Interaction of Gravel Fill, Surface Drainage, and Culverts with Permafrost Terrain

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INTERACTION OF GRAVEL FILLS, SURFACE DRAINAGE, AND CULVERTS WITH PERMAFROST TERRAIN

Final Report

by

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16. Abstract

During the summers of 1981 and 1982, the thaw regime of gravel roads and the performance of culverts were observed in the Prudhoe Bay and Kuparuk River oilfields, northern Alaska. This relatively flat to gently rolling coastal plain is covered by shallow lakes, drained lake basins and interconnecting ice-wedge polygons. Depth of seasonal thaw of the predominantly fine-grained soils is less than 50 cm. The permafrost temperature is about -10°C. A combination of visual frost tube readings and temperature measurements were obtained in the roadbed, in an area immediately adjacent to an insulated culvert, and in areas undisturbed by construction.

Gravel roads up to 2 m thick thaw completely and thaw penetrates into the consolidated active layer. Where depth of thaw exceeds the thickness of the active layer, ice-rich permafrost begins to thaw. Adjacent to the roads, newly formed surface troughs indicate melting of the underlying ice wedges. Shallow impoundments form on the upslope sides of roads where culverts have not been adequately sited or installed. More standardized practices for culvert placement, installation, and maintenance are desirable to minimize disruption of natural drainage.

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FOREWORD AND IMPLEMENTATION STATEMENT

This study must be considered essentially as a reconnaisaance study of culvert performance in the Arctic. It provides data which will be useful to those engineers and researchers who will take the next steps toward understanding the complex interactions between road embankments, drainage structures, and arctic permafrost terrain.

Culverts can interact thermally with embankments in various ways. If they are placed too high the resultant ponding may have the thermal consequences of increased toe-of-slope thawing and thaw-degradation of the adjacent permafrost. Increased thaw and settlement beneath the center of the roadway may also result in ponding from an uplifting of the culvert ends. Snow and ice accumulations in the culverts will retard seasonal thawing and again cause ponding and even washouts.

The primary result of this study was the demonstration that culvert placement and maintenance techniques used in the Prudhoe Bay area have been inadequate to eliminate water ponding, and occasional washouts. The use of insulation beneath culverts has not yet demonstrated any major thermal benefits. A longer term of study, with full temperature instrumentation and settlement observations over several years, is needed to resolve the benefits of insulation.

The major recommendation made is that culverts not in active streams be covered at the onset of winter to prevent plugging by snow and ice, and that covers be removed at the start of snowmelt to provide unimpeded drainage.

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CONTENTS

TABLES

FIGURES

PREFACE

This report was prepared by J. Brown, Soil Scientist; B.E. Brockett, Physical Sciences Technician, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); and K.E. Howe, Hydrologist, formerly, CRREL.

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INTRODUCTION

Before oil was discovered at Prudhoe Bay in 1968, road construction in northern Alaska was limited to villages and Distant Early Warning (DEW) stations along the Arctic Coast. The roads were of limited length and were used primarily as access to airfields, disposal sites, and lakes for water supply and in-town transportation. The first major road building on the flat coastal tundra occurred in 1969 at Prudhoe Bay when the road commonly referred to as the "spine road" was constructed between the Sagavanirktok River near Deadhorse and the Kuparuk River. Spur roads extend from the spine road to regularly spaced drill pads, docks, and a variety of facilities used in oil and gas production. There are now over 300 miles of gravel roads in this area.

During the early 1970's, several projects (Parrish, 1974; Lewellen, 1978) evaluated the subgrade condition of the gravel roads and pads to ascertain how the underlying permafrost was affected by the gravel fills and associated drainage changes. Parrish reported that roads up to 2.1 m thick had completely thawed by mid-July 1973. The concensus was that many roads thawed below the gravel into the consolidated active layer. However, whether or not the annual thaw bulb completely penetrates into and through the buried active layer has not been definitively documented. A recent note by March (1980) suggests that these roads have a frozen subgrade in late summer. Since the vast majority of these roads have been well maintained by the industry, it is difficult to determine if degradation of the underlying permafrost has occurred as a result of thaw consolidation. However, impeded drainage adjacent to the roads has resulted in accelerated melt-out of the underlying ice wedges. In late summer these depressed troughs probably serve as drainage lines beneath the roadbed.

On this flat coastal tundra, roads cause surface impoundments to form and habitats can be altered. The roads themselves can be damaged by accelerated thaw at the toe of the road or by wind-generated wave action in the temporarily high spring-time impoundments. The proper installation and performance of culverts can reduce and even eliminate surface drainage problems, but culverts are often ineffective, mainly because they are not properly located or because they deform due to road settlement and/or thawing of the permafrost adjacent to the toe of the roads. Ponding frequently develops and persists upslope of these culverts. It is probable, although not well-documented, that road thaw is deeper under and near culverts, due to the thermal effects of the air and water passing through them. However, culverts can also act as cooling ducts during winter, depending on wind direction, snow cover, and drifting.

The main objective of the present study was to collect data on the performance of gravel roads and associated culverts in order to improve the design and maintenance of roads constructed in northern Alaska. The existing and newly placed roads in the Prudhoe Bay region and more recently in the Kuparuk River oilfield offered opportunities to observe construction and maintenance techniques and to monitor the effects of roads constructed over cold permafrost. Some site-specific data was obtained over limited time intervals. This study was not intended to collect comprehensive design data, and should be considered only as a reconnaissance.

ENVIRONMENTAL SETTING

The environmental details of the Prudhoe Bay region are portrayed in the geobotanical atlas by Walker et al. (1980). For purposes of this report only climatic and soil thaw data are presented.

Climatic data have been obtained in the Prudhoe Bay area since the late 1960's and more recently in the Kuparuk oilfield. These observations have been obtained at the ARCO-operated airfields and the Deadhorse airfield. In addition, CRREL has maintained a number of thermographs to monitor air temperatures at various locations from the coastline inland in order to establish regional climatic differences (Haugen, 1982). Table 1 contains the monthly and annual air temperature data for the available period of record and the study years 1981 and 1982 for comparison.

July 1981 and 1982 were both warmer than the average for the 14-year period of record at the ARCO airfield. The total of thawing degree days was also slighty greater for these two summers. The study area near the West Dock had a cooler summer than the Kuparuk area.

Precipitation data have not been systematically obtained, largely due to the errors introduced by blowing snow in the winter and the light, intermittant precipitation events in the summer (Benson, 1982). To overcome some of these problems, a modified Wyoming snow gauge has been in operation. The cumulative precipitation for several years is summarized below:

November 1979 through May 1980 = 147 mm water

June 1980 through August 1980 = 74 mm water

November 1980 through May 1981 = 147 mm water

June 1981 through August 1981 = 61 mm water

Table 1. Monthly and annual air temperatures (°C) for the Prudhoe Bay-Kuparuk River region.

Year(s)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Thaw Degree Days (°C)	Freeze Degree Days (°C)
						ARCO AIRFIELD - PRUDHOE BAY									
1970-1982	-26.3	-27.6	-26.0	-18.6	-5.8	3.3	7.2	6.1	0.4	-10.8	-19.2	-26.8	-12.2	586	4706
1981	-16.2	-27.9	-22.1	-16.4	-2.0	4.0	8.9	5.5	-0.6	-8.3	-17.8	-23.9	-9.7	604	4109
1982	-27.0	-23.6	-26.3	-17.8	-6.4	3.4	8.0	6.6	0.3	-14.7	-24.1	-25.5	-12.3	605	5031
						PRUDHOE BAY - WEST DOCK (CRREL)									
1981					-3.4	3.0	7.0	4.2	-0.8					462	
1982					-4.9	2.4	6.1	4.9	-0.8					435	
						ARCO AIRFIELD - KUPARUK									
1981						2.2	7.3	3.8	-2.3	-9.3	-18.6	-24.3		563	
1982	-27.8	-24.0	-26.6	-19.1	-7.3	2.8	7.5	5.7	-1.1	-14.7			(-12.3)	523	(4839)*

*(Combined 1981 and 1982 values); data updated by Haugen (1982)

These data indicate approximately 150 mm of water equivalent are derived from winter precipitation and about 70 mm are from summer precipitation. Much of the winter precipitation, or snow, melts and runs off in a 2 to 3 week period in June.

