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Environmental Studies No. 4

Building and Operating Winter Roads in Canada and Alaska

Kenneth M. Adam, Ph.D., P.Eng.
Templeton Engineering Company.

Published under authority of the
Hon. J. Hugh Faulkner,
Minister of Indian and Northern Affairs,
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Acknowledgements

The author wishes to thank Drs. Lorne Gold, Robert Frederking, and Anthony Yarranton who reviewed the manual and provided many helpful suggestions. Special mention is also due to Derek Martin and Michael Kowalchuk, who assisted the author in setting up and conducting the interviews of winter roads personnel; to Norman Emslie who helped with the interviews in addition to writing several sections of the manual; to Mike Fedak who drew the maps and graphs and Darlene Boisclair who typed the manuscript; and to Martin Gerrard who edited the manual and prepared it for publication.

He wishes to acknowledge and express appreciation to the individuals in industry and government across Canada and in Alaska who so willingly shared their knowledge and experience of winter roads. Because the list of persons contacted or interviewed is so long, it has been included as an appendix to the manual.

CONTENTS

Part 3: Canadian and Alaskan Experience with Winter Roads

INTRODUCTION

This manual is a synthesis of techniques for building and operating winter roads based on the literature and established practices in Alaska and Canada. It was prepared for those who work with winter roads, whether as designers, researchers, planners, builders, operators, or inspectors.

The manual is divided into three parts. The first part deals with the nuts and bolts of winter road work -- route selection, road construction, use, maintenance, and closure. Trails, and roads of snow and ice, are dealt with under these headings in terms of procedures, methods, and equipment. The second part of the manual offers guidance and suggestions including contingency plans and a hypothetical example, for those who are involved in the planning of all aspects of winter roads. The third part summarizes information gathered from interviews with persons in Alaska and Canada who have had first-hand experience with winter roads. It includes descriptions of roads and trails that have been built across Canada and in Alaska, and is replete with practical suggestions and ideas.

The information is presented in a manner that may be understood by those who have not had previous experience with winter roads; but it is complete enough to satisfy the more experienced road builders and operators. Readers who want more detail on engineering design or research in connection with winter roads will find references to more technical material in the "Literature Cited" and "Further Reading" sections at the end of the manual.

The text has been organized so that readers can, in most cases, turn to any category of winter road and read straight through without having to refer to other sections. A certain amount of overlap has been inevitable as a result, because several of the procedures apply to more than one kind of road. To avoid excessive repetition, readers are referred to earlier sections in cases where an entire procedure is the same.

Recently, winter roads have been proposed for protecting sensitive terrain during pipeline construction. This has led to extensive research into various types of roads made of snow and ice. The effectiveness of these special roads for northern pipeline construction over sensitive terrain has now been established, as for example on the Alyeska project where short sections of pipeline were built from snow roads. Despite the importance of these special types of roads, winter trails are still the most common type of winter road, comprising over 90 percent of all winter roads built in Canada. Winter trails are also the cheapest type of road to build, costing about one quarter as much as snow roads and one twentieth as much as aggregate ice roads, the newest type of winter road. Yet, in terms of their ability to protect the environment, winter trails are at the bottom of the list. In view of this, and in recognition of the trend toward environmental protection, particularly in the North where winter roads are destined to play such a key role in the construction of pipelines, roads of snow and ice have been covered in the same detail as winter trails. Construction practices for achieving environmental protection in permafrost areas have also been stressed throughout the manual for the same reasons.

The winter roads personnel interviewed for the manual were accustomed to expressing themselves in imperial units when discussing ice thicknesses, truck speeds, gross vehicle weights, tire pressures, right-of-way widths, and so on. Quantities in the text have therefore been presented in imperial units first, followed by metric equivalents in brackets. In most cases, the metric equivalents have been rounded off in the interests of comprehension.

Opinions expressed in the interviews are generally those of persons we talked to and are not necessarily in keeping with my own views and opinions.

Development of Winter Roads

Compaction of snow for ease of winter travel is a natural process probably first practiced by animals. Caribou migrating in winter thousands of years ago probably adopted single file formation largely because of deep snow conditions. Even man naturally adopted this formation for winter travel early in Canadian history. In 1813, the 104th Regiment from New Brunswick travelled through snow to defend Upper Canada against an anticipated attack. Each man took a turn at breaking trail, after which he stepped aside to remove his snowshoes and rest until the others had passed. Then he continued the march with relative ease over a hard, beaten path until his turn came up again.

The modern winter trail is similar to the soldiers' beaten path, except that the snow is compacted by vehicles and the right-of-way is often about 30 feet (10 metres) wide. Such trails are found in most areas of Canada where frost penetrates the ground deep enough to give a solid base.

Because winter trails develop naturally and improve under use, their main advantage is that they can be advanced quickly at minimal cost with the least amount of equipment. Only a bulldozer might be required to gain access in most cases. The disadvantage of winter trails is that they are not as environmentally acceptable as other types of winter roads since they offer only minimal protection to the terrain and since the slash that accumulates as a result of clearing is seldom properly disposed of.

The logging industry made one of the earliest uses of winter trails for hauling logs by horses. This industry still uses winter trails and other winter roads today for hauling logs by truck.

There is a fine line between winter trails and the lowest class of snow road, the compacted snow road. The difference is simply that snow on winter trails is compacted by traffic as the season progresses. On a compacted snow road, the snow is first compacted by rolling or dragging to form a hard surface before the road is opened to traffic.

The logging industry also had an early hand in developing compacted and ice-capped snow roads. In the days when horses were used for hauling logs, it was common for snow to be shaped and compacted into place, then strengthened with added water to act as guide ruts for sleigh runners -- a form of localized ice-capping.

Actual snow road development studies were first undertaken by the allied military after the Second World War. Intelligence documents indicate Germany had developed drags and rollers for compacting winter roads at least by 1943. The advantages of "processing" snow by agitating it before compaction were recognized at the latest by 1946, although the process of "age-hardening" or allowing a road to "set" before use was not understood at the time. Extensive tests of processed snow roads and some work on the ice-capping of snow roads was completed by the military by 1953.

Snow roads offer many advantages. Snow, the material often obstructing winter travel, is used as a construction fill material to eliminate roughness caused by micro-relief. Vertical alignment can also be improved with snow fill, and a built-up grade offers some protection from drifting snow. Such improvements in road quality allow higher travel speeds. Depending on the success of compaction (or processing and compaction), heavy loads and high-pressure-tired vehicles can use snow roads. Further upgrading is possible by the addition of water if necessary to form an ice-capped snow road.

Snow road construction with manufactured snow was first tested in Canada at Inuvik, Northwest Territories in 1974 for Canadian Arctic Gas Study Limited. Then in 1975-76, a manufactured snow road was used to build two short sections of the Alyeska pipeline project.

The major overall advantage of snow roads is that they offer more protection to the terrain than winter trails. Their disadvantage is the high cost of construction. They require more equipment and manpower, and they take longer to build than winter trails.

Ice roads on frozen lakes and rivers have been used extensively in the past, although their use has declined in recent years. However, construction of solid ice roads over land is a relatively new concept. Solid ice roads have found some use as supply roads for drilling camps in snow-short arctic regions. Their advantages are that they can be built without snow, and they provide a strong, smooth, high-speed surface. They are costly, however, because of specialized equipment and larger manpower requirements, and some concern exists about the use of water for road construction in water-short areas such as the Arctic in winter where depletion could affect over-wintering fish.

The most recent type of winter road developed, the aggregate ice road, was tested by Alaskan Arctic Gas Pipeline Company in 1976-77. It used crushed ice as a fill material. This type of winter road has not yet been used in practice, although it shows good promise for specialized applications.

One great advantage of all types of winter roads in wilderness areas is that they are self-destructive in spring and therefore provide only limited access. Access to an area by winter road need not detract from its wilderness qualities, particularly where no clearing or only intermittent clearing is required. This advantage is best exemplified in tundra regions.

Permafrost and Nonpermafrost Regions

Permafrost is a term used to describe ground that remains below 32^{o}F (0^{o}C) for at least one year. The term, which has nothing to do with the type of ground, applies equally well to solid rock as to frozen sands or gravels.

Permafrost regions in Canada, from the point of view of winter road construction and operation, are considered as areas with widespread or continuous permafrost (see Figure 1, Appendix 1). These are areas where the mean annual air temperature falls below 25^{o}F (-3.9^{o}C). In permafrost regions, particularly where high-ice-content soils are present, surface disturbance can lead to problems, some growing worse with the passing of time. Ground subsidence, thermokarst development, thermal erosion, hydraulic erosion, solifluction, and mudslides are common terrain reactions to surface disturbance in permafrost regions. Extensive terrain damage from winter road activity is not acceptable given today's environmental standards.

Nonpermafrost regions of Canada, from the point of view of winter road construction and operation, are considered to lie south of the southern limit of widespread permafrost. In this region, in the northernmost areas, some sporadic permafrost exists but soils generally do not contain large volumes of excess ice. When the surface cover is removed, little more happens than further south except that soil that was frozen begins to melt. In summer, the consequences can be very significant because construction equipment can become mired and terrain damage is immediately apparent. But in winter, when the ground surface is totally frozen and thaw initiated by construction does not become apparent until spring, some surface disturbance is tolerated during winter road construction. At present, it is Canadian practice to accept severe terrain damage in nonpermafrost areas. This practice should be reviewed, considering the progress that has been made in reducing terrain damage in permafrost regions in the last two decades.

Types of Winter Roads

A winter road is any type of road built of snow, ice, or a mixture of mineral soil*, snow, or ice that remains functional only during the winter season.

Winter roads fall into three broad categories: winter trails, snow roads, and ice roads.

Winter Trails.

Temporary Winter Trail. A trail established for use during one winter season by a single pass of a tracked or wheeled vehicle using a "blade" if necessary to gain access. Seismic lines would generally fall in this category. Temporary trails are not usually acceptable in permafrost regions since surface smoothness is often obtained by blading off the tops of hummocks.

Perennial Winter Trail. A trail established for use over several winter seasons along new or existing rights-of-way. Depressions are filled with snow in permafrost regions or with a mixture of mineral soil and snow in nonpermafrost regions. Drags or blades are used to fill depressions; this often leads to the "scalping" of hillocks or ridges and introduces mineral soil to the snow.

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*Mineral soils should not be used for building winter roads in permafrost areas. The practice can lead to melting of ice-rich soils and ground settlement. See the section on building temporary winter trails in permafrost regions.

Snow Roads.

Compacted Snow Road. A road built primarily with snow as a cut and fill material to establish some semblance of a constructed road grade. Compaction, the final step of construction, is accomplished by crawler tractor, drags, or rollers.

Processed Snow Road. Similar in construction to a compacted snow road, except that the snow is agitated or "processed" to reduce the size of the particles before compaction.

Ice-Capped Snow Road. Either a compacted or processed snow road on which water has been sprayed to produce a bond between snow particles and give added stability to the roadway.

Artificial Snow Road. A compacted snow road built of artificial or manufactured snow hauled and end-dumped into place or manufactured on site. The road is shaped and compacted by crawler tractor.

Ice Roads.

Solid Ice Road. A road built by sprinkling, spraying, or hosing water directly on the ground to fill depressions and produce an ice surface of suitable thickness to support traffic.

Aggregate Ice Road. A road built of crushed ice (ice aggregate) hauled and end-dumped into place. Water is sprinkled, sprayed, or hosed onto the surface to bond particles.

Winter Road on Ice. A road built on the surface of frozen lakes or rivers. This type of road is very common in some areas of Canada because the surface is naturally smooth, no clearing of trees is required, and overall road preparation is minimal.

Ice Bridge. A bridge built across frozen lakes or rivers where the natural ice thickness is normally supplemented by ice formed from water applied to the surface. Timber is sometimes placed longitudinally or laterally in the bridge for reinforcement.

PART 1

BUILDING AND OPERATING WINTER ROADS

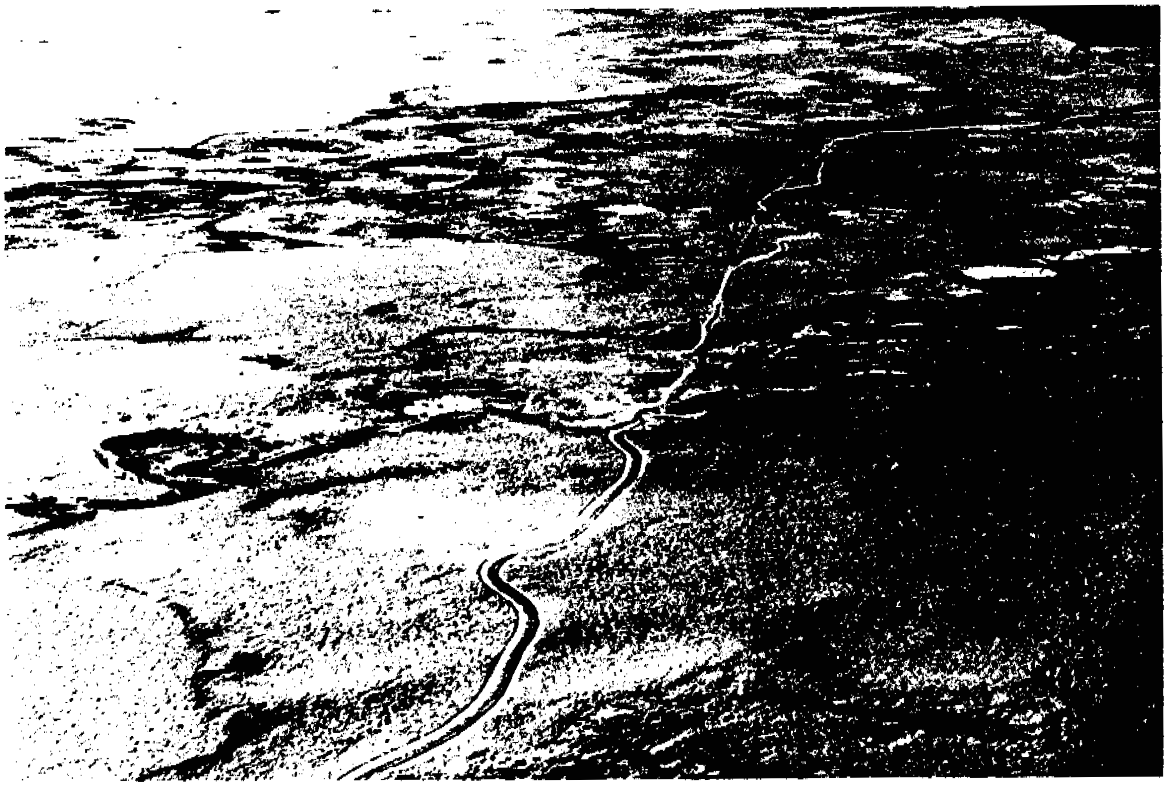
Temporary winter trail, Yukon Territory. (Gulf Oil Limited)

WINTER TRAILS

Winter trails are of two types: temporary and perennial. Temporary winter trails are used for a single winter season, whereas perennial winter trails are used year after year over the same route.

The perennial winter trail is often of slightly superior quality compared to the temporary trail, and involves more planning at the route selection stage. It carries normal highway traffic (particularly semitrailers) in nonpermafrost areas and to some extent in permafrost areas. Temporary winter trails carry all types of traffic in nonpermafrost areas. They normally carry only tracked or balloon-tired vehicles pulling sleighs in permafrost areas.

Neither type should carry highway traffic over tundra.



Temporary winter trail in the Mackenzie Delta. Note seismic line in background. The trail follows the line in some places but skirts it in others to avoid problem areas. (Gulf Oil Limited)

Construction

Equipment for building temporary winter trails normally consists of a crawler tractor with blade.

Clearing begins when the ground is frozen to a depth of 6 to 8 inches (15 to 20 centimetres). Wet areas should be tramped to speed frost penetration.

Tracked equipment is used where clearing is required in permafrost areas. Where no clearing is required and there is little danger of puncturing tires, other low-ground-pressure vehicles can sometimes be used for construction.

In nonpermafrost areas, frost is required only to maintain machine mobility. Snow cover is relatively unimportant because it is not considered essential to protect the terrain. Trees are normally knocked down by blade and bulldozed into windrows. The ground is bladed level or a mixture of mineral soil and snow is moved across the roadway to fill holes and depressions. Levelling and compaction are often accomplished by back-blading. If the trail is built early in the fall, it is normally left to "freeze-in" before it is used by traffic. If it is constructed in mid-winter, as are most seismic lines, then tracked vehicles, including camp, normally follow immediately behind the dozer on the newly completed surface.

In permafrost areas, snow is required to fill hollows and depressions in the trail and protect the surface from disturbance. For these reasons, there should be at least 4 inches (10 centimetres) of snow on the ground to work with before construction begins. Mineral soil must not be used to build trails. In the spring, the soil remains on the surface after the snow melts, presenting a darkened surface that absorbs more radiation. Higher surface temperatures that result can lead to melting and settlement of soils containing excess ice. Breaking of the surface mat of vegetation and peat is also unacceptable in permafrost areas. Stripped of its insulating cover, the exposed mineral soil melts in spring, leading to slumping and ground subsidence.

The solution is to equip dozer blades with mushroom shoes. They prevent the blades from scalping the tops of tussocks and hillocks or removing the surface mat of vegetation and peat.

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Temporary trail through a nonpermafrost area. Note mineral soil on the road and slash windrowed along left-hand side. (J.D. McMillan)

Temporary trail through a permafrost area. (R. Read)

In tundra areas, the terrain will be damaged if tramping of the vegetation or snow cover begins before the active layer is frozen. After compaction by tracked vehicle, all areas of the trail should be protected by at least 2 inches (5 centimetres) of snow.

Despite the utmost care during construction, winter trails on the tundra will often be visible, particularly from the air the following summer(s) even after only a few passes of low-ground-pressure vehicles. This indicates how susceptible northern terrain can be to construction activities.

Operation

In nonpermafrost areas, temporary winter trails are used by rubber-tired vehicles and often by tracked vehicle trains. Since surface protection is not vital, wear and rutting of the trail is common and generally considered acceptable. Truck loads for logging operations are normally limited to highway restrictions but loads up to 300,000 pounds (136,000 kilograms) have been carried on winter trails.

In permafrost areas, only tracked vehicles or balloon-tired, low-ground-pressure vehicles should be used on temporary winter trails. Trailers and mobile camps should be ski-mounted so that surface disturbance is minimal.

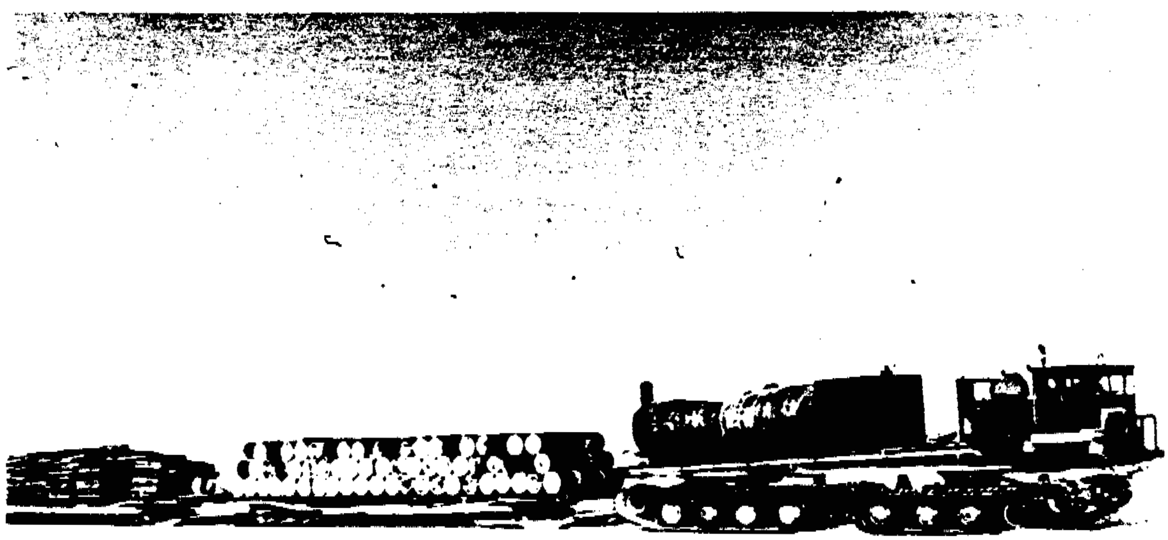
Maintenance

Graders or motor patrols are often used to maintain a smooth surface on winter trails.

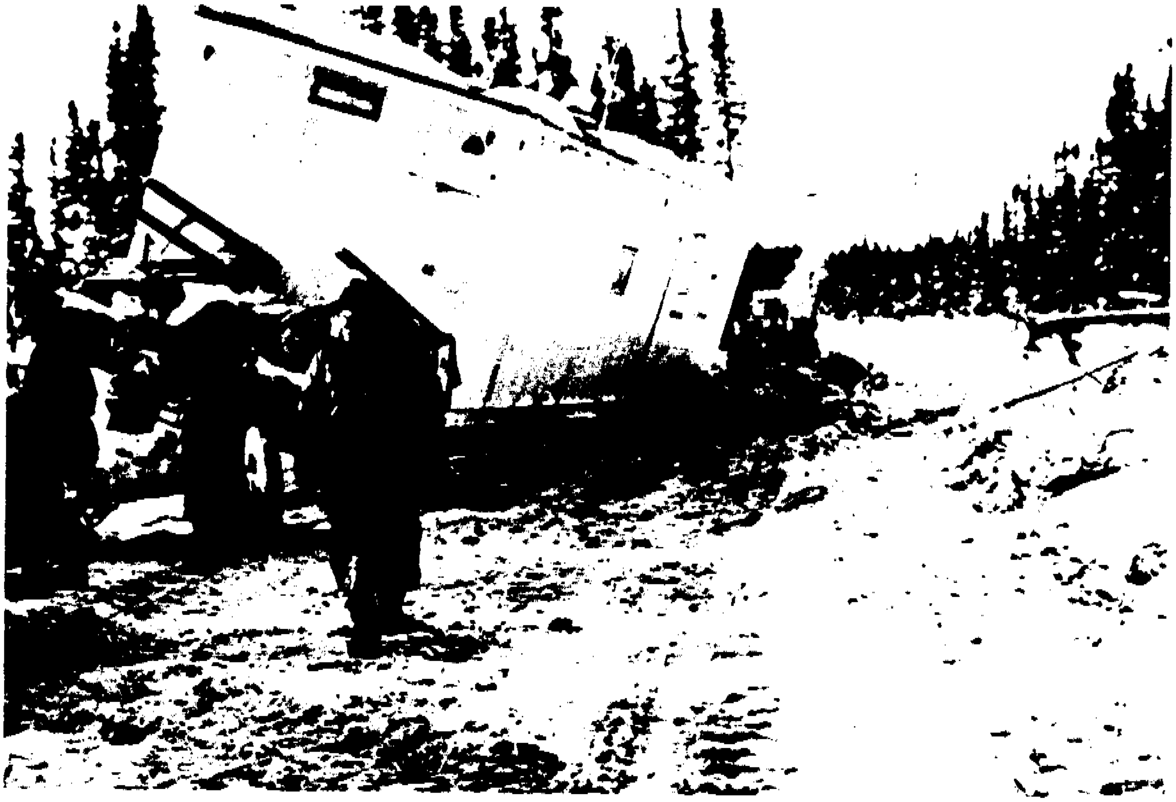
In nonpermafrost areas, the purpose of maintaining temporary winter trails is primarily so that vehicles can travel as quickly as possible. Speeds up to 25 miles per hour (40 kilometres per hour) are considered good on a winter trail.

In permafrost areas, maintenance of temporary trails is minimal, the main objective being to keep the surface covered with snow to delay melting in the spring. Normally, traffic follows so close behind construction equipment that maintenance is unnecessary. However, if trails are used for return access, bare spots caused by wear, radiation, or other factors should be covered with snow and lightly compacted. When the trail is used over most of the winter, the surface should be inspected periodically for bare spots.

Rubber-tired vehicles are often used on temporary winter trails in nonpermafrost areas. (K.M. Adam)



Soft-tracked vehicle pulling sleighs, a combination that minimizes surface disturbance in permafrost areas. (L. Emard)



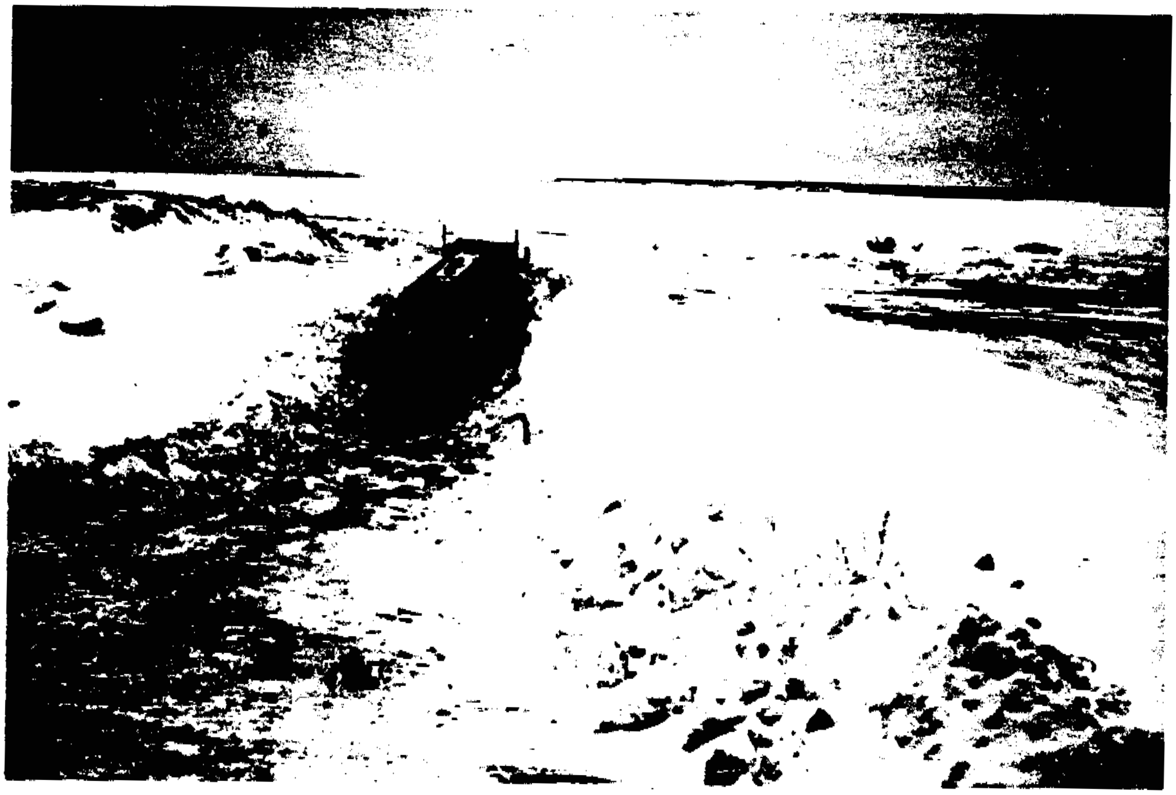
Delay caused by the use of rubber-tired equipment on the trail. (Desourdy Construction Limited)

Maintenance is often speeded with a wooden drag pulled by a dump truck. (J.D. McMillan)

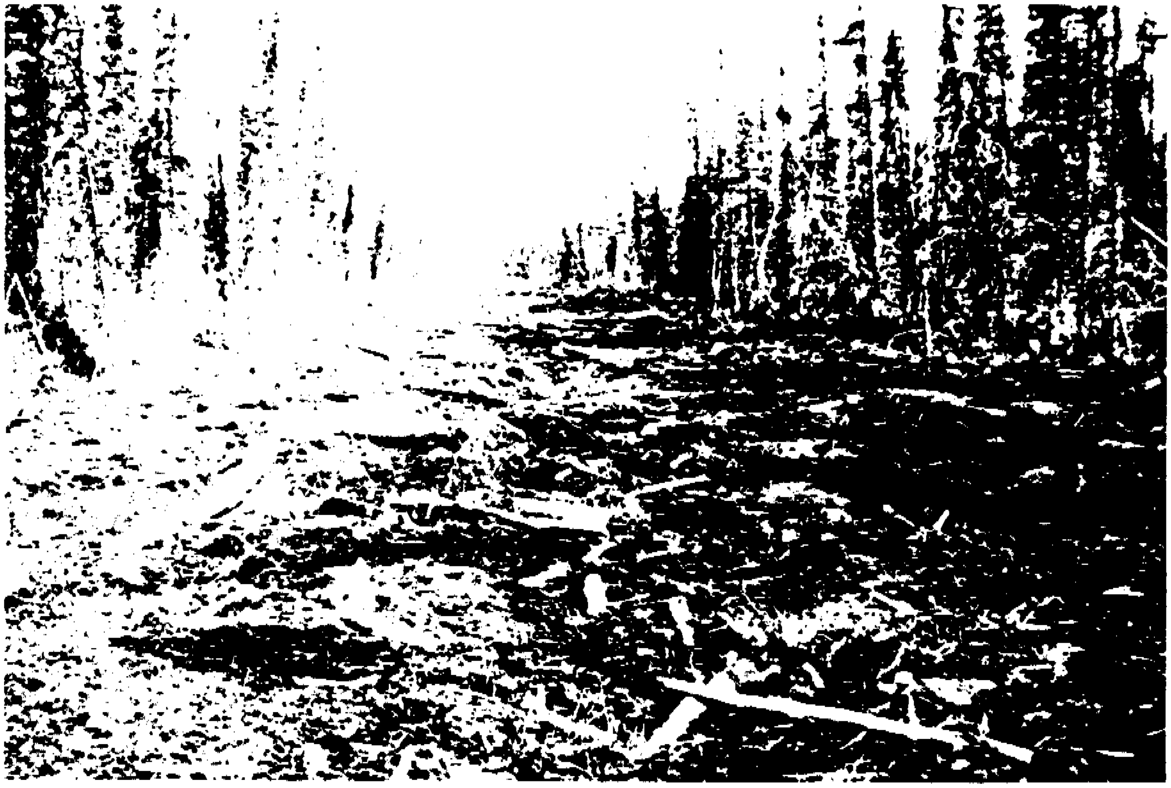
General road conditions and areas in need of repair are most often reported by vehicle drivers. However, over very lengthy winter roads built under contract, low-level fixed-wing aircraft shooting movie film provide a unique way of permanently recording road conditions, construction equipment being used, sequence of construction, and other pertinent data. Review of the film will indicate whether snow is being utilized in the road or being wasted to the side. Experienced viewers can even tell whether the road has been dragged or levelled by motor patrol.

Closure

In nonpermafrost areas, temporary winter trails can be used until vehicles begin to bog down. In permafrost areas, closure will probably be determined by land-use inspectors, generally when surface damage is imminent.

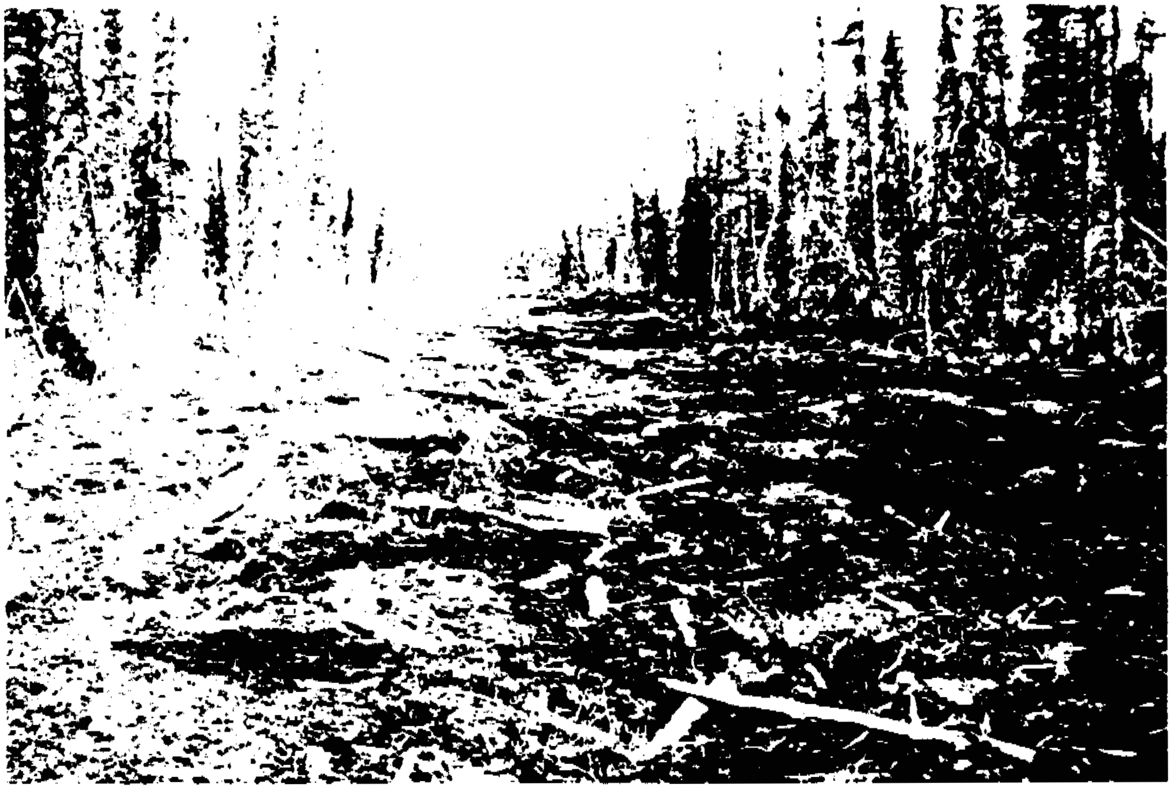


Temporary winter trail nearing time of closure. (K.M. Adam)



Temporary trail in summer. Mushroom shoes on the bulldozer would have prevented much of the damage on the right-hand side. (K.M. Adam)

Winter road right-of-way in summer in nonpermafrost area.



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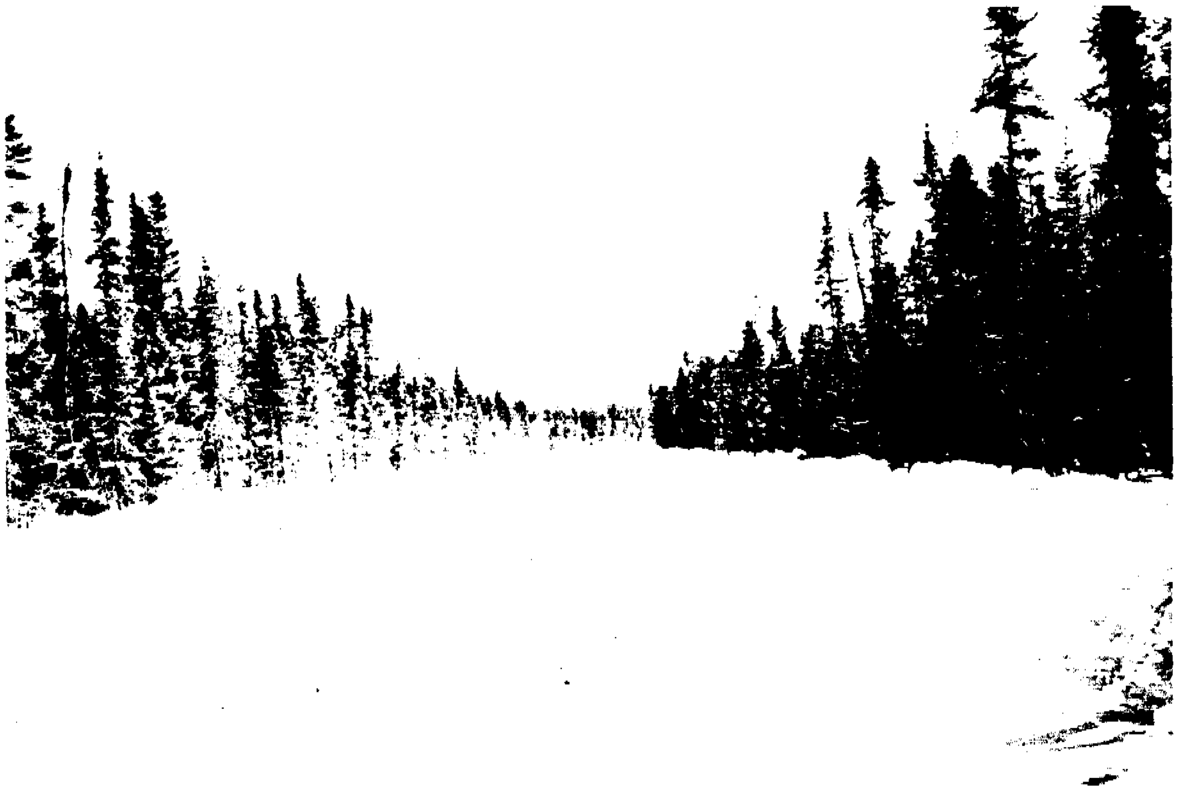


Hole River road, a perennial winter trail in Manitoba. (K.M. Adam)

PERENNIAL WINTER TRAILS

Perennial winter trails are used primarily for supplying remote villages and industrial developments. They are constructed year after year along the same route over both permafrost and nonpermafrost terrain.

Often after years of use, perennial winter roads are upgraded to permanent roads for year-long use. Because they may link communities to existing highway systems, they are often planned with the expectation that they may become permanent roads or may aid in the construction of a permanent road. Sometimes semi-permanent bridges such as Bailey bridges are used for water crossings on perennial winter trails.

Route Selection

The likelihood of permanence associated with perennial winter trails makes route selection an important task. Normally, route selection is in response to a single-purpose requirement such as servicing a new mine site. But it should also reflect at least the short-term plans for an area, since the location of a perennial winter trail can influence the short-term, if not the long-term, development patterns of a region.

When a permanent road is anticipated, the route should be selected using at least minimal permanent road criteria. This normally entails providing for a 100-foot-wide (30-metre) right-of-way and windrowing debris to the edge. Maximum grades should not exceed 8 percent and maximum curves 6 degrees. Both the permanent road and winter trail should be able to handle 5-axle vehicles weighing up to 74,000 pounds (34,000 kilograms).

Perennial winter trails should be located so as to extend springtime use as much as possible. In valleys, alignments should be protected from direct sunlight; this normally means avoiding southfacing slopes. In forested areas, selecting alignments shaded from early afternoon sun can also extend springtime use.

River crossings should be investigated from several points of view. Good ice bridge crossing sites should be identified as described in the section on ice bridges. Permanent bridge crossing sites should also be considered. Criteria for choosing these two kinds of sites could be opposing. For instance, wide, shallow, slow-flowing sections of rivers may be preferable for an ice bridge whereas a narrow, deep section may be preferable for a permanent bridge. A river with both types of sites close together might influence route selection because it would allow the construction of the permanent bridge to be supported from the winter trail. The advantage of building bridges for permanent roads in winter is that construction equipment completing the permanent road the following summer is not held up at river crossings.

Construction

Equipment for building perennial winter trails consists of crawler-type tractors with blades, light- to medium-sized drags, and a small, low-ground-pressure vehicle.

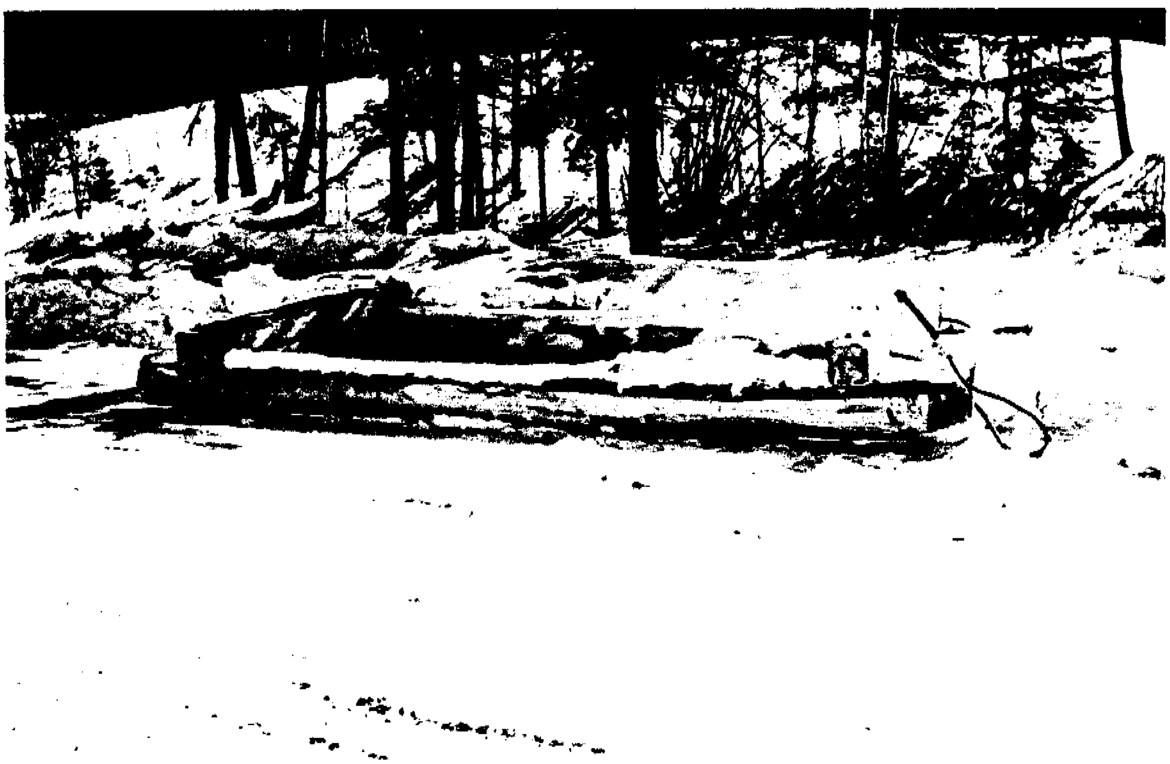
Construction is the same as for a temporary trail except that greater care is usually taken because of the likelihood of higher traffic volumes.

Clearing is accomplished in the first year of use. The low-ground-pressure vehicle normally starts right-of-way preparation by tramping vegetation and ground snow cover as soon as sufficient frost has penetrated the ground to support the vehicle. This activity is most important in low, wet areas where vegetation is dense because any snow compacted down to the surface is wetted and helps form a solid base when frozen. The snow's insulation value is also decreased, allowing frost to penetrate deeper.

In nonpermafrost areas, after sufficient frost has penetrated to support the crawler tractors, a mixture of snow and dirt is moved back and forth across the roadway until the surface is smooth. Snow is desireable at this time to fill hollows and depressions and keep the surface white, thereby providing resistance to melting from the sun's radiation. Next, a light steel or wooden drag is used to finish the surface. The road should then be allowed "freeze-in" and age-harden for at least 2 days before traffic is allowed on it.

In permafrost areas, after sufficient frost has penetrated the ground or the active layer of tundra has frozen completely, a crawler tractor can be used to move snow around on the right-of-way to fill hollows and depressions. Breaking of the surface mat should be avoided and mineral soil should not be used as a fill material. All areas of the roadway should be protected by a compacted snow cover. A light wooden drag is recommended to smooth and compact the surface. Steel drags have been found to cause more surface disturbance than wooden drags when the snow cover is thin. Tracked or balloon-tired vehicles used immediately after construction will normally help compact the road surface, but age-hardening for at least 2 days is recommended before normal rubber-tired traffic should attempt to use the trail.

Steel drags achieve a smooth roadway but tend to scuff the surface. (K.M. Adam)



Because of their length, wooden drags have the capacity to carry snow for considerable distances before depositing it in depressions. (K.M. Adam)

Perennial winter trail with a narrow right-of-way. (J.D. McMillan)

Some scuffing of the surface is tolerated in nonpermafrost areas. (K.M. Adam)

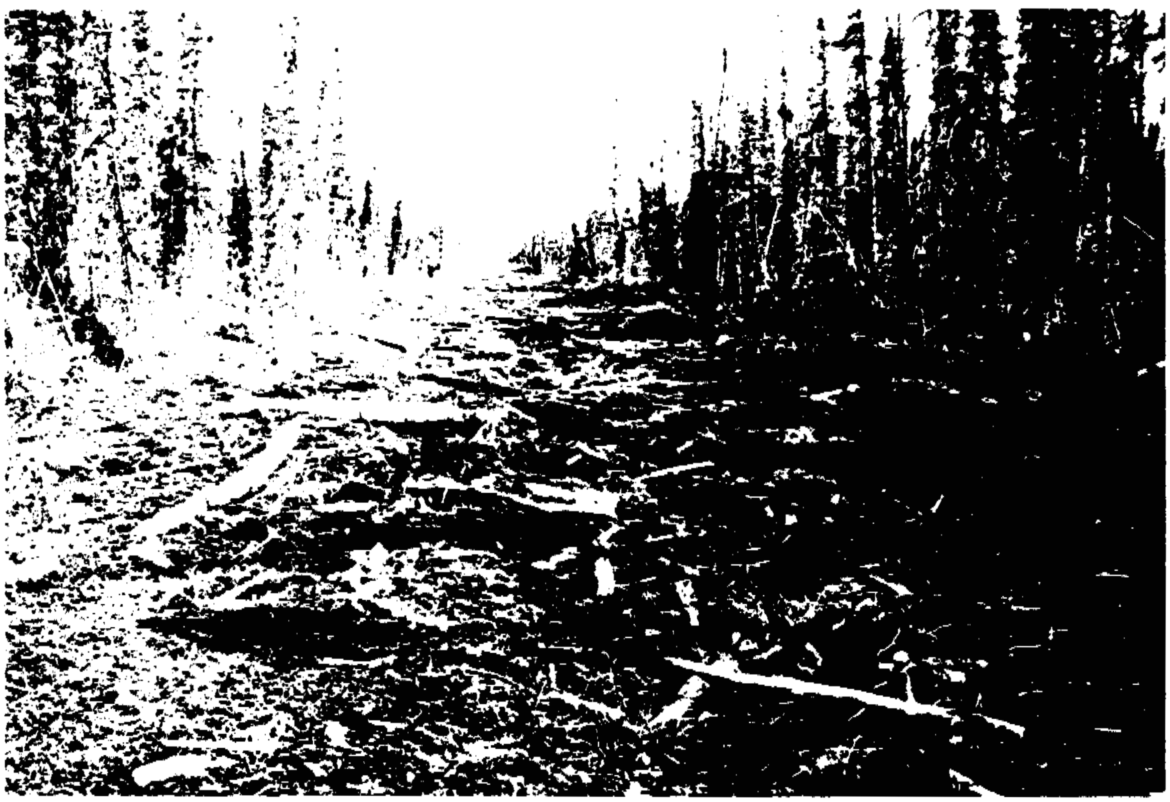
Operation and Maintenance

In nonpermafrost areas, operation and maintenance of a perennial winter trail is the same as for a temporary winter trail. Both wheeled and tracked vehicles can travel the road. Some rutting and scuffing of the surface is tolerated. A drag or blade can be used to smooth the surface so that vehicles can travel faster.

In permafrost areas, the main objective of maintenance is to protect the surface of the trail. Regular maintenance should be carried out with wooden drags rather than steel drags or blades which scuff the surface. Areas on the road without enough snow should be built up with compacted snow when signs of ground surface exposure become apparent. Bladed equipment should not be used for maintenance unless the road is thick enough to ensure that the blades do not come in contact with the ground cover. Because wheeled vehicles cause rutting and wearing, they should not be used on winter trails in permafrost areas. They should only be allowed if the trail has been compacted to the thickness and density of a compacted snow road.

Closure

Perennial winter trails are subject to the same rules for closure as temporary winter trails. See the section on closure of temporary winter trails.



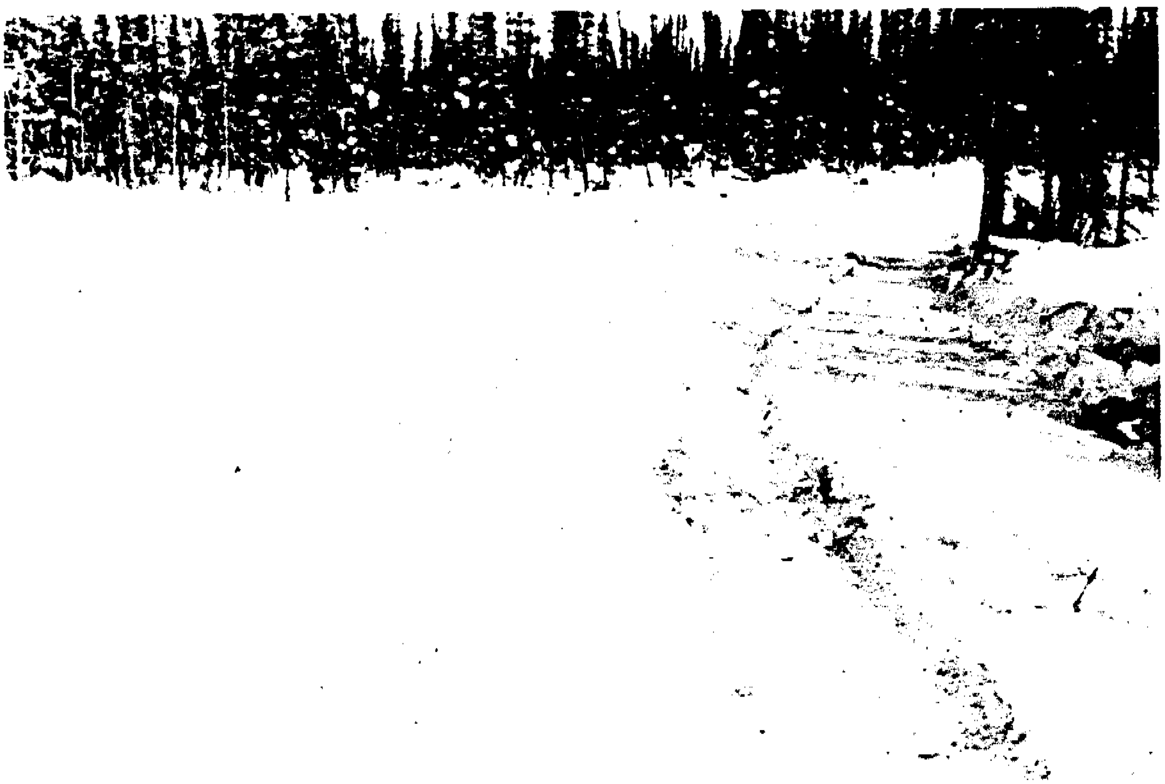
Summer view of a perennial winter trail. (K.M. Adam)

Compacted snow road before trafficking.
(K. M. Adam)

SNOW ROADS

Snow roads are built-up road grades of snow compacted to a density of 25 to 37 pounds per cubic foot (0.4 to 0.6 grams per cubic centimetre). Since they offer considerable protection to the terrain they are used mainly in permafrost areas. The road grade is often modified to increase its density, thereby improving its resistance to damage by traffic.

