INVESTIGATION OF AIRFIELD DRAINAGE
ARCTIC AND SUBARCTIC REGIONS

SUPPLEMENT TO PART I
FIELD RECONNAISSANCE AND ANALYSIS

by
St. Anthony Falls Hydraulic Laboratory
University of Minnesota

Project Report No. 18

Submitted by
Lorenz G. Straub
Director

Prepared by
Loyal A. Johnson

January, 1950

Prepared for
St. Paul District
Corps of Engineers, U. S. Army

PREFACE

This report summarizes observations that were made during a field trip to Alaska in the spring of 1949. Principal objectives of this phase of the Arctic and Subarctic Airfield Drainage Investigation were (1) to make supplemental on-the-ground observations over a wide range of hydrological phenomena, (2) to note the various forms and effects of icing, (3) to observe springtime runoff from natural watersheds, and (4) to crystallize the findings of activity completed at this time into definite recommendations and point out various aspects where continuation and even expansion of research and study are essential.

The field work was conducted under Contract W-21-018-eng-430, dated July, 1947, between the University of Minnesota and the St. Paul District, Corps of Engineers, U. S. Army. Actual research activity was performed by Loyal A. Johnson, Research Associate, under the general supervision of Dr. Lorenz G. Straub, Director, St. Anthony Falls Hydraulic Laboratory and Head of Civil Engineering at the University of Minnesota. In general, this field work consisted of noting conditions along the Alaska Highway in Alaska and Canada and along all the highways in Alaska where travel via automobile was possible during the short time the investigator was there. In addition, various aspects of drainage were noted at the Canadian Agricultural Experiment Station near Haines Junction in Yukon Territory and at the Alaska Agricultural Experiment Station near Fairbanks. Many inquiries were made and consultations held with representatives of local agencies. Some of these are listed as follows:

B. L. Trawicky, Chief, Field Operations Section, Permafrost Branch, St. Paul District, Corps of Engineers, Fairbanks, Alaska.

R. H. Ogburn, Fairbanks Exploration Company, Fairbanks, Alaska.

J. W. Abbott, Officer in Charge, Canadian Agricultural Experiment Station, Whitehorse, Y. T., Canada.

John Osguthorpe, Director, University of Alaska, Agricultural Experiment Station, Fairbanks, Alaska.

Basil Bensin, Agronomist, University of Alaska, Agricultural Experiment Station, Fairbanks, Alaska.

Robert Chapman, Geologist, U. S. Geological Survey, Fairbanks, Alaska.

George W. Gasser, Commissioner, Alaska Department of Agriculture, Fairbanks, Alaska.

Allan Mick, Alaska Soil Survey, Palmer, Alaska.

Ottis Bobbitt, Climatological Supervisor, U. S. Weather Bureau, Anchorage, Alaska.

This report, which is a supplement to the report "Investigation of Airfield Drainage, Arctic and Subarctic Regions," contains eight chapters of written material, nine drawings and fifteen photographic plates. Observations along highways are briefly accounted in Chapter I. Several sites at which icings were observed are discussed and illustrated photographically in Chapter II. Chapter III deals with the influence of a drainage channel on the thermal regime of the ground. This is basic to hydrological aspects of drainage design. Chapter IV points out various forms of erosion which are typical of and peculiar to arctic regions. Hydrological design of river and stream crossings is discussed in Chapter V. Chapter VI was prepared by Meir Pilch and summarizes library research activity that was not contained in Part II of the report "Investigation of Airfield Drainage, Arctic and Subarctic Regions." Chapter VII of this paper is a brief analysis of runoff from selected watersheds. Chapter VIII terminates the report with concise recommendations and conclusions.

Maps and diagrams were made by student assistants. The report was reviewed by Henry M, Morris, Laboratory staff member. Editing and preparation for publication were responsibilities of Lois Fosburgh.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF PHOTOGRAPHIC PLATES

I. OBSERVATIONS OF HIGHWAY CONDITIONS

1. General. The purpose of the 1949 field trip was to make on-the-ground observations of hydrological phenomena over a wide range of conditions. To achieve the objectives set forth in the Preface of this report, it seemed advantageous to travel to Alaska via automobile during the time of year when runoff and spring breakup could be expected to be severe. As difficulties in drainage are most pronounced near the southern limits of permafrost, it seemed reasonable to suppose that present knowledge of the subject could be enlarged by noting field conditions at a critical time. Travel over the Alaska Highway appeared particularly attractive for the purpose, as this highway is located close to and in the southern fringe of permafrost for long distances. Even though the weather did not provide breakup conditions as severe as desired, it is nevertheless of consequence to make an accounting of conditions which were observed. This seems particularly important for areas of Alaska and the portions of Canada which lie north of Edmonton. The investigator did not notice any clear-cut demarcation between lands lying south of and lands within the permafrost region. The transition was very gradual and can hardly be discerned in the photographic illustrations.

While following the outline of the travel from Edmonton, Alberta to Fairbanks, Alaska, it is important to note that river icings occur as far south as Racing River in British Columbia. Here conditions were not particularly severe. Farther on, however, icings on rivers and streams became more pronounced. The situation at Donjek River was actually critical. Surface icings were noted as far south as Muncho Lake, which is only 455 miles from Dawson Creek. Near mile 1012 from Dawson Creek there was a noticeable change in the type of tree growth. From this point north, pine seemed to give way to spruce.

Conditions of highways and other points of interest noted during the field trip are indicated in subsequent sections of this report. Photographs, drawings, and brief descriptive material are arranged in order of actual travel and segregated under several topic headings, each designating a certain section of a particular highway. Many of the pictures illustrate local highway drainage conditions and need no further explanation.

2. Edmonton, Alberta to Fairbanks, Alaska. There are many all-weather roads which lead to Edmonton, Alberta from various sections of the United States. Information with respect to the condition and location of these roads

can be obtained from many sources. Consequently, a report of travel over this section was considered irrelevant and is omitted. For convenience in this accounting, the 2000-mile section from Edmonton to Fairbanks has been divided into five reaches of about equal length. To add to a better understanding of the country, many points of interest known perhaps only to local people are noted. Considering the comparative newness of this route, the numerous establishments built for the convenience of the traveler are surprising. The farthest distance between some type of accommodations is about 90 miles.

(a) Edmonton to Dawson Creek. The 481-mile stretch of road between Edmonton, Alberta and Dawson Creek, British Columbia was traveled April 17 and 18. The highway is paved for the first 45 miles north of Edmonton and then continues 52 miles in a northerly direction over graveled surface to Athabaska. This 52-mile distance was dusty, extremely rough, and winding. From Athabaska the road traverses in a northwesterly direction for about 90 miles to Slave Lake, thence westward to Grand Prairie. In general, this section of road was in good shape, but dusty. The ferry crossing at Smoky River had been in operation for three days. Ferry operators feared that they would have to cease operations at nearly any moment because the hazard of floating ice was expected to become more severe as river flow increased. A bridge is in the process of construction at this location, with completion expected sometime in 1950. From Grand Prairie to Dawson Creek the highway traverses in a northwesterly direction for 92 miles. Nearly half of this distance is not graveled and was extremely dusty. It was contemplated that the unsurfaced section of road would be improved and graveled during the summer of 1949. Figure 1 shows the location of the highway from Edmonton to Dawson Creek. Principal rivers, lakes, and towns are indicated. The approximate sites at which photographs were taken can be ascertained by noting mileages which are included in the titles of some pictures.

(b) Dawson Creek to Racing River. The Alaska Highway has its eastern terminus at Dawson Creek. This town is also the western terminus of the Northern Alberta Railway. Because of its strategic location, the town has grown in population from about 300 in 1942 to more than 4000 in 1949. In addition to being a hub of transportation, it is the center of an area rich in agricultural, timber, gold, oil, and coal resources. Hart Highway, which is in the process of construction, will connect Dawson Creek with Prince George. This will link the Alaska Highway with the Canadian National Railway.

From mile 0 to mile 50 the Alaska Highway traverses fertile farm lands which have been designated as open for settlement. Highway location and other information are given in Fig. 2 and the photographs that follow. The outlined material shows distances from Dawson Creek and indicates points of interest and general topographic features along the route.

Mile 0. Dawson Creek.

Mile 21. Highway maintenance camp.

Mile 35. Peace River bridge.

Mile 36. Drive-in cafe and garage.

Mile 49. Fort St. John. This was an old trading post for the Sikanni Indians. Now it is a thriving town with hospital, hotel, theater, stores, and an airport.

Mile 52½. Charlie Lake. This is a small settlement, the population of which is engaged in lumbering. There are no fish in Charlie Lake because the water is polluted by seepage of natural gas.

Mile 101. Blueberry. At this point there is a lodge and highway maintenance station.

Mile 143. Halfway Lodge.

Mile 147. Beatton River. Here there is a small cafe and trading post.

Mile 159. Sikanni River.

Mile 162. Sikanni Chief Lodge.

Mile 163. Highway maintenance station.

Mile 171. Mason Creek Lodge. This is near the base of Trutch Mountain.

Mile 181. This is the summit of Trutch Mountain and is reported to be the second highest point along the highway.

Mile 190. Crest. Lodge and cafe. The broad valley of the Minaker River can be seen and is visible for 60 miles or more with the snow-capped peaks of the Rocky Mountains in the background.

Mile 201. Trutch Lodge, bus stop, service station.

Mile 233. The Dutch Mill. Meals, lodging, service station, Lum 'N Abner's Trading Post.

Mile 245. Highway maintenance station. The highway in this vicinity is very winding for reasons that are not obvious to the motorist.

Mile 278. Hilltop Cafe.

Mile 296. Muskwa River.

Mile 300. Fort Nelson. This is one of the oldest settlements along the Alaska Highway. The original Hudson Bay Company buildings erected in 1800 still stand. These, however, are located on the Nelson River a few miles to the east of the new installations along the road. Hotel and other accommodations are good. A highway maintenance station is located at Fort Nelson. From this point the road turns westward and enters the wilderness area of the Rocky Mountains.

Mile 351. This is at the summit of Steamboat Mountains and also the location of a cafe and lodge. A heavy snowfall halted traffic for one day, April 20.

Mile 392. Summit Lake. This is reported to be the highest point on the Alaska Highway at an elevation of 4250 ft. There are tourist accommodations at Clark's Hotel and Cafe, and a service station equipped to make minor repairs.

Mile 397. The road here is located in a narrow valley with high mountains on either side. The Rocky Mountain Auto Court is situated in a scenic area amidst a sparse but good growth of pine and spruce.

(c) Racing River to Teslin Lake. The Alaska Highway over this section traverses mountainous terrain in a northwesterly direction to mile 627 where it crosses the boundary between Yukon Territory and the province of British Columbia. From this point the route changes to a westerly direction and, in general, follows the northern boundary of British Columbia to Teslin Lake. The condition of the highway on April 21 and 22 was quite good except for a relatively short stretch in the vicinity of mile 515. Here for a distance of about 50 miles there were numerous soft spots. In each instance repair work was under way and there was no danger of becoming stuck in the mud, although actual progress of travel was necessarily quite slow. Figure 3 shows highway location, principal towns, rivers, and lakes. The sites at which photographs were taken can be ascertained by noting the mileages which are included in the titles of some of the pictures. The following brief outline shows the distance in miles from Dawson Creek and points out items of general interest.

Mile 419. Racing River. Even though the location here is a considerable distance south of the southern limit of permafrost, there is evidence of river icing.

Mile 455. Muncho Lake. Highway maintenance station. From this point the highway parallels Muncho Lake for 9 miles. A high rock bluff immediately adjacent to the north shoulder of the road obscures visibility in that direction. There is a hazard here from falling rocks. Seepage through crevices and seams in the rock causes icings to form even though the location is a considerable distance south of the southern limit of permafrost.

Mile 464. Muncho Lake Lodge.

Mile 476. Trout River. The route of the highway follows and descends along this valley for 20 miles to the Liard River basin.

Mile 496. Liard River. The highway crosses the river at this point on a suspension bridge which is 1140 ft in overall length. The river is one of the large tributaries of the Mackenzie which drains into the Arctic Ocean. Tourist accommodations are available at Liard River Bungalow Camp. A short distance to the north of the river and east of the highway are the Theresa Hot Springs. It is reported that water at a temperature of 115° F flows the entire year. From this point the highway route follows the Liard River valley for a distance of nearly 150 miles. There were numerous soft spots in the first 50 miles of the stretch, indicating poor drainage.

Mile 533. Coal River Hotel.

Mile 543. Highway maintenance station.

Mile 588. Contact Creek. This point is of historical significance, as road construction crews working from the north and south met in November of 1942.

Mile 620. Lower Post. This is the location of an old-time Hudson Bay Trading Post. It now has a modern store, lodge, garage, and service station. Dease River forms a junction with the Liard River at this point.

Mile 627. Enter Yukon Territory.

Mile 632. Public camp grounds.

Mile 635. Watson Lake. Tourist accommodations are available here. It is also the location of a highway maintenance station. The Watson Lake airfield is located 8 miles to the north and is accessible via a good road.

Mile 648. Junction with ungraveled road leading to Moccasin gold mines on McDame Creek. The Alaska Highway from mile 635 to mile 670 was in excellent condition. At mile 642 the Liard River is crossed and the route ascends along the valley of the Rancheria River.

Mile 670. Rancheria River bridge.

Mile 710. Rancheria Hotel.

Mile 723. Drainage divide between the Yukon and Mackenzie Rivers. From here the route of the highway follows the valley of the Swift River.

Mile 733. Highway maintenance station.

Mile 778. Morley River. Cabins, meals, and service station.

Mile 804. Teslin Lake. The longest wooden bridge on the highway is crossed one-half mile east of the village. This bridge spans Nisutlin Bay on Teslin Lake and is 2250 ft long. Teslin Lake is a large body of water, relatively narrow but 85 miles long. Tourist accommodations are available including automobile service station. There is a store and trading post.

(d) Teslin Lake to Yukon-Alaska Boundary. The location of the Alaska Highway from Teslin to the Yukon-Alaska boundary is shown on Fig. 4. This illustration also shows principal rivers, lakes, and villages. Highway conditions, together with notations of other items of interest, are indicated in outline form with distances in miles from Dawson Creek.

Mile 804.	Teslin. From this point the route of the highway parallels the east shore of Teslin Lake for 35 miles.
Mile 826.	Highway maintenance station.
Mile 836.	Junction with Canol Oil pipe line maintenance road. This road traverses rugged terrain in a northeasterly direction to Norman Wells on the Mackenzie River, a distance of 450 miles. It is no longer maintained.
Mile 837.	Teslin River. The bridge at this location is sufficiently high to permit passage of river steamers. Accommodations for motorists are available at Porsild's Hotel.
Mile 843.	Silver Dollar Lodge.
Mile 865½.	Junction with a side road to Carcross, which is located on the Yukon White Pass Railroad.
Mile 872.	Judas Creek and location of Johnnie John's Lodge.
Mile 883.	Marsh Lake. This place is excellently equipped to cater to sportsmen. Transportation is available via small boats, cabin cruisers, and horses.
Mile 897.	Lewes River Dam. Lewes River might be called the headwaters of the Yukon River. The dam, the only one on the Yukon, was built to aid navigation during low-discharge periods.
Mile 919.	Whitehorse. Except for many rough stretches, the road condition from Teslin to this point was good, considering the time of year. The town of Whitehorse is a thriving hub of transportation for the Yukon District. It is accessible the year around by highway, railroad, and airway. River traffic to the north is possible during three months in the summer.
Mile 956.	Highway maintenance station.
Mile 968.	Mendenhall Creek and a public camp ground.
Mile 974.	Champagne. Trading post and Indian cemetery.
Mile 987.	Krak-R-Krik Inn.
Mile 995.	Junction with road to Aishihik Lake and airfield.
Mile 996.	Canyon Creek. Highway maintenance camp. Snow-capped mountains of the St. Elias Range can be seem from this location.
Mile 1012.	Pine Creek public camp ground. From this point on toward the north and west there is a noticeable difference in type of tree growth. Jack pines have disappeared and seemingly are replaced by spruce. Highway conditions continue to be good, but dusty.
Mile 1016.	Haines Junction. As the name implies, this is the junction with Haines Highway which connects Haines, Alaska, on the Pacific Ocean, with the Alaska Highway. Accommodations for motorists are avilable.
Mile 1019.	Agricultural Experiment Station.
Mile 1038.	Boutillier Summit. From this point and for the next 100 miles the scenery is actually magnificent. This route was traveled on April 22 and 23. There was a considerable amount of snow. The road was wet and quite slippery at numerous spots.

Mile 1048.	Cristmas Creek. From this point it is possible to see Kluane Lake. The scenery is of breath-taking beauty. The highway parallels the lake for a distance of 30 miles or more.
Mile 1093.	Burwash Landing. Accommodations for the motorist are available. Settlement at this point dates back to the days of 1904.
Mile 1105.	Public camp ground.
Mile 1131.	Donjek River. River icing and floating ice create conditions which are nearly impossible to repair. On April 23 ice had blocked five separate trestles and the water level on the upstream side of the road was all of 8 ft above the downstream elevation.
Mile 1156.	Koidern Highway maintenance camp.
Mile 1169.	White River.
Mile 1184.	Dry Creek Lodge.
Mile 1188.	Snag Junction. From this point a road leads to the airport at Snag. There are numerous "dwarf" spruce and tilted trees in this region.
Mile 1191.	Niemann's Lodge and Trading Post.
Mile 1206.	Highway maintenance camp.
Mile 1210.	Sourdough Inn.
Mile 1213.	Public camp grounds.
Mile 1221.	Canadian Customs and Immigration Office.
Mile 1221½.	International boundary.

(e) Yukon-Alaska Boundary to Fairbanks. There is a decided contrast between the condition of the Alaska Highway in Yukon Territory and immediately adjacent in Alaska. It is believed that the type of surface material accounts for this difference. The road is quite rough and dusty from mile 1180 to the border, while from the border for 50 miles or so in Alaska it is very smooth and relatively free of dust. In general, from this point the Alaska Highway follows the broad valley of the Tanana River to its terminus and junction with Richardson Highway at mile 1420. This is 103 miles southeast of Fairbanks. Figure 5 shows the location of the Alaska Highway from the border to Delta Junction and the Richardson Highway from there to Fairbanks. Distances from Dawson Creek to various points are indicated in the following outline.

Mile 1223-4.	Big and Little Scottie Creeks. These streams form the headwaters of Tanana River. They originate about 25 miles east of the Alaskan border.
Mile 1248.	Gardiner Creek and bridge.

Mile 1265. Northway Junction. Topography for the next several miles is quite rugged and appears to consist of many large sand dunes. Soil is easily eroded, as there are many gullies in the area and along the road ditches.

Mile 1306. Junction with Forty Mile. This road, which is in the process of construction, will eventually connect the Alaska Highway with Dawson in Yukon Territory.

Mile 1307½. Tanana River. A cantilever truss-type steel bridge of 950-ft length spans the river at this point.

Mile 1314. Tok River.

Mile 1318. Tok Junction. This is the site of the U. S. Custom and Immigration Office and also a junction with a road to Anchorage. An Alaska road commission maintenance station is located here.

Mile 1328. Tanacross Junction. Location of Tanacross airfield is two miles north of this point.

Mile 1353. Robertson River. Nine 200-ft trusses. River icing is commonly quite severe at this location.

Mile 1380. Sears Creek. There was evidence that icing had covered the highway at this location.

Mile 1387. Johnson River bridge. Four 200-ft spans and one 160-ft span. River icing is often very severe at this location.

Mile 1400. Big Gerstle River and bridge. Nine 200-ft steel spans. River icing is severe at this location. The next 20 miles to Delta Junction is a perfectly straight course and was in good condition on April 24.

Mile 1420. Delta Junction. This is the western end of the Alaska Highway. Here a junction is formed with the Richardson Highway, the route of which follows the Tanana River valley to Fairbanks.

Mile 1428. Tanana River bridge at Big Delta.

Mile 1460. Birch Lake.

Mile 1474. Harding Lake.

Mile 1481. Salcha River.

Mile 1497. Eielson Airfield.

Mile 1523. Fairbanks. On April 24, 1949, the condition of the Richardson Highway from Delta Junction to Fairbanks was passable, but not good. There were many soft spots, while other sections were extremely rough. Travel over this route on April 24 left the writer with the impression that nearly the entire distance of 103 miles needs drainage improvement. About the only method by which this could be accomplished would be to raise the grade all the way from 1 to 4 ft. Because of inadequate bridge capacity, a section of road grade near mile 1444 washed out on May 15.

3. Elliot Highway. The Elliot Highway was originally constructed in 1936 to provide access to Livengood, a small town located northwest of Fairbanks and in the heart of a gold mining region. The southeastern terminus of this highway is at Fox, which is situated at mile 11 on the Steese Highway. Several inspections were made of sections of this road in the period from April 27 to May 16. Conditions were definitely not good and at times impassable. Icings covered the road at numerous locations. Some of these were quite severe. Maintenance crews were engaged in repair work, yet after a one-half month period, travel conditions remained bad. On May 14 several locations along the route were inundated to depths of 2 ft or more because of ice-clogged channels and culverts. Further information on icings and repair work is given in a subsequent section. Photographs are included to illustrate these conditions.

4. Steese Highway. The Steese Highway was constructed prior to 1927 and connects Fairbanks with Circle, a small town located on the Yukon River. The route of this highway is in a northeasterly direction and parallels the Chatanika River for nearly 80 miles. The total length of the road is 163 miles. Principal points of interest along the route are outlined by showing distances in miles from Fairbanks.

Mile 11.	Fox. For several miles on either side of this town, which consists of one general store, the road is built over coarse gravel or tailings which result from gold dredging operations.
Mile 14.	Pedro Creek. From this point to mile 20 the road is on a very steep grade with many sharp turns.
Mile 20.	Cleary Summit. From this point the highway descends over a winding route to the Chatanika River valley.
Mile 29.	Chatanika. This is a small town which serves as the headquarters for a large gold dredging operation. From this point the highway traverses relatively flat terrain for approximately 12 miles, then ascends mountainous country to 12-Mile Summit.
Mile 87.	12-Mile Summit.
Mile 109.	Eagle Summit. This is the highest point along the route. The elevation is 3880 ft and above the timber line. A snowfall in July is not uncommon.
Mile 115.	Miller House. Trading post and inn. This point is not far from Mammoth Creek. Here excavations have revealed fossil remains of historic and museum interest.
Mile 129.	Central Road House. From this point a road leads to Circle Hot Springs. It is reported that mineral springs maintain a constant temperature of 140° F.
Mile 163.	Circle.

Several inspections were made of a section of Steese Highway in the period from April 27 to May 16. During this time the road had not been opened for traffic, although maintenance crews were engaged to repair icing conditions and clear the snow. In addition to the photographs that follow, a later section of this report contains data with respect to icings. Even though there were literally hundreds of locations at which icings stopped or impeded traffic, the writer did not find evidence of any preventive measures. The inspection of May 16 disclosed many points along the road that were inundated. Due to ice-clogged channels, the highway at mile 34 was covered with water to depths of from 1 to 2 ft.

5. Ester Creek, Farmers Loop, and Badger Roads. Because of close proximity of Fairbanks, frequent inspections were made to note drainage conditions from April 24 to May 16. Even though spring breakup was very gradual and melting of snow progressed slowly, drainage facilities were inadequate to handle the resulting runoff. Numerous sections of highway were inundated on May 14. Erosion was quite severe at many points. Soft spots at many locations impeded travel for several days.

