INVESTIGATION OF AIRFIELD DRAINAGE

ARCTIC AND SUBARCTIC REGIONS

PART I

FIELD RECONNAISSANCE AND ANALYSIS

by

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Submitted by

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P R E F A C E

Although explorations and surveys of various natures have been in progress for decades, the necessity for drainage investigations in arctic and subarctic regions was not determined until 1945 at an Annual Consultants' Conference. Actual investigational work was initiated by the Office, Chief of Engineers, Corps of Engineers, U. S. Army, September 1946, and the project was placed under the immediate direction of the District Engineer, St. Paul, Minnesota. The original instructions and outline called for a division of the investigation into two phases. The first phase involving compilation of all pertinent data, which were available from the Army, Navy, Civil Aeronautics Administration, Weather Bureau, Geological Survey, libraries, and other sources, has been essentially completed by the St. Paul District Corps of Engineers, and a report is a matter of record. The second phase is outlined in subsequent paragraphs. This was taken from Instructions and Outline for Arctic and Subarctic Drainage Investigations, Fiscal Year 1948, and consists of the correlation of the data previously collected with actual field conditions, the observation of present drainage practices and structures in the field, the development of necessary modifications or innovations, and, if considered necessary, the detailed investigations of selected study areas including measurement and analysis of precipitation and runoff.

Items to be considered in the investigation are indicated in the following outline:

I. SUPPLY

A. General

Data studied in the first phase of the investigation were concerned primarily with supply and all available sources were checked. However, this should not preclude a continuation of the study if necessary.

B. Rainfall Intensity-Duration Data

Develop rainfall intensity-duration relations for arctic and subarctic areas using, if possible, the general methods cited in Figs. 1 to 3, Part XIII, Chapter 1, Engineering Manual.

C. Snowfall Data

Determine average snow depth versus time relation and water content data for arctic and subarctic areas.

D. Spring Breakup

Investigate spring breakup as a source of supply and develop method of estimating supply rates from this source.

E. Ground Water

Establish criteria for determining rates of ground water supply to subsurface drains to provide basis for a reasonable estimate of hydraulic capacity of subsurface drains.

II. RUNOFF CRITERIA

A. Surface Runoff

Investigate reasonableness of applying methods contained in Part XIII, Chapter 1, Engineering Manual for determining design of storm water drains in arctic and subarctic areas, and, if necessary, develop modifications as may be required. Check adequacy of existing arctic and subarctic drainage systems against initial design assumptions.

B. Subsurface Runoff

Investigate reasonableness of applying methods contained in Part XIII, Chapter 2, Engineering Manual for determining subsurface drain design in arctic and subarctic areas, and, if necessary, develop modifications.

III. DRAINAGE STRUCTURES

A. Design

Review normal drainage structures as outlined in Part XIII, Chapter 3, Engineering Manual and determine adaptability to arctic and subarctic conditions. Investigate modifications to standard type structures and (or) develop new designs which will minimize icing effect and provide maximum hydraulic efficiency under all seasonal conditions. Particular emphasis should be given to proper design of culverts, culvert inlets and outlets, ditches, and subsurface drain and combination drain installations to minimize the effect of icing.

B. Maintenance

Determine routine maintenance procedures for drainage structures in arctic and subarctic areas to provide adequate drainage in all seasons. Develop methods for controlling icing in culverts, underground drains, and ditches.

C. Induced Icing

Develop methods and standard procedures for causing and controlling induced icing.

It is with reference to this second phase that a research contract was entered into June 18, 1947, by and between the United States of America, represented by the contracting officer, District Engineer, Corps of Engineers, St. Paul District, and the Regents of the University of Minnesota. The ultimate aim of the investigations and studies is the determination of design, construction, and maintenance procedures suitable for the drainage of airfields located in arctic and subarctic regions.

This report is intended to summarize the outcome of a field investigation of selected sites in Alaska, and subsequent studies which were made at the St. Anthony Falls Hydraulic Laboratory. The project was carried forward under the general supervision of Dr. Lorenz G. Straub, director of the Laboratory. Loyal A. Johnson, research associate, made the field investigations, carried out the library research, and prepared the report. Maps, diagrams, and other drawings were made with the aid of Laboratory draftsmen and student assistants. Professor R. B. Whittington offered many timely suggestions and carried out the mathematics, the results of which are included in Part VII. The entire content of the report was reviewed by Alvin G. Anderson and Henry M. Morris, both Laboratory staff members. The paper was edited and prepared for publication by Lois E. Fosburgh.