The depth of seasonal thaw for soil moisture conditions commonly encountered on the wet, relatively flat tundra of the coastal plain is shown in Figure 1. The less commonly occurring sandy, well-drained soils on ridges normally thaw to 1 m or more. The dry, peaty soils, with their good insulating properties and associated high-centered polygons, thaw less than 30 cm. Wet organic soils can thaw up to 50 cm. Road-induced impoundments result in moisture conditions similar to those of the wet organic soils. Selective diurnal temperatures measured from soils with standing water show higher temperatures at the surface and at shallow depths compared to the drier mesic soils (Fig. 2). These wet soils are analogous to impounded areas adjacent to roads where added heat is accumulated in the soil due to the energy-absorbing effects of the shallow standing water. The Waterflood studies suggest that late summer thaw depths are greater under flooded areas adjacent to the same road we studied (Klinger et al., 1983a,b).

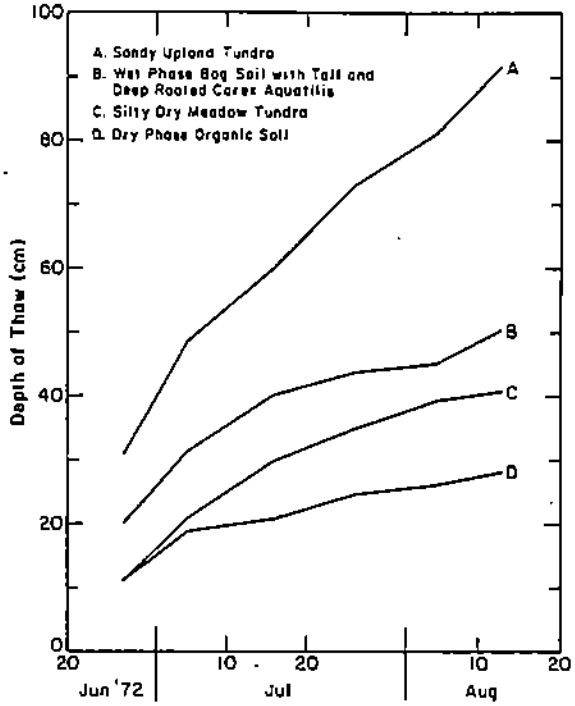


Figure 1. Range of soil thaw (cm) for Prudhoe Bay region (after Bilgin, 1975).

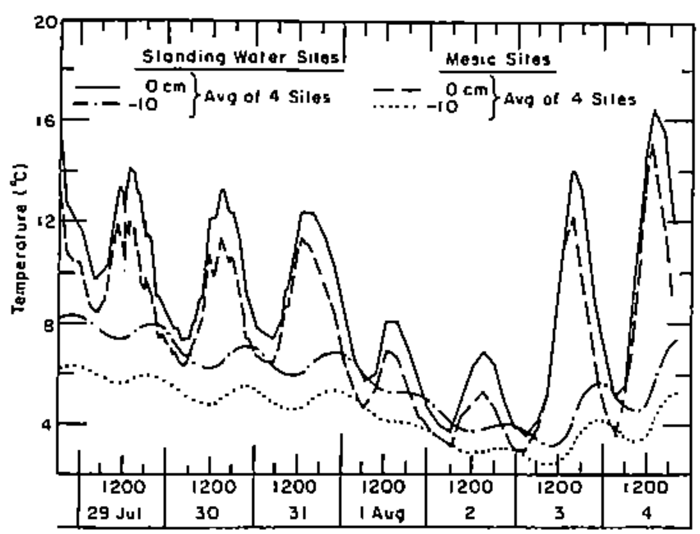
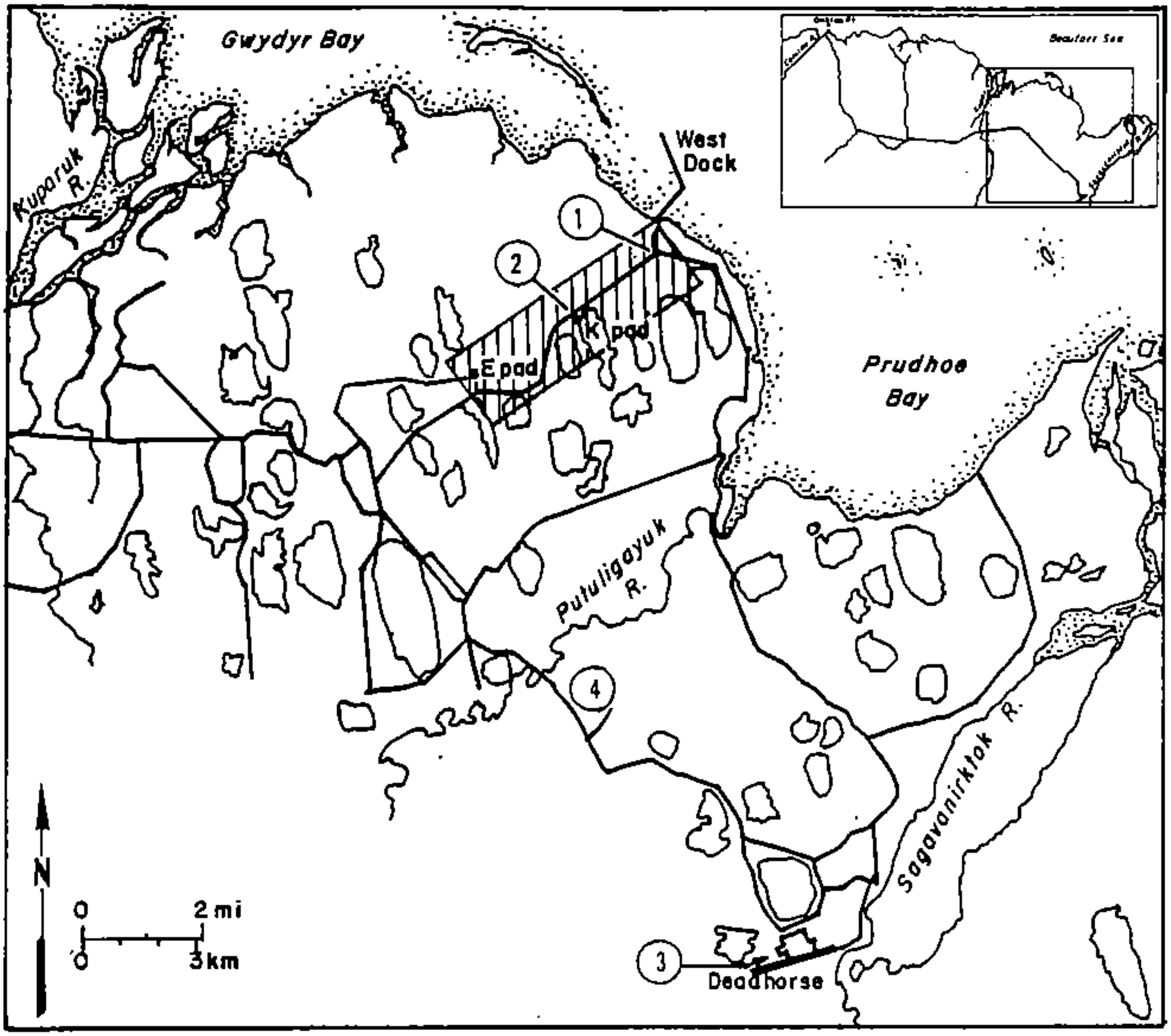


Figure 2. Comparison of soil temperatures for a site with standing water and a mesic slope, Prudhoe Bay, 1981 (unpubl. data, Goodwin).

STUDY SITES

Two main study sites were selected: a new road section in the northwestern portion of the Prudhoe Bay oilfield and a workpad in the Kuparuk field. The Prudhoe site was chosen so that information could be collected on a new road that had little or no prior thermal or drainage disturbances. The Kuparuk site was selected to acquire data adjacent to previously installed insulated culverts with a relatively thin gravel overlay. Figures 3 and 4 show the location of each site.

The Prudhoe site is referred to as the West Road, or the E pad to West Dock road. This road was built for installation of and access to a water pipeline system to be used for the Prudhoe Bay Waterflood Project as well as to transport large modules from the West Dock to the western portion of the Prudhoe Bay field and the Kuparuk field (U.S. Army Corps of Engineers, 1980). The 6.7-km (4.15-mi.) West Road was built in two sections. The first 4.5-km (2.8-mi.) section, from the West Dock to K pad, was constructed during November 1979. The second 4.2-km (2.6-mi.) section, from K pad to E pad, was built in March 1981 and later compacted and upgraded in July 1981. The road consists of fine to coarse gravel. Road orientation trends northeast-southwest, and is generally perpendicular to the primary direction of surface water flow. Although there were 18 culverts, extensive impoundments were formed upslope of the road. When it was originally constructed, the road was 10.4 m (34 ft) wide and 1.5 m (5 ft) thick with 3:1 side slopes. In October 1982 the road was widened about 0.6 m (2 ft) for the installation of the Waterflood pipelines. At that time our roadbed instrumentation was buried and was considered non-operable.