It is difficult to increase the density of a snow road. The snow crystals in the road bed are like tiny ice cubes, each with its own varied but definite shape. During construction, it is impossible to apply enough pressure to squeeze out all the air from between the crystals to form a solid, although measures have been developed that partially achieve this objective. One method, known as "processing", is to break up the crystals and refit them together more tightly. Another is to fill the spaces with water, either by flooding or by melting the snow. Or the snow can be manufactured with sufficient water content such that when it is compacted, it has a density that is high enough to support traffic.



Compacted snow road. Snowbanks are absent along right-of-way, the snow having been used to build the road. (K.M. Adam)

COMPACTED SNOW ROADS

A compacted snow road is the most elementary type of snow road. Once sufficient snow has been shaped into a road grade, the surface is normally levelled by drag. Then the snow is compacted by repeated passes of crawler tractors, heavy drags, or rollers.

Most snow roads begin as compacted snow roads but because of their structural limitations, are often upgraded to processed or ice-capped snow roads.

Route Selection

Route selection is the same for compacted, processed, ice-capped, and artificial snow roads except that in the case of ice-capped and artificial snow roads, a source of water for ice-capping or snow-making is particularly important.

All four types of snow roads should follow the lee side of hills where possible to take advantage of deeper snow. In areas of low snowfall, routes should run as close as possible to lakes and other sources of snow so that haul distances are kept to a mininum. Where snowfall is high, less importance can be given to snow availability; in fact, snow over 3 feet (1 metre) deep may pose mobility problems. In such areas, windswept hillsides may be advantageous. Large drift areas should be avoided because of maintenance unless the snow is needed for construction. In valleys, south-facing slopes melt sooner and should be avoided if extended springtime use is desireable. Slopes over 10 percent should also be avoided if possible. If loads are to be hauled in one direction only, somewhat steeper grades can be tolerated in the unloaded direction of travel.

Construction

Equipment for building a compacted snow road consists of a medium-sized crawler tractor with a mushroom-shoed blade, a light drag for levelling, and a heavy drag or roller for compaction. Many variations in construction equipment and techniques have been used.

After the first major snowfall of the season, the surface is dragged to destroy the insulating effect of the snow and to promote frost penetration. Minor surface irregularities are smoothed, usually with a light drag towed by a low-ground-pressure tracked vehicle. Drags made of wood rather than steel are preferable in permafrost regions because they cause less scalping of the surface.

It is usually desireable to have enough snow available to form a compacted surface at least 8 inches (20 centimetres) thick. Where "natural" snow is insufficient to achieve this depth, "imported" snow can be hauled from lakes, or snow fences can be built along the right-of-way to trap snow.

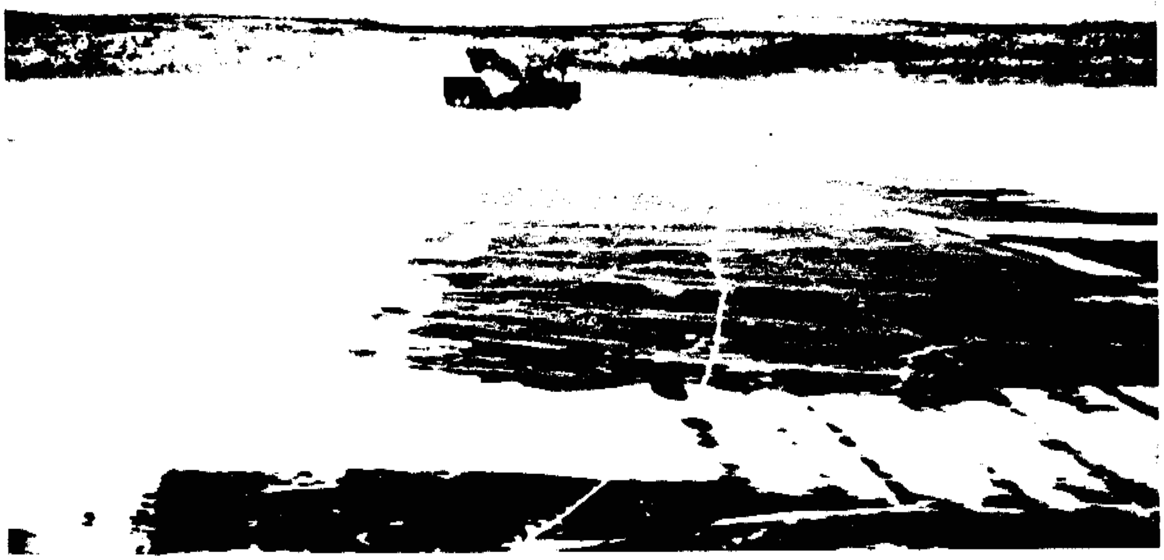
Test sections of compacted snow roads have been measured as thick as 3 to 6 feet (1 to 2 metres). Such depths overcome surface roughness caused by micro-relief. However, the increased cost of this type of construction can only be justified where large volumes of traffic are anticipated, travel time is of the essence, or only short sections are involved.

Construction can begin when sufficient snow cover has accumulated on the right-of-way, normally more than 8 inches (20 centimetres), and when the underlying ground is frozen to a depth of at least 6 inches (15 centimetres). The road is shaped by blade and levelled with a light drag or by backblading. Then it is compacted, often by repeated passes of a crawler tractor. Although this method is sometimes successful, the tractor may be unable to apply enough pressure to ensure a trafficable surface.

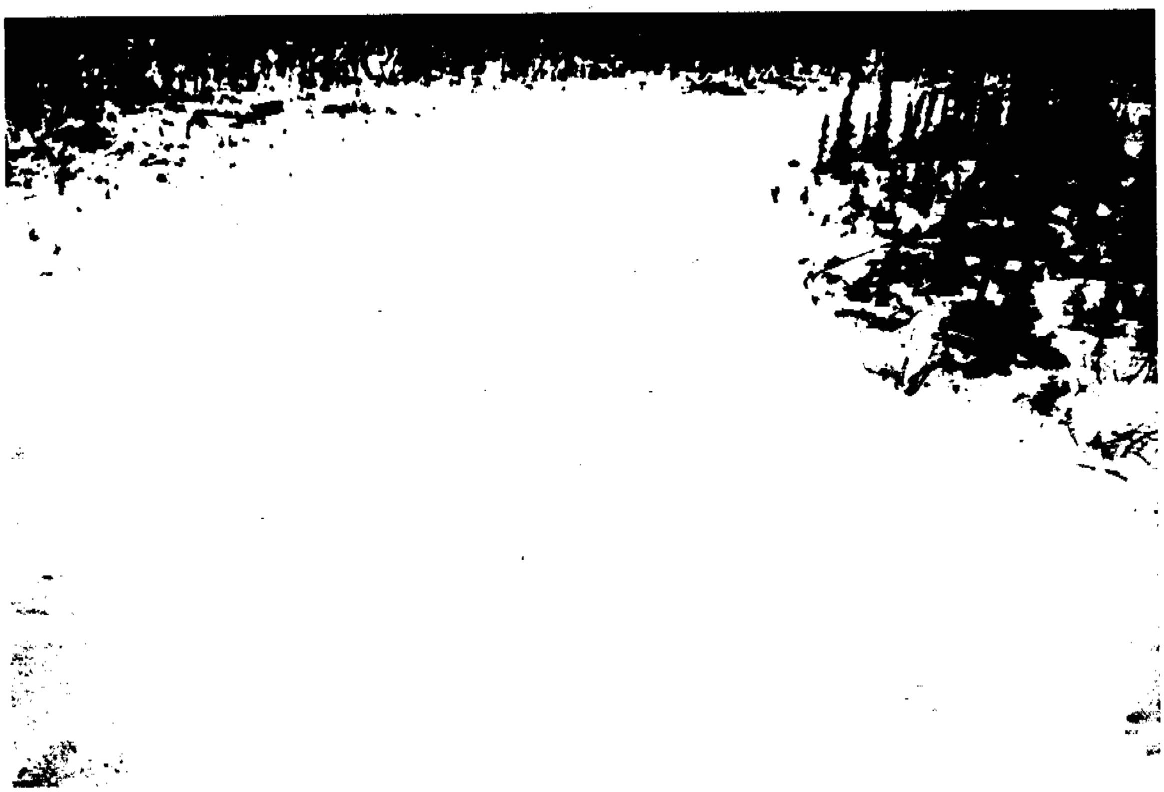
Heavy drags or rollers are recommended to achieve sufficient compaction. They can be used separately or one after another to build trafficable surfaces.

Heavy drags weighing about 3000 pounds (1400 kilograms) have been used as finishing drags. A typical drag is 12 feet (4 metres) wide and over 7 feet (2 metres) long. The curved bottom of each skid is 24 inches (60 centimetres) in diameter and is made of 3/8-inch (1-centimetre) plate. To speed compaction, the drags are often towed in gangs covering a 30-foot-wide (10-metre) swath. This arrangement penetrates 1 to 2 inches (2.5 to 5 centimetres), producing an excellent surface. It can be towed at 4.0 miles per hour (6 kilometres per hour), but requires two passes for best results. Rolling with a pneumatic-tired roller before applying the drag has been found to double the rammsonde hardness index. (The rammsonde hardness index of snow is a numerical measure of hardness obtained by driving a standard cone into the snow. See Appendix 3).

Two types of rollers have been found useful for snow compaction -- a large-diameter roller and the standard 13-wheeled, penumatic-tired, construction roller. The large-diameter roller is used to compact new snow, whereas the 13-wheeled roller is used to strengthen snow that has already been compacted.



Snow from surface of lake to be used to build a compacted snow road. (K.M. Adam)



Compacted snow road. The section shown, across a natural drainage channel, is more than 6 feet (2 metres) thick. (K.M. Adam)

A general-purpose compacting roller should have a single rolling element and towing frame, a smooth face, maximum width and diameter, a scraper blade for removing snow from the roller face, provisions for tandem or gang towing, and easy, knock-down construction to facilitate transportation by air. A typical 8-foot (2.4-metre) diameter roller weighing 10,000 pounds (4500 kilograms) is constructed of 5/16-inch (0.8-centimetre) plate 4 feet (1.2 metres) wide, curved through 90 degrees, and bolted together. Full details of design and construction are given in Technical Report 107, U.S. Naval Civil Engineering Laboratory, 1961.

Rollers work best on new snow. In areas of frequent snowfall, they can build up a compacted snow road in layers by repeated rolling of new snowfall. Large-diameter rollers can be pulled at speeds ranging from 2 to 6 miles per hour (3 to 9 kilometres per hour).

A good, surface-hardening roller is the standard commercial pneumatic-tired type. It consists of a ballast container with six wheels on the front and seven on the back. All wheels are normally inflated to 34 pounds force per square inch (235 kilopascals). Depending on the particular make, the capacity of the ballast container varies from 100 to 140 cubic feet (3 to 4 cubic metres). Such a roller could carry up to 8 tons (7 tonnes) of sand. It has been found most effective for further hardening snow that can support its weight with half an inch (one and one-half centimetres) or less of tire penetration, corresponding to a ram hardness greater than 200. On looser snow, larger diameter rollers are more effective.

It has been found that the combination of dragging and rolling can result in a good, compacted snow road. Normally, the ideal time for the final compaction effort is in the afternoon when ambient temperatures and moisture levels within the snow are at a maximum.

Heavy drags and rollers may fail to produce trafficable surfaces under certain circumstances. This is because the hardness of compacted snow depends on so many variables: geographical location, time of season, type and condition of snow, ambient and snow temperatures, and length of age-hardening period.

In Canada, heavy drags and rollers have not been tried extensively for compacting snow roads, although they have been used successfully in other places, mainly Antarctica. The full extent of their limitations and capabilities has yet to be determined.

After the road has been compacted to a density near or greater than 34 pounds per cubic foot (0.55 grams per cubic centimetre) or a rammsonde hardness index over 450, a short section of the road should be traffic-tested. If it is found that after 24 hours or more of age-hardening, more failures occur than can be tolerated, depth processing or ice-capping is necessary.

Operation and Maintenance

Operation of compacted, processed, ice-capped, and artificial snow roads depends primarily on the density and surface hardness of the road. At densities of less than 34 pounds per cubic foot (0.55 grams per cubic centimetre) or if the rammsonde surface hardness index is less than 450, traffic should be limited to low-ground-pressure vehicles and sleighs unless tests prove otherwise. At densities between 34 to 47 pounds per cubic foot (0.55 to 0.60 grams per cubic centimetre) or if the rammsonde surface hardness index is between 450 and 675, a short section of typical road should be traffic-tested. If it withstands 20 passes of typical anticipated traffic (typical total weight and tire pressure), chances are the road will harden and improve under use. At densities greater than 47 pounds per cubic foot (0.60 grams per cubic centimetre) or if the rammsonde surface hardness index is greater than 675, the road will probably be able to support normal highway traffic and even overweighted construction vehicles without excessive maintenance.

Traffic speeds can influence the amount of maintenance required. Normally, speeds over 25 miles per hour (40 kilometres per hour) can be maintained on a hard, smooth, snow road. At no time should vehicle speeds exceed 50 miles per hour (80 kilometres per hour). Speed limits should be posted. If bumps start to form, speed limits should be substantially reduced. The surface should be restored to smoothness before higher speeds are resumed.

Snow roads should undergo preventive maintenance and routine maintenance. Preventive maintenance consists of keeping the road surface smooth and hard. A road grader should be used to patrol the road and remove bumps when they are small. This is particularly important since bumps have a tendency to grow rapidly once they reach a certain size. Road hardness depends largely on ambient temperature, which cannot be controlled; but if the road shows signs of softening, it should be shut down immediately. Normally it could be re-opened for night-time operation when temperatures are colder. Reducing speed can also help to maintain a temperature-weakened snow road.

Large-diameter roller for compacting snow. The device on the front of the tractor is a makeshift snow processor. (K.M. Adam)

Heavy wooden drags are used for compaction.

Drifted or freshly fallen snow on roads in depths of 2 to 4 inches (5 to 10 centimetres) normally causes no problem because it is compacted by traffic. But if more than 2 to 4 inches (5 to 10 centimetres) of snow accumulate, the snow will tend to form bumps. The solution is to remove loose snow over 4 inches (10 centimetres) thick by plowing or blowing it off the road or by systematically working it into the road surface by continuously rolling or dragging it during the snowfall. Ridges should not be allowed to form on the road because they tend to trap snow.

Routine maintenance consists of patching potholes and ruts, and scarifying or sanding glare ice patches which tend to form at curves or on grades. Potholes and ruts can normally be filled with wetted snow and recompacted or ice-chips can be used, followed by sprinkling. Sometimes a mixture of sawdust, snow, and water is used, but sawdust can clog the gills of fish if it gets into waterbodies.

Ruts form mainly because of use during warm, sunny weather. Keeping the surface clean with graders or drags will reduce the effects of radiation on the road. During periods of unseasonably warm temperatures, more frequent patrol is advised and travel may be restricted to night-time to avoid excessive maintenance. A rammsonde hardness indicator is useful for determining the likelihood of ruts occurring. When temperatures rise above 25°F (4°C) or average rammsonde hardness falls below 450, more frequent monitoring of the snow road condition is advised. The road should be shut down before severe rutting occurs.

Rutting can be reduced by advising drivers to vary their driving patterns and to avoid previous tracks when possible. Drivers should be advised to avoid driving where they see ruts forming. Reduced tire pressures can also help maintain a rut-free surface. Once ruts have formed, corrective maintenance is essential if further use of the road is justified. Shallow ruts can usually be eliminated with a heavy drag followed by a surface finishing drag. Deep ruts need a grader with tire pressures set as low as possible moving snow back and forth rather than cutting into the snow road. Excess material should be removed by plow or blower. A surface finishing drag after the grader is recommended, particularly in spring when rut formation is most common. The finishing drag helps distribute free moisture in the snow road, and will result in a hard surface under colder temperatures.

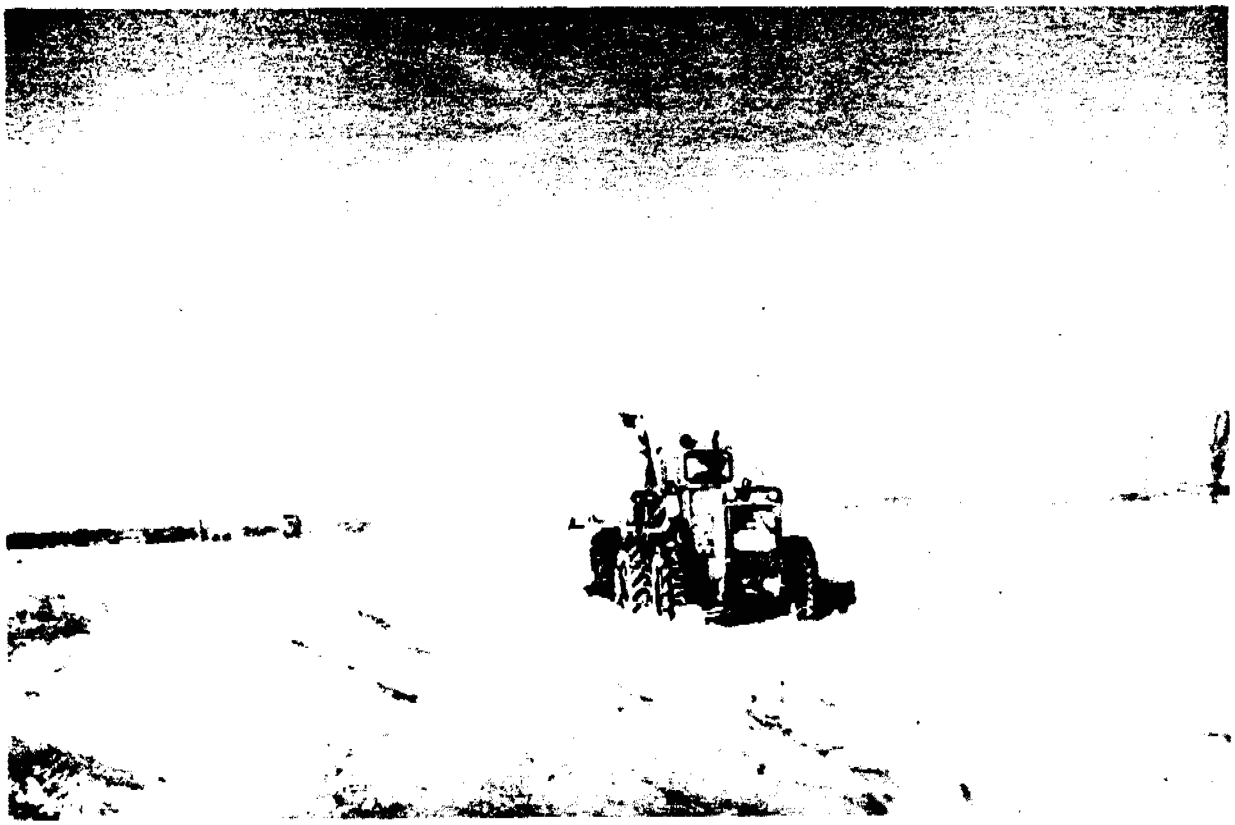
Areas requiring extensive maintenance occur where a snow road abuts a permanent earthfill road. At the junction of the two roads, dirt is carried onto the snow surface causing melting and rutting. Planks laid across the earthfill road will shake much of the dirt off vehicles before it is carried onto the snow road. Dirt that does find its way onto the snow road should be removed as soon as possible. South-facing slopes also require extensive maintenance because traction can wear the road thin and melting is induced by solar radiation. Snow should be blown or pushed onto the roadway and compacted. In extreme cases where a snow road cannot be kept functional by maintenance, complete rebuilding may be necessary. Depth processing followed by compaction is recommended. Ice-capping may be necessary if there is not enough natural moisture in the snow. Appropriate age-hardening periods should be observed.

Closure

In nonpermafrost areas, snow roads of all types are normally closed just before traffic begins to bog down. If the roads are relatively thin, this happens first on south-facing slopes that have begun to melt out. On thicker roads, traffic may begin bogging down in the deteriorated road itself before the ground shows through. In permafrost areas, snow roads should be closed when terrain damage is imminent. A thick snow road may soften to the point where it becomes impassable. Night-time travel -- only after the road has been firmed up -- allows removal of vehicles that might otherwise be stranded over the summer.

Rutting of an insufficiently compacted snow road after fewer than 20 passes of a light van. (K.M. Adam)

Steep, south-facing slopes are often the first sections of a road to melt out. The dark surface developing here will hasten deterioration of the road in spring.



Snow blower, a type of "processor", depositing snow onto the right-of-way before levelling and compaction. (M. Kowalchuk)

PROCESSED SNOW ROADS

A processed snow road is built in the same manner as a compacted snow road except for one additional step: the snow is agitated or "processed" to break the crystals into smaller particles. After "processing", the snow generally can be compacted to a higher density with an equal or lesser compactive effort, thereby improving the carrying capacity of the road.

Although many implements have been tested, including earth tillers and versions of the farm harrow and disc, it has been found that pulvimixers or rotary snow plows are the most effective snow-processing machines.

Route Selection

Route selection for processed snow roads is the same as for compacted snow roads. See the section on selecting routes for compacted snow roads.

Construction

The only equipment required to build a processed snow road besides the crawler tractor, levelling drag, heavy drag or rollers used for building compacted snow roads, is a pulvimixer or rotary snow plow. The pulvimixer is any piece of equipment that uses tangs, chains, cleats, prongs, or rotors to agitate the snow before depositing it on the road. Equipment ranging from standard pavement breakers to soil pulverizing equipment has been used for this purpose. The Peter Snow Miller, which uses a rotor, has an excellent record on snow construction projects. In recent years the conventional rotary snow plow has been used successfully for processing snow.

Processing of snow is referred to as single-depth processing and double-depth processing. In single-depth processing, the snow is processed once or twice, then compacted immediately. In double-depth processing, the snow is processed, allowed to age-harden for 24 to 48 hours, then processed once more and compacted immediately.

Regardless of which technique is used, construction of a processed snow road begins with the same sequence as a compacted snow road. Early snow is compacted with a light-tracked vehicle and light drag to increase the rate of subsurface freezing. Once sufficient snow is available, the road cross-section is shaped by a dozer equipped with mushroom shoes to protect the terrain. A light drag can be used to level the road surface. Processing can then begin.

Single-depth processing has been found to work best with two passes (three passes if snow is granular) of the pulvimixer or rotary snow plow at intervals not exceeding 1 hour. The second pass should be made at twice the rotor speed if possible. Compaction should follow immediately after processing, so that bonds do not have a chance to form.

A variation of single-depth processing is the layered compaction method. It involves single-depth processing of successive layers of snow. The suggested construction sequence, using a snowblower as the processor, is as follows. After enough snow has accumulated and frost has penetrated sufficiently to give a firm working surface, two parallel berms of snow should be constructed at the edges of the proposed road. The berms should be high enough to contain the snow deposited by the snowblower after levelling and compaction. Two layers of snow should be sufficient on fairly smooth terrain, and each layer should be about 4 inches (10 centimetres) thick after it has been compacted.

Immediately after the snowblower has deposited the bottom layer of processed snow, a small crawler tractor pulling a light drag should be used to level the layer. The layer can be compacted with three walking passes of the crawler tractor. Heavy drags or rollers could be tried to speed up compaction, but their usefulness will depend on the condition of the snow. The top layer should be levelled with a finishing drag and allowed to age-harden for at least 24 hours. For surface hardening, the pneumatic-tired roller is recommended. Minor surface levelling can be accomplished with a light drag.

The layered compaction method results in a road that is stronger than a single-layer road. Weak spots, which are associated with most snow roads, appear to be randomly distributed in both layers and the probability of weak spots overlapping in the two layers is small. Even with many rammsonde readings on a snow road surface, it is seldom possible to find weak spots. However, once a weak spot becomes apparent under traffic, rammsonde readings near the failure will confirm the weakness.

If, after 24 hours of age-hardening, surface densities are less than 34 pounds per cubic foot (0.55 grams per cubic centimetre) or if the surface rammsonde hardness index is below 450, consideration should be given to ice-capping the processed snow road.

Double-depth processing involves two cycles of processing with an age-hardening period in between. Additional passes of the pulvimixer after the first cycle have been found ineffectual. After the snow has hardened for at least 24 hours, another depth processing cycle has been found to reduce the maximum particle size by at least 50 percent. This second cycle is very important because it results in smaller particles with a greater number of contact points and hence a stronger surface, since snow strength depends on the number of contact points between particles per unit volume.

Heavy drags or rollers should be used to level and compact the processed snow immediately after the second depth processing is finished. This prevents bonds from forming before compaction is completed. From three to five passes of the compacting equipment are recommended, with no more than 2 hours between passes. The last two passes should be made with the finishing drag or pneumatic-tired roller to ensure maximum hardening of the surface.

At least 24 hours should be allowed for age-hardening before the road is traffic-tested. If densities measure less than 34 pounds per cubic foot (0.55 grams per cubic centimetre) or if the rammsonde hardness index is less than 450 after age-hardening, consideration should be given to ice-capping the road to ensure a trafficable surface.

Operation and Maintenance

Operation and maintenance of processed snow roads are the same as for compacted snow roads. See the section on operation and maintenance of compacted snow roads.

Closure

Processed snow roads are subject to the same rules for closure as compacted snow roads.

Ice-capped snow road in northern Ontario used for hauling logs. Lane on left is ice-capped for loaded vehicles. Other lane is compacted snow for the return trip.

ICE-CAPPED SNOW ROADS

Even after several days of age-hardening, it is sometimes found that a compacted or processed snow road cannot withstand repeated wheel loadings without undergoing numerous failures. If this happens, all is not lost. Application of water to the surface can transform a weak or marginally weak snow road into a very strong, ice-capped snow road within a matter of hours.

Route Selection

Route selection of ice-capped snow roads is the same as for compacted snow roads, except that a source of water for ice-capping must be considered. See the section on selecting routes for compacted snow roads.

Construction

Construction of an ice-capped snow road follows the same sequence as a compacted or processed snow road -- with one further step: water is added to the surface. If water, a pump, and a tanker truck are available, the transformation of a snow road to an ice-capped snow road is relatively simple. All that is required is to sprinkle, spray, or hose water onto the surface of the snow road. Within hours, the road will be strong enough to support wheeled traffic, provided temperatures are well below freezing.

Normally, 1 inch (2.5 centimetres) of water is required to ice-cap a snow road. For reference, it would take 66,000 gallons (300,000 litres) of water to provide the 1 inch (2.5 centimetres) of water necessary to ice-cap a 24-foot (7-metre) wide pavement 1 mile (1.6 kilometres) long.

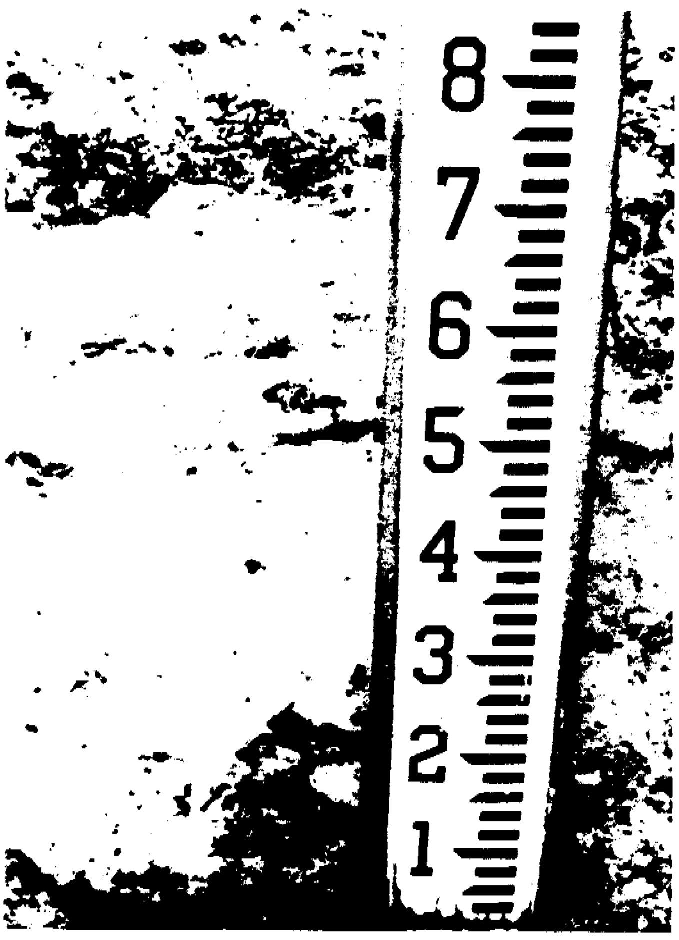
Water should be applied to the surface in one application. The rate should be adjusted to avoid runoff as well as excessive ponding which increases the tendency for channel formation and fingering, resulting in wasted water.

The tanker truck for hauling water should be adapted with a rear spray bar that can apply water immediately behind or in an adjacent lane. Application rate can be adjusted by nozzle size, pressure, or vehicle speed. It has been observed that snow roads that break up under several passes of light vehicles can sometimes withstand a few passes of the heavy, high-tire-pressure vehicles used for ice-capping. Also, three passes of empty water trucks 15 minutes after water has been applied have been observed

Water tanker with spray bar. Tires are leaving tread marks in the road but not breaking the surface. (K.M. Adam)

The hose-end method of ice-capping sometimes wastes water and causes weak spots in the road. (K.M. Adam)

Part of an ice-capped snow road. Dyed water shows nonuniformity of road bed caused by channelling and fingering. (K.M. Adam)



Typical cross-section of ice-capped snow road. Thickness varies from point to point, depending on microrelief. (K.M. Adam) to cause no damage. If it is found that the snow road cannot withstand normal ice-capping traffic, low-ground-pressure vehicles should be used. Once a lane is completed, the other lane can be completed from it.

Thousands of passes of heavy construction traffic with maximum axle loads of 18,000 pounds (8,000 kilograms) have been successfully carried over an 8-inch (20-centimetre) ice-cap. Water application in this case was about 1 inch (2.5 centimetres). The hose-end method was used, resulting in considerable water loss. In another situation, a processed snow road to which three-quarters of an inch (nearly two centimetres) of water had been applied carried loaded truck traffic successfully.

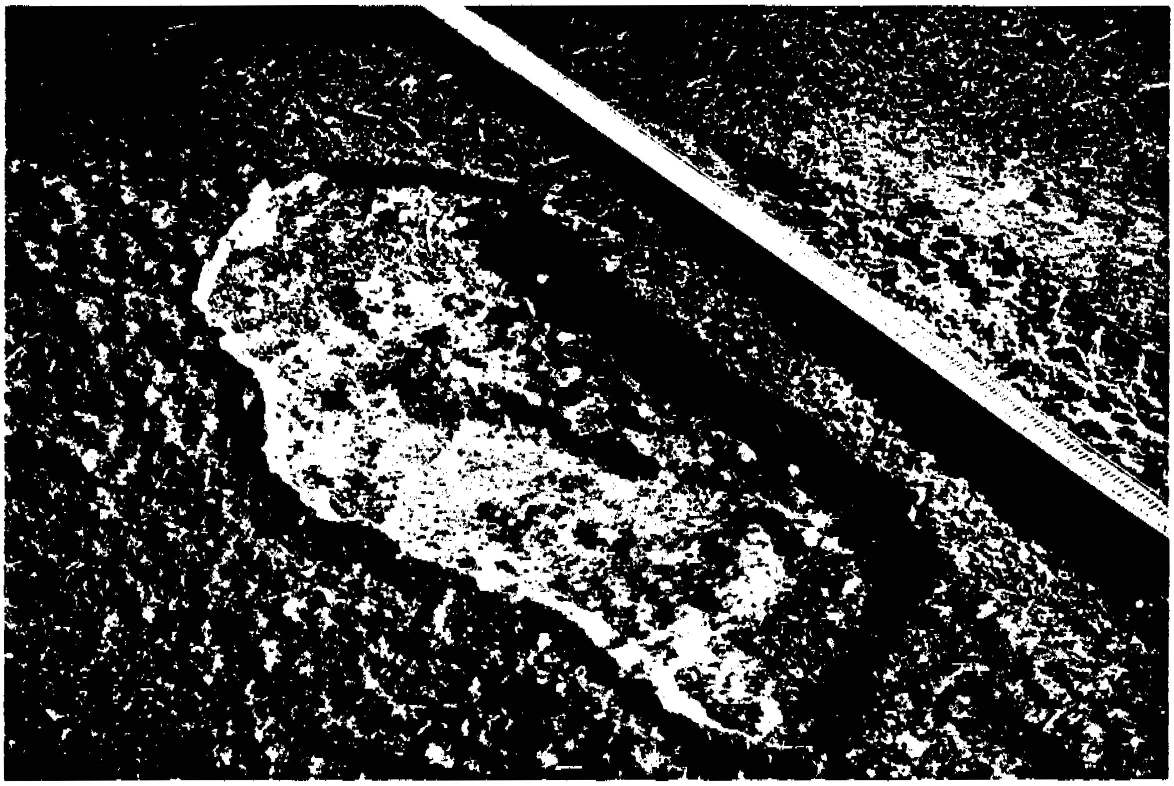
Operation and Maintenance

Operation and maintenance of ice-capped snow roads are the same as for compacted snow roads. See the section on operation and maintenance of compacted snow roads.

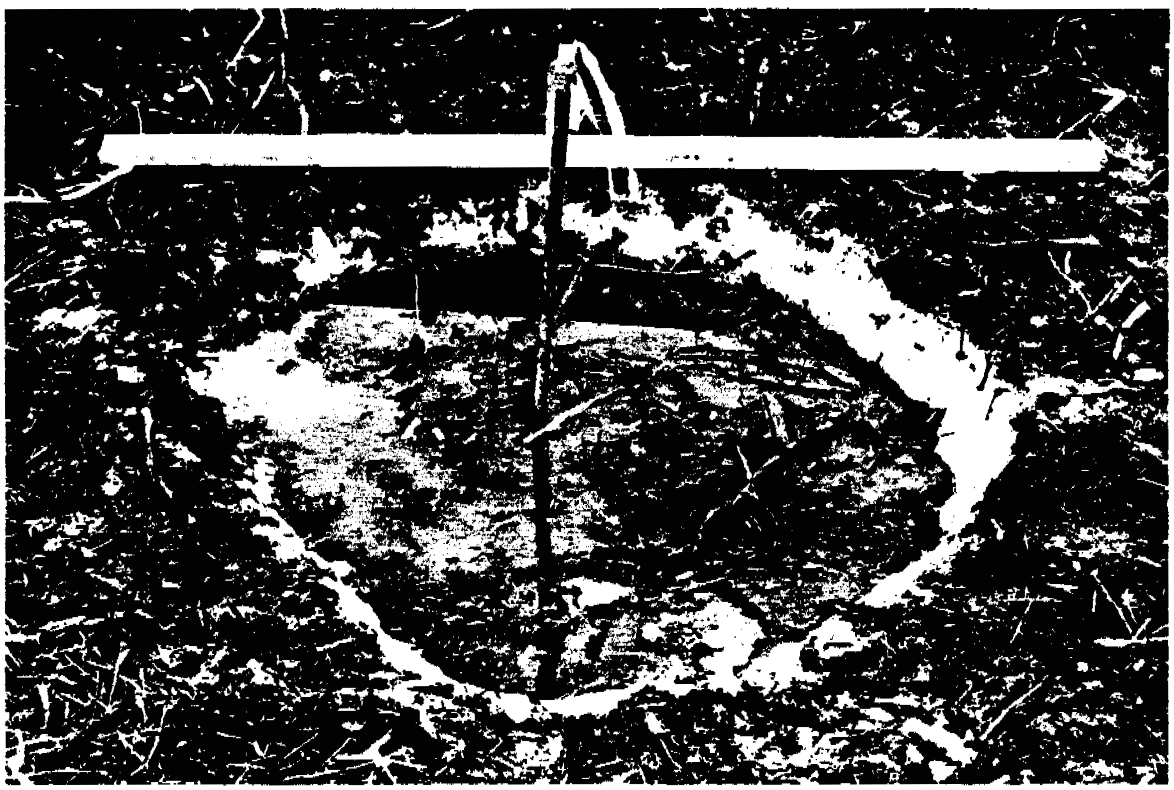
Closure

Ice-capped snow roads are subject to the same rules for closure as compacted snow roads.

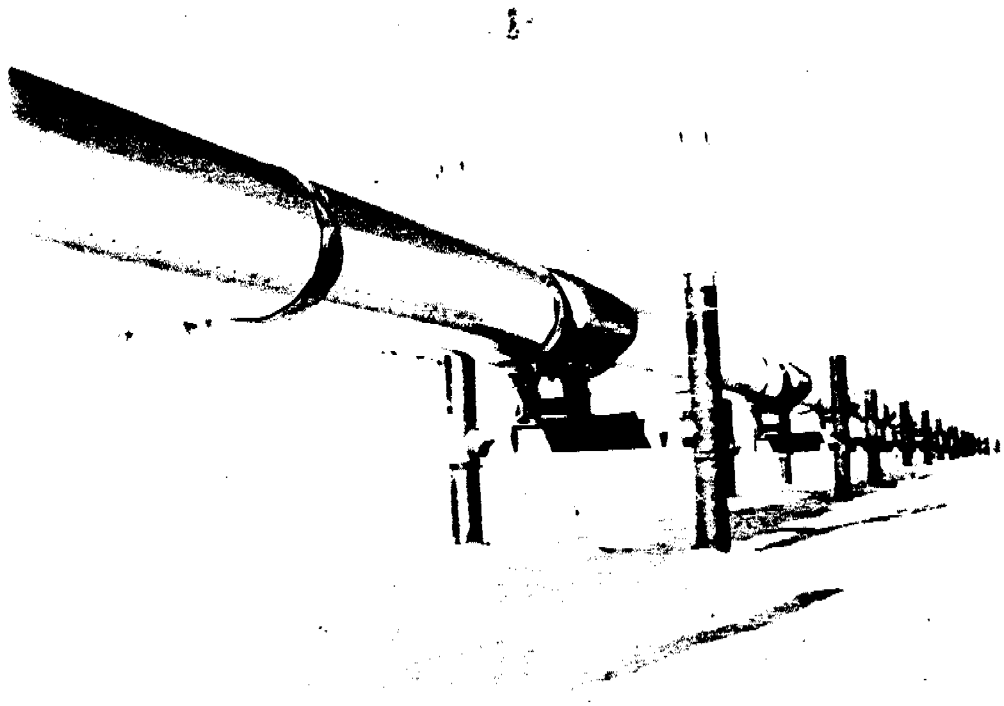
Weak spot caused by poorly compacted sub-base led to this failure of an ice-capped snow road. (K.M. Adam)



"Spalling" on the surface of an ice-capped snow road. (K.M. Adam)



Pot-hole in ice-capped snow road indicates closure is imminent. Dark surface is caused only in first year of use by organic material mixed with snow during clearing of right-of-way. (K.M. Adam)



Artificial snow roads were used to protect sensitive terrain during construction of short sections of the Alyeska pipeline. (K.M. Adam)

ARTIFICIAL SNOW ROADS

When little or no snow is available and a winter road must be built to protect the terrain from surface disturbance, one alternative is to build an artificial or manufactured snow road.

Artificial snow roads are a relatively new concept developed for northern pipeline construction as a contingency in the event of low snowfall. Although expensive, they have been used successfully on short sections of the Alyeska pipeline in Alaska to protect very sensitive vegetation and terrain, and they have served as stream crossings in the Northwest Territories.

Route Selection

Manufactured snow roads need large volumes of water. Routes should therefore be selected with a view to keeping haul distances as short as possible.

Total flows or total volumes of water cannot be taken from streams, rivers, or lakes. Use should be restricted to less than 10 percent of flow or volume.

For general information on selecting routes for artificial snow roads, see under "Route Selection" for compacted snow roads.

Construction

Snow for the road may be manufactured at the source of water and hauled to the site, or water may be hauled to the site and the converted to snow there. The choice depends largely on the availability of dump trucks and water trucks. Either way, considerable hauling is required and it will be necessary to build a road, usually a snow road, connecting the water source to the road site.

Two types of snow-making units are available -- the compressed-air type and the airless type. The compressed air type generally uses a nozzle connected to sources of water and compressed air. The air-water mixture is forced from the nozzle in a variable trajectory to the surrounding air where it dissipates heat, forming snow crystals that fall to the ground. The so-called airless system uses a fan instead of compressed air to create the air-water mixture trajectory.

Snow-making is a complicated task. Unless snow-road builders have considerable snow-making experience, they are advised to consult with people in the business of making snow.

Snow-making machines have been developed primarily for the downhill ski industry, although snow road construction has recently led to development work on larger capacity units. At present, typical output from large-capacity ski equipment is 120 cubic feet (3.4 cubic metres) per minute of snow at densities of 18 to 32 pounds per cubic foot (0.30 to 0.50 grams per cubic centimetre). One such unit, operating about 22 hours per day (2 hours downtime), can produce enough snow for 1.25 miles (2 kilometres) of 24-foot (7.3-metre) wide road at an average thickness of 10 inches (25 centimetres).

Large capacity snow-making equipment is being developed for snow-road construction on proposed Arctic pipelines. It can accept 500 imperial gallons (14,000 litres) per minute and uses a 400-horsepower (300,000-watt) fan motor to manufacture snow at 13,200 cubic feet (375 cubic metres) per hour. In 12 hours, the unit could supply enough snow to build a road 30-feet (9-metres) wide and 1 mile (1.6 kilometres) long to a depth of 2 feet (0.6 metres).

If snow is manufactured at the water source, it can be loaded on dump trucks with front-end loaders and later end-dumped on the road. It can also be manufactured at the road site with portable equipment and placed where required. In either case, the road is shaped by bulldozer and normally compacted by repeated passes of the dozer track and back-bladed. It has been found that manufactured snow contains sufficient moisture that compaction alone can provide sufficient density and hardness to sustain traffic. Furthermore, artificial snow may freeze in place at a density of 25 pounds per cubic foot (0.40 grams per cubic centimetre) yet be capable of supporting traffic without levelling or compaction. The reason is that manufactured snow, despite its low density, has sufficient free water around the snow crystals to allow the road to freeze as a rigid but porous mass.

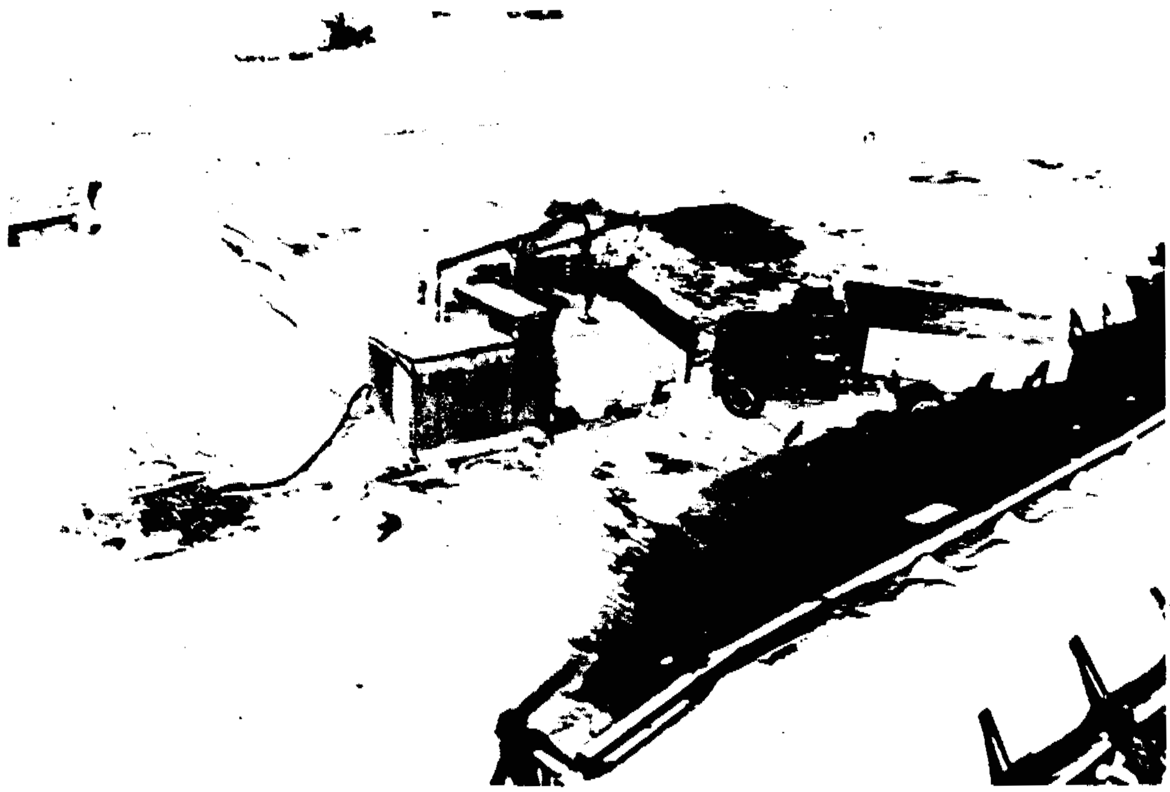
When compaction is necessary, heavy drags or rollers could possibly be faster than tramping by track.

Operation and Maintenance

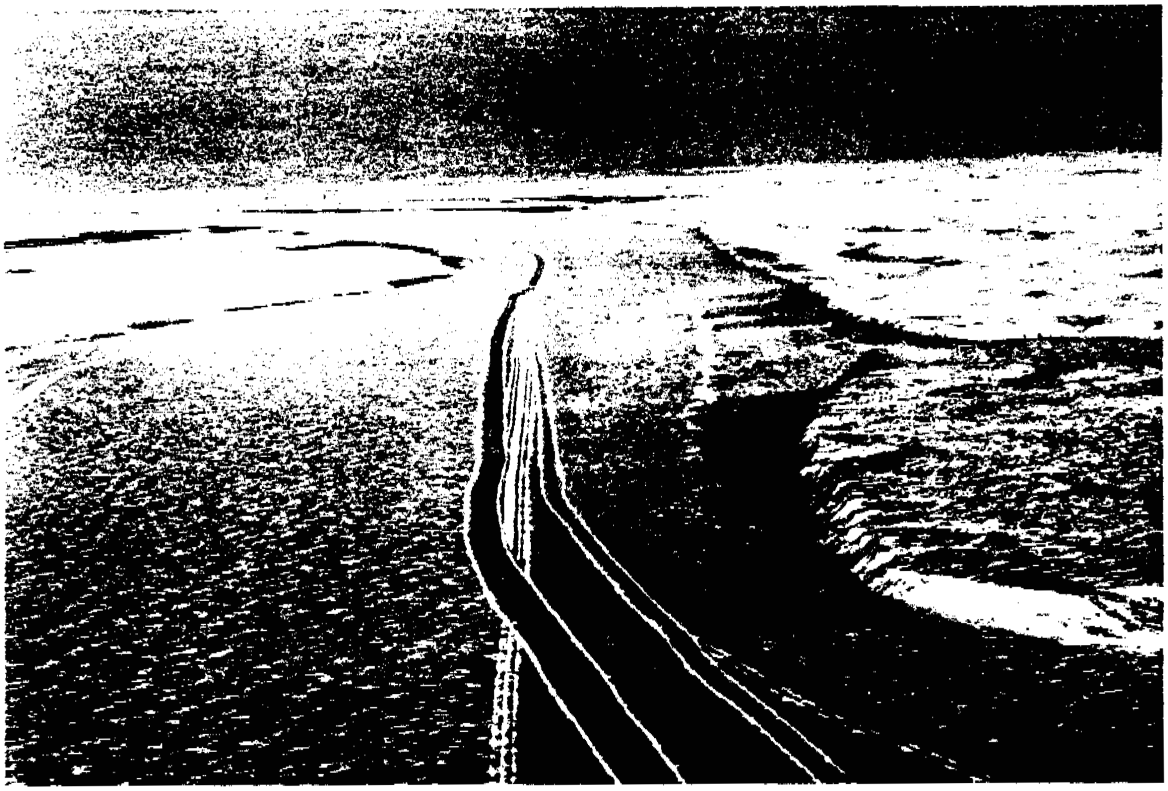
Operation and maintenance of artificial snow roads are the same as for compacted snow roads. See the section on operation and maintenance of compacted snow roads.

Closure

Artificial snow roads are subject to the same rules for closure as compacted snow roads.



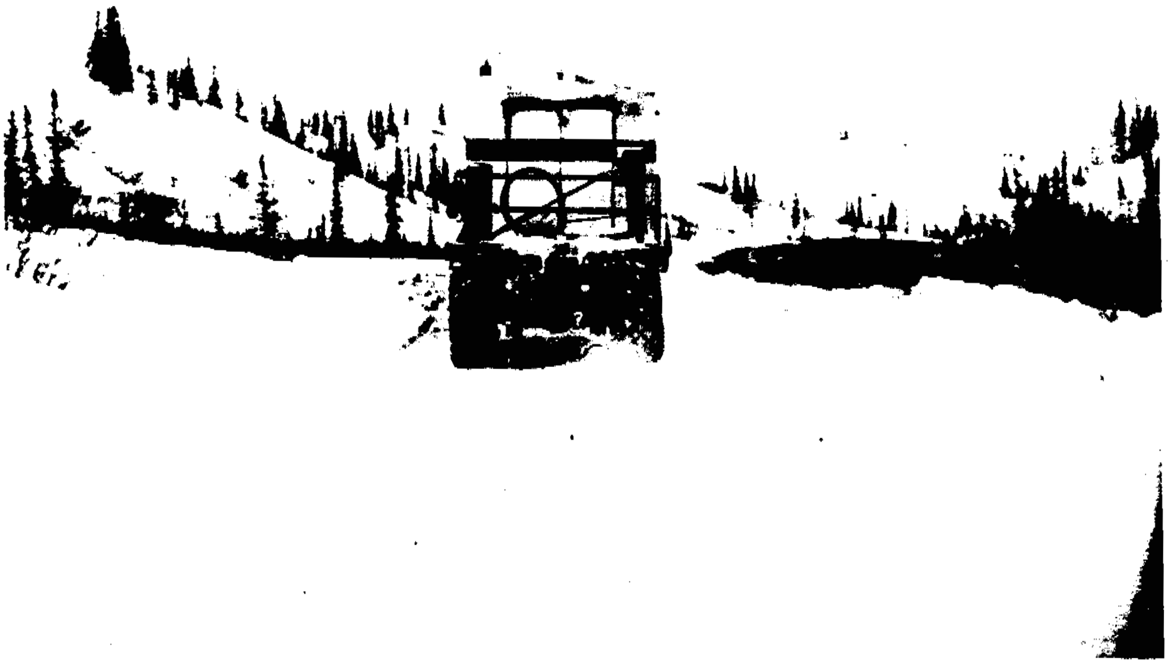
Pumping facilities for filling water trucks. Such facilities are necessary when the contractor chooses to haul water to snow-making machines at the road site. The other option is to set up the snow-making machines at the source and haul snow to the site.



