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FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

Second Annual Progress Report June 1976 to July 1977

(10) T. McFadden, T. Jenkins, C. Collins, L. Johnson, B. McCown and E. Sparrow

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A study was initiated in 1975 to evaluate the fate and effects of crude oil spilled on a taiga-covered permafrost site in Alaska. During this second year of the study the logistical portion of the experiments was completed with a spill of hot Prudhoe Bay crude oil in July 1976. This spill was compared with one that took place in February 1976 (reported upon in the first annual progress report). Studies on the differences in the fate of the oil, its effects on the permafrost, and its impact on the biological communities were continued and

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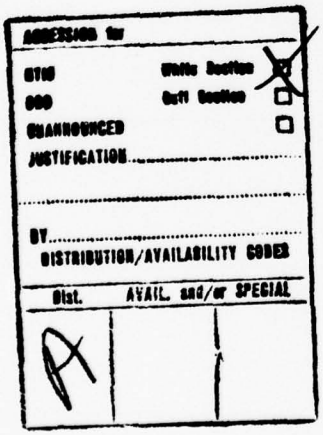
expanded. Oil moved downslope at a much faster rate during the summer spill than during the winter spill. In the winter the oil cooled and pooled rapidly. The summer spill covered approximately one-third more surface area than did the winter spill in the final configuration, even though the two spills were of almost identical volume. Increases in microbial populations and activities during the months following the spill were evident. Increased counts of bacteria, yeasts, denitrifying bacteria, and petroleum-degrading bacteria following the oil spills were particularly evident. Analysis of the oil's decomposition using gas chromatography techniques indicated that the low molecular weight fractions, methane and ethane, were lost almost immediately after the spill in each case. Fractions in the C_3 to C_9 range were reduced significantly in two months and were nearly zero at the end of five months. An obvious adverse effect on vegetation was noted in both spills. Biological damage from the summer spill appeared to exceed that from the winter spill. Not only was the area of spill larger, but the damage caused by inundation during the growing season appeared more intense. However, observations over several growing seasons and after at least two winter stress periods will be needed to fully evaluate the impact on the vegetation.



CONTENTS

FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

Second Annual Progress Report - June 1976 to July 1977

INTRODUCTION

Review of project plan

Under the sponsorship of the Arctic Environmental Research Laboratory of the Environmental Protection Agency, the Alaskan Projects Office of the U.S. Army Cold Regions Research and Engineering Laboratory initiated a study to evaluate the fate and effects of crude oil spilled on a taiga permafrost site in interior Alaska. The objectives of the project were three-fold:

1. To determine the fate of petroleum contaminants in subarctic terrestrial environments.

2. To detail the physical effects of crude oil spills in taiga watersheds, emphasizing effects on permafrost levels.

3. To detail the biological effects of crude oil spills in taiga watersheds, including the responses of soil microorganisms and vegetation.

In short, the plan entailed establishing three permanent research plots - a control, a winter spill and a summer spill - and monitoring the impact of petroleum contaminants on the taiga ecosystem. Of particular importance was making these spills as representative of actual conditions as possible. Important steps included:

1. Utilization of realistic quantities of crude oil. Although spills of under 100 gallons are instructive for determining general responses of individual species to the presence of petroleum contaminants, such small spills cannot provide realistic data applicable to whole biological communities. Thus the spills in this study were as large as could be logistically handled (2000 gallons or 7570 liters).

2. Preheating of crude oil before spillage. The pipeline transportation of crude oil necessarily entails handling a product whose temperature is considerably above the ambient temperature. In the case of the Trans-Alaska Pipeline, crude oil temperatures of 60 to 75°C are common. The physical behavior and the biological effects of "hot" crude may be considerably different from those of crude at ambient temperatures. The crude oil spilled in these studies was preheated to 50 to 60°C before spillage.

3. Application by flow over the ground surface. Although in pressurized pipelines a leak can result in loss of oil in a spray pattern, very large spills will result in significant spreading of the oil by flow over soil surfaces. Such flow will be especially important in sloping terrain and will present some of the most difficult detection and clean-up problems. In addition, flow down slopes in watersheds will present some of the most environmentally destructive situations, as both terrestrial and freshwater ecosystems can be impacted. The oil in these studies was applied by release on the ground surface and on a sloping terrain in a controlled research watershed.

A study that attempts to analyze the effects of a pollutant such as crude oil on a complex community such as the taiga must encompass a diversity of disciplines. During the past year, the following individuals have been working on the site:

1. Chemist: to determine the changes in the petroleum contaminants over time and the extent of coverage of petroleum fractions along the watershed slope (Thomas Jenkins).

2. Geologist: to determine the effects on thermal regimes and physical soil properties (Charles Collins).

3. Engineer: to determine the factors influencing the maximum areal coverage of the flowing crude oil and advise on possible clean-up technology (Terry McFadden).

4. Microbiologist: to determine changes in the soil-based microorganisms and the importance of microbial degradation of the petroleum contaminants (Elena Sparrow, formerly with the Arctic Environmental Research Laboratory, EPA, Fairbanks, Alaska).

5. Plant scientists: to determine the short- and long-term effects of the pollutants on the primary production of taiga systems (Larry Johnson and Brent McCown, University of Wisconsin).

Chronology of activities

A full chronology of the major activities from the beginning of the experiment (June 1975) through this reporting period (July 1977) is shown in Table 1. The activities that took place before June 1976 involved primarily the winter spill application and subsequent monitoring and were reported on in the First Year Progress Report (Appendix B). The activities that took place during this reporting period (June 1976 to July 1977) can be put in two categories:

Table 1. Chronology of activities.

Date	Accomplishment
July 1975	Final site selection: Caribou-Poker Creeks Research Watershed west of Fairbanks
July-Aug-Sept 1975	Physical preparation for the spill and subsequent monitoring
	Research site pre-spill baseline studies completed Topographical analysis (see Figure 1) Soils characterization (see Table I, App. B) Permafrost monitoring (see Table II, App. B) Vegetation composition, vegetation sampling and photo point establishment (see Table III, App. B)
Feb 1976	Winter spill applied (26 Feb)
Winter 1976	Winter spill impact studies begun Areal spread monitoring (this report) Microbial analyses (this report) Fate of petroleum constituents-chemical analysis (this report)
June-Sept 1976	Winter spill impact studies continued (this report) Areal spread of winter spill after spring break-up Microbiological analyses; intensive studies Analysis of fate of petroleum constituents Permafrost monitoring Vegetation impact
July 1976	Summer spill applied (14 July)
July-Sept 1976	Summer spill impact studies begun (this report) Areal spread monitoring Microbiological analyses; intensive studies Analysis of fate of petroleum constituents Permafrost monitoring Vegetation impact
June 1977	Summer and winter spill impact studies continued Areal spread after spring break-up (this report) Permafrost monitoring Vegetation impact

1. Application of the summer spill. On 14 July 1976 a total of 2000 gallons (7570 liters) of crude oil was applied on the plot previously designated for the summer spill (Figure 1). Methodology similar to that utilized in the winter spill was employed. The oil was preheated in a tank to a temperature of 57°C and then allowed to run out of a 5-m-long pipe perforated at 10-cm intervals. The oil was applied at the upper end of the plot. Under the force of gravity, the oil flowed at a rate of about 45 gallons per minute and was fully dispersed in less than one hour.

2. Continued monitoring of the winter spill site and initiation of monitoring of the summer spill site. The data recorded during this period are critical in that this period includes both the compounding effects of spring break-up on the movement of the oil and the effect of winter stress on the already-oil-impacted biological community.

PHYSICAL FATE OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

Extent of areal spread

Oil movement on the two experimental spill plots was periodically monitored by probing in the moss on a 1-m grid using wooden rods. The oil was readily discernible by sight and smell on the bare wood, and when detection of the presence of oil was questionable by such sensory methods, verification was readily achieved by UV-fluorescence (Deneke et al. 1975). The pattern of oil movement differed significantly between the two treatment plots, winter and summer.

In the winter study plot the oil moved 18 m downslope in the first 24 hours after it was applied on 26 February 1976. There was very little further movement until spring break-up in late April when the oil was remobilized and moved downslope another 17 m (Figure 2a). The oil has stabilized since then with no further remobilization occurring during the 1977 spring break-up.

Oil was applied to the summer treatment plot on 14 July 1976. The oil, as might be expected, progressed much further downslope initially than during the winter spill (Figure 2b). In less than 2 hours, the oil was some 15 m from the point of application. Further rapid movement continued for 2 days to a distance of 35 m downslope. From the end of July to freeze-up, however, the oil in the summer plot moved only another 1 1/2 m. No further mobilization of the oil occurred during the 1977 spring break-up.