6. Richardson Highway. On May 16 the Richardson Highway from Fairbanks to Black Rapids was inspected. Snow-removal operations were in progress beyond Black Rapids. Highway maintenance men reported that drifts were more than 20 ft high and thought that the section of road would not be open for traffic for two weeks or more. Generally speaking, the condition of the road was quite good, considering the time of the year and also that construction operations were in progress between Fairbanks and Delta Junction. In preparation for contemplated bituminous surfacing, the grade was being raised at many locations. A section of grade in the vicinity of Shaw Creek had washed out. On May 18 a section of Richardson Highway between Copper Center and Paxson was inspected. Except for a few locations at which the grade had been inundated, the condition of this section was very good.

7. Tok-Slana Road. This road connects Tok Junction at mile 1318 on the Alaska Highway with Richardson Highway near Gakona. The relatively narrow road traverses a distance of 137 miles over rugged terrain necessitating many sharp turns and steep grades. The entire route is in the process of reconstruction, with major activity concentrated on the section between Slana and Gakona. Observations made on May 17 and again on May 22 disclosed washouts of the road grade at several points and severe damage to the bridge over the

Chistochina River, caused by the action of floating ice. The Chistochina bridge is a long timber structure with bents at 30-ft intervals. Each bent is protected on the upriver side by a dolphin made up of three piles. A lightweight railroad rail was secured to the upriver pile of each dolphin. Floating ice sheared one of these along with an entire bent. Diversion of flow to another section of the bridge was necessary before piles could be driven to avoid the hazard of floating ice with, probably, a consequent loss of pile-driving equipment. Considerable preliminary work was necessary to divert a portion of the river discharge. However, before pile-driving operations commenced, another bent was dislodged, this time at the site of the diverted water. The bridge maintenance foreman thought that with luck he might have the bridge ready for traffic in about two weeks' time. While this destructive process was under way at the Chistochina crossing, another bridge at some distance to the northeast washed out, leaving several motorists marooned on the section of road between the two sites. Photographs that follow illustrate conditions along this highway. Figure 6 shows the location of the Tok-Slana road with mileages shown at various points to indicate the distance from Tok Junction.

8. Glenn Highway. The location of this highway is shown on Fig. 6. The mileages at various points indicate the distances from Anchorage. At the time of the investigation the road was in good shape and no unusual drainage conditions were noted. Remnants of icings were evident at several points, some nearly as far south as Anchorage.

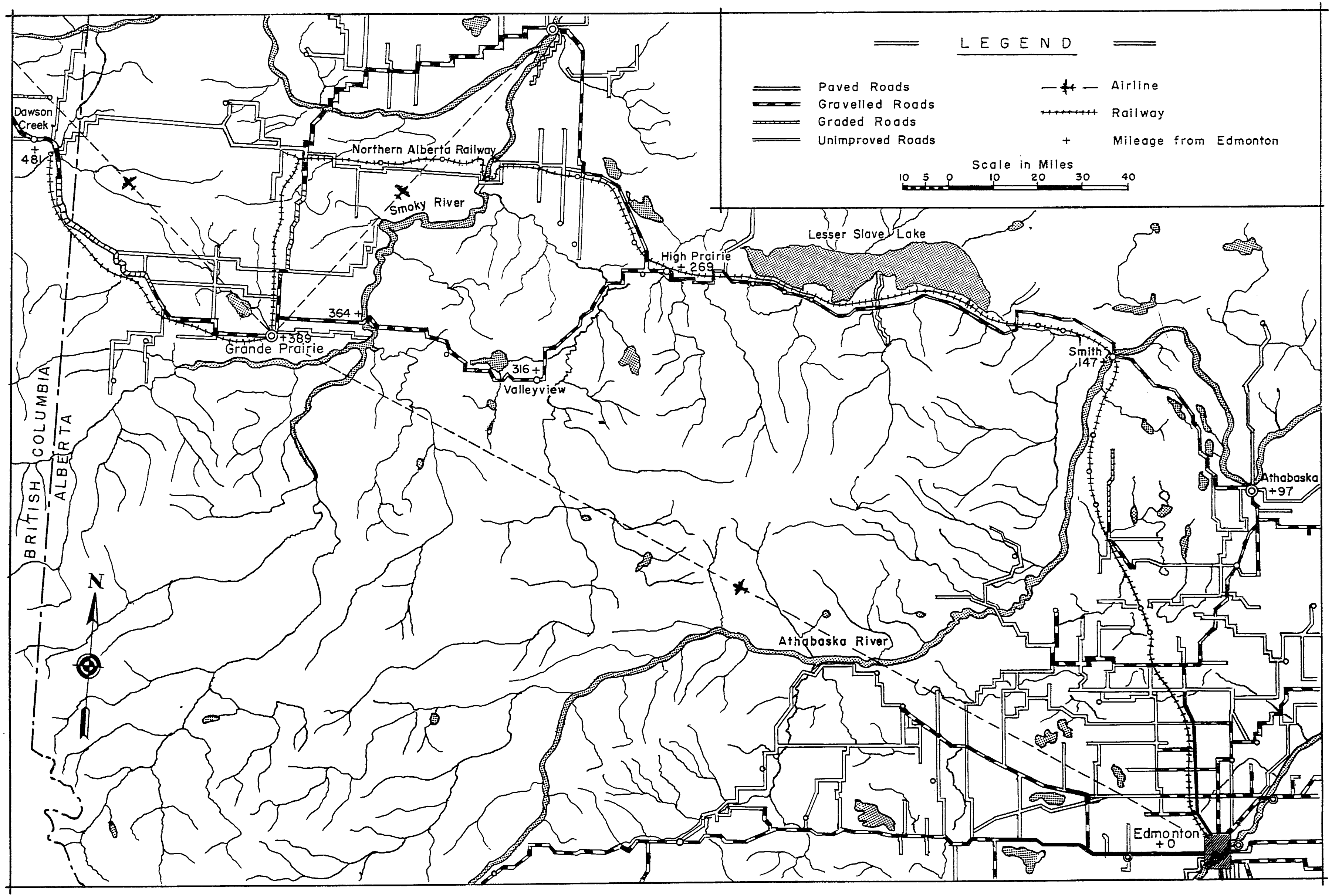


Fig. 1 — Edmonton to Dawson Creek

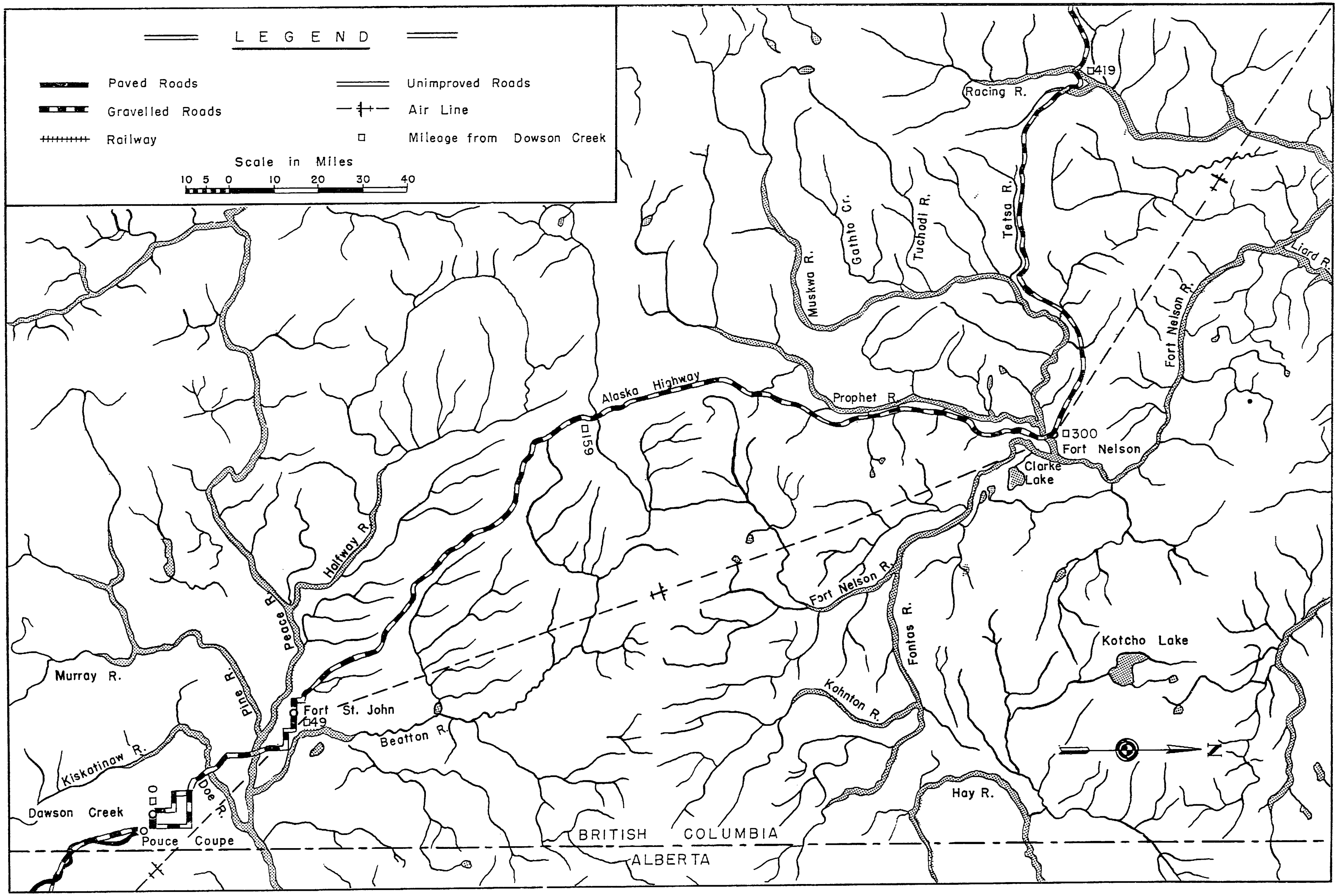


Fig. 2 — Dawson Creek to Racing River

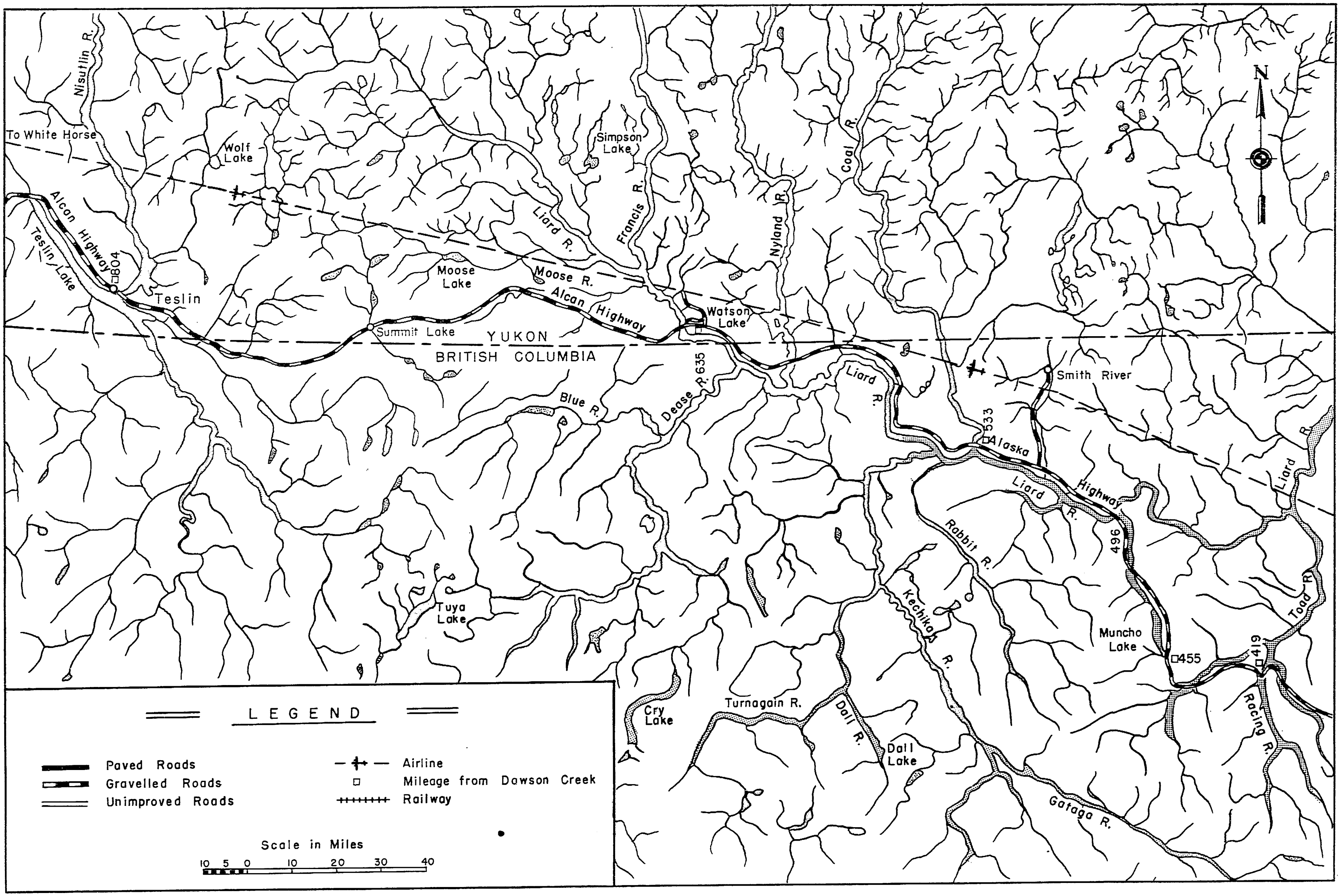


Fig. 3 — Racing River to Teslin Lake

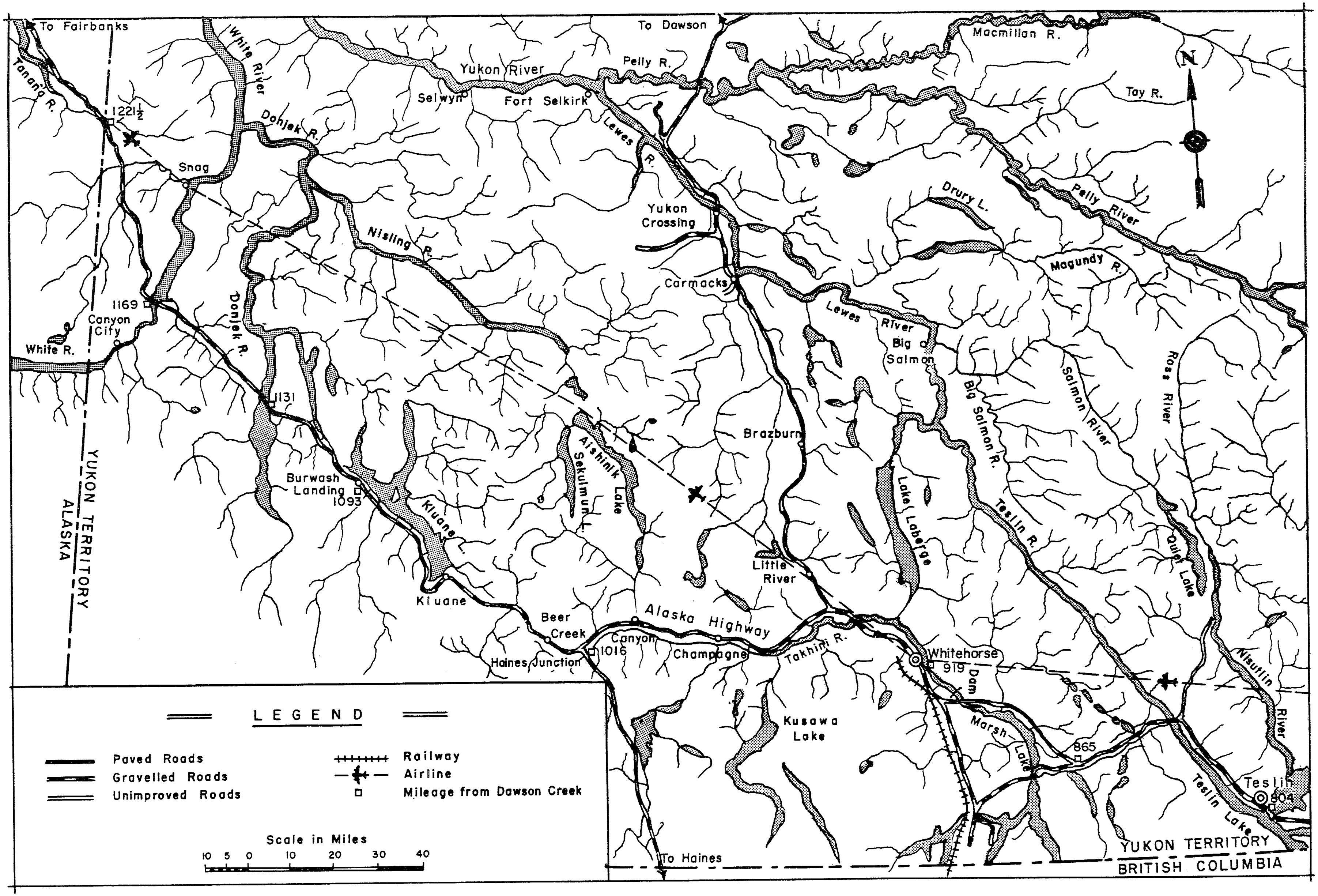


Fig. 4 - Teslin Lake to Alaska - Yukon Boundary

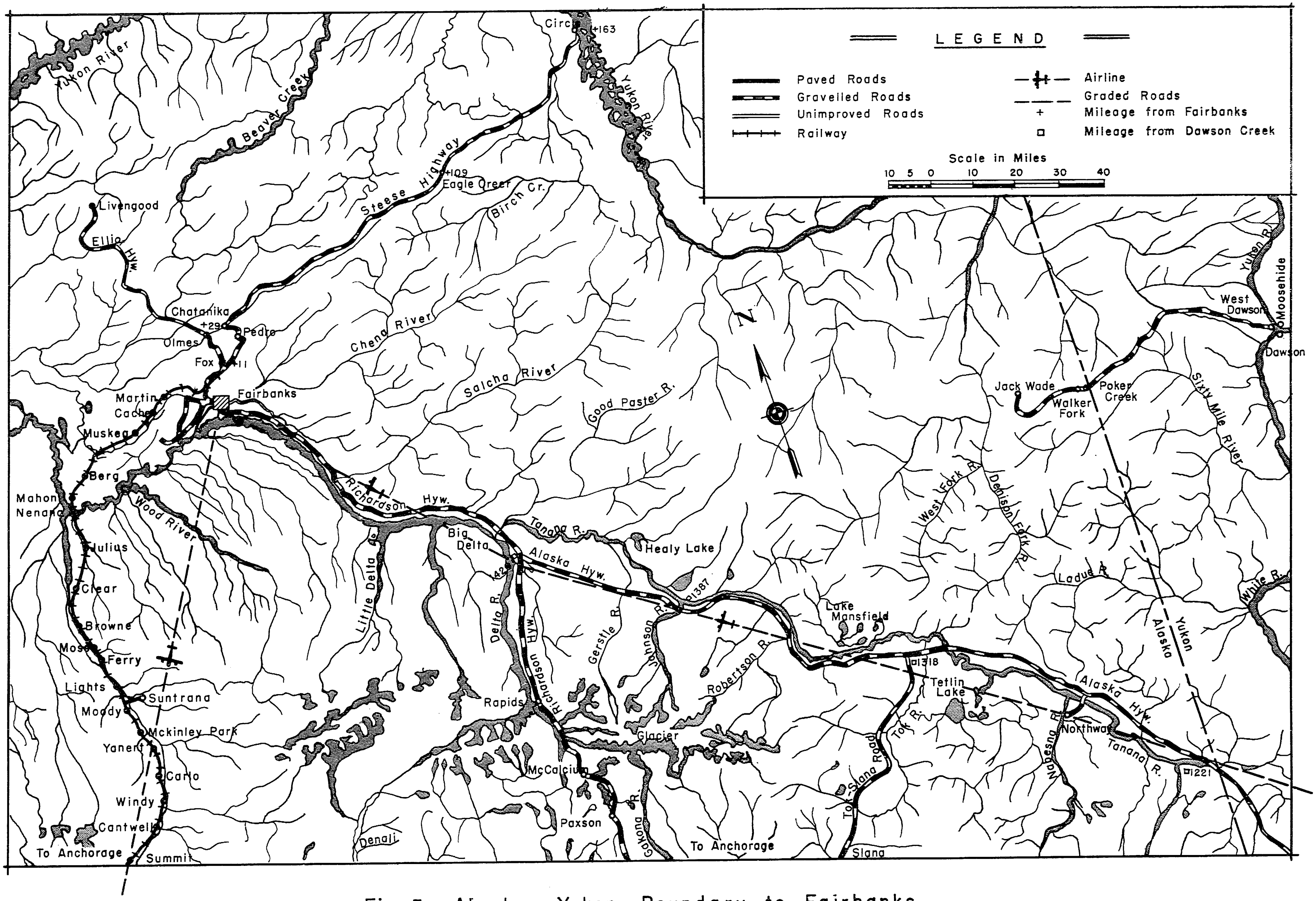


Fig. 5 — Alaska – Yukon Boundary to Fairbanks

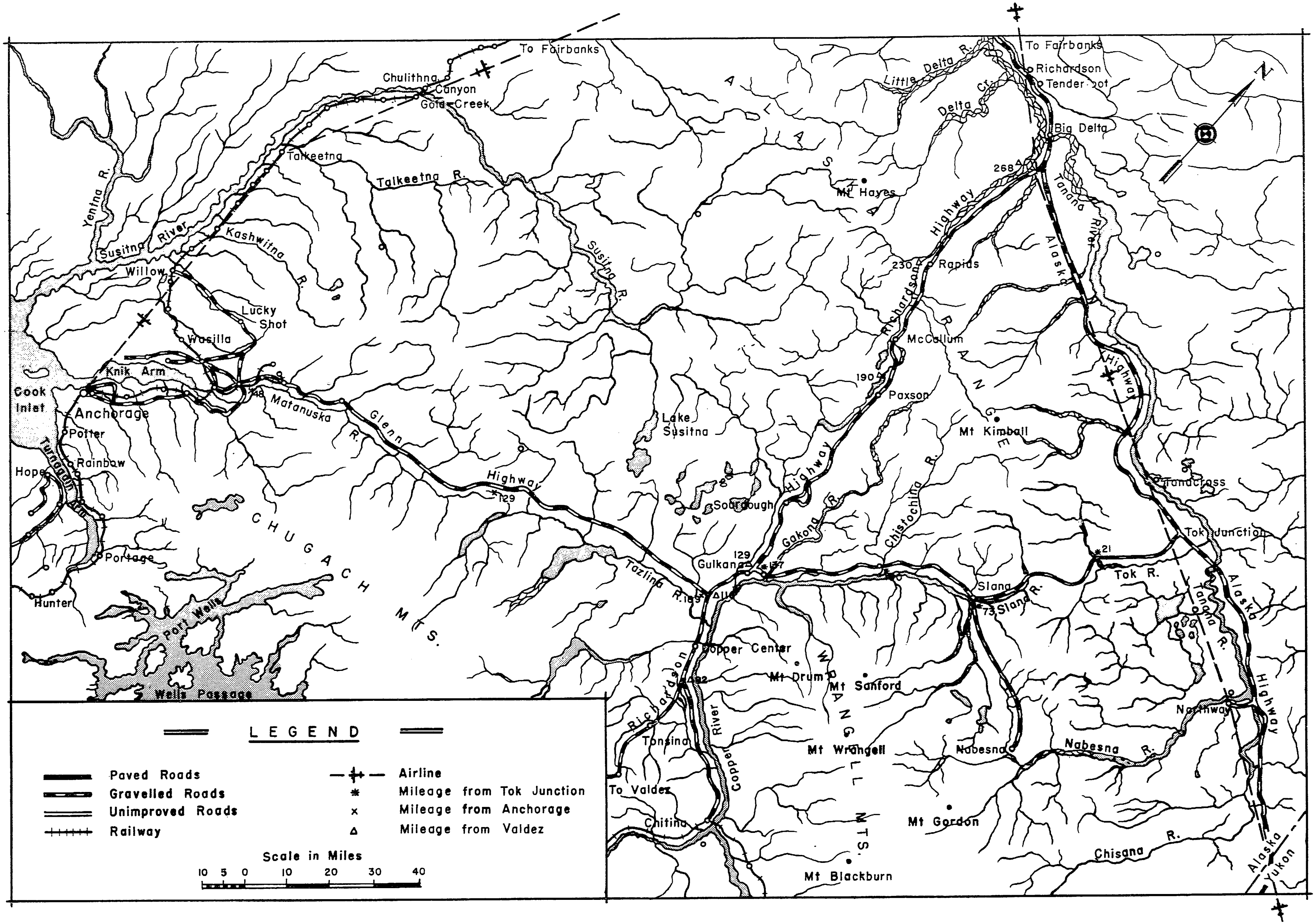


Fig. 6 — Alaska — Yukon Boundary to Anchorage

Road conditions are good despite a lack of drainage ditches.