Ice road down the Mackenzie River. (Gulf Oil Limited)

ICE ROADS

Ice roads are of three basic types: solid ice roads, aggregate ice roads, and winter roads on ice. The solid ice road is a sheet of ice built up on the ground by applying successive applications of water until the desired thickness and smoothness is attained. It is used occasionally in flat areas or on the tundra. The aggregate ice road, the newest concept in winter road construction, is built of ice "aggregate" -- chunks of ice that have been chipped from frozen water surfaces and end-dumped onto the roadway. Binding of the aggregate is accomplished by applying water that freezes the particles together. The aggregate ice road is still at the development stage and has not been used in practice. Its use will probably be extremely specialized where access must be provided in winter through areas with very limited snowfall. Winter roads on ice are simply roads cleared on the frozen surfaces of lakes and rivers. They are by far the most common type of ice road.



Solid ice road nearing completion. (Gulf Oil Limited)

SOLID ICE ROADS

The solid ice road is the highest class of winter road. It is capable of carrying greater loads and higher volumes of traffic without breaking down than any other type of winter road. Construction is relatively simple and little maintenance is required.

Solid ice roads are best suited to relatively flat terrain and areas where there is not enough natural snow to build snow roads. They are, however, expensive to build. That, and the relative unavailability of water in Arctic areas in winter, have limited their use.

Route Selection

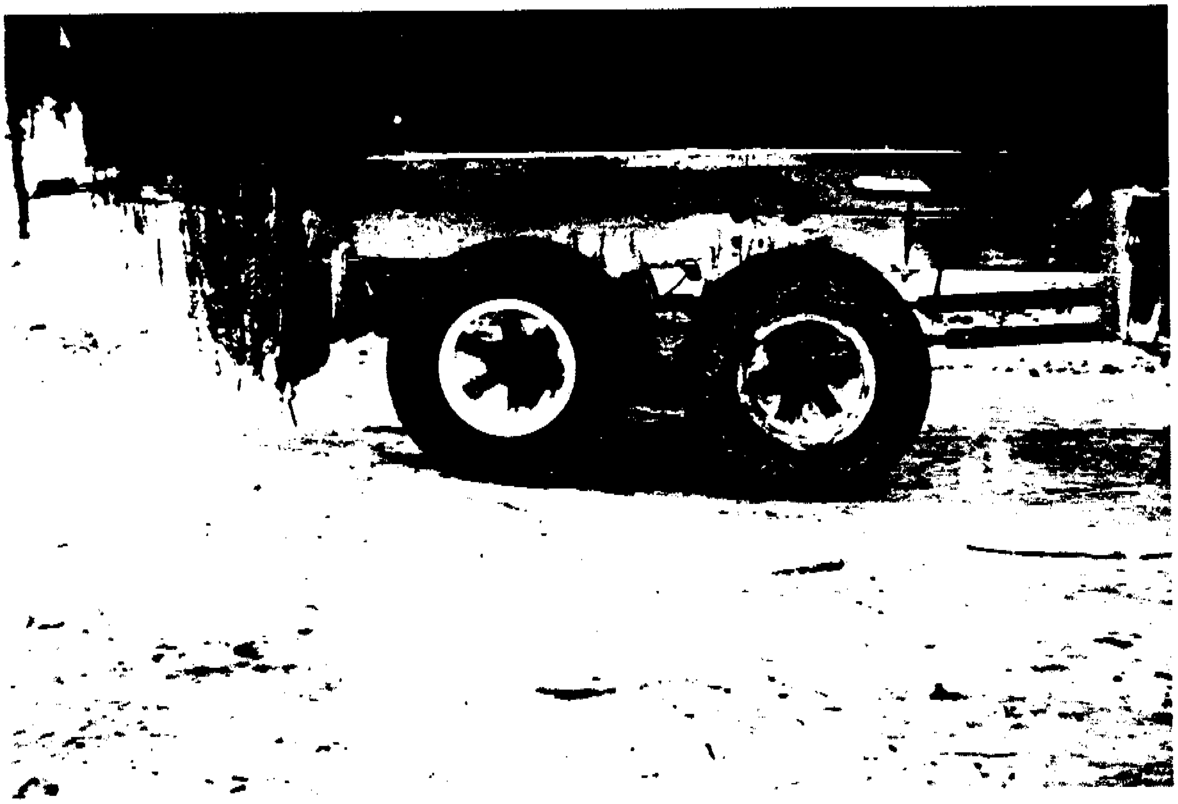
Ease of access to water sources is the key consideration in route selection. Construction of long access routes and excessive hauling costs may preclude ice-road construction. Trucks transporting water must be able to reach the water, load up quickly, and negotiate grades on the return trip -- all within a reasonable time.

Sources of water include lakes or streams with sufficient volume to supply the vast amounts of water needed for ice-road construction -- over 400,000 gallons per mile (1 million litres per kilometre). But sufficient amounts of water must be left in water sources to ensure survival of overwintering fish.

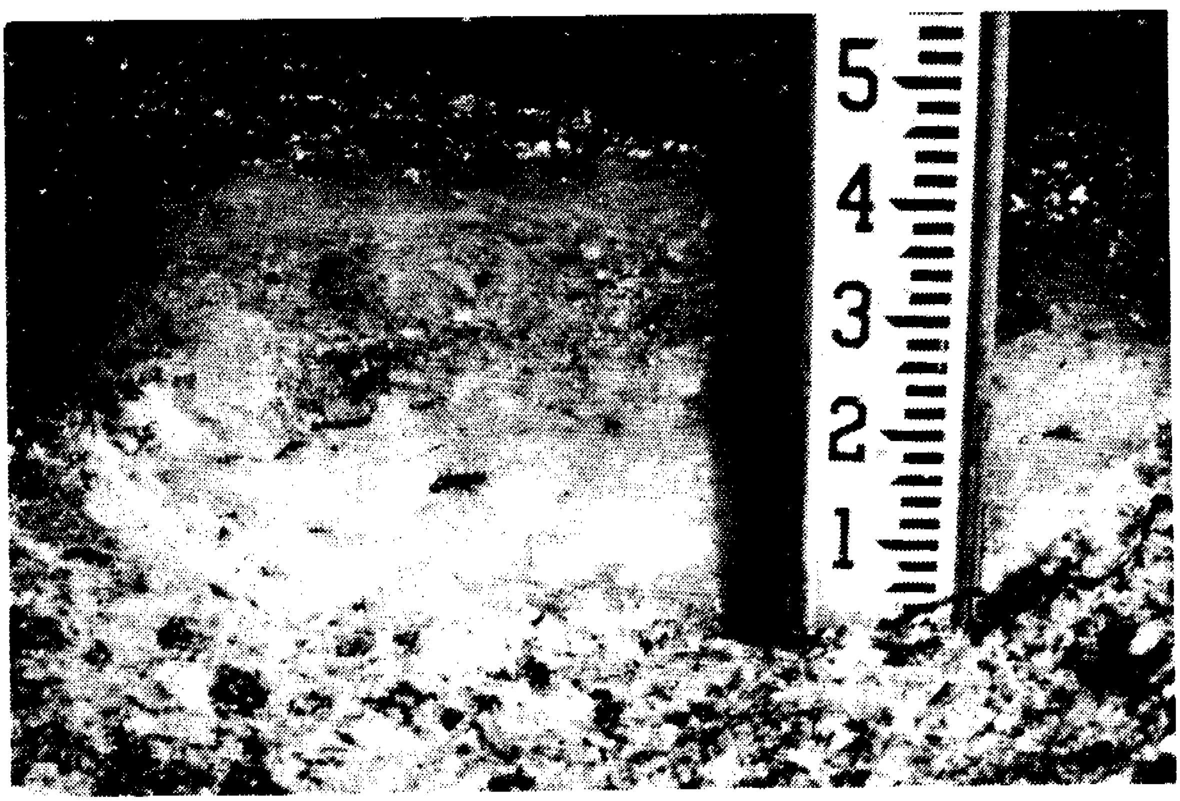
The road itself should be routed over relatively smooth terrain where possible. The more uneven the ground, the thicker the road required. Slopes of over 5 percent should be avoided because of construction difficulties and problems with traction and safety. Roughening of the finished surface might allow use of slightly steeper grades. Sideslopes should also be avoided because of the extra ice build-up necessary on one side to obtain a level surface. Areas obviously containing high-ice-content soils should be avoided where possible because of the serious implications of ground disturbance.

Construction

Equipment for building a solid ice road comprises a medium-sized crawler-type tractor, a light drag, and several tanker trucks with pumps and spraybars.



A solid ice road is strong enough to support heavy water trucks even in the early stages of construction. (K.M. Adam)



Cross-section of a solid ice road. The ground was covered with a layer of snow before watering started. (K.M. Adam)

The first step is to prepare the road bed to receive the water. If snow is available, it should be used to fill depressions. The road bed should then be allowed to age-harden without traffic for 4 to 5 hours before watering starts.

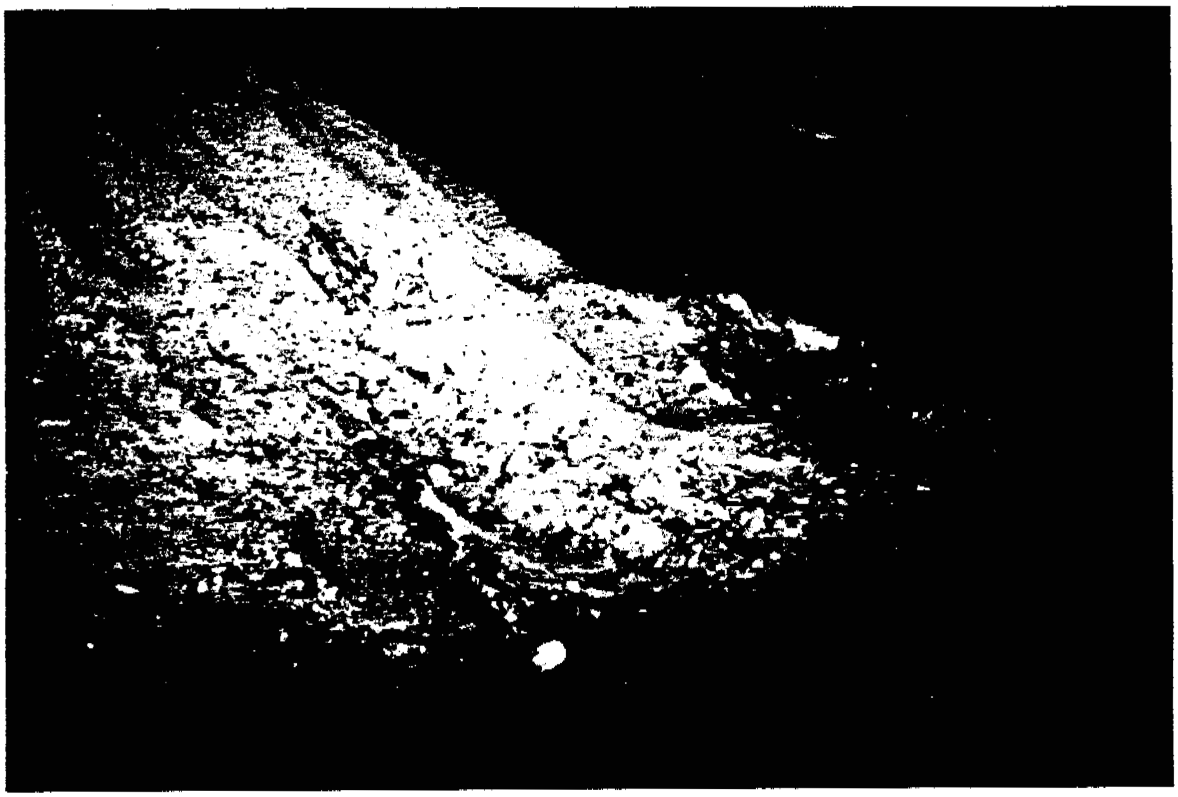
Watering is accomplished using tanker trucks equipped with spray bars to ensure even distribution. On the first pass, water is applied in sufficient quantity to thoroughly wet any snow accumulated in depressions. It is desireable to form an ice seal over the ground as soon as possible to prevent later applications from escaping into the ground before they freeze. Watering continues at a rate that does not result in ponding over 2 inches (5 centimetres) deep. Enough time must elapse between passes for the previous application to freeze. Many applications are required until the ice has been built up to form a smooth surface capable of supporting anticipated loads. Ice over high spots should be at least 2 inches (5 centimetres) thick.

Water should not be allowed to run to one side of the road, thereby leaving the other side too thin to protect the terrain. Sloping road sections require close observation to ensure level build-up of ice.

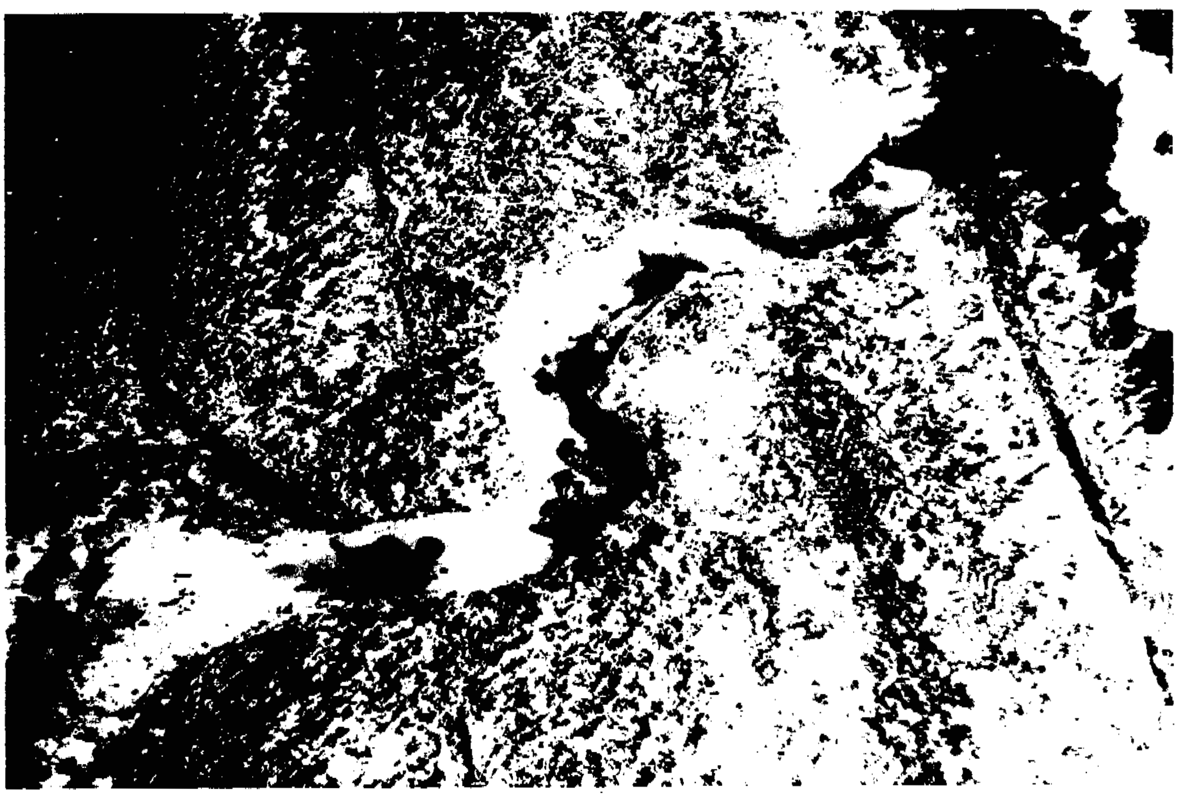
Operation and Maintenance

Operations may begin as soon as the ice road is thoroughly frozen. During very cold weather without snowfall, traffic should cause few problems; however, with rising temperatures and the accumulation of snow on the road, the ice may become slippery and vehicle speeds must be reduced. Sanding of the surface, particularly at curves and hills, will aid traction but the sand will darken the surface, promoting melting during warm weather. Tire chains may be used on vehicles but they may damage the road.

Generally, maintenance of ice roads is limited to snow clearing and spot repairs of the surface. Repairs may be made easily with water or slush by filling failures and allowing them to freeze. General surface damage, such as caused by vehicles with tire chains, may be repaired by thoroughly watering the damaged area by sprinkler truck. Limited surface scuffing and light snowfalls compacted on the road can be advantageous because they improve traction.



Failure of a solid ice road. Such failures are relatively uncommon. (K.M. Adam)



Ice roads deteriorate by channelling and undermining of the surface, signs that closure is imminent. (K.M. Adam)

Closure

Observations of the deterioration and closure of an ice-road test section reveal that ice-road closure is a function of daily air temperature. Rising temperatures, along with the the appearance of ponded water on the road, signal the beginning of possible deterioration. Drainage holes and channels in the ice are a sign that deterioration has reached a point where closure or restricting traffic to night-time may become necessary very shortly. The appearance of saucer-shaped depressions that pump and blow water with the passage of vehicles indicates that the road is becoming very thin and is in danger of failing completely at such places. The road may begin breaking up where tree branches or other debris embedded in the ice begin showing through. After this, the road may support limited emergency night-time traffic if overnight temperatures drop enough to refreeze the ice surface. Complete closure will likely be necessary within days.

The date of closure is best determined by an experienced land-use inspector, who will close the road when it is apparent that terrain damage is imminent.

Solid ice road in spring, just before closure. (K.M. Adam)

Ice aggregate road, one of several in Alaskan Arctic Gas's test plot at Fairbanks. (K.M. Adam)

AGGREGATE ICE ROAD

The aggregate ice road is a new concept in winter road construction. Its development was inspired by Alaskan Arctic Gas Pipeline Company as a technique to protect sensitive terrain from heavy traffic in areas where a lack of snow or lack of available water precludes the use of snow roads or solid ice roads. The aggregate ice road could be used as an overland winter road where large quantities of ice are available.

Ice from the surface of frozen ponds, lakes, rivers, or possibly sea ice* in coastal areas must be broken into aggregate, loaded onto trucks, hauled to the right-of-way, and end-dumped into place. Although initial tests near Fairbanks, Alaska in the winter of 1976-77 were very successful, aggregate ice roads have yet to be used for practical purposes. As with manufactured snow roads and solid ice roads, an aggregate ice road involves hauling large quantities of material. This is the main reason aggregate ice roads are so expensive.

An aggregate ice road is normally built for specialized land-based operations such as pipeline construction. Otherwise, the road would normally follow the frozen surfaces of ponds, lakes, or rivers, giving a much cheaper type of winter road. Aggregate ice roads may be built overland between lakes to join winter roads on ice.

Although this type of winter road has been used only for experimental purposes, its initial trials indicate it to be at least as practical, if not more so, than manufactured snow roads. It apparently requires less specialized equipment, but it will remain expensive because of hauling costs. One drawback is that an early start to construction is not possible because ice must be relatively thick before it can be mined. Furthermore, unless waterbodies are frozen to the bottom, the safety of men and equipment becomes a prime concern, particularly since the operation involves reducing ice thickness.

Route Selection

An aggregate ice road should be routed as close to sources of ice as possible to keep hauling costs down. This also reduces the length of haul road that must be built from the ice borrow site to the right-of-way. Because water is required to bind the aggregate, access to a water source must be considered.

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*Effects of brine from sea ice on vegetation have yet to be determined.

Since an ice aggregate road provides better traction than a solid ice road, steeper slopes may be permissible. An aggregate ice road is probably more suited to uneven terrain than a solid ice road, but as in the case of most winter roads, it should avoid, where possible, areas of rough terrain and high-ice-content soils.

Construction

Basic equipment for building an aggregate ice road includes a medium-size tractor to pull the aggregating machine, a front-end loader, several dump trucks, a medium-size crawler tractor with blade for shaping the road, and a water tanker truck with spray bar for binding the aggregate.

Construction starts with the preparation of aggregate. A small roto-tiller pulled by a rubber-tired tractor has been found to work well. Aggregate should contain a full range of particle sizes up to about 2 inches (5 centimetres) so as to reduce the size of voids in the road.

A 24-foot (7.2-metre) roadway averaging 1 foot (0.3 metres) in thickness requires 5900 cubic yards of ice aggregate per mile (2800 cubic metres per kilometre). One small experimental tiller has produced aggregate fast enough to complete such a road at the rate of 0.6 miles per day (1 kilometre per day). Considerably faster production rates are anticipated with larger aggregating units presently under development.

Shorelines and other areas frozen to the bottom should be used for "mining" ice aggregate. This reduces the hazards of break-through to men and equipment, but it may interfere with aquatic life. The involvement of aquatic ecologists and wildlife biologists is recommended during selection of mine sites.

Once aggregate has been mined, it can be scraped up and loaded onto dump trucks by front-end loaders for transporting to the site.

Site preparation will not usually be necessary because an aggregate ice road would normally be built in areas where snowfall is light. Loaded trucks should end-dump the aggregate directly on the ground; the crawler tractor can then shape the road to the desired width and thickness. Side slopes at one-to-one appear stable. Water trucks can be used to finish the road by sprinkling with 1 inch (2.5 centimetres) of water.

If the water trucks cause ruts in the surface, one solutions is to alternate construction of lanes. Another is to mount the water tanks on sleighs and pull them with crawler tractors. Alternate lane construction consists of finishing one lane to grade while laying only a 3- to 4-inch (8- to 10-centimetre) layer of aggregate on the other lane to protect the terrain from the water truck. The lane at finished grade is sprinkled, then used to support the tanker truck for sprinkling the other lane.

After sprinkling, several hours should elapse before heavy or large numbers of vehicles are allowed on the road. This will allow time for the bonds between aggregate particles to freeze solidly before the road is opened to traffic.

Operation and Maintenance

Experience with operation and maintenance of aggregate ice roads is very limited. On experimental sections, 1000 passes of loaded gravel trucks caused no apparent problems. It is anticipated that traction will be better on an aggregate ice road than on a solid ice road and that higher speed limits will be possible.

Maintenance of aggregate ice roads is expected to be minimal. If potholes do form, the surface can be restored with aggregate and water. Snow clearing should be minimal because of low snowfall where these roads will be used. Drifting snow should not accumulate because of the elevated height of the road. Small amounts of snowfall should not harm the driving surface because they will be compacted under traffic. Fingering drifts or large snowfalls should be removed before they cause bumps to form. Motor graders or snowblowers should be able to remove snow satisfactorily.

Closure

Aggregate ice roads are subject to the same rules for closure as solid ice roads, although they may be closed earlier than the latter if vehicles begin getting stuck in the road itself. For more details, see the section on closure of solid ice roads.

Winter road on ice. Cracks are caused by changes in temperature. (Department of Northern Saskatchewan)

WINTER ROADS ON ICE

Winter roads over lakes and rivers were once more common than they are today. The hazardous nature of travel on ice due to the dependence of ice strength on meteorological conditions has contributed to the decline of roads on ice. Today such roads owe their existence to the prohibitive construction costs of overland alternatives.

Roads on ice require little preliminary work, advance quickly, are relatively cheap to construct, and require little maintenance. Construction is generally limited to clearing the snow off the ice. This allows the ice to thicken naturally and rapidly until it can support heavy loads. Maintenance consists of snow clearing, thickness testing, and routine inspection of the ice for cracks.

Route Selection

Winter roads on frozen lakes and rivers are normally routed so as to take advantage of suitable portages. Of course, lakes and rivers are seldom aligned properly to allow for the most efficient hauling routes between points. Short portages are normally preferred because portages are usually the roughest and most difficult sections of winter roads on ice. Safety should be the prime criterion for choosing a route between portages. Straight-line routing is not particularly important because of the low construction cost per unit distance (although payload haul costs are also relevant).

Lakes and rivers used for hydroelectric generation should be avoided because large fluctuations in water elevations can weaken ice covers. Large forebays are not as affected by large water withdrawals as smaller ones. Even large forebays with large fluctuations have been used for winter roads on ice when the near-shore slope is gentle and the shore-ice rests on the bottom.

Selection of a safe route for a road over ice requires some knowledge of the water conditions below the ice. Warm or fast-flowing currents should be avoided, such as may occur where rivers or streams join lakes. Most operators avoid these areas by detouring around them. Pressure ridges, which are upheavals in the ice sheet on large waterbodies caused by changes of wind and temperature, should only be crossed if absolutely necessary. The added safety of detouring around pressure ridges should be weighed over any advantage in time gained by crossing them. Pressure ridges tend to form in nearly the same place on the ice surface every year. Their location can often be anticipated by road builders who are familiar with the area.

Patches of open water known as leads often exist all winter on rivers with particularly fast currents. It is wise to keep well away from them, even though the ice around them may be thick.

Construction

Building roads on ice is relatively simple. When sufficient ice has built up on a lake or river, a test crew travelling by snowmobile or bombardier begins checking ice thickness. Snow clearing of the ice to induce faster thickening can begin when the test crew verifies an ice depth of 10 to 12 inches (25 to 30 centimetres), which is capable of supporting light equipment. Light, truck-mounted plows or small tractors begin the clearing operation; larger, heavier plows follow to speed clearing as the ice gets thicker.

The ice is cleared of snow to a width of 100 to 200 feet (30 to 60 metres), the cleared snow being windrowed along the edges. In time, the weight of this snow will depress the ice, sometimes causing it to crack along the windrows. These cracks present no danger to travel in the centre of the road but travel near the windrows should not be allowed.

Pressure ridges and leads are hazardous to builders of roads on lake ice. They should be avoided if possible. If they must be crossed, some method of bridging should be used such as ice bridges or timber ramps. However, a certain amount of risk will still be involved in travelling across them. Special heavy equipment that crushes and levels ice has been developed for building winter roads on rough sea ice.

Operation

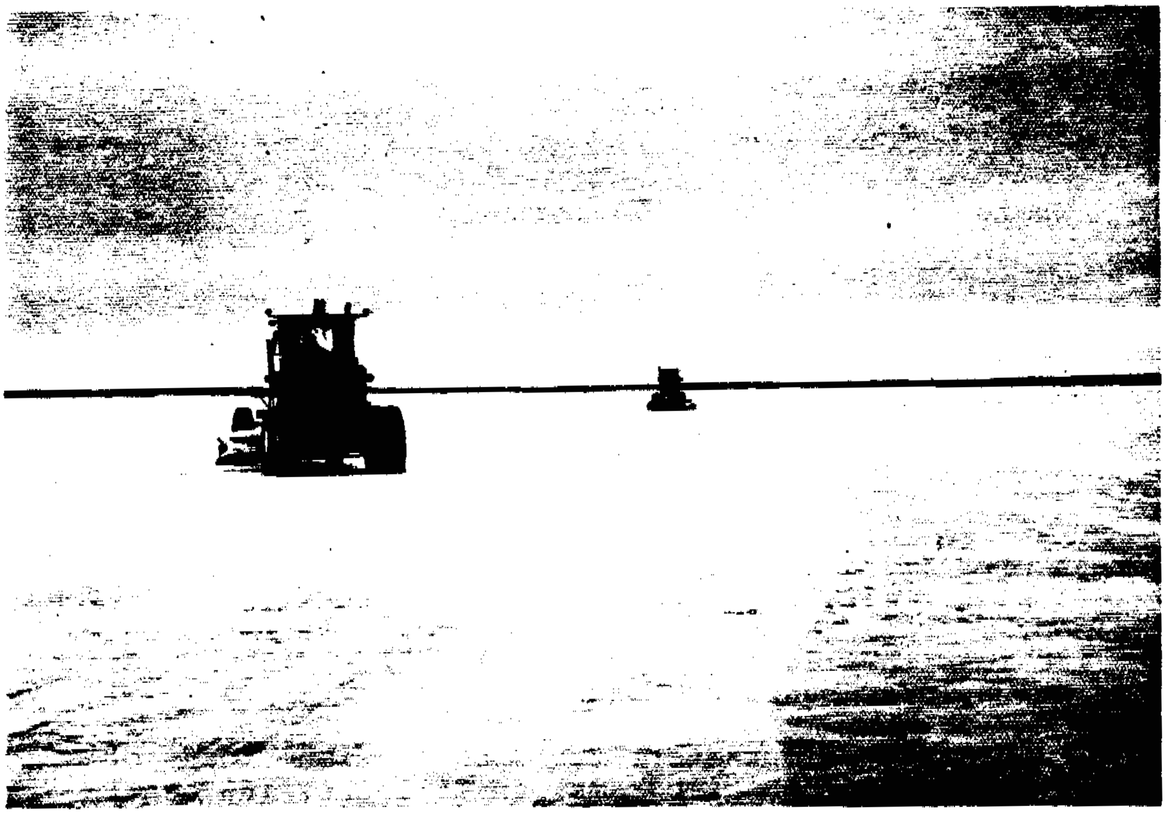
Bearing Capacity. The bearing capacity of ice used by operators varies from region to region. Saskatchewan operators use Gold's (1960) formula to determine bearing capacity:

$$P = Ah^2$$

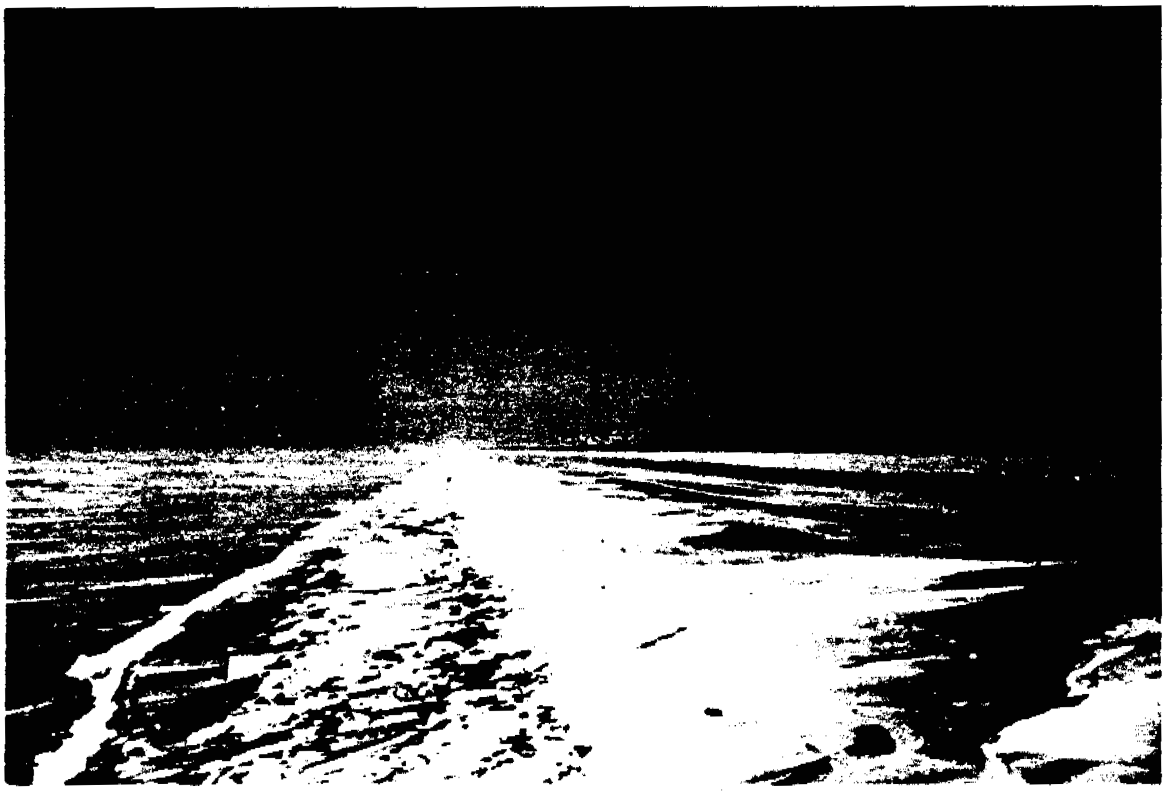
where P = load in pounds

h = ice thickness in inches

A = constant (recommend 50)



Clearing a road on ice to a width of 100 to 200 feet (30 to 60 metres) using graders. (Department of Northern Saskatchewan)



Drifting snow on a road on ice. Weight of windrowed snow has caused ice to crack along the left of the windrow. (J.D. McMillan)

Gold's Formula in metric Units:

$$P = Ah^2$$

where P = load in kilograms

h = ice thickness in centimetres

A = constant (recommend 3.52)

Note: "A" in the metric version = 0.07036 "A" in the imperial version

Saskatchewan operators assign a value of 90 to 110 for "A" resulting in a typical maximum load capacity of 72,000 pounds (32,500 kilograms) for ice that is 28 inches (70 centimetres) thick. A lower "A" value is recommended for ice less than 20 inches (50 centimetres) thick, because it gives a lower bearing capacity.

Manitoba operators transport maximum loads of 80,000 pounds (36,000 kilograms) on 25 inches (63 centimetres) of ice. The value of "A" in this case is 130. Eleven inches (28 centimetres) of ice is sufficient to support 10,000 pounds (4500 kilograms), using an "A" of 83.

Northwest Territories operators carry 56,000-pound (25,450-kilogram) loads on 18 inches (46 centimetres) of ice and 90,000-pound (40,825-kilogram) loads on 36 inches (92 centimetres) of ice.

Speed Limits. Speed limits are usually imposed on roads on ice due to the possibility of damage caused by the water wave generated beneath the ice by vehicles travelling at high speeds. Some operators insist on low speeds at all times. Others ask only that vehicles reduce speed when approaching the shore so that the water wave reflected off the shore will not damage the ice as the vehicle passes over it.

Vehicles also generate waves in the ice itself. Known as ice waves, they vary in size depending on the weight and speed of the vehicle. The critical velocity of a vehicle, which is the velocity that results in ice waves with the greatest amplitudes, has generally been accepted as the velocity most damaging to the ice sheet. However, Eyre and Hesterman (1976) estimate that maximum fracturing of the ice occurs at about 84 percent of the critical velocity.

Gold (1971) indicates that in many cases, critical velocity falls between 20 and 30 miles (32 and 48 kilometres) per hour. Assuming that Eyre and Hesterman's 84-percent-of-critical-velocity criterion is correct, this

Signs marking a pressure ridge are important for safety of drivers and equipment. (J.D. McMillan)

Timber ramps allow traffic to cross a pressure ridge in safety. (Department of Northern Saskatchewan) means that in general vehicles should travel well below 17 miles (27 kilometres) per hour on natural ice or ice bridges.

Gold also recommends that for ice 30 inches (75 centimetres) thick, vehicles should travel at less than 10 miles (16 kilometres) per hour, which is well below critical velocity.

Assur (1961) has calculated velocity on ice as a function of water depth, ice thickness and the modulus of elasticity of the ice. It would be impractical to apply his method in the field because laboratory tests would be needed to measure the modulus of elasticity. As a rough guide for operators, we have determined vehicle speeds for two combinations of ice thickness and water depth, based on his findings:

Ice Thickness	Water depth	Vehicle speed
40 inches	50 feet	15 miles per hour
60 inches	130 feet	20 miles per hour

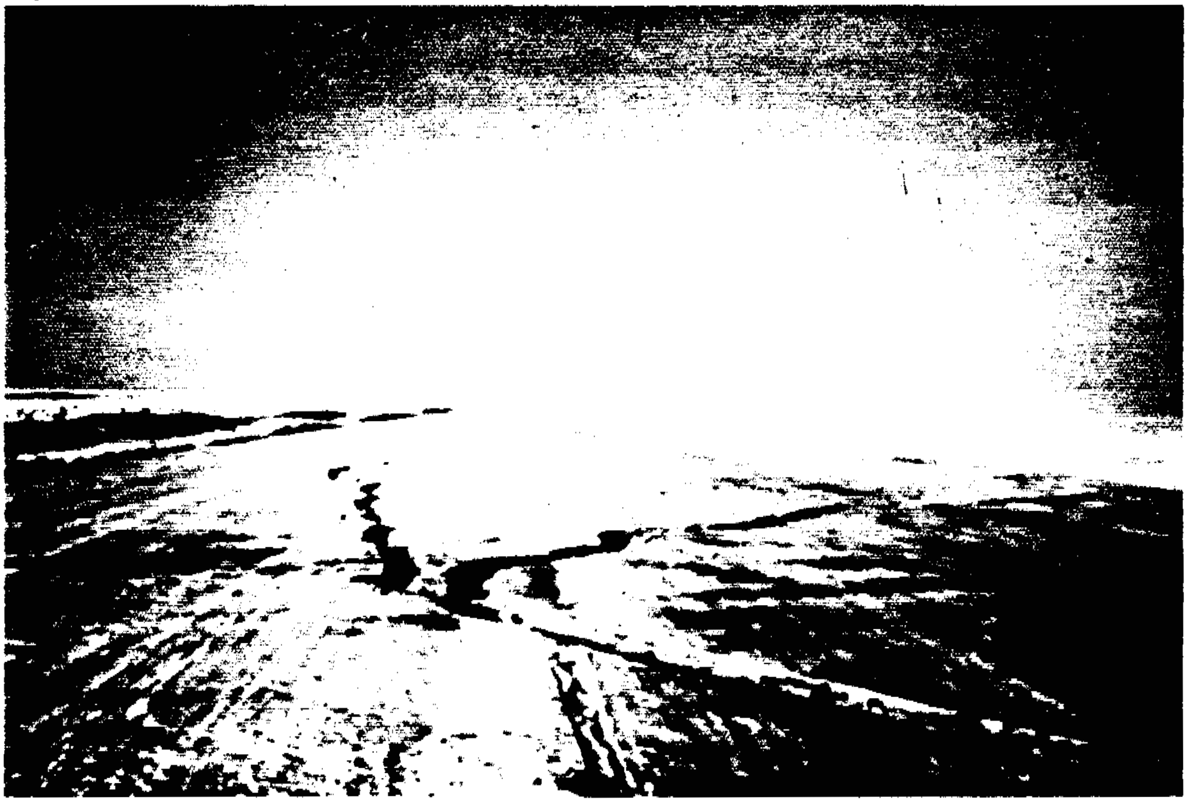
Note: Multiply inches by 2.54 to calculate centimetres.

Multiply miles per hour by 1.61 to calculate kilometres per hour.

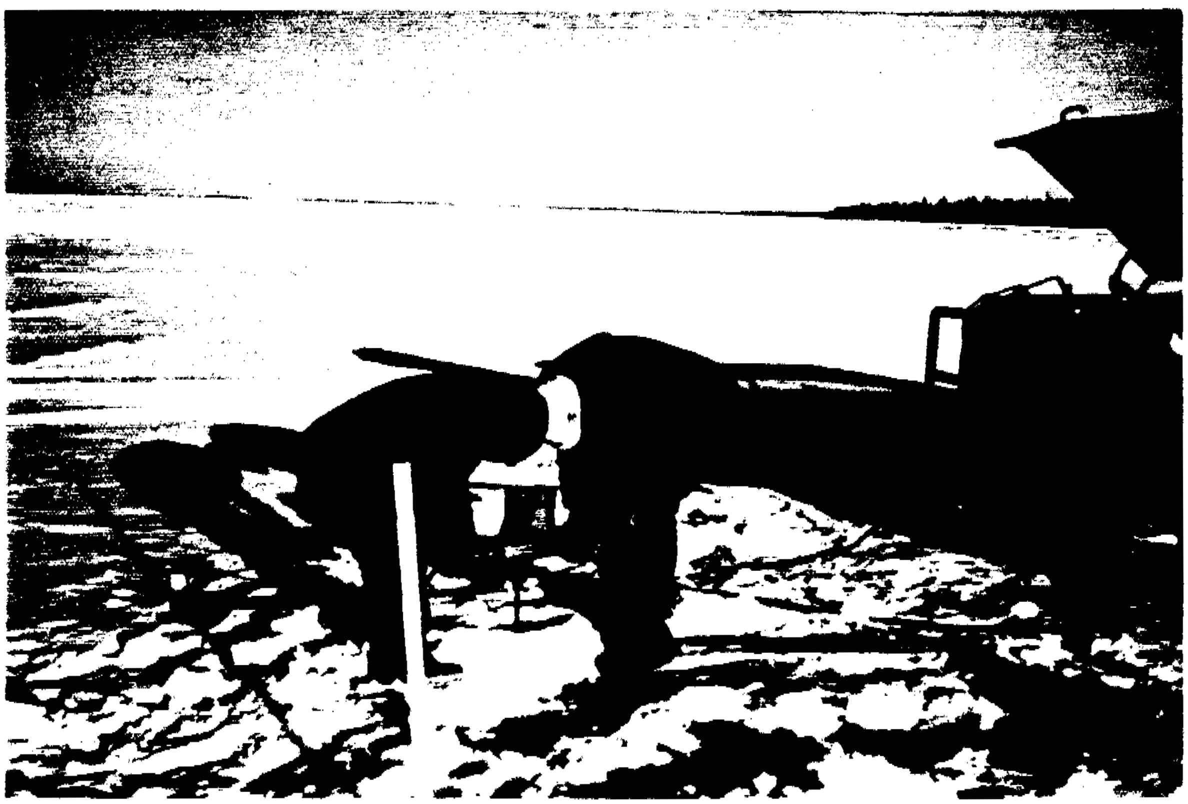
In both cases, the speeds are considerably less than the critical velocity as defined by Eyre and Hesterman (1976). In view of this -- and provided good quality ice exists -- the suggested vehicle speeds should not contribute to unsafe conditions on the ice.

Among operators, speed limits for travel on ice vary from 10 miles (16 kilometres) per hour to 25 miles (40 kilometres) per hour for heavily loaded vehicles. The lower limit is enforced near shorelines to reduce damage to the ice by water waves reflected from the shore. Roads constructed along rivers are unaffected by reflected waves. As a result, they are assigned an upper speed limit of 25 miles (40 kilometres) per hour. Speeds below 5 miles (8 kilometres) per hour or the practise of stopping on ice should be avoided. The "A" values for these figures range from 70 to 173, with the higher value assigned to thinner ice.

Load configuration is also important in travel on ice. Large loads should be distributed over as large an area as possible. Vehicles in convoys should not travel within 900 feet (300 metres) of one another, and should decrease speed when approaching other vehicles.



Loads across cracks like these should be reduced or the road realigned. (Department of Northern Saskatchewan)



Measuring ice thickness. Knowledge and posting of ice thickness improves safety and confidence. (Department of Northern Saskatchewan)

All operators interviewed who use ice roads on rivers or lakes exceed Gold's recommended "A" value of 50 in calculating load capacity, some by as much as 250 percent. Their years of experience and knowledge of ice conditions make this possible, but with added risk.

When determining the bearing capacity of ice, operators should not go beyond an "A" value of 50 without expert advice. Even an "A" value below 50 is no guarantee of safety, particularly for uncontrolled ice crossings.

Temperature Variations. Large changes in ambient air temperature cause the ice to expand or contract, resulting in a buildup of thermal stresses. Often loads are reduced or roads are closed following such changes for periods of from 6 to 24 hours. Speed limits may also be reduced. Some operators feel that lighter loads transported over the ice during this period will induce minor cracking and relieve stresses.

Cracks in the Ice. Cracks may form in the ice as a result of rising or falling water levels, temperature variations, or frequent heavy loading. Surface cracks a few inches deep (several centimetres) are not considered serious, but cracks that pass completely through the ice sheet permitting water to rise to the surface usually require load reductions on the road. Gold (1960) suggests the following load reductions for cracked ice:

- For cracks crossing the road perpendicular to the path of travel, reduce load limit to one-half of that for uncracked ice.

- For cracks intersecting at 90 degress or cracks parallel to the path of travel, reduce load limit to one-quarter of that for uncracked ice.

In time, cracks in the ice usually refreeze and load limits may be raised to normal after a thorough inspection to determine if travel is safe.

Vibrating Loads. Pieces of equipment, such as large crawler tractors that generate considerable vibration when in motion, are not usually transported under their own power over roads on ice. Should the situation arise, however, load limits should be reduced. A reduction of 25 to 30 percent is used by some operators.

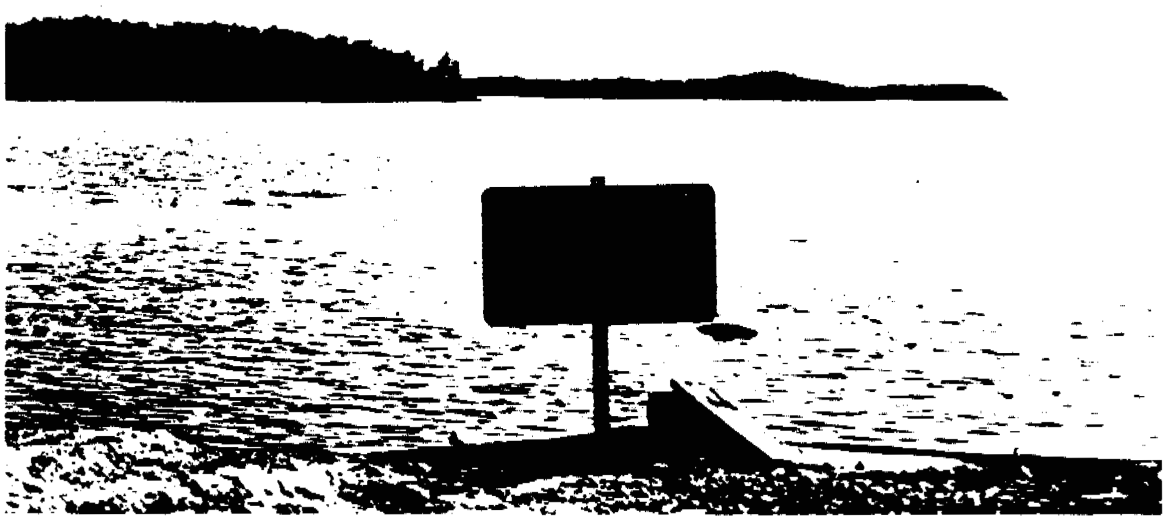
Maintenance

Maintenance of roads on ice is generally limited to clearing away snow, monitoring ice thickness, and inspecting the ice surface. Snow clearing is usually carried out by motor grader on a limited basis since the extreme width of the original clearing tends to allow the road to blow clear of snow.

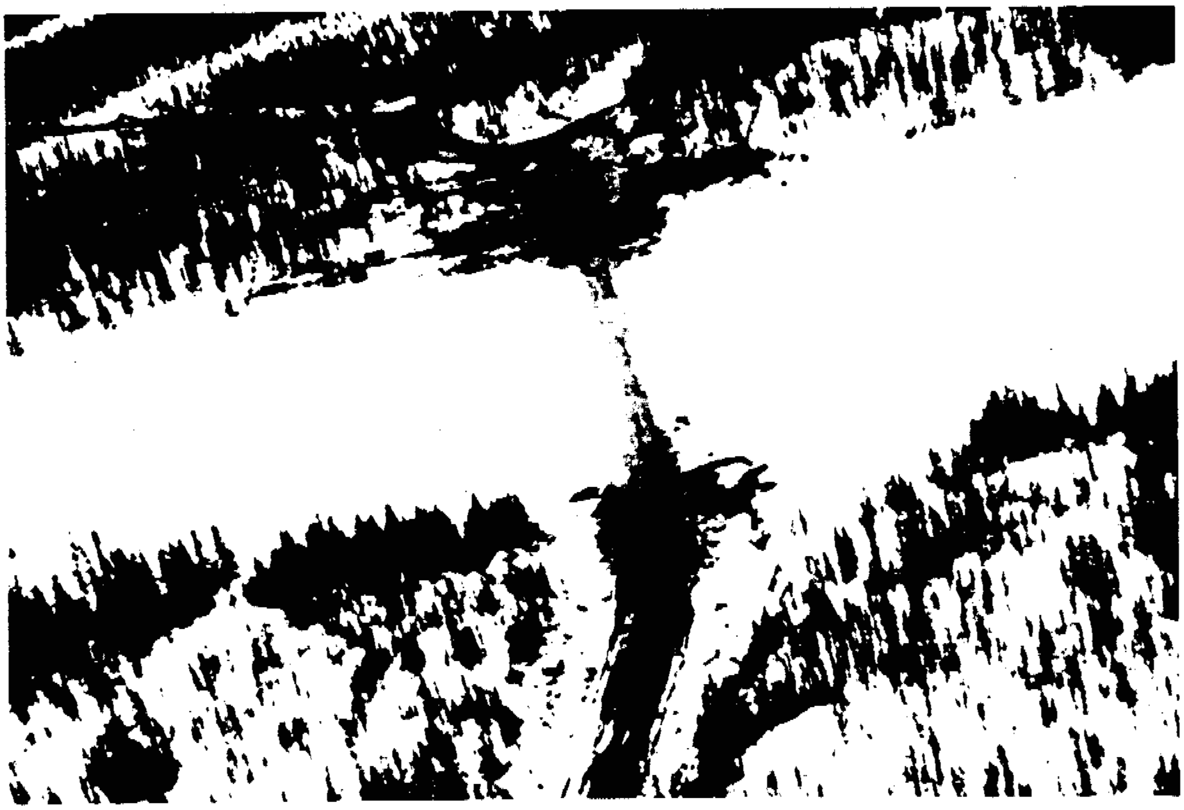
Monitoring ice thickness on a regular basis may be carried out by two-man crews with power augers. Posting of ice thicknesses along the road gives confidence to drivers. Periodic inspection of the ice surface helps locate problem areas and cracks.

Closure

Roads on ice that connect with overland winter roads are usually closed when the overland sections become impassable. This generally occurs long before the ice surface is unsafe for travel. In many areas, the responsibility for determining when to close the road rests with a government department. Officials set a closing date based on the weather of that particular year. Final closure may be preceded by a period when nighttime travel is permitted subject to 24 hours' notice of final closure.



(J.D. McMillan)



Ice bridge in nonpermafrost terrain. Soil from approaches carried onto the bridge by vehicles will lead to early closure of the bridge. (Desourdy Construction Limited)

ICE BRIDGES

Although they have been in use for many years in northern Canada, ice bridges have been the subject of little serious study to define the best and safest methods for their construction and operation. Operators still generally rely on past experience and rules of thumb to determine speed limits, load limits, and whether or not to use corduroy for reinforcement.

Practise varies considerably across Canada. For instance, the load limit for 25 inches (64 centimetres) of good ice in Manitoba and Ontario is 80,000 to 90,000 pounds (36,000 to 41,000 kilograms) whereas in Quebec, one operator limits the same thickness of ice to 19,000 pounds (8600 kilograms). Speed limits on ice bridges vary from 2 to 20 miles (3 to 32 kilometres) per hour. Corduroy, which is used by some operators in Quebec, Manitoba, and British Columbia, is not used by other operators in Quebec and Ontario. In the Northwest Territories, corduroy, once used extensively, is no longer permitted because of environmental restrictions.

Comparing such a wide variety of practises to arrive at standard procedures for ice bridge construction and operation is almost impossible. No two bridge sites are exactly alike.

Site Selection

The choice of site helps determine the usefulness, load capacity and longevity of the bridge. Gently sloping banks, or banks that can be easily modified to a negotiable grade, are necessary to allow easy access to the bridge and reduce high speeds on bridge approaches. In permafrost regions, riverbank grading should be avoided to prevent slumping of high-ice-content soils. In such cases, gentle entrance and exit ramps can be built with snow fills. Steep exit grades may result in trucks losing power and rolling backward onto the ice.

