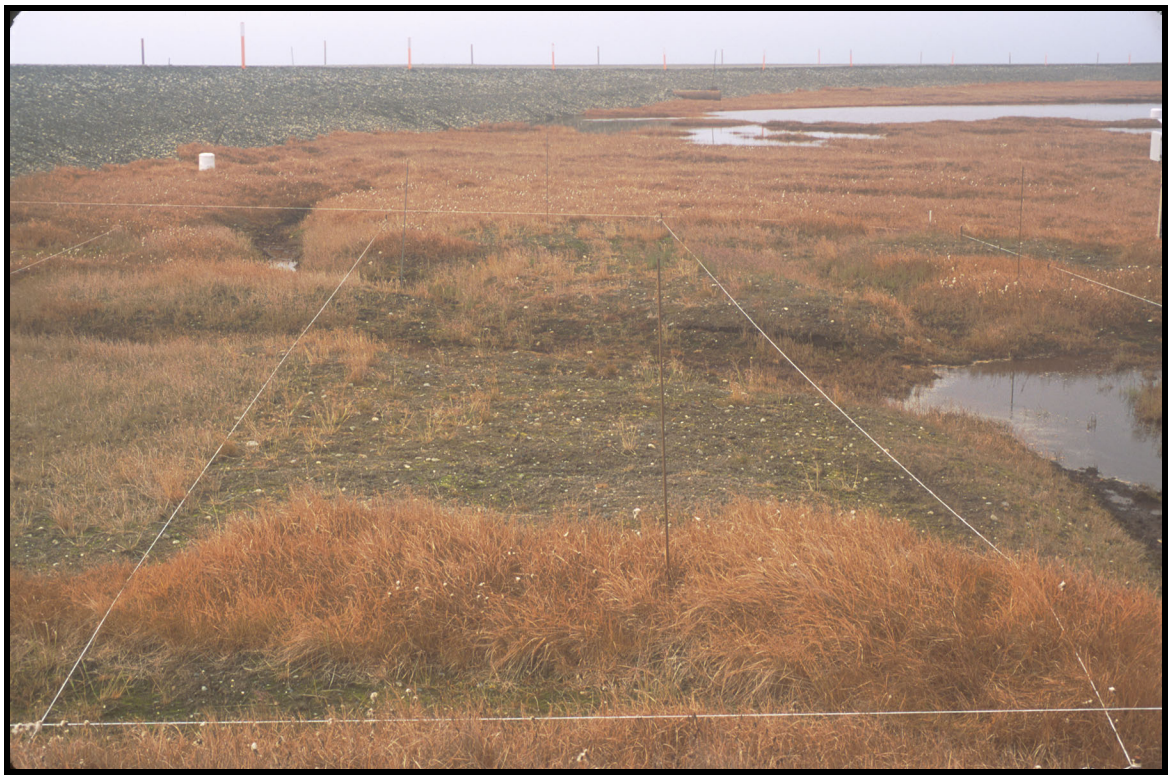
12 September 1997



30 August 1998



26 August 1999

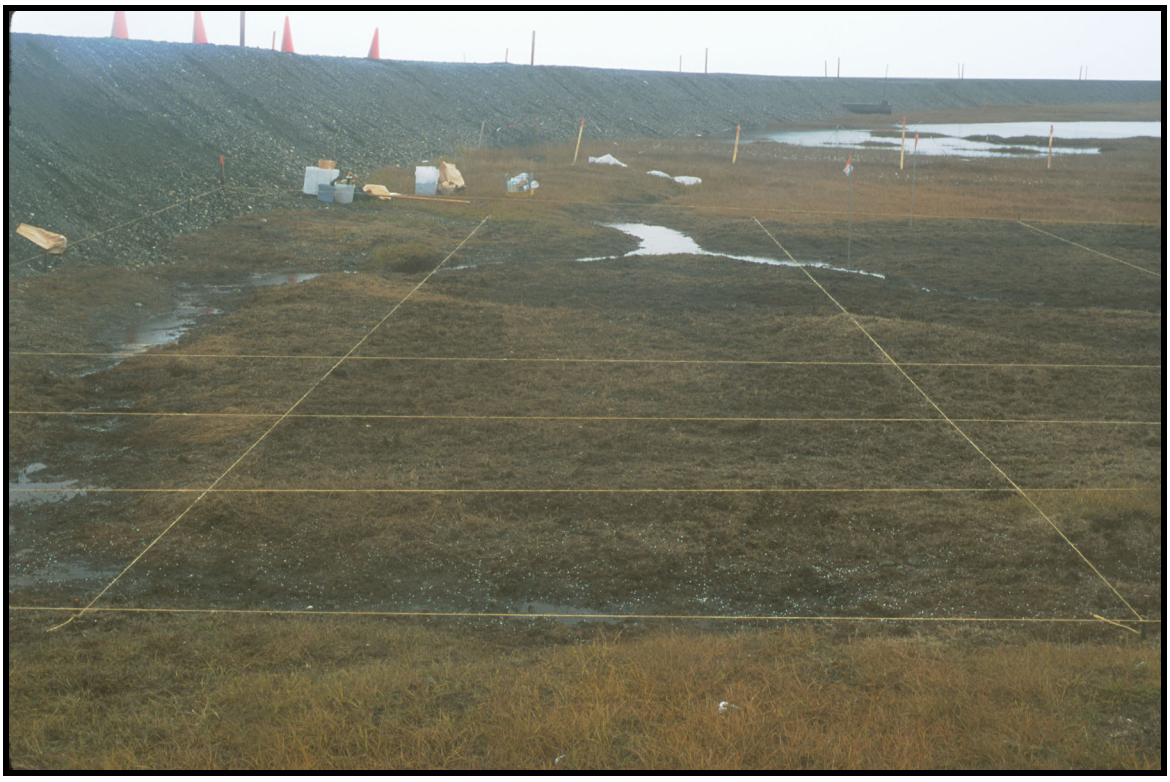


23 September 2001

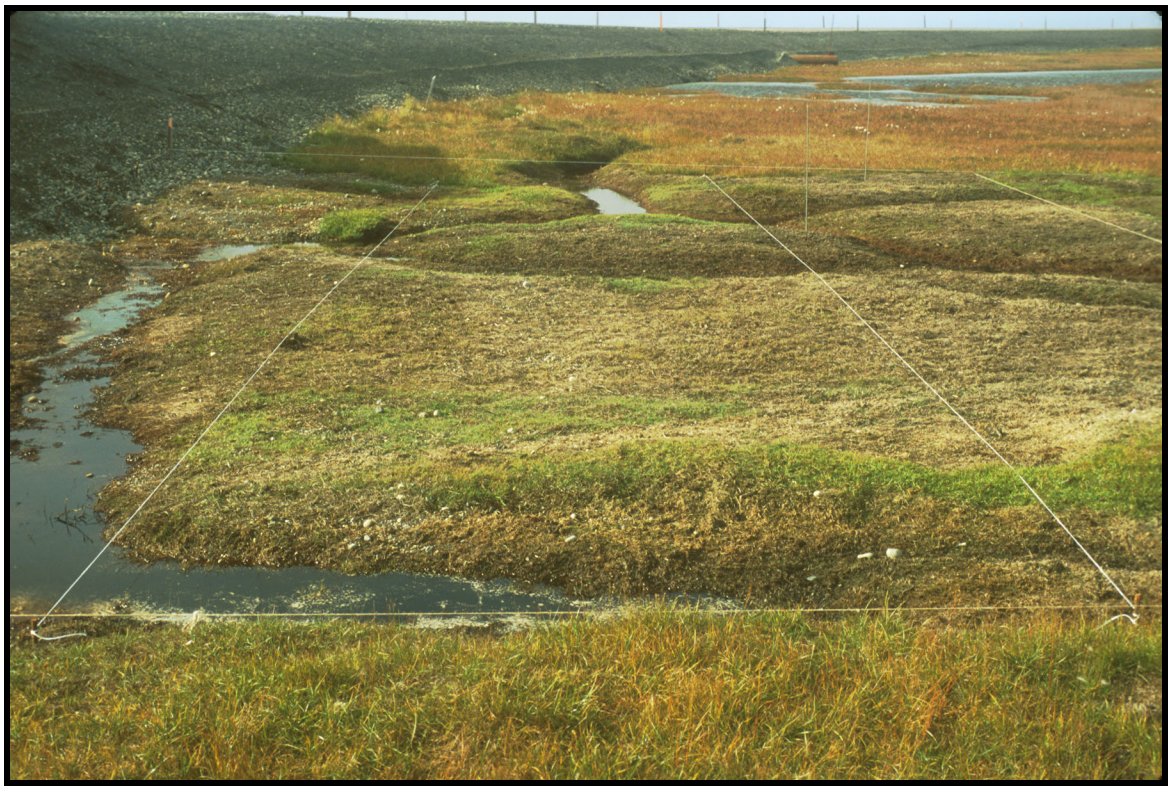
Most of the vegetation in this image is natural species that survived the spill, and scattered individuals of northern alkaligrass that were accidentally seeded.