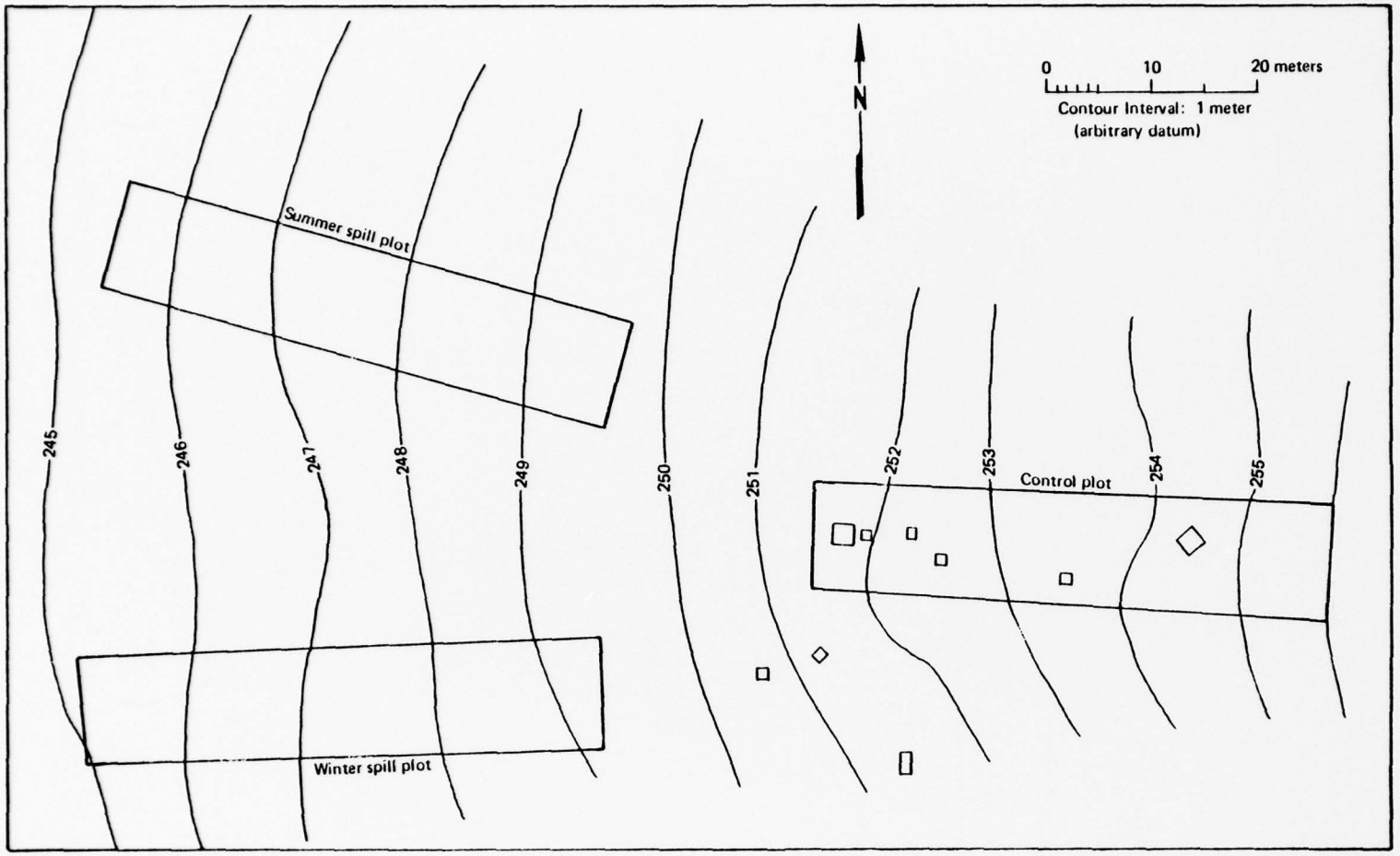
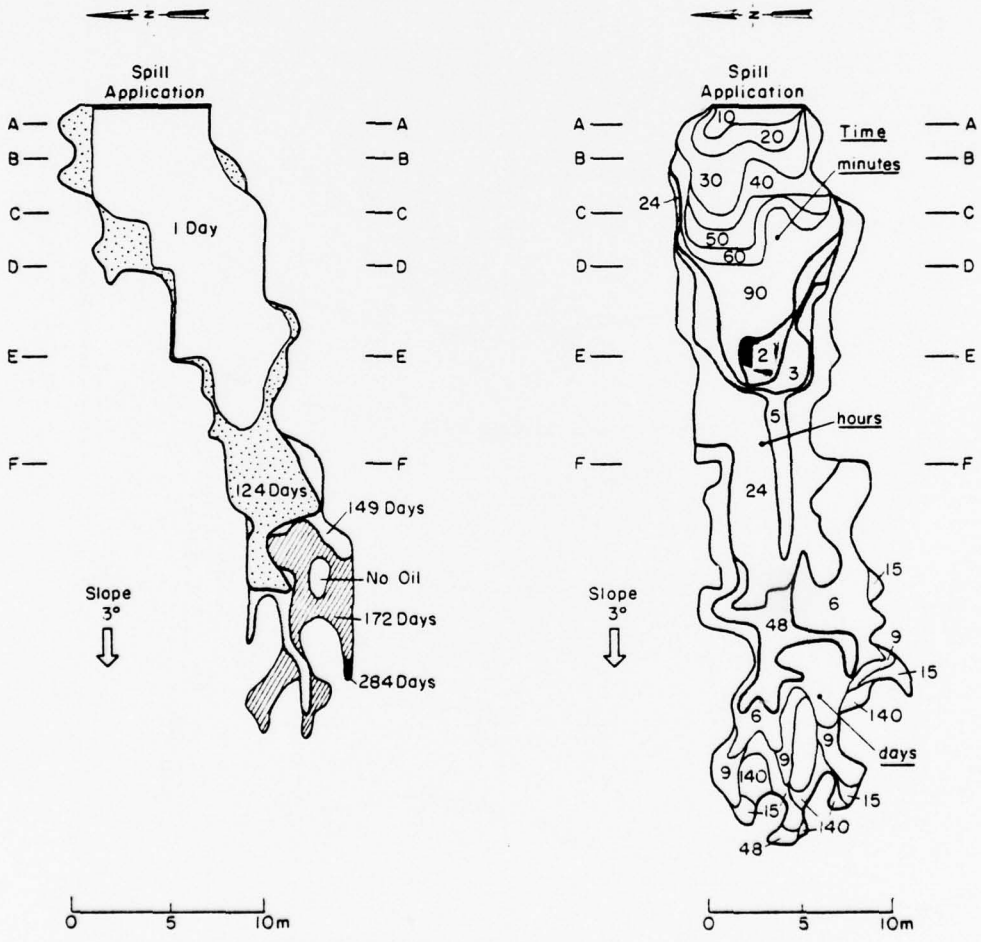


Figure 1. Layout of oil spill plots in study area.



a. Winter spill, 26 February 1976. b. Summer spill, 14 July 1976.

Figure 2. Downslope movement of oil following summer and winter spills.

During the summer spill application, the oil flowed downslope with little lateral spreading. All flow was subsurface, with only a few depressions downslope of the application point showing as saturated areas. The flow was under the moss cover, mostly undetectable except by probing. This differs from the observations of MacKay et al. (1974) of spills at Norman Wells and Inuvik, where surface flow occurred over the saturated moss during the application and ceased only after the spill ceased and the saturated moss layer started to drain.

The winter spill showed indications, after the snow had melted, of some over-surface flow beneath the snow. The reasons are uncertain but possibly the moss was saturated with ice and/or water from the previous freeze-up, or, more likely, from melting snow caused by the hot oil application. The winter spill also resulted in several pools of thick crude oil, something that did not occur during the summer spill.

The area covered by the summer spill was a third larger than that of the winter spill, 303 m^2 vs 184 m^2, even though both consisted of the same amount of crude oil (7.57 m^3 or 2000 gallons). Probably the oil in the winter spill cooled more quickly, congealed under the snow, lost some of its more volatile fractions, and was not completely remobilized the next spring.

In both cases, however, the area covered by the spills falls well within the range of area contamination projected by MacKay and Mohtadi (1975) based on actual spills in Alberta and experimental spills in the Mackenzie Valley, NWT.

Permafrost monitoring

A program of probings to determine the depth of the permafrost table in the three research sites was continued. The soil was probed at 1-m intervals along six cross sections in each of the treatment plots.

A marked increase in the thawing rate from July to August in the summer plot as compared to the winter plot was evident (Figures 3 and 4). The increased thaw rate was probably due to the initial heat input of the hot crude oil; however, the permafrost table at the July reading was lower in the winter plot than in the summer plot. Possibly, increased absorption of radiation in the oil-soaked upper portions of the winter plot may have increased final thaw depths. However, MacKay et al. (1974) originally discounted the effect of oil in decreasing the albedo of the moss in their forested (and thus shaded) plots. Further analysis of the soil temperature data may indicate differences in temperatures between the plots, which may in turn reflect albedo differences. MacKay et al. (1974) found such temperature differences in their plots, and thus modified their original conclusions about the importance of oil-induced albedo changes.

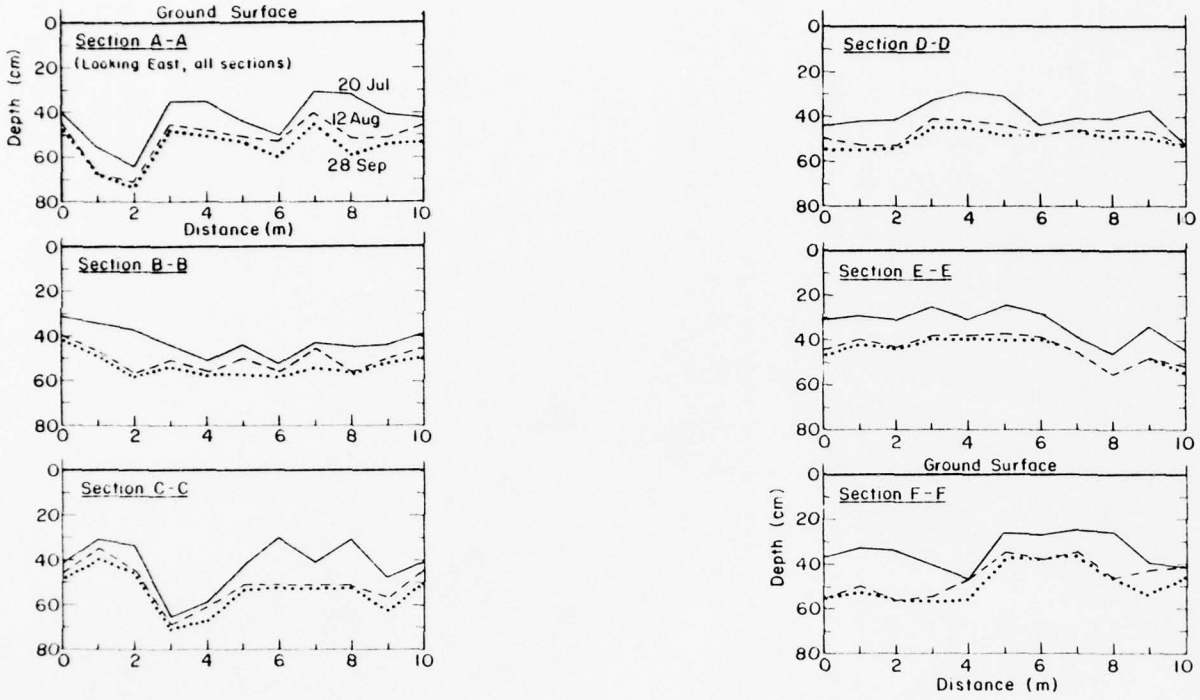


Figure 3. Depth of thaw on three dates during the first growing season after a winter oil spill on a taiga site underlain by permafrost.

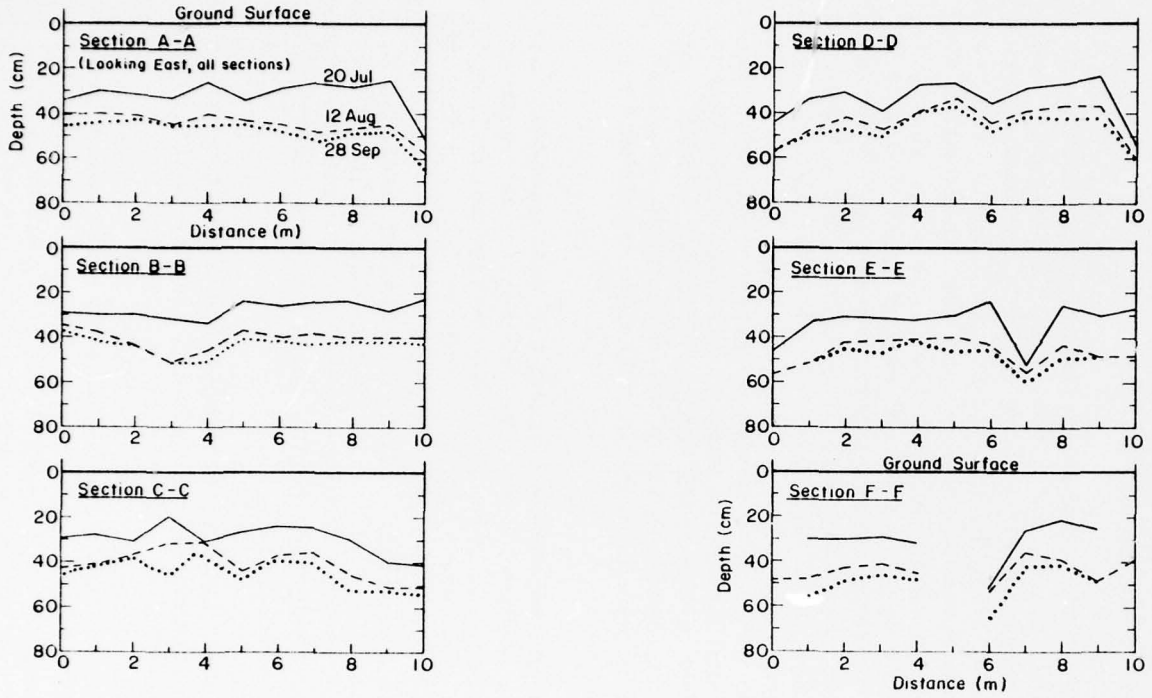


Figure 4. Depth of thaw on three dates during the summer after an oil spill (14 July) on a taiga site underlain by permafrost.