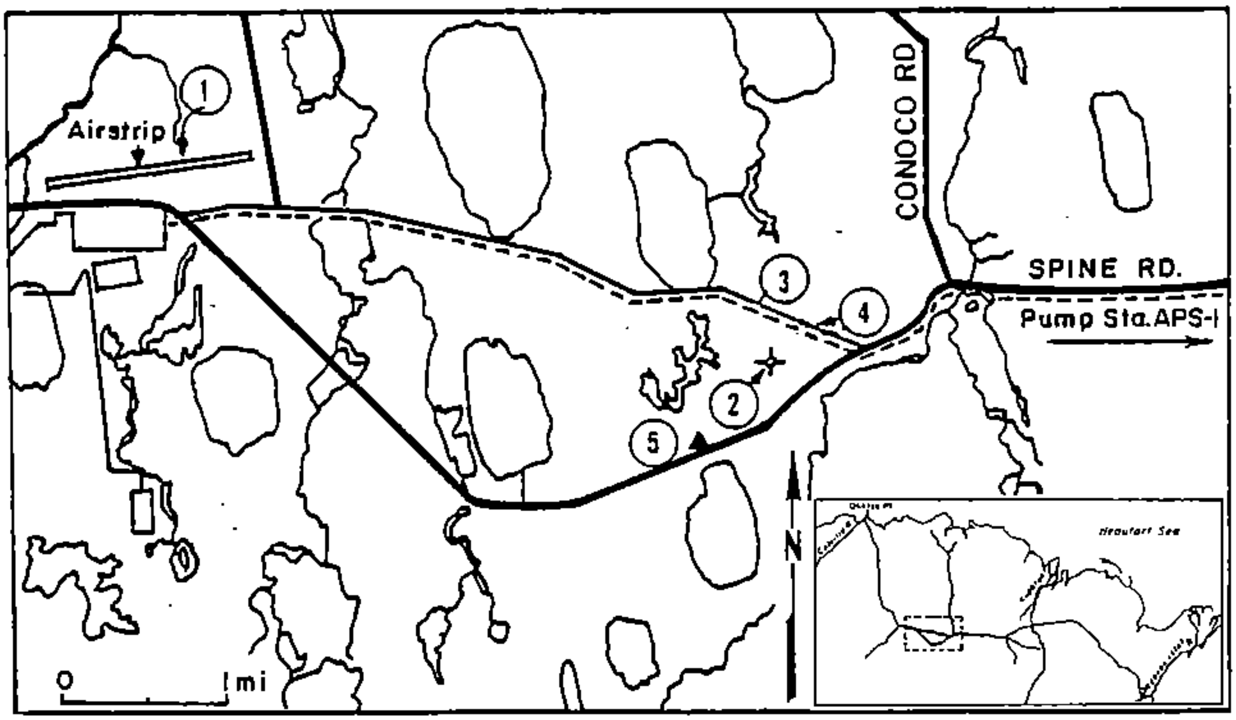
(1) West Dock instrument shelter

(2) Culvert with data logger

(3) Deadhorse airport instrument shelter and deep ground temperature well

(4) Weather pingo

Figure 3. The Prudhoe Bay oilfield and the location of the West Road study site.



(1) Instrument shelter at airport

Thermocouple Cables:

(2) Tundra - 27-ft cable

(3) Insulated culvert section

(4) VSM 185 (non-insulated road section)

(5) 90-ft hole in pingo (non-instrumented)

Figure 4. The location of the study sites in the Kuparuk River oilfield.

INSTRUMENTATION

Measurements were obtained for both thaw penetration and ground temperature. Frost tubes (Rickard and Brown, 1972) were used at both locations to obtain visual determinations of the depth of thaw penetration. To obtain a bottom temperature, a thermistor or thermocouple was attached to the bottom of the frost tube casing. A drawing of an idealized frost tube installation is shown in Figure 6.

Frost tubes were installed in April and May 1982 using a drill mounted on a Nodwell. A metal plate or cap was buried over each tube. A metal detector and/or careful distance measurements were used to relocate the tubes when observations were made. Figures 7 and 8 show the locations of the tubes and culverts along the West Road. Frost tubes were read from June through August to observe rate and depth of thaw in the road. During early summer (June) the green-brown boundary was often diffuse, so estimated thaw was only accurate to ± 0.25 m (0.8 ft). Some access tubes were filled with methanol, and a thermistor was lowered in increments to obtain temperature profiles.

In the Kuparuk field, both frost tubes and methanol-filled tubes were employed immediately adjacent to the insulation under the culvert (Fig. 9) and through the uninsulated road section. To protect the integrity of the pre-installed insulation, the access tubes were not placed directly through the insulation. The uninsulated section is occasionally referred to as VSM 185, as this vertical support member for the pipeline is immediately opposite the access tube and is used to locate the site.

In addition to temperature measurements associated with the road and culverts, temperatures were measured periodically in three CRREL test holes

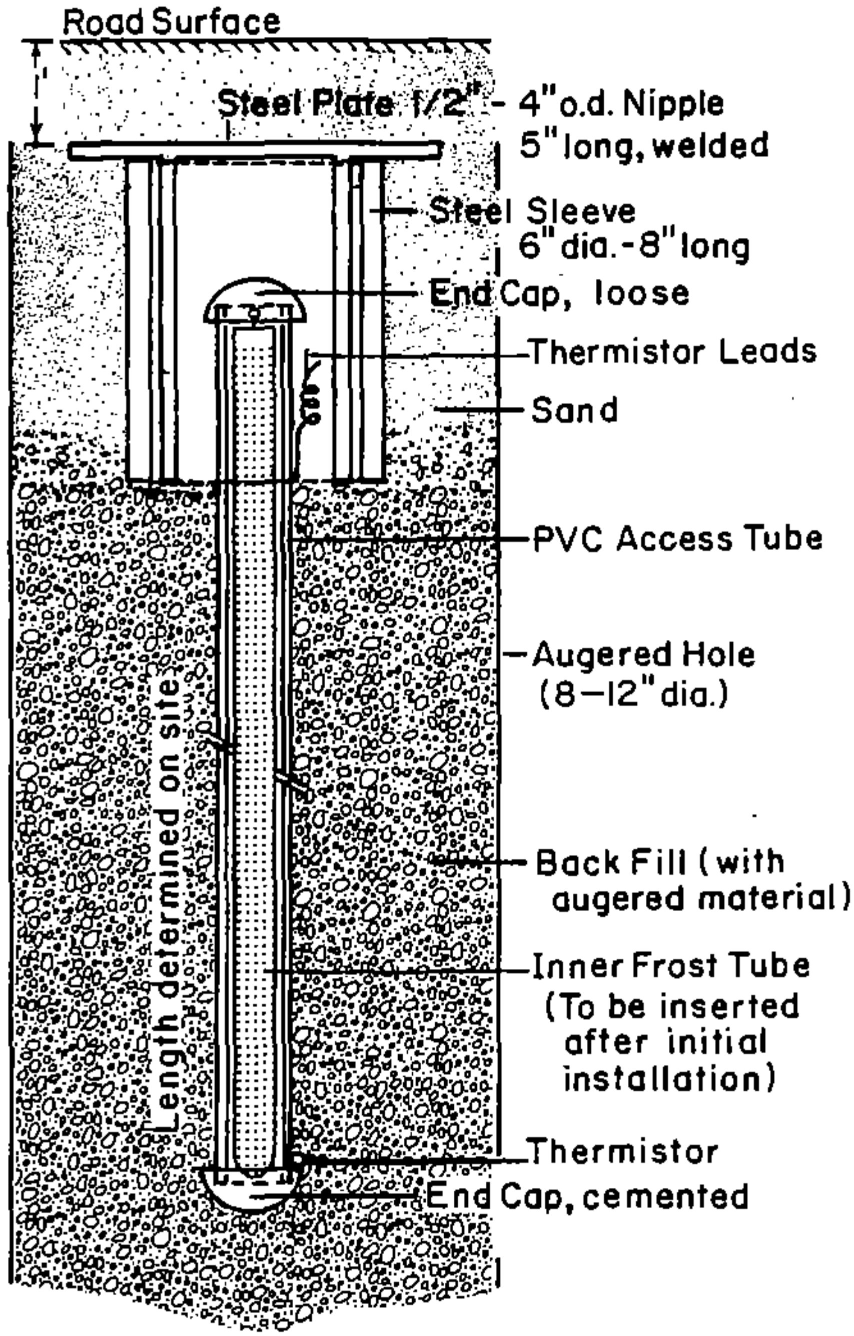


Figure 6. Idealized drawing of frost tube and temperature access tube installation.