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I. GENERAL PLAN OF INVESTIGATION BY THE UNIVERSITY

1. <u>Preliminary Reconnaissance</u>. The first phase of field work contemplated and completed by the University was to obtain an overall perspective of drainage problems peculiar to the region of Alaska lying north of the 30° F mean annual isotherm. In the field this phase consisted of a hurried reconnaissance during the first 10 days of May by Dr. Lorenz G. Straub, Head of the Civil Engineering Department and Director of the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota and Loyal A. Johnson, Research Associate. This trip involved discussion of problems with numerous agencies and individuals including:

Corps of Engineers, Alaska District
- W. E. Potter, Colonel, District Engineer
- Warren George, Chief, Engineering Division
- H. L. Moats, Engineer, Engineering Division
- J. M. McAnerney, Geologist
- R. E. Lyle, Office of Resident Engineer, Fairbanks

Fay, Spofford and Thorndike, Architect-Engineer, Boston
- B. K. Beebe, Chief Engineer, Anchorage
- R. E. Charles, Assistant Chief Engineer, Anchorage

Permafrost Division, Corps of Engineers, St. Paul District
- B. L. Trawicky, Chief, Field Operations Branch

Navy Installation at Point Barrow
- L. P. Frate, Lieutenant Commander
- E. D. Spaulding, Superintendent of Construction, Lytle and Green, Arctic Contractors

Nome Air Base (Marks Field), Nome
- J. H. Whittington, Post Engineer
- A. C. Steinwandel, Engineer

Brief visits or inspections were made at the following points:

Experimental Area, Permafrost Division at Fairbanks
Steese Highway, Fairbanks to Pedro Point
Mile 26 (Eielson Field), Air Force Base under construction
Big Delta Airport
Tanacross Airport
Northway Airport
Richardson Highway, Fairbanks to Big Delta
Alaska Highway, Big Delta to Northway
Tok-Cutoff, Tok to Mentasta Pass
Umiat Navy Airport
Barrow Navy Airport
Marks Field at Nome

2. Second Phase of Field Work and Investigation Procedure. University investigations for the second phase of the field work were essentially the same as the first with the exception that each project was allotted more time and considerably more detail was obtained. The overall intent was to make observations of existing drainage facilities at numerous locations, check their adequacy against design assumptions, and correlate the findings with data previously collected, with the objective of developing design criteria. At the time, it seemed of importance to follow the breakup of rivers to gain knowledge of ice jams and consequent damaging floods. This general scheme of conducting observations would result in another advantage in that it would permit more time to note snow melting and resulting runoff.

The outline contemplated inspection of the more southerly located sites first and gradually working north as fast as progress permitted. Investigations were completed for airports along the Kuskokwim River by May 25. Field information was obtained for airports at Bethel, Nyac, Aniak, McGrath, Farewell, Lake Minchumina, and Nenana, and drainage conditions along roads in the Fairbanks vicinity were observed. May 26 marked the opening of investigation of airports along the Yukon River. The airstrip at Ruby was inspected while the chartered plane delivered freight and passengers to Long, a nearby small town and landing field. Galena was next on the schedule, but the inspection there was hurried in order to reach Nulato that same day. On the return trip from Nulato, engine failure made a forced landing in a forest inevitable. Injuries resulting from the crash forced the University investigator to return to Minneapolis and actual field work was abruptly terminated.

3. Work Conducted at the Laboratory. As a first step, work conducted in the office has entailed a review and study of all literature on the immediate subject, as well as numerous articles and data relating to permafrost. Information from all available sources has been examined including translations of Russian and Swedish material. Maps, diagrams, and graphs have been developed with reference to rainfall intensities and durations. Field notes and photographs have been studied and the data correlated for presentation in subsequent paragraphs. Informative data in the form of bulletins, professional papers, water-supply papers, and maps have been obtained from the U. S. Geological Survey. Reports and air photographs were made available by the U. S. Air Force. "Cold Weather Engineering" by the U. S. Navy Civil Engineer Corps presents a world-wide perspective of arctic, subarctic, and antarctic