Fate of petroleum constituents

The major processes which act to modify the composition of the oil in the soil are evaporation of volatiles, solubility and translocation of water-soluble components, photochemical reactions at the surface, and microbiological degradation. Analytical procedures have been and are being developed to assess the importance of each of these mechanisms in transforming the oil contaminants on site.

During the past year, samples of the original Prudhoe oil, oil collected from pools on the test sites, and oily soil have been analyzed by headspace gas chromatography. This technique allows observation of changes in the C_1 - C_9 fraction of the oil with time. The results indicate that in the case of pooled oil on the winter spill site, methane and ethane were lost during the first two hours after the spill (Fig. 5). Volatiles in the C_3 - C_9 fraction were reduced drastically after two months and were nearly absent after five months. Soil samples from the winter duff layer indicate that C_1 - C_4 components were lost entirely five months after the spill while C_1 - C_9 persisted in detectable concentrations throughout the first year. Volatiles present in the moss layer on the winter spill site seemed to behave similarly while volatiles carried to the mineral layer depleted at a slower rate, with measurable amounts of C_4 present after seven months. Similar behavior was observed in the soils from the summer spill plots except that the duff sample seemed to retain a rather significant volatile component even after the first winter.

Since benzene and toluene are among the most water-soluble components of the oil, observations of their behavior as compared to alkanes of similar volatility will help determine whether solubility is playing a major role. The preliminary results seem to indicate that the loss rates of these two substances are similar to the less soluble alkane components of equal volatility. Thus, evaporation seems to be a much more important process in natural weathering than solubility. Water samples collected downslope from the spill will be analyzed for soluble organics in the next reporting period to get a more direct measure of the importance of this process.

Probably the most dominant mechanism for changes in the total quantity of oil components after the spill and for modification of specific components will be microbiological degradation. It has been shown that organisms capable of metabolizing oil components are widely distributed in nature. The normal alkane fraction seems to be the most readily decomposed by the process of ß-oxidation. Whether this preference will be observed in a large scale field spill is still unclear. In order to specifically look at the effects of microorganisms on the components of the oil, a fractionation scheme utilizing silica gel column chromatography was developed. This procedure fractionates oil,

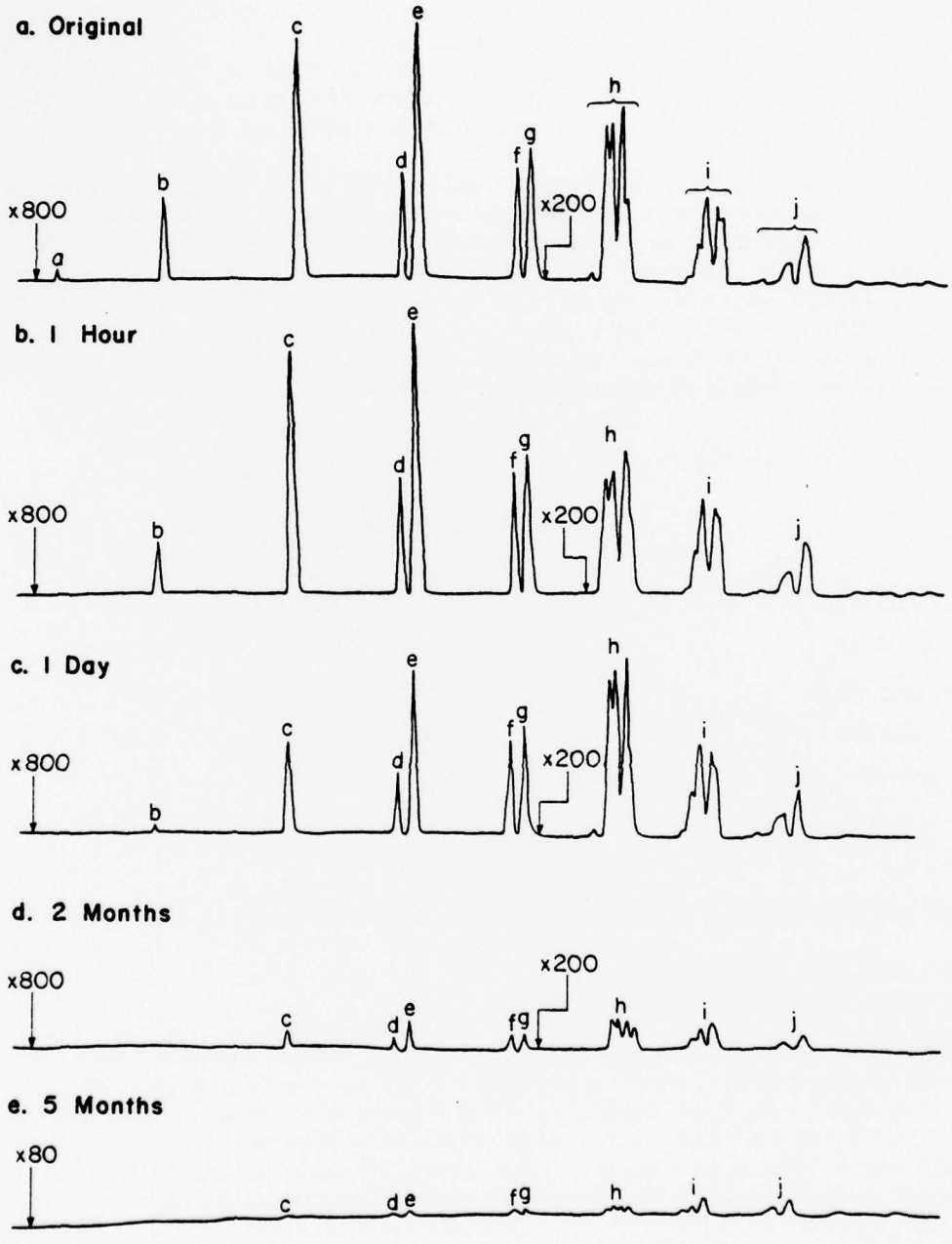


Figure 5. Chromatograms of volatiles from pooled oil on winter spill site, 1976.

or oil extracted from soil, into alkane, aromatic, asphaltene and soluble and insoluble NSO components. These components can be further analyzed by instrumental techniques, such as gas chromatography, infrared spectroscopy, or ultraviolet spectroscopy. Gas chromatographic analyses of the oil fractions are being completed. The ratio of C_{17} and C_{18} normal alkanes will be compared with pristane and phytane (isoprenic branched chain alkanes) to determine if the organisms are showing preference for the normal alkanes as has been demonstrated in laboratory studies.

The assessment of the effects of oil on the soil chemical environment has been hampered by a lack of soil chemical methods to analyze oily soil. Most methods are based on extraction with water-based solutions that do not readily wet oily soil. A procedure based on pre-extraction of the oil with a volatile organic solvent followed by drying and then extraction with the water-based extractant has shown promising results. Exchangeable cations and soil pH values in the control soils and the spill areas have remained quite similar (Table 2).

Table 2. Exchangeable cations from soils, 15 July 1976.

	Exchangeable cations (meq/100 g)			
	Na	K	Ca	Mg
Control duff (A_1)	0.16	1.80	45.25	9.22
Summer duff (A_1)	0.32	1.48	89.25	13.52
Winter duff (A_1)	0.26	1.38	23.99	4.48
Control mineral (C_2)	0.10	0.24	15.97	3.16
Summer mineral (C_2)	0.10	0.37	15.06	3.25
Winter mineral (C_2)	0.09	0.35	12.69	2.61

BIOLOGICAL EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

Microbiological responses to the presence of petroleum

Soil samples for microbiological analyses were collected from the oiled and unoiled plots from late February 1976 (one day after the winter oil spill) to late September 1976 (seven months after the winter oil spill and two and one half months after the summer oil spill). Soil sampling was confined to the first 5 m from the line of oil application in the oiled plots, where the concentration of oil was highest.

Viable cell counts of bacteria were determined using the spread plate technique and plate count agar with actidione. Bacterial numbers

in the oiled and control plots are shown in Table 3. In both the A_1 and C_2 soil horizons of the test plots, bacterial counts were higher at 20°C incubation than at 4°C. Bacterial counts in the control plot showed a seasonal increase from February to July and a decrease in September.

Table 3. Bacterial counts (in millions)* in oiled and unoiled plots.

Month	Control plot		Winter oil plot		Summer oil plot	
	4°C	20°C	4°C	20°C	4°C	20°C
			A_1 Soil horizon			
Feb	2.7	12.0	5	11	---	----
June	6.8	26.8	125	298	---	----
July	3.9	28.4	434	436	3	18
Aug	2.4	16.2	174	276	339	567
Sept	0.5	12.8	213	257	642	1278
			C_2 Soil horizon			
Feb	1.2	6.6	2	5	---	----
June	2.2	11.4	2	8	---	----
July	0.9	8.7	41	42	0.6	7
Aug	1.4	8.3	14	24	25	28
Sept	0.3	3.3	12	19	207	277

*Mean of five replicate plate counts, expressed per gram oven-dry soil.

One day after hot crude oil was spilled on the winter test plot in February, the oil had not had an apparent effect on bacterial numbers. Counts of bacteria at both 20°C and 4°C in the A_1 and C_2 soil layers in the winter plot were comparable to those in the control plot. By June, bacterial counts in the A_1 soil layer of the winter plot increased at both incubation temperatures and exceeded bacterial numbers in the control plot. In the C_2 layer, at 20°C, bacterial counts in the winter plot were significantly lower than those in the control plot. Bacterial counts in the winter plot reached their peak in July. It is interesting that in July, counts at 4°C were similar to counts obtained at 20°C. In August and September, bacterial counts in the winter plot seemed to level off but were still higher than those in the control plot.

One day after the summer oil spill, the oil had already had an effect on bacterial numbers. In the A_1 layer of the summer plot, at 20°C incubation, bacterial counts were significantly lower than those in the control plot (5% level). The same result was obtained using Frazier's gelatin medium to estimate bacterial numbers (10% level). By August, bacterial numbers in the A_1 and C_2 soil layers of the summer plot had increased at both incubation temperatures and exceeded bacterial counts

not only in the control plot but also in the winter plot. This was also true in September; at this time, the highest bacterial counts in the summer plot were obtained while counts in the winter and control plots leveled off.

Filamentous fungal numbers obtained using Martin's medium are shown in Table A1 (Appendix A). Plate counts at 20°C were higher than those at 4°C for both the A_1 and C_2 soil horizons in all test plots. One day after crude oil was spilled on the winter plot in February, an analysis of variance showed that crude oil had had a significant effect on fungal counts. Fungal numbers in the A_1 layer of the winter plot were significantly lower than those in the control plot (5% level) at 4°C; similarly, counts in the C_2 soil layer at both incubation temperatures were significantly lower than those in the control plot (1% level). Counts of filamentous fungi in the winter plot were even more depressed in June compared to counts in February and to those in the control plot. Fungal counts obtained in July, August and September in the winter plot were generally lower than those in the control plot except for counts obtained from the 20°C incubation of soil from the C_2 soil horizon in July.

One day after the summer oil spill, fungal numbers in the A_1 layer were significantly lower than those in the control plot (1% level). However, the reverse was true for counts in the C_2 layer. In August, fungal counts in the A_1 layer in the summer plot were comparable to those in the control plot but in the C_2 layer fungal counts were significantly lower than those in the control plot (5% level). By September, fungal numbers in the summer plot in both soil layers had increased and exceeded numbers in both the control plot and the winter plot.

Using DiMenna's medium for plating yeasts, viable cell counts of yeasts were estimated in the oiled and unoiled plots. Yeast numbers in the oiled plots were higher than those in the control plot (Appendix A, Table A2).