PHOTO SERIES 6

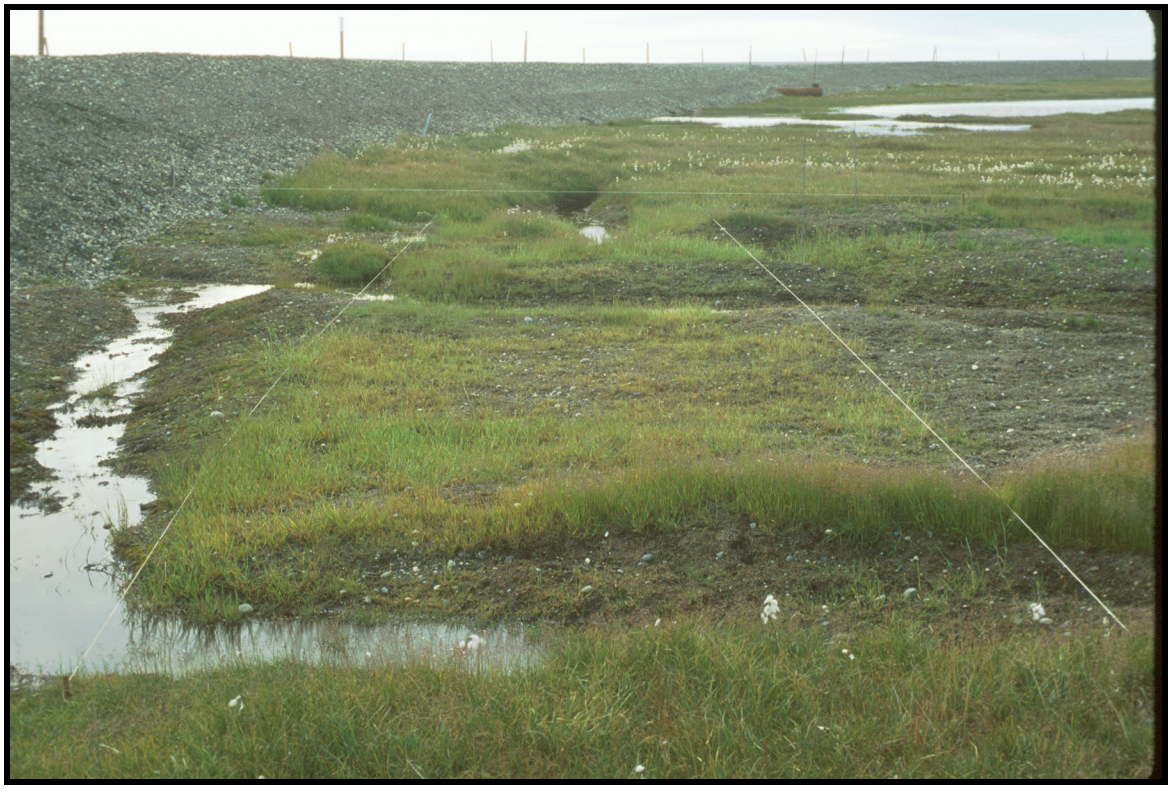
This sequence of photos shows the robust development of *Puccinellia borealis* (Umiat ecotype). Seed was applied on 12 September 1997, and germinated during the 1998 growing season. Seedlings were intensely grazed by caribou and geese. This grazing was enticed by the plants' succulence, their phonological age and effects from fertilizer. As the plants aged and began developing inflorescences, their attractiveness to grazers diminished. By 1999, the grazing intensity was markedly lower. By 2001, there appeared to have been little grazing on these plants, even though other graminoids in the vicinity had been grazed. This ecotype developed well on the raised micro-topography within the spill area, and responded positively to fertilizer applications. It appears to be a desirable grass species for revegetation in this region.