Soft spots could be improved by drainage.

About 30 Miles East of Smith, Alberta, the Road Traverses Flat Terrain

Road side ditches are conspicuously absent along this highway.

Scene near Slave Lake, Alberta

The Athabaska River flows north and contains much floating ice in the spring.

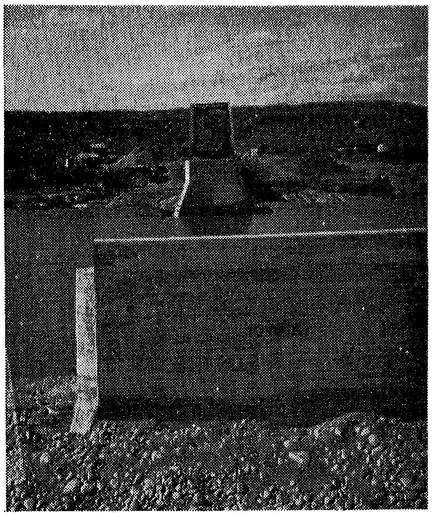
Scene near Smith, Alberta

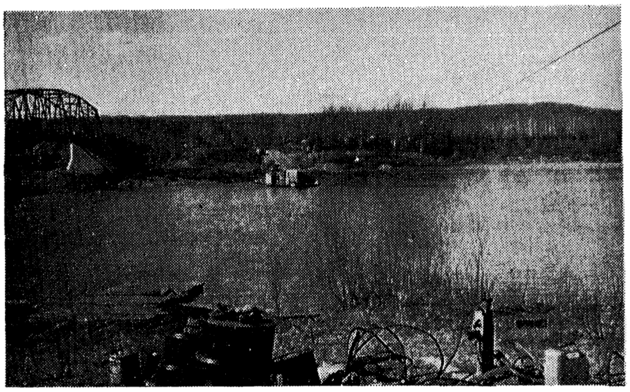
There are no side ditches to convey runoff.

Burned-over Area near Valley View

Anticipated erosion was not found even at grades as steep as indicated in the above picture.

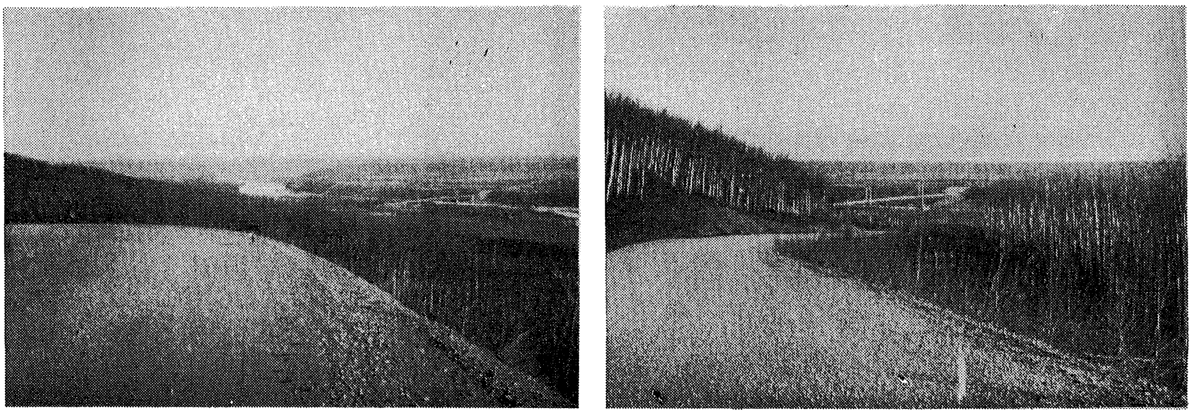
Looking East over Smoky River Valley





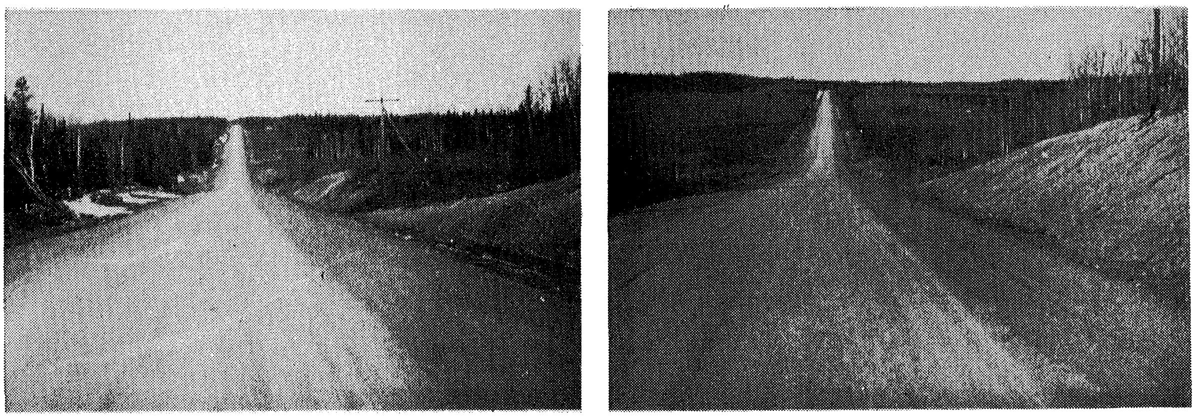
The bridge is expected to be completed sometime in 1950.
The ferry was in operation April 18, 1949, even though
there was a hazard due to floating ice.

Smoky River near Goodwin, Alberta



The Peace River suspension bridge is the longest on the Alaska Highway. This graceful structure once spanned Tacoma Harbour but collapsed during the height of a Pacific storm.

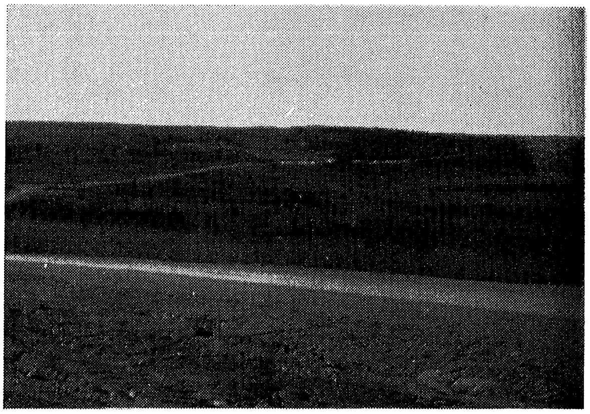
Peace River Valley, 35 Miles from Dawson Creek



The cut slopes have been exposed to the weather for about four years
without noticeable damage due to erosion.

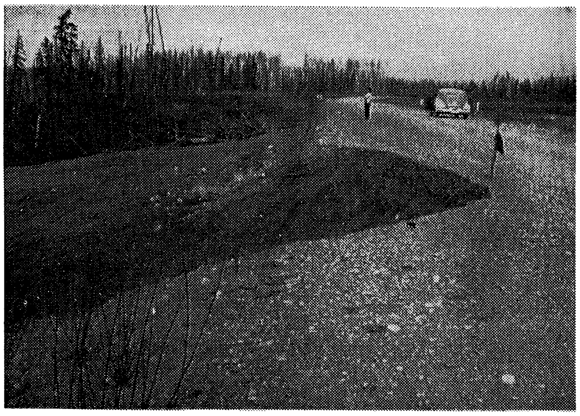
Typical Scenes of Alaska Highway near Blueberry, British Columbia

At mile 128 there was evidence of erosion in road ditches.



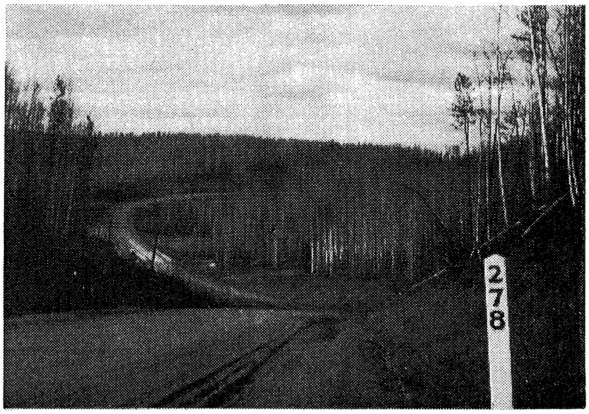
At mile 187 the broad valley of the Miniker River can be seen.

Alaska Highway in British Columbia



Water had not overtopped the road at this point.

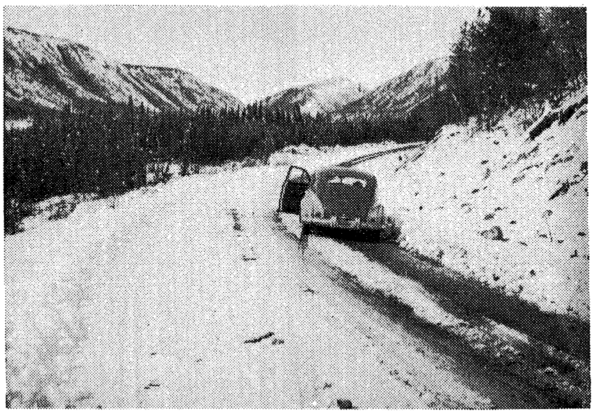
Mile 227 on Alaska Highway



At each mile along the highway there is a marker similar to the one in the photograph indicating the distance from Dawson Creek.

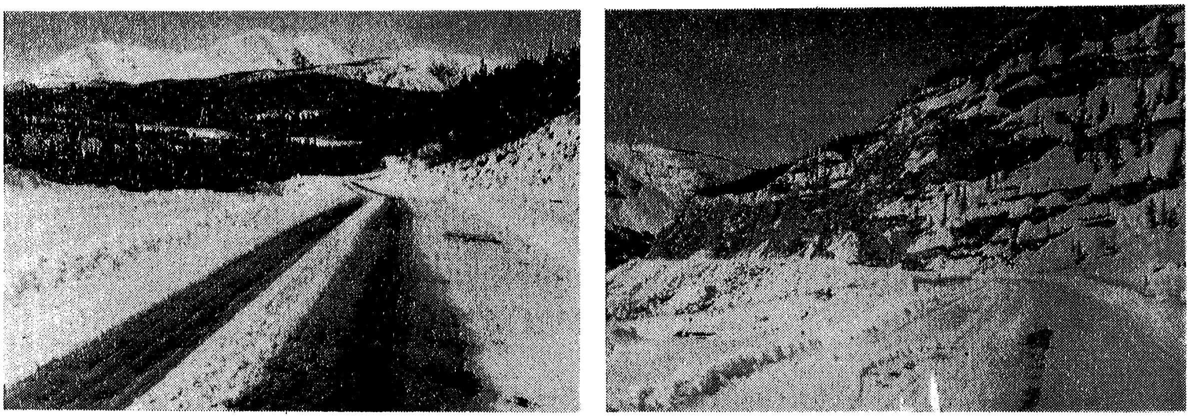
Mile 278 on Alaska Highway

Heavy snowfall on April 20, 1949 halted travel for one day.



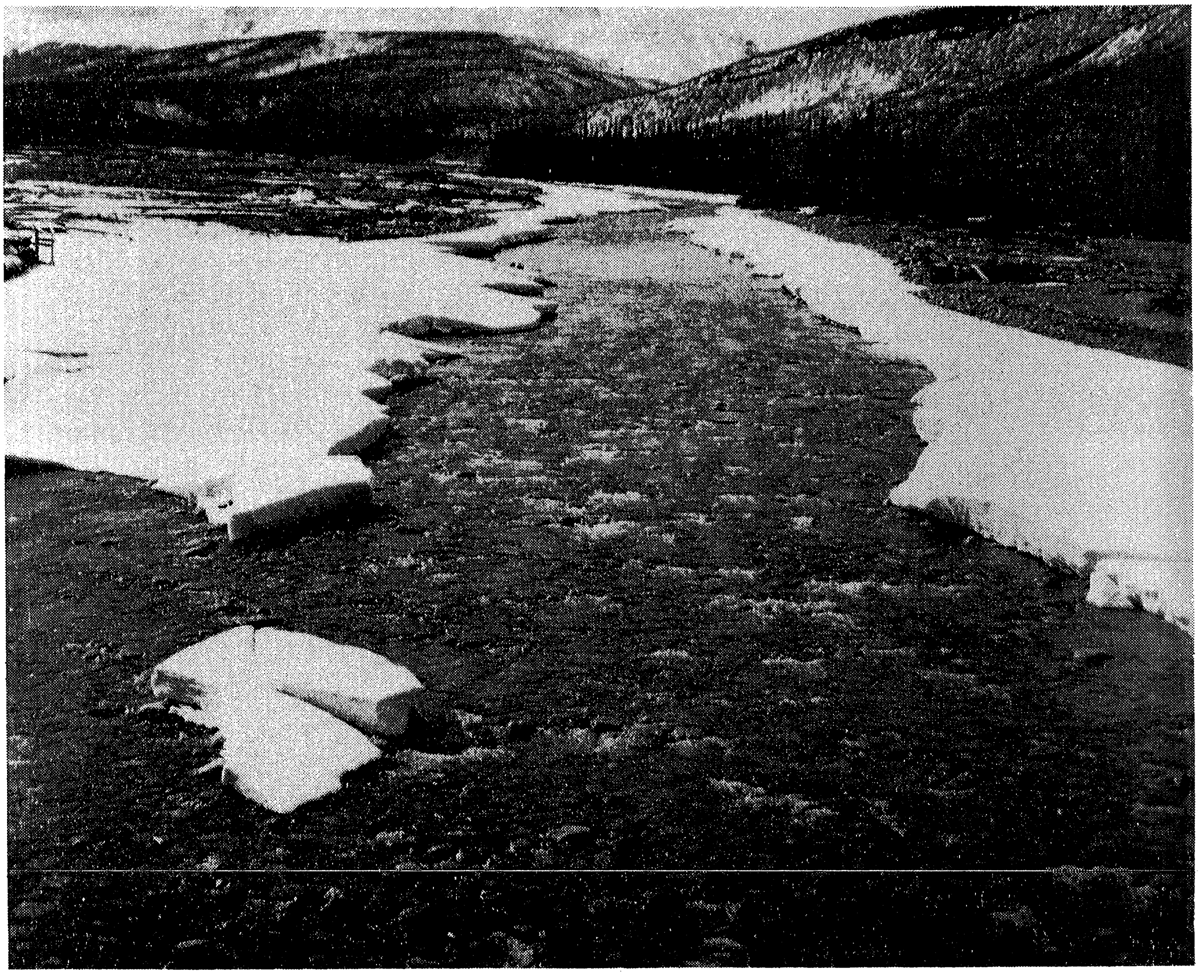
The road was quickly cleared of snow by personnel and equipment from strategically located maintenance stations. Travel could be resumed on April 21.

Steamboat Mountain Area



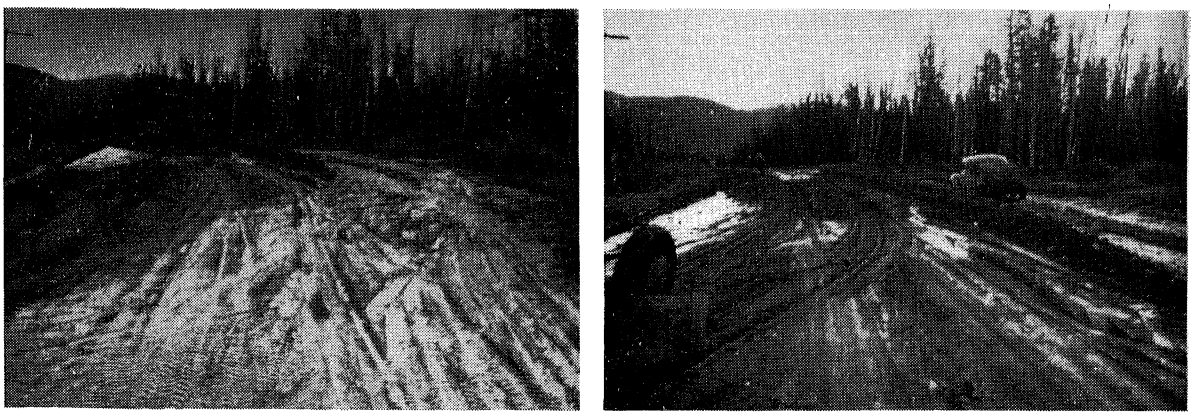
Shoulder markers to guide snow-removal operations were not observed along the route of the Alaska Highway which lies outside of the permafrost zone.

Rocky Mountain Area



River icing is ordinarily associated with permafrost. Here, however, remnants of icing are evident at a location which is definitely south of the sub-Arctic.

Racing River at Mile 419 on the Alaska Highway



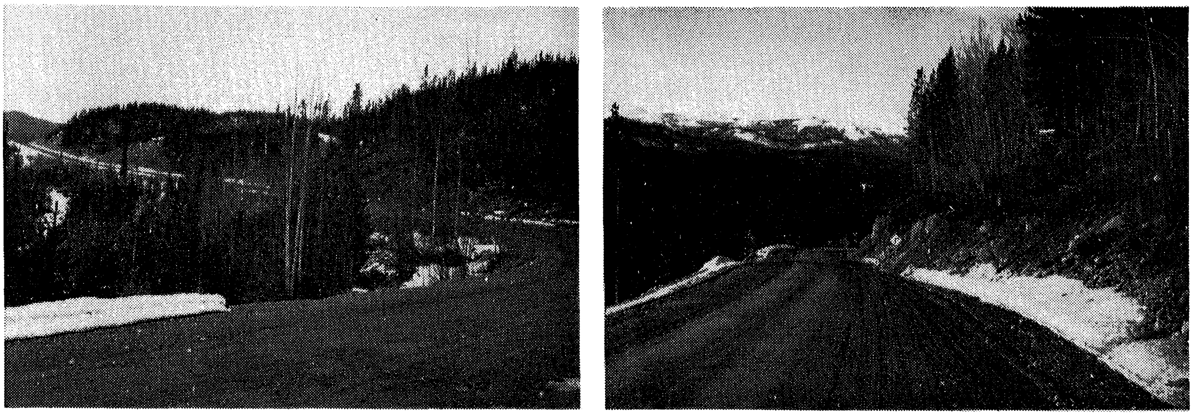
Other sections of road in this vicinity on April 21, 1949 were frozen. Subdrainage to remove water from underground sources is obviously essential.

Scenes near Mile 515 on the Alaska Highway

A prominent center crown would eliminate this situation.

Thawing along north-facing slopes was not advanced when compared to other orientation.

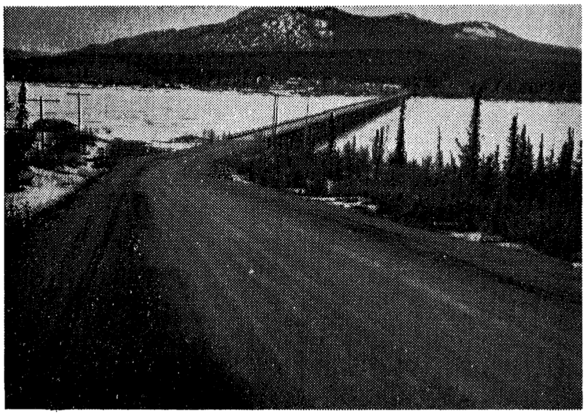
Scenes near Coal River on the Alaska Highway



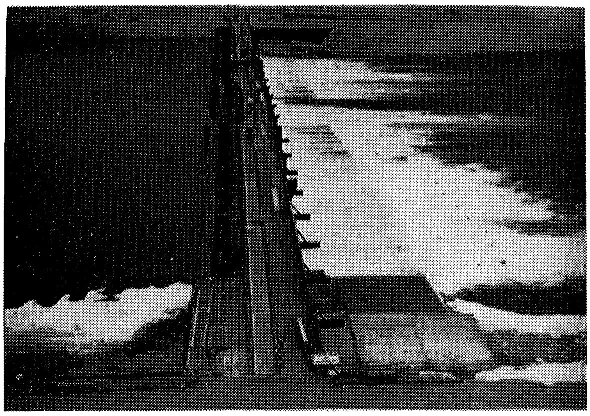
No peculiar drainage conditions were noted in the rugged terrain near mile 688.

Steep-cut slopes have not eroded badly at mile 696.

Scenes along the Alaska Highway



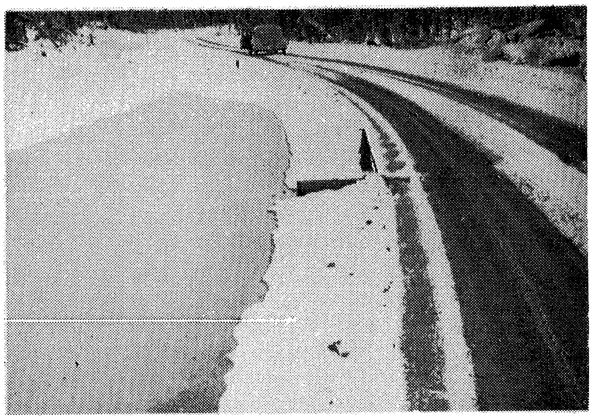
The longest wooden bridge on the highway crosses Nisutlin Bay of Teslin Lake.



The Lewes River Dam near Whitehorse is the only dam on the entire Yukon River.