history, development, physical conditions, and construction problems. By a special field arrangement, data on rains of short duration and high intensity were obtained from the U. S. Weather Bureau, Anchorage office. Maps and engineering data were furnished by the Civil Aeronautics Administration, Anchorage office. All the reports by the Corps of Engineers, St. Paul District, dealing with airfield construction and related subjects in arctic and subarctic conditions have been reviewed. Engineering data showing flood peaks and stream bed behavior of the Knik River were obtained from the Alaska Road Commission. Maps, photographs, and other information were made available by the Corps of Engineers, Alaska District. Fay, Spofford and Thorndike, Architect-Engineer, presented data dealing with current design technique and construction difficulties applicable to subarctic regions of Alaska.

4. General Statement of Results. Obviously, complete understanding and thorough treatment are unattainable for as comprehensive a subject as represented in this study. A complete investigation into the subject from an analytical and practical point of view would require field investigations, laboratory research, and consequent study far beyond the actual limits of this project. It has been necessary, therefore, to pass over many interesting and important phases and select but a few of them for detailed consideration. This procedure, it was thought, would have better chance to give rise to certain generalizations as to the broader features and at the same time make advancements toward acceptable and workable design criteria. It has been possible to formulate and develop some points of immediate usability and others in less advanced stages. A supply curve which has been developed for use in Alaska is an example of the former. The descriptive paragraphs that follow, especially those pertaining to individual airport sites, corroborate the view that methods contained in Engineering Manual, Part XIII, Chapter 1, for determining design of storm water drains are applicable and workable for subarctic regions of Alaska. Some innovations as regards the maintenance of drainage facilities are noteworthy, and observations along highways lead to some practical generalizations. These are mentioned in subsequent sections. Timing of field work along the Kuskokwim River to coordinate with operations of the 57th Fighter Group of the U. S. Air Force led to observations of flood control procedure unique to subarctic areas of Alaska. It is possible that future safety of both military and civilian installations from devastating springtime river floods will depend on the success of ice-jam bombing.