Counts of proteolytic bacteria (on Frazier's gelatin medium) in the oiled and unoiled plots were generally higher than those in the control plot except in February (Appendix A, Table A3). Counts in the A_1 and C_2 layers at 20°C in the winter plot and in the C_2 soil layer at 4°C in the summer plot were lower than those in the control plot.

Counts of autotrophic nitrifying bacteria were variable in all test plots. Numbers ranged from zero to 8000 per gram soil in the control plot, zero to 26000 per gram soil in the winter plot and zero to 28000 per gram soil in the summer plot. Numbers of denitrifiers were comparable at 4°C and at 20°C (Appendix A, Table A4). In July, denitrifiers were definitely more abundant in the winter plot than in the control plot or in the summer plot. By September, densities of denitrifiers were higher in the summer plot compared to the control and the winter plots. Although

counts in the winter plot decreased in September, they still exceeded those in the control plot. The existence of a large population of denitrifiers in the oiled plots points to a large denitrifying potential. The 100- to over 1000-fold increase in denitrifiers in the summer plot between 1 day (July sampling) and 2 1/2 months (September sampling) after oil was spilled indicates that conditions in the oiled plot may have been suitable for denitrification. After the addition of the oil, with mosses and other low-growing plants being killed, a supply of readily oxidizable organic compounds may have been available. In addition, the oil together with the high moisture content (153% soil water) in the summer plot may have affected the aeration status by decreasing oxygen availability which would favor denitrification.

Counts of oil-utilizing bacteria and fungi (obtained using Bushnell and Haas Cab-O-Sil Oil Silica Gel medium and a modified Most Probable Number method) in the oiled and unoiled plots are presented in Appendix A, Tables A5 and A6, respectively. One day after the oil spill (in February for the winter plot and in July for the summer plot), counts of oil utilizers in the oiled plots were comparable to counts in the control plot. By September, counts of oil-degrading bacteria in the oiled plots exceeded those in the control plot, the increase being of a higher magnitude in the summer plot. This increase was similarly true for fungal hydrocarbon degraders, the higher numbers of fungal oil utilizers in the oiled plots being more apparent at 20°C incubation temperature.

Numbers of cellulolytic bacteria and fungi (obtained using a Bushnell and Haas Cellulose Silica Gel medium and a modified Most Probable Number technique) are shown in Appendix A, Tables A7 and A8, respectively. Similar counts of cellulose-utilizing bacteria and fungi were obtained from the oiled plots and the unoiled plot, one day after oil was applied. In September, numbers of cellulose-degrading bacteria were greater in the oiled plots than in the control plot. Fungal cellulose degraders likewise increased in the oiled plots in September and exceeded numbers found in the control plot, particularly at 20°C.

For <u>in vitro</u> soil respiration measurements, soil samples were brought into the laboratory for respiration rate measurements determined as CO_2 evolved per 24 hr per 100 g soil using biometer flasks. Carbon dioxide evolution rates were generally higher at 20°C than at 4°C (Table 4). Oil had a significant effect on soil respiration. One day after the winter oil spill, carbon dioxide evolution rates were lower in soil samples collected from the winter plot than in those obtained from the control plot (significant at 1% level). By July, respiration rates increased in soil samples from the winter plot and remained significantly higher than those in the control plot through September.

One day after the summer oil spill, there was no inhibitory effect of oil on soil respiration rate in soil from the summer plot except in soil from the C_2 layer incubated at 4°C. In soil samples from the A_1

Table 4. Soil respiration* in oiled and unoiled plots.

Date	Control plot		Winter oil plot		Summer oil plot	
	4°C	20°C	4°C	20°C	4°C	20°C
			A_1 soil horizon			
26 Feb	27	104	11	50	---	----
16 July	8	40	16	97	20	146
12 Aug	9	26	16	42	31	88
29 Sept	4	22	16	49	38	121
			C_2 soil horizon			
26 Feb	2	10	1	3	---	----
16 July	4	12	6	20	1	15
12 Aug	3	8	8	15	6	9
29 Sept	3	5	7	18	14	34

*Mean of five replicate determinations, expressed per gram oven-dry soil.

layer, respiration in the summer oil plot was greater than in the control and winter plots in July, August and September. In soil samples from the C_1 soil horizon, respiration rates in the summer plot were also significantly higher than those in the control plot and the winter plot but only in September.

In situ soil respiration was determined by measuring carbon dioxide evolution rates in the field using open-ended cylinders sunk into the test plots. Alkali was used for absorbing carbon dioxide evolved over a 24-hr period. The live moss-plant layer was removed in the control plot before cylinders were embedded. In the oiled plots two sets of cylinders were embedded, one with the moss layer intact and another with the moss layer removed. High variability between replicate respiration measurements within test plots made it difficult to interpret the effect of crude oil on in situ respiration (Table 5). In the oiled plots, respiration was generally higher in cylinders implanted without removal of the moss layer. The difference in respiration is significant only in September for the winter plot (25% level) and in August (both dates) for the summer plot (10% level). Carbon dioxide evolution rates in the control plot were not significantly different from those in the oiled plots in cylinders embedded after removal of the moss layer. However, in cylinders with moss, respiration rates in the summer plot were significantly higher than those in the control plot in August and September (1 to 10% level). Similarly, respiration rates in cylinders with moss in the winter plot were significantly higher than those in the control plot on 12 August (1% level). Mosses and lichens are sensitive to crude oil. The moss layer was killed in the oiled plots in the areas of maximum oil saturation where the respiration cylinders were buried. The increased carbon dioxide evolution in the oiled plots in cylinders with the moss layer could be due to increased carbon substrate from the spilled oil and the dead plant material.

Table 5. *In situ* respiration (g CO_2/24 hr-m^2)* in oiled and unoiled plots.

Date	Control plot	Winter oil plot		Summer oil plot	
	a	a	b	a	b
10 June	4.7 ± 4.8	-	7.0 ± 3.3	-	-
16 July	3.7 ± 1.6	-	5.1 ± 4.4	-	5.7 ± 2.5
3 Aug	4.8 ± 2.5	4.6 ± 1.7	5.8 ± 3.0	5.7 ± 3.0	8.6 ± 3.2
12 Aug	2.2 ± 0.9	3.3 ± 1.0	4.8 ± 1.7	2.7 ± 1.7	5.7 ± 2.4
1 Sept	2.9 ± 2.1	1.6 ± 0.6	4.0 ± 3.1	4.5 ± 1.8	6.4 ± 3.7

*Mean value ± one standard deviation.
a-Respiration cylinders embedded after removal of moss layer.
b-Respiration cylinders embedded without removal of moss layer.

Results of soil moisture and soil pH measurements are shown in Appendix A, Tables A9 and A10. Percentages of oil in soil samples, extracted with benzene, are presented in Appendix A, Table A11.

These microbiological analyses conducted the first year after a crude oil spill on taiga show the following general trends:

1. The simulated oil spills conducted in the winter and in the summer resulted in increases in bacterial counts in the oiled plots. The greatest magnitude of increase occurred in the A_1 layer, the upper soil horizon and in the summer plot.

2. One day after crude oil was spilled, there was a reduction in fungal numbers in both the A_1 and C_2 layers in the winter plot and in the A_1 layer in the summer plot. The depression in fungal counts in the winter plot was still apparent even after four months. On the other hand, fungal numbers in the summer plot had increased within a month and were comparable to counts in the control plot. After 2 1/2 months, fungal numbers exceeded those found in the control plot. Fungal counts in the summer plot showed not only a quicker recovery from the initial depression but also a stimulation from the addition of the oil.

3. The oil also seemed to have a stimulatory effect on yeasts. Numbers of yeasts in the oiled plots were significantly higher than those in the control plot. Similarly, numbers of denitrifiers significantly increased in the oil-treated plots, indicating an increase in denitrifying potential. Proteolytic bacteria, oil-utilizing bacteria and fungi and cellulolytic microorganisms were also favorably affected by the oil, as indicated by their increase in numbers in the oiled plots.

4. Crude oil seemed to have an adverse effect on respiration in soil from the winter plot, one day after oil was applied. However, this effect was not long-lasting. Respiration rates

in soil from the winter plot and the summer plot increased and were significantly greater than those in soil from the control plot. In situ carbon dioxide evolution rate measurements showed higher respiration rates in the oil-treated plots than in the unoiled plot.

Plant cover responses

Observations of vegetation damage associated with the winter oil spill continued during the 1976 growing season. The vegetation analysis for the summer spill plot was completed in June 1976 according to the methods described in Appendix B. Photographic and written records of both oil spill plots (winter and summer) as well as of control areas were kept throughout the 1976 growing season in order to assess differences in phenology, growth, and general condition between treated and untreated areas. Samples of spruce needles were collected from treated and untreated areas of both plots. The current year's needles from these samples and from similar 1975 samples of the winter spill are being analyzed for selected nutrients in order to determine if oil has a significant effect upon mineral nutrient uptake and utilization.

The initial season of observations has indicated that there are a number of oil-related effects on the vegetation cover in the plots. The general trends for both spills are summarized below:

1. Oil tended to flow in the depressions and low areas so that vegetation on the higher microtopography was not in physical contact with the oil. These higher areas did not show any immediate impact.

2. Virtually all aboveground vegetation parts that came into immediate contact with the oil were killed. The zone of contact was generally limited to the immediate areas below the 5-m-wide oil feeder and to areas of low microtopography which were in the path of aboveground flowing oil.

3. Lichens and mosses were particularly susceptible to damage by the oil. Almost all mosses and lichens that were directly in the path of the oil were killed. Such high susceptibility was at least in part due to their low growth form and their prevalence in the more heavily impacted lower microtopographical areas.

4. Some clear differences in susceptibility (or at least in length of time before visible symptoms of injury appeared) were apparent between different species and between the winter and summer oil spill plots. It was not possible to determine how many of these differences in appearance of injury were due to the application of the oil at different times of the year (July 1976 vs February 1976) or to differences in toxicity between winter- and summer-applied oil.

The winter oil spill showed the following impacts on the vegetation:

Cotton grass (Eriophorum vaginatum) tussocks continued to flower despite oil on all sides of the tussocks in May.

By mid-July the cranberry (Vaccinium vitis-idaea) leaves were turning reddish brown and Labrador tea (Ledum groenlandicum and L. decumbens) leaves were starting to brown on the plants that were located in and beside the areas of surface flow. This trend continued throughout the summer until affected leaves became entirely brown.

Vegetation in the summer spill plot also showed some obvious responses to the presence of the petroleum contaminants:

The dwarf birch (Betula glandulosa) showed a rapid response near areas of visible oil flow. By late July, foliage was turning brown and by mid-August the foliage in these areas was completely brown.

Rubus chamaemorus leaves began browning at their edges by late July and were completely brown by mid-August near surface oil flows. Blueberry (Vaccinium uliginosum) showed a similar response.

Labrador tea leaves did not begin turning brown until mid-August and by mid-September they were almost completely brown.

Spruce (Picea mariana) needles began yellowing in mid-August and by mid-September some smaller spruce in the upper part of the plot were entirely brown.

There was a gradual progression of browning foliage, as the season progressed, that moved downslope along the plot and also laterally, at least to some extent, away from the surface oil flows. For example, by late July no damage was evident below 15 m and by mid-August damage was evident at 20 m below the spill.

In summary, it appeared that damage from the summer spill exceeded that from the winter spill. The area of damage from the summer spill seemed to continue enlarging during the growing season, whereas damage from the winter spill was more localized. This may have been due to greater penetration of the oil into the soil in the summer spill plot and consequent damage to adjacent root systems. Another factor may have been the presence of a higher percentage of volatile fraction during the active growing season in the summer spill than the winter spill.