Scenes along the Alaska Highway

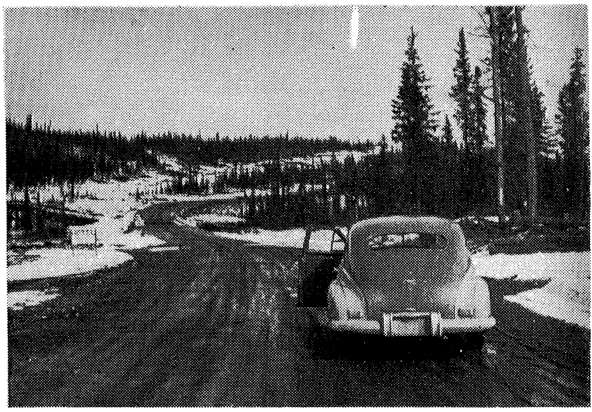
Burwash Creek Road at mile 1104. Many trees are in a tilted position.



A six-inch diameter pipe had been placed across the road at mile 1134 to relieve a poor drainage condition.

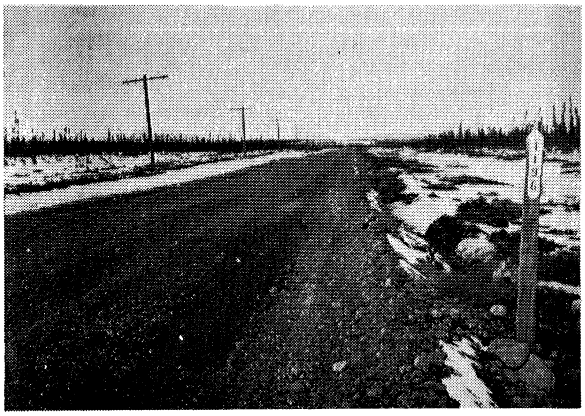
Scenes along the Alaska Highway near the Southern Fringe of Permafrost

Local residents reported that tilted trees like the one at which the arrow is pointing were common occurrences.



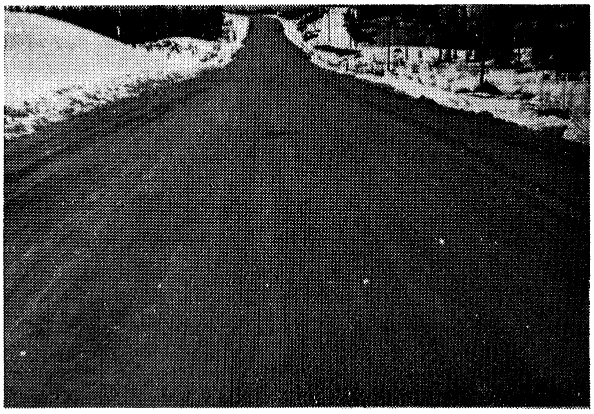
Permafrost exists quite close to the ground surface in this region.

Dry Creek Lodge and the Alaska Highway at Mile 1184



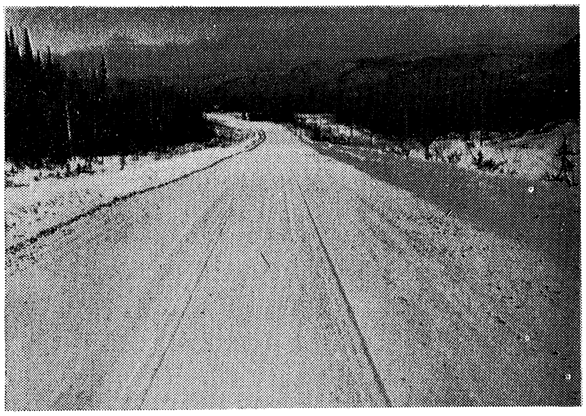
Settlement of the road grade was very uneven through this section which traversed flat terrain where the permafrost table was close to the ground surface.

Alaska Highway in Western Yukon Territory



The condition of the highway here was good despite sloughing shoulders at numerous locations.

Alaska Highway at Mile 1250 in Alaska

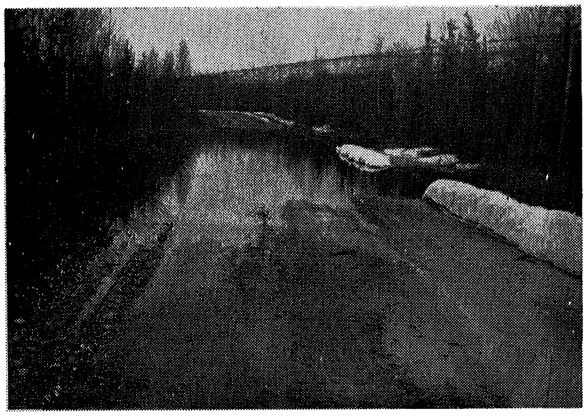


It is not a good policy to leave snow windrows on the road shoulder as indicated in the above picture.

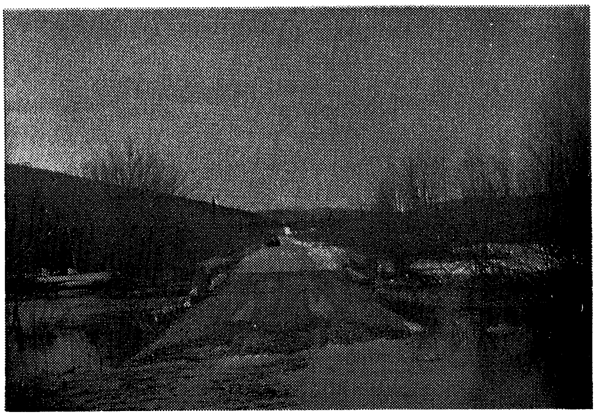
View from Mile 1354 on Alaska Highway

View from mile 1385 on Alaska Highway.

A Peculiar Pattern of Melting Snow



Steese Highway at mile 34.



Steese Highway at mile 38.

Many Sections of Road were Innundated during Spring Breakup of 1949

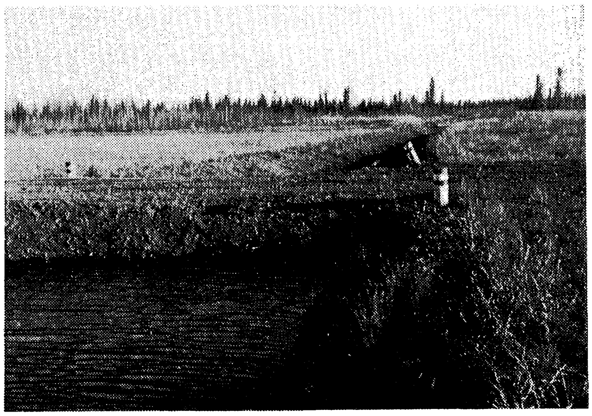
Even though spring breakup occured very slowly, many sections of road were inundated on May 14, 1949.

Ester Creek Road near Fairbanks

Farmers Loop Road near Fairbanks

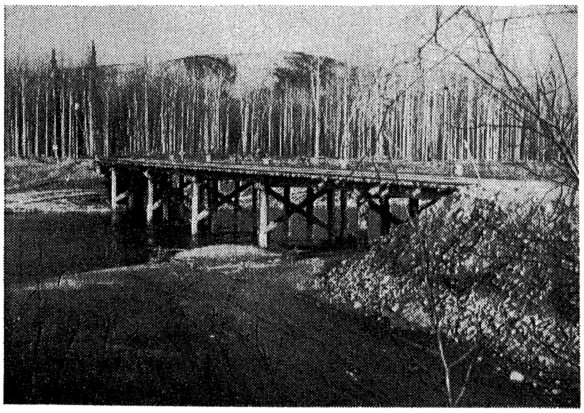
On May 15, 1949, high stages of Shaw Creek overtopped the highway and washed out a section of the grade.

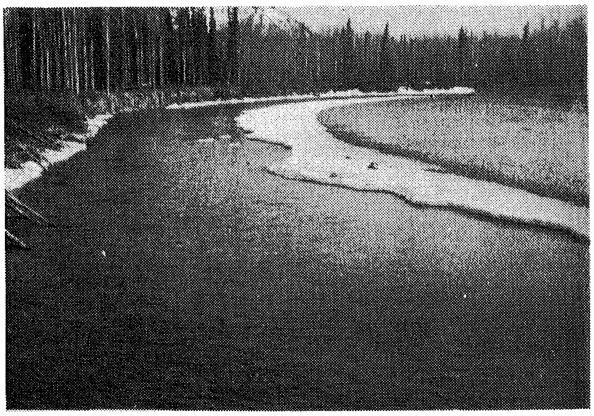
Richardson Highway at Shaw Creek



The culvert through this road grade was completely filled with ice.

Road Ditch near Gulkana





River icing is ordinarily not severe at this point. This would indicate that the stream-bed is composed of coarse gravel which provides a high sub-bed flow capacity. Fall and winter stages are very shallow and freeze to the bottom.

Tok-Slana Road at Tok River

Looking Westerly over Tok River

II. ICINGS

9. Statement of Observations. After making observations at many sites where either surface icing existed or remnants of the phenomena were evident, the writer fully agrees that further research is essential for developing preventive measures. It is apparent, however, that the formation of surface icings is not confined to areas where permafrost exists. Remnants of icings were noted as far south as Anchorage in Alaska and Muncho Lake in British Columbia. Under special circumstances, surface icings can form even in Minnesota, as indicated by the photographs showing Minnehaha Falls in April 1949. It was further apparent that the major causative factor was not the formation of a frost dam at the site of the road. This may or may not be a contributing factor, depending largely upon the age of the road.

The icings inspected were either irregular sheets or fields of ice with no uniformity as to shape, thickness, or size. The only similarity was the laminated structure of each, indicating that irrespective of shape, size, or cause, the actual process of formation is the same. Thin films of water traverse over layers of ice or other material and, exposed to the cold air, freeze and form the first or an additional layer of ice. As the flow of water continues, the process is repeated and an icing with horizontal laminations continues to grow until either the source of water supply is exhausted or warmer weather begins.

Individual icings are arranged in an arbitrary manner and each is briefly described. Photographs are arranged to illustrate the respective sites.

(a) Minnehaha Falls, Minneapolis, Minnesota. Two photographs on Plate 9 are included merely to illustrate that icings can occur in temperate zones and are not confined to areas where permafrost exists.

(b) Muncho Lake, British Columbia. The source of water for the icing at Muncho Lake at mile 459 on the Alaska Highway is apparently from seepage along a seam in the rock bluff. While the major portion of the ice is in the form of a huge icicle, as indicated in the picture, there was evidence that at one time it had covered the road. It is of interest to note that this site is also a considerable distance south of the southern limit of permafrost.

(c) Palmer-Anchorage Highway. Springtime thaw has nearly obliterated the icing near Eklutna on the Palmer-Anchorage Highway. The photographs were taken on May 21, 1949. There is no permafrost in this area. The source of water is a spring at some distance to the northeast and up the steep slope of the right-hand side of the picture (Plate 9).

(d) Birch Hill Road. The icing shown on Plate 10 was the result of a frozen culvert. Seepage waters from the steep hill to the right had no place to flow except to spread out over the cold roadway which had been cleared of snow. The ice is 30 in. thick at the point where Mr. L. A. Johnson is standing. Both ends of the culvert had been cleared of ice by steam thawing, yet there was no flow through the culvert, as the position of the ice diverted runoff waters along its left edge.

(e) Mile 15 on Steese Highway. The icing at this location was quite large and all of 4 ft in thickness at the shoulder of the road. The photograph in the left central section of Plate 10, taken on May 16, shows a general view of the field of ice. One of the lower pictures of this plate shows a detail of the inlet to the culvert at this point. Water is flowing on top of the ice, then into a steam-thawed hole through the ice to the upstream end of the culvert. The other lower photograph of Plate 10 shows the downstream end of the same culvert. The source of water is a small valley that faces southeast. The watershed area is approximately one square mile. Divide elevations are in the neighborhood of 2000 ft, while the level of the road at the site of icing is about 1100 ft. The writer estimates that there is approximately 1 acre-ft of water stored in the form of ice at this location. If formation and growth took place uniformly in 100 days, the quantity of supply water would have to be at the rate of approximately 0.005 cfs or 2.25 gpm.

(f) Near Mile 18 on Steese Highway. The icing at this location was comparatively small in areal extent, with well-defined boundaries. The ice was quite thick. The source of water supply is from a slope of a hill which faces southwest. The altitude of the road here is quite high, about 1900 ft. The overall quantity of water stored as ice at this location is probably less than 0.1 acre-ft. If an assumption is made that formation and growth took place uniformly in 100 days, the quantity of water supply would have to be at the rate of approximately 0.0005 cfs or 0.225 gpm.

(g) Elliot Highway at Fox. At this location ice freezing beneath the bridge spanning Fox Creek resulted in an ice dam sufficiently high to divert water through coarse gravel tailings and overtop a low section of highway a few hundred feet to the south of the bridge. The icing on the road was not over 18 in. thick and the areal extent was small.

(h) Elliot Highway near Dome Creek. At this point about 300 ft of highway was overlaid with ice to depths that ranged from a few inches to 4 ft. or more. On April 27 repair work was in progress, as indicated on Plate 11. Charges of dynamite were placed to clear Dome Creek below the site of the road. The photographs taken on May 6 show results of the blasting. One of these photographs indicates the depth of ice at the bridge. The ice surface was actually 1 ft above the top of the handrail. The view taken longitudinally on May 6 indicates that this section of road was passable. The frame of the car dragged at several points and without considerable momentum the vehicle would hang up as the low parts of the car made contact with high points of ice. On May 14 the ice between the two ruts had disappeared, but then the road was inundated to 2-ft depths. Apparently the bridge spanning Come Creek still was restricted by ice and could not handle springtime runoff.

(i) Elliot Highway beyond Chatanika River. On April 27 and May 6 inspections were made of an icing located a few miles northwest of the Chatanika River bridge and at a crossing of a valley that is tributary to the Chatanika River. This icing was of large areal extent and ranged in thickness from a few inches to about 3 ft. About 700 ft of highway at this location was covered with ice having a very uneven surface. Snow had been removed to provide a detour along the downstream side of the road. Because of snow it was very difficult to determine the actual areal extent. It is estimated, however, that the total volume of water stored as ice in the vicinity would approximate 2 acre-ft. On the assumption that formation and growth takes place in 100 days, a flow of water at the rate of about 4.50 gpm would be required. Highway maintenance crews had chopped narrow trenches in a direction transverse to the road to facilitate the flow of water. The trenches were then filled with small-diameter aspen or birch poles to provide means of crossing by cars and trucks. This icing is shown in plan view on Plate 12 which is an aerial photograph taken on May 6 from a low altitude. The oval-shaped darker shaded area in this photograph represents an area of ice that has sagged about 1 ft. Evidently hydrostatic pressure had been released by highway maintenance operations.

(j) Mile 48 on Steese Highway. At this location a small timber culvert was completely blocked by ice. The ice surface on the upstream side of the road was at an elevation equal to or above the level of the highway. Unless the waterway opening is cleared before runoff results from thaw, serious consequences can be expected. Photographs on Plate 13 illustrate conditions at this site.

(k) Mile 83 on Tok-Slana Road. The condition at this location is represented by the photographs on Plate 13. It is similar to the icing noted at mile 48 on the Steese Highway, except that the waterway opening is much larger. At the time of the inspection, May 18, 1949, water was discharging beneath the icing. A small increase in runoff would cause the road to overtop and no doubt would wash out the bridge and sections of the grade.

(l) Near Mile 50 on Steese Highway. For relatively long distances in both directions from mile 50 on Steese Highway the road was covered with a very irregular icing. The thickness of the ice varied from a few inches to several feet. At one location a bulldozer had slipped off the side and, in the course of the fall, the operator was killed. In this vicinity the highway traverses in a northeasterly direction along a slope of a mountain that faces southeast. A relatively short but variable distance uphill from the position of the road is a mining company diversion canal which conveys water from Chatanika River. Spillways are located at several points along the canal to discharge water in case summer rains and consequent runoff would otherwise exceed the channel capacity.

It is the writer's view that the action of flowing water in this canal has degraded the permafrost considerably. It seems reasonable to suppose that accelerated thaw has created a secondary channel the bottom of which is well below seasonal frost. Inasmuch as the diversion canal is on a grade, it seems possible that the secondary channel would also be on a grade sufficient to create ground water flow along the route but below the bed of the canal. At irregular intervals seepage could be expected by reason of overtopping at low points along the permafrost brim of the underground waterway. Seepages of this sort would be very small, yet a small fraction of a gallon per minute is sufficient to cause a sizeable icing. Figure 7 diagrammatically illustrates what the writer believes to be the cause of surface icing near mile 50 on Steese Highway. Further research activity is recommended.

10. General Discussion of Icings. For the purpose of analysis, icings may be divided into three groups depending largely on the nature of the source of water supply. If the source of water is from river flow either above or below the river bed, the term "river icing" applies. If the source is from ground water flow above the permafrost table, "ground icing" is the term most commonly used. This term should not be confused with ground ice which is often encountered as deposits in fine-grained soils of the Arctic and sub-Arctic. The term "spring icing" should be confined to the occurrence when the source of water is from subpermafrost levels. Spring icings are commonly quite large in thickness and areal extent. Human activity can disturb the ground regime sufficiently to cause or accelerate the formation of all types of icings.

(a) River Icings. Most streams of Alaska carry large loads of sediment which is not fed into the channels in uniform quantities. Consequently, the rivers are quite wide and relatively shallow. Many rivers have a braided pattern of several smaller streams within the confines of the main channels. These streams frequently shift in transverse position and often do so during one period of high stage. Winter flow is ordinarily very small and does not require any appreciable depths. Ice freezing penetrates to the bottom quite readily, but river discharge continues as ground water flow beneath the river bed. Because of thermal effects of flowing water, the soil below stream beds is unfrozen to greater depths than soil located elsehwere. As a consequence there is a large space for ground water storage and flow above the permafrost and below all river beds. The head motivating ground water flow is ordinarily quite large and can result in large pressures above sections where the ground water flow is retarded. Ground water flow retardation is a natural process at many river sections because river beds are not homogeneous in water-carrying capacity. Freezing of the surface water reduces channel area and capacity in some sections more than in others. The water then finds avenues of escape to the top of the ice via weak points, cracks, and fissures. Here, exposed to the cold atmosphere, the water quickly freezes in thin sheets. This action is progressive and icing develops to increasing thicknesses until the supply of water is exhausted or finds a new outlet, or until the beginning of warmer weather. A bridge may shade the stream bed and also prevent the deposition of snow. Freezing then would be more rapid beneath the bridge than at either upstream or downstream locations. Subsequent penetration of frost would diminish ground water flow capacity at the bridge section and induce the formation of an icing above or at the site. These icings can be of various shape and size, depending upon valley topography, depth of snow, intensity of cold, water supply, and other factors. There is need for research to evaluate and weigh the effect of each of the influencing factors.

(b) Ground Icings. Ground icings may take the form of mounds having quite large thicknesses but small areal extents. They may also form as crustations if ground water flow is induced to the surface at points which are not of long lateral spacing and of about equal elevation. In addition to a supply of water, there is another necessary requisite to the formation of an icing. This other requisite is an area where the water can be exposed to the cold atmosphere. A road which is kept cleared of snow offers an excellent site over which flowing water can spread out into a thin film and then freeze. Icings from ground water above the permafrost are not likely to occur in the Arctic, as there the permafrost table is too close to the surface to permit any appreciable storage in the active layer. It is in the southern zones of the sub-Arctic and on slopes which face south that this occurrence is the most severe. Ground water flow may be induced to the surface in various ways. It is not essential that the seasonal frost reach the permafrost table, although this very effectively blocks ground water flow. Partial freezing of the active layer reduces the area of the section through which ground water must pass. The path of least resistance may lead to the ground surface via a frost crack or fissure, or through holes which have previously been made by burrowing animals. Water coming to the surface in this way may flow considerable distances down slopes in rills beneath a snow blanket without freezing.

Various innovations and methods have been tried in attempts to prevent the occurrence of icings. Some of these have met with partial success. The frost belt or dam has been advocated by Russian investigators, but it has been found that this method is effective for a few years only. Observations show that thawing in summer is accelerated at the site of the frost dam, and that eventually the permafrost table becomes degraded sufficiently to permit ground water flow below the frost dam. Fences and barriers have been used quite effectively under special circumstances. As a general rule, there are not sufficient basic data from which to plan preventive measures. Further research is recommended to isolate, evaluate, and weigh the effect of contributing factors.

(c) Spring Icings. Icings that occur from subpermafrost water or springs are ordinarily quite thick and cover a considerable area. Reference is often made to the icing in the Momy River valley of Siberia. This spring icing is about 15 miles long, 3 miles wide, and averages about 12 ft in thickness. However, it does not melt and form each year. Spring icings can be controlled quite readily. The temperature of the water emerging from the ground is ordinarily quite high and the water does not freeze quickly if confined to a conduit of some kind. In some cases an insulated conduit may be required to convey the spring water to locations where the formation of icing will do no damage.

(d) Measures Against Icings. Although a great deal remains to be learned about the control of the three types of icings, certain generalized aspects may prove helpful from the standpoint of practical application.

(1) If the source of water forming the icing is a spring, then it is necessary to resort to drainage or diversion to control the occurrence. This sometimes requires insulated channels. In the case of springs, flows are ordinarily too large to permit storage of ice at or upstream from the site.

(2) In the case of river icings, depths to the permafrost table are ordinarily too large to be effectively blocked by accelerated freezing such as is induced by the frost dam or belt. In addition, the sub-bed river flow often is in excess of what can be stored as ice above the location of the bridge. The control of river icings then must be concerned with insulation of stream beds at the critical section. Several methods of channel insulation are described on pages 136-39 of Part II, "Investigation of Airfield Drainage, Arctic and Subarctic Regions."

(3) Ground icings can be controlled to some extent by inducing the ice to form upstream from the site in question. This can be accomplished by the installation of frost belts. In open terrain some success can be achieved by merely keeping snow removed from a strip crossing the affected area in a direction transverse to ground water flow. Ground water flow will be blocked by freezing and forced to the surface upstream from the cleared area. The snow-free area also provides a cold space on which surface flow can spread out and freeze. If necessary, the depth of stored ice can be increased by erecting some barrier to the flow, such as an ordinary

wood stave snow fence on top of the ice initially formed at the site of the frost belt. In the process which employs the removal of snow, it is essential to shift the position of the belt from year to year in order not to influence unduly the depth to permafrost. In timbered regions it is obviously necessary to maintain the frost belt at one location to save expense of tree removal. Here consideration should be given to a method proposed by Bykov and Kapterev. This is explained on page 132 of Part II, "Investigation of Airfield Drainage, Arctic and Subarctic Regions."

11. Icing Research. The objective of research dealing with icings is to develop preventive measures. This could probably be accomplished by two methods: (a) various innovations and schemes could be tried arbitrarily and discarded if found unsuitable, or (b) systematic research could be initiated to obtain basic information as to causative and contributing factors. The latter method appears to be the more logical approach. In general, icing research would require surveys and observations of the formation and growth at selected sites and correlation of the data with climatological information. The project should continue for a sufficient length of time to permit evaluation of the factors influencing the occurrence. Presumably this activity could become a routine function of an organization such as the Permafrost Branch at Fairbanks.

12. Research Procedure. Icing research should be initiated in the summer or before freezeup in the fall by making detailed topographic surveys of several sites where icings are known to occur from year to year. This initial survey should include the following:

(a) Position of site with reference to orientation of relief.
(b) Thickness of the ground above the permafrost table.
(c) Direction of ground water flow.
(d) Soil texture and structure above the permafrost.
(e) Density and type of vegetal growth.
(f) Geologic formation.
(g) Information on surface water flow.