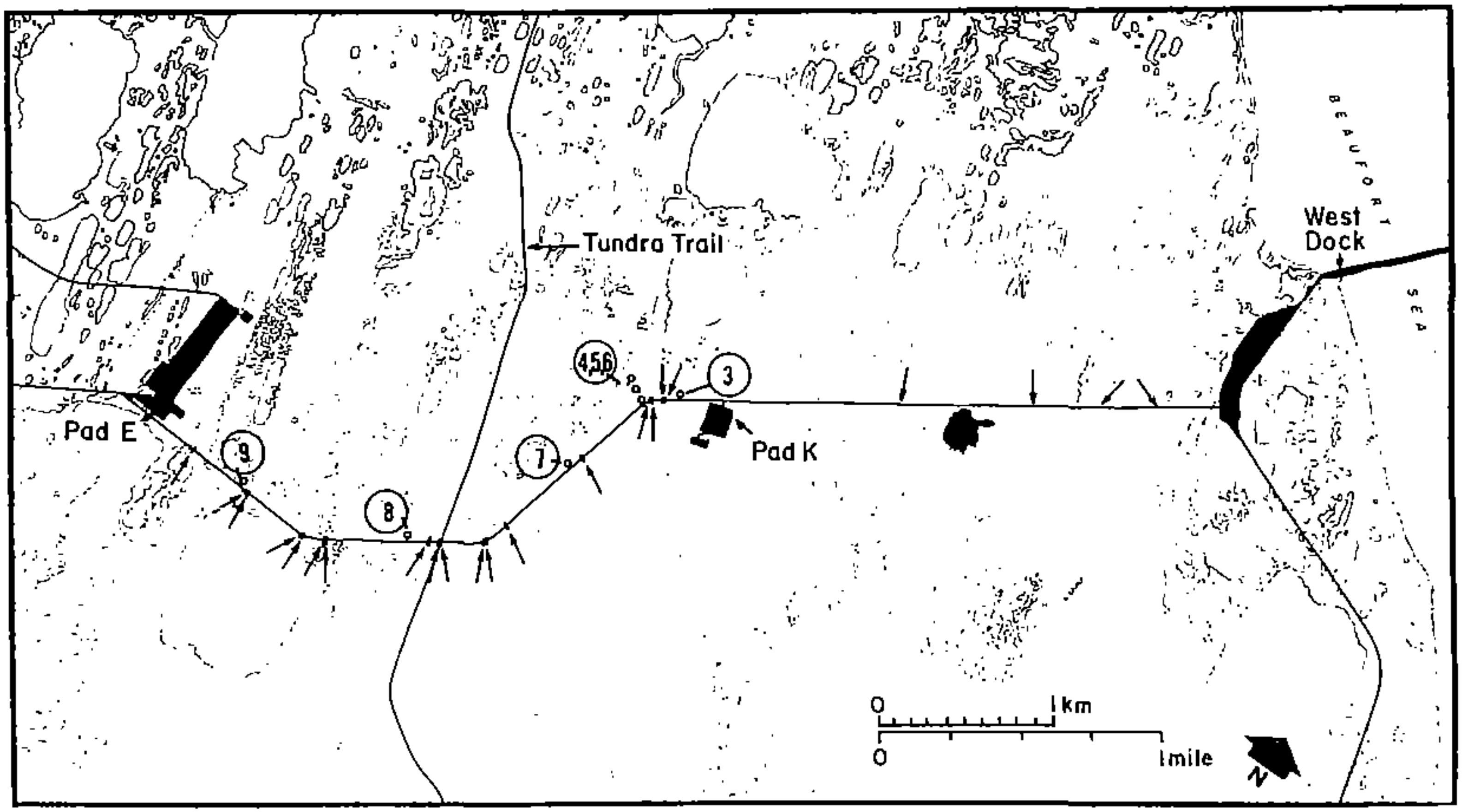


Figure 7. Location of culverts and frost tubes along the West Road. Circled numbers are locations of the instrumented access tubes. Arrows indicate locations of culverts.

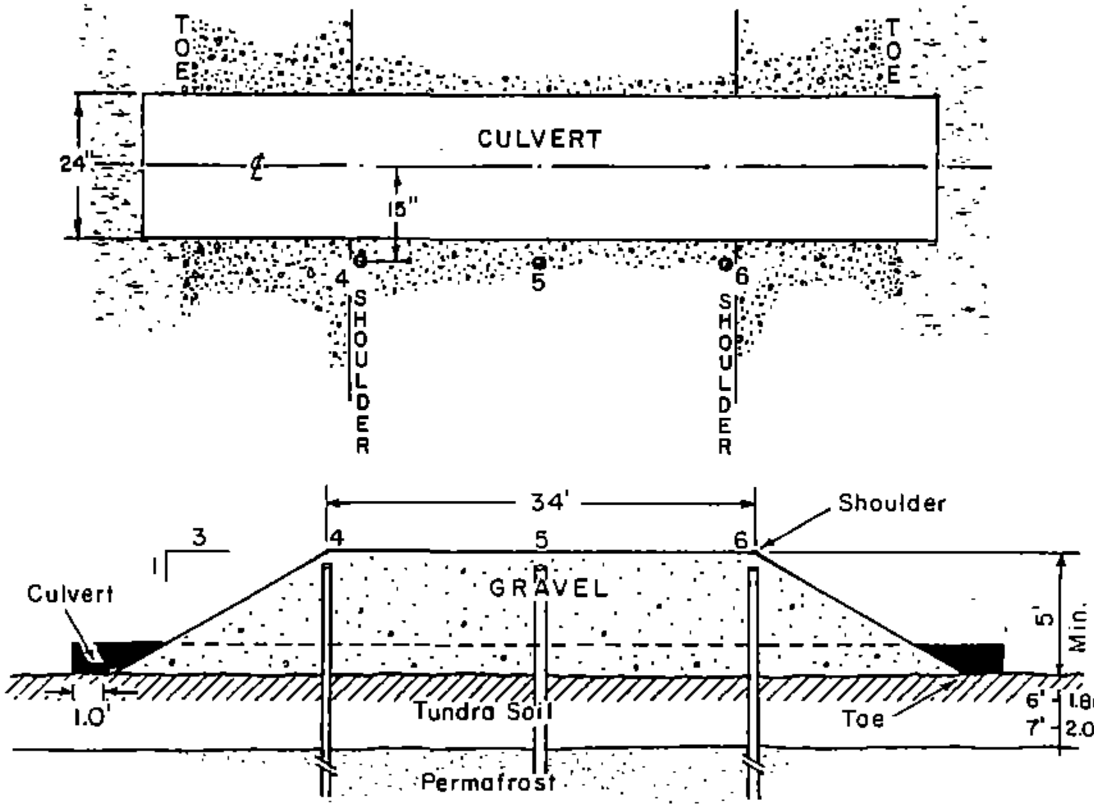


Figure 8. Location of access tubes in relation to culvert.