CONCLUSIONS

The early results of these experiments have shown that some rather clear differences and similarities are apparent when comparing the impact of summer and winter oil spills. Of particular note is the mobility of the crude oil. In winter, the oil showed less than 50% of the mobility in downslope movement that it did in the summer, probably as a result of low temperature increase in viscosity. However, immobility appears only temporarily, as once temperatures rose above freezing during the spring thaw, the oil moved nearly as far downslope as it did in the summer spill. However, of even greater importance is the observation that there was no further substantial oil movement downslope on either spill plot after a summer season. These observations may indicate that the highly organic soils in these taiga areas have a relatively high capacity of sorption for petroleum constituents and thus may act as a natural trap for petroleum contaminants.

As regards the full area impacted by the spills, the summer spill appeared to be more detrimental than the winter spill. Although the winter spill covered 1/3 less area than the summer spill, at least part of this difference is attributable to differences in microrelief between the two plots (the oil was more channelized in the winter spill plot). However, the low temperature immobilization of the crude during winter allowed evaporation of volatiles, which undoubtedly reduced mobility during the subsequent spring and summer months, thus decreasing the total area impacted. The presence of pooled, thick oil areas on the winter spill site supports the latter conclusion.

The impact on the taiga vegetation cannot be fully evaluated at this early date. Although surface contact of crude oil on vegetation results in rapid death of the affected parts, petroleum in the soil horizons is a sublethal agent. Of particular interest is the combined effect of the stress placed on the plants by the oil and the subsequent winter stress. Other studies (McCown et al. 1973) have shown that these combined stresses may prove lethal while either one alone may be tolerated by plants. Further observations over subsequent winter seasons are needed to evaluate this possibility.

In contrast to the higher plants, the microorganisms show rather rapid responses to the presence of sublethal amounts of petroleum in the soil environment. Although timing differences are apparent in the responses of the organisms to summer and winter spills, the ultimate response is quite similar. Microbial growth is stimulated, at times drastically above that observed in control plots. Such increased activity may be due to the combined effect of the presence of the petroleum substrates and to the release of the substrates from dying higher plants. The practical consequences of large increases in the denitrifying and oil-degrading bacteria have yet to be fully evaluated but may direct the type and timing of fertilizer applications.

Finally, the effect on the thermal regime of these permafrost soils appears to be minimal, whether the spill occurs in the summer or winter. The heavy organic mat in northern regions appears to act as enough of an insulating agent to prevent rapid permafrost degradation even though death to the vegetation occurs. This obviously has consequences for future recommendations for clean-up technology in such areas.

ACKNOWLEDGMENTS

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APPENDIX A: MICROBIOLOGICAL RESPONSES

Table A1. Fungal counts ($x10^4$)* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	132	190	92	160	---	----
June	118	234	14	15	---	----
July	95	161	18	27	49	60
Aug	34	106	23	80	31	84
Sept	24	62	10	72	106	465
			C_2 Soil horizon			
Feb	19	25	4	8	---	----
June	24	33	0.7	3	---	----
July	13	13	8	20	17	35
Aug	15	19	3	5	5	11
Sept	5	7	2	3	7	91

*Mean of five replicate plate counts, expressed per gram oven-dry soil.

Table A2. Counts ($x10^4$) of yeasts* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			Duff layer			
June	23	23	2258	3329	---	----
Aug	8	30	137	6221	6728	10362
Sept	4	85	221	1181	737	9911
			Inorganic soil layer			
June	8	14	14	24	---	----
Aug	3	4	122	480	648	1005
Sept	2	16	8	106	5486	10410

*Based on five replicate plate counts and expressed per gram oven-dry soil.

Table A3. Counts ($x10^5$) of proteolytic bacteria* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	0.2	66.9	2.6	60.1	---	----
June	1.7	196	2.7	2912	---	----
July	0.3	68.1	105	802	1.0	113
Aug	0.9	33.5	56.8	151	1031	3864
Sept	1.0	23.7	95.1	627	1110	3964
			C_2 Soil horizon			
Feb	0.6	16.0	0.6	9.5	---	----
June	0.2	60.8	6.3	24.7	---	----
July	0.7	16.9	22.6	213	0.2	40.4
Aug	0.2	8.1	5.1	10.6	109	245
Sept	0.2	8.2	5.3	64.1	372	1371

*Mean of five replicate plate counts and expressed per gram oven-dry soil.

Table A4. Counts ($x10^2$) of denitrifiers* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
July	0	19	63000	63000	35	51
Sept	2	30	2100	4700	43600	43600
			C_2 Soil horizon			
July	0.5	13	3300	5100	0.5	40
Sept	2	2	100	350	2200	6800

*Based on an MPN technique, expressed per gram oven-dry soil.

Table A5. Counts ($x10^5$) of oil degrading bacteria* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	0.2	0.2	0.4	0.2	---	----
July	0.4	10	14	31	0.2	3
Sept	0.2	0.8	86	17	357	231
			C_2 Soil horizon			
Feb	.01	.02	.009	.009	---	----
July	.02	2	5	16	.08	2
Sept	.10	.5	12	5	13	83

*Counts based on a modified MPN technique, expressed per gram oven-dry soil.

Table A6. Counts ($x10^4$) of oil degrading fungi* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	3.1	2.2	1.8	2.5	---	----
July	5	24	.8	18.6	2.4	35.9
Sept	5	19	6.7	66.5	26.4	522
			C_2 Soil horizon			
Feb	0.1	0.3	0.1	0.1	---	----
July	0.7	5	0.5	30	1	7.5
Sept	0.1	0.2	0.1	6.4	9.8	225

*Counts based on a modified MPN technique, expressed per gram oven-dry soil.

Table A7. Counts ($x10^5$) of cellulolytic bacteria* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	2	8	0.2	4	---	----
July	1	31	≥140	32	1	12
Sept	2	10	≥1141	114	≥1586	≥1586
			C_2 Soil horizon			
Feb	0.2	0.7	0.03	0.2	---	----
July	0.2	7	16	16	0.3	10
Sept	0.1	2	90	12	784	451

*Counts based on a modified MPN technique, expressed per gram oven-dry soil.

Table A8. Counts ($x10^4$) of cellulolytic fungi* in oiled and unoiled plots.

Month	Control plot 4°C	Control plot 20°C	Winter oil plot 4°C	Winter oil plot 20°C	Summer oil plot 4°C	Summer oil plot 20°C
			A_1 Soil horizon			
Feb	11	22	60	18	---	----
July	33	123	10	13	8	51
Sept	4	10	5	80	12	522
			C_2 Soil horizon			
Feb	12	9	1	0.9	---	----
July	1.4	5	6	5	4	4.5
Sept	1.2	10	0.06	6	0.1	83

*Counts based on a modified MPN technique, expressed per gram oven-dry soil.

Table A9. Soil water content (%)* in oiled and unoiled plots.

Month	Control plot	Winter oil plot	Summer oil plot
		A_1 Soil horizon	
Feb	295	154	---
June	214	119	---
July	155	122	171
Aug	113	96	161
Sept	95	81	153
		C_2 Soil horizon	
Feb	56	70	---
June	114	56	---
July	71	71	99
Aug	62	63	52
Sept	55	50	83

*Means of three determinations, reported as precentage of oven-dried soil.

Table A10. Soil pH of oiled and unoiled plots.

Month	Control plot	Winter oil plot	Summer oil plot
		A_1 Soil horizon	
Feb	4.8	5.5	---
June	5.6	5.7	---
July	5.5	6.2	6.1
Aug	5.4	5.7	5.5
Sept	5.2	5.7	5.7
		C_2 Soil horizon	
Feb	5.2	5.2	---
June	5.0	5.5	---
July	5.1	5.2	4.8
Aug	5.3	5.5	5.7
Sept	5.3	5.6	6.7

Table All. Concentration of oil (%)* in soil samples from oiled plots.

Month	Winter oil plot	Summer oil plot
	A_1 Soil horizon	
Feb	8.0	---
June	17.9	---
July	8.8	12.2
Aug	4.3	6.3
Sept	5.1	6.5
	C_2 Soil Horizon	
Feb	0.2	---
June	0.1	---
July	1.5	1.3
Aug	1.0	0.2
Sept	1.4	0.9

*Mean of three replicate determinations.

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The long-term effects and ultimate fate of crude oil spilled on permafrost-underlain tundra is the subject of this study. The project involves two experimental oil spills of 2000 gallons (7570 liters) each on 500-m^2 test plots near Fairbanks, Alaska. A winter spill, discussed in this progress report, took place in February 1976. Another spill will take place at the peak of the growing season in the summer. This allows conditions prevailing during these climatic periods to be studied as to their effect on oil spills, and makes it

20. Abstract (cont'd)

possible to study the reaction of the spilled oil to these temperature extremes. The spill discussed in this report was designed to simulate a real pipeline leak, and was large enough to approach reality while remaining within the limits of logistical capabilities. Monitoring of the spill and control plots includes: oil movement, temperature regime, biological effects, microbiological changes, permafrost impact, and chemical degradation of the oil.

FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN

First Year Progress Report

by

C. Collins, F. Deneke, T. Jenkins, L. Johnson
T. McFadden, C. Slaughter and E. Sparrow

Introduction

Under the sponsorship of the Environmental Protection Agency, the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory, has initiated a study to evaluate the fate and effects of crude oil on a permafrost taiga site in interior Alaska.

Crude oil to be transported by the Trans-Alaska pipeline will be 60°-74°C (140°-165°F). For this study Prudhoe Bay crude oil is being heated and applied to undisturbed sites underlain by permafrost. Both summer and winter spills are possible; and since each may have different characteristics, the project was designed to evaluate both. Study of oil fractionation and breakdown over time, thermal effects in the soil mantle, effects on vegetation, and microbiological aspects are included in the project.

Summary of study plan

The basic plan is to apply hot oil to instrumented plots during both summer and winter, and monitor thermal changes, oil movement, changes in oil composition, microbiological effects and plant response. A realistic simulation of possible oil spill conditions called for relatively large quantities of oil, applied rapidly over a small area. The experimental design formulated consisted of three study plots, each 10 m × 50 m with the long axis downslope. One plot was to be designated control, and was located upslope from the other two to avoid the possibility of contamination from treated plots. Two treated plots, one for winter and one for summer, were designated. At each, 7570 liters (2000 gal) of hot oil was to be applied along a 5-m-wide front at the top edge of the plot. Pre-treatment site characterization included vegetation, soil, and microbiological analysis. Instrumentation for monitoring thermal responses was installed prior to the treatment. The final study area layout is shown in Figure 2.

Results to date

1. Site selection. Final site selection was completed in July 1975. The study site chosen lies in the lower reaches of the Caribou-Poker Creeks Research Watershed, 48 km (30 miles) north of Fairbanks, Alaska (Fig. 1). It has a moderate (7-8%) west facing slope. The study plots were located, boundaries flagged, and a plane-table map of the area prepared (Fig. 2).