Weekly inspections should begin shortly after the freezeup in the fall. Each inspection should note carefully all the conditions at the time, including depth of snow, depth of frost, size, shape, and position of ice formation, location of source of water, temperature of water, rate of discharge, color of water, and presence of air bubbles. Marked alterations in size and position of icings should be mapped and shown by contours, photographs, and sketches. The position and movement of trees should be noted.

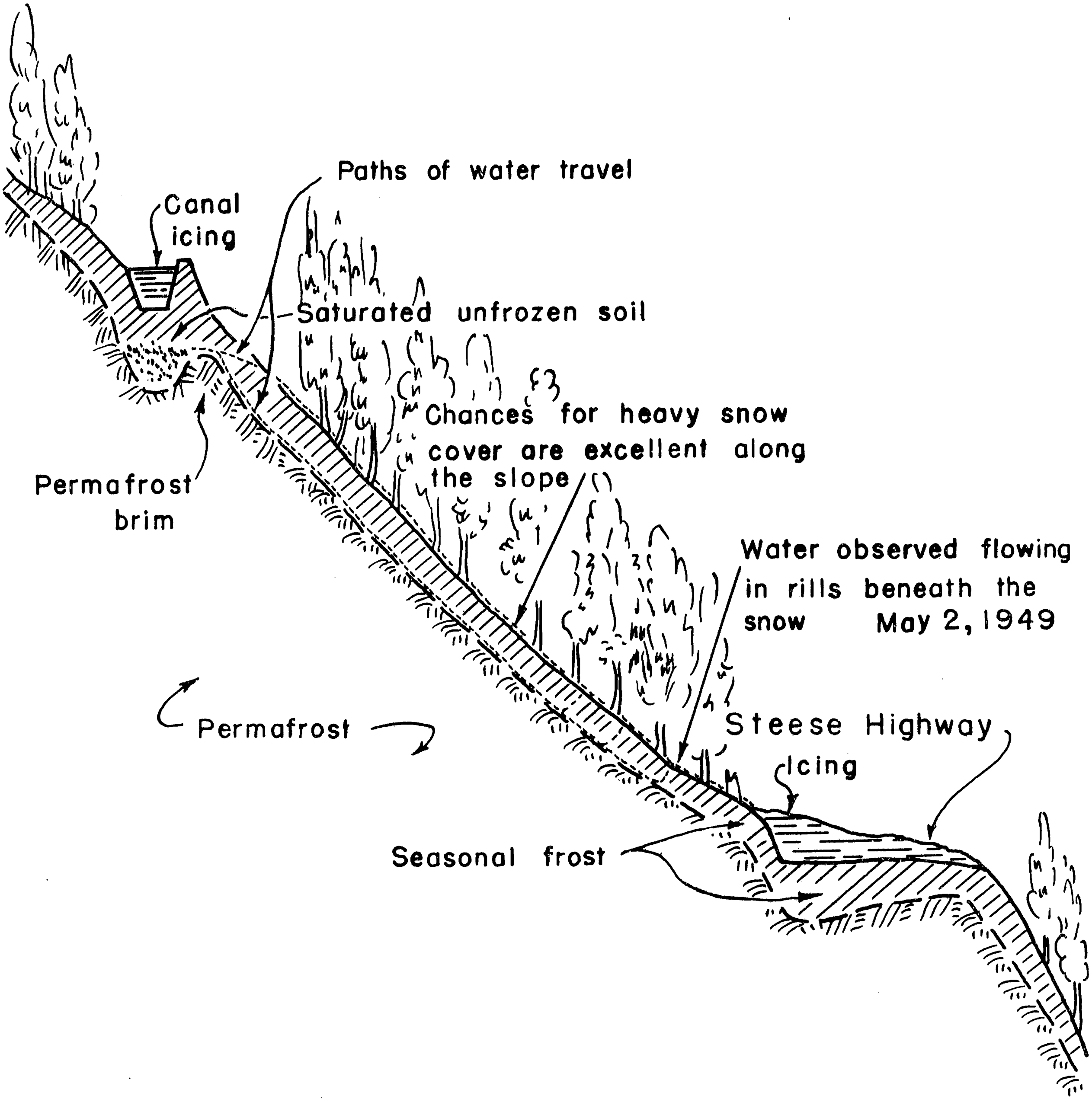
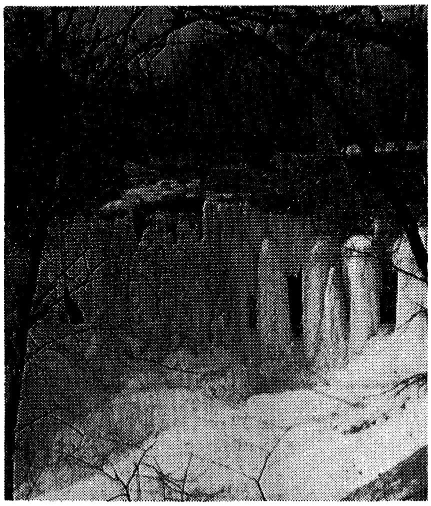
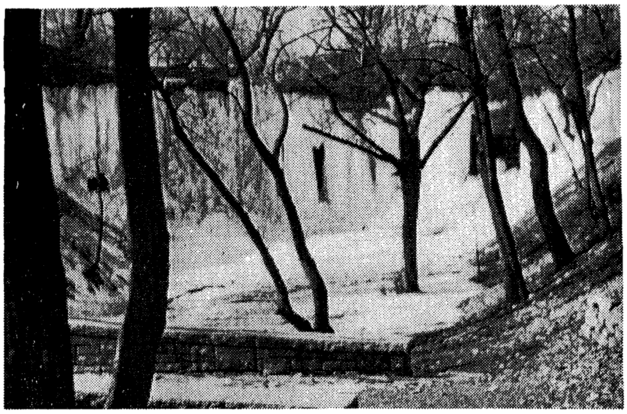


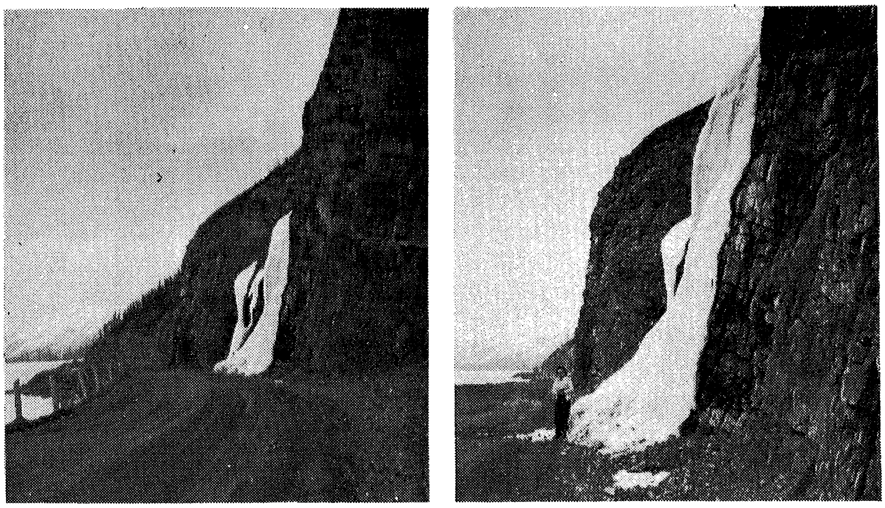
Fig. 7 Sketch Showing Typical Section of Steese Highway Near Mile 50





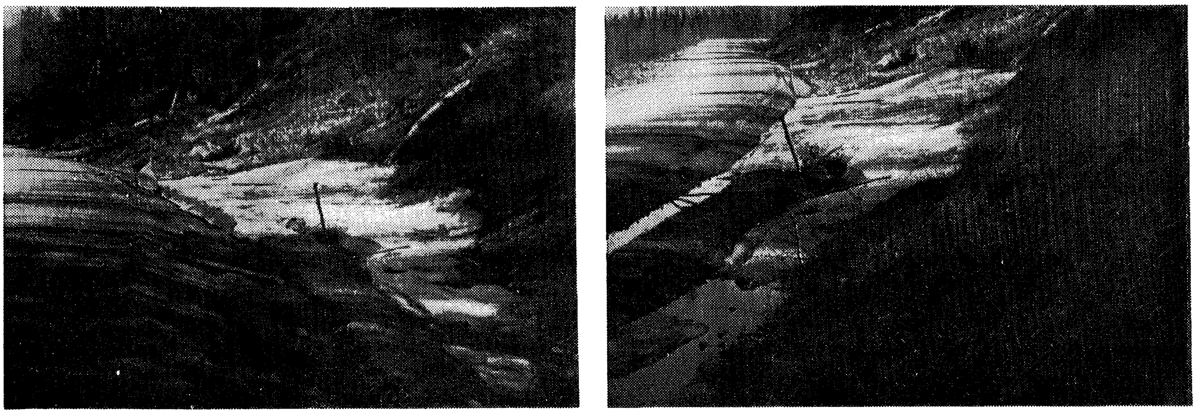
Minnehaha Falls is located several hundred miles south of the southern limit of permafrost.

Icing at Minnehaha Falls in Minnesota, April 10, 1949



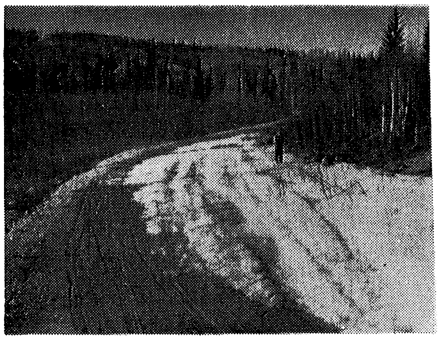
Water forming the icing comes from seepage through the fissures and crevices in the rock bluff.

Icing at Muncho Lake

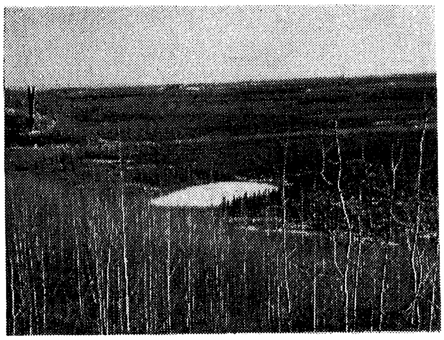


Springtime thaw had nearly melted this icing by May 20, 1949, the time the pictures were taken. The source of water is a spring.

Icing along the Anchorage Palmer Highway near Eklutna, Alaska

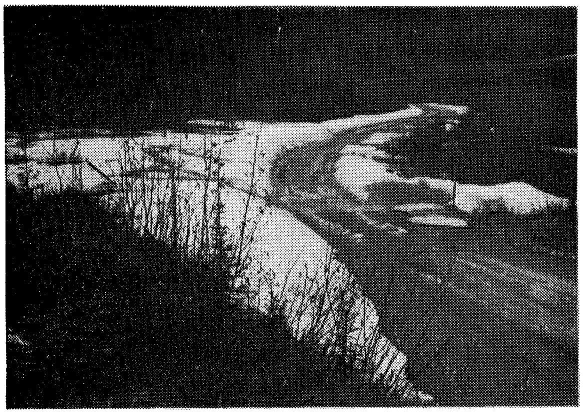


The ice is 30 in. thick at the point where the man is standing.



The arrow indicates the location of the icing.

Icing on Birch Hill Road near Fairbanks



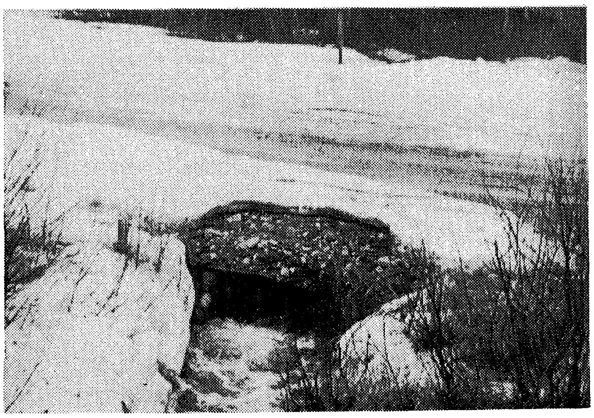
It is estimated that one acre-foot of ice is stored at this location.

Icing at Mile 15 on Steese Highway

This icing is relatively small in areal extent, but it is quite thick.

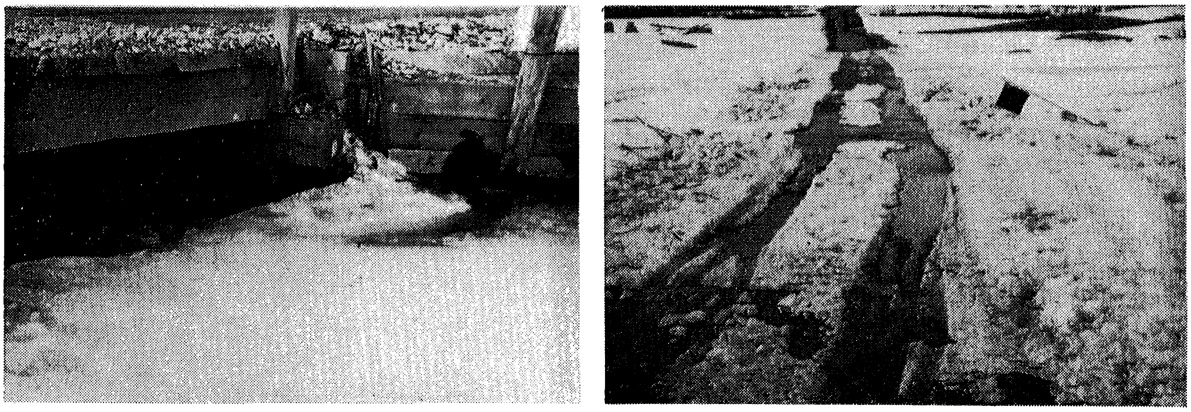
Icing at Mile 18 on Steese Highway

Water is flowing into a steam-thawed hole that leads to the upstream end of a culvert.



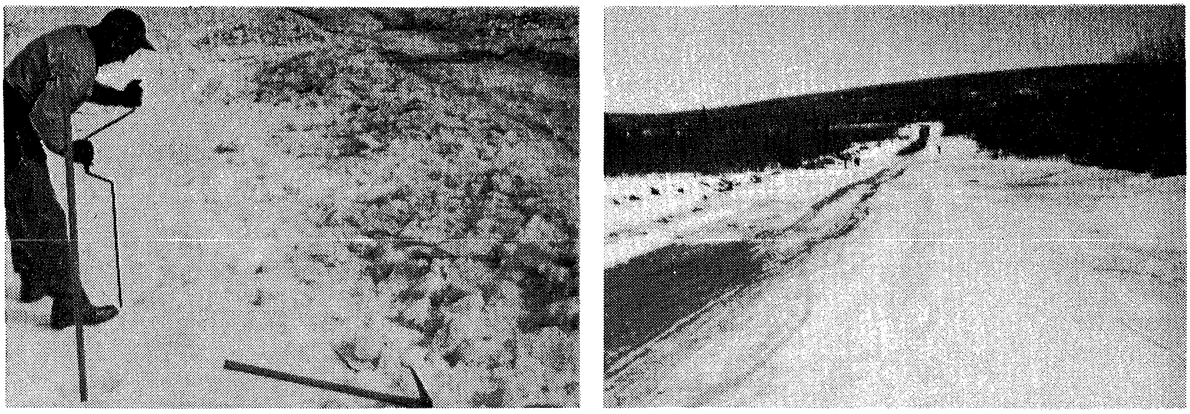
This is a view of the downstream end of the culvert.

Icing at Mile 15 on Steese Highway



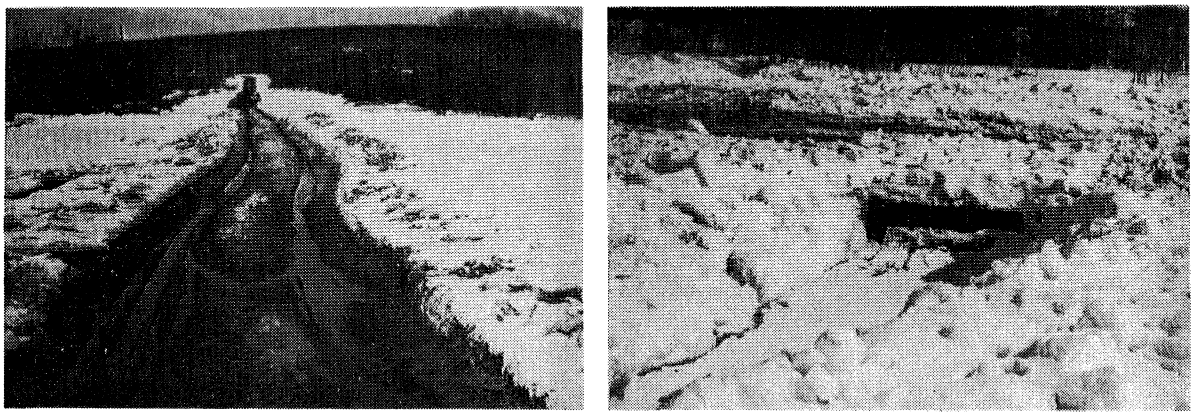
The bridge over Fox Creek was nearly filled with ice. This caused seepage through pervious tailings and overtopping of a low section of the road a short distance from the bridge.

Icing on Elliot Highway at Fox Creek near Fox, Alaska



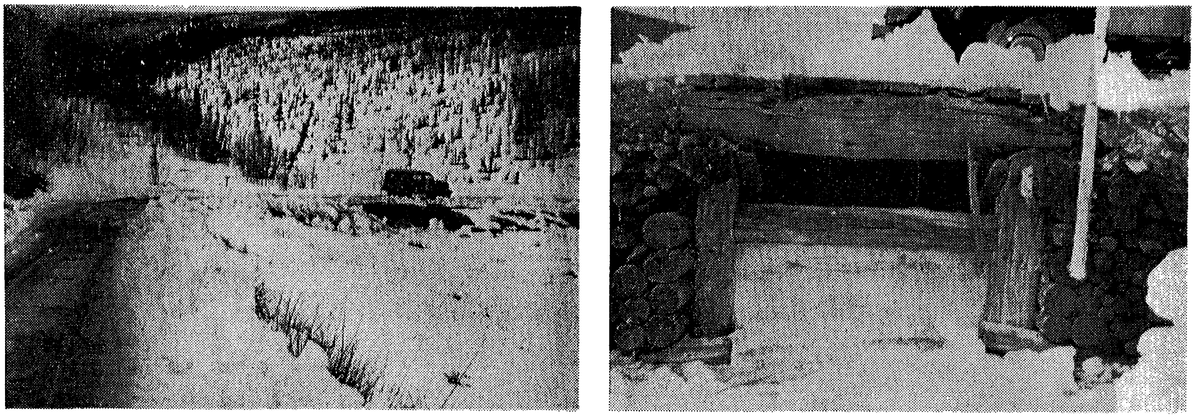
On April 27, 1949, highway maintenance men were drilling holes through the icing preparatory to a blasting oparation to clear an outlet channel.

Icing on Elliot Highway at Dome Creek



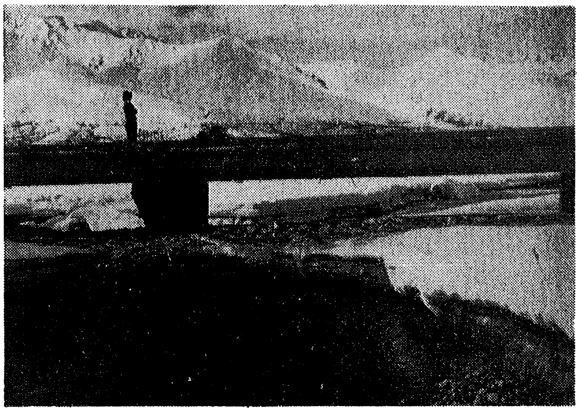
On May 6, 1949, the blasting operation of April 27 revealed the handrail of a culvert which had been completely covered with ice.

Icing on Elliot Highway at Dome Creek



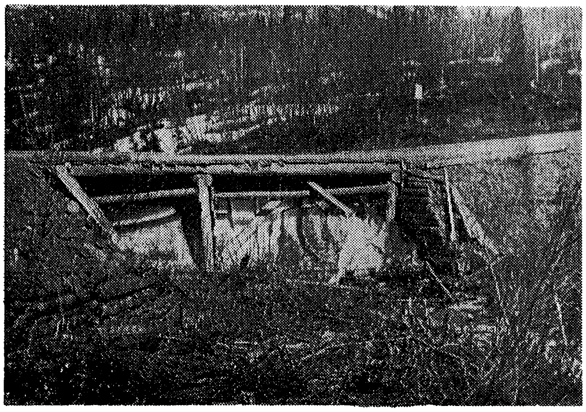
The upstream end of the culvert at this location was completely filled with ice.

Icing at Mile 48 on Steese Highway



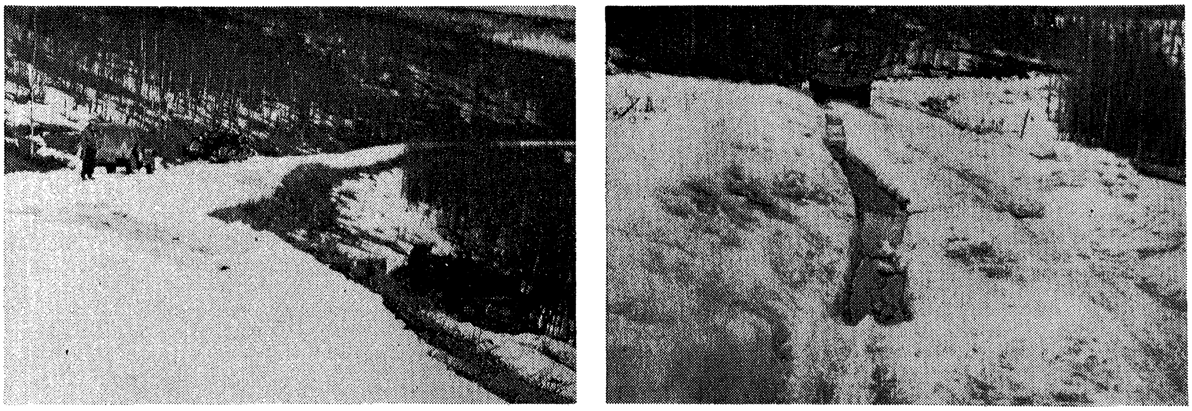
Horizontal laminations are visible in the ice
on the far side of the bridge.

Icing at Slana River on Tok Highway



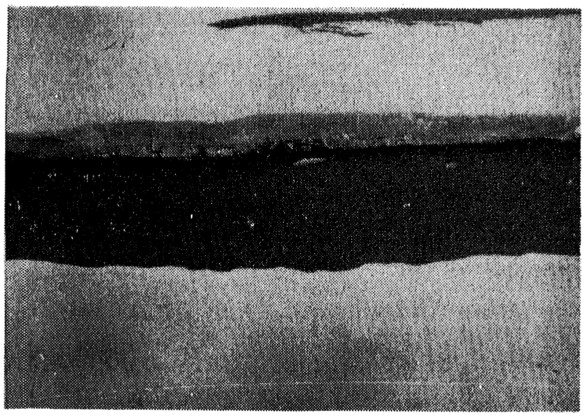
This bridge was completely filled with ice
at the time of inspection on May 18, 1949.