Strong currents tend to erode the underside of the ice and should be avoided. This normally excludes fast-flowing sections of rivers as sites for the bridge. However, deep, slow-flowing sections may be ideal in view of a reduced hydrodynamic wave effect or shorter length of crossing. Warm currents also erode the underside of the ice but this may be offset if the site is located below a rapids where the water is cooled (often supercooled) by the action of the rapids. Outlets and inlets of lakes are often poor locations for crossings. Fluctuating water levels caused, for example, by a power dam may crack the ice, particularly along shorelines.

Construction

Ice-bridge construction usually begins when sufficient ice has formed to support the weight of a man and a pump. Three inches (8 centimetres) of ice are probably sufficient if the ice is clear and solid. If the ice has been broken up by wind action or formed by ice jamming, greater care and a thicker ice cover up to 12 inches (30 centimetres) may be necessary before it is safe to venture onto the ice.

Snow only a few centimetres deep may be left in place and wetted down. Deeper snow should be compacted by trampling to reduce its insulating effect.

Banks of snow are built up along the sides of the proposed bridge to contain the water used to build up ice thickness. (In the absence of snow, logs have been used to contain the water.) Snow dams are also constructed around holes drilled in the ice for pumping water. Flooding is begun using small pumps that can be supported by the ice. First flooding is usually to a depth of 1 inch (2.5 centimetres) or less as the ice will not support the added weight of too much water.

Subsequent floodings may be up to 2 inches (5 centimetres) or more. Each flooding must freeze solidly before the next is applied otherwise a layer of water will develop between two layers of ice and the water will take a long time to freeze. Flooding and freezing should continue, with the addition of corduroy reinforcement if required, until the ice is thick enough to carry heavier equipment. Larger, heavier pumps may be used to speed flooding after the ice can support their weight.

The ice in the vicinity of the bridge should be cleared of snow to a distance of 75 to 100 feet (25 to 30 metres) on either side of the bridge to promote thickening of the ice. The edges of the bridge may be "feathered" by flooding to provide a transition between the built-up portion and the normal river ice.

The bridge should be checked every few days to determine ice build-up. Flooding may cease after a predetermined ice thickness has been reached. At this point the bridge may be opened to traffic at reduced loading. The bridge will usually continue to thicken naturally by freezing at the bottom of the ice surface. As thickening continues, load limits may be increased accordingly until the full load capacity has been reached.

A J-5 compacting slush to speed thickening of the bridge.

Applying first lift to bridge.

Timber is sometimes embedded in the ice as a reinforcing material. Some operators believe this adds strength to the bridge while others believe it is a source of weakness. At least one operator uses timber for approach construction only and not in the centre span; however, he adds extra ice to the center of the bridge. Construction of a timber reinforced bridge takes more time and effort than a pure ice bridge. No definitive study has determined the advantages or disadvantages of timber reinforced ice. One advantage is psychological; but if timber does in fact weaken the ice, it is a definite disadvantage.

Operation

Bearing Capacity. Gold (1960) recommends the formula $P = Ah^2$ for establishing a safe operating limit for ice. (Refer to the section on winter roads on ice.) This formula, based on a survey of past ice-loading failures, represents a safe lower limit below which failure is unlikely to occur.

Effective ice thickness "h" depends on the type of ice in the bridge. White or snow ice is considered to be only half as strong as clear, blue ice. Effective ice thickness is the sum of blue ice thickness and one-half the thickness of white ice.*

In practice, ice may support far greater loads than suggested by the formula. Bridge operators with many years of experience tend to use higher load limits than given by the formula. Less experienced operators add additional safety factors by reducing load limits.

No reliable method exists at present for calculating ice-bridge bearing capacity.

Speed Limits. Some bridge operators impose a minimum as well as a maximum speed limit on bridges. Ice bridges will support heavier moving loads than static loads, and slow-moving loads may place greater stress on the ice than the same loads carried at higher speeds. Stopping or parking of heavily loaded vehicles should not be allowed on ice.

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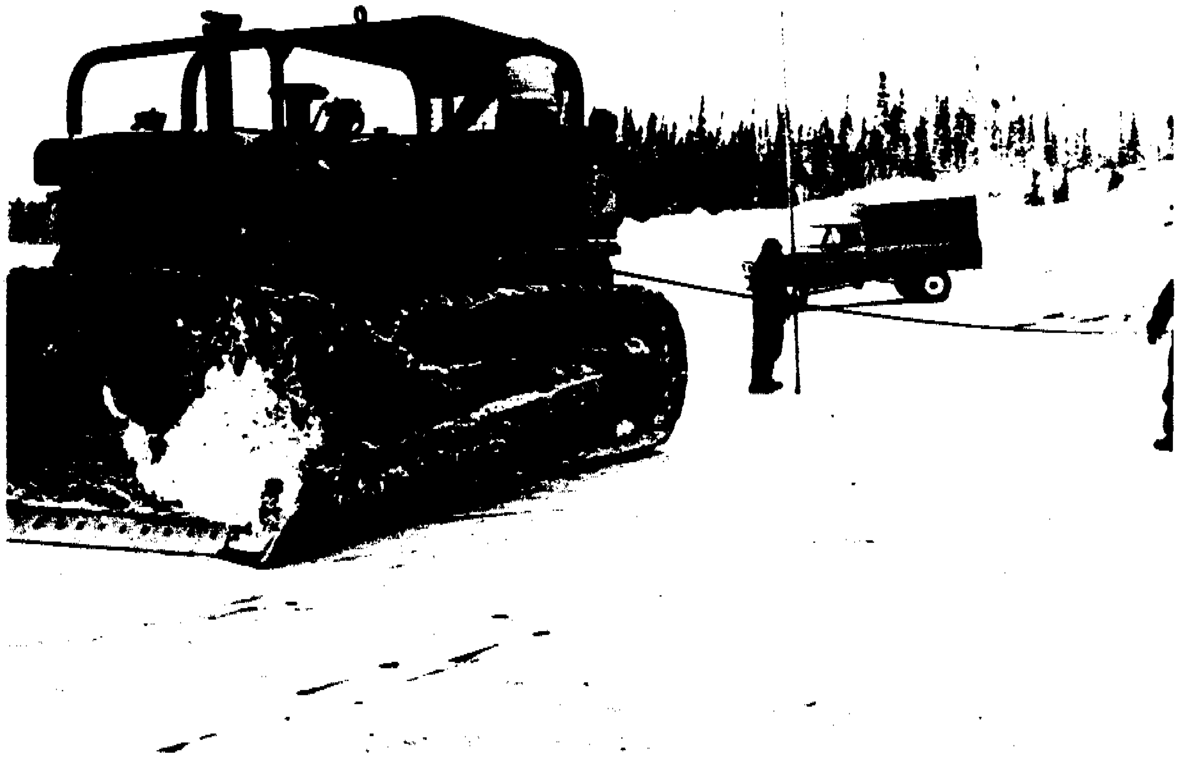
*Studies show that white ice with a density greater than 55 pounds per cubic foot (0.87 grams per cubic centimetre) has a strength almost equal to that of blue or black ice. For many situations, therefore, assigning to white ice only half its thickness is an added safety factor.



Checking deflection of the ice bridge while crossing with heavy equipment. (Desourdy Construction Limited)

(Desourdy Construction Limited)

The section on speed limits for roads on ice, which also applies to travel on ice bridges, offers several recommendations on speed limits as a function of ice thickness and water depth.

Temperature Variations. Large variations in air temperature create thermal stresses and cracking in the ice sheet due to expansion and contraction. Because of the structural weakening of bridges caused by cracking, most operators close the bridges to heavy loads or reduce the load limits for awhile following a large change in temperature. This period varies from 6 to 24 hours. Eyre and Hesterman (1976), as well as others, estimate that the ice sheet does not reach a temperature equilibrium until 48 hours after the change in air temperature.

Caution is advised in transporting heavy loads across bridges following a large temperature change.

Cracks in Bridges. Due to temperature changes or heavy loadings, cracks may appear in the ice. Small surface cracks have little effect on load capacity, but large, deep cracks should be treated with some respect. Cracks which pass completely through the ice sheet and allow water to rise to the surface are dangerous. Heavy loads should not be allowed to cross or travel near them.

Many bridge operators reduce load limits when cracks are observed in the ice, although the amount of load reduction varies widely. Transverse cracks, intersecting cracks, and cracks parallel to the bridge, particularly down the center, are believed to affect ice-bearing capacity in different ways and are assigned different load reduction factors. In general, the following rules have been applied by Gold (1960):

- Load limits for vehicles crossing a wet crack perpendicular to the path of travel should be reduced to one-half the limit for uncracked ice.

- Load limits for vehicles crossing cracks that intersect 90 degrees or for vehicles travelling parallel to the edge of an open crack should be reduced to one-quarter the limit for uncracked ice.

Since ice cracks are self healing, load limits need not be applied indefinitely on ice which has a past history of cracks. Inspection of the ice surface to determine if cracks have refrozen should be carried out before load limits are returned to normal.

Vibrating Loads. To date, no studies are available on the effects of vibrating loads on ice sheets. Application of some factor of safety to these types of loads is probably adviseable. Some operators, who work with large, heavy, tracked equipment such as crawler tractors, reduce load limits by 25 to 30 percent to allow for machine vibration. Other operators, wishing to reduce the amount of vibration, often transport a large crawler tractor on a steel sled pulled by a much smaller tractor.

Maintenance

Ice bridges require little maintenance other than snow clearing and periodic inspection for bridge safety. Approaches can be expected to require the most maintenance.

Snow loads caused by snow buildup near the ice bridge will affect the bearing capacity of the bridge, so any accumulations greater than 4 inches (10 centimetres) should be cleared back 75 to 100 feet (25 to 30 metres) on either side of the bridge. Cracks in the ice due to the weight of snow windrows will likely occur but will not affect the bearing capacity of the bridge if they are pushed far enough back.

Light falls of snow can be left in place because they improve traction and reduce the effects of sunlight and warm weather. They also make it easier to spot new cracks and they obscure some ice features that are quite safe but may appear dangerous to drivers.

Closure

Most operators agree that the date of closure of ice bridges does not normally present a problem. In most cases, the associated winter road becomes impassable before the ice bridge becomes unsafe for travel.

Ice bridges served by gravel or all-weather roads present a different problem and various methods are used to determine a date of closure. Accumulated thawing degree-days (see "Notes", Figure 2, Appendix 1), deterioration of ice thickness, and ponding of water on the bridge and approaches are all used as indicators to determine closure date. All are valid indicators although they may not all occur simultaneously. Any one indicator may be cause for closing the bridge.

PART 2

PLANNING WINTER ROADS

GUIDE FOR PLANNERS

Planning a winter road, as described here, begins with the initial selection of a road type and a suitable route for it based on a review of maps and aerial photographs of the area, climatic records, and proposed use of the road. The choice of route is gradually refined in the light of expected costs and the results of field reconnaissance work, until a "best" route has been found. The preparation of contingency plans for alternate routes or road types in case of unexpected field conditions concludes the planning process.

When a prospective route is to cross environmentally sensitive areas, environmental protection should be an integral part of the planning process. However, to avoid confusion, environmental protection has been covered in a separate section immediately following this one.

Initial Route Selection

The first step is to locate the destination of the road on contour maps showing the general area at a scale of 1:250,000 or larger. Several possible starting points should then be considered to ensure that plausible corridors are not overlooked. At this stage, the number of corridors can often be reduced to one or two that look feasible.

The next step is to review aerial photographs of the feasible corridors. Consideration of least length, least amount of clearing, the number and width of water crossings, and avoidance of very steep grades -- over 10 percent -- will normally point up the most desireable corridor.

Climate

Meteorological records for stations near the corridor should be analysed to establish the following:

- average date of start of freeze-up
- average date of first snowfall
- average date of first snow depth of at least 4 inches (10 centimetres) (See Figure 3, Appendix 1)

- average date of mean accumulation of 550°F (306°C) freezing degree-days (See Figure 2, Appendix 1)
- average date of freeze-up of lakes (12 inches or 30 centimetres of ice)
- average date of the start of thawing days (first day in spring when the mean daily temperature exceeds the melting point for several consecutive days)
- total snowfall
- snowfall by month

The source of such records is the Meteorological Branch of Environment Canada.

The average date of mean accumulation of 550°F (306°C) freezing degree-days gives an estimate of when construction of the road can begin because this "amount" of frost is necessary to provide a firm base. The average date of the start of thawing days gives an idea of when winter roads must be abandoned. The difference between these dates is an estimate of the expected duration of winter road use.

How much snow is going to fall and when must be considered because a certain amount of snow is required for most winter road construction. On the other hand, snow can also insulate the ground from freezing temperatures, thereby limiting the depth of frost penetration. This too must be taken into account unless the snow is dragged or compacted to reduce its insulative effect.

In cases where a full season of use is not a critical factor, the analysis of weather records for the proposed corridor assumes less importance.

Road Type

A preliminary choice of road type for various sections of the route should be made at this stage because road type influences route selection within the corridor. For instance, solid ice roads would require relatively flat terrain and easy access to large quantities of water. Snow roads in areas of low snow might require that snow be hauled from the surface of lakes, an important factor in locating the alignment within the corridor.

The type of road selected depends to some extent on how the road is to be used. A cat train making two passes would need only a temporary trail. Sixteen wheelers carrying 72,000-pound (33,000-kilogram) loads making 50 passes a day for a total of 500 passes over the season would need either snow roads or ice roads. Vehicle type, intensity of traffic, wheel loads, tire pressures, and total number of passes should be estimated. Such information, together with the date when the road must be ready, the length of time the road will be needed, and the analysis of weather records will go a long way toward determining the type of road required.

Field Reconnaissance

Summer field reconnaissance, preferably by helicopter, should be used to adjust the route to avoid local problems not obvious from the maps or aerial photography. In addition, such reconnaissance is particularly important in unfamiliar areas because it provides an opportunity to observe the effect of past activities on the terrain. Evidence of erosion, thermal erosion, thermokarst development, ground subsidence, riverbank damage, rutting, mudflows, slides and ground-ice conditions should be recorded. Causes of terrain reaction should be recorded where possible and the type of ground activity causing the terrain disturbance should be determined and avoided. The amount of damage or lack of it caused by a particular type of ground activity is invaluable in determining the type of winter road required in a particular area.

Before any field activity is undertaken, jurisdiction of land use in the area to be crossed should be established. Copies of pertinent regulations should be obtained and complete familiarity with the regulations should be required of all field personnel. Many conflicting situations can be avoided by involving all parties at the early planning stage.

Before starting field reconnaissance with either helicopter or fixed wing aircraft requiring low-level flight, it is recommended that flight plans be reviewed with government forestry, fish and wildlife personnel to check for any potential environmentally sensitive areas. For instance, in the North when final winter road inspections are carried out in the spring, many wildlife species are particularly susceptible to disturbance. Checking first with government officials is simply a courtesy to those charged with the protection of our resources as well as being a safeguard against environmental destruction.

Clearing

Clearing of the right-of-way is an integral part of any type of winter road construction in the first year the road is built in forested regions. The winter road builder should become familiar with the regulations that govern the operation and necessary support facilities, and with the department or departments having jurisdiction in the provinces or territories of operation.

By far the greatest amount of winter road construction through forest is in the boreal forest region (see Figure 4, Appendix 1). Some winter roads used for logging in British Columbia are located in subalpine and montane regions; in New Brunswick, some are in the Acadian Forest. Extensive clearing and salvage of timber are usually required in British Columbia before winter road construction can take place.

In nonpermafrost areas, bulldozer blades without mushroom shoes are normally allowed. Clearing in summer, removal of roots, ripping of the surface, and exposure of mineral soil are common. Piling of debris and burning normally would be permitted, although some carryover of regulations from permafrost regions into nonpermafrost regions is to be expected.

Detailed Route Selection

The following points may prove helpful during detailed route selection.

Sidehills should be avoided if possible because of potential icing problems and the interruption of melt water in the spring. In river valleys, south-facing slopes should be avoided because of increased exposure of the road to sunlight. Many winter road operators have found that winter roads deteriorate first on south-facing slopes. Suitability of river crossings, including low banks, gentle approaches, slow-flowing water, and avoidance of lake inlets and outlets can often influence detailed route selection between major rivers.

In years when frost penetration is deep enough by the time construction is scheduled to begin, low, wet ground such as muskeg is preferable to treed uplands because it will freeze early to form a hard, level surface for the road. But when frost penetration is "late", treed uplands are preferable to low, wet ground.

Construction, Operation, and Maintenance

Procedures on which to base plans for the construction, operation, and maintenance of all types of winter roads are presented in the first part of the manual.

Costs

The cost of building, operating, and maintaining any type of winter road will vary considerably from region to region depending largely on remoteness. In northern Canada, winter road construction may cost twice as much as in more southerly or habited areas, largely because of the high cost of moving men and equipment to remote locations.

Costs per mile have been listed in two tables in this section based on interviews with winter road operators across Canada and in Alaska. Since they are average figures, they should not be taken as applicable to all situations. Further details on the figures in the tables are presented below.

The cost of clearing must be considered when a right-of-way is being used for the first time. Machine clearing costs can vary by a factor of 20 depending on tree density. In lightly treed areas, clearing may run as low as \$300 per mile (\$200 per kilometre). In heavily forested areas, such as north-central British Columbia where considerable salvage is involved, clearing can run as high as \$3,000 to \$6,000 per mile (\$2,000 to \$4,000 per kilometre).

In areas of high-ice-content soils, clearing by hand may be required to avoid damaging the terrain. Hand-clearing trials have shown that in medium density forest, trees can be hand-cleared, grubbed, and piled at a rate of 200 man-hours per acre (500 man-hours per hectare) using chain saws. These trials were conducted in snow 20 inches (50 centimetres) deep and temperatures below $-4^{\circ}F$ ($-20^{\circ}C$). Adjusted time requirements based on tree size, tree density, weather conditions, and local labor costs should be used for estimating hand-clearing and grubbing costs.

Winter Trails. Clearing and construction costs of winter trails depend on terrain, snow conditions, and construction techniques. At one extreme, costs of \$6,000 to \$10,000 per mile (\$4,000 to \$6,500 per kilometre) have been recorded for winter trails used for logging in British Columbia. Extensive clearing, salvage, and rough terrain were involved. Temporary trails normally cost less than \$1,000 per mile (\$600 per kilometre) to build, exclusive of clearing. The same applies to perennial winter trails because clearing has been done in previous years.

Guide to Clearing Costs

Tree Density	Machine Clearing	Hand Clearing
Light	$ 300-$1,000	$2,000-$6,000
Medium	$1,000-$3,000	$6,000-$9,000
Heavy	$3,000-$6,000	Over $9,000

Note:

These are costs per mile to clear a 60-foot-wide right-of-way. Multiply by 0.7 to convert to costs per kilometre for a 20-metre-wide right-of-way.

Guide to Construction and Maintenance Costs

Type of Road	Construction	Maintenance
WINTER TRAILS		
Temporary	$ 400-$1,500	$ 400-$1,500
Perennial	$ 400-$3,000	$ 400-$1,500
SNOW ROADS		
Compacted	$3,000-$4,000	$ 900-$1,500
Processed	$3,500-$5,500	$ 900-$1,500
Ice-Capped	$6,000-$9,000	$ 900-$1,500
Artificial	$30,000	$400
ICE ROADS		
Solid	$2,000-$20,000	$500
Aggregate	$20,000-$30,000	$500
On Natural Ice	$1,000-$3,000	Under $3,000

Note:

These are costs per mile to build and maintain a 30-foot-wide road. Clearing costs are not included (see above). Multiply by 0.7 to convert to costs per kilometre to build and maintain a 10-metre-wide roadway.

It usually costs about the same to maintain a winter trail as it does to built it. In areas of high snowfall or where high winds cause large drifts, snow removal can add substantially to the cost of maintenance.

Snow Roads. Snow roads are normally used where little or no clearing is required. Construction depends largely on the amount of compaction, processing, or ice-capping required. A compacted snow road involves increased compactive effort and often more specialized equipment. Processing a 30-foot (10-metre) roadway can be expected to add an additional $500 to $1,000 per mile ($300 to $600 per kilometre). Ice-capping alone, consisting of the addition of 1 inch (25 centimetres) of water to a 30-foot (10-metre) roadway will add an extra $3,000 to $5,000 per mile ($2,000 to $3,000 per kilometre). Haul distances for snow and water over 5 miles (8 kilometres) would incur additional costs.

Manufactured snow roads, being very expensive, are used only under very special circumstances. With the development of snow manufacturing machines to produce large volumes of snow, the costs of building manufactured snow roads can be expected to drop to some extent. At present, however, the experience with short sections of manufactured snow roads indicates costs of up to $30,000 per mile ($20,000 per kilometre). This cost, based on figures from sections of a manufactured snow road less than 1 mile (2 kilometres) long, can be expected to be less for sections of manufactured snow road several kilometres long because of the distribution of start-up costs over a longer distance. But regardless of efficiency, economy of scale, or advances in the manufacturing of snow, manufactured snow roads will remain expensive.

The cost of maintaining snow roads is variable. Maintenance can involve minor repair of potholes to complete reconstruction. Snow removal can also be a substantial item particularly in high snowfall areas or in exposed areas where drifting is common. Well constructed snow roads should normally be maintained for less than $1,000 per mile ($600 per kilometre). Where extensive snow clearing is expected, maintenance budgets of $3,000 per mile ($2,000 per kilometre) are reasonable.

Solid Ice Roads. Cost of solid ice road construction depends on thickness which in turn depends on the roughness of the micro-relief. With haul distances in the order of 2 to 5 miles (3 to 8 kilometres), a 24-foot (7-metre) solid ice road with an average thickness of 8 inches (20 centimetres) will require about 475,000 gallons per mile (1.3 million litres per kilometre). This could be expected to cost about $12,000 to $20,000 per mile ($8,000 to $13,500 per kilometre). Costs for lesser or greater thicknesses or widths should be adjusted accordingly.

Aggregate ice road costs are the total of aggregating, hauling, shaping, and sprinkling costs. Haul distances for ice aggregate and water are variable. However, for typical haul distances of 2 to 5 miles (3 to 8 kilometres) aggregate ice roads can be expected to cost between $20,000 to $30,000 per mile ($12,500 to $18,500 per kilometre).

Ice roads on natural ice surfaces are by far the cheapest form of ice road. The cost of preparing this type of ice road varies mainly with the amount of snowfall that must be removed. Typical costs are between $1,000 to $3,000 per mile ($700 to $2,000 per kilometre).

The cost of maintaining ice roads depends on the cost of minor repairs and snow removal. On solid ice roads and ice aggregate roads, costs of snow removal would be expected to be minimal because it is the lack of snow that encourages their use. Overall maintenance of well constructed solid and aggregate ice roads should be less than $500 per mile ($300 per kilometre). Ice roads on natural ice surfaces can involve considerable snow clearing. Other maintenance costs involve the bridging of pressure ridges. Sometimes it is cheaper to reroute a road on ice than to maintain it by removing snow. Therefore, it is safe to assume that maintenance costs normally would run less than $3,000 per mile ($2,000 per kilometre) for roads on ice.

Contingency Plans

Winter road construction, operation and maintenance depend mostly on the weather, which, unfortunately, does not always cooperate. To deal with unexpected weather, the winter road contractor or operator must be prepared to change his plans to suit conditions.

A road contractor may arrive on site fully equipped to construct a snow road, a choice made many months earlier, only to find that a lack of snow makes this impossible. Rather than wait until sufficient snow has fallen, he should have an alternate plan that allows him to begin construction of, say, an ice road, if that is feasible. Later, a change back to the original snow road may be worthwhile if enough snow has fallen in the meantime.

Too much snow, too little frost in the ground, unseasonably warm weather, or insufficient ice at river crossings may cause similar problems. Unexpected construction costs, changing traffic patterns, or heavier loads may also force a contractor to change road type or upgrade what he has already built.

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Too much snow, too little frost in the ground, unseasonably warm weather, or insufficient ice at river crossings may cause similar problems. Unexpected construction costs, changing traffic patterns, or heavier loads may also force a contractor to change road type or upgrade what he has already built.

Extra pieces of equipment such as dump trucks, a water truck, a soft-tracked vehicle, or a 6-inch (18-centimetre) water pump on hand or quickly available may save time and money.

The following table lists some of the options open to winter road builders when conditions force a change of plans.

Construction Contingencies

Condition	Contingency Plan
Little snow, little frost in ground, or little ice on water	Not much can be done on higher classes of roads; however, route relocations to higher ground and the use of earth fill may allow a winter trail to proceed in nonpermafrost areas.
No snow, but sufficient frost in ground and sufficient ice on water	Trails can probably proceed normally as can ice roads and roads over ice. Snow roads will require manufactured snow or they may be changed to ice roads. Later, snow accumulations may allow a change back to natural snow roads.
Sufficient snow, but little frost in ground and little ice on water	Frost penetration may be accelerated by compacting snow with soft-tracked vehicles. Ice at river and stream crossings may be built up by flooding.
Too much snow, little frost in ground, and little ice on water	Frost penetration may be accelerated by compacting excess snow with soft-tracked vehicles. Trails over high ground may only require the blading off of excess snow. Ice roads may be changed to compacted or processed snow roads. Ice at river and stream crossings may be built up by flooding.
Too much snow, but sufficient frost in ground and sufficient ice on water	Trails can proceed normally with excess snow bladed off. Snow may be compacted by tracked vehicles to build snow roads. Excess snow must be removed from water crossings.

Condition	Contingency Plan
Too warm, but sufficient snow, sufficient frost in ground, and sufficient ice on water	Trails can proceed normally with some snow left in place on roads. Snow may be compacted by tracked vehicles to build snow roads. Ice roads or ice-capped snow roads may be changed to compacted or processed snow roads.
Little water available	Snow may need to be melted to cap ice-capped snow roads. Ice roads may need to be changed to snow roads.
Construction costs too high	Original road type may need to be changed to next lowest road type which will serve purpose and support anticipated traffic. May entail authorization from government jurisdiction responsible.
Road cannot support normal traffic	Road can be upgraded to next highest type which can support traffic, that is, compacted snow road to processed snow road or ice-capped snow road. Compacted snow roads may be ice-capped.
Road cannot support abnormally high traffic volumes or abnormally heavy traffic	Snow roads may be ice-capped or ice roads thickened.
Daytime thawing and weakening of road	Night-time traffic only should be allowed.

ENVIRONMENTAL PROTECTION

Environmental protection should apply to all types of winter roads, although the presence of permafrost along the route is usually a sign that it is particularly important (see Figure 1, Appendix 1).

Recommended environmental protection measures vary from province to province and region to region. Land-use agencies may require certain definite procedures to be followed or they may exert little control over winter roads, depending on the area. It is best to check with local land-use departments early in the planning process. They can advise whether the route crosses any environmentally sensitive areas and point out construction difficulties along the proposed routes.

This section offers a comprehensive review of environmental protection measure as they apply to planning winter roads. Although many of the ideas appear in other parts of the manual, they have been repeated here in the interests of presenting a complete treatment of this important subject.

Environmental Protection - The Problem

In the more northerly regions of Canada, where permafrost is widespread, large quantities of ice often exist immediately below the surface. This ice, generally in the form of ice crystals and small lenses in the discontinuous permafrost zone, increases to large ice lenses, massive ice, and ice-wedge polygons further north. On the other hand, the organic or peat layer, which forms a protective layer of insulation over the soil, is generally thick in the southern boreal forest, decreases in thickness northward, and is generally thin on the tundra. As a rule, the more ice in the soil and the thinner the peat layer, the more sensitive the terrain to disturbance. For these reasons, the further north winter roads are built, the more effort is required to protect the terrain.

Complete blading of the surface is often permitted in southern areas because of low-ice-content soils and because the relatively fast reestablishment of natural plants normally prevents excessive gullying through erosion. Above 60^{O}N, more care must be taken to protect the peat layer. Clearing of trees alone in the boreal forest can lead to ground subsidence because it changes the thermal regime at the ground surface. But provided the peat layer is left intact, only minor terrain reaction, if any, occurs. Once the peat layer is frozen, low-ground-pressure vehicles will cause little compression -- at least in terms of what could affect the thermal balance.*

Terrain damage from winter roads shows up in summer but is rarely apparent in winter. Since few operators in the North ever see their rights-of-way in summer, they seldom believe terrain damage to be significant. However, there is no doubt that good planning, co-operation with land-use officials, and properly constructed winter roads can go a long way in reducing terrain disturbance common in permafrost areas.

Initial Route Selection

Protection of the environment begins with initial route selection. Existing precleared rights-of-way such as old trails or seismic lines should be followed whenever possible. In fact, this is often a stipulation of land-use permits for building winter roads.

Road Type

In the southern parts of provinces where winter roads are used, winter trails are common because even in areas with permafrost, there is little excess ice in the soil and as a result the need for surface protection has been considered less important. But in all areas of high-ice-content soils, particularly on the tundra, it is usually necessary to build the more sophisticated types of winter roads to protect the terrain. Either snow roads or ice roads will probably be required in these areas, although trails may be acceptable in seismic work involving only light-tracked vehicles. Selection of the particular type of snow road or ice road will depend on local conditions, particularly the amount of snowfall, sources of water, project requirements, and availability of equipment.

Detailed Route Selection

Permafrost areas obviously susceptible to terrain degradation because of excess ice should be avoided. Places to stay clear of are patterned ground, and areas of ground settlement, ponding, or thermal erosion.

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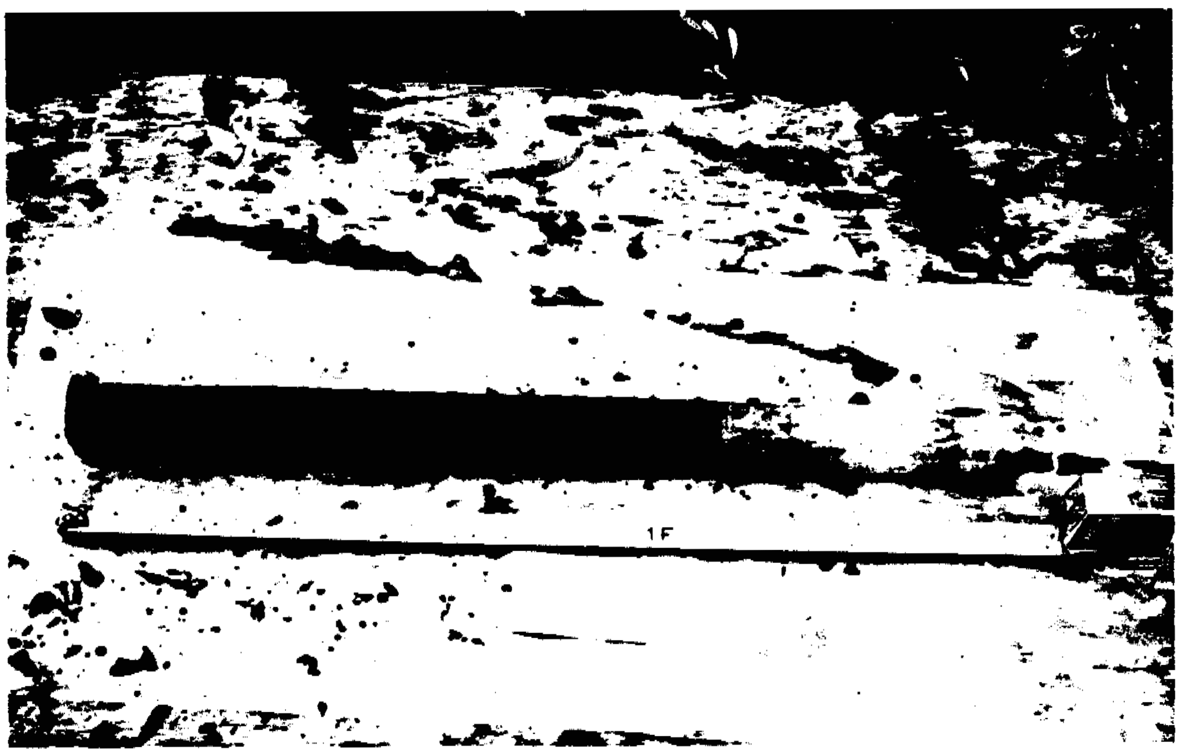
*Frozen peat can be compacted by low-ground-pressure vehicles. In areas of low snowfall, such as the Arctic coastal plain, sublimation of ice occurs, leaving voids in the peat layer.

Massive ice formation exposed on a landslide. The ice measures 30 feet (10 metres) across along the top and is covered by a 2- or 3-foot (about 1 metre) thick mat of soil, peat, and tundra plants. (I. Reinart)



Drill core taken from the continuous permafrost zone. Note frozen material containing nonvisible ice in upper section (left) and clear ice at lower level (right). (R. Read)

Building roads within 300 feet (100 metres) of streams or rivers, except when it is necessary to install a crossing, is not recommended because of the possibility of silt from the right-of-way contaminating fish habitat.

Route selection of winter trails for exploration work is sometimes left to the lead dozer operator. This is not recommended because it can lead to problems, such as several attempts to get up the slopes of a valley. Such unnecessary damage can be avoided by completing route selection before field operations begin.

Clearing

Much greater care is required in clearing rights-of-way in permafrost areas than in nonpermafrost areas. Bulldozer blades should be equipped with mushroom-type shoes so that the blade cannot remove the surface vegetation or the surface mat of peat.

Clearing should only take place in winter when the trees are brittle and will break off at ground level when the blade hits them at 1 to 3 feet (0.3 to 1.0 metres) above the ground. Snow will offer some protection to the terrain. Underpowered vehicles should not be used for clearing as a slipping track tends to tear the surface mat. Root systems should be left intact, otherwise mineral soil will become exposed, leading to terrain reaction.

Trees and debris should be windrowed to one side away from standing timber and compacted as tightly as possible. Breaks in windrows at intervals, alternating from side to side of the right-of-way, are recommended to retard the spread of forest fires. Burning of slash is not allowed as it burns the surface mat, reducing its insulative effect. No leaners or debris should be left in standing timber.

Special precautions during clearing might be demanded by the responsible agency in some areas of Canada. For instance, in the Northwest Territories, it is generally required that width of clearing be limited to 33 feet (10 metres) or that slash be cut into suitable lengths and branches lopped off to facilitate compaction. Final compaction might be required by crushing with heavy machinery. Under special circumstances, hand-clearing and piling may be desireable.

Construction

Environmental protection measures necessary during construction are few if the proper route and type of road is selected, sufficient frost is present in the ground, and the vegetative mat is left intact where required.

Scuffing of surface caused by machine clearing, unacceptable practice in ice-rich permafrost terrain. (K.M. Adam)

Burn piles are unacceptable in permafrost areas because they destroy the vegetative mat. (K.M. Adam)

Regulations on the use of corduroy in ice bridges vary throughout Canada. Corduroy, which can obstruct streams, may be prohibited in some areas but permitted in others provided it is removed before spring breakup. To facilitate removal, some operators cable the corduroy logs together and anchor them to shore. A tracked machine can easily pull the cabled logs to shore as breakup progresses.

Regulations for crossing small streams also vary by region. In some areas bridges over small streams are constructed by laying logs longitudinally and transversely in layers across the stream channel. The bridge is then topped with snow and brush and watered down. Crossings of this type are removed before spring breakup. The approaches to the crossings are established by grading the stream banks.

In other areas where stream blockage in spring may hamper fish movements, only snow may be used in filling small stream beds -- timber or brush is not permitted. Removal of the snowfill in spring may be required.

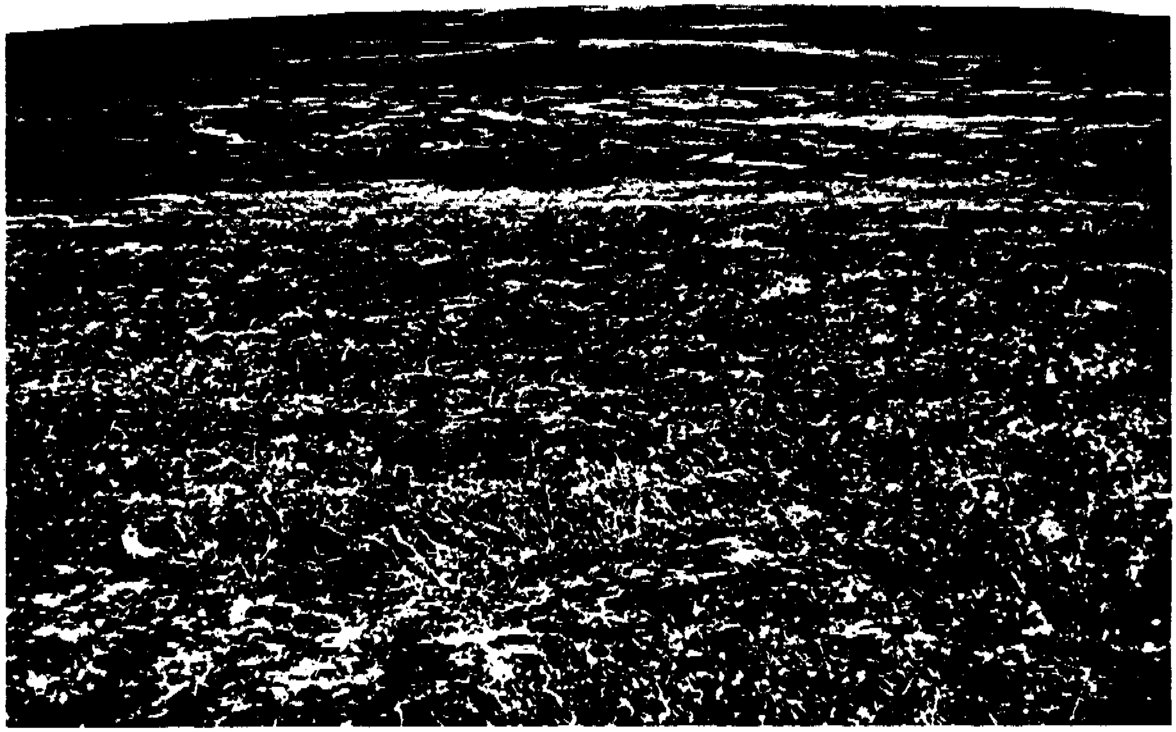
During construction of the higher classes of winter roads, care should be taken to avoid removing too much snow from lakes or too much water from lakes and streams. Thickening of the ice cover resulting from excessive snow removal, or depleting water supplies, may endanger overwintering fish.

Operation and Maintenance

In permafrost areas, only tracked vehicles or balloon-tired low-ground-pressure vehicles should be used on temporary winter trails. Trailers and mobile camps should be ski-mounted so that they do not come in contact with the vegetative cover and surface disturbance is kept to a minimum. In tundra areas, even with construction that results in minimal disturbance, winter trails will often be visible, particularly from the air, the following summer(s) even when they have been subjected to only a few passes of low-ground-pressure vehicles.

Continuous maintenance is to be expected if wheeled vehicles utilize the winter trail. Normal wheeled highway traffic should not use winter trails on the tundra because it causes compaction, rutting, and damage to surface vegetation.

Maintenance of winter trails in permafrost areas is minimal. Bare spots caused by wear, radiation or other factors should be covered with snow and lightly compacted by



Seismic line constructed the previous winter, scarcely visible the following summer. (H. Hernandez)

Seismic line bulldozed in summer eight years earlier. Summer construction of seismic lines is no longer allowed in areas of potential terrain disturbance. (H. Hernandez) track. Periodic inspection should be carried out. Keeping a snow cover over the trail surface is the primary objective of maintenance.

Maintenance of the higher classes of winter roads is not a problem outside of patching weak spots. Sand can be used on the road surface to improve traction. Sawdust used on the road surface for pothole repair or to prevent melting should not be allowed to enter waterbodies.

Care should be taken with the onset of spring that a winter road is not travelled to the point where severe rutting occurs. Regulation and inspection by land-use agencies may require that a road be closed to traffic by a given date before damage occurs. Night travel may be permitted for a short period prior to complete closure, provided the road surface freezes overnight.

Result of 100 passes in spring of a medium weight tracked vehicle across the tundra. (H. Hernandez)

ILLUSTRATION FOR PLANNING WINTER ROADS

This section describes the planning of a hypothetical winter road. It is intended to give planners an idea of the kinds of situations they might encounter in practice when selecting a winter road and a suitable route for it.

The road is located in the discontinuous permafrost zone. It is to be used for transporting equipment and materials to a mine site over a distance of some 200 to 300 miles (320 to 480 kilometres), depending on the final alignment chosen. Total weight of the equipment to be transported is 10,000 tons (9,000 tonnes). Maximum loads are 40 tons (36 tonnes) and average loads, 20 tons (18 tonnes). The most satisfactory vehicles for hauling such quantities of material and equipment in a short time would be semi-trailer trucks. Some 500 truck loads would be required.

Although there is no set budget for the road, the owners want a satisfactory road at the least expense. There is also a future requirement for a permanent road to be built to the mine.

Initial Route Selection

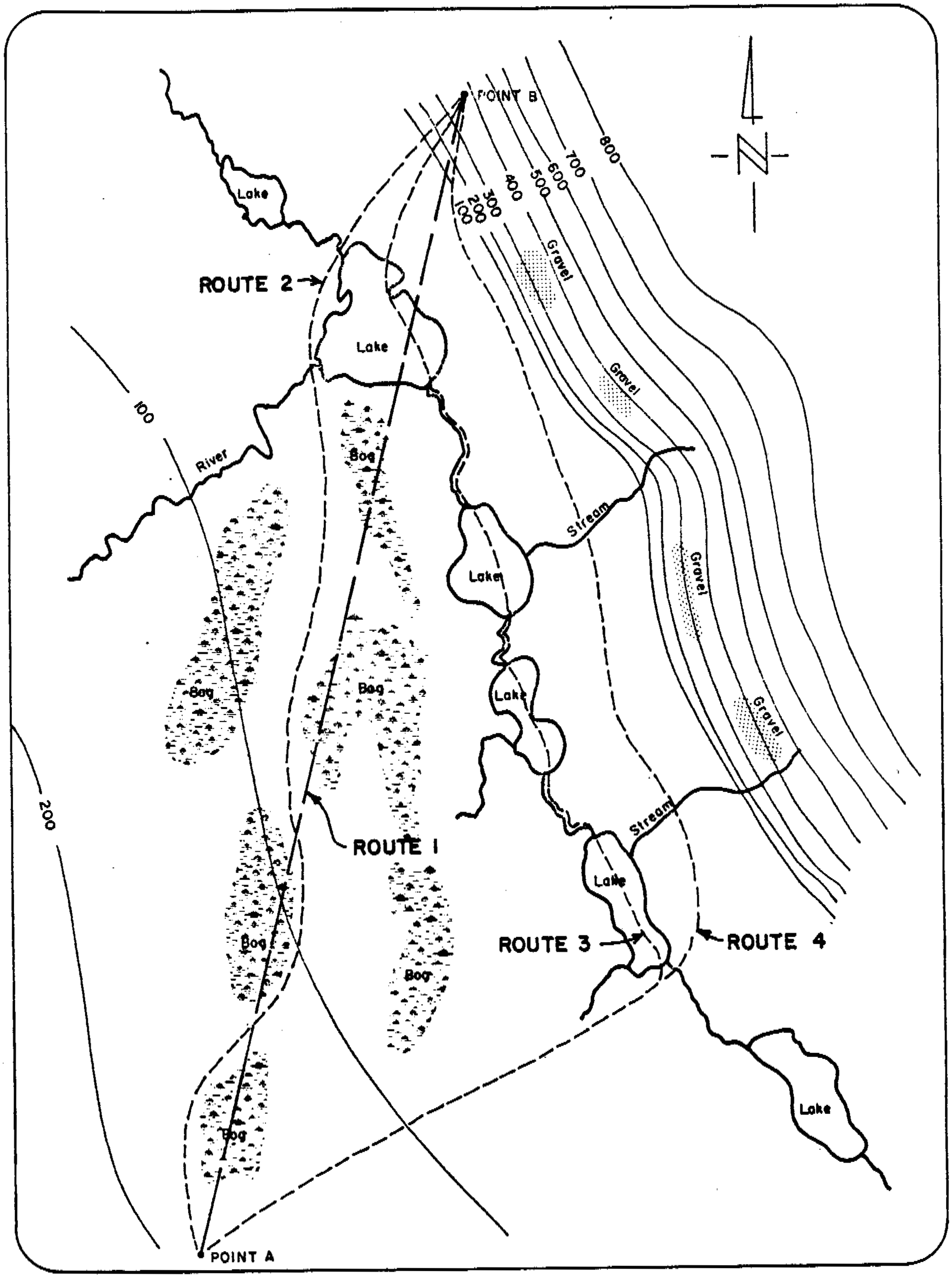
To begin planning a route for the road, a topographical map of the area on a satisfactory scale such as 1:250,000 or larger would be essential. For the purposes of this example, the map shown overleaf has been used.

The route in this instance lies in the discontinuous permafrost zone; if it crossed more difficult terrain, aerial photographs might be helpful.

Some obvious topographical features of the area are apparent from the map. Low-lying and boggy terrain lies along much of the route in a direct line between Point A and Point B, the origin and destination of the road. A string of lakes also lies between the two points, but the lakes are not aligned along any direct route. East of the lakes the terrain rises abruptly into a dry and somewhat sheltered area.

Route selection begins with the drawing of a straight line on the map between Point A and Point B. This is Route 1, the shortest possible route -- some 200 miles (320 kilometres) long. It crosses flat terrain without any

Illustration for
Planning Winter Roads



Area to be crossed by the winter road.

steep grades, but it also crosses several large bogs and one fairly large lake; these latter features may cause difficulties if frost penetration is late or ice thickness develops slowly.

Route 2 maintains the best qualities of Route 1 while avoiding the worst. It bypasses large swamps or lakes, it crosses only one major river, it is the shortest possible overland route with the least difficulties -- 230 miles (370 kilometres) long -- and it encounters relatively flat terrain with no steep grades. One new problem, though, is the major river crossing. But since the river happens to be fairly wide and slow-flowing where the route intersects it, it is not considered a problem for ice-bridging.

The alignment of the chain of lakes suggests a third alternative, Route 3. Some 290 miles (470 kilometres) long, Route 3 is part overland road, part road on ice. The sections on ice can be built more quickly and cheaply than an overland route, and the sections on land encounter no steep grades. But, construction of the sections on ice can only begin when the ice is at least 12 inches (30 centimetres) thick, and heavy loads can only be transported when the ice is 40 inches (100 centimetres) thick.

A final possibility is Route 4. It crosses higher and drier terrain than the other routes. There are no major river crossings in the way, and the two minor streams it crosses will probably freeze to the bottom or be completely dry in winter. Gravel sources may be available in the area to the east of the route, although this would be of little help in building the winter road. A definite disadvantage is that the route is the longest of the four -- 320 miles (510 kilometres) long.

Environmental Protection

Consultation with local land-use officials reveals that of the four routes, only Route 2 poses a potential environmental problem. The route crosses a river used by fish as an overwintering habitat. Problems could arise if corduroy or sawdust were used in the ice bridge, or if the crossing were to freeze to the bottom. It is agreed that if Route 2 is selected, no corduroy or sawdust will be used in building the bridge, and that the final location of the crossing will be selected in consultation with officials from the local department of fisheries.

Road Type

Road type can be limited to winter trails and roads on ice in this illustration for several reasons. First, traffic volumes for the road are relatively light. With the exception of light vehicles such as cars and small trucks, only 500 loads averaging 20 tons (18 tonnes) per load will pass over the road. Any well-constructed winter trail or road on ice could easily support these loads as well as the maximum load of 40 tons (36 tonnes). Second, all other types of roads would be more costly to build and maintain. And third, there is no requirement for environmental protection along any of the routes other than the river crossing for Route 2.

Climate

Given the four possible routes and the road type, climatic data are now required to assist in selecting the "best" route.

A review of weather records for the area furnishes the following information:

- normal start of freeze-up	October 1
- normal accumulation of 4 inches (10 centimetres) of snow	November 15
- normal accumulation of 550°F (306°C) freezing degree-days	December 1
- normal freeze-up of lakes (12 inches or 30 centimetres of ice)	December 15
- normal start of thawing days	April 1

Under these conditions, which represent a normal year, construction of a trail over dry terrain could begin on November 15 with the accumulation of 4 inches (10 centimetres) of snow. A trail over wet terrain could begin on December 1 with the accumulation of 550°F (306°C) freezing degree-days. Construction of a road on ice could begin on December 15 with 12 inches (30 centimetres) of ice on lakes. Generally, a winter road is closed in spring after a few days of above-freezing temperatures. Closure would be considered to occur at the average start of thawing degree day accumulation -- April 1.

Illustration for
Planning Winter Roads

These tables were drawn up to facilitate a comparison of the routes. They are based on data gathered to this point in the planning process.

Hauling Days

Route	Construction Start-up	Days to Construct*	Opening Date	Hauling Days
Route 1 ("straight-line")	Dec. 1	67	Feb. 5	55
Route 2 ("winding")	Nov. 15	77	Jan. 30	59
Route 3 ("lakes")	Nov. 15	73	Jan. 25 (limited load) Feb. 9 (full load)	66 (part load) 51 (full load)
Route 4 ("high")	Nov. 15	107	Apr. 1	31

* Construction progress for a winter trail is assumed to be 3 miles (5 kilometres) per day and for a road on on ice 5 miles (8 kilometres) per day.

Costs

Route	Construction	Maintenance	Total Cost
Route 1 ("straight-line")	$ 200,000	$ 78,500	$ 278,500
Route 2 ("winding")	$ 230,000	$ 97,000	$ 327,000
Route 3 ("lakes")	$ 202,500 (50% on land, 50% on ice)	$ 63,000 (land only)	$ 265,500
Route 4 ("high")	$ 320,000	$69,000	$ 389,000

Note: Winter trails cost $1000 per mile ($630 per kilometre) to build and $50 per mile per week ($32 per kilometre per week) to maintain. A road on ice costs $500 per mile ($320 per kilometre) to build and maintain. Costs of clearing have not been included since clearing is not required along any of the routes in this example.

Selecting A Route

Route 1, the "straight-line" route, would be fairly cheap to build and maintain, at $278,500. But its shorter operating life of 55 days might make it a poorer choice, particularly in a winter with a late freeze-up.

Route 2, the "winding" version of Route 1, would be expensive to build and maintain, at $327,000. However, its full-load operating life of 59 days, the longest full-load operating life of all the routes, might allow sufficient time to transport all required loads whereas the shorter lives of other routes might not.

Route 3, the "lakes" trail, would be the cheapest to build and maintain, at $265,500. It would also offer the longest operating life, 66 days, although load restrictions would have to be imposed during the first 15 days. Late formation of ice on lakes might reduce the operating life of the road.

Route 4, the "high" road, would not only be the most expensive to build and maintain at $389,000, but it would also have the shortest operating life of all -- 31 days. In a late freeze-up, the road might not be completed in time to allow traffic to start. If gravel deposits were located east of the route, they would make it more attractive for construction of a permanent road.