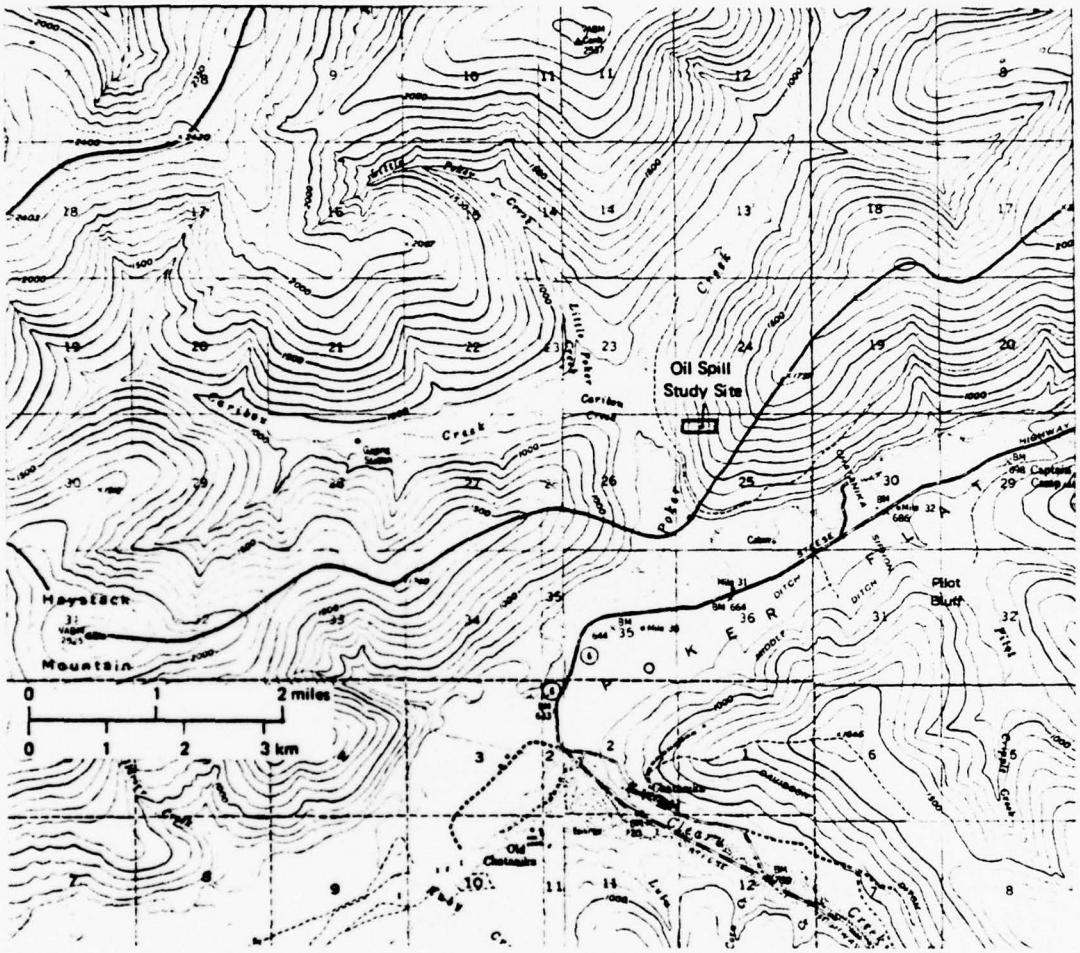


Figure 1. Study area in Caribou-Poker Creeks research watershed.

The area is approximately 300 m (1000 ft) above sea level; the nearest watercourse is Poker Creek, approximately 800 m (900 yards) to the west. The Chatanika River, into which Poker Creek flows, is approximately 2.4 km (1½ miles) to the south. An abandoned water diversion ditch built in 1910 lies between the oil study site and Poker Creek, providing a guard against possible oil contamination of Poker Creek.

2. Soils. The initial site characterization task, plane table mapping, was followed by soils, vegetation, and microbiological classification. Soils are classified as Saulich silt loam (Rieger et al. 1972). The Saulich series consists of poorly drained soils on the foot slopes of hills; the soils are almost always wet and have shallow permafrost. They differ from Ester soils in that they are deeper over bedrock and are not as acid. A representative profile of Saulich silt loam taken about 1.3 miles west of Caribou Creek is given in Table I.

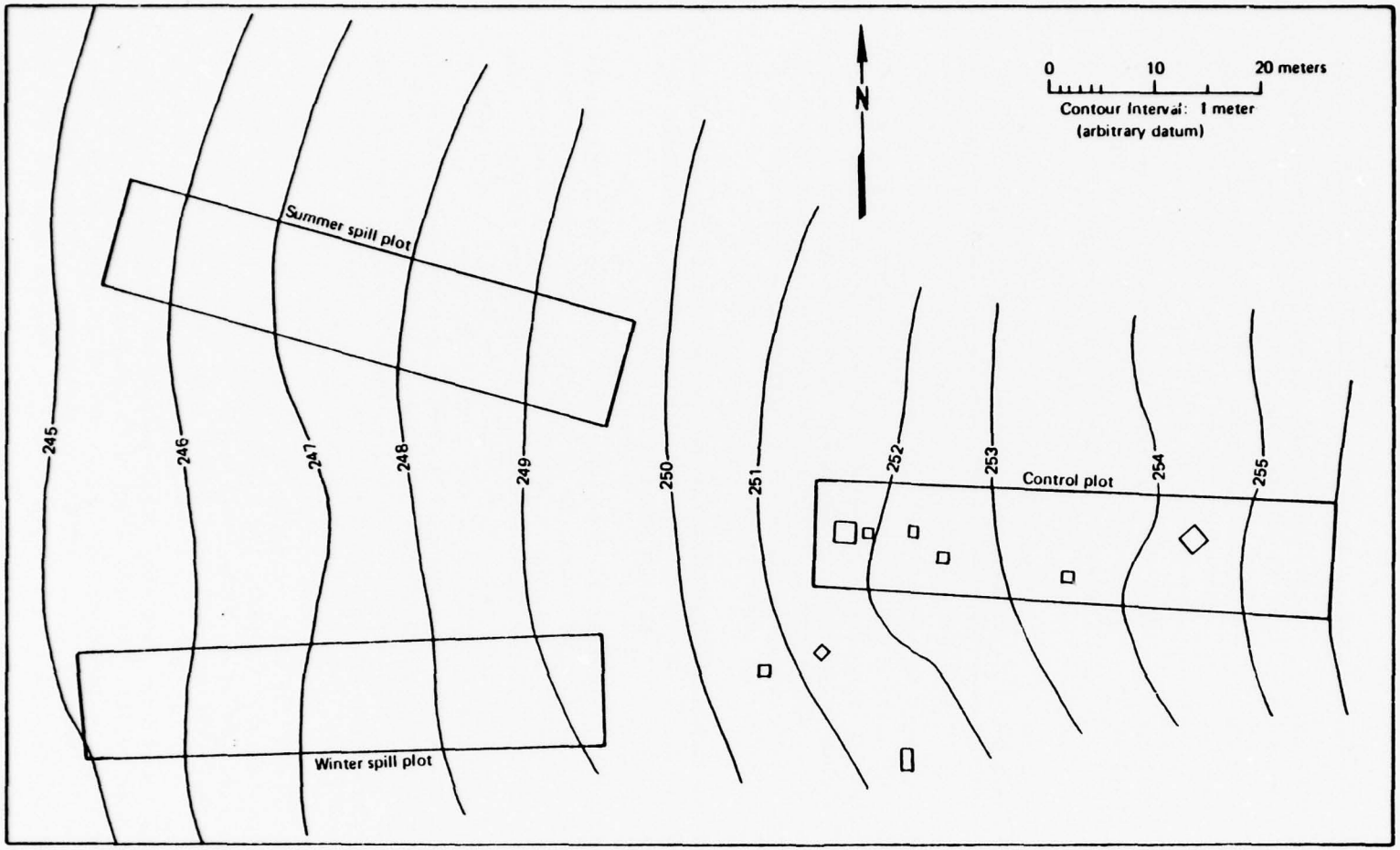


Figure 2. Layout of oil spill plots in study area.

Table I. Profile of Saulich silt loam.

Horizon	*Depth*	*Description*
O1	33-7 cm (13-3 in.)	Relatively undecomposed sphagnum moss peat; abrupt smooth boundary.
O2	7-0 cm (3-0 in.)	Dark reddish brown (5YR 3/2) finely divided peat; many roots; charcoal fragments; abrupt wavy boundary.
A1	0-7 cm (0-3 in.)	Very dark grayish brown (2.5Y 3/2) silt loam mixed with lenses of moss peat and charcoal fragments; massive; roots common; strongly acid; abrupt wavy boundary.
C2f	7-30 cm (3-12 in.)	Dark grayish brown (2.5Y 4/2) silt loam; frozen, with clear ice lenses; medium acid.

A typical profile has a thick mat of moss peat over a thin layer of mixed mineral and organic matter and, beneath that, dark grayish brown silt loam. Depth to permafrost ranges from a few centimeters to 75 cm (30 in.), depending largely on the thickness of the mossy mat on the surface. A few "frost scars" with little or no vegetation occur; the depth to permafrost is greater under the scars. Shattered bedrock is at a depth of 0.5 to 1.0 m (20 to 40 in.).

The maximum depth of the active layer was determined by probing at 1-m intervals along six cross sections in each plot; average depths to the permafrost layer are given in Table II.

3. Vegetation. Vegetation cover was characterized by sampling a number of 1 m × 1 m plots according to an accepted classification system (Ohmann and Rheam 1971) previously utilized in the Research Watershed (Troth et al. 1975). Sample quadrats were located at 5-m intervals downslope from the planned oil application point. Ten quadrats were sampled in the winter and summer spill sites and five in the control plot. All trees in each quadrat were measured, all shrubs counted by species, all forbs and herbaceous species counted by species, and occurrence and projected ground cover of trees, shrubs, and forbs visually estimated. Each vegetation sample plot was marked on the ground for further remeasurement. The results of this vegetative survey are provided in Table III. Essentially the area is typical permafrost-site plant community (Fig. 3): black spruce (*Picea mariana*) overstory; shrub understory of blueberry (*Vaccinium uliginosum*), Labrador tea (*Ledum groenlandicum* and *L. decumbens*), occasional willow (*Salix* sp.) and dwarf birch (*Betula glandulosa*), underlain by a thick (10-40 cm; 4-16 in.) mat of moss and lichens.

Photographs of each plot were taken during the growing season for a permanent visual record. Finally samples of needles from a number of black spruce trees in the winter spill, summer spill, and control areas were taken to be analyzed for nitrogen and phosphorus. Other samples from the same black spruce will be taken in the fall of 1976 and analyzed

Table II. Depth (cm) of active layer to permafrost in winter oil spill plots, July 1976.

Distance from top edge (m)	*Distance from south edge (m)*										
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
20 July											
1	40	56	64	35	35	44	50	31	32	41	42
3	31	34	37	44	51	44	52	43	45	44	39
6	41	31	34	65	59	42	30	41	31	48	41
9	44	42	42	33	29	31	44	41	41	37	51
14	31	29	31	25	31	24	28	39	46	34	44
20	37	33	34	41	47	26	27	25	26	40	41
26 July											
1	41	63	67	38	39	47	51	35	41	45	44
3	35	38	42	48	55	51	52	45	50	46	43
6	45	31	38	67	61	44	38	45	40	51	46
9	46	47	45	33	35	38	46	44	38	35	47
14	35	33	36	30	36	31	33	40	50	36	42
20	42	41	36	50	47	28	30	32	30	43	41

for N and P to determine if there are any significant changes in nutrient content associated with the trees near the spill sites.

4. Physical preparations. Elevated crosswalks were installed at 5-m intervals across the treatment plots to allow direct access to the plots while minimizing surface trampling and disturbances (Fig. 3). Aluminum I-beams were supported on timber blocking.

An extensive thermocouple array was designed and installed in the plots. Temperature measurement was desired at five levels (Fig. 4), from within the permafrost up to the overlying moss/lichen ground cover. This vertical array was replicated 36 times (Fig. 5), to allow adequate spatial monitoring of thermal effects. Thermocouple leads were connected to centrally located switches, facilitating manual read-outs. Measurement of the soil temperature regimen was initiated 6 Aug 75. Temperature trends for selected thermocouple arrays are given in Figure 6.