Bridge at Mile 83 on Tok Highway



A bulldozer had slipped off the ice-covered grade at one location. A short distance away two trucks were stuck in deep ruts.

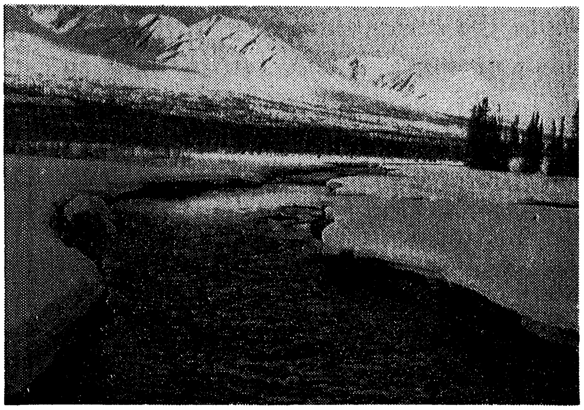
Icing near Mile 50 on Steese Highway



Horizontal lamination in the ice are visible.

The discharge during formation and growth of the icing was considerably less than indicated.in the photograph.

Icing on Johnson River, Alaska



The elevation of the top of the ice is several feet higher than the river stages even though discharges at the time of the pictures were greater than at the time of ice formation.

Icing on Slana River, Alaska

Icing on Chistochina River, Alaska

Water was flowing beneath the icing.

Remnants of icings are indicated by arrows.

Icing in a Drainage Channel

III. INFLUENCE OF DRAINAGE CHANNEL ON THE THERMAL REGIME OF THE GROUND

13. General Aspects. During the course of the 1949 investigation, the investigator had an opportunity to discuss various phases of drainage with Mr. R. H. Ogburn of the Fairbanks Exploration Company. It was of particular interest to learn that mining companies have considerable difficulty in maintaining some reaches of their diversion canals. Their maintenance crews have observed that some lengths of channel settle so that it is almost impossible to maintain a grade. Many washouts have been noted that are not associated with overtopping or rates of discharge in excess of channel capacity. Many sections of channel have to be cleared of icings before diversion begins each spring.

In some localities conditions along highways indicated that road ditches were affected adversely by a process of unequal settling. Large longitudinal cracks appeared near the shoulder of some sections of road. Banks of ditches had sloughed down into channels at locations where it was quite evident that the phenomena could not be caused by the abrasive action of flowing water. In some cases it appeared that the bottoms of the ditches were perceptibly lower than the originally constructed grades.

The shape and position of vegetation along some reaches of natural channels create the impression of thermokarst and subsequent settling action. It was noted in several instances that trees growing adjacent to and on the inside of stream bends had assumed a tilted position. Growth subsequent to the tilting was vertical. Figure 8 schematically illustrates what is believed to have taken place. Undercutting by erosion and later settlement is discounted, as the location of the tilting trees can be found at points where deposition of material rather than scour occurs.

14. A Specific Illustration. Figure 9 was prepared from information obtained by the Permafrost Branch, Corps of Engineers, Fairbanks. This clearly indicates a considerable degradation of permafrost subsequent to the construction of a drainage channel. It does not seem reasonable to attribute the entire dip in the permafrost table to increased thaw resulting from the removal of an insulating cover of vegetation. It is to be noted that the maximum depth of thaw is directly beneath the drainage channel. There are no records available to support the view that considerable settlement has taken place

along this ditch. The amount of such settlement, of course, would depend on the composition of the permafrost layer over which the ditch traverses. If the permanently frozen ground consisted of ground ice, very irregular settlement could be expected.

15. Design Implications. Without further basic research data it is impossible to specify either the shape of a drainage channel or the distance it should be located from a runway or highway shoulder. Conceivably, drainage facilities may be required at locations where it is impossible to avoid fine-grained soils and attendant ground ice conditions. If so, is it possible and practical to insulate channels and in that manner prevent degradation of permafrost? It may also be desirable in the layout of a development to abandon a natural waterway and use that area as a site for construction. What then are the implications? Will the permafrost aggrade? If so, what will be the consequent changes in surface elevations? These and other questions cannot be answered quantitatively, and general trends can be appraised only qualitatively at the present time.

16. Research Needed. Knowledge of the influence of flowing water on the thermal regime of the ground over which the discharge occurs is basic to drainage design. Many contributing variables, each difficult to isolate, control the phenomena. It is essential to isolate these factors by research, weigh the effect of each, and coordinate the findings with the thermal conductivity tests that have been made. Some of the factors are listed as follows:

(a) Discharge regime of the channel.
(b) Temperature regime of the flowing water.
(c) Width and depth of the stream of flowing water.
(d) Duration of discharge.
(e) Composition of the active layer.
(f) Composition of the permafrost.
(g) Temperature of the permafrost.
(h) Topographic position of the channel.

17. General Research Procedure and Statement of Objectives. Because of the complex nature of the problem, it is recommended that initial research be confined to exploratory surveys of existing drainage channels at points where one or more of the factors can be controlled. A systematic scheme of probing and drilling at selected cross sections covering a wide range would

yield information of intrinsic value. It is expected that the information thus gathered would lead the way to long-range research by some local organization such as the Permafrost Branch at Fairbanks. Quantitative evaluation and significance of the contribution of each of the influencing factors are ultimate objectives.

18. Permission of Local Mining Companies. The first step in carrying forward a project of this nature would be to secure permission from local mining companies to conduct research activity at selected sites along their diversion canals. No difficulty is anticipated in this respect, as a better understanding of the phenomena would be useful in the solution of many of their problems.

19. Site Selection. The second step would be site selection. Accessibility, although of importance, is not a limiting criterion, as eventual choice of a research site must be made on the basis of isolating the various contributing factors. To illustrate a suggested procedure, some aspects of each of three hypothetical sites are outlined as follows:

(a) Site 1. Orientation and topographic position are influential factors. It is believed possible to obtain some knowledge with respect to these factors by investigating conditions at a site where a conduit carrying measurable or known discharge and temperature regimes traverses slopes facing north, south, east, and west. Many mining company diversion siphons are so located and appear favorable for consideration as research sites.

(b) Site 2. It seems quite probable that sites could be found where orientation and altitude, as well as discharge and temperature regimes, would remain constant throughout the length of a reach of open channel which traverses varying compositions of soil. At these places effects of items (e), (f), and (g) of paragraph 16 could be noted.

(c) Site 3. The effects of discharge aspects could be observed by comparing conditions at sites where the other influencing factors are similar.

20. Research Data. A detailed topographic survey should be made of each site. Borings for determination of soil moisture should be made and progressive logs maintained at strategic locations. Drilling operations should begin

as soon as possible in the spring and continue through the summer and fall. Actual cross sections for drilling should be spaced about 500 ft apart. It is anticipated that four to six drill holes and possibly two probings will be required at each section. A continuous record of discharge and water temperature should be made at each site. It will be essential to record climatological data also.

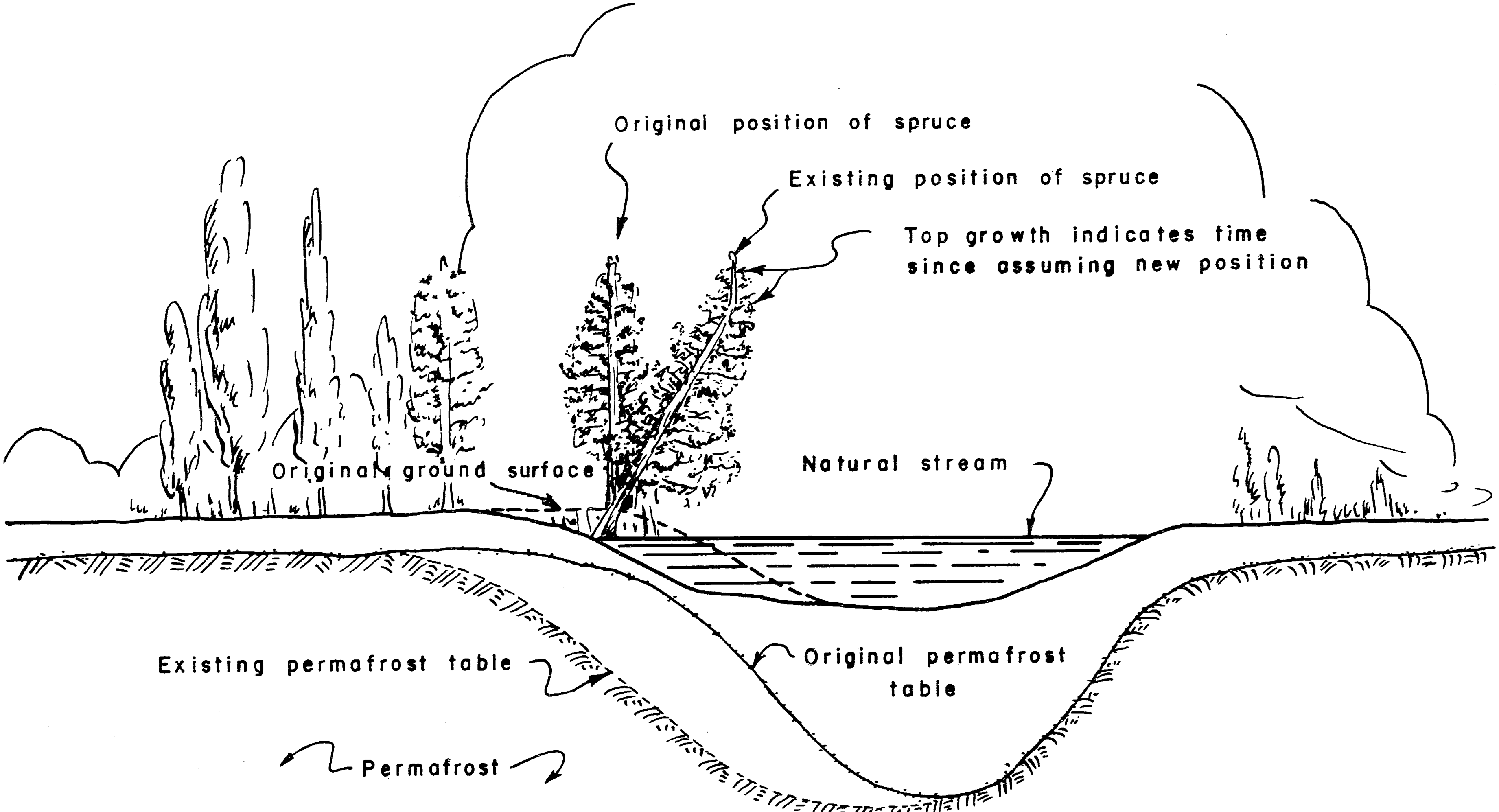


Fig. 8 Thermokarst Action Along Rivers and Streams

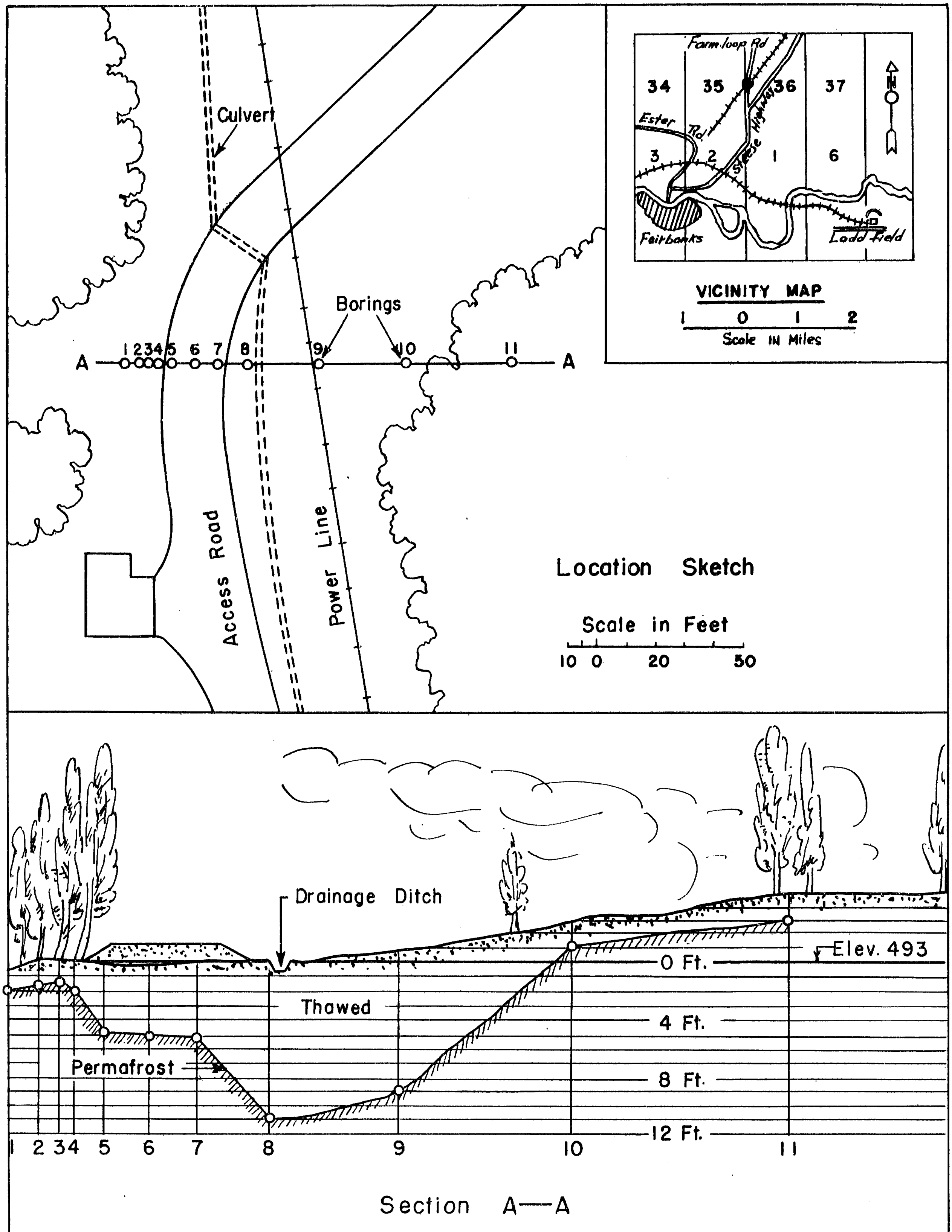


Fig. 9. Influence of a Drainage Ditch on the Thermal Regime of the Ground

IV. EROSION

21. General Statement. In polar regions there are two types of erosion to consider in addition to the type ordinarily associated with the term. These two new types depend on thawing of frozen ground. The first does not take place unless permafrost is thawed by action of moving water with which it is in contact. The other results when the active layer thaws.

22. Erosion, the Result of Thawing Permafrost. When permanently frozen ground is in contact with water, as indicated in the photograph on Plate 15, melting of the permanently frozen material is accelerated at the water line. When the frozen material melts, it disintegrates from a mass into many small soil particles which are washed into the lake or stream by action of the moving water. This action continues and progressively undermines the bank. Eventually the weight of the ever-increasing undermined portion becomes too heavy to be held in a cantilever position and huge chunks break off. These large chunks are then subjected to accelerated thaw and the melted material washes away. Under proper circumstances this form of erosion can be very severe. Plate 13 of Part I, "Investigation of Airfield Drainage, Arctic and Subarctic Regions" is illustrative of this condition in the Bethel area of Alaska. Here several hundred feet of shoreline measured normal to river flow has been washed away since 1913. Buildings must be moved back periodically.

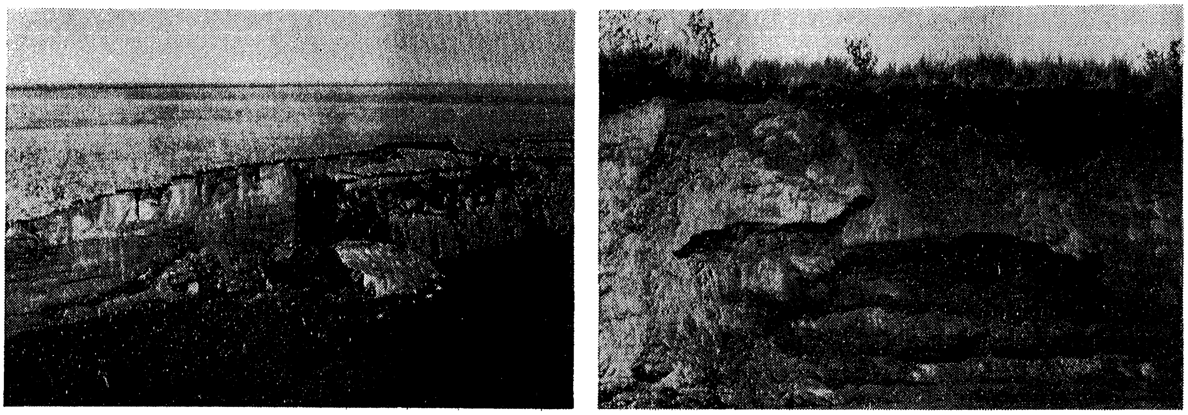
23. Thawing Active Layer and Erosion. When saturated soil of medium texture and single-grain structure melts, it forms a mud of paste-like consistency. If this is subjected to the action of even a very small flow of water, erosion takes place. Flowing water also accelerates thaw and the material washes away from the stream bed as quickly as it thaws. The active layer is, of course, neither uniform in thickness nor homogeneous in composition. Consequently, some sections will melt perceptibly in advance of others. In the case of a ditch or small stream, the thaw may penetrate the entire depth of the seasonal frost in the active layer. Water would then percolate into the comparatively dry material below the depth of winter freeze. As runoff continues, this material would become saturated and a hydrostatic head would develop. Eventually, when subjected to pressure, a weak point at some distance downslope would erupt upward. Flow would then commence through the new outlet and follow underground between this erupted outlet and the eroded inlet at some distance upslope. Unfrozen material above the permafrost and below the bottom of seasonal frost would be excavated by erosion, leaving a

cavern which eventually collapses. Continued runoff then washes out the collapsed material and a gully is formed which increases rapidly in size. Some of the photographs on Plate 15 illustrate this particular type of erosion.

24. Solifluction. This process is very common in the permafrost region of Alaska. It is closely related to erosion in that it consists of a downslope movement of saturated soil. It differs from the ordinary erosion process in that the abrasive action of flowing water is not essential for movement of the mass of soil. Sufficient water for saturation is all the moisture that is required. This phenomenon is particularly troublesome in the maintenance of drainage ditches in areas where the active layer is or will be quite deep. Care must be taken to provide quite flat side slopes. The side slopes of ditches in fine-grained soils should not be steeper than 1-ft vertical rise in 6-ft transverse or horizontal distance, unless protected by sod or other measures. The natural vegetal cover on the uphill slopes above side-hill channels should be disturbed as little as possible. Flat-ditch side slopes are to be preferred from the standpoint of snow removal also.

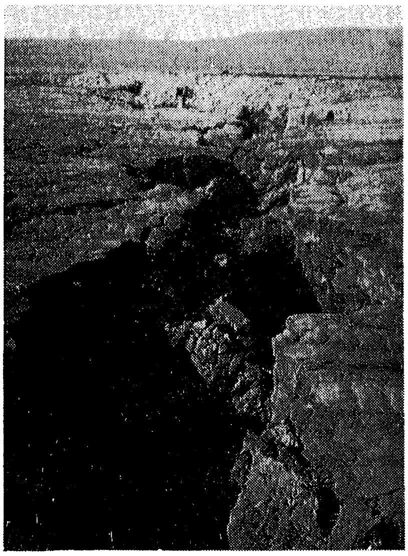
25. Landslides. For the purpose of this paper all forms of earth movement that entail considerable mass depth are included in this term. Other terms ordinarily used in connection with these phenomena are creep, slump, and slip. As the word implies, creep denotes a very slow but persistent movement over long periods of time. Slump is distinguished by a backward rotation of the descending material. Slip usually refers to a relatively short movement of a quite small mass. In arctic and subarctic areas landslides are commonly associated with two physical features, both of which are requisites to the occurrence: (1) there must be a perceptible declivity in the permafrost table, and (2) there must be an increase in moisture content at the interface of permanently frozen ground and the overlying unfrozen material. Steep slopes of the permafrost table are encountered below steep-surface slopes and may be found also below relatively flat-surface lands near lakes, streams, and rivers. An increase in moisture at the top of the permafrost table may result in a number of ways. The most common manner, however, is by alteration of the thermal regime of the ground which results from the removal of natural vegetation, construction of a ditch, road, or other physical improvement. Serious difficulty can be expected in the case of a drainage ditch because the action of flowing water has an accelerating effect on the degradation of permafrost. Water will be released in the process of permafrost thaw and this might be augmented by seepage from the ditch.

26. Measures Against Landslides. So far as is known, there are no innovations or methods which have been developed to give adequate protection against landslides. In general, the routes of drainage facilities should avoid traversing land under which the permafrost table lies on a steep slope. This, however, is not possible in all cases. Mining companies in the Nome area have had some success with lining of the canals with an impervious clay material to prevent seepage. In other cases ditch bottoms have been built over an insulating layer of peat and moss. Russian engineers have resorted to artificial freezing where steep banks were endangering excavations. Deep cuts should be avoided if possible.



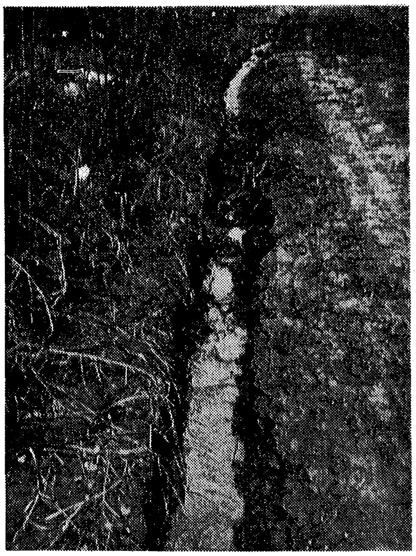
Permafrost thaws quickly at the waterline creating an undermining action which causes huge chunks of earth to break off. This action is severe along the Kuskokwim River at Bethel.

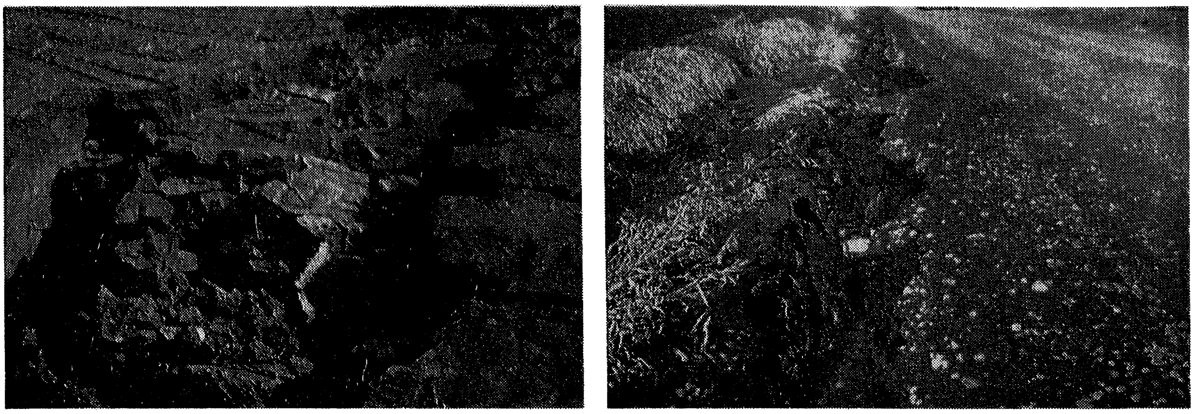
Erosion Resulting from Thawing Permafrost



At both of these sites runoff water disappears beneath the channel bed then emerges again at a lower point along the slope.