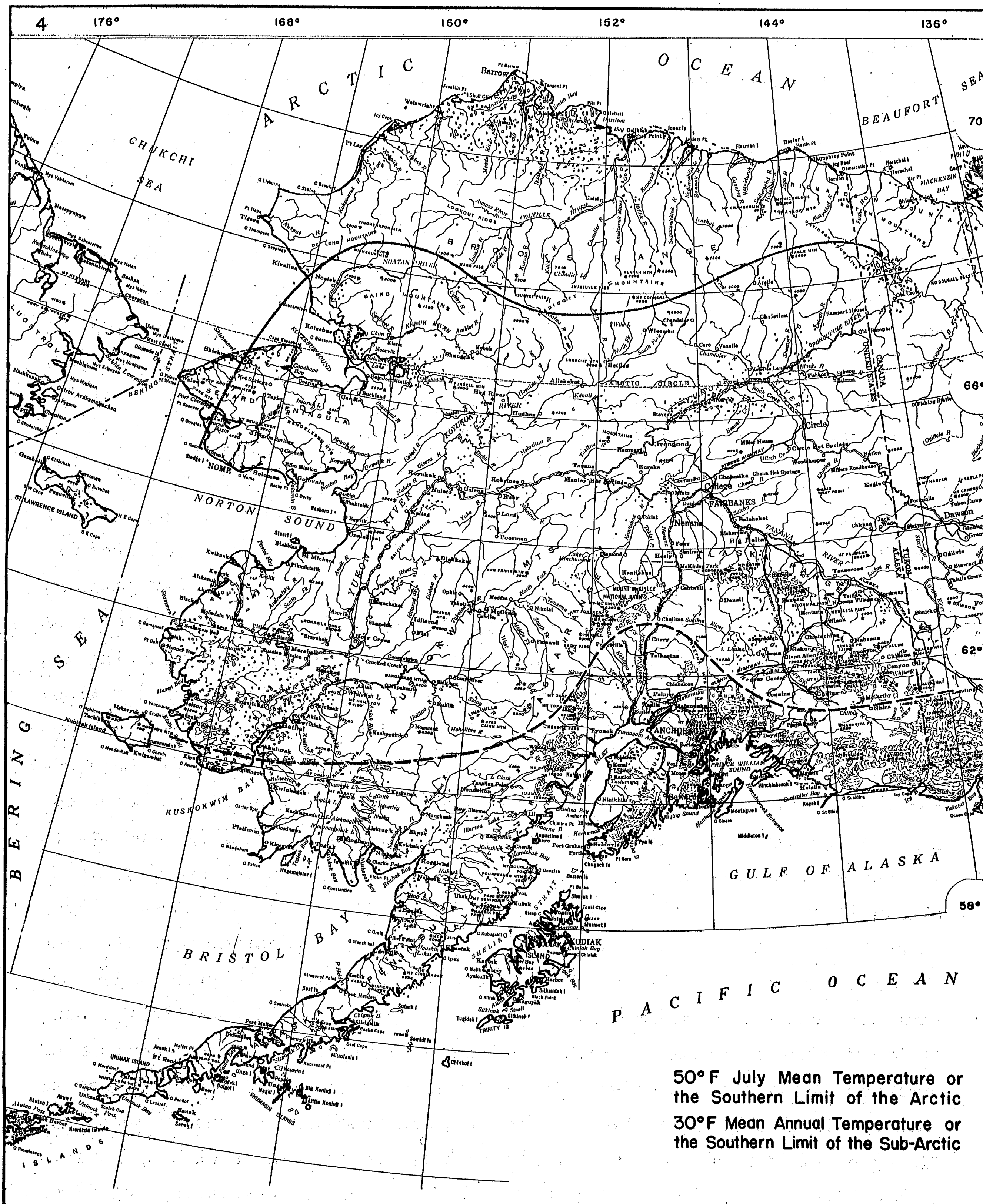


Fig. 1 - Chart Showing Boundaries of Arctic and Subarctic Regions of Alaska

II. GENERAL DESCRIPTION OF ALASKA

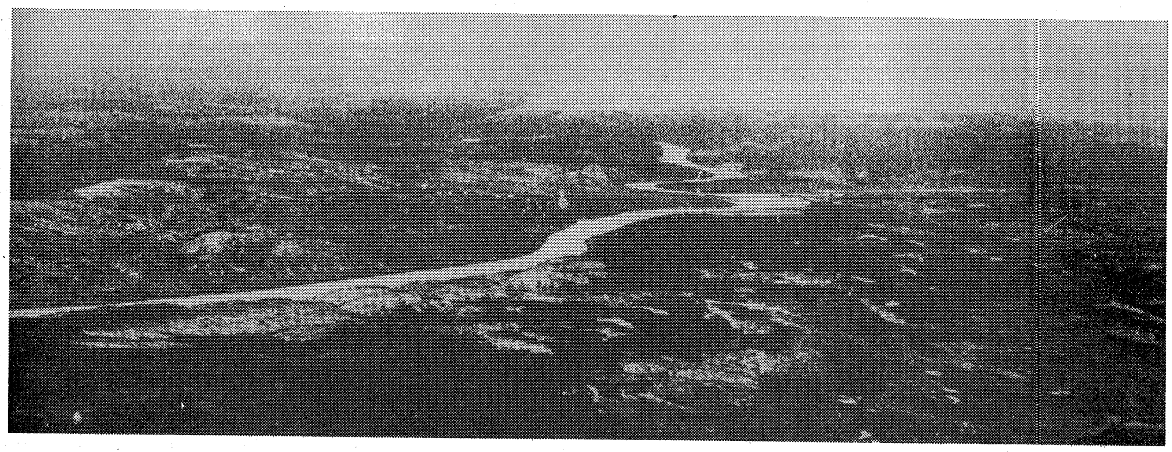
5. Limits of Research Area. The portion of Alaska with which this report is concerned lies to the north of the 30° F mean annual isotherm. This invisible boundary is presumed to be the southern limit of permafrost. There is some evidence to corroborate this view. Figure 1, showing the boundaries, is a general map of the research area.