Subject to the results of the field reconnaissance, it is evident that Route 3, with its lowest cost and long operating life, is the best overall choice for a winter road to the mine. In the event of a late freeze-up, Route 2 might be preferable because it would buy more time for transport operations at an additional cost of $83,500.

Field Reconnaissance

A field reconnaissance of the routes shows that the bogs along Routes 1 and 2 are deep and therefore not likely to freeze quickly. A deeper-than-normal snowfall may require either of these routes to be compacted by soft-tracked vehicles to speed frost penetration. This situation would lead to higher costs and longer construction periods. Some minor changes in Route 2 would avoid problem areas.

Route 3 is found to be much as expected. Minor route relocations would be necessary to avoid the inlets and outlets of rivers at lakes which can be hazardous because of changing water levels.

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Route 3 is found to be much as expected. Minor route relocations would be necessary to avoid the inlets and outlets of rivers at lakes which can be hazardous because of changing water levels.

Route 4 also proves as expected. Large gravel deposits are confirmed in the area east of the proposed route.

Given these results and the arguments presented earlier, Route 3 appears to be the best route for a winter road to the mine.

Construction Sequence

Because a permanent road will be needed soon, it is decided to save on costs by combining construction of the winter road along Route 3 and a permanent road along Route 4. Route 4 is the logical choice for the permanent road, largely because of the gravel sources located to the east of the route.

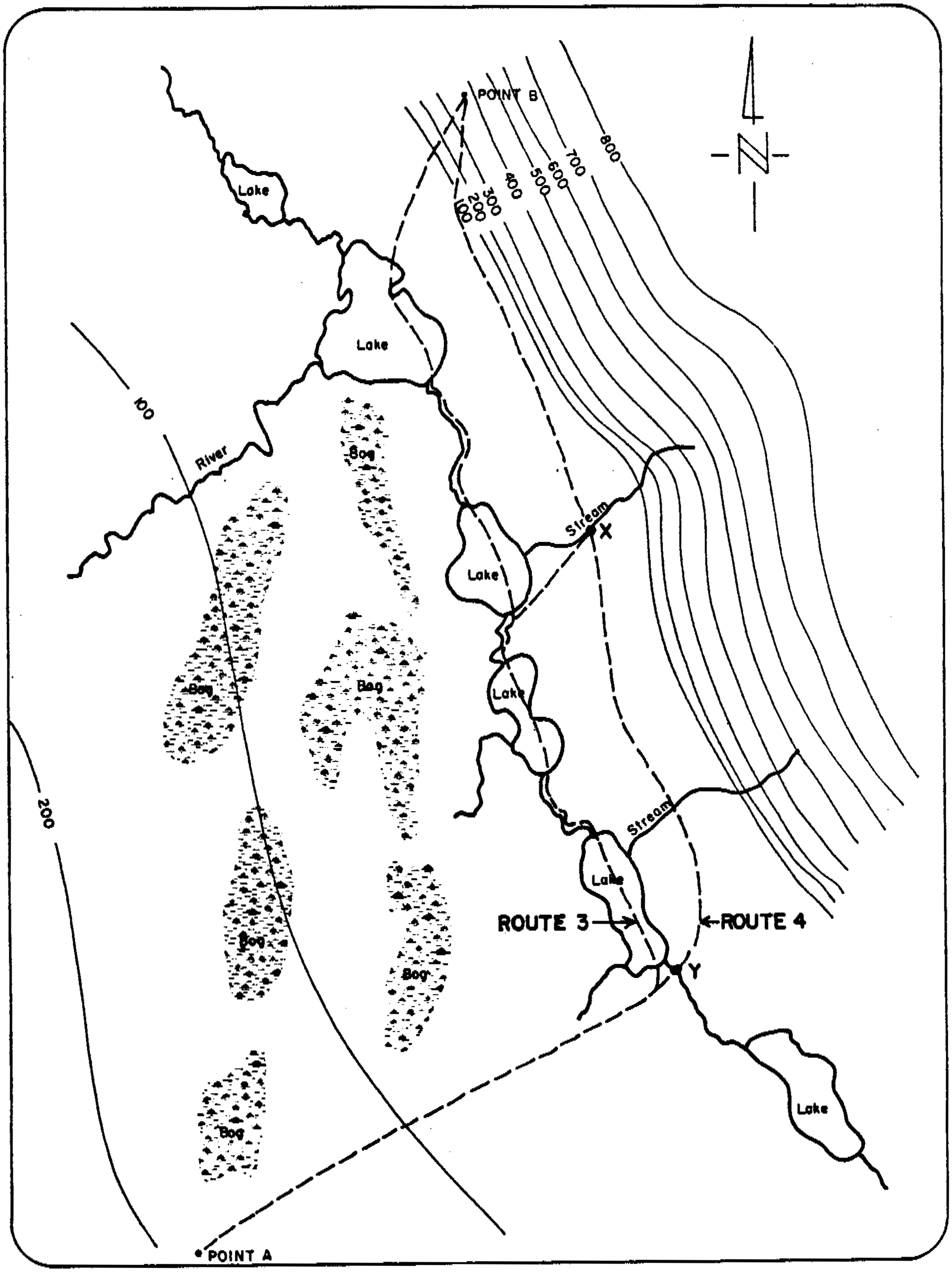
The construction sequence planned is as follows (see map overleaf). After the winter road has been built the first winter, it will be used to transport road-building equipment to the mine so that work can begin on the permanent road south from the mine during the first summer. The section of the permanent road from the mine to Point X is expected to be completed by the end of the summer; this will provide a northern section of ready-built road for the winter trail to follow during the second winter. By the end of the second summer, the permanent road should be completed to Point Y, making it necessary to build only a short section of winter road during the third winter. The end of the third summer should see completion of the permanent road and abandonment of the winter road.

Pre-Construction Checks and Contingency Plans

As the time approaches to begin winter road construction, a close check should be kept on freeze-up conditions, snowfall accumulations, and freezing degree-days. Field crews on snowmobiles can check frost penetration and ice thickness on lakes. A relatively normal freeze-up will allow the proposed construction plan to proceed.

Any large deviation from normal freeze-up conditions may require a change in plans. A very late freeze-up and poor ice formation on the lakes may require that one of the other routes be chosen rather than wait for conditions to improve. This decision will allow winter road construction to progress along the next most desireable route and winter hauling to begin as soon as possible.

Illustration for
Planning Winter Roads



Construction sequence for the winter road and permanent road to the mine.

PART 3

CANADIAN AND ALASKAN EXPERIENCE WITH WINTER ROADS

Winter road operators customarily have a wealth of practical knowledge on ways of building roads for specific uses in their own area. To tap this source of information, we conducted interviews of over 250 winter roads personnel in Canada and Alaska. The results are reported in the following section to make this valuable experience available to others.

The interviews were conducted in 1977. Questionnaires to expand our contacts with people knowledgeable about winter roads were sent to individuals across Canada and Alaska, in government departments as well as private industry. Wherever possible, personal interviews were arranged or phone calls were made in order to gather as much insight as possible into each person's experience with winter roads. The results of the interviews were organized and assembled to focus on specific techniques from region to region.

The personnel interviewed were classified as either supervisors or contractors/builders. Although some of them are now in other walks of life, they have all worked with winter roads, some for as long as 30 years.

Much of the material from the interviews has found its way into the earlier parts of the manual but in a general form that applies to the various types of winter roads. Here, the emphasis is on techniques used in a particular region or by a particular industry to build a particular road. The roads described range from winter trails for moving and servicing drilling rigs to aggregate ice roads built for experimental purposes. Some of the roads, such as those of the Manitoba winter roads network, are built year after year in the same locations; others, such as forestry roads, are built for one season and then abandoned.

The interviews reflect as accurately as possible what the operators and builders had to say about winter roads and do not necessarily reflect my own views and opinions. For this reason, I have provided a brief commentary to conclude this part of the manual.

It is hoped that the interviews will benefit people in the winter road business, whether by providing them with a new slant on an old way of doing things, an interesting commentary on regional practises, or some insight that spares them the need to "reinvent the wheel".

BRITISH COLUMBIA

Winter roads in British Columbia are primarily haul roads for the pulp and paper industry. Some are used by oil exploration companies for seismic work and for servicing drill sites in the northeastern part of the province. A few winter roads like the one north from Fort Nelson to the Yukon and the one northeast from Fort Nelson to north of Kotcho Lake are re-established most winters.

A few contractors from northern British Columbia have built winter roads in the Yukon and Northwest Territories, including the Arctic Islands. Their experiences are discussed in the appropriate geographical section (Yukon and Northwest Territories).

Roads for the Pulp and Paper Industry

Few, if any, forest roads in British Columbia cross permafrost soils and for this reason little care is taken to preserve the surface mat. Most trails are bulldozed down to mineral soil to form a smooth surface. Although referred to as "winter roads" the following definition given by one pulp and paper company best exemplifies their use in that industry: A winter road allows industrial access to haul logs during the winter months in areas that are inaccessible in summer except for light vehicles during dry periods. Therefore in British Columbia, many winter roads run through low wet areas. Because of this, winter roads are normally quite short, running usually from a main haul road to a cutting area.

Alignments are chosen with grade as a prime criterion. Loaded upgrades are limited to 6 to 8 percent and downgrades to less than 14 percent. Even 12 percent grades require sanding for traction.

Roads are planned 18 months in advance and the plans submitted to the British Columbia Forest Service for approval. Stream crossings are often a point of contention. After modification of plans as required, construction can begin.

In swamps and bogs, a light, tracked vehicle is used to tramp the snow and vegetation. Swamps are avoided if possible because frost is not guaranteed. But if swamps must be crossed, winter roads are used. If mild weather persists and an early snowfall comes, tramping is done by men on snowshoes.

In forested areas, preparation involves logging the right-of-way usually to a 66-foot (20-metre) width the year before anticipated use. Merchantable timber is salvaged and stockpiled. Debris is disposed of by burning or is incorporated into the road grade. Normally only a slight grade is built. Snow is beneficial for levelling. Culverts are used to cross most small streams, but sometimes log bridges are used. Semi-permanent bridges such as Bailey bridges have been used at some water crossings on perennial winter trails in British Columbia.

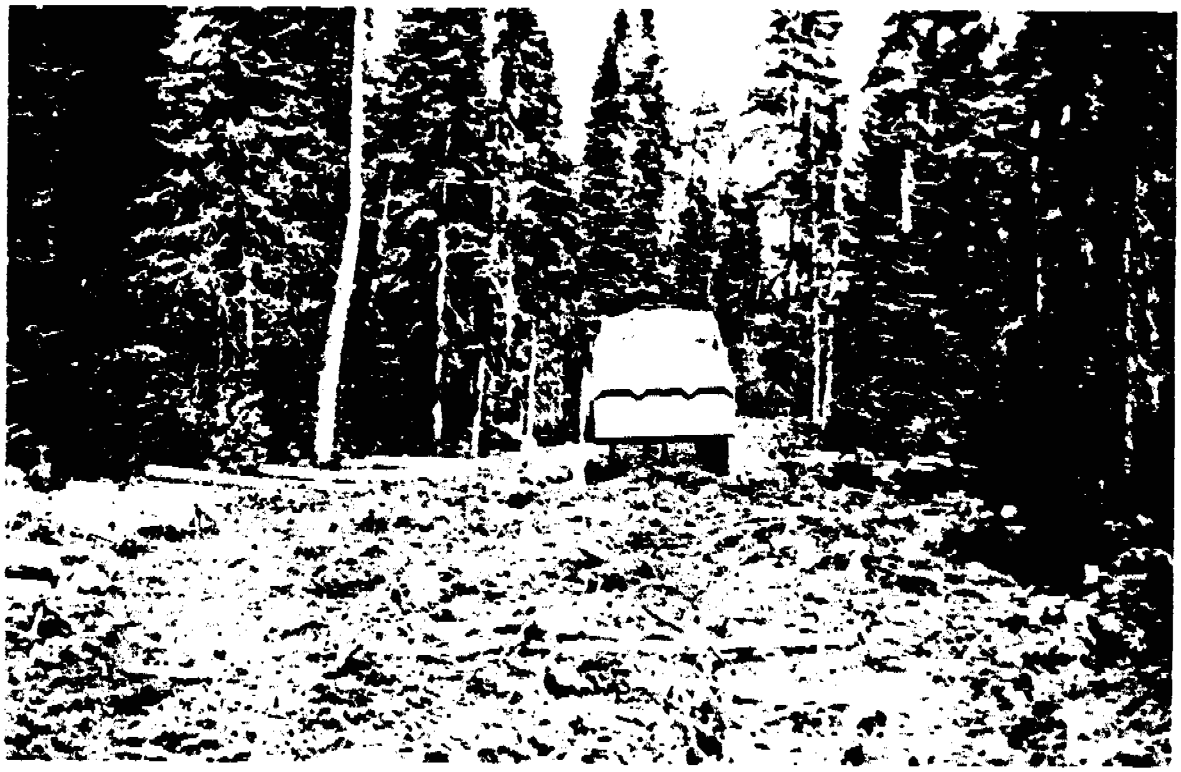
Fisheries Service requires bridges across spawning streams or streams servicing spawning areas; they have been known to shut down operations because of siltation. Roads are the biggest contributors to siltation because soil is totally exposed along roadways. Some corduroy is used, but generally over less than 2 percent of the road length. The road is shaped the winter before use.

Use of the road the following winter is no problem provided there is sufficient frost to freeze the road solid. Near Prince George, use normally begins in early November. As with most logging roads, loads up to 300,000 pounds (136,000 kilograms) on 5 axles are common. Speeds of 15 to 20 miles (24 to 32 kilometres) per hour are normal on the winter roads and 30 miles (48 kilometres) per hour on the main haul roads. Up to 4000 vehicle passes are typical.

Cost of winter road construction runs from $3,000 to $6,000 per mile ($2,000 to $4,000 per kilometre), the higher figure being associated with more timber clearing.

Maintenance consists mainly of snow clearing although some levelling with motor patrol is often required. As spring approaches, culverts are checked to ensure they are open, and steaming is carried out where required. Use of the roads normally ceases between March 15 to April 1.

Most problems with permanent trails become apparent early and are rectified in the first year of use. Erosion bars, small ditches across grade to facilitate drainage, are dug on trails that have been taken out of service. Vegetation on the right-of-way of temporary winter trails recovers naturally within 2 or 3 years. In northern British Columbia, seismic lines could not be detected after 30 years.



Granular material being used to fill holes on a right-of-way. The practice is typical in nonpermafrost areas.

Fraser River and Williston Lake Crossings

Two unique water crossings are used in British Columbia -- a low-water crossing of the Fraser River at Prince George and an ice crossing of Williston Lake. The low-water crossing, constructed each winter by Northwood Pulp and Paper Company, gives more direct winter hauling access to the mill. Piles are driven to refusal in two parallel rows on 10-foot (3-metre) centres, starting from shore. Re-useable deck modules 10 feet (3 metres) long are set on the piles, allowing the piledriver to move out onto the partially completed bridge. This procedure is repeated until the 400-foot (122-metre) wide river is spanned. After full winter use, the deck is removed before breakup and the piles are removed by ice floes. Annual cost of re-installing the bridge is about $20,000.

The ice crossing of Williston Lake is built annually by B.C. Forest Products of Mackenzie, B.C. Pre-constructed rafts 600 feet (183 metres) long and 70 to 80 feet (20 to 25 metres) wide (length of trees), stored along shore the previous spring, are towed into place by tugs each fall and tied together from shore to shore. A full length cable on each side secures the rafts to form a crossing 7,500 feet (2,300 metres) long. Timing is critical: if the rafts are placed too early, waves will break them up; if they are placed too late, thick ice will interfere with installation. After the lake freezes, water is pumped over the rafts, building up layer after layer of ice until the required thickness is attained. Gold's formula $P = Ah^2$, where "P" is the allowable load and "h" is the ice thickness, is used as the operating criterion. On this basis (but using higher "A" values than recommended by Gold) a 140,000-pound (63,400-kilogram) load requires 36 inches (92 centimetres) of ice; and a 200,000-pound (90,600-kilogram) load requires 42 inches (107 centimetres) of ice. Flooding is normally over a 100- to 120-foot (30- to 36-metre) width, but often extends 200 feet (60 metres). Pumps are moved back and forth along the right-of-way until the ice is built up to the required thickness. One complete 1-inch (2.5-centimetre) lift can be placed along the full length of the bridge in 8 hours by one large hydraulic pump. This must freeze solid before additional water is applied or water will remain sandwiched between two layers of ice resulting in a weak area in the bridge.

Snowfall is a potential problem during construction of the Williston Lake Crossing. It is important to either remove or compact the snow. Removal is not possible during the early stages of bridge construction because the ice is too thin. In this case the snow is wetted down, resulting in compaction and a low quality slush ice. Once the bridge is thick enough to carry a snow plough, snow is ploughed to the sides. The banks formed in this way retain water during flooding and help prevent drifting snow from covering the bridge.

The log mats provide a binder to reduce the occurrence of cracks. They also have a positive psychological effect on truck drivers. However, their contribution to the strength of the bridge is considered low relative to the overall strength of the ice.

Loads up to 100 tons (90 tonnes) and as many as 200 loads a day use the the crossing. The rear dual-axle loads are often 55 tons (50 tonnes) because of poor weight distribution caused by full-length logs. Some problems are caused by dropping water levels, Williston Lake being part of the forebay of Bennett Dam. However, the crossing is checked regularly for cracks and maintenance flooding is carried out if necessary. No breakthroughs on the crossing have occurred, but one driver lost in ice fog caused by flooding left the right-of-way and dropped his rear axles through the ice. The truck was towed back onto the right-of-way without further incident.

Vehicle speed is considered very important on the Williston Lake crossing. Vehicles travelling at less than 5 miles (8 kilometres) per hour can open fissures, presumably because the vehicle acts as a static load. Vehicles travelling too fast set up a hydrodynamic wave that causes a gap in the ice at the shore after the wave hits.

Hauling logs over a perennial winter trail in British Columbia. (Environment Canada)

ALBERTA

The Alberta Government Forest Land Use Branch defines winter roads as access roads not requiring any means of drainage and constructed during the winter season. This is in contrast to all-year access roads which must be properly ditched to provide adequate drainage. Winter roads are allowed a maximum right-of-way width of 40 feet (12 metres). In 1976-77, approximately 2000 miles (3200 kilometres) of winter roads were constructed to service oil and gas exploration in northern Alberta. Most of these roads have an average length of 5 miles (8 kilometres) and a maximum length of 15 to 20 miles (22 to 32 kilometres).

In 1961, the Alberta Government formed its Forest Land Use Branch. Today there are 11 district field offices scattered throughout the province which are responsible for the overall inspection of winter road construction. A company proposing to build a winter road should first apply to the district field office to ensure that the route selected satisfies local environmental conditions. Once the route has the approval of the local district office, the application is forwarded to the Edmonton head office for final approval.

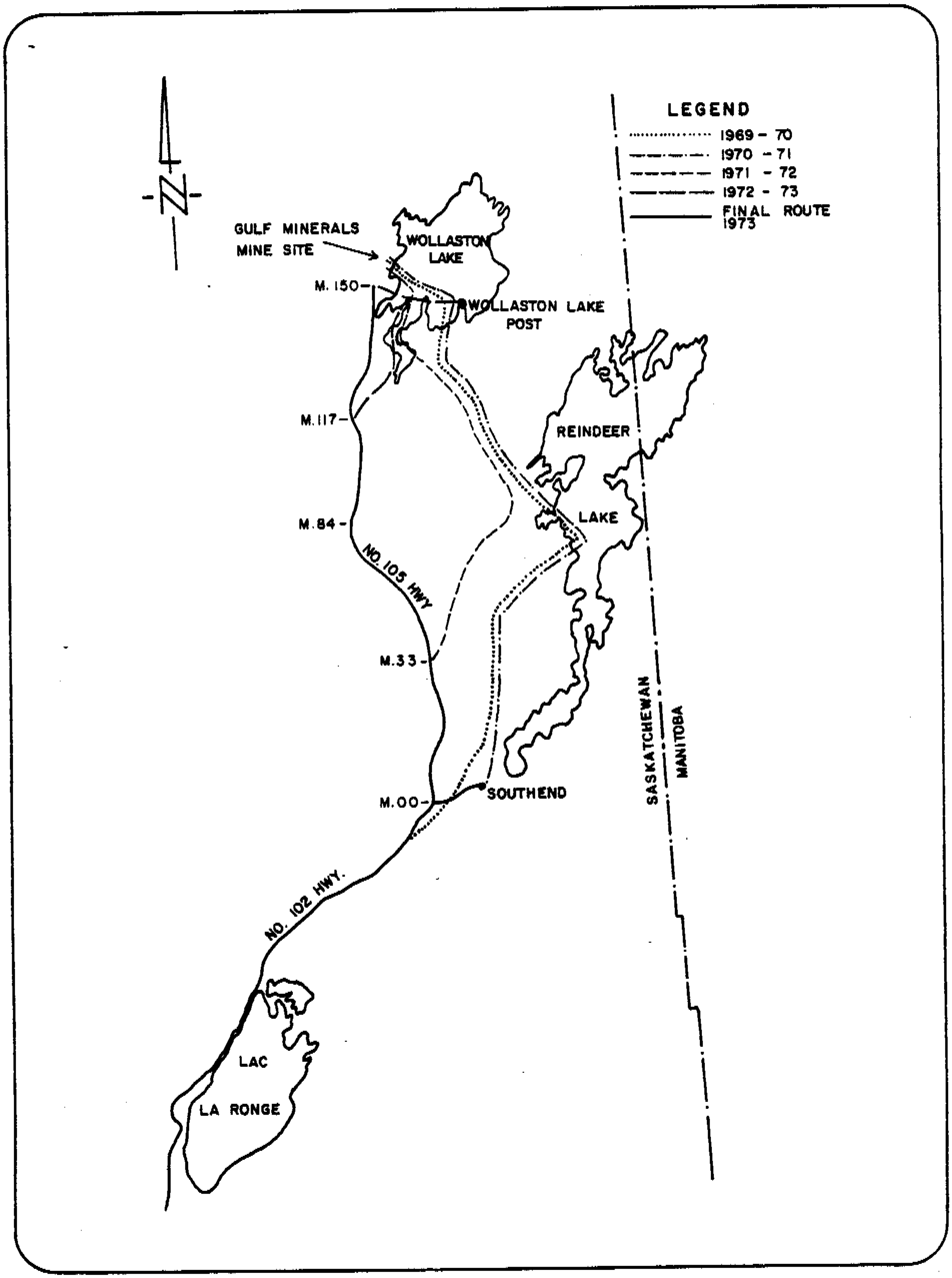
Construction of winter access roads is generally carried out with D7, D8, or D9 crawler tractors. These are used to clear the trails and also to compact the snow. Levelling is achieved by back-blading. In areas south of latitude 55°30', the Land Use Branch requires that all merchantable timber be salvaged. This does not apply north of latitude 55°30' unless salvaging is economically feasible. Approaches to streams may be cut to provide suitable grades provided material is not pushed into the stream. Timber can be used in ice-bridge construction although such bridges must be removed before break-up. Land Use does not object to the removal of the vegetative mat or to cuts and fills if these are necessary to achieve a suitable grade; however, once the road is no longer needed, such areas must be returned to their natural contours and revegetated. Trees windrowed during construction must be spread over the trail and crushed to aid decomposition. This is usually accomplished with large crawler tractors.

Start-up and closing dates are determined by the contractor, <u>not</u> the land use inspector. The land use inspector's main function is to prevent environmental damage and to ensure that adequate clean-up and restoration is carried out. If a contractor causes damage because he uses a road too early or too late in the season, he is the one who is held responsible. Once final restoration has been carried out to the satisfaction of the land use inspector, a Reclamation Certificate is issued relieving the contractor of further responsibility.

Seismic lines are restricted to a right-of-way width of 25 feet (8 metres). In environmentally critical areas, only portable helicopter equipment is permitted, with the right-of-way restricted to a maximum of 8 feet (2.4 metres).

To restrict the amount of new road construction, the Alberta Forest Land Use Branch requests that all existing access roads and cut lines be utilized wherever possible. To give industry a better understanding of their aims and guidelines, the Branch is publishing a book entitled "Guidelines for Land Use Operations". The booklet is intended to pictorially describe what is required of industry for access roads. It was scheduled to become available to the public in the fall of 1977.

Seismic lines in northern Alberta. (K.M. Adam)



Wollaston Lake Road.

SASKATCHEWAN

In recent years winter road activity in Saskatchewan has been on two main northern arteries -- the Wollaston Lake road and the Uranium City road. Both are referred to as development roads. The Wollaston Lake Road is operated by the Department of Highways. It has short off-shoot winter roads to service remote communities. The Uranium City road is operated by the Department of Northern Saskatchewan which also builds winter roads into other remote communities.

Wollaston Lake Road

The Wollaston Lake road was first built in 1969 to haul freight to a new uranium project on Wollaston Lake. It is now 230 miles (371 kilometres) long and crosses Precambrian terrain, although 173 miles (279 kilometres) of the road once crossed lake ice. As a result of continual work on this road between 1970-73, it was upgraded to a permanent overland route. This technique of upgrading a high-volume winter road into a low-class overland pioneer road is used to provide early benefits at the least possible cost (Tuer and McMillan 1974).

The sequence of development of the Wollaston Lake road is noteworthy because it shows how the winter road was gradually replaced by the permanent road. In 1969-70, the winter road began as an extension of Highway 102, starting just south and west of Southend. It proceeded northeast to Reindeer Lake, then northwest to Wollaston Lake. During the summer and fall of 1970, Highway 102 was extended to Southend; consequently, the following winter, the winter road began at Southend, following the same route as before from there to Wollaston Lake.

In 1971, a 150-mile (240-kilometre) pioneer (permanent) road was started at Mile 0.0 at the old junction of Highway 102 and the winter road. By fall, the pioneer road was completed to Mile 33 so that in 1971-72 it was only necessary to build a 140-mile (225-kilometre) winter road over a new right-of-way to a point near Reindeer Lake where it joined the old right-of-way to Wollaston Lake. The following autumn, Highway 105 had been extended to Mile 87. The winter road in 1973-73 followed the route of the permanent road to Mile 117, then turned northeast to utilize the frozen surface of Wollaston Lake. Near the end of 1973, Highway 105 had been completed to the mine site.

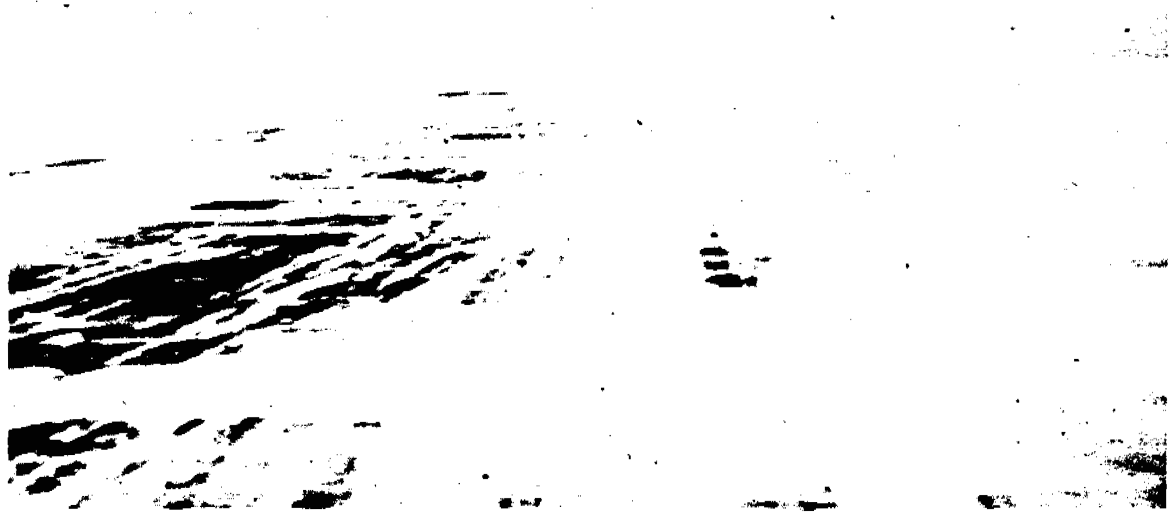
The following table shows the tonnage that was hauled annually on the winter road when the permanent road was being built. The total yearly winter road mileage and the length on lake ice are also given.

Winter road mileages and build-up of use during extension of a pioneer (permanent) road to Wollaston Lake, Saskatchewan.

	Pioneer Road	Winter Road		
Year	Miles	Total Miles	on Ice	Approximate Tons Hauled
1970	-	225	173	1200
1971	33	185	145	2900
1972	54	140	117	5500
1973	63	75	50	9200
TOTAL	150	625	485	18800

Notes: A detailed description of the preparation of the Wollaston Lake winter road is given by Tuer and McMillan (1974).
Multiply miles by 0.6 to calculate kilometres.
Multiply tons by 0.9 to calculate tonnes.

Each winter, men and equipment started preparation work as soon as freezing conditions would permit, usually around mid-December. Reconnaissance ice testing and location assessment were carried out by helicopter. Due to the tight schedule and the 5-axle truck haul requirement, the route was located on lake ice wherever possible. A standard Bombardier personnel carrier was used by the advance party in route selection, marking the right-of-way and testing the ice. Snow plows mounted on 2-axle, 19,000-pound (7,100-kilogram) G.V.W. trucks were the first plows out on the ice and could safely operate on 10 to 12 inches (25 to 30 centimetres) of good ice. Small D-4 crawler tractors were moved to the overland portages as soon as possible to prepare the overland section. Clearing generally extended over a 50-foot (15-metre) width. The overland sections, the most difficult sections to prepare, caused some delay when the muskeg had to be "frozen down" in order to support the larger equipment. A rubber-tired universal carrier was used to tramp and drag the muskeg to accelerate the required freezing-in process. This unit was also used in slush ice and on sections where the thickness was less than 10 inches



Wollaston Lake road showing the wide right-of-way maintained on ice. (J.D. McMillan)

(25 centimetres). A 10-inch (25-centimetre) I-beam drag was used to aid in developing ice thickness. As soon as the ice thickness had developed to about 20 inches (50 centimetres), larger truck plows and motor grader plows cleared a 100-foot (30-metre) width. Larger crawler dozers and I-beam drags were used to improve the overland portages. Spot blasting of rocks was also necessary for levelling the surface.

The main objective was to keep the head end moving as quickly as possible to allow snow removal and faster ice build-up.

During preparation of the ice road and initial hauling, a continuous ice testing program was carried out. Considerable testing was done when the ice thickness was in the 10- to 28-inch (25- to 72-centimetre) range. Test holes were drilled using 12-volt power augers. The 5-inch (12.7-centimetre) diameter cup-type augers could drill through 24 inches (61 centimetres) of ice in less than a minute. These augers operated satisfactorily on the electrical systems of skidoos, helicopters, trucks, etc.

Test results and dates were posted on small blackboards measuring 12 x 12 inches (30 x 30 centimetres) so that they could be read by the operators and truck drivers. This procedure helped to instill some confidence and avoid possible overloading of the specified allowable limits.

Equipment availability was very important on the tight schedule involved. Precautions were taken to combat the -50°F (-45°C) and colder temperatures. Arctic lubricants were used and found very successful.

Little maintenance was required on the winter road. A small crew was stationed on site to patrol the road, handle minor snow removal, and drag the overland portages. Construction maintenance costs were $1000 per mile ($625 per kilometre) for the overland winter roads and $420 per mile ($260 per kilometre) for the winter roads on ice.

Traffic on the Wollaston Lake road has been estimated to be 90 percent semi-trailers and 10 percent cars and trucks. Speeds are limited to 25 miles (40 kilometres) per hour on ice and 30 miles (48 kilometres) per hour on land. Grades over 8 percent are avoided in design, and sanding has been necessary on grades from 5 to 8 percent.

Since completion of the Wollaston Lake permanent road, only 130 miles (210 kilometres) of winter roads have been built from it. Of these, 27 miles (43 kilometres) serve the community of Wollaston Lake on the opposite side of the lake and 3 miles (5 kilometres) run across a bay of Reindeer Lake to the community of Southend. The remaining miles give winter access to Key Lake.

Uranium City Road

The Uranium City winter road is still constructed annually, although it was initially planned so that it could be upgraded to a permanent road. It runs north for 288 miles (464 kilometres) from Turnor Lake mainly overland to the Eldorado mine site at Uranium City. A winter road on ice is required over the most northerly section across Lake Athabasca (see the map on page 126).

Planning of the Uranium City winter road was influenced by the possibility of upgrading. The road was routed to follow high ground near borrow areas in contrast to most winter roads which follow low ground with muskeg and lakes. Horizontal and vertical alignment were considered in choosing the route, grades as large as 10 percent being acceptable for an all-weather road provided straight, horizontal, alignment was available. The centre-line was located on air photos.

In the field in the first year, clearing was conducted after freeze-up so that trees broke off at ground level. Merchantable timber within an economic haul distance was salvaged and slash was windrowed at least 15 feet (5 metres) from standing timber. Although it was known that less erosion would be experienced if the surface layer was maintained, some cutting and filling was done. Culverts were also installed along the road. River crossings were chosen with a view to velocity of flow, ease of fording, and suitability as permanent crossings.

Each year, construction of the road begins during freeze-up when bogs are dragged and compacted to speed freezing. After freeze-up, the surface is dragged either with steel drags or with large-diameter rubber tire drags. Right-of-way width varies but is generally 40 to 50 feet (12 to 15 metres).

Across Lake Athabasca, the winter road on ice is constructed in a similiar manner as the Wollaston Lake road. As soon as 20 inches (50 centimetres) of ice have formed on the lake, motor graders move onto the surface to clear snow from a 100-foot (30-metre) wide right-of-way. If ice is slow in forming, lighter vehicles are used to clear snow. Regardless of the vehicle used, the snow clearing should be done in short sections that can be completed in one day so that snow windrows are not left on the 100-foot (30-metre) wide right-of-way. Such static loads can induce cracks; in

Uranium City road. This section of the perennial road lies in sandy silts. (Department of Northern Saskatchewan) fact, longitudinal cracks are often observed near the edges of the completed right-of-way. This is why the right-of-way is so wide. The measure also helps prevent snow drifts, although severe snow drifting has necessitated alignment changes and new road preparation.

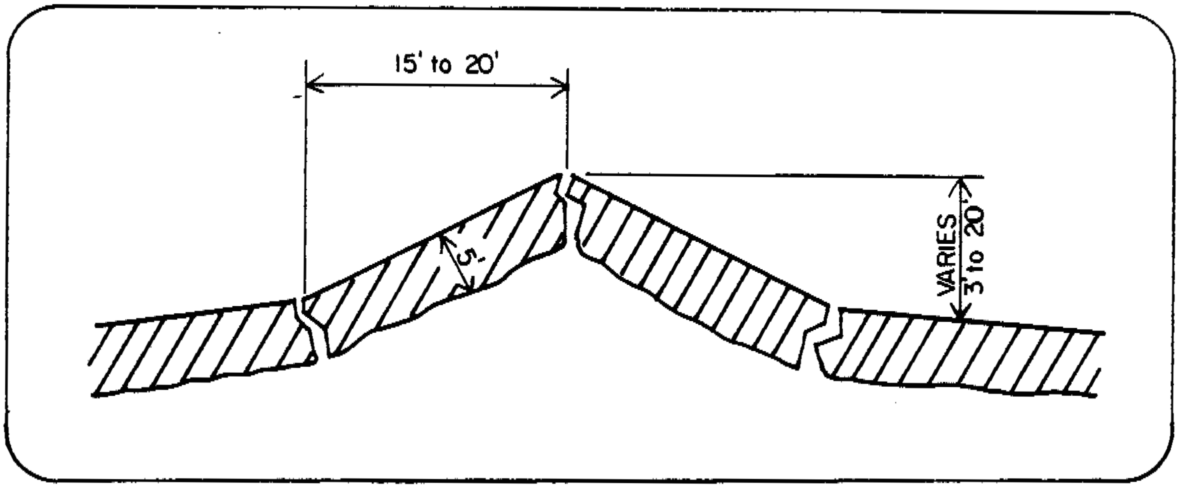
Traffic is concentrated on the road from February 1 to 28, although the road is usually open until about March 15 to April 1. Light traffic goes first, then loaded vehicles after a week to 10 days. Maintenance is only carried out during the high-use period. It has been experienced that the less time the road is open the fewer the problems, although there is often local, political, and social pressure to get the road open early and keep it open longer.

Operation of the road involves marking the alignment on lakes with reflectors spaced at 1500-foot (460-metre) intervals. Continuous checking of ice thickness at 5-mile (8.5-kilometre) intervals on Lake Athabasca and 1-mile (1.6-kilometre) intervals on small lakes is required. Ice thickness and date tested are posted at the test locations to give assurance to users.

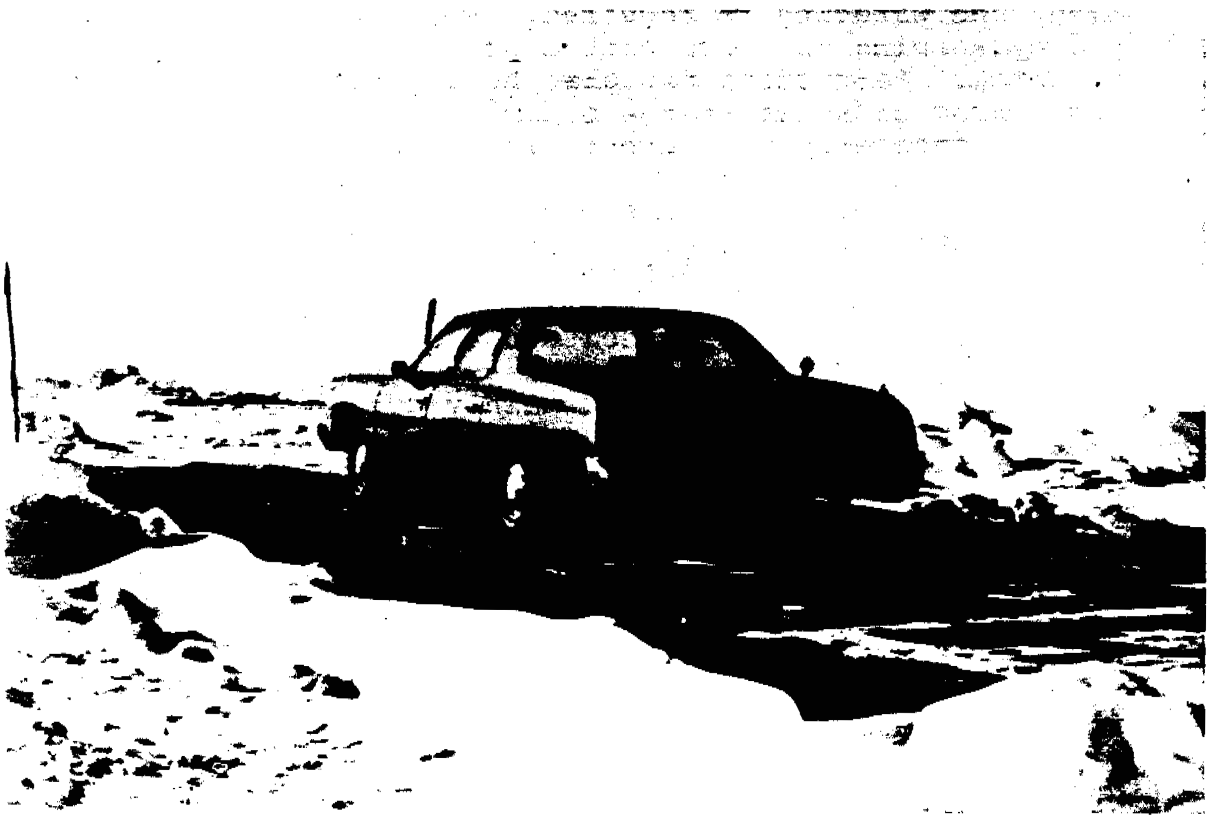
Maintenance mainly entails snow clearing, but some dragging and watering is required. Requirements can be gauged by keeping in touch with truckers or by use of a pilot truck. Re-routing can also be used if severe drifting occurs. Erosion holes at the outlets of culverts are filled soon after freeze-up when access is first available.

Detailed costs have been kept for the Uranium City permanent winter road. Total average cost to put the road in service annually is \$1000 per mile (\$620 per kilometre). The cost is split almost fifty-fifty between construction and maintenance. The Athabasca crossing on ice costs \$1500 per mile (\$935 per kilometre); the additional \$500 over the cost of the overland section is mainly due to the need for more personnel, testing, and servicing, and to cover the cost of transporting equipment to the north end from the south where it is left every spring. On this particular road there is no advantage in starting at the north end and building south because the Lake Athabasca crossing is normally the last section to be completed.

Traffic on the road is not heavy. In 1976, 400 vehicles travelled the road with 600 expected in 1977. Traffic is generally one-third cars and two-thirds trucks. Cars generally average 30 to 35 miles per hour (50 to 60 kilometres per hour) and trucks average 25 miles per hour (40 kilometres per hour).



Sketch of a pressure ridge.



Timber bridge over a pressure ridge on the Wollaston Lake road. (Department of Northern Saskatchewan)

Drivers are advised to reduce speed on the road on ice when meeting vehicles or approaching shore, because of the wave generated beneath the ice. Other damage is caused by extremely cold temperatures or large drops in temperature that cause dangerous cracks to form. Cracks often fill with water and freeze; then, when temperature rises, the ice expands, heaving upward to form pressure ridges. Pressure ridges are an annual hazard on both Lake Athabasca and Wollaston Lake. Special crossings are required to build safe roads across them.

Use of heavy equipment should be avoided near a pressure ridge. Since pressure ridges can project several feet above the ice surface, considerable quantities of ice must be removed to put a crossing through. Such a crossing should be perpendicular to the pressure ridge. Timber laid longitudinally across the crack will provide an initial crossing for vehicles. A solid wood deck is often used over pressure ridge cracks. Corrugated metal has been tried but it is not recommended because it gets bent out of shape easily.

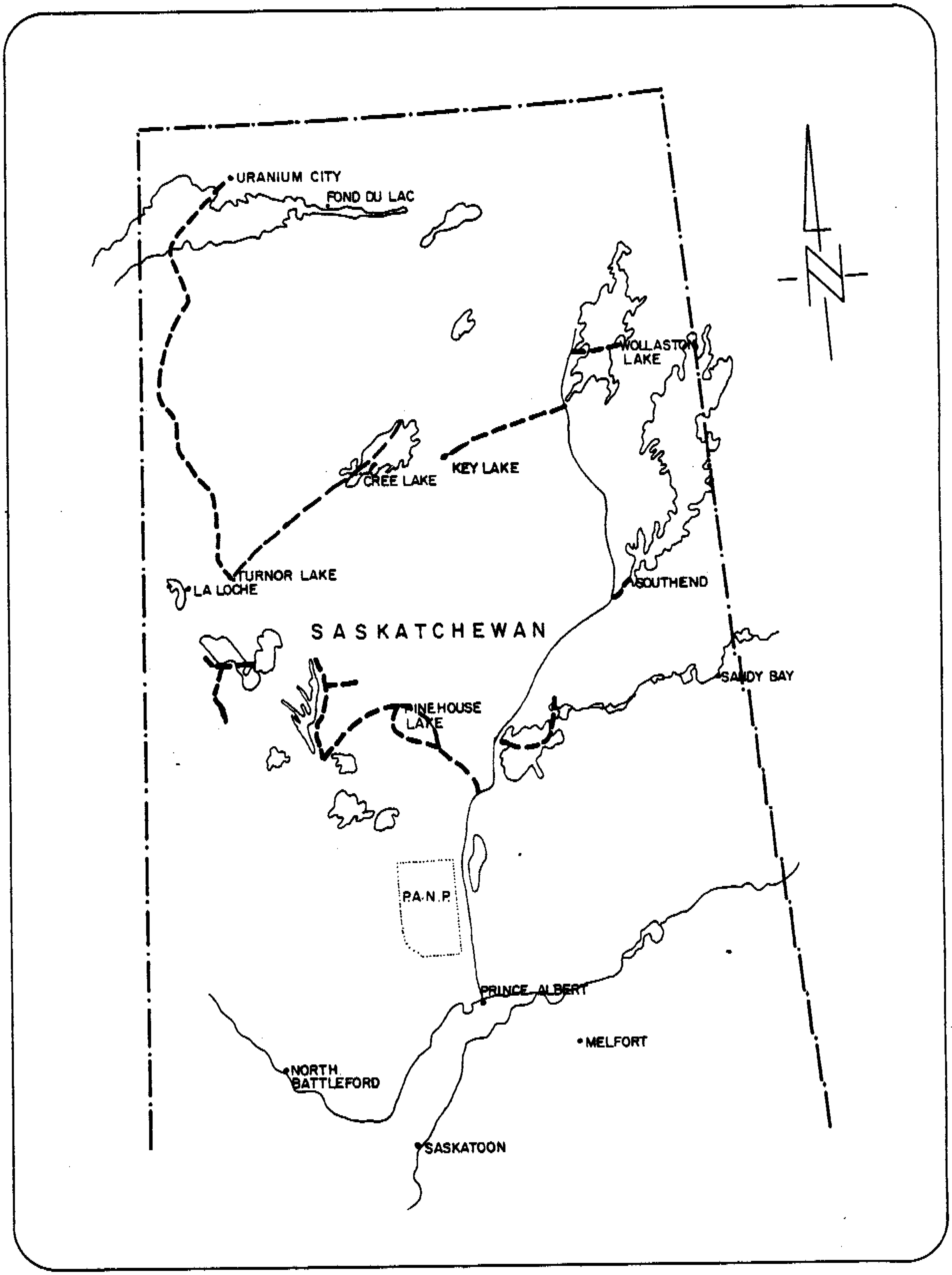
Other Saskatchewan Winter Roads

In addition to the Uranium City road, the Department of Northern Saskatchewan annually constructs several other shorter winter roads. The most southerly one is overland east from Cumberland House to near the Manitoba border, then north to Sturgeon Landing. Another road, mainly on lake ice, goes from La Ronge to Stanley Mission. In the west-central part of Saskatchewan, three main winter roads are constructed annually. One small network connects Beauval-Pinehouse Lake-Highway 2, another connects Ile A La Crosse-Patuanak-Knee lake, and another Buffalo Narrows-Dillon-Michel. Dillon is also connected by winter road to Canoe Narrows and Cree Lake can be reached via the Turnor Lake winter road.

About 60 percent of these winter roads are perennial overland trails, with about 40 percent of their length on ice. Rivers are used as an ice surface, but lake inlets and outlets are avoided.

Construction methods, maintenance and costs of these roads are similar to those previously discussed.

Other work of interest in Saskatchewan is the research conducted by the Saskatchewan Research Council (Eyre and Hesterman 1976) on a deep water crossing. They instrumented a public ice crossing of Lake Diefenbaker; recorded meteorological conditions, ice features, shore

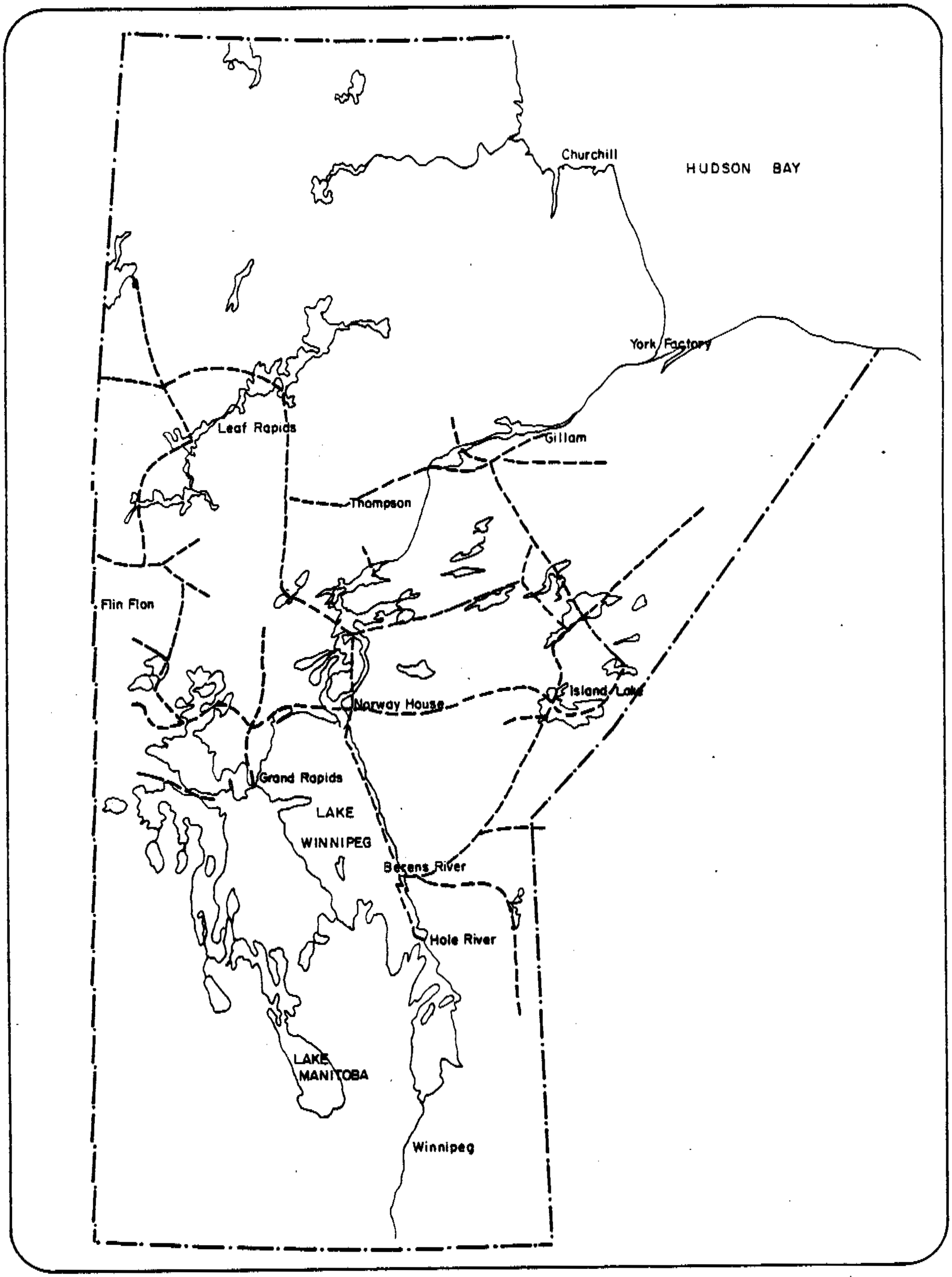


Winter roads in Saskatchewan.

effects, and operational and safety aspects; conducted static and dynamic loading tests; and compared the results of their tests to theory. Many of their findings are not transferable to other crossings, particularly shallow ones. However, a few of their more general findings are noteworthy for deep water crossings.