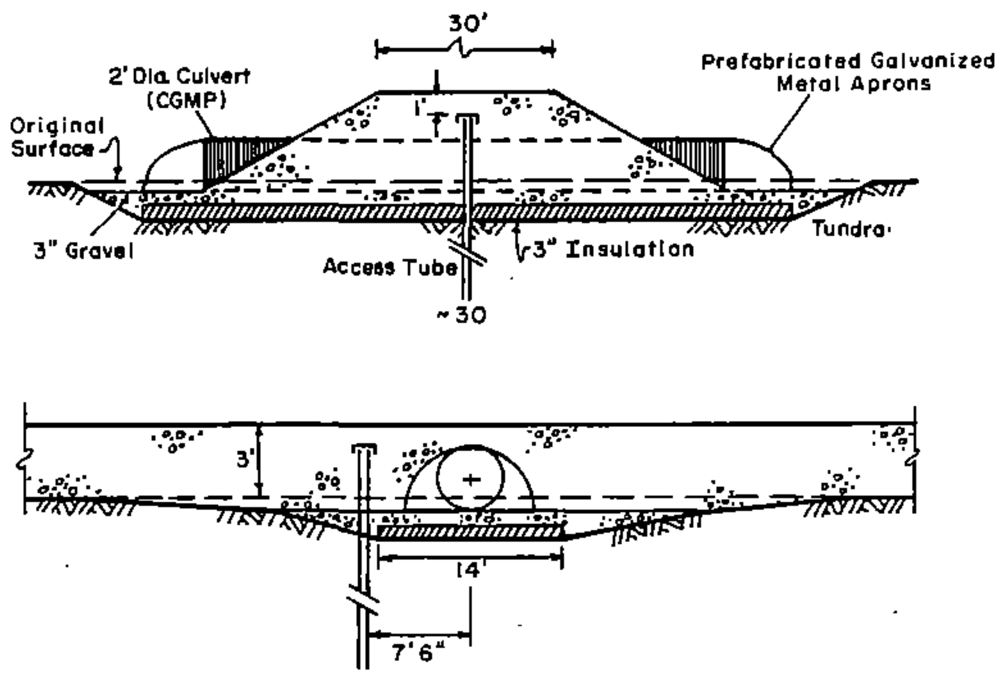


Figure 9. Location of frost tubes and temperature measurements at the Kuparuk site.

located in undisturbed areas to obtain long-term ground temperature variations. The Deadhorse airfield access tube is approximately 23 m (75 ft) deep and consists of a PVC casing filled with diesel fuel. The Weather Pingo tube is a methanol-filled PVC casing and is 13 m (43 ft) deep. The Kuparuk tundra site was installed in April 1982 and has an 8.5-m (27-ft) thermocouple cable frozen into backfilled materials. Locations of these sites are shown in Figures 3 and 4. Data are presented in Appendix A.

A Keithley Model 135 digital multimeter was used for manual readings of calibrated thermistor resistances. The Keithley was modified to reduce the current output and thus minimize the self-heating effects of the thermistors, which cause the resistance to drift and produce subsequent data error. A Rubicon Wheatstone bridge was occasionally used to verify the measurements made with the Keithley.

An Omega model digital thermocouple meter manufactured by Fluke was used to read the thermocouples. This meter has an internal zero reference point allowing for direct temperature readings in °C or °F. The instrument was kept inside the investigator's parka while measurements were taken. Periodic routine on-site zero-point calibrations were conducted to ensure that comparable data sets were collected.

RESULTS

Thaw Penetration

Thaw penetration and temperature in the West Road are presented in Tables 2 and 3 for the culvert site. As the daily air temperatures rose above freezing, thaw penetration advanced rapidly. By 15 June 1982, although snow was still present at the toe of the road and on much of the tundra, the road had thawed 0.8 m (2.5 ft). The road was thawed to approximately 2 m when measurements were made on 26 August.

When a trench was excavated to place additional culverts in late July 1981, the road still had 15 cm (6 in.) of frozen gravel at its base (Fig. 10). In mid-September 1981, two borings conducted by industry to test the subgrade for bearing capacity revealed approximately 0.5 m (1.5 ft) of thaw beneath the center of the road (Ross and Christensen, 1981).

At the Kuparuk site, there are temperature differences between the uninsulated roadbed and that adjacent to the insulated section near the culvert. The causes are not conclusive at this time, partly because temperatures directly under the insulation were not measured. The temperatures shown in Figure 11 demonstrate the apparent buffering effect of the insulation adjacent to the culvert, as compared to the totally uninsulated road section. In June, the ground adjacent to the insulated section was warmer than the uninsulated section through the entire gravel overlay, and by August temperatures were 2°C higher to depths approaching 3 m (10 ft). Interestingly, in October the 0°C isotherm adjacent to the culvert was at 1.8 m (6 ft), while in the uninsulated section the front was at 2.5 m (8 ft) (Table 4).

Table 2. Thaw depths (cm) and subgrade temperatures (°C) in the West Road, 1982.

Location	15 June Thaw	15 June Temp*	18 June Thaw	18 June Temp*	20 June Thaw	20 June Temp*	24 June Thaw	24 June Temp*	27 June Thaw	27 June Temp*	26 Aug Thaw	26 Aug Temp*
3 (center)	75	-7.5	90	-7.1	75	-6.8	90	-6.4	135	-6.1	185	-
4 (shoulder)	95	-7.4	95	-7.0	100	-6.8	105	-	115	-	185	-
5 (center)	105	-8.8	135	-8.5	110	-8.2	115	-7.7	145	-7.2	190	-
6 (shoulder)	145	-8.5	95	-8.0	130	-7.7	125	-7.3	125	-6.9	185	-

* Temperature measured at 2.9 m beneath the road surface; road thickness = 155 cm. Frost tube data in June ± 25 cm (0.8 ft). See Figure 8 for location of tubes 4 to 6. Tube 3 was offset 100 m from the culvert.

Table 3. Temperature (°C) from access tubes in the West Road, 1982.

Depth from road surface (m)	(ft)	16 June	18 June	21 June	24 June	27 June	26 Aug
				Access Tube 7			
0.5	1.5	1.1		1.4	4.2	5.4	
						2.4	2.8
0.8	2.5	-0.2	-0.2	-0.1	-0.1	2.4	2.4
0.9	3.0						
1.1	3.5			-1.2	-1.0	-0.3	
1.2	4.0						1.3
1.4	4.5	-3.1	-2.6	-2.2	-2.0	-1.3	
1.5	5.0						0.4
1.7	5.5			-3.6	-3.4	-2.9	
1.8	6.0						-0.3
2.0	6.5		-5.1	-4.7	-4.5	-4.1	-1.4
2.3	7.5			-5.6	-5.3	-5.0	-2.1
2.6	8.5	-7.1	-6.8	-6.4	-6.0	-5.7	-2.9
2.9	9.5						-3.6
3.2	10.5	-7.9	-8.3	-7.9	-7.6	-7.3	-4.2
3.5	11.5						-4.7
3.8	12.5						-5.1

Table 3 (cont.). Temperature (°C) from access tubes in the West Road, 1982.

Depth from road surface (m)	(ft)	16 June	18 June	21 June	24 June	27 June	26 Aug
				Access Tube 8			
0.5	1.5	0.9	3.4	1.4	4.9	6.3	
0.6	2.0						
0.8	2.5	0.2	1.8	0.2	1.6	3.8	
0.9	3.0						2.8
1.1	3.5			-0.7	-0.6	0.7	
1.2	4.0						2.0
1.4	4.5	-2.3	-2.0	-2.0	-1.7	-0.7	
1.5	5.0						1.1
1.7	5.5			-3.0	-2.8	-2.2	
1.8	6.0						0.4
2.0	6.5		-4.4	-4.1	-3.9	-3.4	
2.1	7.0						-1.0
2.3	7.5			-5.2	-5.0	-4.6	
2.4	8.0						-1.8
2.6	8.5	-6.8	-6.3	-6.1	-5.9	-5.3	
2.7	9.0						-2.6
3.0	10.0						-3.2
3.2	10.5		-7.9	-7.5	-7.4	-7.0	
3.4	11.0						-3.8
3.7	12.0	-8.9					
				Access Tube 9			
0.5	1.5	1.1	1.2	1.4	4.6	4.8	
0.8	2.5	-0.5	-0.6	0.3	1.6	3.0	2.9
1.1	3.5			-0.6	-0.5	-0.2	2.8
1.4	4.5	-1.8	-2.7	-1.7	-1.5	-1.1	2.2
1.7	5.5			-2.6	-2.5	-2.1	1.4
2.0	6.5		-5.8	-4.1	-3.9	-3.6	0.9
2.3	7.5			-5.3	-5.1	-4.8	-0.8
2.6	8.5	-7.2	-7.8	-6.6	-6.3	-6.1	-2.0
2.7	9.0						
3.0	10.0						-3.1
3.2	10.5		-8.5	-8.2	-7.9	-7.7	-3.9
3.4	11.0						
3.7	12.0						-4.4
3.8	12.5		-9.4	-9.1	-8.8	-8.6	-4.9
4.0	13.0						
4.3	14.0						-5.3
4.4	14.5		-9.8	-9.6	-9.3	-9.2	-5.7
4.6	15.0						
4.9	16.0						-6.0
5.0	16.5	-10.3	-10.1	-9.9	-9.8	-9.6	-6.3