6. Mountain Ranges. Alaska represents a territory of strongly diversified topographical relief. In the northern and arctic section Brooks Range is found with many peaks reaching elevations of 8000 ft or more. To the south is a large crescent-shaped ridge about 50 miles in width, which extends all the way from Lake Clark on the west to the St. Elias Range on the east. In this section, the Alaska Range, are numerous peaks in excess of 10,000 ft in elevation. The highest peak in North America, Mount McKinley, at a 20,300-ft elevation, forms the northwest portion of the Alaska Range. Other lofty peaks are Mount Spurr, Mount Forakar, Mount Hayes, and Mount Natazhat. Near the eastern border, but some distance north of the Gulf of Alaska, is a ridge of peaks called Wrangell Mountains. Here Mount Wrangell, Mount Blackburn, and Mount Sanford are 13,940, 16,140, and 16,200 ft in height, respectively.

7. Yukon River. Lying just south of Brooks Range and rising in Canada is the legend-famous Yukon River. This river with its tributaries drains an estimated area of over 300,000 sq miles, and is recognized as the fifth largest river system in North America. It is navigable from June to October and drains into the Bering Sea. Special geologic features of this basin are the Yukon Flats near the Arctic Circle, and also the low coast land and delta region extending inland nearly 100 miles from the Bering Sea. Principal tributaries are the Koyukuk which rises in the southern slopes of the Endicott Mountains and the Tanana which has its origin in glaciers of the Wrangell Mountains and the Alaska Range. The gradient of the Yukon is relatively flat. The elevation at the confluence with the Tanana is about 200 ft above sea level and the stream bed level at the Canadian border is about 800 ft.

8. Kuskokwim River Valley. To the south of the Yukon River, and separated from it by the Kuskokwim Mountains, is Alaska's second largest river, the Kuskokwim. The valley of this river is broad and free of strong relief. Both the upper and lower reaches can be described as "flats" studded with lakes and sloughs. The lower flat is a broad expanse, probably 50 miles or

Looking east over Yukon River near Stephens, May 8, 1948.



Looking southwest over Yukon River near Stephens, May 8, 1948.

Looking northeast over Yukon River near Kaltag, May 10, 1948 more wide, of tundra of low elevation and, for the most part, subject to much spring flooding, a process which no doubt furnishes the water supply for the many lakes and sloughs seemingly without a watershed or outlet of their own. The more important tributaries have their sources in glaciers of the western slopes of the Alaska Range.

9. Copper and Susitna River Valleys. The mean annual 30° F isotherm crosses the Copper and Susitna River valleys. The Susitna has a drainage area of about 8000 sq miles, flows west, then south into Cook Inlet. The Alaska Range forms the western and northern boundaries while to the east there is a hardly noticeable separation from the Copper River basin whose watershed is nearly triple that of the Susitna. It has a glacial origin on the southern slopes of the Wrangell Mountains, takes a very pronounced circuitous course, and empties into the Gulf of Alaska. Sizeable portions of both the Susitna and Copper River basins are relatively flat.

10. Seward Peninsula. The Seward Peninsula, although mountainous, is not as rugged as other sections. It is almost completely devoid of timber and in that manner is similar to areas north of the Arctic Circle. No peaks exceed a height of 5000 ft, although Mount Osborn of the Kigluaik Mountains has been scaled at 4720 ft and Mount Bendeleben of Bendeleben Mountains is known to reach an elevation of 3760 ft. Generally speaking, about two-thirds of the area of Seward Peninsula drains to the south through a network of rivers and streams, the principal ones being the Koyuk, Fish, Niukluk, Kuzitrin, Kougarok, and Agiapuk. The main rivers flowing north include the Kiwalik, Kugruk, Inmachut, and Goodhope into Kotzebue Sound, and the Serpentine River into Shishmaref Inlet.

11. Region which Borders the Arctic Ocean. The part of Alaska bordering the Arctic Ocean extends from Cape Prince of Wales on the western tip of Seward Peninsula to Demarcation Point which is located on the western Canadian boundary. This represents about 1300 miles of shoreline, most of which has relatively shallow offshore waters. Harbors are few along this coast and the bottom is gently shelving, requiring ships to anchor some distance from shore. With the exception of Cape Lisburne, the arctic coast of Alaska, like most land bordering the Arctic Ocean, is low and flat, slightly undulating, and actually monotonous in appearance because of the utter absence of any form of tree growth. Drainage is to the west via the Noatak and Kobuk Rivers, and to the north via the Meade, Cliff, Colville, and Canning Rivers. Most of the Arctic

is covered with a variety of plants and grasses known as tundra. This forms an excellent insulating material and consequently the ground a few feet below the surface remains frozen the year around. This condition precludes good drainage, and is not confined to depressions alone, but is also found on slopes and summits of hills. The insulating effect of the tundra varies with the variety of plant and density of growth. Consequently, the depth of thaw in summer months is very uneven and leaves holes, many of which are sufficiently large to mire tractors. Walking over tundra in the summer is a difficult task because at unexpected moments the surface fails.