"Oil detection stakes," 32-mm (1¼-in.) wooden dowels, were inserted into the soil (Fig. 5). Rapid absorption of any oil reaching the untreated wood of the dowel can be readily detected either visually, by smell, or with a fluorescent light.

A station for monitoring local climate was installed by the Fort Wainwright Detachment, Meteorological Support Command. Air temperature, ground temperature in the moss, wind run, and precipitation are monitored (Fig. 7).

Table III. Results of initial vegetation analysis and soil thaw measuring - winter treatment (spill) and control plots.

Live ground cover - total		Frequency of occurrence (%) Spill	Frequency of occurrence (%) Control	*Cover class (range) Spill	*Cover class (range) Control	Aug thaw Spill	Aug thaw Control	No. of individuals (range) Spill	No. of individuals (range) Control
Trees	*Picea mariana*	80	60	0-8	1-5	26	32	0-7	1-4
	Rubus chamaemorus	70	100	0-2	2-3	25	33	0-15	16-54
Dwarf	*Equisetum sylvaticum*	80	40	1-2		37	31		
shrubs and	*Petasites hyperboreus*	30	100	1-2	1-3	28	49	1-3	1-20
herbs	*Eriophorum vaginatum*	100	60	1-5	1-2	27	40		
	Grammea spp.		40	1					
Mosses	Total	100	100	4-7	6-8	33			
	Pleurozium schreberi	100	100	3-6	4-6	37			
	Polytrichum spp.	100	100	1-3	1-2	30			
	Dicranum spp.	80	80	1-2	1-3	28			
	Sphagnum spp.	40	40	1-5	5-6	35			
	Other	10		1					
Lichens	Total	100	100	3-6	4-6				
	Foliose	100	100	1-4	1-3				
	Fruticose	100	100	3-6	4-6				
	Cladonia spp.	100	100	3-6	4-6				
	Cetraria spp.	100	100	1-3	1-4				
	Peltigera spp.	100	100	1-3	1-3				
Mushrooms		10		1					
Medium and	*Betula glandulosa*	90	60	1-3	1-4			1-14	1-27
low shrubs	*Ledum decumbens*	70		1-3				4-122	
	Ledum groenlandicum	80	100	1-4	2-4			6-96	25-86
	Vaccinium uliginosum	100	100	1-4	2-5			8-135	35-138
	Vaccinium vitis-idaea	100	100	2-5	3-5				

*Cover classes: 1: present 3: 6-10% 5: 21-40% 7: 61-80%
2: 1-5% 4: 11-20% 6: 41-60% 8: 81-100%

Figure 3. Typical permafrost plant community.

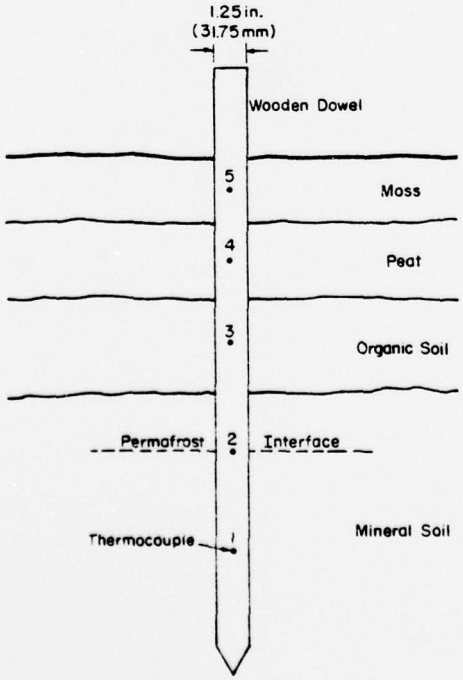


Figure 4. Thermocouple levels.

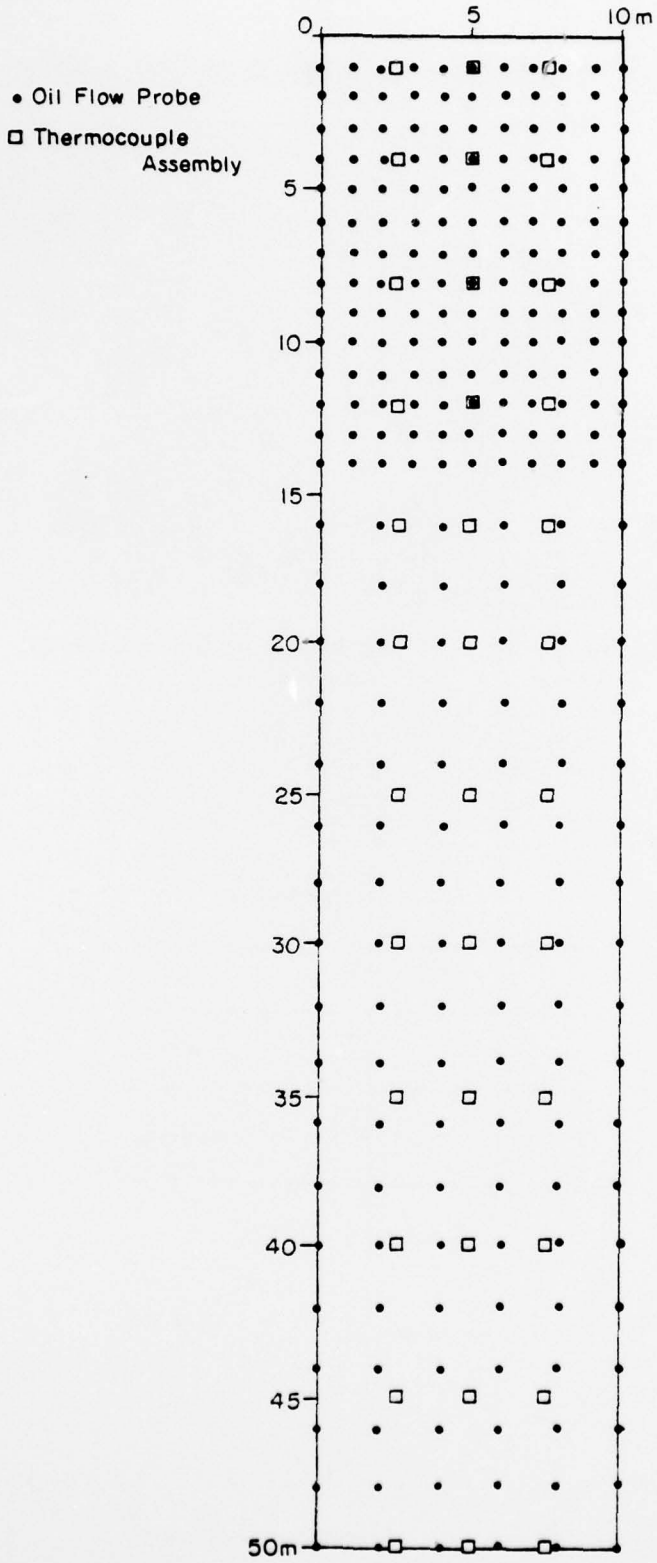


Figure 5. Layout of oil detection stakes and thermocouple arrays.

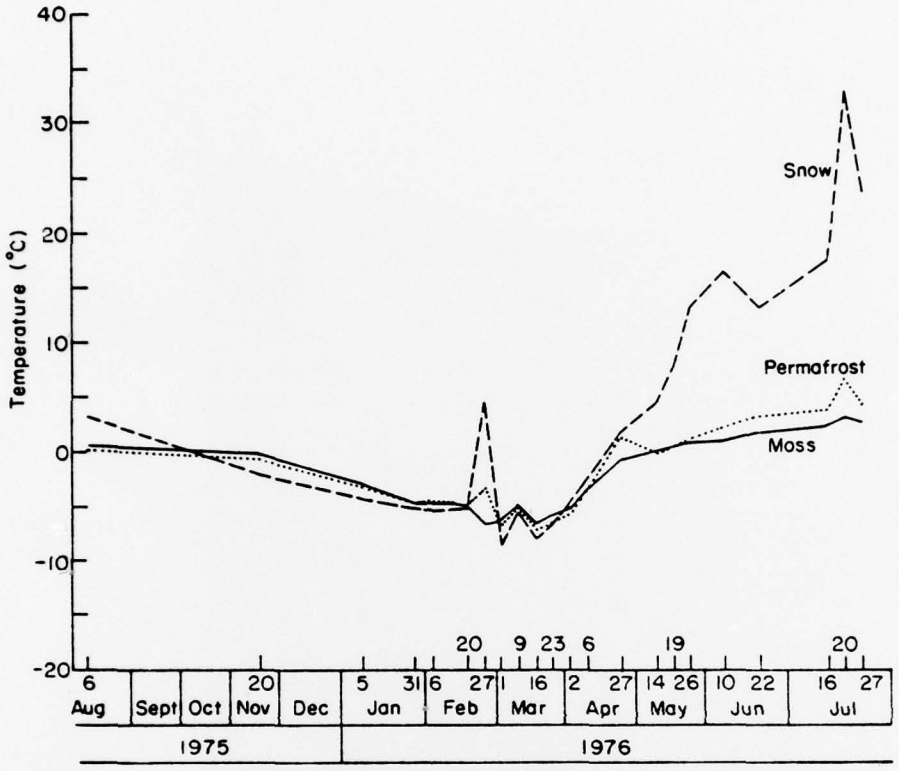


Figure 6. Temperature trends for selected thermocouple arrays.

Figure 7. Climatic station.

Figure 8. Ice bridge across Chatanika River.

Access to the study area was improved during summer and fall. A bridge was built, crossing the abandoned water ditch downslope from the study site, and a trail and turn-around cleared to the south side and top of the study area. Following freeze-up, an ice bridge was constructed on the Chatanika River (Fig. 8), and 300 m^3 (400 yd^3) of gravel was spread on the primary access trail to the research watershed. This allows access to the site by 4-wheel-drive vehicles during times when the Chatanika River is fordable or has adequate ice cover.

Oil for this project was obtained from Prudhoe Bay. It was shipped by truck in 55-gallon drums, which were stockpiled at the Poker Flats Rocket Range. A physical analysis of the oil is provided in Figure 9.

Transportation and heating of the crude oil for application received major effort. The concept of airlifting the oil, in a bulk tank, directly to the study site by "sky crane" helicopter was considered but finally rejected. Problems foreseen included site disturbance by the strong downblast of the helicopter rotors (which would undoubtedly have removed much of the snow cover in winter and many site markers) and vulnerability to weather fluctuations. The method utilized was to mount a 2000-gallon (7570-liter) bulk tank on an RN-110 Nodwell tracked vehicle (Fig. 10a). This tank was externally insulated with 7½ cm (3 in.) of fiberglass to minimize heat loss and maintain oil temperature. Heat was provided by

Company U.S. Army Cold Regions Research and Engineering Lab. Date May 4, 1976 Lab. No. 4121

Well No. Location

Field North Slope Formation

County Depth

State Alaska Analyzed by To

PRUDHOE CRUDE OIL

GENERAL CHARACTERISTICS

Specific gravity @ 60/60 °F.	
A.P.I. gravity @ 60 °F.	37.7
Saybolt Universal Viscosity @ 70°F., seconds	198.5
Saybolt Universal Viscosity @ 100°F., seconds	89.9
B. s. and water, % by volume	0.6
Pour point, °F.	0
Total sulphur, % by weight	1.0

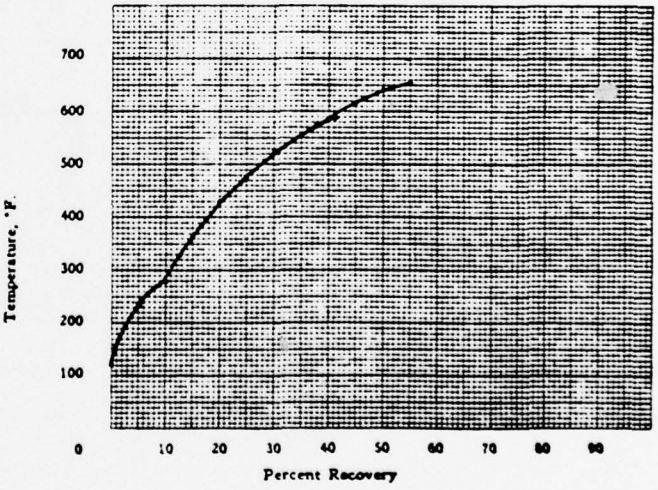
REMARKS: Thermal Cracking Point at 654°F

ENGLER DISTILLATION

Recovery, %	Temperature, °F.
IBP	122
5	235
10	280
15	368
20	430
25	478
30	524
35	556
40	586
45	618
50	646
55 Thermal Cracking Point	654
60	
65	
70	
75	
80	
85	
90	
95	
E.P.	