Erosion Resulting from a Thawing Active Layer





At both sites gullies had formed in a matter of a few days even though the active layer was still frozen.

Typical Erosion along the Farmers Loop Road near Fairbanks

V. HYDROLOGICAL DESIGN OF RIVER AND STREAM CROSSINGS

27. General Observations. During the investigations of 1948 and 1949, the University investigator noted frequent instances where roads were impassable due to washed out bridges and culverts and because many sections of highway were inundated. Of course, it seldom is economically justifiable to erect crossings sufficiently large to accommodate the highest stages and the largest discharges. In many instances it seemed that hydrological aspects of culvert and bridge design had not been fully considered. No doubt, the availability of materials was an influencing criterion for size of structures in many cases.

28. River Performance. In arctic and subarctic regions, factors in addition to those of more temperate zones influence the behavior of rivers and streams. Stage-discharge relations are altered as a result of ice jams. High discharges may be the result of a structural failure of a glacier. The frequency with which high stages occur is independent of the frequency of high discharges, and this in turn is independent of rainfall. Records of river flow are very meager and practically nonexistent. River channels shift in position from year to year, often as much as 1000 ft. Obviously, ordinary tools of the hydrologist cannot be employed in design. The unit hydrograph is not applicable. The size of the watershed is not an accurate indicator of expected floods. Superposition of intense storms is futile.

29. Only One Available Procedure. There is only one procedure by which hydrological design can be determined. It consists of an analysis and interpretation of nature's exhibit in the form of physical features at the river section. However, this procedure is neither systematized nor developed. No one will dispute the desirability of having river-discharge records from which the behavior of streams can be studied. An aggressive program of flow measurements is to be recommended. This requires a long and continuous process before criteria of design importance can be evaluated. In the meantime, it is essential to base hydrological design on standards that can be developed and systematized in a comparatively short time. The writer suggests that nature in all probability has left a record that can be analyzed.

30. Research. A research project for the purpose of developing hydrological design criteria, applicable particularly to subarctic regions of Alaska, would not be especially difficult to undertake. Field work would

require the services of not less than two men, one a professional engineer with a knowledge of soils and plant growth. Very little would be needed in the way of equipment outside of ordinary survey tools and means of transportation. The investigation would entail surveys and observations of rivers and streams at several selected sections. The importance and significance of the many physical features which are relevant to hydrological design could be pointed out.

VI. LIBRARY RESEARCH

31. General. It is recognized that a logical and important beginning for any research project is a thorough analysis of all literature which may deal with the topic. In addition to the translations and abstracts contained in Project Report No. 17, a cursory review of bibliographies of Russian literary works has been under way. A member of the Laboratory staff, during a vacation in New York, examined publications at the New York Public Library, Stefansson Library, American Geographical Society, Geological Society of America, and Amer Russian Institute. This was done without cost of travel for the project. More than 200 volumes were investigated as to availability and about 80 volumes were located. Of these 80 publications, 52 contain information which deals entirely or in part with arctic drainage.

32. Results of the Review. The results of this cursory examination are contained in a card file at the Laboratory. A summary is as follows:

Berezantsev, V. G., "Strength of Permafrost Under Building Foundations," Merzlotovedenie, Ac. Sci. USSR, Vol. 2, No. 1, 1947, pp. 48-54, 7 figs., 2 refs. (New York Public Library, Call No. *QCB).

The article contains a theoretical and experimental evaluation of the strength of permafrost. Valuable formulas are derived.

Bilibin, Yu. A., "Active and Passive Permafrost," Izvestia Russkovo Geogr. O-va, Vol. 69, No. 3, 1937, pp. 409-11. (Stefansson Library).

The author discusses two opposing theories on the origin of permafrost. Reference is made to the occurrence of various phases of permafrost in the USSR.

Chirikhin, U. D., "Permafrost in the Basin of the Indigirka River," Trudy Kom. po Izuch. Vech. Merzloty, Ac. Sci. USSR, Vol. 3, 1934, pp. 21-39. (University of California, Berkeley).

The author establishes relationships between the water in the active layer and the water present in the ground, the temperature of the air, and the snow cover.

Dementyev, A. I., "Effects of Suprapermafrost Flow During Winter Freezing of the Ground," Vestnik Ac. Sci. USSR, No. 9, 1945, pp. 75-76, 1 fig. (Amer Russian Institute).

The author describes a case of an icing formed by water in the active layer and the resulting damage to structures.

Dementyev, A. I., "Classification of Permafrost from the Engineering Point of View," Merzlotovedenie, Vol. 2, No. 1, 1947, pp. 55-57, 8 refs. (New York Public Library, Call No. *QCB).

The author presents the current classification of permafrost according to horizontal distribution, vertical distribution, and physical state of the ground. He maintains that this classification is inadequate for engineering characterization and that an additional factor of stability is needed.

Efimov, A. I. et al., "Instructions for Taking into Consideration the Peculiarities of Frozen Ground During Exploration, Planning and Construction of Airfields in the Southern Permafrost Region," Trudy Instituta Merzlotovedenie, Ac. Sci. USSR, 1946. (Library of Congress).

The authors discuss various aspects of airfield construction under conditions of permafrost. (A detailed abstract appears in "Abstracts of Scientific Research Investigations for 1944," Ac. Sci. USSR, pp. 120-21.)

Efimov, A. I., "Deep Freezing of the Ground and the Regime of the Water above the Frozen Ground under Heated Buildings," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Vol. 4, 1944, pp. 205-25, 10 refs. (Stefansson Library).

This article presents results of observations and experiments. It includes numerous data on permafrost and seasonal freezing and gives a diagram of the thawing and the resulting water pressure.

Fedosov, A. E., "Phase Composition of Frozen Ground," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Issledovanye Vechnoi Merzloty v Yakutskoi Respublike, vyp. 1, Yakutsk, 1942, pp. 18-43. (Library of Congress).

This article presents a study of the phase composition of permafrost in the province of Yakutsk.

Glazov, N. V., "Methods for Studying the Degradation of Permafrost," Trudy Komiteta po Vechnoi Merzlote, Ac. Sci. USSR, Vol. 4, 1938, pp. 155-61.

The author suggests that the proper method for studying the degradation phenomena is by means of observations on traces left in the ground by freezing. These traces are sinking of the ground, infiltration and chemical effect of soluble salts, and difference in salt concentration and coloration of the ground.

Grigoriev, A. A., "The Subarctic," Trudy Instituta Geographii, Ac. Sci. USSR, 1946, pp. 3-161. (Geological Society of America, New York).

This work includes an extensive study of permafrost as a factor of the geomorphological process and of the nature and behavior of lakes and rivers under permafrost conditions.

Kachurin, S. P., "Evidence of Permafrost in the South of the West-Siberian Plain," Merzlotovedenie, Vol. 2, No. 1, 1947, pp. 23-30, 2 figs., 41 refs. (New York Public Library, Call No. *QCB).

The article is a discussion on the existence of permafrost in the region under consideration.

Kachurin, S. P., "Regression of Permafrost," Doklady Ac. Sci. USSR, New Series, Vol. 19, No. 8, 1938, pp. 593-97. (University of Minnesota).

This brief article discusses the need for revision of the permafrost boundaries.

Kachurin, S. P. et al., "Permafrost Investigations in the Regions of Objects Nos. 1460 and 193," (Abstract given in "Abstracts of Scientific Research Investigations for 1944," Ac. Sci. USSR, p. 121).

This work presents the results of investigations conducted for the purpose of selecting proper locations for airfields and recommending drainage procedures. Six recommendations are listed.

Khomichevskaya, L. S., "Compressive Strength of Natural Permafrost and Ice," Trudy Kom. po Izuch. Vechnoi Merzloty, Ac. Sci. USSR, Vol. 10, 1940, pp. 37-83, 13 figs., 8 refs. (University of California, Berkeley).

The results of laboratory experiments on the compressive strength of permafrost under natural conditions were verified in the field by different methods and processes. Comparative data are compiled in two tables.

Koloskov, P. I., "Depth of Winter Freezing of Ground in European USSR and Kasakhstan," Merzlotovedenie, Vol. 2, No. 1, 1947, pp. 36-43, 2 figs. (New York Public Library, Call No. *QCB).

The article represents a study of the depth of winter freezing of the ground under natural conditions and under conditions of bare surface. The corresponding formulas are derived.

Kudriavtsev, V. A., "Degradation of Permafrost," Trudy Kom. po Izuch. Vechnoi Merzloty, Vol. 8, 1939, pp. 81-117, 17 figs. (University of California, Berkeley).

The article presents an account of degradation phenomena observed in a given region and discusses the corresponding engineering implications.

Kushev, S. L., "Morphology and Genesis of Hilly Swamps and their Geographical Distribution," Trudy Kom. po Izuch. Vechnoi Merzloty, Ac. Sci. USSR, Vol. 8, 1939, pp. 119-61, 16 figs. (University of California, Berkeley).

The author made a study of the mechanical deformation resulting from freezing of the ground. The study is based on observations of mounds formed in permafrost regions within subarctic and temperate zones.

Lukashev, K. L., "The Permafrost Region as a Special Physico-Geographical and Engineering Region," Leningrad University, 1938, 187 pp., 59 figs., 2 maps. (New York Public Library, Call No. *QH, p.v. 72).

This work is a treatise on permafrost. It discusses the physical and geographical aspects of permafrost and particularly the aspects that are important for engineering considerations.

Lukashev, K. I., "Granulometric Composition of Ground in the Permafrost Area of the Russian Arctic Region," Uchennie Zapiski, Leningrad University, No. 16, Ser. Geol., Poshvoved. i Geogr., vyp. 4, 1937, pp. 170-84, 11 tables, 41 refs. (New York Public Library, Call No. *QDB).

The article presents the results of a study of the granulometric composition of numerous soils in the permafrost region. The soils investigated are maritime transgression, old lake and river soils, soils of the active layer, and soils of definite geographical locations.

Lukashev, K. I., "Mound Formation as a Manifestation of the Tension in Permafrost," Uchennie Zapiski, Leningrad University, No. 10, Ser. Geol., Pochvoved. i Geogr., vyp. 3, 1936, pp. 147-58, 2 figs. (New York Public Library, Call No. *QCB).

The author discusses the following aspects of mound formation: causes, morphological properties, soils, freezing, hydrogeological regime, and effects of various factors.

Lukashev, K. I., "Soil Creeping and Flow under Permafrost Conditions," Ezhegodnik Leningrad University, No. 26, Ser. Geolog., Poshvoved. i Geogr., vyp. 6, 1938, pp. 5-22, 9 figs. (University of Washington, Seattle).

The article is a study of the mechanical deformation of ground under conditions of permafrost.

Meister, L. A. and Melnikov, E. I., "The Adfreezing Forces Acting Between Permafrost and Wood or Concrete and the Shearing Resistance of Permafrost under Field Conditions," Trudy Kom. po Vechnoi Merzlote, Ac. Sci. USSR, Vol. 10, 1940, pp. 85-108.

The author presents the results of investigations conducted in the field.

Melnikov, P. I., "Conference on Transport Construction under Permafrost Conditions," Vestnik Ac. Sci. USSR, No. 1-2, 1940, pp. 103-07. (Corps of Engineers).

A report on the problem of transport construction under conditions of permafrost.

Mordvinov, A. I., "Topography and Permafrost in the Region of the Byssa River and the Turanian Mountains," Trudy Kom. po Vechnoi Merzlote, Ac. Sci. USSR, Vol. 9, 1940, pp. 57-133, 71 refs. (University of California, Berkeley).

The author discusses the topography of the region and the aspects of permafrost, drainage, ground temperatures, frost mounds, and the relation between permafrost and the topography.

Moskvitin, A. I., "Concerning Traces of Permafrost and the Need for Determining these Traces," Merzlotovedenie, Vol. 2, No. 1, 1947, pp. 3-22, 20 figs., 59 refs. (New York Public Library, Call No. *QCB).

The author analyzes the occurrence of traces of permafrost and discusses the importance of ascertaining these traces for engineering and other purposes.

Obruchev, V. A., "Progress of Frost Science in the USSR," Memorial Volume, Ac. Sci. USSR, Part 2, 1947, pp. 217-37. (Amer Russian Institute).

This paper contains an historical review of the progress achieved in all major phases of the study of permafrost.

Redozubov, D. V., "Laws of the Temperature Field of the Permafrost in the Vorkuta Region," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Vol. 1, 1946, pp. 137-66, 12 figs., 9 tables, 9 refs. (New York Public Library, Call No. *QCB).

The article is an analytical and experimental study based on geophysical interpretation of permafrost.

Romanov, V. V. and Rozhanskaya, O. D., "Physical Properties of the Frozen Stratum of Swamps," Priroda, No. 3, 1946, p. 57. (New York Public Library, Call No. *QCA).

This brief note describes the results of experimental analysis of 51 samples of the frozen stratum. The analysis indicates the existence of seven distinct physical properties.

Rubinstein, L. I., "Process of Freezing of Soil," Izvestia Ac. Sci. USSR, Ser. Geogr. i Geophys., Vol. 11, No. 6, 1947, pp. 489-96, 1 ref. (New York Public Library, Call No. *QCB).

This paper is an analytical study of the freezing process of soil containing moisture having a series of different freezing temperatures, for the case of infinite half-space under Stefan's boundary conditions.

Sedletski, I. et al., "X-Ray Studies of Processes of Ground Freezing," Comptes Rendus, Ac. Sci. USSR, Vol. 47, No. 4, 1945, pp.294-95. (In English) (University of Minnesota).

This first study in a projected series of studies was planned to collect evidence on the migration of water during thawing and freezing in various types of sediment.

Sedov, V. P. and Shvetsov, P. F., "Connection Between Icings and Ground Water in the Basin of the Yana River," Sovetskaya Geologia, No. 12, 1940, pp. 86-92, 4 figs. (Corps of Engineers).

Observations have disclosed that frozen ground and surface ice have a definite effect on the flow regime of ground water.

Shimanovski, S. V., "Influence of Cover Upon Thermal Regime of Ground," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Issledovanie Vechnoi Merzloty v Yakutskoi Respublike, vyp. 1, Yakutsk, 1942, pp. 45-51. (Library of Congress, Call No. 1A 710 A454).

The article presents results of investigations showing the extensive effect of cover on the surface of the ground upon the thermal regime in the ground.

Shvetsov, P. F., "Permafrost and Engineering and Geological Conditions of the Anadyr Region," Glavsevpromput, Leningrad, 1938, 77 pp., 34 figs., 22 tables, 14 refs. (Stefansson Library).

The author describes the physical, geographical, geological, hydrogeological and permafrost aspects of the region with the objective of determining its suitability for engineering construction.

Shvetsov, P. F., "New Data on the Effect of Subpermafrost Water on the Capacity and Rate of Flow of the Indigirka River," Doklady Ac. Sci. USSR, Vol. 57, No. 7, 1947, pp. 711-14, 5 refs. (University of Minnesota, Call No. 506 AK 13dcR).

Observations show that the subpermafrost water affects the flow in the river.

Shvetsov, P. F., "Ground Water and Ground Ice in the Region of Anadyr and Ugolnaya Bay," Nedra Arktiki, Vol. 2, 1947, pp. 204-12, 2 figs., 4 tables, 4 refs. (Library of Congress).

The author classifies the ground water and ground ice of the region.

Shvetsov, P. F., "Relation of Temperature of Permafrost and Depth of Frozen Ground to the Geological Structure and Ground Water Conditions," Izvestia Ac. Sci. USSR, Ser. Geol., No. 1, 1941, pp. 114-24. (New York Public Library, Call No. *QCB).

The author finds that the temperature and depth of permafrost in Northern Russia bear no relationship to the climate, but rather are determined by geological and ground water conditions. Tables of temperature and of depth of frozen ground are given.

Shvetsov, P. F., "The Role of Permafrost and Subpermafrost Waters in the Hydrology of the Basins of the Indigirka and Yana Rivers," Izvestia Ac. Sci. USSR, Ser. Geol., No. 6, 1946, pp. 137-52, 22 refs. (University of Illinois).

The author describes the peculiarities of the water runoff in the region and finds that they are influenced by both permafrost and meteorological conditions. The origin of the subpermafrost water is not determined.

Soloviev, P. A., "Ground Ice in the Anadyr Region," Nedra Arktiki, Vol. 2, 1947, pp. 213-32, 8 figs., 10 refs. (Library of Congress).

The author classifies the ground ice in six distinct groups.

Sukhodolski, E. I., "Construction of Railroad Beds in Northern Permafrost," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Vol. 2, 1945, pp. 1-129, 62 figs., 10 tables, 22 refs. (Stefansson Library).

The article presents a thorough analysis of engineering aspects of earth beds for railroads in permafrost regions. Chapter 5 deals in part with drainage aspects of the beds.

Sukhodolski, E. I., "Conditions of Frozen Ground and the Behavior of Experimental Drainage at the Ksenievskaya Station of the Amur Railroad," Referati Nauchno-Issledovatelskikh Rabot za 1944, Ac. Sci. USSR (in the form of an abstract given on pp. 121-22). (Amer Russian Institute).

The article is a report on the investigation of operating conditions of the drainage system installed in 1938 at the experimental permafrost station of the civil aviation authority. Five recommendations are made.

Sumgin, M. I. et al., "General Frost Science," Ac. Sci. USSR, 1940, 340 pp. (Corps of Engineers).

The book contains the following chapters: (1) Introduction, Terminology, A Brief History of Frost Sciences, (2) Physical and Mechanical Processes in Freezing and Frozen Ground, (3) Seasonal Freezing and Thawing of the Ground in Permafrost Areas, (4) Permafrost Distribution and Thickness, (5) Thermal Regime of the Ground in Permafrost Areas, (6) Physical Properties of Frozen Ground, (7) Genesis of Permafrost, (8) Degradation of Permafrost.

Sumgin, M. I. et al., "Research on Permafrost," Gossizdat, Yakutsk, 1942, 101 pp. (Corps of Engineers).

The book presents the results of permafrost research done in the USSR to date.

Sumgin, M. I. and Demchinski, B., "The Permafrost Region," Glavsevpromput, Moscow, 1940, 238 pp. (Corps of Engineers).

This book is a treatise on the region and phenomena of permafrost.

Tolstikhin, N. I., "Artesian Water of the Frozen Geozone in USSR," Merzlotovedenie, Vol. 2, No. 1, 1947, pp. 31-35, 2 figs., 2 refs. (New York Public Library, Call No. *QCB).

The author discusses and classifies the artesian waters in permafrost regions.

Tolstikhin, N. I., "Subterranean Waters of the Lithosphere," Gossizdat Geol. Lit., Geol. Kom. Sovnarkoma, Moscow, 1941, 200 pp. (Library of Congress).

This work discusses various phases of ground water, subterranean water and surface water in permafrost regions.

Tolstov, A. N., "Formation of Ice Plugs in Drainage Systems of Airfields in Southern Permafrost," Merzlotovedenie, Ac. Sci. USSR, Vol. 2, No. 1, 1947, pp. 69-72, 2 figs. (New York Public Library, Call No. *QCB).

The author describes cases of swellings formed on airfields located in the southern region of permafrost and where hilly swamps existed prior to construction. Measures against the swellings are recommended.

Toomel, V. F., "Surveying Permafrost," Izvestia Ac. Sci. USSR, Ser. Geogr. i Geophys., Vol. 9, 1945, pp. 135-44, 2 figs. (New York Public Library).

The author discusses methods and procedures for surveying permafrost.

Toomel, V. F., "Changes in Permafrost Due to Incineration of Vegetative Cover," Trudy Kom. po Izuch. Vechnoi Merzloty, Ac. Sci. USSR, Vol. 8, 1939, pp. 3-80, 4 figs. (University of California, Berkeley).

The article describes results of observations showing that forest and brush fires play a significant role in modifying the physical and geographical features of an area, and, consequently, the conditions in the permafrost zone.

Toomel, V. F., "Some Aspects of Permafrost Beneath Building Foundations under Conditions of Northern Permafrost," Trudy Instituta Merzlotovedenia, Ac. Sci. USSR, Vol. 1, 1946, pp. 5-26, 10 figs., 5 tables, 27 refs. (New York Public Library, Call No. *QCB).

The article includes a comparison of various climatic factors in different regions with the thermal regions of the permafrost.

Tsytovich, N. A., "Certain Mechanical Properties of Permafrost in the Yakut Region," Trudy Kom. po Vechnoi Merzlote, Vol. 10, 1940, pp. 109-36. (University of California, Berkeley).

The author develops an analytical and experimental method for determining the coefficient of compressibility at thawing of frozen ground.

Tsytovich, N. A., "Theory of Equilibrium of Water in Frozen Ground," Izvestia Ac. Sci. USSR, Ser. Geogr. i Geophys., Vol. 9, No. 5-6, 1945. (American Geographical Society).

This article is an analytical study.

Tsytovich, N. A., "Elastic and Plastic Deformation of Frozen Ground," Trudy Kom. po Izuch. Vechnoi Merzloty, Ac. Sci. USSR, Vol. 10, 1940, pp. 5-35, 16 figs. (Corps of Engineers).

The author reports on experimental investigations of deformations in permafrost under load, and establishes relationships between these deformations and the negative temperature of the ground.

Tsytovich, N. A., "Peculiarities of Construction on Permafrost in the Yakutsk Region," Trudy Kom. po Izuch. Vechnoi Merzloty, Ac. Sci. USSR, Vol. 9, 1940, pp. 27-38, 5 figs. (Corps of Engineers).

This study includes recommendations for preservation of permafrost designed to avoid deformations of the ground.

Tsytovich, N. A. and Sumgin, M. I., "Principles of Mechanics of Frozen Grounds," Ac. Sci. USSR, 1937, 432 pp. (Amer Russian Institute).

This book was prepared by two of Russia's greatest specialists on permafrost. It contains 10 chapters. One part deals with theory and experiments, while the other part deals with the practical application of the principles developed in the first part.

Vedernikov, V. V., "Concerning the Drainage Theory," Doklady Ac. Sci. USSR, Vol. 59, No. 6, 1948, pp. 1069-72, 1 fig. (University of Minnesota, Call No. 506 Ak13dcR).

The author presents an analytical solution of the drainage problem for the case when both atmospheric precipitation and seepage from the layer containing artesian water are taken into consideration.

Vedernikov, V. V., "A Physical Picture of Free Seepage," Doklady Ac. Sci. USSR, Vol. 55, No. 3, 1947, pp. 203-06, 2 figs. (University of Minnesota, Call No. 506 Ak13deR).

The author reports on results of experiments on seepage from earth channels under various conditions.

Vedernikov, V. V., "Solution of the Two-Dimensional Problem of Steady Flow of Ground Water with a Free Surface," Comptes Rendus, Vol. 202, 1936, pp. 1155-57, 1 fig. (University of Minnesota, Call No. 506 qAel).