For instance, they found that high winds can easily damage ice during its early stages of formation by producing fractures, cracks, and ridges that render the ice temporarily unsafe for vehicles. They found also that at the critical velocity, there is no tendency for the vehicle to generate waves of dangerously large amplitude as predicted by some theories, although near the shore, the vehicle may produce potentially dangerous wave reflections, an effect that was not investigated. The ice wave and water wave generated by a moving vehicle were found to have the same speed as the vehicle (for all vehicle speeds and vehicle masses). They found that the rate of ice fracture varies with vehicle speed but shows a maximum at 84 percent of critical speed (defined as the peak fracture speed). In other words, the maximum ice deflection that occurs at the critical speed is not sufficiently large to cause a dangerous situation for vehicles travelling on ice; the greatest danger is more likely to occur at 84 percent of critical speed, where damage to the ice is maximum.

Studies of two approaching vehicles did not show any tendency for waves generated to interact strongly enough to be dangerous. However, this phenomenon was not studied for shallow water.



Manitoba winter roads network, 1969.

MANITOBA

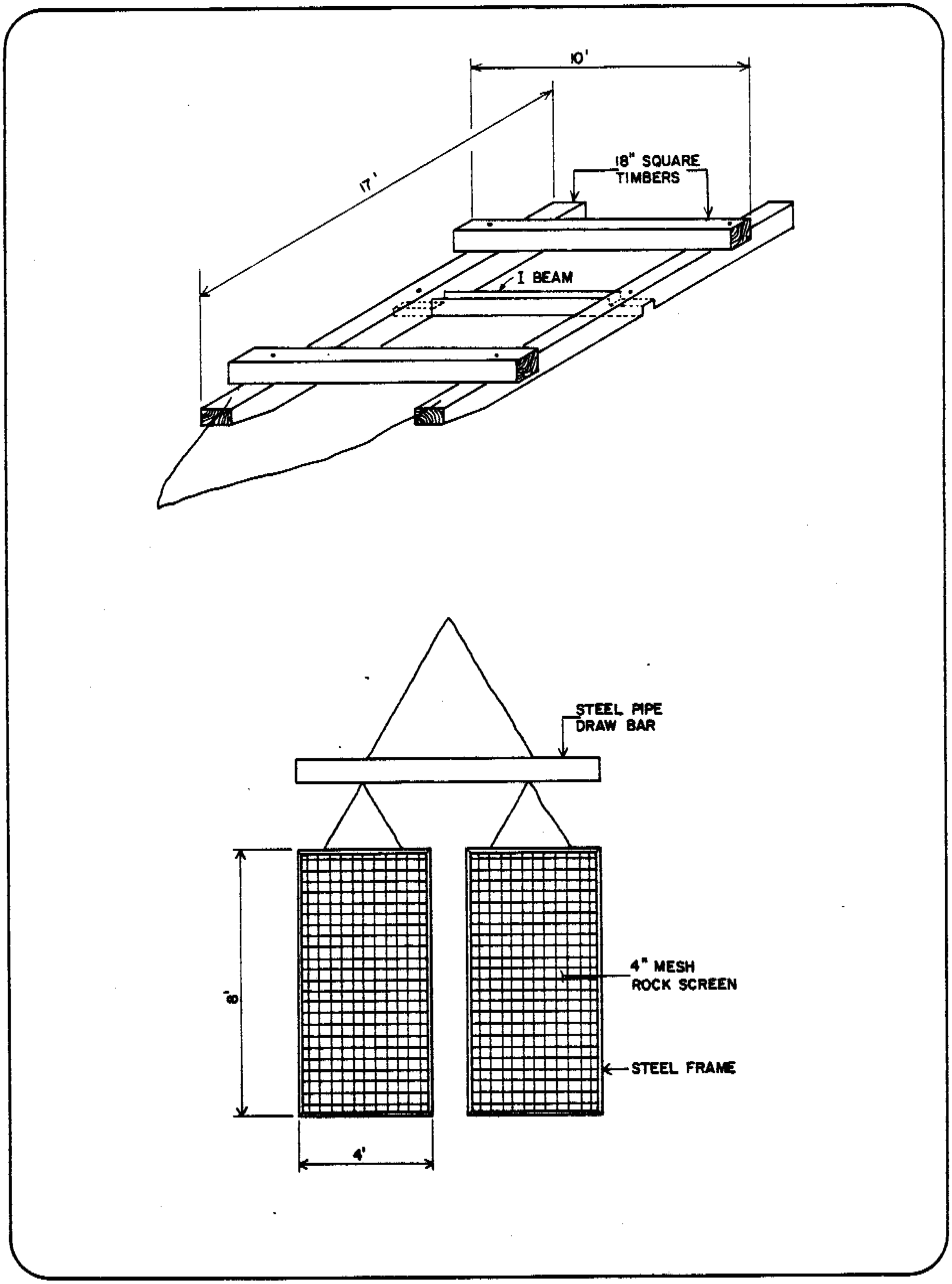
In 1969, the Manitoba winter roads network was over 2500 miles (4000 kilometres) long. Many of the roads were little more than rough trails used by tractor trains. Travel over lake ice was common.

Since then, the total mileage of winter roads in the province has dropped considerably. Some roads have been replaced by permanent all-weather roads, some have been displaced by the use of aircraft, and some have been abandoned. Tractor trains are no longer in use; truck traffic on winter roads is now preferred. The present system of roads is over 1000 miles (1600 kilometres) long. Most of the roads are overland.

Most winter roads in Manitoba are under the jurisdiction of the Department of Northern Affairs. It has been the practice of the Department to choose winter road routings which will be adaptable to permanent road access at a later date. These routings, which may be rough in the first year, are refined in later years toward a permanent road alignment. Cuts, fills, and rock removal may be involved, increasing the cost of winter road construction but decreasing the cost of later permanent road construction. Roads are cleared to 60 feet (18 metres) for a 40-foot (12-metre) wide top-of-road.

On the Hole River-Island Lake road, two weeks of hard frost before snowfall usually provide for good startup conditions. Startup of winter road construction is determined by Department inspectors who travel the route by snowmobile measuring frost penetration. If the depth of frost is insufficient, deeper penetration is achieved by compacting the snow with soft-tracked vehicles. Water is brought to the surface in swampy areas by passage of these machines causing peat and grasses to become saturated and later freeze hard in a smooth, level surface. After compaction the road is graded and dragged to prepare it for traffic.

Maintenance is carried out by motor graders that push most new fallen snow off the road leaving some in place on the road to be compacted by a Nodwell low-ground-pressure vehicle and drag. Two types of drags are used: one is a conventional drag consisting of an I-beam mounted in a log frame and the other is a screen drag consisting of two pieces of rock screen measuring 4 feet x 8 feet (1.2 metres x 2.4 metres) attached to a draw-bar. The snow pack is normally built up to 12 inches (0.3 metres) by continuous maintenance.



Drags commonly used to maintain winter roads in Manitoba.

Construction of the Hole River-Island Lake road usually starts about November 15 and the road is open for traffic about January 15. Travel time from Hole River to Island Lake, a distance of 270 miles, is 13 to 14 hours.

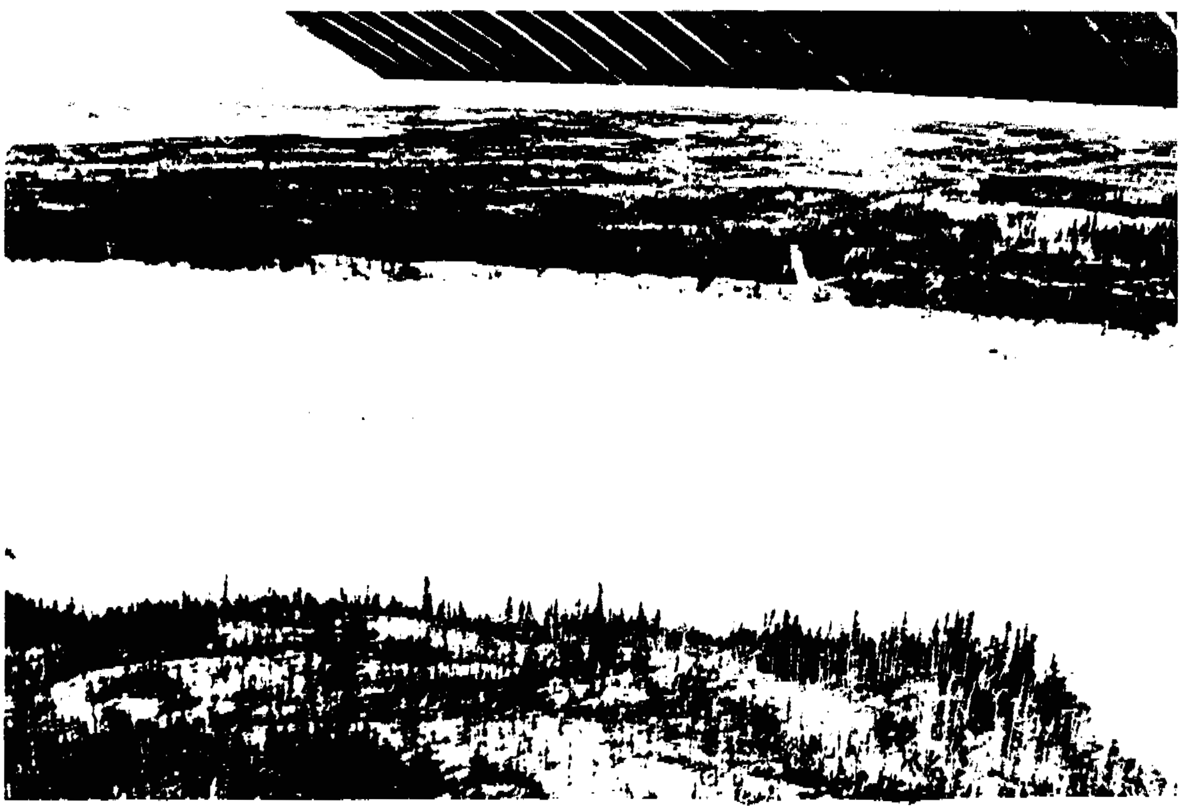
River and stream crossings may be built by various methods. Culverts and fill are used in small streams that flow all winter. Corduroy, cabled together and anchored to the shore for spring removal, is frozen in place by flooding to form a bridge at larger streams. Large rivers are ice-bridged, preferably at a rapids, with logs laid longitudinally on the ice surface and frozen in place by flooding. Ice can be built up at a rate of 1 inch (2.5 centimetres) per day on bridges. Snow, ice, or fill are used to construct approaches to river and stream crossings.

Roads on lake ice are cleared to 200-foot (60-metre) widths. During construction, 11 inches (35 centimetres) of ice will support a load of 10,000 pounds (4,520 kilograms). Later, when the roads are open to traffic, the 25 inches (65 centimetres) of ice will support a load of 80,000 pounds (36,000 kilograms). Cracks in the lake ice, which usually develop in the same place every year, are ice-bridged. The speed limit on lakes for loaded trucks is 8 to 12 miles per hour (13 to 19 kilometres per hour) and trucks must travel at least 1000 yards (1000 metres) apart.

Hole River road, a key winter road in Manitoba linking Winnipeg with northern communities. (K.M. Adam)

On land, a layer of packed snow up to 12 inches (30 centimetres) deep is built up on the road in a normal snowfall year. In the first year of construction, traffic can usually travel at 10 miles (16 kilometres) per hour and in subsequent years, up to 35 miles (56 kilometres) per hour. First year construction costs for a road are about $2400 per mile ($1500 per kilometre) including clearing. In subsequent years, construction costs are $600 to $1400 per mile ($370 to $870 per kilometre) depending on the amount of upgrading and re-alignment. Maintenance costs are $50 per mile ($30 per kilometre) per week.

The Hole River-Island Lake road is normally closed about March 15. Fast-flowing rivers and streams that flood crossings are usually the cause. More northerly roads have a longer operating season and are often closed by melting out of the road surface on the sunward side of hills and riverbanks.



Ice bridge across the Churchill River south of Granville Lake. (Manitoba Hydro)

Ice bridge across the Nelson River at Bladder Rapids showing corduroy just before breakup. (Manitoba Hydro)

ONTARIO

Winter roads in Ontario, used primarily by the pulp and paper industry, are distributed throughout the commercial timber regions. Their use for access to isolated northern communities is now very limited. Many winter roads have been replaced by all-weather roads or air service.

The following winter roads used by a few companies in the pulp and paper industry of Ontario are typical of the winter roads currently used in that province.

Winter Roads for Reed Ltd.

Timber harvest operations of Reed Ltd. are dispersed from Kenora to Nipigon Lake and north to Red Lake. The company builds about 30 miles (48 kilometres) of winter roads annually to serve as tributaries from their cutting spreads to all-weather roads.

Tentative routes are first selected from air photos, then flagged by a two-man ground crew that makes any necessary revisions as it goes along. Where possible, winter roads are located along alder swails, shallow muskegs, and swamps skirting the merchantable timber stands. This practice is considered to be more expeditious and thus more economical than one where winter road rights-of-way are incorporated simultaneously into the normal cutting operation.

Precompaction of swamp areas is often required to aid frost penetration. This is accomplished using a light tracked vehicle such as the Bombardier J-5 to tramp the snow and brush cover. In average fall freeze-up conditions, access to all areas by D-7 crawler tractor is usually possible by December 15. At this stage, frost penetration in large areas is about one foot (one-third of a metre).

A D-7 tractor is used to establish a 24-foot (8-metre) wide right-of-way by shearing the trees and shrubs at ground level and blading the snow and debris to the sides. In swamp areas, where precompaction is necessary, the mat of tramped brush and snow is left intact. Makeshift drags, made of large-diameter timbers cabled together to form a kind of raft or ballasted large-diameter tires, are used to level the driving surface. Root hollows and other depressions are filled in with snow by the dragging procedure which is performed continually during road use. These roads are subjected to a variety of truck traffic including tandems, tandems plus pups, and 5-axle vehicles loaded to a gross weight of 50 tons (45 tonnes). Average speeds of 10 to 15 miles per hour (16 to 24 kilometres per hour) are maintained over these roads. Winter roads of this standard, not including the precompaction or dragging, can be constructed at a rate of 1 mile (1.6 kilometre) per day per D-7. By March 15, the roads are no longer serviceable, the overland stretches becoming impassable first.

Shallow streams are crossed by filling the channel with snow. When the channel is deeper than about 2 feet (half a metre), timber is first laid in the stream bed and then topped with snow and ice. The timber is bound together into bundles with steel cable to facilitate removal during spring break-up. Ice bridges are not constructed over major streams and rivers.

In the construction of ice landings, which are used for storing pulp wood, a natural ice build-up of about 10 to 12 inches (25 to 30 centimetres) is required before flooding is undertaken. Using 4- or 6-inch (10- or 14-centimetre) pumps, the flooding is performed in stages, with the addition of about 1 to 2 inches (2.5 to 5 centimetres) of ice per flood until the ice is about 3 feet (1 metre) thick. The ice landing is kept clear of snow during and after flooding. On these ice landings, cord wood is stacked about 6 to 8 feet (2 metres) high delivering a static pressure of about 10 to 15 pounds per square inch (70 to 105 kilopascals).

Winter Roads for Spruce Falls Power and Paper

Two standards of winter road are used by Spruce Falls Power and Paper -- a two-lane high standard road and a secondary one-lane access road. The haul lanes of the two-lane roads are capped with 4 inches (10 centimetres) of ice. The return lanes and the one-lane roads are formed by dragging the ground surface smooth, and filling in the holes and depressions with packed snow or granular material. Some 500 miles (800 kilometres) of two-lane roads and 100 miles (160 kilometres) of one-lane roads are built annually.

The woodlands operations of the company are distributed over 63,000 square miles (163,000 square kilometres). Val Cote and Missanabie mark the western limit, Fauquier and Groundhog River the eastern limit, Peterbell the southern limit, and Smokey Falls the northern limit. Of the total area, about 75 percent is swamp and 25 percent varved clays overlain by a thin organic mat. Very little granular material is available in this area.

Winter road routes are largely determined by established company cutting practices. When possible, the roads are located to intersect plots of merchantable timber, thus allowing right-of-way clearing to be incorporated into the normal cutting patterns. Terrain type is a secondary

Flooding the haul lane of an ice road used for transporting logs.

Graders are often used to maintain trails and ice roads.

consideration in winter road location. From tentative routes located on air photos, survey crews stake out the alignment in the field. A profile of the transit lines is obtained and swamps are probed. Minor changes in alignment are made at this stage if necessary. Maximum gradients are held below 5 percent and curvatures less than 3 degrees.

Timber is harvested along the alignment in a swath 500 feet (150 metres) wide. A 50-foot (15-metre) right-of-way is then "stumped" with a D-7 size tractor equipped with a shear blade. In subsequent years, this 50-foot (15-metre) right-of-way is precompacted in early winter to aid frost penetration. As freezing progresses, a bombardier pulling an I-beam drag is used to smooth the road surface. Dragging and tramping continues until the road is scraped down to bare ground and the dips and hollows have been filled with snow and dirt mixtures. The final smoothing of the driving surface -- 18 feet (5.5 metres) wide for the one-lane road and 36 feet (11 metres) wide for the two-lane road -- is done by motor grader.

Flooding of the haul lanes is performed in stages. Tandem trucks equipped with 2000-gallon (9000-litre) tanks deliver the water and apply it while in motion without the use of spray bars. To remove all irregularities, the flooded area is then dragged with a steel-rail drag towed by a four-wheel-drive skidder. The flooding-dragging operation is performed in 3-mile (5-kilometre) sections, utilizing four tankers per section. When a continuous 1-inch (2.54-centimetre) layer of ice has been built up, the operation is moved on to the next 3 miles (5 kilometres). The cycle is repeated until a 4-inch (10-centimetre) layer of ice has been built up over the entire length of the road. In an average year, the flooding is completed and the roads are open by January 1.

Maintenance of the uncapped lanes consists of continuous dragging and levelling with motor graders. On the ice roads, maintenance involves patching cracks and periodically roughening the ice with specially designed grader-mounted scarifiers. The patching is done with either sand and water or snow and water, depending on the availability of the sand. The snow and water method is slow, usually requiring a temporary suspension of traffic; however, the advantage of using a snow-water mixture is that reflection from the road surface is not reduced.

Ice bridges are used as crossings for major streams, construction being initiated as early as possible after freeze-up. When the natural ice cover at the proposed bridge site reaches approximately 2 inches (5 centimetres), which is sufficient to hold a man, two barriers of snow saturated with water are built up marking the outer edges of the bridge. The barriers serve to contain the water during the flooding operation. Water is brought to the surface with auger-type pumps through holes in the ice located within the barriers. The snow cover inside the barriers is not removed but usually tramped down before flooding. Ice is accumulated by repeated flooding; each application of water is allowed to freeze completely before the next is added. A total thickness of 50 inches (130 centimetres) is considered necessary to carry 100-ton (90-tonne) gross loads with safety. By January 1, ice bridges are generally open to traffic.

The following ice thickness guide is used by Spruce Falls Power and Paper. Thicknesses quoted apply to clear blue ice on lakes. The bearing capacities are reduced by about 15 percent for clear blue river ice and by about 50 percent for slush ice.

Permissible Loads for Clear Blue Lake Ice.

Permissible Load	Ice Thickness (inches)
one person on foot	2
group in single file	3
passenger car (2 ton gross)	7 1/2
light truck (2 1/2 ton gross)	8
medium truck (3 1/2 ton gross)	10
heavy truck (7-8 ton gross)	12
10 tons	15
25 tons	20
45 tons	25
70 tons	30
110 tons	36

Note: Multiply inches by 2.54 to calculate centimetres. Multiply tons by 0.907 to calculate tonnes.

Maintenance of ice bridges involves checking ice thicknesses at least once a week and flood-patching cracks. A break is usually maintained between the bridge and approach sections to permit the bridge to rise and fall freely with water-level fluctuations. As an added precaution, the haul lanes and return lanes are interchanged periodically to avoid the possibility of ice fatigue. The maximum speed allowed on the ice bridges is 10 miles per hour (16 kilometres per hour). The cost (1977) of constructing a bridge 200 feet (60 metres) wide is in the order of $5000 per 500 feet (150 metres) of bridge length. During the spring thaw, all ice bridges are destroyed by dynamiting.

The bridge approaches are constructed by grading the stream banks and pushing the cut material uphill away from the stream channel. Gradients are kept below 6 percent on all approaches. To ensure adequate traction, the approaches are generally heavily sanded.

During operation, the network of ice roads and ice bridges is subjected to 100-ton (90-tonne) gross loads carried on 4 and 5 axles. The intensity of this traffic often reaches 100 loads per day. Haul at this rate is continued until a predetermined timber quota is reached after which the roads are no longer used. The roads themselves become impassable usually around mid-March.

Winter Roads for Abitibi Paper Co. Ltd.

The Abitibi forest harvest operations extend from Marathon to the Quebec boundary. Some 200 miles (320 kilometres) of winter roads are constructed annually to provide access for the timber extraction.

Where possible, winter roads are located through stands of merchantable timber. On high ground, the right-of-way may be cleared and stumped during the summer. In swampy areas, compaction of the snow and brush (in early winter) is necessary to promote frost penetration and to ensure early completion of the road network. Light-tracked vehicles or wheeled skidders towing drags provide the compaction and preliminary levelling of the roadways.

When frost penetration reaches about 6 inches (15 centimetres), D-7 tractors equipped with wide tracks and standard blades further compact and trim the road bed. Tied together by steel cable, the D-7's work in pairs about 100 feet (30 metres) apart.

The machines assist one another when either machine breaks through the thin frozen crust. In this manner, passes are made every two or three days until a single machine can walk the length of the road without bogging down.

After thorough back-blading and dragging by the single D-7's, motor graders do a final levelling and smoothing-out of the driving surface. On the average for construction, each mile (one and a half kilometres) requires about 55 hours of D-7 time.

Makeshift bridges are generally used to span small streams. These bridges, typically 15 to 20 feet (5 to 6 metres) long, consist of timber stringers extending across the stream, supported at each end by timber shoring. Earth fill approaches are used in conjunction with these bridges. The smaller streams are bridged by blading the bank material directly into the stream channel. Removal of these earth fill dams before spring breakup is considered unnecessary. Major streams and rivers are crossed by permanent timber pile bridges.

Under average conditions, a winter road network can be completed by the end of December. Typically, between forty to eighty 50-ton (45-tonne) loads are trucked over these roads per day at speeds of 10 to 15 miles per hour (16 to 24 kilometres per hour). Maintenance of these roads consists of levelling the rough spots as they develop with motor grader. The end of the winter road season can be expected before March 15.

Winter Roads for Kimberley-Clark of Canada Ltd.

Approximately 200 miles (320 kilometres) of winter road are constructed annually throughout the area ranging from Longlac to Geraldton and extending southward to Terrace Bay. Of the total area, 70 percent is mineral terrain and 30 percent organic terrain or muskeg. The winter roads which are used exclusively for timber haul are located directly through the timber stands.

The initial right-of-way (30 feet or 9 metres wide) is hand cleared and the merchantable wood is salvaged. On mineral soils, the stumps are sheared off at ground level by D-7 crawler and the debris is bladed to the sides. During this "stumping" operation, the vegetation mat is usually completely removed exposing the mineral soils. In organic terrain, the right-of-way is tramped with D-7 tractors punching the stumps into the organic mantle. When frost penetration is less than 1 foot (one-third of a metre), wheeled skidders are used to tramp the vegetation. A day or two later heavy timber drags fixed with steel-rail screens are towed over the roadway. Small mounds are sheared off during this process and small depressions filled in. More serious levelling is done by blading with a D-7 tractor. Dragging of the roadway is performed on a continual basis for the duration of road use.

Crossing of lakes is accomplished by means of un-reinforced ice roads. These are constructed, to 100-foot (30-metre) widths by ice build-up through flooding. Flooding starts as soon as the natural ice cover can support a man. It continues in stages with the addition of about 1 inch (2.54 centimetres) at a time up to a total thickness of 20 to 30 inches (50 to 75 centimetres). Each layer of water is allowed to freeze completely before the next layer is applied. The ice roads, usually completed by late December, support 45-ton (40-tonne) tandem and semitrailer truck traffic. Speeds are restricted to 10 miles per hour (16 kilometres per hour) or less. Snow removal and flood-patching of cracks constitute the only maintenance. Full-time inspection of the lake ice roads is not provided.

Bridges are constructed over small streams by laying logs longitudinally and transversely in layers across the stream channel. The bridge is then topped with brush and snow and watered down. These bridges are removed before spring breakup. Major streams are spanned by permanent bridges.

The winter road haul season usually ends by March 31. The closing date is determined by the loss of traction on southern exposures.

Winter Roads for M.J. Labelle Co. Ltd.

Winter roads which provide access to isolated communities are built annually from Cochrane to Moosonee and north along the west coast of James Bay to Attawapiskat. Of the total 500 miles (800 kilometres) of winter roads that are built, between 100 and 250 miles (160 and 400 kilometres) are constructed each year by M.J. Labelle Co. Ltd. Some 20 percent of the terrain crossed is high land or mineral terrain and 80 percent is organic terrain or swamp and muskeg. Except for the region immediately south of Attawapiskat, the entire length of road is south of the discontinuous permafrost zone.

Winter road routes are selected from air photos, then roughly flagged-out in the field. Natural openings and seismic lines or previously established rights-of-way are followed as much as possible. When frost conditions permit, light, tracked vehicles or low-ground-pressure wheeled vehicles tramp the swamps to promote frost penetration. When the ground has frozen firmly enough, D-6 and D-7 tractors clear the right-of-way of trees and shrubs. By "backblading" and dragging with heavy timber drags, the preliminary road surface, 25 feet (8 metres) wide, is established. The final levelling and smoothing of the road surface is done with motor grader. In mineral terrain, exposed mineral soils form the driving surface. In the swampy areas, the relatively undisturbed organic mantle is capped with compacted snow and depressions are filled in to form the driving surface. Maximum gradients are held below 5 percent and curvatures to less than 3 degrees. The roads, usually complete by January 1, accommodate 50-ton (45-tonne) semi-trailer traffic and permit sustained speeds of 50 miles per hour (80 kilometres per hour).

Unreinforced ice bridges are used over the major streams and rivers. These are constructed in the usual manner by flooding to build up the ice. Once the natural ice cover reaches 3 to 4 inches, the snow is compacted by snowmobile and flooding begins. Flooding progresses in stages of 1 to 2 inches (2.5 to 5 centimetres) per flood until the desired thickness is achieved. By January 1, ice bridges are complete and open to traffic. A speed limit of 10 miles per hour (16 kilometres per hour) is imposed at all crossings.

The ice thickness guide in the section on Spruce Falls Power and Paper represents the minimum thicknesses of solid blue ice required for various loads. White ice thickness is taken to be half the thickness of solid blue ice.

Bridges over small streams are constructed by laying logs longitudinally and transversely in layers across the stream channel. The bridge is then topped with snow and brush and watered down. Crossings of this type are removed before spring break-up. The approaches to the crossings are established by grading the stream banks.

Maintenance of the overland road sections consists of keeping the driving surface levelled smooth with motor grader. On the ice bridges, ice thicknesses are checked weekly and cracks are patched by flooding. Full-time bridge attendants and road inspectors are not necessary because road conditions are reported directly to the maintenance crews by the truck drivers.

At the first signs of surface thaw, trucks and road equipment begin to move out. The reason for early evacuation is that persistent use of the roadways into the thaw period could easily result in equipment being stranded along the roadway until the next winter season. In an average year, the end of the winter road haul season can be expected by March 15.

QUEBEC

Winter road activity in Quebec centres chiefly around the pulp and paper industry, but in recent years the heavy construction industry associated with the James Bay project has also used winter roads extensively. The first part of this section describes two winter road operations associated with pulp and paper activities. The second part deals with winter roads used in construction.

Winter Roads for Domtar Woodlands Ltd.

In the Quevillon area, winter logging operations by Domtar Woodlands Ltd. are located predominantly in mineral terrain. Construction of winter roads starts in mid-November with the removal of stumps and moss in a 25-foot (8-metre) wide right-of-way by D-7 bulldozers, right down to the clay soil. The exposed soil, when frozen, serves as the driving surface for the roadways. Small creeks are spanned by steel pipe-culverts which are recovered each spring. Some 12 miles (20 kilometres) of this standard of winter road are constructed annually at an average cost of $2,000 per mile ($1,200 per kilometre). The company does not use ice bridges over rivers or ice roads on lakes.

By early January construction is complete and hauling begins. Gross loads as high as 75 tons (68 tonnes), distributed on 6 axles, are hauled over these roads. In an average year, hauling continues until about March 10. After this date, loss of traction due to surface thaw forces road closure. During the haul season, snow removal with motor graders constitutes the only road maintenance.

Winter Roads for Consolidated-Bathurst Ltd.

Consolidated-Bathurst uses 10 to 20 miles (16 to 32 kilometres) of winter roads each year for its woodlands operations, which are located throughout the Peribonka Watershed and Lake St. John areas. The roads follow lightly treed areas as much as possible, skirting deep swamps and irregular terrain. Side hills, being potential icing problem areas, are also avoided. Where slopes are unavoidable, 15 percent gradients are the maximum tolerated.

In the standard manner, the right-of-way is established by D-7 tractor as soon as frost conditions permit. With all merchantable timber cut and salvaged first, the stumps and brush are sheared off at ground level and bladed to the sides. From this point onward, motor graders maintain a smooth driving surface for the duration of road use. A typical cross-section of an overland winter road is comprised of an organic mat overlain by a thin "pavement" of compacted snow about 1 inch (2 centimetres) thick. The cost (1977) of constructing a 30-foot (10-metre) wide winter road of this standard ranges from $2,000 to $3,000 per mile ($1200 to $1900 per kilometre).

Unreinforced ice bridges are built over the major streams and rivers. The bridges, which are 150 to 200 feet (46 to 60 metres) wide, are built by flooding in stages of 1 to 2 inches (2 to 4 centimetres) of ice per flood until a safe ice thickness is achieved. Snow overlying the natural ice cover is compacted either by snowshoe or with snowmobile or light tracked vehicle before flooding. A natural ice thickness of 2 to 3 inches (5 to 7 centimetres) is usually sufficient for the initial tramping and flooding.

Small dykes of snow are first pushed up along the outer edges of the alignment. Water is then pumped up through holes augered in the ice. With ambient temperatures well below freezing, up to 2 inches (5 centimetres) of water can be applied per flood. At depths greater than 2 inches (5 centimetres) there is the danger that a layer of supercooled water will be held between the old surface and the new layer of ice, forming weak spots on the bridge.

The most common type of pump used for flooding is the centrifugal pump. Powered by an air-cooled engine, it has a capacity of about 40,000 gallons (180,000 litres) per hour. These units are generally mounted on a sled and are capable of being moved by snowmobile or small tractor. Ice augers have also been used. A typical unit consists of a powered ice auger which in turn acts as a pump impeller. It can pump about 30,000 gallons (135,000 litres) per hour and can be moved easily by hand sled.

Approaches to the ice bridges are constructed by grading the banks and using embankments of granular material to bridge the ice-shore interface. Small streams are crossed using granular fills over rough wood culverts.

Maintenance of the roadway consists of levelling with motor grader, snow removal, and sanding of hills and curves. On ice bridges, periodic checks are carried out for cracks which are repaired by flood-patching. The cost of this maintenance is in the order of $1000 to $1500 per mile ($600 to $900 per kilometre).

Minimum Thicknesses of Solid Blue Ice

Vehicle/load	Minimum Thickness (solid blue ice)	Spacing Between Units
Car or pick-up	8 inches	65 feet
Small truck, light load (3 tons)	10 inches	85 feet
Truck (20 tons GVW)	16 inches	130 feet
Truck (45 tons GVW)	24 inches	165 feet

Note: Thicknesses should be doubled for slush ice.
Multiply tons by 0.9 to calculate tonnes.
Multiply inches by 2.54 to calculate centimetres.
Multiply feet by 0.33 to calculate metres.

By December 15, construction is usually completed and the winter roads are opened to traffic. Semi-trailer trucks loaded to 55 tons (50 tonnes) gross weight use the roads for the duration of the haul season. Road closure can be expected at any time after March 15 due to loss of traction on southern exposures.

Winter Roads to James Bay

The James Bay region is characterized by relatively flat terrain, subarctic temperatures, and ample snowfall. These conditions are conducive to winter road construction and operation.

In 1971-72, a 365-mile (590-kilometre) winter road using 13 ice bridges was constructed from Mattagami to James Bay. It allowed the James Bay hydro project to proceed before a permanent road could be built. Initially it facilitated camp and stockpile preparation.

The alignment, which was marked on air photos, was cleared to a 30-foot (10-metre) width. Then construction equipment was used to pack the snow to speed frost penetration. Bogs were generally avoided because they freeze last. North of the Rupert River, about 3 to 6 miles (5 to 10 kilometres) of road were constructed daily. The right-of-way was widened every 1 mile (1.6 kilometres) or so to enable vehicles to meet or pass.

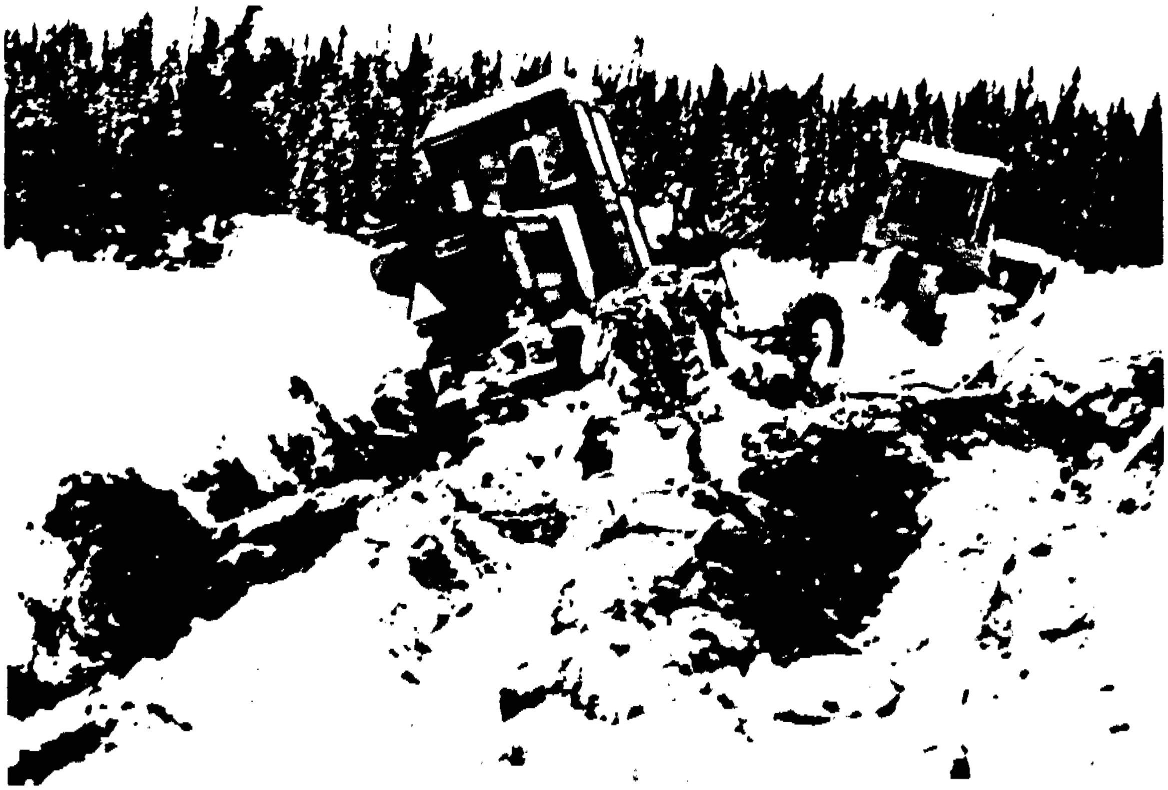
By the winter of 1972-73, a permanent road had been completed to the Rupert River, so the winter road was constructed along the same right-of-way as had been used the year before. When warm temperatures hampered use of the road, snow was cleared, resulting in a rough surface that forced vehicles to travel at reduced speeds. Some gravel was used to improve the road, but a warm spell early in March necessitated further use of gravel. Speeds averaged 15 miles per hour (24 kilometres per hour). In total, 3300 vehicles passed over the road. Accumulated loads amounted to some 91,000 tons (82,000 tonnes). The road was closed on April 2, 1973. The ice bridges were still operative at that time.

The initial cost of opening this road in 1971-72 was $7200 per mile ($4500 per kilometre). In the second year, the cost increased, even without clearing costs, to $8200 per mile ($5100 per kilometre) largely because of rerouting and intense maintenance.

Winter Roads for Desourdy Construction Ltd.

Since the launching of the James Bay hydro development project, some 400 miles (650 kilometres) of winter roads have been constructed by Desourdy Construction Ltd. The roads have extended from Matagami to LG2 (the first powerhouse site near Radisson), west to Fort George, and east to other power stations on the LaGrande River. They are used for trucking heavy construction equipment, building supplies, and fuel to the dam and powerhouse construction sites.

Winter road corridors are selected, keeping in mind that an all-weather road will eventually follow. Granular deposits and terrain type are carefully identified before the route is located. Potential bridge sites are also identified; however, the sites ideally suited for ice bridges are often unsuitable for permanent bridge installation. At the river crossings, major right-of-way realignment is eventually necessary to complete the permanent road.



Problems with tire type equipment on a winter road in Quebec caused by inadequate frost penetration. (Desourdy Construction Limited)

In non-swampy areas, a right-of-way 36 feet (11 metres) wide is established using TD-25's. A road surface 22 feet (7 metres) wide is then prepared by levelling and grading with TD-20's. After frost has penetrated the exposed soils to a minimum of 1 foot (30 centimetres), motor graders do the final grading of the road surface. In swampy areas, muskeg tractors travel the right-of-way back and forth until water is forced to the surface. After the saturated organic layer freezes solid, the process is repeated using TD-20's. The final driving surface consists of packed snow and ice up to one or two feet thick (about half a metre).

In the company's experience, bulldozers that turn by means of variable track speed rather than braking one track cause less tearing of the surface mat. A significant reduction in the incidence of breakthrough was observed on spreads where variable track speed tractors were used.

During the construction phase, fuel is sledded to main fuel caches along the route. Foremost (Flextrack) carriers equipped with 1000-gallon (4500-litre) tanks are used to deliver the fuel to the construction equipment.

By working around the clock, construction crews can advance at an average rate of 6 miles (nearly 10 kilometres) per day. Including clearing, construction, and maintenance, winter road costs range from $6,000 to $10,000 per mile ($4,000 to $6,000 per kilometre).

Maintenance consists of levelling with a motor grader. Gravel is used for reinforcing certain sections of swamps and for filling in potholes. Full-time road inspection is provided.

The river crossings were located by the James Bay Development Corporation. The basic considerations given to site selection were: rate of formation of natural ice, the possibility of thermal erosion, and the potential for frazil ice accumulation. (Frazil ice, also known as slush ice, is granular or spiky ice formed in rapids or other agitated water.) The bridge designs, also provided by the Corporation, called for timber reinforcement. Construction of the ice bridges started when 10 to 12 inches (25 to 30 centimetres) of natural ice had formed. It consisted of laying timber longitudinally across the river at 4-foot (1.2-metre) spacing center-to-center within 4-foot (1.2 metre) lapped joints. The timber was then flooded over and another layer added in the same configuration with about 12 inches (30 centimetres) between the layers. Following additional ice build-up of 2 feet (0.6 metres) by flooding, a final layer of reinforcing was added in the transverse direction and capped with 8 inches (20 centimetres) of ice. The width of the reinforced bridge section was 34 feet (10 metres), the total bridge width 150 feet (46 metres), and the total ice thickness 48 inches (120 centimetres).

The speed limit on ice bridges was restricted to 2 miles (3 kilometres) per hour. The ice bridges, constructed as described, could carry 70-ton (63-tonne) gross weight wheeled vehicles and 50-ton (45 tonne) bulldozers.

Reinforced ice bridge, 60 to 70 inches (150 to 170 centimetres) thick and 1400 feet (425 metres) long, across the Rupert River. The surface deflected 1 foot (30 centimetres) when a 45-ton (40-tonne) TD 25 crossed it. (Desourdy Construction Limited)

MARITIMES AND LABRADOR

In Nova Scotia and Prince Edward Island, moderate winter temperatures essentially eliminate winter roads as a viable transportation option. In New Brunswick, colder temperatures are sometimes experienced, but they are unreliable and this reduces winter road use here. However, in Newfoundland and Labrador, winter trails are used to some extent.

New Brunswick

Small forestry companies in New Brunswick use winter haul roads in areas not accessible in summer. Generally, winter roads are limited to low-lying areas, but the trend is for large companies to move away from their use altogether. This is because of their unreliability due to periodic thaws in midwinter and because of the uncertainty of ice quality for ice bridges.

One ice bridge in New Brunswick that is installed year after year is the Washademak Lake crossing. This crossing is unique because the local people are always the first to use it each year. Some long-time users cross with cars before the ice is 1 foot (0.3 metres) thick and the right-of-way has been cleared.

The Department of Transportation keeps snow off the crossing and installs markers and signs, but it takes no responsibility for the safety of users and it does not provide markers until the ice is over 1 foot (0.3 metres) thick.

The ice is allowed to thicken naturally to 1 foot (0.3 metres) over the 1-mile (1.6-kilometre) crossing. Then a jeep or 4-wheel-drive half-ton truck equipped with a plow prepares two rights-of-way. The first, about 40 feet (12 metres) wide, is staked along one side to guide traffic. The second is plowed so as to intercept drifting snow. Ice thickness is checked early in winter by chopping through the ice. Over the winter, ice buildup reaches 30 to 32 inches (75-80 centimetres). Pulpwood trucks at gross weights of from 15 to 20 tons (13 to 18 tonnes) have used the Washademak Lake crossing.

The crossing requires no maintenance other than snow clearing since no problems have been encountered with cracks or pressure ridges.

Spring use of the crossing is normally curtailed by melting snow along shore that rots the ice or floods the approaches. Normal use of the crossing is from early January to late March. Extreme winters have allowed use to begin as early as December 10 and continue as late as April 10.

A few years ago when a permanent bridge upstream of the Washademak Lake crossing went out, the local people used a temporary ice crossing to maintain direct access to Saint John.

Other ice bridges, such as the one at Evandale, are used to cross the St. John River. The life of these crossings is shortened by tides and power plant reservoirs which weaken the ice by causing water levels to vary.

Newfoundland

In Newfoundland, Price Newfoundland and Bowater Newfoundland Ltd. are the two main companies using winter roads. Their methods of construction, operation, and maintenance are similar. Winter roads are normally used for one season only. However, they are often planned so that they can be upgraded and incorporated later on into the permanent road networks of the companies. Rights-of-way are first prepared by salvaging pulp. Medium weight crawler tractors move wet mineral soil (sometimes mixed with snow) into a road grade. Most mineral soil is obtained from ditches parallel to the roadway. Surface vegetation over the rest of the right-of-way and beneath the roadway is normally left in place. Road smoothness is often achieved by back-blading.

Roads are normally completed before freeze-up, then left until they have completely "frozen in". Once the roads are frozen-in, minor touch-up by grader makes them operational.

Public use of these winter roads is forbidden: they are operated specifically for hauling pulp wood. Heavy trucks carrying between 7 and 17 cords make up the bulk of the traffic.

The roads are used over all types of terrain and ascend grades up to 12 percent (and 15 percent grades have been used on occasion). Ditches, wood box culverts, and timber bridges are commonly used to facilitate drainage along and across the roads. When the roads are viewed in summer, it is often hard to believe that they are passable even in winter.

Labrador

In Labrador, early development of mines and forestry operations involved more temporary landing strips than winter roads. This was because of Labrador's remoteness from early development centres and the fact that it began developing in the same era as air cargo transports.

Today, use of winter roads in Labrador is minor, and stems from the need for access to remote communities, although in the past some winter roads were used for hauling pulpwood.

Many communities in Labrador are coastal and summer access between communities is by boat and motor. However, in winter, because of the lack of wheeled vehicles, winter trails are developed mainly for snowmobile use and the occasional tracked vehicle. Trails are merely cutlines between communities. Little use of ice cover is made for intercommunity travel. Some traplines use trails that follow the frozen surfaces of lakes and rivers. Here, too, the majority of use is by snowmobile.

In the old days when pulpwood was hauled by team and sleigh, snow was often levelled and wetted down. In later years, winter roads of the type used in Newfoundland were used mainly by tracked rather than wheeled vehicles.

In one recent instance, an ice bridge was built close to a permanent highway bridge to carry pulpwood trucks with loads too heavy for the highway bridge. It was constructed by pumping water between small snow containment berms. Wood slabs were installed for reinforcement.

In Labrador today, there is very little use of winter roads largely because the last operating forestry company recently shut down.

NORTHWEST TERRITORIES

Winter roads in the Northwest Territories are concentrated in three main areas: the Mackenzie Delta, Yellowknife, and the Arctic Islands. In the Delta and around Yellowknife, winter roads are essentially snow and ice roads used in oil and gas exploration and to service mining companies. The exception is the ice road from Aklavik to Tuktoyaktuk, a public road built annually and controlled by DPW of the Territorial Government. On the Arctic Islands, winter roads are used as haul roads or seismic lines.

Winter Roads in the Mackenzie Delta

In the Delta in 1976-77, about 550 miles (880 kilometres) of winter roads were built to move and service oil exploration drill rigs. The roads varied from snow roads and ice-capped snow roads to river ice roads. In general 50 to 70 percent of the roads were overland. The rights-of-way ranged from 33 feet (10 metres) on land to 100 feet (30 metres) on lakes and rivers. Some of the roads were capable of supporting vehicles carrying as much as 60,000 pounds (27,000 kilograms) of freight.

Dates for startup and shutdown, and to a certain extent construction methods, are governed by land use regulations, and enforced by land use inspectors of the Northwest Lands and Forest Service, Department of Indian and Northern Affairs. Before permission is granted to construct a winter road, the contractor must submit a plan showing his proposed route. The land use inspectors check the route for areas of possible conflicts, such as stream crossings, steep slopes and side hills, and areas of polygons and pingoes. Once the route location has been approved, the contractor must wait until the inspector is satisfied that there is sufficient snow and frost for environmental protection. Normally, at least 6 inches (15 centimetres) of snow and 6 inches (15 centimetres) of frost are necessary to prevent damage to the vegetation before construction commences. Inspectors will often check a road daily during the construction phase to ensure there is adequate frost and snow, then conduct bi-weekly inspections after the road has been built.

Most contractors use similar methods of construction. Equipment used at the beginning of construction consists of crawler tractors, rubber-tired loaders, and graders. Once the snow has been compacted, large rubber-tire drags or steel drags and water are used to prepare the final surface. Water is used to form an ice cap. The amount of water required to prepare the final surface will govern the number of water trucks. In 1976-77, steel drags were not permitted in the Delta because land use inspectors believe they were causing too much damage to the vegetation as compared to the rubber tire drags.

Stream crossings are a concern in the Delta. Major rivers require the construction of an ice bridge and approaches. Small streams can be spanned by timber although snow fills sprayed with water are usually sufficient. The lack of snow in the Delta has prompted one company to use a snow-maker at some stream crossings. All stream crossings are selected with regard to grade.

Each year an ice river road is constructed from Aklavik to Inuvik to Tuktoyaktuk. The road is about 150 to 200 miles (240 to 320 kilometres) long and comes under the jurisdiction of the DPW, Territorial Government. Ninety-nine percent of it is constructed on the Mackenzie Delta channels. Construction usually starts January 1 when 16 inches (40 centimetres) of ice have accumulated. Graders and V-plows are used to keep the snow off the ice to speed frost penetration.

The right-of-way is kept to about 100 feet (30 metres) to prevent drifting in. The snow banks are also kept low for the same reason. Once the road has been constructed, graders are used for continuous maintenance. Pressure ridges present some maintenance problems, but where they occur the road is usually rerouted.

The cost of the road is approximately \$350 to \$400 per mile (\$220 to \$250 per kilometre). A total of 50 to 100 tons (45 to 90 tonnes) of freight is transported over it.

Winter Roads in the Yellowknife Region

Winter roads around Yellowknife are built primarily to service the mining industry. In 1976-77, about 400 miles (650 kilometres) of roads were in use. This included the 300-mile (500-kilometre) long road built each year from Rae to Echo Bay to move freight to the mine at Port Radium and to haul out ore. In 1976-77, 1 million gallons (4.5 million litres) of fuel, 1500 tons (1400 tonnes) of freight, and 2600 tons (2400 tonnes) of ore were transported to and from the mine along the road.

The Echo Bay road is constructed on approximately 80 to 90 percent lake ice. This restricts startup until the ice is 18 inches (46 centimetres) thick, usually January 1. Initial construction is accomplished using 6 x 6 trucks with V-plows and graders. On lake sections, the snow is removed to speed ice buildup and the snow banks are kept low to prevent drifting. Snow roads on land are constructed with

Gulf's winter road in the Mackenzie Delta area, 1977. A permanent wooden bridge was permitted to allow earlier starts. (D. Martin) similar equipment and a variety of steel drags. Initial dragging is with chains and an H-beam drag 16 feet (5 metres) long by 18 feet 6 inches (5.7 metres) wide. Final surfacing is with a light screen drag 14 feet by 6 feet (4 metres by 2 metres) constructed out of channel iron and light gauge mesh. Once construction is completed, maintenance is carried out daily.

The road is usually open for about three months, from January 1 to April 1. Traffic is restricted to highway tandem trucks with a maximum GVW of 90,000 pounds (40,000 kilograms). Speeds average 20 to 25 miles per hour (32 to 40 kilometres per hour) round trip. Speeds higher than 25 miles per hour (40 kilometres per hour) are not permitted to prevent wave buildup below the ice.

Construction costs for the Echo Bay Road have increased from $100 per mile ($60 per kilometre) 5 years ago to $200 per mile ($120 per kilometre) for the 1976-77 season.

Other roads in the Yellowknife area are the extension of the Echo Bay road to Dismal Lakes and several smaller roads branching out of Yellowknife. These roads are constructed in the same manner as the Echo Bay road to service the local mining industry.

Land use inspectors play a major role in selection and construction of winter roads in the Yellowknife area just as they do in the Delta. They determine if the route the contractor has selected is suitable, when construction can start, when the road must be closed to traffic, and whether or not construction methods and equipment are acceptable.

Seismic Trails

Each year throughout the western Northwest Territories, seismic lines are cut for oil and gas explorations. The number of miles of seismic lines varies from year to year, depending on the amount of activity. Since the land use regulations came into effect, the number of new lines cut each year has decreased. Land use inspectors require that all existing trails be utilized where possible.

Land use regulations, as described previously, also govern seismic trail construction. However, the methods of construction are somewhat different as all equipment is either track- or ski-mounted. After frost has penetrated far enough and sufficient snow is available, D6 and D7 Cats are brought in to construct the road after low-ground-pressure vehicles compact the snow.