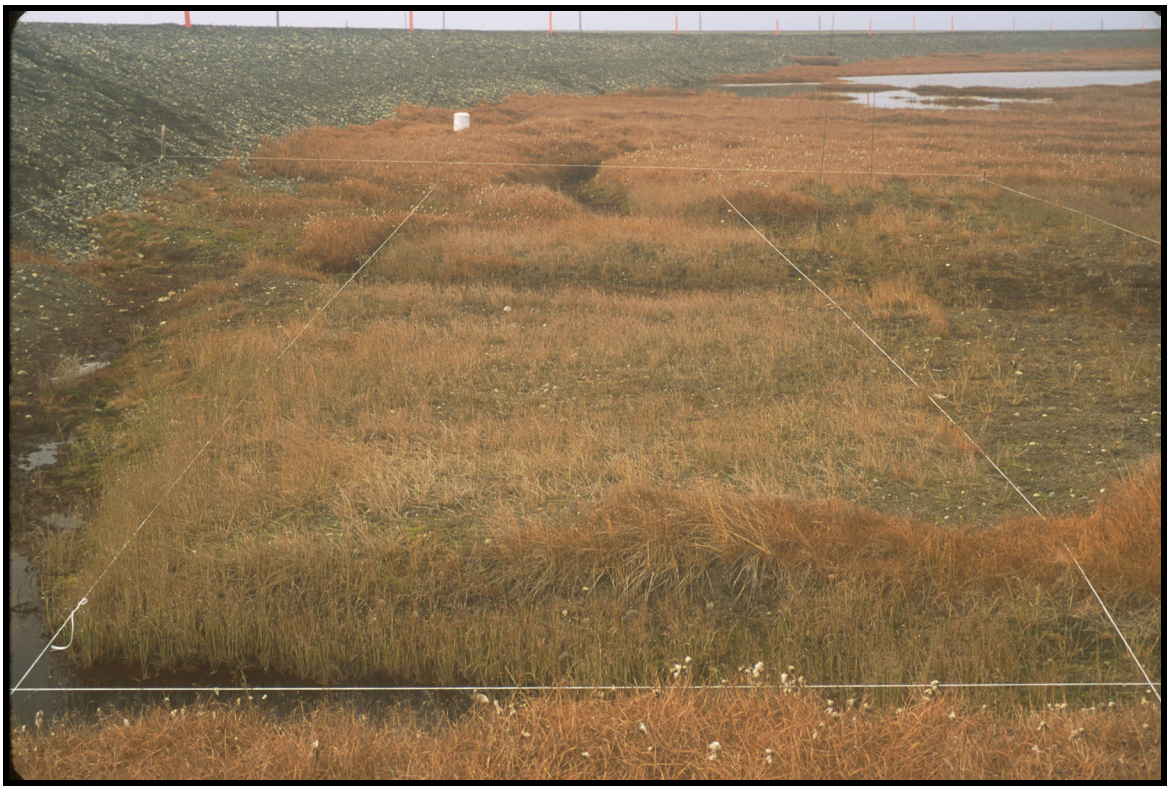
12 September 1997



30 August 1998



26 August 1999



23 September 2001