Figure 2 schematically illustrates the topography of Alaska. The relative positions of mountain ranges are very important. Later paragraphs indicate that these areas of higher altitude are considered as weather-affecting factors.

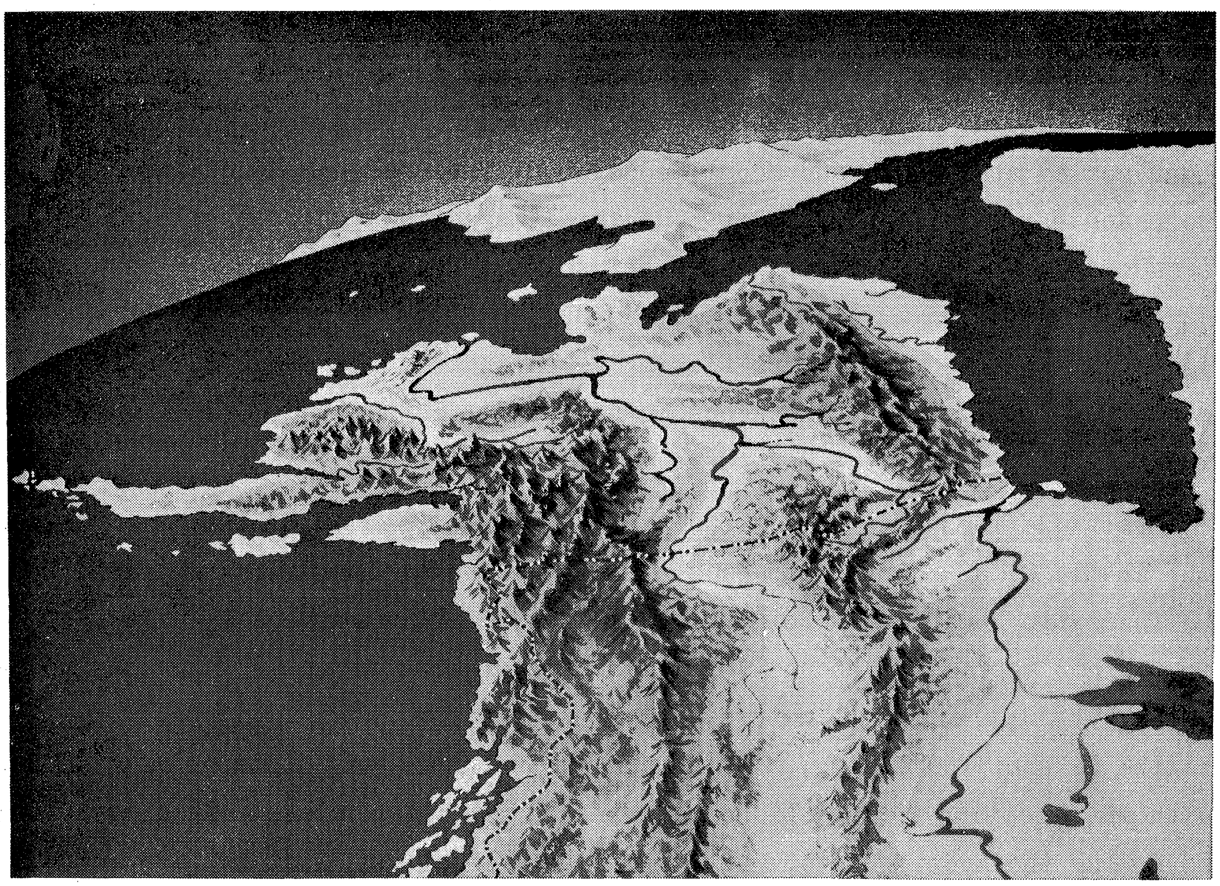


Fig. 2 - Schematic Perspective of the Topography of Alaska

III. CLIMATE OF ALASKA

12. The Southern Limit of the Arctic. Contrary to popular belief, the Arctic Circle drawn at 66° 30' north latitude is not the boundary between the arctic and subarctic zones. The modern scientific delimitation of the Arctic is that area in which the mean temperature for the warmest summer month is less than 50° F. The 50° F July isotherm also approximates the northern limit of trees. This new concept of boundary between arctic and subarctic zones is more than just of passing interest as it divides the area of Alaska into two regions, each distinct from the other in many ways. It should be noted that the actual location of the 50° F isotherm on Fig. 1 has been moved in a southerly direction from the position obtained by interpolation of Weather Bureau temperature data. This was thought advisable in view of the absence of Weather Bureau stations in the higher altitudes and consequent colder regions of Brooks Range. The amount of change is partly on the basis of observation of the northern limit of tree growth during a flight to Barrow. Field notes taken during the trip indicate nearly a total absence of trees on the slopes of Brooks Range which face north. It is certain also that the mean July temperature, in the parts of Brooks Range that exceed altitudes of 3000 ft, is below 50° F. For the reasons thus stated, the 50° F July isotherm, or the southern limit of the Arctic, occupies a position on the slopes of Brooks Range which face south (Fig. 1).

A. The Arctic Region

13. General. The climate of the Arctic is decidedly polar with consistently long cold winters and short cool summers. Even though freezing temperatures occur each month of the year, extremes in winter cold intensity are not as great as in some sections of the sub-Arctic. It is of interest to note that southern valleys of Alaska have a record low of -74° F, the Yukon valley a -76° F, as compared with an extreme of -61° F reported for the arctic region. Of design importance is the fact that freezing temperatures prevail for more than 300 days of each year. The station at Barrow has reported as many as 15 days of frost in the warmest month, July. Obviously, drainage design cannot anticipate that infiltration will take a part of the rainfall, as it may fall on either frozen or sleet-covered ground.

14. Precipitation in the Arctic. Records to show precipitation intensity for this region are meager, with none available from which to formulate