Old seismic line used as a perennial winter trail. Icings are caused by groundwater flow across road. (K.M. Adam)

Seismic trail traffic usually consists of approximately 80 percent tracked and 20 percent crawler equipment. Average speed is about 3 miles per hour (5 kilometres per hour). In areas where seismic readings are taken, about 20 to 25 passes with vehicles averaging 20 tons (18 tonnes) is required to complete the seismic work.

Steep side hills are always a problem for tracked vehicles because the tracks tend to slip and often damage the moss or surface mat.

Winter Roads in the Arctic Islands

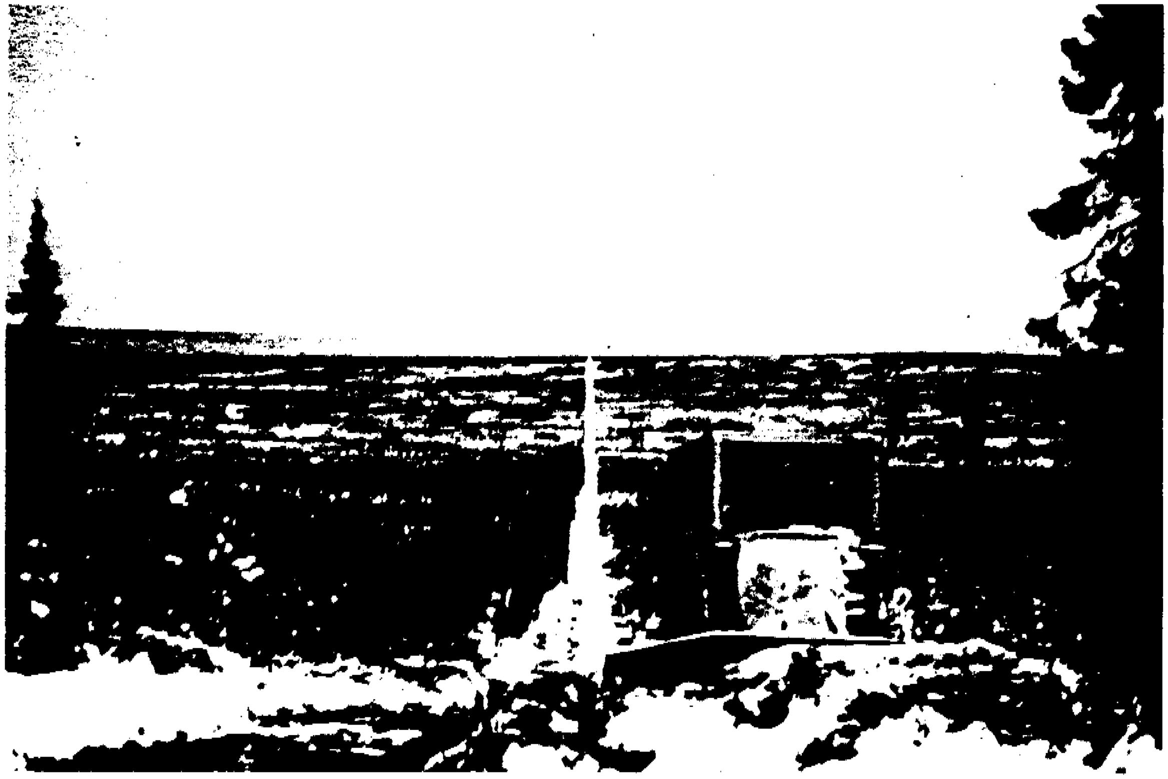
In the high Arctic, including Banks, Prince Patrick, Melville, Meighen, Prince of Wales, and Cornwallis Islands, trails are generally used for one of two purposes -- seismic lines or haul roads. Haul roads are built by leaving snow in its drifted position and travelling over the top. Seismic lines require that the trail be at ground surface, so large quantities of snow are often removed.

Terrain on the islands is mostly rolling, with some gentle slopes. Up to 30 percent of a road is often over rock and the remainder on tundra. Few rocks are moved, particularly in the case of haul roads which go over the top on drifted snow; but, in the odd place like Melville Island, the route must skirt rocky areas.

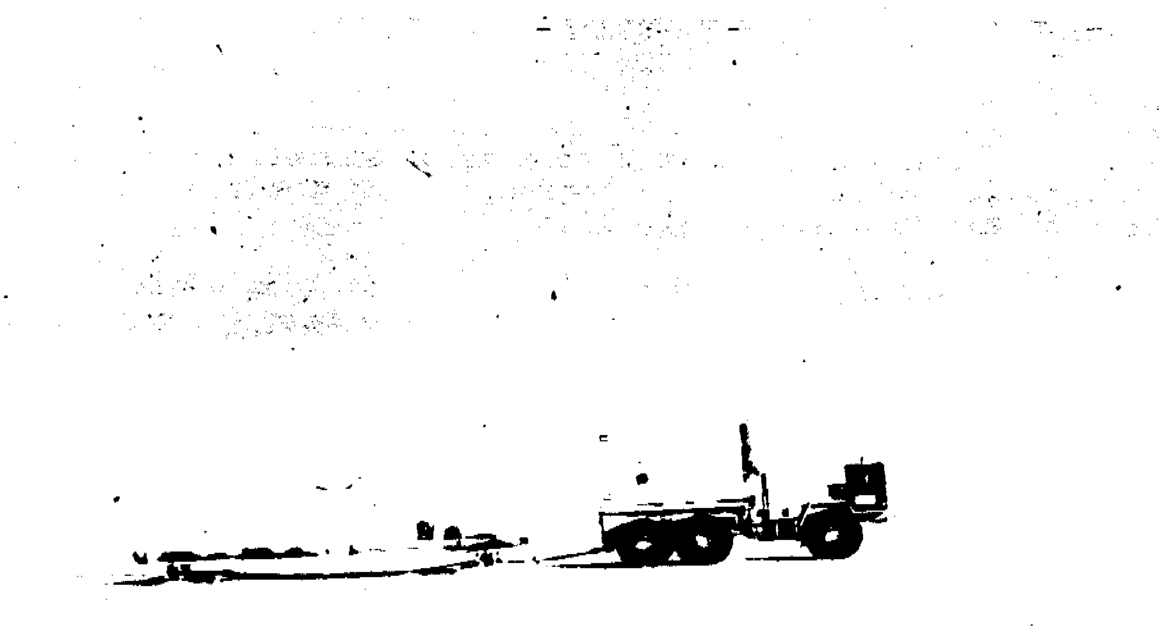
Because there is more wind and blowing snow here than in the Mackenzie Delta, snow tends to accumulate in enormous drifts well over 10 feet (3 metres) deep, particularly in valleys or on the lee side of hills. Snow in these areas is naturally very hard and will support a D-8 crawler tractor and sleighs. This is the reason why haul roads can be built on top of the snow. Seismic lines are bulldozed down to the ground by blade. Large mushroom shoes on the bottom of the blade prevent most disturbance to the surface in tundra areas.

The persistent cold freezes the islands solid. Streams blow in with snow so that stream crossings pose no problem whatsoever. The 7-foot (2-metre) thick ice on lakes would make for excellent travel, and avoid detours around lakes which add considerable distance to some routes. But travel along river bottoms and across lakes is not always allowed in some cases by Environment Canada.

Activities on the islands normally start in October and end on the predetermined date of June 10.



Bulldozer building a seismic line near Fort Norman. (L. Emard)



Supply road over snow on Banks Island in the Canadian Arctic Archipelago. (L. Emard)

Traffic on trails consist primarily of crawler tractors and sleighs, although some large low-ground-pressure vehicles are used. A few trucks have been used on the islands for moving drill rigs. Crawler tractors usually pull four sleighs each carrying up to 30 tons (27 tonnes).

Because no compaction is required for winter road construction, very little maintenance is required. Maintenance consists mainly of snow removal. Large quantities of snow must be moved for seismic line construction and maintenance. Cost of seismic line construction normally ranges from $5,000 to $6,000 per mile ($3,000 to $3,750 per kilometre). Haul roads cost considerably less to build, normally little more than $500 per mile ($300 per kilometre).

Summer clean-up in areas of activity is carried out by helicopter. Trails on the islands do leave a mark on the surface but other than that, few serious terrain problems are encountered.

Norman Wells Winter Road Study

In order to assess the feasibility of using winter roads for pipeline construction, Canadian Arctic Gas Study Limited sponsored testing of a section of winter road at Norman Wells, Northwest Territories in March and April of 1973. A 1200-foot (395-metre) oval test loop consisting of one-half ice road and one-half ice-capped snow road was constructed and tested to failure under wheel and tracked traffic. Observations were also made of the effects of hand and machine clearing and the degradation of the permafrost table in the vicinity of the loop.

Clearing and grubbing of the test loop began on March 6 and was completed to a width of 50 feet (16 metres) by March 8. Later clearing on the inside of the loop widened the right-of-way to 70 feet (23 metres).

Construction of the ice road section began on March 7. Excess snow on the road bed was bladed off (to simulate a low snow condition) leaving an average snow depth of about 4 inches which was levelled and dragged by a D7 dozer pulling a Euclid tire as a drag. Watering was then begun and continued until March 14 when a total of 44,700 gallons (200,000 litres) of water had been applied to the road surface for an equivalent average depth of 5.35 inches (13.5 centimetres) of ice.

Norman Wells test loop. Ice road is on the right, and ice-capped snow road on the left. (W. Sol)

Part of Norman Wells test loop in summer. Note lack of disturbance after 36,000 passes. (K.M. Adam)

Compacted processed snow road construction began on March 8 with snow from the side of the right-of-way bladed onto the road bed and compacted with a log drag. Processing of the snow began the following day with a Massey-Ferguson disc tiller attached to the bucket of an IHC-TD6 front end loader. Compaction was then accomplished by four complete passes of the D7 dozer over the full road width and a final dragging of the road surface with a log drag.

After 42 hours of age-hardening, the density of the snow road was 31 pounds per cubic foot (0.5 grams per cubic centimetre) and rammsonde readings rose to 251.

Trafficking of the road was attempted using a 15-passenger Fargo bus on March 11. After 25 passes of the bus, the road surface failed and it was decided to completely rebuild the road to a higher standard by ice-capping.

Rebuilding began on March 12 with additional snow from the sides of the right-of-way bladed onto the road and compacted by four complete passes of the D7. Dragging with the Euclid tire drag and an I-beam drag followed. After a few hours of age-hardening, 3500 gallons (16,000 litres) of water were applied to the road surface. Over a 7200-square foot (670-square metre) area, this amounted to 0.5 gallons per square foot (25 litres per square metre). Average road thickness was 14 inches (35 centimetres). Within 12 hours rammsonde readings on the ice-capped snow road rose to an average of 646 and trafficking began.

Trafficking of the test loop began on March 14 using the Fargo 15-passenger bus. Additional traffic added later included tandem dump trucks, a Ford F-500 truck, a Ford F-350 truck, and several pick-up trucks. Maximum gross vehicle weight varied from 5,000 to 43,000 pounds (2,300 to 19,500 kilograms).

Full trafficking began on March 19 on a 24-hour basis. Minor patching of the ice-capped snow road was accomplished using snow and water. A continuous daily record of rammsonde readings and maximum and minimum temperatures was kept during the traffic period. Sanding of the curves became necessary when warm weather caused the road surface to become slippery.

Trafficking ceased on April 9 after 36,000 vehicle passes when, in the opinion of a Mackenzie Forest Service land use inspector, the road was no longer suitable for daytime traffic. Tracked traffic tests were completed on April 10.

Some of the conclusions of the Norman Wells Winter Road study were:

- The traffic applied to the test loop simulated pipeline traffic very well in terms of vehicle passes, wheel loads and total tonnage. The test loop was capable of supporting such sustained traffic.

- In general, rammsonde readings on the road increased with decreasing air temperature and decreased with increasing air temperature.

- The lower limit of density of winter roads that would be structurally acceptable was confirmed as 37 pounds per cubic foot (0.60 grams per cubic centimetre) or average rammsonde readings of 450.

- Rammsonde readings are of little use in gauging spring traffic curtailment as bare spots developed on the road before average rammsonde readings fell below 450.

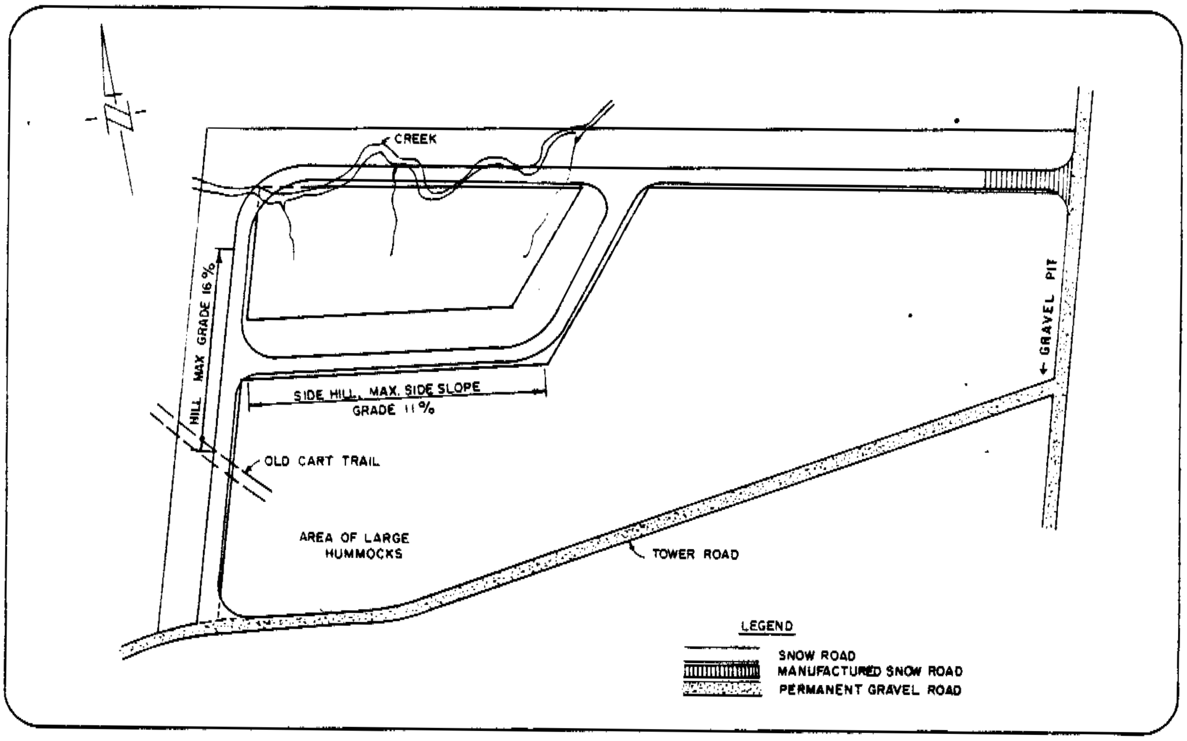
- Snow roads not trafficable after 4 days of age-hardening are not apt to become trafficable.

- Unless sufficient moisture is available in the snow, it is impossible to construct a trafficable snow road without the use of heavy drags and rollers.

- An ice road can withstand rubber-tired traffic with less maintenance than an ice-capped snow road. However, an ice road breaks down under tracked vehicles more severely.

- Ice-capped snow roads should have a uniform ice cap at least 4 inches (10 centimetres) thick at at density of 0.80-0.85 to sustain pipeline traffic.

- An experienced land use inspector can assess the suitability of a road for traffic during spring runoff better than any other available means.



Inuvik snow road test site. (Source: Northern Engineering Services)

Inuvik Snow Road Study

As an extension of the Norman Wells Winter Road study of March 1973, Canadian Arctic Gas Study Limited sponsored further testing of snow roads at Inuvik, N.W.T. during the winter of 1973-74. Two test sections of road were constructed and trafficked during the latter part of 1973 and early 1974. Trafficking was then suspended until the spring of 1974 when the sections were trafficked to impassability.

The main road consisted of an L-shaped section of snow road 2600 feet (800 metres) long joining two intersecting permanent gravel roads. The resulting loop was half snow road and half gravel road. A second L-shaped section of snow road 1100 feet (330 metres) long was later constructed to form a small loop in the northwest corner of the first loop (see illustration). Hand clearing of the right-of-way commenced in late October followed by compaction of the existing snow to speed frost penetration. A J-5 bombardier was used for this purpose.

Snow manufacturing began in early December using a Larchmont Twin snow gun to construct 175 feet (50 metres) of the main test section. Snow for the remainder of the test road was borrowed from a nearby lake and hauled to the site by truck. End-dumped snow at the road head was compacted by a D6 dozer. Depth of snowfall varied from a minimum of 1 foot (0.3 metres) to a maximum of 3 feet (1 metre).

Processing and levelling of the road was accomplished using a rotary plow pulled by a D6 dozer followed by a second D6 dozer pulling a levelling drag. Four passes of the processing machine, followed alternately by passes of the levelling drag, completed this process. A D6 pulling a vibratory roller then made two passes to improve compaction.

Density of the snow at this point varied from 38 pounds per cubic foot (0.61 grams per cubic centimetre) in the middle 20 feet (6 metres) of the road to 34 pounds per cubic foot (0.54 grams per cubic centimetre) near the edge. Rammsonde readings, taken after 24 hours of age hardening, were 236, 525 and 580 for the top 4 inches (10 centimetres), 4 to 6 inches (10 to 15 centimetres), and 6 to 8 inches (15 to 20 centimetres) respectively. A further 72 hours of age-hardening produced readings of 590, 620 and 685 for the same zones.

Trafficking of the road began after only 15 hours of age-hardening with a GMC tandem dump truck and a passenger car. Weaknesses at the 90 degree corner and at the base of the uphill section of the road were revealed during this early trafficking. Repairs were made by ice capping the weak sections. Water was applied at a rate of 0.37 gallons per square foot (18 litres per square metre). Trafficking resumed using the empty water truck 15 minutes after the last application of water with no damage to the road.

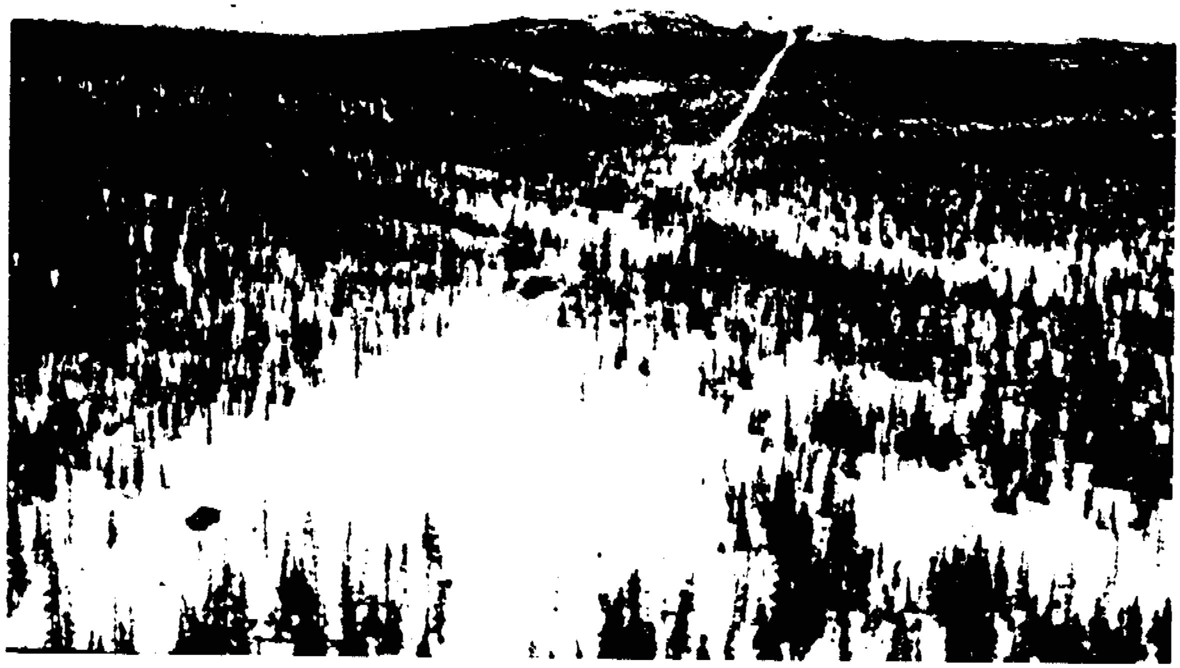
Three days later, full trafficking tests began with a Kenworth tractor and tandem trailer carrying 43,000 pounds (19,500 kilograms) for a gross vehicle weight of 72,000 pounds (32,500 kilograms). Traffic tests continued with this unit travelling both circuits in clockwise and counter-clockwise directions. Gross vehicle weights were up to 78,000 pounds (35,500 kilograms). Minor repairs were made to the road with a snow-sawdust-water mixture that froze in place very quickly and could carry traffic loads 15 minutes after placement. Trafficking ceased on January 22 for this phase of testing with the road in good condition.

Spring trafficking commenced on April 6 and continued intermittently until May 6 when the road became impassible to truck traffic.

Some of the conclusions of the Inuvik Snow Road study were:

- Manufacturing of all snow required for general road construction is impractical; however, manufactured snow may be useful for construction of small portions of road bed before enough snowfall has accumulated.
- Borrowed snow from lakes is denser and compacts better than free-fall snow.
- Surface processing is essential in constructing a uniform, hard surface.
- Corners and grades are subject to excessive wear and reinforcement is necessary.
- Tire chains cause little damage to a snow road surface.
- A satisfactory patching material for snow roads can be made from equal parts of snow and sawdust mixed together and saturated with water. The mixture freezes quickly, appears to be as strong or stronger than the original snow surface, and can carry traffic within minutes of placement.

Typical winter road near Peel River, Yukon. (Gulf Oil Limited)



Road along a seismic line. Patchy areas are developing on this south-facing alignment. (Gulf Oil Limited)

Maintenance consists of keeping the snow off the road and some levelling by a motor grader. Truck drivers help locate damaged sections. Maintenance usually runs about $100 per mile per month ($70 per kilometre per month).

Traffic on the haul roads normally consists of about 400 loads per drill site. About half of these are in connection with the service industries.

Roads are normally abandoned when the high spots become mucky and the trucks start bogging down. Some extension can be gained by pulling snow onto the road to keep it white. Abandonment normally occurs about April 1 in northern British Columbia and the southern Yukon. Bridges and culverts are removed on the way out and erosion ditches are dug across the road.

Few environmental problems are encountered if the land use people are kept involved. Co-operation usually results. Experience has been that "if they give you trouble, you usually have it coming".

Ice bridges are built using normal procedures, although, if construction begins early in the fall, some streams are forded. Normally, 20 inches (50 centimetres) of ice are required before light equipment can be used to clean the snow off. Fifteen inches (60 centimetres) of ice are required for heavier equipment. Snow is ploughed off to form banks used to contain water during flooding. Two-inch (5-centimetre) lifts are placed on the bridge until 40 inches (100 centimetres) have been established. Approaches are built up with snow and frozen with water.

Dawson Ice Bridge

Each year, an ice bridge 1600-feet (500-metre) long and 200-feet (60-metre) wide is built across the Yukon River at Dawson. The bridge will normally support 126,000 pounds GVW (57,000 kilograms). Construction and maintenance of the ice bridge falls under the jurisdiction of the Department of Highways and Public Works, Government of the Yukon Territory. Cost of building the bridge in 1976-77 was $13,000.

Construction of the bridge commences in mid-November and is usually completed by January 1. Once the river has sufficient ice to support men, the bridge is marked out and depending on temperature, flooding commences in 1- or 2-inch (2.5- or 5-centimetre) lifts. Approaches are reinforced with timber to bridge the river bank when water levels fluctuate. A steel drag and grader are used to level rough ice and approaches, and a 6-inch (15-centimetre) gas motor ice auger is used to drill holes for the 2-inch (5-centimetre) pumps used in flooding.

ALASKA

Winter roads have been used extensively in Alaska by the mining and forestry industries, but it is the Alaskans' experience with winter roads for pipeline construction that adds a new dimension to Canadian knowledge. In Canada, only limited experimental work with simulated pipeline traffic has been available to assess the ability of winter roads to protect permafrost terrain, particularly in the high-ice-content soils along the Yukon coast. In Alaska, a wide range of observers have gained considerable field experience in the construction of short sections of Alyeska oil pipeline using snow roads and work pads. This practical experience is invaluable in assessing proposals to build pipelines from winter roads in Canada.

Major winter road activities after the Prudhoe Bay oil discovery began with the construction of the "Hickel Highway". Since that time, winter road technology has advanced markedly, no doubt inspired by petroleum and pipeline industry activities. The newest concept in winter road construction -- the ice aggregate road -- was tested in Fairbanks during the winter of 1976-77.

The Hickel Highway

In late 1968, the Alaska Department of Highways undertook the task of building 540 miles (870 kilometres) of overland winter road to the North Slope. This road is locally referred to as the Hickel Highway.

Starting the day after Christmas, a 22-man crew worked its way north from Livengood (71 miles or 110 kilometres north of Fairbanks) along a route that would connect Stevens Village and Bettles, proceed through Anaktuvuk Pass, and finally head towards Sagwon. The crew followed a route that involved little or no ground engineering design or construction technique. In the stunted tamarack and willows of the interior section, the trees were bowled over and bulldozed to the side, and gullies were crossed directly or by-passed. Reconnaissance was provided by a light plane that located dangerous areas and detours. A road surface was obtained by bulldozing the surface mat or litter down to a level where the frozen ground gave a smooth base for vehicles. About 2 miles (3.2 kilometres) of road were constructed each day in favourable weather. A particularly cold spell with temperatures of -70°F (-57°C) halted work until the weather "warmed" to -55°F (-48°C), enabling men and equipment to proceed.

Ice bridges had to be constructed at the Yukon and Koyokuk Rivers. Several small shallow streams were crossed without bridges, and in some places the road followed the frozen surface of streams. At the Yukon River crossing, brush, logs, and ice were frozen in alternate layers until the ice was thick enough (about 70 inches or 180 centimetres) to support the construction equipment -- three bulldozers, several graders and drags, and a cook shack on skids. Three-inch (7.5-centimetre) lifts of water, pumped through holes in the river ice, froze in 8 hours at -20^{o}F (-30^{o}C).

North of Bettles, the greatest problems were encountered in the John River canyon where repeated attempts were necessary before a passable route was found. Grades were 20 to 24 percent in some areas. Once out of the mountains and on the Arctic plain, route selection and progress were easier. The entire road was completed in 74 days.

Maintenance consisted of grading to fill in the "chuck-holes". No water was used. Soft spots on the road were merely avoided to extend use as long as possible. Road closure occurred when the Yukon River crossing went out.

Built with the intention of repeated yearly use, the Hickel Highway was used only in 1969. During its short life, it carried only a small fraction (less than 4 percent) of the volume of freight normally hauled by air to the North Slope. Time of travel on the overland route was about 50 hours (an average of 10 miles per hour or 16 kilometres per hour).

Cost of opening the road totalled $450,000, or nearly $1,000 per mile ($600 per kilometre). It was estimated that reopening the road the following year would have cost $100,000 less. A permanent road would have cost $35 to $40 million and would have taken several years to complete.

As might have been expected from the description of construction methods used in permafrost terrain, the Hickel Highway is experiencing severe thermal erosion over at least 5 to 10 percent of its length. Considerable subsidence and ponded water is evident when the road is observed from the air in summer. Because of current land practices in Alaska, the construction techniques used in 1968-69 could not be used now.

Alaskan Winter Roads for Pipeline Construction

Before the main pipeline haul road was completed to Prudhoe Bay, winter roads were used to extend hauling north from the Bay's northern extremity. Although the rights-of-way of some of these roads are visible from the air, virtually no erosion is resulting from them. This is largely because road-builders in the early 1970's realized that if they retained the surface mat, used snow to fill the depressions, and avoided knocking off the tops of cotton-grass tussocks, they could build more environmentally acceptable winter roads on the North Slope.

The Alaskan experience with pipeline construction directly off winter roads centres on two research projects and two instances of use on the Alyeska pipeline. Considerable use of snow work pads in constructing the gas feeder lines to Alyeska pump stations has also been successful.

The first winter road research work on the North Slope involved the Arctic Gas research pipeline installation at Prudhoe Bay. Referred to as the Prudhoe Layered Method, windblown and granular snow was built up in 2-inch (5-centimetre) lifts, any initial excess snow being pushed aside for subsequent lifts. Water was added to each lift, then the lift was dragged smooth. The finished road was 6 to 10 inches (15 to 25 centimetres) thick.

In 1977, research sections of ice aggregate road were tested at Fairbanks. An ice aggregate road is made of ice that is chipped from the surface of ponds or lakes, hauled to the site, and end-dumped in place.

The concept of an aggregate ice road originated from criticism of Arctic Gas' proposal to use either snow or ice roads across the North Slope where there is often a lack of snow and where shallow ponds freeze to the bottom, making water unavailable for ice roads. As a concept, the ice aggregate road for tundra areas of the North is appealing because if snow is unavailable for snow roads, at least the lack of snow facilitates more rapid freezing of ponds where the aggregate can be "mined".

At the Fairbanks test site, a small adapted roto-tiller pulled by a tractor was able to chip 1 to 2 acre-feet per day (1250 to 2500 cubic metres). Ice aggregate was then loaded, hauled, and end-dumped at the test site. Four sections of ice aggregate road were built, each about 100 feet (30 metres) long. Average thickness was about 2 feet (0.6 metres), with the top width ranging from 20 to 24 feet (6 to 7 metres). Once shaped and levelled, the sections were sprinkled with water to bind the upper 1 foot (30 centimetres) of ice aggregate. Freezing and binding of the ice aggregate took little time because of the large heat sink provided by the aggregate. A wide distribution of ice aggregate size was believed to have aided stability, but in addition it undoubtedly added to the number of frozen contact points, thereby adding strength to the top surface.

Traffic tests involving about 1000 vehicle-passes with loaded tandem trucks resulted in no damage to the road surface. The effects of tracked construction vehicles on ice aggregate are unknown at this time.

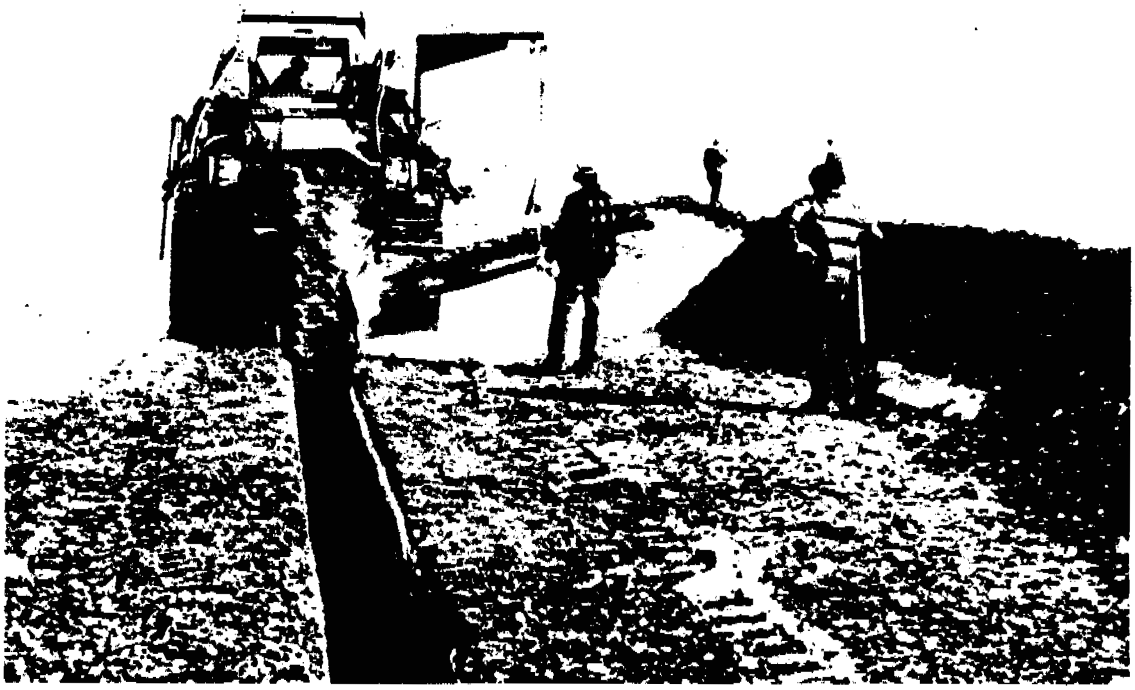
Other research pertaining to winter roads on the North Slope of Alaska has involved snow fence research by Arctic Gas in conjunction with the U.S. Forest Service on the collection of snow for roads. Snow fences were set perpendicular and parallel to the prevailing winds and most were effective in trapping snow, particularly those set perpendicular.

On the Alyeska pipeline, construction of the main-line from a snow road took place at least at two locations: Little Globe Creek and east of Toolik Camp.

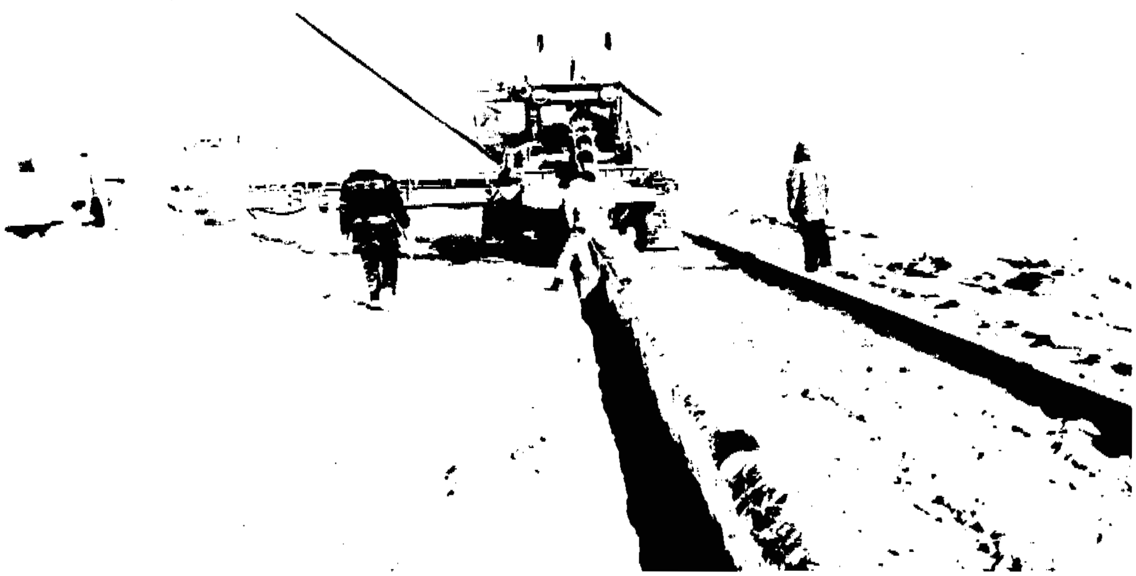
At Little Globe Creek, drill holes in 1972 indicated that excess ice from 4.5 to 14 feet (1.4 to 4.3 metres) thick existed in the ground. It was evident that surface subsidence and continued thermal erosion would result if measures were not taken to protect the environment. Of five alternatives (reroute, insulation, removal of mineral soil work pad, heat tubes, or construction of a snow work pad) the snow work pad was chosen. The thick cover of moss and natural insulating layer could be protected by loose snow fill that would allow the vegetation to survive, and a hard work surface would be constructed on top.

The final work pad at Globe Creek had an average snow depth of 3 feet (1 metre) over a width of 65 feet (20 metres) for a length of 2500 feet (760 metres). A 12 percent grade was within this length. At the time of construction in the winter of 1975-76, there was little natural snow in the area and the decision was made to manufacture snow to ensure a clean material. Mineral soil or dark organic material could not be used since it would end up on the surface in spring and cause early melting.

As is often the case with winter road construction, availability of equipment dictated the sequence of construction (but in this case not the type of snow road). The volume of water required (approximately 1.3 million gallons or 6 million litres) was not available from Globe Creek or from wells. Water had to be hauled from a source 32 miles (52 kilometres) away. It was decided to manufacture snow at the source and haul it, rather than water, to the work pad because of the large number of dump trucks available compared to water tankers. In addition, the three water tankers available could not have kept the snow-maker continuously supplied, so freezing and loss of prime would have been a problem. Moreover, the snowmaker could be operated 24 hours per day while trucks hauled on a reduced schedule.



Building the Alyeska gas feeder lines through a snow work pad. Note 48-inch Alyeska oil pipeline in background at right. (Joint Fish and Wildlife Advisory Team)



Ditcher clearing snow from trench before laying in of the gas feeder line south of Prudhoe Bay. (K.M. Adam)

Snow was hauled from the source, end-dumped at the work pad, and levelled by dozer. Water was sprinkled on the pad to form a hard working surface in the upper 4 to 6 inches (10 to 15 centimetres) of the snow.

At the source of water, snow was manufactured by two air-water-mix nozzles of the Quad Jet type requiring 600 cubic feet (17 cubic metres) of air per minute and 125 to 150 gallons (560 to 675 litres) of water per minute. A 1200-cubic-foot (34-cubic-metre) per minute air compressor and a 6-inch (14-centimetre) pump supplied the air and water. Snow was produced at a rate of about 50 cubic feet per minute (1.4 cubic metres per minute).

Equipment required for the entire operation comprised 3 front-end loaders, 30 dump trucks, 2 crawler tractors, a grader, and several support vehicles. After stockpiling snow at the source, the pad was built in 16 days. The building of this short section of snow work pad involved over 9,000 man-hours, 30,000 loaded truck-miles, and 1200 equipment-hours of machines and support vehicles. Cost was probably in the order of $150,000 for the 1200 feet (370 metres) built.

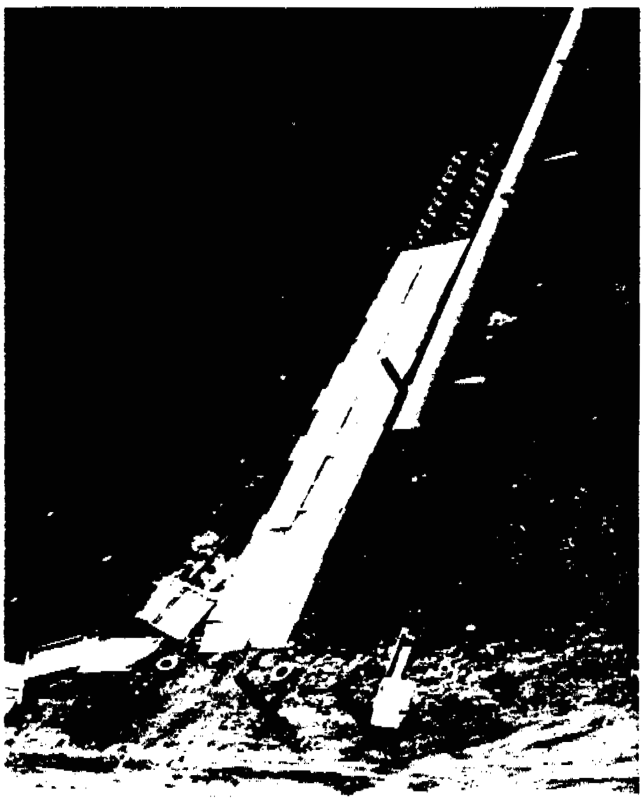
In 1975-76, a second snow pad was used to build the 48-inch (122-centimetre) elevated pipeline east of Toolik Camp between the Kuparuk and Sagavanirktok Rivers over a distance of about 5 miles (8 kilometres). Terrain here is generally flat, with minimal slopes and grades less than 10 percent.

Snow fences were erected along the 5-mile (8-kilometre) section of right-of-way. Snow was quickly deposited by the wind, enabling construction to proceed. Tractors with dozers, a motor patrol with drags, and a snow blower were used to spread and compact the snow over a 50-foot (15-metre) wide work pad. Construction was accomplished in two weeks. A density of 38 pounds per cubic foot (0.60 grams per cubic centimetre) was achieved over the pad which ranged from 12 to 18 inches (30 to 45 centimetres) thick. This pad successfully supported pipeline equipment during installation of vertical support members and support cross members, stringing, welding, and "lowering-up" of the pipeline.

After the snow pad melted, the underlying vegetation mat was undisturbed. Unfortunately, early spring melt necessitated rebuilding of the snow pad the following year (1976-77) to complete construction.

The buried gas fuel line for the four most northerly Alyeska pump stations is being constructed (1975-76 and 1976-77) directly through a snow work pad adjacent to the permanent haul road. Natural snow accumulated along the haul road was used to build a berm to catch additional snow. Once sufficient snow was collected, 3 dozers, 2 drags, 2 motor patrols and 2 grade-alls could build a 50-foot (15-metre) snow pad at a rate of 1 mile (1.6 kilometres) per day. About 60 miles (100 kilometres) of snow work pad were constructed in 1975-76 over grades up to 20 percent and cross slopes to 10 percent. Use was discontinued May 1, 1976.

Surface disturbance caused by construction activities using winter roads or snow work pads has been minimal in Alaska. The greatest hazard results from ditch material getting spread and mixed into the snow pad surface. This is a problem particularly where ditching of frozen gravels by conventional ditchers is impossible, requiring blasting which results in the littering of a large area. Litter from the blast changes the thermal regime at the surface, thereby inducing ground subsidence and thermal erosion in ice-rich areas.



Sheets of plywood laid on rubber tires -- an impractical alternative to winter roads for protecting the terrain. The technique was tried in summer, proved to be unsuccessful, and as a result this section of the Alyeska pipeline had to be completed the following winter from snow work pads. (Joint Fish and Wildlife Advisory Team)

COMMENTARY ON THE INTERVIEWS

Environmental standards for permafrost areas have been substantially upgraded in Canada and Alaska over the last 16 years (1962-1977). Whereas winter roads and seismic lines used to be constructed in permafrost regions with little concern for surface disturbance, this practice has been essentially eliminated. But, environmental standards for nonpermafrost areas have not undergone the same upgrading. In fact, during our interviews it became apparent that terrain disturbance is now much more accepted in nonpermafrost regions than in permafrost regions. It is my opinion that environmental standards for nonpermafrost regions should be brought up to levels more closely approximating those for permafrost areas. This is not to say that the terrain surface should not be broken in nonpermafrost areas during winter road or seismic line construction. It merely recognizes that at present, winter roads and seismic lines in nonpermafrost regions could be left in much better condition (particularly aesthetically). Admittedly, blading or grading the surface is generally accepted in nonpermafrost regions, with the result that winter roads and seismic lines will always appear in worse condition in these regions than in permafrost areas where blading or grading is not accepted.

The degree of terrain protection required in both permafrost and nonpermafrost areas is difficult to establish. Several people we talked to mentioned the need to more clearly define "acceptable terrain disturbance" for both permafrost and nonpermafrost areas. Possibly a conference to address this problem would be in order.

My overall impression is that builders of winter roads in Canada are not presently making full use of the winter road technology developed throught the world. In some cases, the more elaborate techniques are not justified on the basis of either cost or terrain protection. But where elaborate techniques are justified, the correct procedures are not always being followed to give the best road for a given sum of money.

In Alaska, a great deal of experience has been gained in the use of winter roads and snow work pads for pipeline construction. This experience should prove invaluable to future northern pipeline projects in Canada.

The Alaskan experience indicates that natural or artificial snow roads can be constructed to protect the terrain during pipeline construction. This has been proven on the Alyeska pipeline where two short sections of 48-inch (122-centimetre) oil pipeline were constructed from snow roads, and several miles of pump station feeder gas lines were laid directly through snow work pads.

An interesting aspect of snow roads for the 48-inch (122-centimetre) line is that they were chosen for use in areas of very high-ice-content soils. They were successful, although they were not used continuously much over 4 consecutive miles (6 kilometres) and, in cases where snow was manufactured, they were very costly.

However, the question is not whether winter roads can protect the terrain, but whether they can be built over full-length pipeline spreads in time to allow construction of the line itself during the coldest months of winter. At present, the answer to this question seems to be no. The consensus in Alaska, in my opinion, is that snow roads take too long to build, using up valuable time which could be spent on pipeline construction which itself moves at a slow pace during the winter months. For example, weekly construction rates on the Alyeska line often fell below half a mile (nearly one kilometre) per day for even the relatively warm winter months of October, November, April, and May. During the extremely cold mid-winter months with still-air temperatures or wind-chill equivalents below -35°F (-37°C), the productivity of construction workers drops markedly to perhaps one-fourth or less of normal and the operation of heavy equipment becomes more difficult.

If pipeline construction techniques are developed to the point where winter construction rates are three-quarters to one-and-a-half miles (about one to two-and-a-half kilometres) of pipeline per day, winter roads will have to be built at comparable rates if the roads are to keep up with the pipeline.

It is my firm belief that faster rates for building winter roads will come about through the development of specialized road-building equipment. Such equipment might take the form of a low-ground-pressure vehicle carrying a machine much like an asphalt paving machine that could ingest natural, borrowed, or manufactured snow, process it, and lay it down and compact it in a continuous process.

Even though the consensus in Alaska is that snow roads have limited use for full northern pipeline spreads, I believe the consensus will change as technologies improve in the cold weather construction of both pipelines and winter roads.

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APPENDIX 1

MAPS

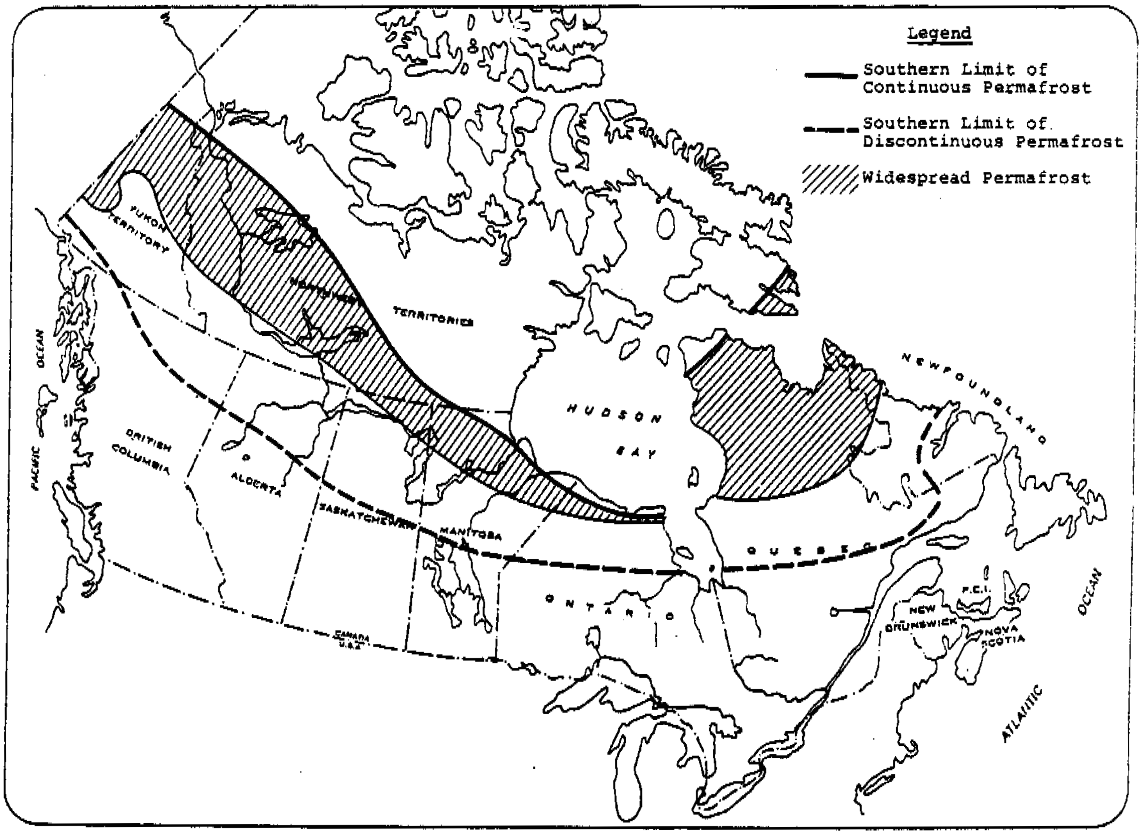


Fig. 1. Permafrost in Canada. (Source: Geological Survey of Canada and the Division of Building Research, 1967)

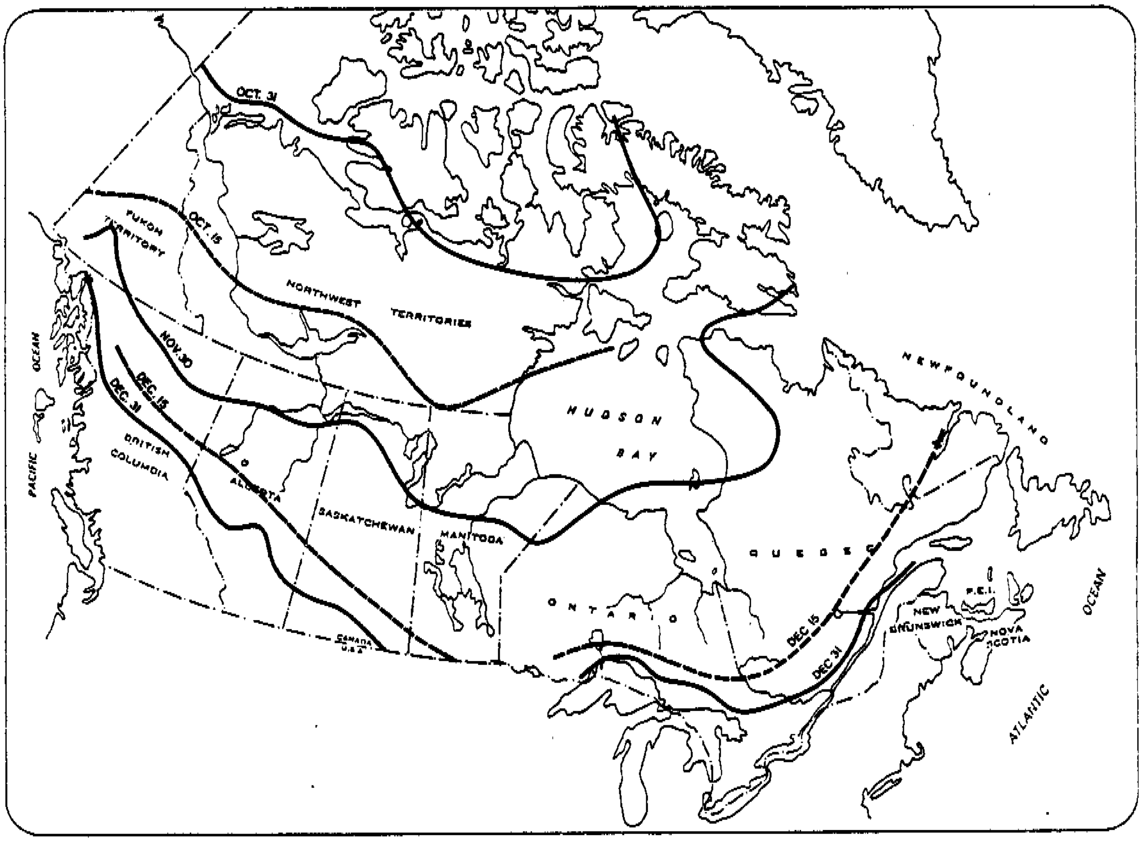


Fig. 2. Average date of mean accumulation of 550°F (306°C) freezing degree days (degree-days below 32°F or 0°C).