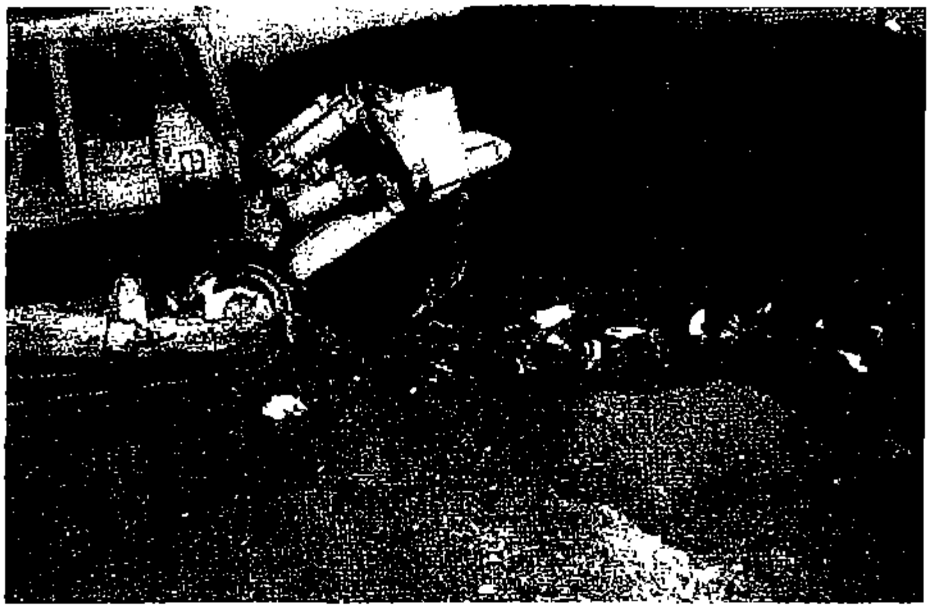
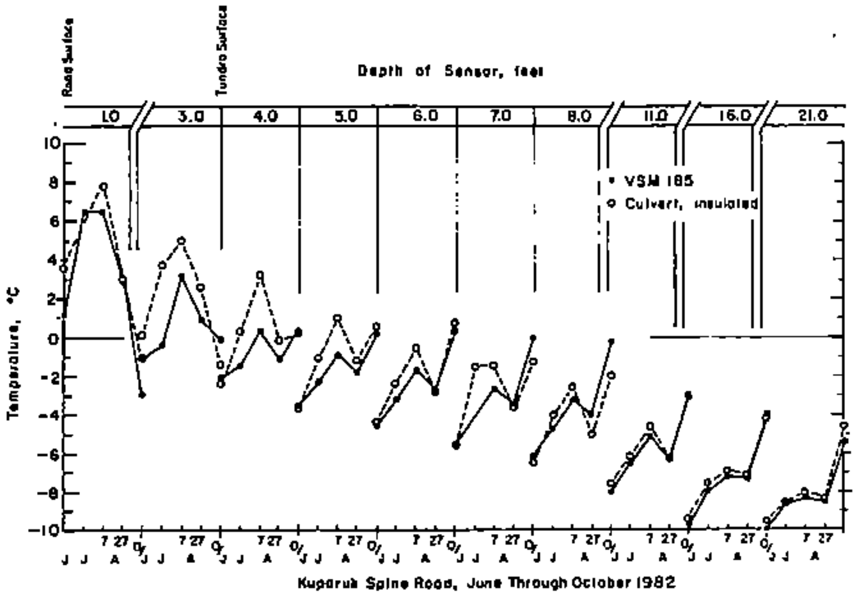
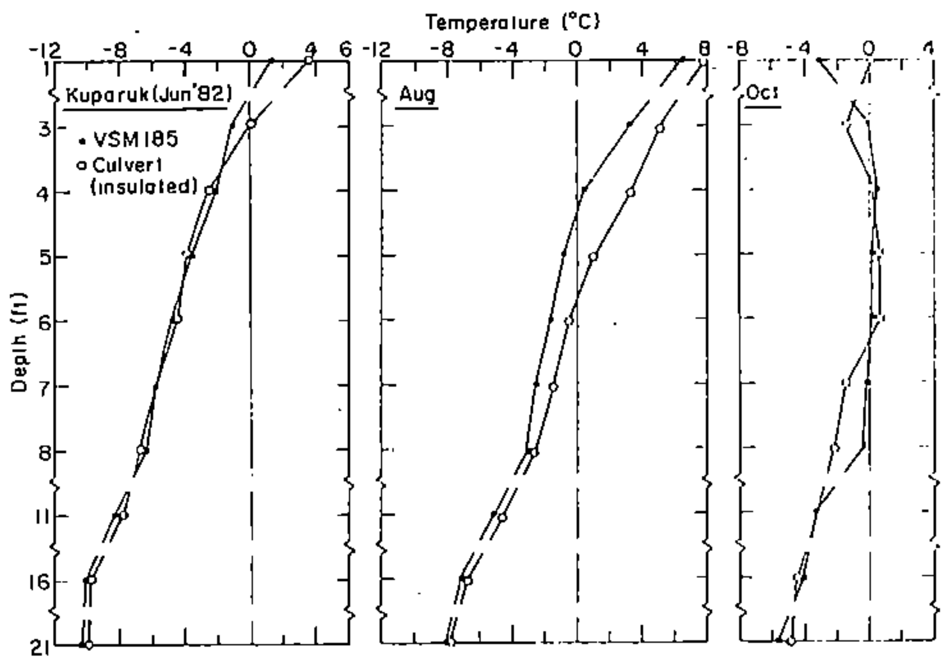


Figure 10. Frozen gravel encountered at the base of the West Road (28 July 1981).



a. Comparison of ground temperatures at given depths.



b. Temperature profiles.

Figure 11. Ground temperatures (°C) under uninsulated road section and adjacent to insulated culvert, Kuparuk site, 1982.

Table 4. Ground temperatures (°C) in Kuparuk of road and adjacent to insulated culvert.

Depth	23 June 1982		27 July 1982		7 Aug 1982		27 Aug 1982	
(ft)	VSM 185	Culvert	VSM 185	Culvert	VSM 185	Culvert	VSM 185	Culvert
1	1.2	3.5	6.5	xx	6.5	7.8	3.0	3.0
3	-1.1	+0.1	-0.4	3.7	3.2	5.0	+0.8	2.6
4	-2.2	-2.4	-1.5	+0.3	+0.3	3.2	-1.2	-0.2
5	-3.5	-3.7	-2.3	-1.1	-0.9	1.0	-1.8	-1.2
6	-4.6	-4.5	-3.2	-2.4	-1.7	-0.5	-2.6	-2.8
7	-5.5	-5.5	xx	-1.5	-2.6	-1.5	-3.4	-3.6
8	-6.2	-6.5	-4.7	-4.0	-3.2	-2.6	-4.0	-5.0
11	-8.0	-7.6	-6.5	-6.2	-5.1	-4.6	-6.4	-6.4
16	-9.8	-9.5	-7.8	-7.6	-7.2	-6.9	-7.4	-7.2
21	-9.9	-9.6	-8.7	-8.6	-8.3	-8.1	-8.6	-8.4
31	xx	xx	-9.0	-8.8	-8.8	-8.7	xx	xx

Depth	15 Oct 1982		14 May 1983		27 July 1983	
(ft)	VSM 185	Culvert	VSM 185	Culvert	VSM 185	Culvert
1	-3.0	-3.2	-3.8	-4.2	10.2	9.2
3	-0.1	-1.4	-7.0	-4.2	2.0	4.2
4	0.4	0.2	-9.2	-9.2	-1.8	-1.2
5	0.2	0.6	-9.8	-10.0	-2.8	-2.4
6	0.4	0.8	-10.4	-10.8	-3.8	-3.4
7	0.0	-1.2	-11.0	-11.4	-4.6	-4.4
8	-0.2	-2.0	-11.2	-11.6	-5.2	-5.2
11	-3.2	-3.0	xx	-11.8	Open	-6.8
16	-4.0	-4.2	-11.4	-11.6	-8.0	-8.0
21	-5.4	-4.6	-10.8	-11.2	-9.2	-9.4
31	xx	xx	-9.2	-9.1	-10.0	-10.0

Culvert Performance

Several corrugated galvanized metal culverts were installed when the West Dock road was first built in March 1981. Three more were added in July 1981 in an attempt to drain extensive areas of impoundment. Eight noncorrugated (steel pipe) culverts were installed in the autumn of 1981 because the original culverts were subsiding and deforming and additional strength was desired for transport of heavy building modules. Observations of culvert performance were conducted during the summers of 1981 and 1982 and pertinent information was documented.