Recovery, %	55
Residue, %	45
Loss, %	0

DISTILLATION GRAPH



Approximate Recovery

300 EP gasoline, %	11
392 EP gasoline, %	18
500 EP distillate, %	70

Figure 9. Physical analysis of crude oil.

a. RN-110 Nodwell with tank.

b. Second tank on trailer.

Figure 10. Oil tanks mounted on RN-110 Nodwell and trailer.

two 750-watt heating cables suspended in the tank and six 75-watt heating tapes encircling the tank beneath the insulation.

Since it was determined that a full 2000-gal. tank would far exceed the load capacity of the Nodwell, a second tank of 1000 gallons (3785 liters) capacity was mounted on a tracked trailer and similarly insulated (Fig. 10b).

The bulk tank on the Nodwell was equipped with valves and electric pumps to allow pumping both into and out of the tank, or to allow emptying by gravity feed. For actual oil application, a "header" was fabricated from 10-cm (4-in.)-ID pipe. This 5-m-long pipe was sealed at each end and perforated at 10-cm (4-in.) intervals along one side for release of the oil. The intake was centered on the back side of the pipe. Transfer from tank to header was through 7½-cm (3-in.)-ID flexible hose, insulated for heat retention.

Physical procedures

Several weeks prior to the winter treatment, 2000 gallons (7570 liters) of oil, still in 55-gallon drums, was moved to warm storage at the CRREL Alaskan Projects Office in Fairbanks. After it had warmed to room temperature, the oil was transferred to the Nodwell-mounted tank; the full tank was then heated (while still parked in a warm garage) by the electrical heating tapes, previously described, to an oil temperature of 63°C (145°F). The loaded Nodwell was then transported by "lo-boy" trailer to Poker Flats where heating elements were reconnected to line power. At Poker Flats half the oil was then transferred to the smaller trailer-mounted tank for final movement to the site. On 21 February two 5-kW generators were moved to the study site for use in maintaining oil temperature, operating pumps, etc. On 23 February the Nodwell and the trailer with their respective loads of hot oil were moved to the study site. The oil in the trailer was transferred back to the Nodwell.

Winter oil spill

The winter spill was applied 26 February 1976. Snow depth on the plot was approximately 45 cm (18 in.). At the time of treatment (1145 AST) the air temperature was -5°C (23°F) and the wind was calm. The oil was applied on a 5-m front (Fig. 11) at the upper end of the winter treatment plot. The temperature of the oil when it left the header was 57°C (135°F). 2000 gallons (7570 liters) was applied by gravity feed in 45 minutes for a flow rate of 44.5 gallons per minute (168.2 liters per minute).

As expected, the heated oil followed the microrelief of the frozen soil surface underlying the snow and moss. In the immediate vicinity of the point of application snow collapse was rapid, a result of both oil saturation and melt from the heat (Fig. 12).

For the first few hours following treatment, oil moved downslope under the snowpack in the moss overlying the frozen silt; the oil's position was detected by probing with a wooden lath. The presence of the oil

Figure 11. Oil application.

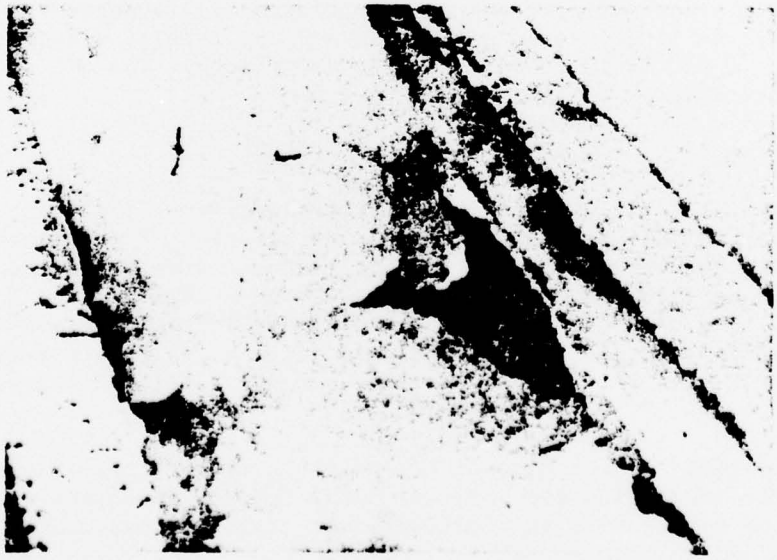


Figure 12. Snow collapse during application.

Figure 13. Oil on wooden probe.

Figure 14. Oil-saturated snow/moss interface.

was readily discerned by sight and smell on clean wood (Fig. 13). Oil spread, as detected by wooden probe, had extended 18 m (59 ft) downslope approximately 24 hours after application, and the oil was obviously following microrelief which had not been detected when the plot was designed. Spread was to the south side of the plot, and downward movement along the south side was clearly influenced by compacted snow along a path utilized prior to treatment along that side. Figure 14 shows the oil-saturated snow/moss interface.

The thermal effects of the oil were immediately obvious at the application point.

A damping of effects with time was noted; no lateral thermal influence (away from actual oil presence) was noted.

Microbiological analysis

Soil samples were collected with a gasoline engine-powered soil corer from the control plot and the winter plot about 24 hours after the heated oil was applied. The following determinations were made:

1. Soil pH
2. Soil moisture
3. Bacterial population - viable cell count on plate count agar
4. Fungal population - viable cell count on Martin's medium
5. Proteolytic microorganisms on Frazier Gelatin medium
6. Cellulolytic microorganisms on Bushnell & Haas Cellulose Silica Gel medium
7. Hydrocarbon degraders on Bushnell & Haas Cab-O-Silica Gel medium
8. Enrichments for hydrocarbon degraders
9. Nitrifiers by multiple tube (MNP) method
10. Soil respiration-carbon dioxide evolution of soils in biometer flasks
11. Oil analysis of the enrichment cultures

For items 3 to 10, two incubation temperatures (4° and $20^{\circ}C$) were employed. Portions of the soil samples were set aside and frozen for future nutrient analysis. The results of the soil pH and soil moisture measurements are shown in Tables IV and V. There is a 0.7 unit increase in soil pH in the duff layer of the winter oil plot. Microbiological analysis has not been fully completed. From preliminary examination of the available data, oil had neither a stimulatory nor an adverse effect on bacterial and fungal populations. However, oil seemed to have an inhibitory effect on soil respiration. Carbon dioxide evolved from soil samples taken from the winter plot (oiled) was half that evolved from soil samples taken from the control plot (unoiled). The data will be statistically analyzed.

Chemical analysis

Samples of oil were collected during the winter spill and returned to CRREL (Hanover) for analysis. Initial fractionation indicated that 25% of the oil was lost during the topping procedure which corresponds to the volatile fraction of the oil. When the remainder was fractionated, 39.7% was found to be alkane, 28.5% aromatic, 12% asphaltene, and 19.8%

Table IV. Soil pH, one day after winter oil treatment.

Soil layer	*Control plot*	*Winter plot*
Duff layer	4.8	5.5
Inorganic soil	5.2	5.2

Table V. Soil moisture (%)*, one day after winter oil treatment.

Soil layer	*Control plot*	*Winter plot*
Duff layer	295	154
Inorganic soil	56	70

* Mean of 3 replicate determinations.

NSO fractions. Physical analysis of the Prudhoe Bay crude oil used in this study is shown in Figure 9.

Oil/snow samples were also collected 1 hour and 24 hours after the spill. It was of interest to investigate the rate of loss of the volatile fraction of the oil after the spill. The oil/snow samples as well as the original oil were subjected to headspace analysis to determine if significant loss of these volatiles occurred rapidly at the low temperatures present during the spill. Headspace analysis of the original oil by gas chromatography indicated volatile components as light as methane to be present in measurable quantities. The sample exposed to the atmosphere for one hour following the spill prior to collection indicated a loss of the methane component and a reduction of C_2, but little change in C_3 and above. The 24-hour sample indicated almost total loss of the C_2 component, 70% reduction of C_3, and 50% loss of C_4, but little change at C_5 and above. The major components of the volatile fraction were considerably more persistent in the spilled oil than expected, due undoubtedly in large part to the temperature.

Fractionation of the oil/snow samples, as well as the oil extracted from soil cores into alkanes, aromatics, asphaltenes, and NSO's, as well as gas chromatography of these fractions, will be accomplished in the next quarter. Initial analysis of the oil for the fatty acid component will also be completed for comparison with samples collected later after prolonged exposure to the environment.

Vegetative analysis

Photographs were taken at the time of the winter spill to document the extent of visible oil contamination. Later observations after snowmelt were made to delineate the area of the visible oil. Oil covered all the mosses and lichens between the Eriophorum tussocks, and standing water was present in many of the oil-contaminated troughs. It was too early in the season to discern any leaf growth, but it was noted that at least some of the Eriophorum tussocks which were surrounded by oil in the troughs were flowering. Several photographs were also taken at this time.

Summary

Sites for summer and winter crude oil spills were designated, described, and instrumented during the first year of this project. The area was sampled for background information (soils, vegetation, microbiology, thermal) to monitor changes that might occur following the application of crude oil.

Crude oil was obtained from Prudhoe Bay, Alaska, moved onto the site, and heated to 60°C (140°F) to correspond to Trans-Alaska pipeline oil temperatures.

The winter spill of 2000 gallons (7570 liters) was conducted on 26 February 1976. Oil was applied on a 5-m (16½-ft) front. The oil melted the snow in the immediate area of application, then moved into the organic layers and followed the frozen microrelief of the site, moving downslope under the snowpack. Flow patterns and rates were established, thermal changes monitored, and chemical and microbiological samples obtained for analysis.

Thus far soil pH of the organic layer has increased and soil respiration has decreased within the winter spill plot. Chemical analysis showed a 25% loss of the oil in the form of volatiles after application; however, the major components of the volatile fractions were more persistent than theorized, probably because of the low temperature at the site of the spill.

Early spring observations indicate vegetative kill where oil had inundated the root zone or had been in considerable foliage contact.

Future plans

The summer crude oil spill was conducted during the week of 11 to 17 July 1976. Chemical, microbiological, thermal, and vegetation sampling will be conducted according to schedule to monitor fate and effect of the crude oil as applied to both the winter and summer spill plots. In addition, flow rates and patterns will be continually updated.

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