The author derives formulas for various cases of flow under consideration.

Vedernikov, V. V., "Concerning the Drainage Theory," Doklady Ac. Sci. USSR, Vol. 23, No. 4, 1939, pp. 335-37, 1 fig., 2 refs. (University of Minnesota, Call No. 506 Ak13de).

The article contains an analytical solution of the problem of motion of ground water when the free surface is not a streamline.

Velmina, N. A., "Observations of Permafrost and Ground Ice in the Dixon Region," Nedra Arktiki, Vol. 2, 1947, pp. 189-203, 11 figs. (Library of Congress).

The author reports on observations indicating that snow sheets occasionally occur under the solid ice in permafrost, and that human activity has a definite effect on the surface conditions of the permafrost.

Vittenburg, P. V., "Temperature Changes and Ground Water in the Permafrost of the Vaigach and Amderma Islands," Problemy Arktiki, No. 9, 1939, pp. 5-29. (New York Public Library, Call No. *QCB).

This pamphlet deals with the following problems: depth of active layer, lower limits of permafrost, depth of water, presence of water and its state.

---------"The Work of the Obruchev Institute of Frost Science in 1944," Referati Nauchno-Issledovatelskikh Rabot za 1944, Ac. Sci. USSR, 1945, pp. 114-32. (Amer Russian Institute).

This reference contains abstracts of 41 papers dealing with various phases of the permafrost problem and submitted for publication. Five of these papers deal with problems of airfield construction in permafrost zones.

---------"Permafrost," Materialy Kom. po Izuch. Estestv. Proizvod. Sil USSR, Ac. Sci. USSR, Sbornik No. 80, 1930, 231 pp. (New York Public Library, Call No. QCB).

This book is a compilation on the following subjects, prepared by various authors:

(1) Sumgin: Present Status of Permafrost Investigations.
(2) Grigoriev: Permafrost and Old Icings.
(3) Malchenko: Climatic Conditions in Permafrost Regions.
(4) Gorodkov: Permafrost and Vegetation.
(5) Kalitin: Role of Actinometry in Solving Permafrost Problems.
(6) Petrovski: Electrometric Methods for Determining Depth of Permafrost.
(7) Tsytovich: Permafrost as a Foundation for Structures: Changes in Properties of Ground During Freezing (Analytical); Compressive Strength: Tests on Disturbed and Undisturbed Samples, Effects of Freezing Temperature, Moisture and Structure; Program for Test on Permafrost.

(8) Koloskov: Heat Melioration in Permafrost Regions; Study of Heat Regime of the Ground and Influencing Factors.

Koloskov, P. I., "The Science of Seasonally Frozen Ground."

Obruchev, V. A., "Engineering Work under Permafrost Conditions," Polevaya Geologia, 4th ed., Vol. 2, 1932, pp. 242-50.

Sumgin, M. I. et al., "Instructions for Investigation of Permafrost for Engineering Purposes: Supplement to Instructions and Program Directions for the Study of Frozen Ground and Permafrost," Ac. Sci. USSR, 1938, pp. 253-72.

Tolstikhin, N. I., "Manual for Study of Icings: Instructions and Program Directions for the Study of Frozen Ground and Permafrost," Ac. Sci. USSR, 1938.

Vedernikov, V. V., "Theory of Filtration and its Application in the Fields of Irrigation and Drainage," 1939.

Yanovski, V. K., "Methods for Investigation of Permafrost for Engineering Purposes," Trudy 1-oi Geol.-Razved. Konf. Glavsevpromputi, Vol. 3, 1936, pp. 42-77.

33. Additional Sources of Russian Literature. Although the Laboratory staff member did not examine the following publications, he is confident that further research would bring out important aspects of arctic drainage.

Geologia i Poleznie Iskopayemie Severa USSR, Trudy 1-oi Geologo-Razvedochnoi Konferentsii Glavsevpromputi. (Geology and Mineral Deposits of Northern USSR, Proceedings of the First Geological and Mineralogical Conference of the Office of Northern Industrial Routes).

Gidrotekhnicheskoe Stroitelstvo. (Hydrotechnical Engineering).

Iziskania i Issledovania Svirstroya. (Researches and Investigations of the Svir Project).

Materialy Kommisii po Izucheniu Proizvodstvennikh Sil USSR. (Reports of the Committee for the Study of the Resources of USSR).

Materialy Vsesoiuznovo Soveshchania po Osnovaniam i Fundamentam. (Proceedings of the Federal Conference on Foundations).

Sovetskaya Arktika. (The Soviet Arctic).

Sovet po Izucheniu Proizvodstvennikh Rezursov i Komitet po Izucheniu Vechnoi Merzloty, Seria Severnaya. (Committee for the Study of Resources and Permafrost, Northern Series).

Trudy Dalnevostochnoi Kompleksnoi Ekspeditsii. (Reports of the General Expedition to the Far East).

Trudy Polyarnoi Kommisii. (Reports of the Polar Committee).

Za Industryalizatsiu Sovetskovo Vostoka. (Industrialization of the Soviet East).

Teknicheskie Ukazania na Vozvedenie Iskoostvennikh Sooruzheniy pree Postroyke Baikalo-Amurskoi Magistrali. (Technical Recommendations for Erection of Structures on the Baikal-Amur Road).

Problemy Sovetskoi Geologii. (Problems of Soviet Geology).

34. Recommendations. In this library research it has been noted that literature may contain important information which pertains to drainage even though the titles do not imply any relationship. It is recommended that library research work be continued and expanded with the preparation of a complete annotated text as an ultimate objective.

VII. RUNOFF FROM SELECTED WATERSHEDS

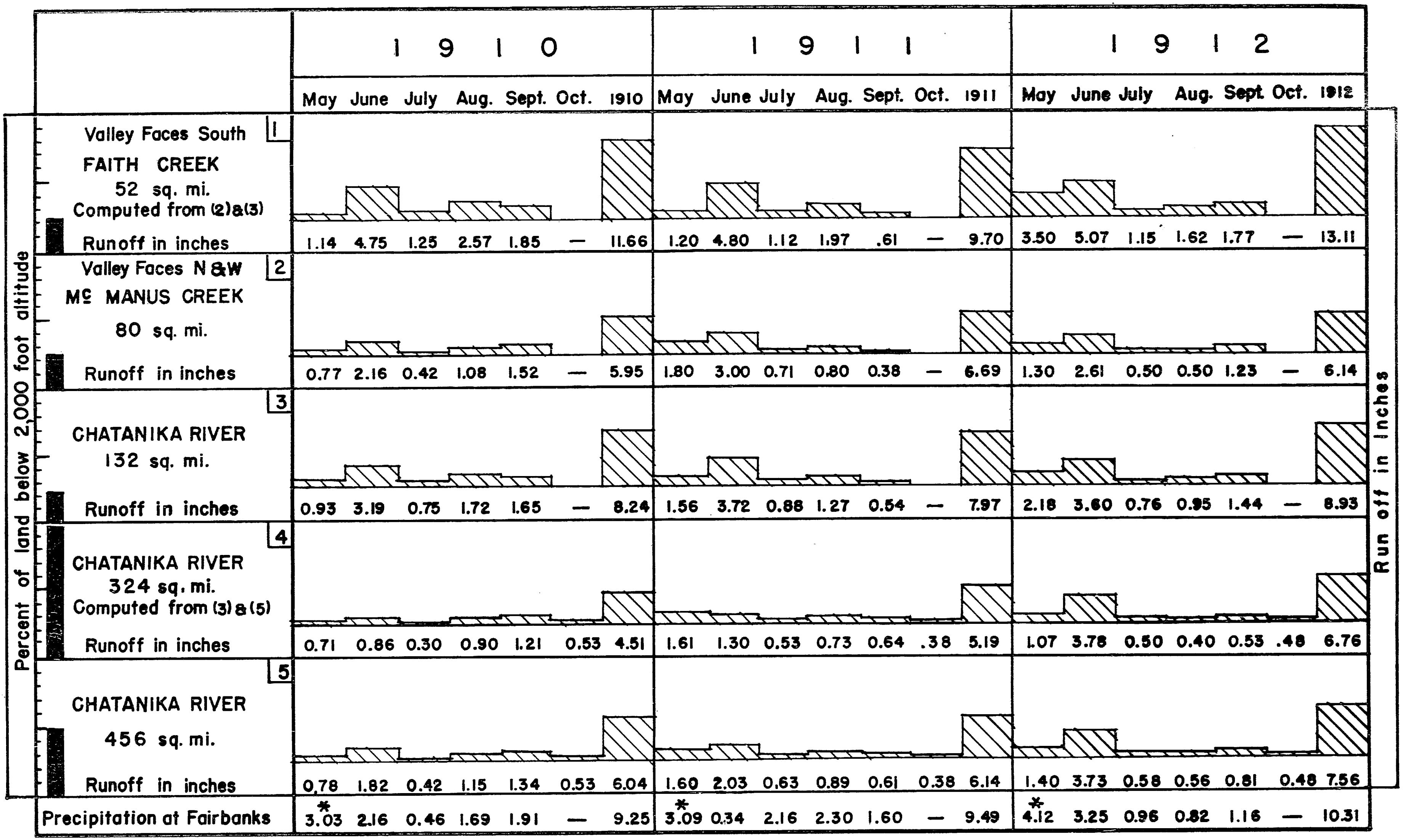
35. General. Drainage of airfields ordinarily does not encounter large watersheds. Quite often, however, it is essential for access roads to cross rivers and streams, and sometimes it is necessary to re-route a natural channel to provide additional space for development. It would be difficult, indeed, to single out an airfield site where runoff from large basins would not have to be considered to some extent in the drainage plan. In addition to providing data basic to hydrological design, records of stream flow can be analyzed from the standpoint of infiltration, evaporation, and supply. In this manner, records of runoff may point to important vagaries of precipitation which may modify the eventual design.

36. Stream Flow Records in Alaska. The U. S. Geological Survey established gaging stations and made stream discharge measurements from 1906 to 1915. As the purpose of this work was to study stream flow from the standpoint of water supply for gold mining operations, the work was confined to areas where such operations were in progress. Several stations were established in the Yukon-Tanana watershed and several drainage basins of the Seward Peninsula were investigated. The results of these investigations are contained in water-supply papers 314 and 342, both of which are now out of print.

37. Greater Precipitation at Higher Altitudes. Although the available runoff records do not extend over a sufficient length of time to include extremes of meteorological phenomena, an analysis of the data indicates that precipitation would be greater at altitudes above 1000 ft than on lower areas. It is impossible to develop quantitative trends. Table I contains runoff data for the Chatanika River Basin on the basis of yield. Note the difference in runoff from the lower part of the watershed, as compared to the yields from higher lands. Faith Creek is particularly productive, with annual and monthly amounts nearly double the corresponding figures of watershed 4. McManus Creek, however, which originates at elevations comparable to Faith Creek altitudes, yields considerably less runoff. This indicates that local topography has a marked influence on the hydrological regime of a watershed and, as pointed out in Part I, "Investigation of Airfield Drainage, Arctic and Subarctic Regions," should receive consideration at time of design.

Runoff records of streams in Seward Peninsula indicate large variations in precipitation. The greatest amounts seem to occur in the higher

Table I
Runoff data for five watersheds in Alaska



	1910							1911							1912						
	May	June	July	Aug.	Sept.	Oct.	1910	May	June	July	Aug.	Sept.	Oct.	1911	May	June	July	Aug.	Sept.	Oct.	1912
1 Valley Faces South FAITH CREEK 52 sq. mi. Computed from (2)&(3) Runoff in inches	1.14	4.75	1.25	2.57	1.85	—	11.66	1.20	4.80	1.12	1.97	.61	—	9.70	3.50	5.07	1.15	1.62	1.77	—	13.11
2 Valley Faces N&W Mc MANUS CREEK 80 sq. mi. Runoff in inches	0.77	2.16	0.42	1.08	1.52	—	5.95	1.80	3.00	0.71	0.80	0.38	—	6.69	1.30	2.61	0.50	0.50	1.23	—	6.14
3 CHATANIKA RIVER 132 sq. mi. Runoff in inches	0.93	3.19	0.75	1.72	1.65	—	8.24	1.56	3.72	0.88	1.27	0.54	—	7.97	2.18	3.60	0.76	0.95	1.44	—	8.93
4 CHATANIKA RIVER 324 sq. mi. Computed from (3)&(5) Runoff in inches	0.71	0.86	0.30	0.90	1.21	0.53	4.51	1.61	1.30	0.53	0.73	0.64	.38	5.19	1.07	3.78	0.50	0.40	0.53	.48	6.76
5 CHATANIKA RIVER 456 sq. mi. Runoff in inches	0.78	1.82	0.42	1.15	1.34	0.53	6.04	1.60	2.03	0.63	0.89	0.61	0.38	6.14	1.40	3.73	0.58	0.56	0.81	0.48	7.56
Precipitation at Fairbanks	* 3.03	2.16	0.46	1.69	1.91	—	9.25	* 3.09	0.34	2.16	2.30	1.60	—	9.49	* 4.12	3.25	0.96	0.82	1.16	—	10.31

* Accumulated total precipitation from Oct. 1 of the preceding year.
Data taken from Water Supply paper. 342 U.S. Geological Survey.

altitudes of the Kigluaik and Bendeleben Mountains. The flow of Kruzgamepa River is of particular significance. Here annual runoff sometimes exceeds 50 inches. This is nearly triple the recorded precipitation at Nome. Table II is a summary of runoff data of several drainage basins in Seward Peninsula. The information on Goodhope and Kiwalik Rivers, both of which discharge into Kotzebue Sound, indicates very small precipitation magnitudes in these two areas.

38. Watershed Descriptions. The following brief descriptive material pertaining to the drainage basins of Table II is contained in greater detail in water-supply paper 314 of the U. S. Geological Survey.

(a) Ophir Creek at Canyon Ditch. Ophir Creek rises in the Bendeleben Mountains at the foot of Mount Chauik. It flows south to a junction with the Niukluk River. At the gaging station the drainage area is 24 sq mi. and constitutes the upper of two sections of the drainage basin. The valley floor varies in altitude from 400 to 600 ft above sea level, while watershed boundaries reach elevations of more than 2000 ft.

(b) Paragon River. Paragon River rises in the heart of the Bendeleben Mountains between the headwaters of Boston Creek on the east and Niukluk River on the west. It flows southeast through a U-shaped valley for 15 miles, then winds through Fish River Flats and eventually enters Fish River. There are no springs or lakes in this glaciated area. At the gaging station the drainage area is 20 sq mi., all of which lies above an altitude of 730 ft.

(c) Nome River. Nome River is formed by the junction of Buffalo and Deep Canyon Creeks which rise in the Kigluaik Mountains. The drainage basin is long and narrow with the main axis in a north-south direction. The river flows south and discharges into the Bering Sea. Headwater elevations exceed 3000 ft. There are many springs on the tributaries and much of the gravel stream bed remains unfrozen to considerable depths.

(d) Grand Central River. Grand Central River drains a high rugged area which lies in the heart of the Kigluaik Mountains. The west fork rises south of Mount Osborn, flows easterly about 4 miles and is then joined by the north fork. Below this point the river flows southeast for 8 miles to Salmon Lake which is the headwaters of Kruzgamepa River. The upper basin is surrounded by mountains 3000 to 4000 ft high, except for a relatively narrow pass to the Nome River valley. There are many springs in the massive limestone, which is the lowest of the exposed rocks.

TABLE II

RUNOFF DATA FOR SEVERAL WATERSHEDS OF SEWARD PENINSULA

Watershed	YEAR	Runoff in Inches for the Month												Runoff in Inches for Period
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Ophir Creek at Canyon Ditch	1909							0.83	0.85	0.60				2.28
Paragon R. at 24 sq mi.	1909							1.97	1.38	0.68				4.03
Nome River at Miocene Intake 15 sq mi.	1906							4.25	3.88	4.88				13.01
	1907							5.11	2.59	4.91				12.61
	1908						1.62	1.19	3.36	1.30				7.47
	1909						3.93	2.16	1.19	0.92				8.20
Grand Central R. below the forks 14.6 sq mi.	1906						2.0	14.64	6.73	9.25				32.62
	1908							4.95	9.71	4.02				18.68
	1909							7.98	4.18	1.70				13.86
	1910						11.97	26.40	12.68					51.05
Kruzgamepa R. at Salmon Lake 80 sq mi.	1906	1.10	0.74	0.69	0.57	12.19	14.73	7.90	3.66	6.19	2.88	1.46	1.23	53.44
	1907	0.96	0.74	0.69	0.54	6.96	24.88	7.62	4.76	6.44	2.06	1.19	0.96	57.84
	1908	0.82	0.65	0.69	0.54	5.67	9.72	2.58	4.10	2.14	1.10	0.90	0.89	29.80
	1909	0.82	0.62	0.55	0.54	4.77	11.60	4.78	2.04	1.44	0.96	0.80	0.69	29.61
	1910	0.69	0.56	0.55	0.54	2.58	10.06	14.00	6.77	12.97	2.64	1.20	0.82	53.38
Kuzitrin R. at Homestake Ditch	1907						2.26	0.27	0.40	0.24				3.17
	1908					1.72	2.71	0.44	0.24	0.20				5.31
	1909					1.53	3.84	1.81	1.24	1.75	0.09			10.26
Kougarok R. at Homestake Ditch	1907							0.18	0.60	1.34				2.12
	1908							0.15	0.14	0.09				0.38
	1909						0.61	0.24	0.32	0.08				1.25
Goodhope R. below Esperanza Creek	1909						0.10	0.23	0.12	0.07				0.52
Kiwalik River below Candle	1909							0.20	0.14	0.06				0.40

(e) Kruzgamepa River. The Kruzgamepa River rises in Salmon Lake at an altitude of 442 ft. Most of the watershed above Salmon Lake is very rugged and many points reach an altitude of 4000 ft. From Salmon Lake the river flows northeast and north for 18 miles, then swings westward and outlets into Imuruk Basin which is a large bay of the Bering Sea.

(f) Kuzitrin River. The Kuzitrin River rises in the central part of Seward Peninsula and flows southwest to Imuruk Basin. A part of the drainage is furnished by the north-facing slopes of the Bendeleben Mountains. The largest tributary, the Noxapaga River, enters from the north. Most of the land in the watershed is relatively flat and much of the lower valley area is marsh land which remains frozen a few inches beneath the surface the entire year. Northern, eastern, and western headwaters reach altitudes of about 1000 ft, while the southern boundary rises to more than 2000 ft.

(g) Kougarok River. The Kougarok River drains rugged terrain of the Kougarok Mountains. It flows nearly due south and is a tributary of the Kuzitrin River. A relatively narrow valley floor ranges in elevation from below 200 ft at the southern extremities to about 600 ft at the northern terminus. Headwater elevations are generally less than 2000 ft, and no point in the basin reaches the 3000-ft altitude.

(h) Goodhope River. The Goodhope River rises a short distance northwest of Imuruk Lake and empties into Kotzebue Sound. In general, the terrain is not very rugged and most of the land lies below an altitude of 1000 ft. The headwater area of the Right Fork is a large flat plateau. Cottonwood Creek, which is the left fork, receives drainage from the west slopes of a terrain which reaches the highest altitude in the entire basin. Here one point exceeds 1800 ft and another is noted at 1696 ft.

(i) Kiwalik River. The Kiwalik River, which drains the northeastern part of Seward Peninsula, flows in a northerly direction and empties into Kotzebue Sound. The valley floor is relatively flat and quite wide. The western basin limit is a ridge, the long axis of which is located in a north-south direction. Some points of this ridge exceed 2000 ft in altitude. The divide between the Koyuk River to the south is quite low and uniform in elevation. The eastern watershed boundary consists of an irregular-shaped terrain, some points of which reach an elevation of 2400 ft.

39. Drainage Aspects. Even though there is no direct relationship between the records of runoff from large areas and airfield drainage, analysis of the records leads to generalized conclusions. The discharge records indicate vagaries of precipitation that were not apparent from Weather Bureau observations, as their stations were located at the lower altitudes. In view of this information, particularly the data on the Kruzgamepa River, there arises a question as to whether or not the drainage design criteria which were developed in Part I, "Investigation of Airfield Drainage, Arctic and Subarctic Regions," are sufficiently high to be applicable in the higher elevations. Unfortunately, the available data are too meager either to confirm or disprove prior results of intensity-duration-frequency studies.

In connection with this matter, it seems of importance to relate another situation. At a meeting with Mr. Ottis Bobbitt, climatological supervisor for the Weather Bureau at Anchorage, it was pointed out that the use of all recording rain gages had been discontinued in areas of Alaska that lie north of the Alaska Range. In view of this and the indicated runoff trends, further research is to be recommended, particularly if a future building program calls for construction on lands which lie above an altitude of 1000 ft.

40. Recommended Research. If military installations are contemplated for lands above an elevation of 1000 ft in Alaska, further hydrological research is essential to corroborate old or develop new drainage design criteria. Obviously, it would not be financially possible to equip the entire region with a network of recording equipment. Much could be gained, however, by instrumentizing a few selected watersheds which should be strategically located from the standpoint of hydrological regime. Each of these could be thought of as an independent laboratory at which data with respect to snow, rain, wind, clouds, temperature, humidity, runoff, and soil moisture could be gathered. Upon analysis these data would form the basis for various hydrological aspects of design.

VIII. CONCLUSIONS

41. General. The concise statements that follow are conclusions based on the observations and studies made during and subsequent to the field trip of 1949.

(a) According to observations along the Alaska Highway, the transition from the temperate to permafrost zone is gradual. Surface icings were noted as far south as Muncho Lake in British Columbia and river icings were quite common as far south as Racing River. Both of these locations are definitely south of the southern limit of permafrost. There was a conspicuous change in species of timber at mile 1012 in Yukon Territory. At this location pine seemed to give way to spruce.

(b) Physical conditions observed at hydraulic structures and road ditches along the route from Edmonton, Canada to Fairbanks, Alaska created the impression that high intense rainfall must be an uncommon event.

(c) Further research for developing measures to control river and surface icings are recommended.

(d) Spring icings can usually be controlled by drainage systems.

(e) Frost dams or belts are inexpensive measures by which ground icings can be temporarily controlled in open territory.

(f) Degradation of permafrost can be expected in the vicinity of a drainage ditch. Research to evaluate effects is recommended.

(g) A very unstable surface condition can be expected in the sub-Arctic after clearing and drainage of an area that contains fine-textured soil.

(h) Hydrological aspects of drainage channel design must include the effects of two additional types of erosion: (1) when permafrost comes in contact with flowing water, and (2) the type associated with flowing water and a thawing active layer.

(i) Drainage channel design should avoid deep cuts and areas where the permafrost table lies on a steep grade.

(j) In the sub-Arctic and especially near the southern fringe of permafrost, ditches with flat side slopes are recommended to minimize solifluction and to permit clearing of snow with heavy snow-moving equipment. In colder arctic areas, this may not be possible economically.

(k) Further field research is recommended for developing criteria and hydrological aspects for the design of river and stream crossings.

(l) Further library research is recommended. Actual translation of some Russian literature, together with a cursory review of other literary work, indicates that many articles pertain to drainage even though their titles may not imply it.

(m) Analysis of records of runoff from selected watersheds confirms the view that there is an increase in total precipitation with an increase in altitude in the subarctic area of Alaska. Consideration should be given to instrumentizing widely scattered and carefully selected watersheds for future study.