The 1981 observations began after snowmelt runoff had commenced, so there is no record of when water initially flowed through the culverts. Due to subsidence and/or non-effective placement, by early July water was no longer flowing through culverts 10, 15, and 18.

Following the 1981 snowmelt, water was impounded over a large area east of the road between E and K pads. To improve drainage, three new culverts (5, 6, and 11) were installed on 27 and 28 July. Trenches were excavated across the roads and into the underlying tundra. About 15 cm of frozen ground was still present in the base of the road (Fig. 10). Gravel was laid 30 cm (1 ft) thick as a subbase and cambered 15 cm (6 in.) from the center. The camber was employed to counteract subsidence due to thaw consolidation. After the culverts were laid, the trenches were backfilled with gravel and compacted.

The following summarizes the 1981 observations and conclusions:

1. The road surface immediately over all culverts installed in March 1981 showed subsidence, probably due to inadequate winter compaction. Settlement occurred as the gravel thawed.

2. Differential subsidence had caused some of the culvert ends to bow upwards, elevating the opening above the level of impounded water.

3. Many of the culverts were installed at an elevation above the level of meltwater.

The 1982 culvert observations were made after the addition of eight steel culverts. Six of the steel culverts (3,4,7,12,16, and 17) were placed next to the CGMP culverts at a lower elevation, extending farther out on the tundra (Fig. 12).

The following was observed in 1982:

1. Most of the culverts were blocked with ice and snow until mid- to late June (Klinger et al., 1983b). By this time, snowmelt was almost completed and water remained impounded.

2. When the noncorrugated steel pipes were installed, some CGMP culverts remained clogged and did not allow water to pass.

3. The road surface over all the new culverts showed subsidence. This was probably due to a lack of adequate compaction following placement of the frozen gravel.

4. As late as 21 June, piping or channeling of water along the exterior of culverts 17 and 18 occurred while the culverts were blocked with snow and ice.

In general, culverts that performed well were in the very wet low-lying areas, several of which are permanent bodies of standing water. Discharge conditions included blocked, flowing, and submerged inlets and dry culverts.

Maps of areal extent of impoundments within the West Road corridor (extending 610 m, or 2000 ft, from the road) were prepared using available

Figure 12. Upslope view of steel replacement culvert installed at a lower elevation than the CGMP.

sequential aerial photography. On color aerial photographs, standing water areas had distinct boundaries and uniform, darker tones than the surrounding area. Maps of flooding were prepared in 1980, after the section of the road from K pad to the West Dock had been built, and in 1981, when the road was completed. Figure 13 shows the extent of standing water in July 1981 caused by construction of the road. Water coverage was progressively reduced over the summer as drainage and evapotranspiration continued. The degree of initial flooding varied from year to year due to variable snow-cover conditions. Similar maps were prepared for the Waterflood Project environmental study (Klinger et al., 1982a,b); that study showed that 75 acres of impoundments per mile of road had been created by the West Road.

In the Kuparuk field, as a maintenance practice, the ends of the culvert are covered with polyethylene in the fall to prevent their clogging with ice and snow. The snow that drifts over each end of the culverts is excavated prior to the spring melt. This practice prevents culvert blockage and water impoundments as spring runoff begins. Tundra streams or drainage channels carry large volumes of water during snowmelt, and it is not uncommon for a series of culverts to be laid side by side or in tiers. The optimum number of culverts needed is largely determined by trial and error, as virtually no reliable runoff data exists for these small, rapidly peaking streams.

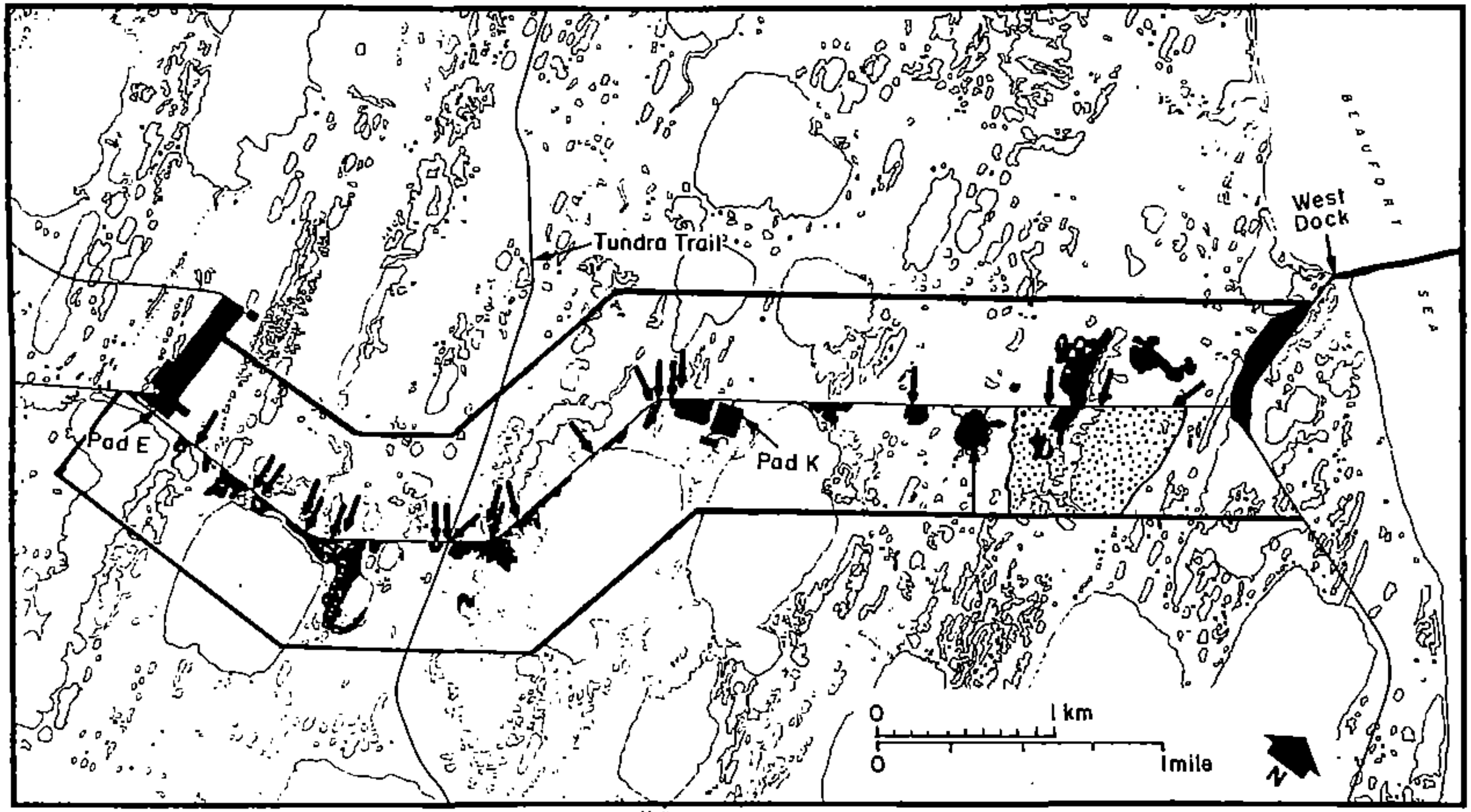


Figure 13. Areas of ponding along the West Road, July 1981. Arrows indicate approximate locations of culverts.

DISCUSSION AND CONCLUSIONS

Thaw penetration and temperature data from the Prudhoe Bay area indicate that gravel road embankments up to 2 m (6.5 ft) in thickness thaw completely in the summer and that thaw penetrates into the consolidated active layer. Under these circumstances, water should be able to flow through the road embankment by late summer. Ice wedges adjacent to roads are observed to melt, indicating that permafrost degradation is occurring, at least adjacent to the roads and perhaps under them. Acceleration of ice wedge melt is probably due initially to the warming effects of the impounded water.

Many roads in the Prudhoe Bay area are inadequately culverted, and shallow impoundments form on the upslope side. Shallow fills and heavy traffic loads contribute to the structural failure of culverts. Improved placement, proper compaction of gravel bedding and backfill, and covering the ends of the culverts each fall and reopening them each spring are desirable to prevent impoundments.