Notes:

A degree-day is defined as one degree of deviation, on a single day, of the daily mean temperature, from a given standard temperature. For a given standard temperature of 32°F, a single day with a mean temperature of 27°F would be recorded as 5 freezing degree-days, and a single day with a mean temperature of 37°F would be recorded as 5 thawing degree-days.

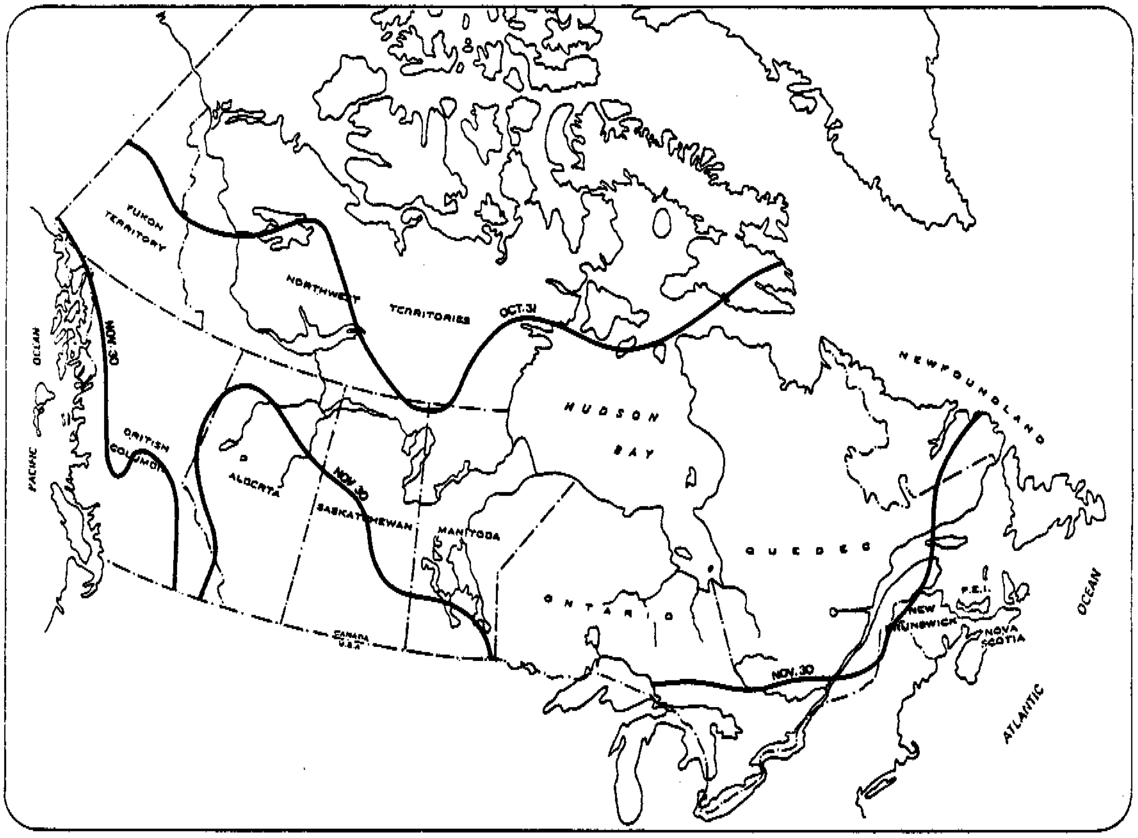


Fig. 3. Average date of first snow depth of at least 4-inches (10 centimetres).

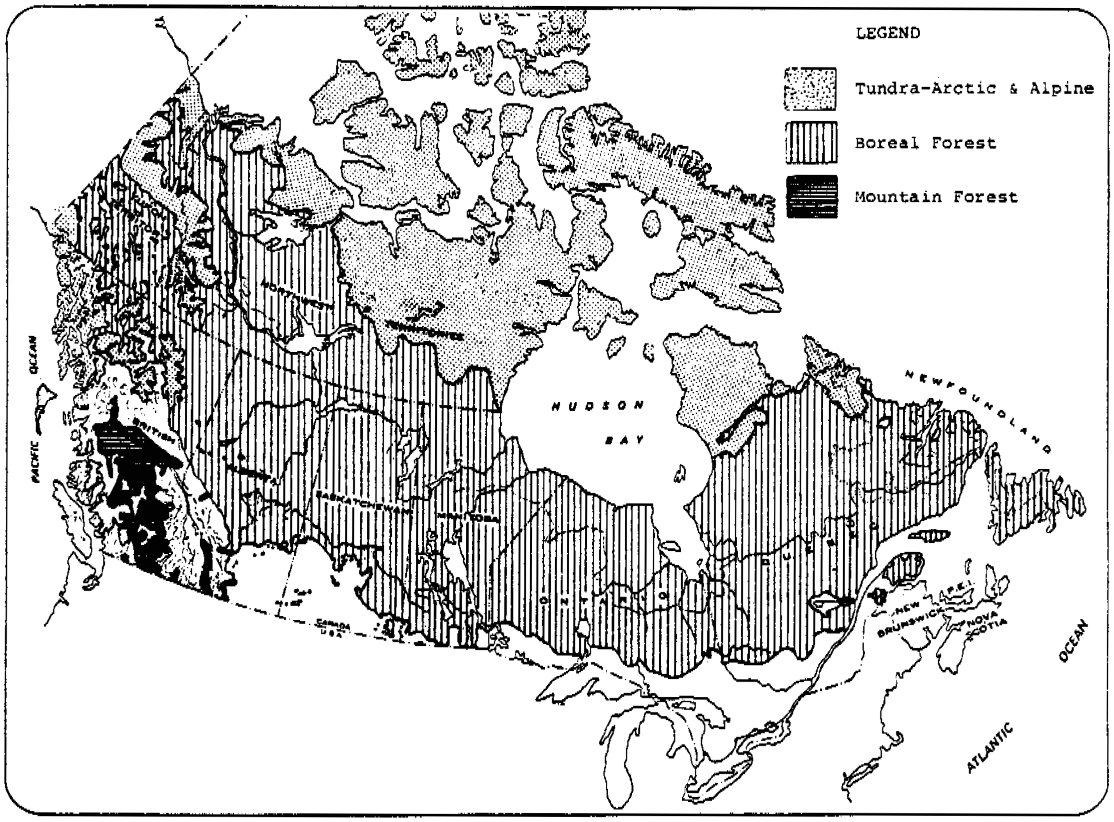


Fig. 4. Natural vegetation regions of Canada.
(Source: Rowe 1972)

APPENDIX 2

BEARING CAPACITY OF ICE

BEARING CAPACITY OF ICE

The following paragraphs discuss the bearing capacity of ice in terms of the thickness of the ice sheet, and the effects of marked changes in temperature and duration of loading. Those who use ice covers for transportation are cautioned that the bearing capacity of ice also depends on the quality of the ice, the presence of cracks, and other properties.

It is possible to develop a knowledge of the load which can be transported safely over ice of given thickness and quality. However, as John Denison points out, the novice operator may be better off than the veteran when it comes to assessing ice strength. In "Denison's Ice Road" (Iglauer 1975), Denison quotes a friend of his as saying that "...the only fellow who knows anything about ice is in his first or second year working on it, because he still has some confidence left. The longer you stay with it, the less you know."

Thickness

The much-used Gold (1960) formula $P = Ah^2$ for computing the bearing capacity of an ice sheet is not meant to give a true measure of the bearing capacity of an ice sheet. Rather, it is the limit below which failure of any ice sheet is unlikely, and it takes into account many of the variables which may exist in ice. Use of this formula allows for a number of safety factors for an ice sheet under less-than-ideal conditions. As such, practical use of this formula may be made with considerable safety.

Temperature Changes

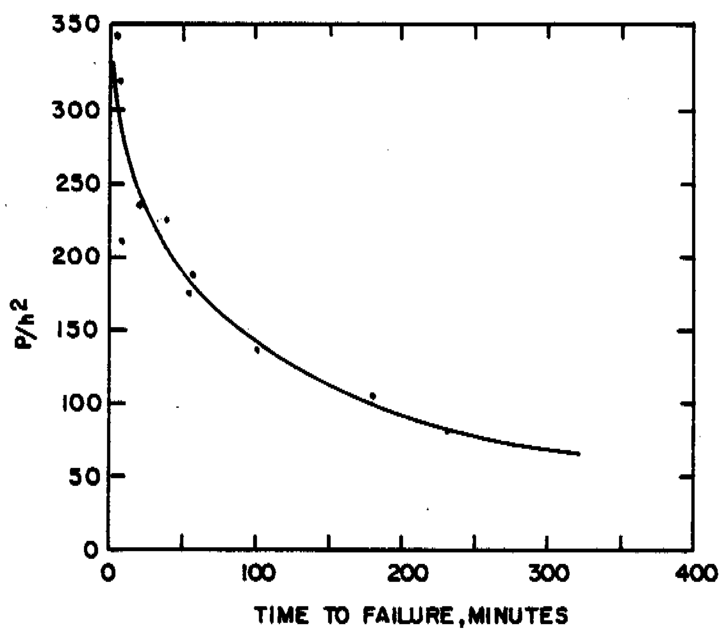
As the temperature falls, the compressive and flexural strength of the ice increase. Hansen and Linell (1956) have recorded the results of tests in which specimens of St. Lawrence River ice were subjected to compressive loads at different temperatures. The compressive strength of the ice increased from 300 pounds per square inch (2100 kilopascals) at 28°F (-2°C) to 797 pounds per square inch (5500 kilopascals) at 2°F (-16°C). The flexural strength of other specimens increased from 156 pounds per square inch (1080 kilopascals) at 28°F to 30°F (-2°C to -1°C) to 240 pounds per square inch (1550 kilopascals) at 14°F to 16°F (-10°C to -9°C).

The temperature of the surface of an ice sheet is generally equal to the temperature of the air immediately above it, whereas the lower surface of the ice is at its melting point. Changes in the air temperature are transmitted slowly through the ice. It has been observed that an increase in freezing rate at the bottom of an ice sheet lagged the drop in surface temperature by some 8 to 10 days.

Because of this thermal time lag, rapid changes in air temperature change the temperature gradient through an ice sheet. This may induce thermal stresses which may be relieved by cracking. Ice that does not crack under these circumstances should be considered unsafe for heavy loads. Ice that does crack may be weakened in the vicinity of the crack and should not carry normal loads for 48 hours or more. After this recovery period, thermal stresses will be relieved by deformation of the ice and load limits can be returned to normal. Some operators, preferring not to wait until the ice has become more stable, move light loads over the ice to induce surface cracking and relieve stresses before proceeding to cross with heavier loads.

Duration of Loading

The longer a static load is applied to ice, the lower the capacity of the ice to support it. Assur (1961) showed this relationship for different static loads and ice thicknesses. Some consideration of this characteristic of ice may be necessary for slow-moving loads since such loads may act as if they were stationary.



Dependence of the time to failure on the loading $A = p/h^2$. (From Assur 1961)

APPENDIX 3

SNOW PROCESSES AND PROPERTIES

SNOW PROCESSES AND PROPERTIES

Snow is a porous material composed of ice crystals (snow flakes) and/or clusters of rounded ice crystals known as ice grains. Spaces between the crystals or grains contain air, water vapor, and sometimes liquid water if the snow is wet.

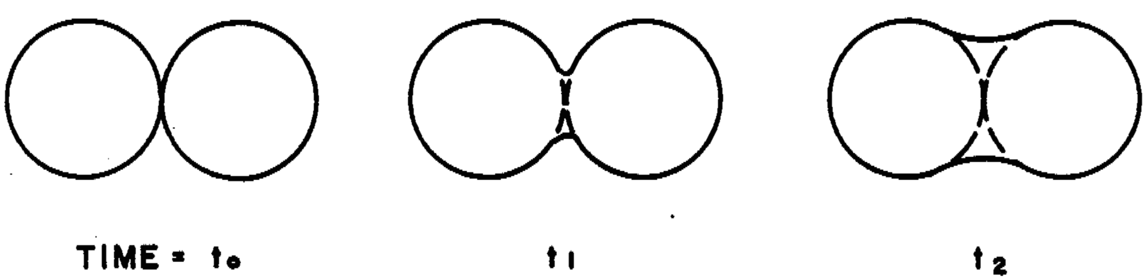
Processes

Snow is not so much a substance as a process. In its natural state, from the time it falls to the ground to the time it becomes meltwater, it is continuously changing with time and other variables such as temperature. Application of pressure, either by compaction or naturally through snow build-up, also causes changes in snow.

After the snow has fallen, the sharp points of the individual snow flakes gradually become blunt. The six-sided crystals become small rounded granules of ice, and the larger granules or grains grow at the expense of the smaller ones by an evaporative process. Grains range from .02 to 0.04 inches (0.5 to 1 millimetre) in diameter, with one or two small crystallographic faces. They tend to bond together by freezing. The density of this fine-grained snow usually ranges from 9 to 16 pounds per cubic foot (0.15 to 0.25 grams per cubic centimetre).

Age-Hardening

In compacted snow, the particles tend to join at their contact points, giving strength to the snow mass. When two grains are placed together, the area of contact between them increases even when the force that brought them together is removed. This phenomenon, well known in powder metallurgy, is called sintering. It is also referred to as age-hardening, and explains the practice of leaving a road to "set" for 24 hours after it has been packed down.



Stylized representation of sintering.

Temperature

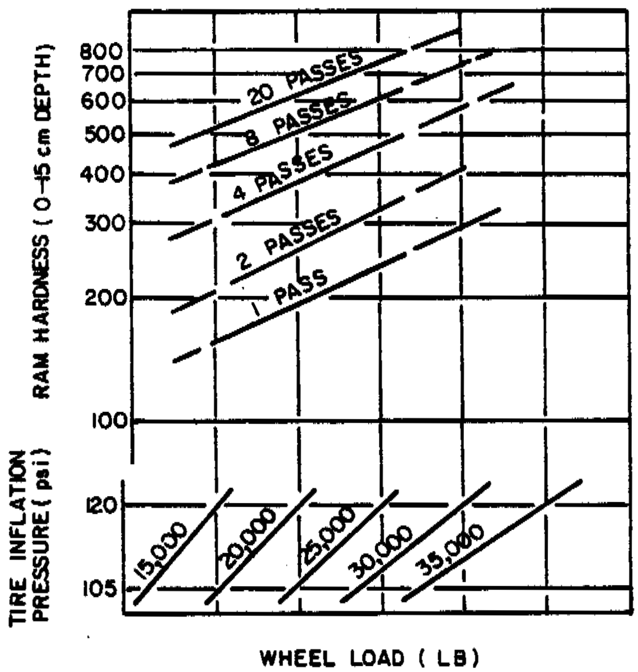
In the classification of materials, temperature is not usually considered to be a property. However, since temperature determines so many properties of snow, it has been discussed in the following paragraphs.

An interesting aspect of temperature in relation to snow roads is that at temperatures approaching 32°F (0°C), snow rapidly loses its hardness. With rising ambient temperatures, the grains of ice stick together in groups, forming large polycrystalline grains with diameters reaching 0.6 inches (15 millimetres). Bonding between these large grains is very weak, and within a few days, the well-known "rotten" snow of the thaw season is produced. Upon re-freezing, however, the wet snow acquires more strength due to the larger bond areas that have developed between the grains.

Ager (1964) studied the influence of temperature on the density and hardness of snow in the temperature range from 30°F to -10°F (-1°C to -23°C). He found that for a given compactive effort, highest densities were achieved at 30°F (-1°C). Subsequently, highest hardness values were obtained when the compacted sample was cooled to -10°F (-23°C). In the ideal situation in the field, snow would be compacted when ambient temperatures were as high as possible, probably late in the afternoon. The road would then be opened to traffic only when temperatures had dropped considerably below freezing and after sufficient time had elapsed to allow for age-hardening.

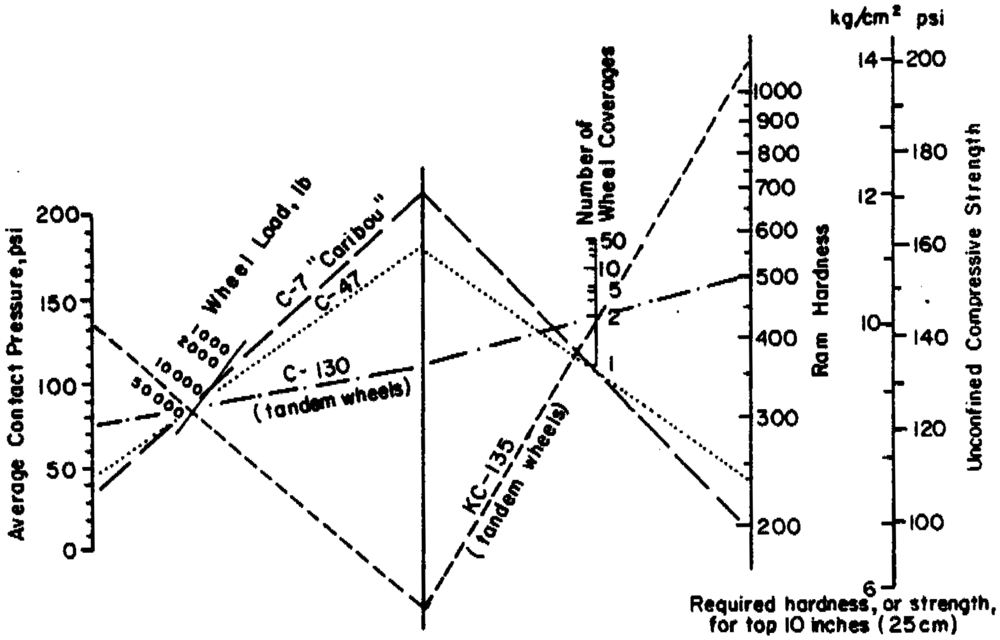
Strength

The strength of snow in relation to winter roads is indicated by rammsonde hardness (see the appendix on snow-testing equipment). The rammsonde hardness needed to support various wheel loads and tire pressures for a specified number of wheel coverages has been given by Wuori (1962). (Wheel coverage refers to the passage of a wheel over a surface.) The hardness values in the graph represent the lowest hardness permissible in the top 6 inches (15 centimetres) of the prepared snow surface. An additional requirement is that the underlying layers have a hardness of at least 75 percent of the surface layer. For example, a snow road with a rammsonde hardness of 600 in the top 6 inches (15 centimetres) and 450 in the underlying layers would be able to sustain one pass of an 8-wheeler with wheel loads of 25,000 pounds (11,000 kilograms) and tire pressures of 120 pounds per square inch (830 kilopascals).



Required ram hardness for supporting various wheel loads. The abcissa indicates wheel loads at various tire inflation pressures. (After Wuori, Supporting Capacity of Processed Snow Runways, CRREL, 1962)

The rammsonde hardness of a snow pavement has also been correlated to the unconfined compressive strength. Clark, Abele, and Wuori (1974) present a nomograph in which the unconfined compressive strength is related to various wheel loads, contact pressures and number of wheel coverages. The use of the Rammsonde penetrometer in conjunction with a nomograph, as shown in the illustration, facilitates quality control during construction of snow pavements as well as the monitoring of performance during operation.



Required hardness of a snow pavement for various wheel load conditions. Examples in the use of the nomograph are shown for various aircraft. (After Clark, Abele, and Wuori, Expedient Snow Airstrip Construction Technique, CRREL, 1973)

APPENDIX 4

EQUIPMENT FOR TESTING WINTER ROADS

EQUIPMENT FOR TESTING WINTER ROADS

Four basic sets of equipment are used to collect winter road test site data: a Rammsonde snow hardness instrument, a 3-inch (8-centimetre) ice-coring auger kit, a snow observation kit, and an ice-thickness kit.

Rammsonde

The illustration shows a Rammsonde cone penetrometer used in the field to measure snow hardness. It can be used to measure the hardness of undisturbed snow covers as well as the compacted snow surfaces of snow roads and runways.

It consists of a stainless steel shaft with a 60 degree conical tip at one end and a drop hammer mounted on a guide rod at the other. The instrument measures the hardness of snow based on the penetration of the cone under the impact of the drop hammer.

The hammer is raised by hand to a certain height, which is read in centimetres on the guide rod, and then allowed to drop freely. The depth of penetration of the cone is read from the centimetre scale on the shaft. The resistance to penetration or hardness of the snow can be determined by counting the number of blows necessary to obtain a certain penetration. In relatively hard, homogeneous snow, it is usually more convenient to determine the number of blows needed to penetrate through some predetermined depth increment. Recording the number of hammer blows after each 5-centimetre (2-inch)* depth increment is a convenient procedure commonly used. In layered and new, soft snow, the more satisfactory procedure is to observe the amount of penetration after each hammer blow.

The standard Rammsonde kit contains 2 drop hammers, 1 kilogram (2.2 pounds) and 3 kilograms (6.6 pounds) in weight. A combination of one of the hammer weights and some drop height up to 50 centimetres (up to 20 inches) usually allows a suitable rate of penetration in a great variety of snows. A suitable penetration rate is between 1 centimetre (0.4 inches) for 5 hammer blows to 4 centimetres (1.6 inches) for 1 blow.

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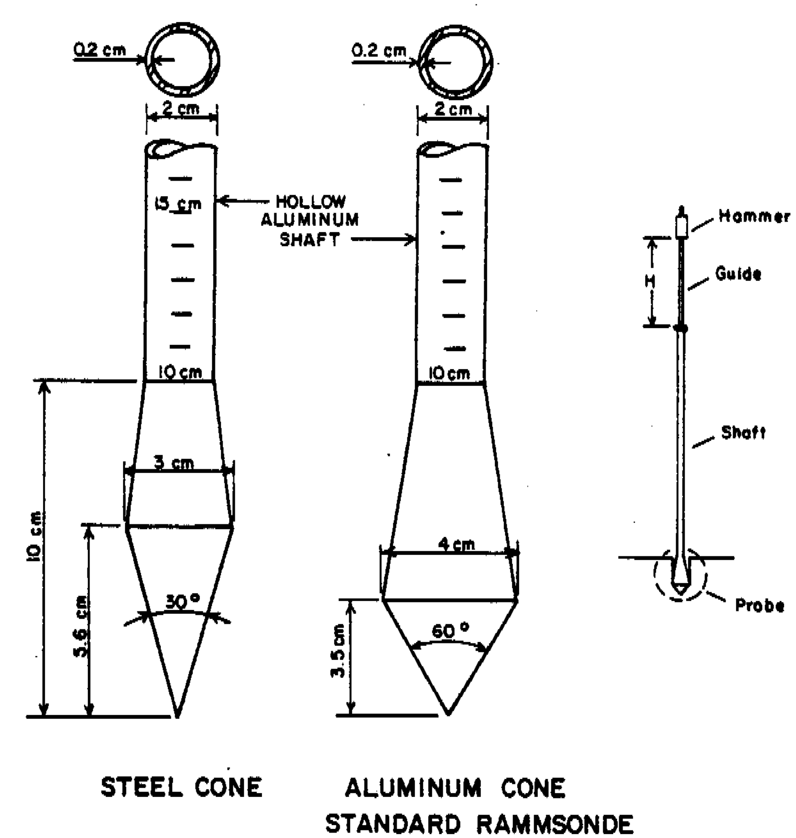
*Metric units are shown first in this section because the shaft of the Rammsonde penetrometer is graduated in centimetres and the hammer weights are in kilograms.



Rammsonde cone penetrometer with 60° and 30° tips.

The fewer combinations of hammer weight and drop height used during a series of tests, the more convenient is the subsequent data reduction.

The rammsonde hardness is computed from the following expression:

$$R = \frac{Whn}{X} + W + Q$$

R = ram hardness number

W = weight of drop hammer (kilograms)

h = height of drop (centimetres)

n = number of hammer blows

x = penetration after n blows (centimetres)

Q = weight of penetrometer (kilograms)

The rammsonde hardness number, R, is an arbitrary index that indicates the resistance in kilograms offered by snow to the vertical penetration caused by ramming a metal cone of given dimensions. The hardness reading at any depth, obtained when the tip of the cone is at that depth, represents the mean hardness through the depth increment between the final and the previous reading.

Although R has units of kilograms, the magnitude of R has no real significance except in relative terms.

A limitation of the 60° Rammsonde cone penetrometer is that it becomes unreliable as an indicator when hardness values exceed 800 kilograms. This has lead to development of a 30° Rammsonde penetrometer which achieves penetration into harder snow.

Ice-Coring Auger Kit

This instrument is a hand-operated auger used to obtain ice cores. Designed for one-man operation, it is capable of augering 3-inch (7.5-centimetre) cores to a depth of 20 feet (6 metres).

The all-stainless-steel core barrel has an outside diameter of 4.5 inches (11 centimetres) and an overall length of 36 inches (92 centimetres). It has a welded double helix flight configuration welded around the outside, eight holes through the wall along its length, and a large flange at the top to allow passage of the cuttings and recovery of the core. A stainless steel cutting shoe with removeable cutting inserts fastens to the bottom of the barrel. Extensions can increase the boring depth to about 20 feet (6 metres) for one-man operation. A driving head couples the augers to the extensions and permits the core to be recovered through the top of the barrel.

Snow Observation Kit

This kit has been designed to provide information on the properties and physical features of the snowcover, its magnitude, distribution, and variability. The instruments it contains are adaptable to many types of snow-cover studies.

The complete kit includes 12 sampling tubes each with 2 rubber caps in a fiber case, tube mandrel, temperature compensated spring scale, graduated grid plate, hand lens, 6 bi-metallic thermometers, snow cutter, 2 punches for insertion of thermometers, and high- and low-capacity hardness penetrometers.

Snow density is determined by carefully inserting the 30-cubic-inch (500-cubic-centimetre) capacity stainless steel snow tubes into snow, capping them, and then carefully weighing the filled tubes on the special spring scale provided. Temperature is measured with the bi-metallic, stainless steel thermometers. The hardness index is determined by use of special push type spring penetrometers with provision for mounting several different sizes of discs on the end of the push rod.

Ice Thickness Kit

The ice thickness kit was developed for rapid manual drilling and measurement of ice thickness. It drills 1-inch (2.5-centimetre) diameter holes through dense ice with great speed and ease. The kit includes a stainless steel close-flighted auger 1 inch (2.5 centimetres) in diameter and 37 inches (1 metre) long. Graduated extension rods, a brace, and an adapter for extensions to the driving auger are also included.

APPENDIX 5

SAFETY, SURVIVAL, AND EQUIPMENT RECOVERY

SAFETY, SURVIVAL, AND EQUIPMENT RECOVERY

One hazard of winter roads on lakes and rivers is the possibility of ice failure. Loss of life and equipment is an ever present danger.

Testing and monitoring of ice conditions are the main prevention methods, combined with reasonable safety factors. However, even with good testing and monitoring, accidents can happen.

Early in the year when the ice is thin, personnel testing ice should work in groups of not less than two. People should not walk close together, and one or both should carry a safety rope. If one member of a party falls through the ice, a rope or pole should be extended to the victim. Where neither is available, an article of clothing can be extended to the victim but the rescuer should lie flat out on the ice to do so. Since ice in the vicinity of a breakthrough is thin, it may be necessary for the victim to break ice until he reaches thicker layers. The victim should slowly extend himself up until his upper body lies flat on the ice. He should slowly edge forward bringing his thighs and legs slowly onto the ice sheet. The rescuer should edge backward, keeping the greatest possible distance between himself and the victim at all times. The victim should move away from the breakthrough several feet while lying flat.

Survival after a breakthrough can be difficult. Foresight in the light of possible difficulties is important. All personnel should carry matches in waterproof containers <u>on their person</u>. Additional clothing or sleeping bags can also be invaluable.

Knowing what to do and what to expect when a vehicle goes through the ice greatly improves one's chances of survival. Operators should mentally prepare a survival plan. They should also understand that their first responsibility is to save themselves, not their vehicles.

Once a vehicle starts to break through, it is not possible to save it by driving it out. Most rubber-tired vehicles do not break through instantly: there is usually enough time to jump clear. Heavy vehicles break through more quickly. But even here it is possible to get out, even if the vehicle is under water. If the operator has gone down with the machine, he will descend rapidly until he can get free of the suction. Once free, he should look for daylight through the opening of the breakthrough. If disoriented, he can release a little air and follow the

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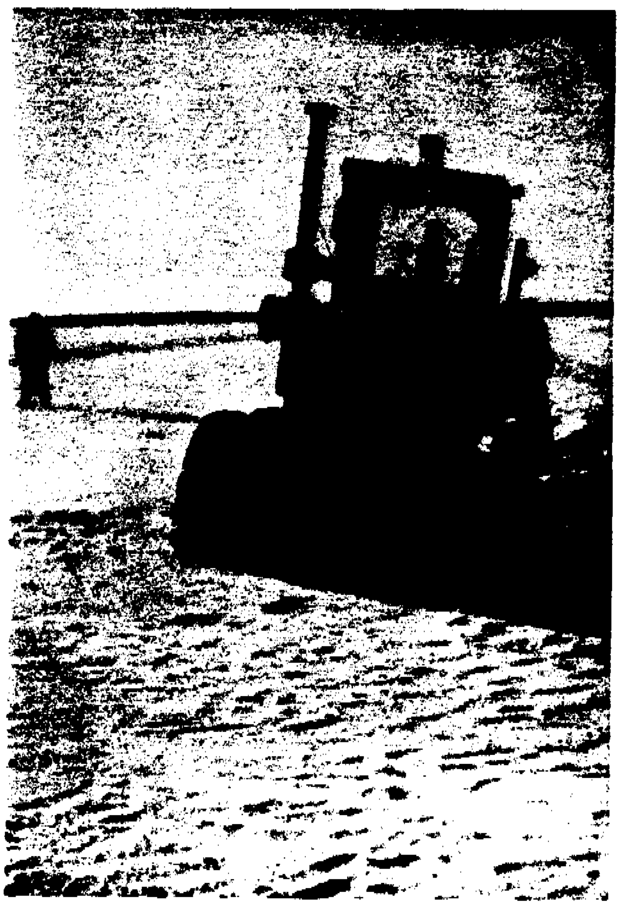
In one incident (Iglauer 1975), the driver of a Cat crossing ice only 14 inches (35 centimetres) thick stood on the running board ready to jump free if the machine went through. But he was under water before he knew what had happened. The suction pulled him down until the Cat stopped falling. Then the displaced water boiled up, pushing him to the surface where he was able to pull himself onto the ice.

The ice may sometimes return to its original position after a breakthrough, sealing off the opening and blocking escape. To protect themselves from such an eventuality, some operators have been known to "walk" large pieces of equipment across the ice, steering them from several yards (metres) behind by means of ropes.

After a machine breaks through the ice, it is important to stay well away from the breakthrough, particularly with other vehicles. The biggest mistake to be made in this case is to attempt recovery immediately. Equipment will not rust below water in a few days or weeks. Immediate recovery is not important.

(Department of Northern Saskatchewan)

This happens frequently on winter roads.
(K.M. Adam)



The blade on this grader prevented it from falling through the ice.
(Department of Northern Saskatchewan)

Accidents happen when recovery is attempted too soon. Even fatal accidents can result, as happened recently when a car fell through the ice. The driver survived, went for help, and returned immediately with a tow-truck which also went through the ice. The truck driver jumped free; but the original driver of the car, who was riding in the cab of the tow-truck, did not get out in time.

Once a vehicle is through the ice, leave it there until the ice thickens naturally. Thickening can be speeded up by removing the snow around the breakthrough by hand or by light-weight machine. After the ice has thickened, a workpad can be built-up by pumping water onto the surface in 2-inch (5-centimetre) lifts as for ice bridge construction. A long crane that extends over the breakthrough from the workpad is recommended for recovery.

The proposed recovery system and ice thickness should be checked by a professional engineer before recovery is attempted. The ice should also be checked for cracks and if necessary, appropriate load reductions applied.

Signs are an important part of safety programs. (K.M. Adam)

APPENDIX 6

PERSONS CONTACTED OR INTERVIEWED

PERSONS CONTACTED OR INTERVIEWED

Mr. Gunar Abele
Cold Regions Research
and Engineering Laboratory
Hanover, New Hampshire

Mr. Bruce Adamson
Ministry of National Resources
Thunder Bay, Ontario

Alberta Dept. of Environment
Edmonton, Alberta

Alyeska Pipeline Service Co.
Anchorage, Alaska

Amoco Canada Petroleum Co. Ltd.
Calgary, Alberta

Mr. Paul Amyot
Hydro-Quebec
Montreal, Quebec

Mr. G.R. Appleton
Canadian Arctic Gas Study Ltd.
Calgary, Alberta

Arctic Institute of North America
Calgary, Alberta

Arctic Petroleum Operators Assoc.
Calgary, Alberta

Mr. George Armstrong
Ft. Francis, Ontario

Mr. Gilbert Aubin
Domtar Woodlands Ltd.
Deolbeau, Quebec

Mr. Ken Baker
Government of Yukon Territory
Whitehorse, Yukon

Mr. Ken Baker
McMillan Construction
Inuvik, N.W.T.

Mr. Vern Bannerman
Dept. of Northern Saskatchewan
Prince Albert, Saskatchewan

Mr. Ed Barrie
Ontario Dept. Highways
Cochrane, Ontario

Beattie Contractors Ltd.
Inuvik, N.W.T.

Mr. Tom Beck
Aquitaine Company of Canada
CaCalgary, Alberta

Mr. John Becker
Dept. of Highways
Douglas, Alaska

Mr. Jean Belanger
Real Ste-Marie Ltee
Montreal, Quebec

Mr. D.A. Beliveau
Saskatchewan Dept. of Highways
Regina, Saskatchewan

Mr. Carl Benke
Shell Canada Ltd.
Calgary, Alberta

Mr. Basil Benson
Ministry of Natural Resources
Toronto, Ontario

Dr. Carl E. Benson
University of Alaska
Fairbanks, Alaska

Mr. Jim Bentley
Dept. of Highways
Yellowknife, N.W.T.

Mr. Y. Bergevin
F.A. (Canada) Tucker Ltd.
Montreal, P.Q.

Mr. J.P. Betteridge
Imperial Oil Limited
Inuvik, N.W.T.

Mr. Ivan Bishko
Northern Geophysical Ltd.
Calgary, Alberta

Dr. Larry Bliss
University of Alberta
Edmonton, Alberta

Mr. Fred Boness
Dept. of Law
Juneau, Alaska

Mr. Carl Bonke
Shell Oil Limited
Calgary, Alberta

Mr. Ted Boodle
Dept. of Forestry
Inuvik, N.W.T.

Ken Borek Limited
Dawson Creek, B.C.

Mr. Clive Boyd
General Enterprises
Whitehorse, Yukon

B.P. Oil and Gas Ltd.
Calgary, Alberta

Mr. W.R. Bradette
M.J. Labelle Co. Ltd.
Cochrane, Ontario

Mr. Gene Bretton
Dept. of Indian Affairs and
Northern Development
Sioux Lookout, Ontario

Dr. Max C. Brewer
Husky Oil
Anchorage, Alaska

Dr. M.E. (Max) Britton
Arlington, Virginia

Brock Construction
Swimming Point, N.W.T.

Dr. Jerry Brown
Cold Regions Research and
Engineering Laboratory
Hanover, New Hampshire

Dr. Roger Brown
National Research Council
Ottawa, Ontario

Mr. Alexander Buchanan
Spruce Falls Power and Paper
Kapuskasing, Ontario

Mr. Mark Buckley
Alaska Dept. of Fish and Game
Anchorage, Alaska

Mr. John Burnett
Bureau of Land Management
Anchorage, Alaska

Mr. G.R. Burt
University of Alaska
College, Alaska

Byers Transport
Yellowknife, N.W.T.

Mr. Keith Byran
General Enterprises
Whitehorse, Yukon

Mr. G. Campbell
North Star Service & Const. Ltd.
Inuvik, N.W.T.

Mr. L. Cardinal
Cardinal Transport Ltd.
Inuvik, N.W.T.

Mr. J. Carpenter,
Northwest Lands and Forest
Service,
Inuvik, N.W.T.

Mr. Allan Carson
Joint Fish/Wildlife Advisory Team
Anchorage, Alaska

Mr. G. Caron
Bannister Pipelines
Edmonton, Alberta

Mr. William L. Clithero
U.S. Dept. of the Interior
Fairbanks, Alaska

Mr. Jim Coan
U.S. Dept. of the Interior
Anchorage, Alaska

Mr. Grant Conlin,
Dept. of Northern Saskatchewan
Prince Albert, Saskatchewan

Mr. Jim M. Collins
Winnipeg, Manitoba

Mr. J. Corej
BG Checo Engineering Ltd.
Montreal, P.Q.

Mr. Joe Costa
Dept. of Northern Saskatchewan
Prince Alberta, Saskatchewan

Mr. Chris Cuddy
Dept. of Indian Affairs and Northern Development
Yellowknife, N.W.T.

Mr. R.W. Culley
Dept. of Highways
Regina, Saskatchewan

Mr. H.J. Brian Curran
Environment Canada
Hull, Quebec

Mr. Lorne Dalke
Chetwynd Forest Industries Ltd.
Chetwynd, B.C.

Mr. N.R. Dawson
F.A. (Canada) Tucker Ltd.
Montreal, P.Q.

Mr. R. Davies
Dept. of Public Works
Whitehorse, Yukon

Mr. M. Thomas Dean
Bureau of Land Management
Fairbanks, Alaska

Mr. John Denison
c/o Robinson's Trucking
Yellowknife, N.W.T.

Mr. Jerry Desourdy
Desourdy Construction
St. Hubert, Quebec

Mr. Don Dickson
Ontario-Minnesota Pulp and Paper
Kenora, Ontario

Mr. V. Dirk
Bannister Pipelines
Edmonton, Alberta

Mr. Al Diteman
Forestry Dept. Alberta Government
Edmonton, Alberta

Mr. Lee Doran
Polar Gas
Toronto, Ontario

Mr. Murray Drope
Northern Engineering Services
Calgary, Alberta

Dr. Marc Drouin
James Bay Energy Corp.
Montreal, Quebec

Mr. Fleming Einfeldt
Netherlands Overlands
Prince George, B.C.

Mr. Lance G. Elphic
Dept. of Environmental Conservation
Juneau, Alaska

Mr. L. Emard
c/o Borek Construction
Dawson Creek, B.C.

Estabrook Construction Ltd.
Grimshaw, Alberta

Mr. Harold Evenson
Northwest Wood Preserves
Dawson Creek, B.C.

Dr. Kaye Everett
Ohio State University,
Columbis, Ohio

Falcon Transport Ltd.
Edmonton, Alberta

Mr. Dale Fickenger
Pancana Industries Ltd.
Calgary, Alberta

Foothills Pipe Lines Ltd.
Calgary, Alberta

Dr. Karl Francis
Alaskan Arctic Study Ltd.
Anchorage, Alaska

Dr. R. Frederking
National Research Council
Ottawa, Ontario

Mr. Ken Fulton
Public Works of Canada
Toronto, Ontario

Dr. H. William Gabriel
Bureau of Land Management
Anchorage, Alaska

Mr. Harry Gairns
Industrial Forestry Service Ltd.
Prince George, B.C.

Mr. Armand Garneau
Ministry of Transport
Hauterive, Quebec

Mr. Jon Globig
Alyeska Pipeline Service Co.
Anchorage, Alaska

Dr. Lorne Gold
National Research Council
Ottawa, Ontario

Goodsec Construction
Hay River, N.W.T.

Mr. Louis Goulet
St. Lawrence Construction
Co. Ltd.
Beaufort, Quebec

Mr. Eric Gourdeau
Quebec City, Quebec

Gulf Oil Canada Ltd.
Inuvik, N.W.T.

Mr. Jake Gunther
Northwood Pulp and Paper Co.
Prince George, B.C.

Mr. Jim Guthrie
Gulf Oil Canada Ltd.
Inuvik, N.W.T.

Mr. John Halkowich
Dept. of Northern Affairs
Hole River, Manitoba

Mr. Dick Hamilton
Alaska Dept. of Highways
Juneau (Douglas), Alaska

Mr. Bill Hanna
Public Works of Canada
Toronto, Ontario

Mr. Frank Harrison
Reed Paper Ltd.
Dryden, Ontario

Mr. A.K. Hartnett
Ministry of Natural Resources
Toronto, Ontario

Mr. Roy Hatch
Northwood Pulp and Paper Co.
Prince George, B.C.

Mr. J.W. Hawryzsko
Transport Canada
Ottawa, Ontario

Mr. James E. Hemming
Joint Fish/Wildlife
Advisory Team
Anchorage, Alaska

Mr. R.A. Hemstock
Canadian Arctic Gas Study Ltd.
Calgary, Alberta

Dr. L. Hettinger
R.M. Hardy and Associates
Calgary, Alberta

Mr. Ford Hewlitt
Springdale, Newfoundland

Mr. G.R. Higginson
Environment Protection Service
Ottawa, Ontario

Mr. R.M. Hill
Inuvik Research Laboratory
Inuvik, N.W.T.

Mr. Hilliker
Domtar Woodlands Ltd.
Quevillon, Quebec

Mr. Robert W. Huck
Office of the Pipeline
Co-ordinator
Anchorage, Alaska

John Hudson
Dept. of Public Works Canada
Whitehorse, Yukon

Imperial Oil Limited
Inuvik, N.W.T.

Mr. Paul Jarvis
Unies Ltd.
Winnipeg, Manitoba

Mr. J. Jackson
Dept. of Transportation
Wickham, New Brunswick

Mr. Jackie H. Johnson
Clearwater Lake, Manitoba

Mr. Jan Johnson
Cardinal Trucking
Inuvik, N.W.T.

Mr. Philip Johnson
Cold Regions Research and
Engineering Laboratory
Fairbanks, Alaska

Mr. R. Johnson
Bowater Newfoundland
Cornerbrook, Newfoundland

Dr. G.H. Johnston
National Research Council
Ottawa, Ontario

Kaps Transport Ltd.
Hay River, N.W.T.

Keen Industries Ltd.
Fort Simpson, N.W.T.

Mr. Bob Keen
Keen Industries Ltd.
Edmonton, Alberta

Kenaston Contractors Ltd.
Inuvik, N.W.T.

Mr. K.E. Kepke
Dept. of Indian Affairs and
Northern Development
Ottawa, Ontario.

Mr. Jim Kerr
Brock Construction
Edmonton, Alberta

Mr. Don Keyes
Dept. of the Interior
Anchorage, Alaska

Mr. Richard Knowles
Atlantic Richfield Company
Anchorage, Alaska

Mr. Bill Kuzemchuk
Ministry of Natural Resources
Sioux Lookout, Ontario

Prof. B. Ladanyi
Ecole Polytechnic
Montreal, Quebec

Mr. W. Victor Lancaster
Canadair Flextrac Ltd.
Calgary, Alberta

Mr. Howard Leslie
Panarctic Oils Ltd
Calgary, Alberta

Mr. Dale Longlitz
Dept. of Indian Affairs and
Northern Development
Yellowknife, N.W.T.

Dr. Fred Lotspeich
University of Alaska
Fairbanks, Alaska

Mr. Warner Loven
Western Geophysical
Calgary, Alberta

Mr. Daun Lowther
Dept. of Northern Affairs
Thompson, Manitoba

Dr. Ross MacKay
University of British
Columbia
Vancouver, B.C.

MacMillan Const. Peace River Ltd.
Peace River, Alberta

Mr. Bruce MacNicol
B.C. Forest Products Ltd.
Mackenzie, B.C.

Mr. D. Manual
Dept. of Transportation
Chipman, New Brunswick

Mr. Lynn Marcellus
Ontario Dept. of Highways
Kenora, Ontario

Mr. Michael McArthur
Bailey Bridge and
Pitts Associates Ltd.
Vancouver, B.C.

Mr. Jeffrey McGrath
Les Constructions du
St-Laurent Ltee
Beauport, Quebec

Mr. R.D. McKelvie
Price Newfoundland
Grand Falls, Newfoundland

Mr. J.D. (Doug) McMillan
Dept. of Highways
Prince Albert, Saskatchewan

Dr. B. Michel
Laval University
Montreal, Quebec

Mr. Lorne Milbourn
Borek Construction
Dawson Creek, B.C.

Mr. Cliff Miller
Imperial Oil Ltd.
Edmonton, Alberta

Mr. Gary Milke
Alaska Dept. of Fish and Game
Fairbanks, Alaska

Mr. David Mowbray
Gulf Oil Canada Ltd
Calgary, Alberta

Mr. D.V. Myles
Environment Canada
Ottawa, Ontario

Mr. Murray Orbanski
M.J. Orbanski Construction
Riverton, Manitoba

Mr. John D. Ostrick
Inuvik Research Laboratory
Inuvik, N.W.T.

Mr. Jean-Louis Parent
Consolidated-Bathurst Ltd.
Grand'Mere, Quebec

Mr. Walter B. Parker
Federal-State Land Use Planning
Commission for Alaska
Anchorage, Alaska

Mr. Vladimir Pasicnyk
Takla Logging Company Ltd.
Prince George, B.C.

Mr. Bill Patterson
A.D.I. Limited
Fredricton, New Brunswick

Mr. R. Pelley
Dept. of Forestry and
Agriculture
Pleasantville, Newfoundland

Mr. Milton Penttila
Kimberly-Clark of Canada Ltd.
Longlac, Ontario

Mr. Perron
Consolidated-Bathurst Ltd.
Grand-Mere, Quebec

Mr. Perry Pike
Abitibi Paper Co. Ltd.
Iroquois Falls, Ontario

Mr. Don Propp
Northern Geophysical Ltd.
Calgary, Alberta

Mr. Bill Quirk
Western Geophysical
Calgary, Alberta

Mr. J.R. Radforth
Venture Technical Services
Bracebridge, Ontario

Mr. N.W. Radforth
Radforth and Associates
Fredericton, New Brunswick

Mr. Bill Rainney
Ontario Dept. of Highways
Thunder Bay, Ontario

Mr. Doug Readman
Tower Trucking
Edmonton, Alberta

Reed Paper Company
Forestville, Quebec

Mr. Gerry Rempel
Imperial Oil Ltd.
Calgary, Alberta

Mr. Ron Richardson
Chevron Standard
Calgary, Alberta

Mr. Dick Robinson
Robinson's Trucking
Yellowknife, N.W.T.

Mr. R. Rollefson
Dept. of Indian Affairs and
Northern Development
Yellowknife, N.W.T.

Mr. J. Routledge
Mobil Oil
Edmonton, Alberta

Mr. W.H.D. Rowan
MHTR
Guelph, Ontario

Mr. John Rymen
J.E. Rymen Engineering
Calgary, Alberta

Mr. W.N. (Bill) Sanregret
Indian and Northern Affairs
Whitehorse, Yukon

Mr. David O. Scott, Jr.
Bureau of Land Management
Fairbanks, Alaska

Mr. Bob Seeiran
Ontario Dept. of Highways
Kenora, Ontario

Mr. B.E. Seppala
Dept. of Northern Affairs
Province of Manitoba
Thompson, Manitoba

Mr. Mickey L. Sexton
Atlantic Richfield Company
Anchorage, Alaska

Shell Oil Canada Ltd.
Inuvik, N.W.T.

Mr. Tom Sigfusson
Sigfusson Transportation
Winnipeg, Manitoba

Mr. Ross Silverside
Forest Management Institute
Ottawa, Ontario

Mr. Nelson Skidmore
Ontario Dept. of Highways
Cochrane, Ontario

Mr. Otto Slavik
Netherlands Overseas
Prince George, B.C.

Mr. Bob Smiley
Transportation Division, DIAND
Ottawa, Ontario

Mr. W.N. Sorensen
Alyeska Pipeline Service
Company
Anchorage, Alaska

Mr. K. St. George
Bowater Newfoundland Ltd.
Cornerbrook, Newfoundland

Mr. John H. Stephenson
Bureau of Land Management
Fairbanks, Alaska

Mr. Gerald Stuart
Energy and Natural Resources
Edmonton, Alberta

Mr. Dave Sturdevant
Environmental Conservation
Juneau, Alaska

Mr. John Tait
Abitibi-Price Co. Ltd.
Toronto, Ontario

Mr. Hugh Taylor
Dept. of Forestry
Hay River, N.W.T.

Mr. Roy Taylor
Acrow Canada Limited
Vancouver, B.C.

Mr. Jack Thompson
Canfor
Chetwynd, B.C.

Mr. Kip Thompson
Ilford, Manitoba

Mr. Roy Thurm
Northern Engineering Services
Calgary, Alberta

Mr. A. Tink
Mobil Oil
Edmonton, Alberta

Mr. A.B. Tompkins
Thompkins Contracting
Fort St. John, B.C.

Mr. Al Townsend
Joint Fish/Wildlife Advisory Team
Fairbanks, Alaska

Mr. James K. Trimble
Alaska Arctic Gas Pipeline
Anchorage, Alaska

Mr. W.R. Tuer
Dept. of Highways and
Transportation
Regina, Saskatchewan

Mr. Turner
Dept. of the Interior
Anchorage, Alaska

Mr. A.G. Turnock
Imperial Oil Ltd.
Edmonton, Alberta

Mr. M.J. Wagner
Bannister Pipelines
Edmonton, Alberta

Mr. Tom Watmore
Imperial Oil Ltd.
calgary, Alberta

Mr. Lloyd Webber
Netherlands Overseas
Prince George, B.C.

Dr. R.B. Weeden
Office of the Governor
Juneau, Alaska

Dr. Warren Weikert
Cold Regions Research and
Engineering Laboratory
Hanover, New Hampshire

Dr. Ross W. Wein
Department of Biology
University of New Brunswick
Fredericton, New Brunswick

Mr. G.L. Williams
Williams Brothers Canada Ltd.
Calgary, Alberta

Mr. Don Wilson
Reed Paper Ltd.
Dryden, Ontario

Mr. R.G. (Bob) Wilson
Imperial Oil Ltd.
Edmonton, Alberta

Mr. T. Murray Wilson
Imperial Oil Ltd.
Calgary, Alberta

Mr. Cliff Wolfe
Dept. of Indian Affairs and
Northern Development
Ottawa, Ontario

Woodlands Dept.
Spruce Falls Pulp and Paper Co.
Kapuskasing, Ontario

Mr. Al Wright
Government of the Yukon
Territory
Whitehorse, Yukon

Mr. Carl Yanagawa
Joint Fish/Wildlife Advisory
Team
Anchorage, Alaska

Dr. G.A. Yarranton
Dept. of Indian Affairs and
Northern Development
Ottawa, Ontario

Dr. W.E. Younkin
Northern Engineering Services
Calgary, Alberta