Limited temperature data from the insulated culvert in the Kuparuk field indicate the ground adjacent to the insulation was up to 2°C warmer in summer next to the culvert, as compared to an uninsulated road section 30 m (98 ft) upslope. Heat transfer from the flowing water into the surrounding ground may contribute to these warmer conditions.

The thin gravel fills (1-1.5 m, or 3-5 ft) thaw completely, and thaw penetrates into the buried active layer. Where thaw exceeds the active layer, ice-rich permafrost begins to thaw. This is observed on roads that are not maintained. Depressions form where ice wedges melt.

Continued monitoring of gravel roads and adjacent ground temperatures is recommended for this region of Alaska, and thermal study of insulated sections is advisable to ascertain the specific benefits of insulation. However, future studies need to instrument the sections directly under the insulation at the time of culvert placement.

Acceptable practices for culvert placement, installation, and maintenance should be agreed upon and documented. The environmental impacts of impeded surface drainage due to roads is being documented (Klinger et al., 1983b) and will presumably continue in order to establish the long-term effects.

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APPENDIX A

GROUND TEMPERATURES

APPENDIX A

GROUND TEMPERATURES

Ground temperatures from other study sites in the Prudhoe Bay and Kuparuk River regions are included in this report to make them available to other designers and scientists. The Deadhorse record is the longest and deepest and shows temperatures at 70–75 ft fluctuating between −8.3 and −9.0°C. Pingo temperatures at comparable depths are less than 1°C lower than at the Deadhorse site. This seems reasonable in that the pingo is elevated 10–15 m above the surrounding terrain and is expected to be colder. Ground temperatures at the Kuparuk site are slightly lower than at Deadhorse.

Table A-1. Ground temperatures (°C) adjacent to Deadhorse airfield.

Depth (ft)	10 Aug 1978	28 Aug 1978	13 Dec 1978*	2 Aug 1979	17 Aug 1980	4 May 1982	27 Aug 1982	15 Oct 1982	2 Jul 1982	10 Dec 1982*	14 May 1983	16 Jun 1983*	26 Jul 1983	24 Aug 1983
1			-16.2			-9.7	0.6	-6.4			-0.9		4.4	
2	1.2	1.2		1.0	0.4		-0.7	-5.8	0.4		-8.2		0.1	
3	-0.2	-0.5	-13.5	-1.2	-1.2	-9.9	-1.8	-5.0		-13.1	-10.5	-3.1	-1.7	0.2
4						-12.6	-2.7	-4.3			-11.7		-2.8	
5					-2.9	-13.6	-3.4	-4.0	-3.7		-12.3		-3.7	
6	-3.4	-3.3	-10.8	-4.0		-13.9	-4.1	-4.0		-11.9	-12.9	-7.6	-4.8	-3.1
7					-4.2	-13.9	-4.7	-4.0	-5.3		-13.2		-5.6	
8						-13.8	-5.4	-4.1	-6.5		-13.4		-6.5	
9							-5.8				-13.4		-7.2	
10	-5.6	-5.2	-8.5	-6.3	-6.2	-13.5	-6.2	-4.2	-7.7	-9.5	-13.5	-10.0	-7.7	-5.6
12	-7.1	-6.6	-7.6	-7.6	-7.3	-13.3	-6.9	-4.5	-8.5	-7.9	-13.4	-11.2	-8.5	-7.2
14						-12.1	-7.4	-5.5	-9.0		-13.2		-9.0	
16	-8.0	-7.5	-7.2	-8.3	-8.0		-7.7	-6.0	-9.4	-7.1	-12.9	-11.3	-9.4	-7.8
18							-8.0				-12.7		-9.7	
20	-8.5	-8.1	-7.1	-8.8	-8.4		-8.2		-9.6	-6.8	-12.4	-11.3	-9.9	-8.7
22			-7.1			-11.3		-6.6		-7.0		-11.2		-9.2
24							-8.6		-9.6		-11.7		-10.0	
26	-9.1	-8.8	-7.3	-9.2	-8.9			-7.2	-9.6	-7.2		-11.0		-9.4
28														
30			-7.6			-9.5	-8.7	-7.8		-7.5	-10.9	-10.7	-10.1	-9.6
32	-9.3	-9.1	-7.9	-9.3	-9.0					-7.7				-9.6
34							-8.8	-8.2	-9.4		-10.1	-10.4	-10.0	
36			-8.2							-7.9				-9.6
38	-9.3	-9.2	-8.4	-9.2	-9.0									
40							-8.7		-9.3	-7.9	-9.5		-9.7	-9.5
42			-8.5							-8.1				-9.5
44											-9.0		-9.4	
46	-9.2	-9.2	-8.7			-8.5		-8.3	-9.0	-8.2				-9.3
48			-8.8	-9.0	-8.9					-8.3				-9.3
50							-8.6				-8.7			
52	-9.1	-9.1	-8.9						-8.7	-8.4				-9.1
54										-8.4	-8.6	-8.7	-9.0	-9.1
56			-8.9			-8.2		-8.5						
58	-9.1	-9.1	-9.0						-8.5	-8.4		-8.5		-8.9
60							-8.5				-8.5			
62			-9.0											
64	-9.0	-9.1		-8.7	-8.7	-8.2				-8.5	-8.5	-8.5	-8.7	-8.8
66								-8.5	-8.4	-8.5		-8.5		-8.7
68			-9.0											
70							-8.4	-8.5		-8.5	-8.4	-8.5		-8.7
72						-8.3								
74	-9.0	-9.0	-9.0	-8.8	-8.7	-8.5		-8.5	-8.4	-8.5	-8.4	-8.4	-8.6	-8.6

*Data provided by T. Osterkamp, University of Alaska.

Table A-2. Ground temperatures (°C) in the Weather Pingo, Prudhoe Bay.

Depth (ft)	19 June 1982	27 Aug 1982	15 Oct 1982	14 May 1983	16 June 1983	26 July 1983
1	-1.3	1.2	-8.3		-1.4	4.0
2	-1.5	0.7	-5.9		-4.8	0.1
3	-4.9	-0.2	-2.3	-12.4	-6.2	-1.0
4	-5.9	-0.7	-1.7	-13.6	-7.6	-1.6
5	-6.8	-1.3	-1.7	-14.2	-8.8	-2.3
6	-7.9	-2.0	-1.9	-14.7	-9.8	-3.1
7	-8.3	-2.6	-2.2	-15.0	-10.6	-3.8
8	-9.4	-3.2		-15.2	-11.3	-4.6
9	-9.8	-3.8	-2.9	-15.3	-11.8	-5.4
10	-10.3	-4.4		-15.3	-12.3	-6.1
11	-10.7		-3.5	-15.2	-12.6	-6.6
12				-15.1	-12.8	-7.2
13	-11.3		-4.3	-15.0	-12.8	-7.8
14				-14.8	-12.8	-8.4
15	-11.6	-6.8	-4.9	-14.6	-12.7	-8.8
16						-9.3
17			-5.6			-9.6
18	-11.6					-10.0
19						-10.2
20	-11.4	-8.4	-7.0	-13.0	-12.2	-10.5
25	-10.7			-11.3	-11.0	-11.0
30		-9.4	-8.0	-9.9	-9.5	-10.9
35			-8.5	-8.8	-8.8	-10.7
40		-9.0	-8.7	-8.3	8.7	-10.3

Table A-3. Ground temperatures (°C) from Kuparuk tundra site.

Depth (ft)	25 June 1982	July 1982	25 Aug 1982	15 Oct 1982	14 May 1983	27 July 1983
Surface	12.8	12.2	10.2	0.2	-11.0	6.6
2	-3.6	-0.8	-1.2	0.2	-13.2	-1.2
3	-6.0	-3.0	-3.0	-0.6	-14.2	-3.2
4	-7.0	-3.9	-3.4	xx	-14.4	-4.2
5	-7.8	-4.6	-4.2	-2.4	-14.6	-5.0
6	-8.6	-5.4	-4.8	-3.0	-14.2	-5.4
7	-9.4	-5.8	-5.4	-3.6	-14.2	-6.2
10	-10.4	-7.4	-7.0	-4.6	-14.2	-8.2
15	-11.0	-8.5	-8.2	-5.6	-13.5	-9.0
20	-10.6	-9.6	-9.4	-7.6	-12.2	-10.2
27	-11.4	-9.3	-10.0	-6.8	-10.4	-10.6