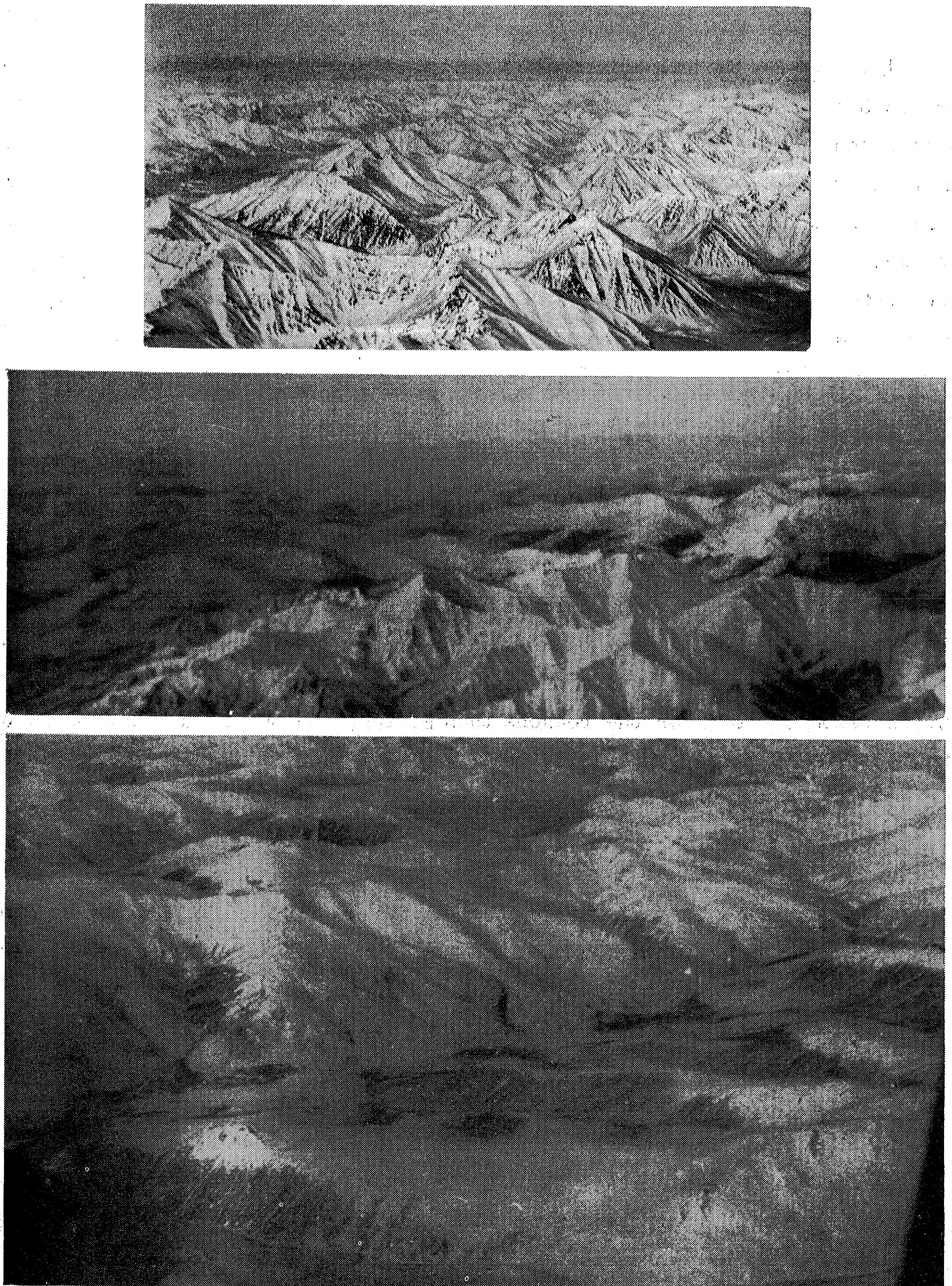


Plate No. 2 – Northern Limit of Trees on Brooks Range frequency-duration curves. In general, however, rainfall is light and of very low intensity. Heaviest precipitation occurs in July, August, and September, with nearly all falling as rain. Sleet and even traces of snow are not uncommon in this period. Table I, showing rainfall data for Point Barrow from 1929 through 1947, indicates the frequency with which specified daily magnitudes occur. In this 19-year period, a daily rainfall of 1 in. has never been equaled or exceeded. A 24-hr rain of 0.25 in. was equaled or exceeded 43 times in the same period. Daily amounts of 0.01 in. are equaled or exceeded about 90 times in one year. Even though there are no stations in northeastern Alaska, it is evident that high-intensity rains are physically improbable in the area of the Arctic north of Brooks Range. Air temperatures are too low to hold much water and the possibility of replenishment from a warmer source is very remote, as the path is cut off by mountains which reach altitudes corresponding to temperatures of below freezing. Moisture-laden air masses coming from a warmer southerly direction, then, would dissipate their contents either as orographic rain on the slopes of the range facing south or as snow in the higher altitudes of the mountains. For replenishing air moisture there remains only evaporation from the land itself and from the Arctic Ocean, southern portions of which thaw out for a few months each year.

Data on snowfall in the arctic region are very limited. No additional information has been found to that shown in the report of the Corps of Engineers, St. Paul District. The overall average annual snowfall for the period from 1907 to 1946 for the entire permafrost region of Alaska is 59.5 inches. The highest of the list of Weather Bureau averages occurred in 1918 and is 91.5 inches. Individual station readings, however, may vary considerably from the average. It is fairly certain that snowfall in the area to the north of the 50° F isotherm is perceptibly less than in more southerly districts even though high winter winds and the absence of trees, both conditions conducive to formation of drifts, create the impression of the reverse.

15. Wind Velocity and Direction in the Arctic. The prevailing wind direction at Barrow is from the east or east-northeast. The average velocity is high, probably somewhere between 10 and 15 miles per hr. It is reported that June is the calmest month and November is the windiest. The highest known velocity at Barrow is 100 miles per hr from the southwest. This high wind occurred January 22, 1882, and resulted in considerable damage and hardship. The average velocity for that day was 59 miles per hr.

TABLE I

PRECIPITATION AT BARROW

Year	Days With Precipitation of 0.25, 1.00, and 2.00 Inches												
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1929	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	3/0/0	0/0/0	0/0/0	0/0/0	0/0/0	4/0/0
1930	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0
1931	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0
1932	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1933	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1934	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1935	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0
1936	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1937	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	1/0/0	0/0/0	3/0/0
1938	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	2/0/0	1/0/0	1/0/0	0/0/0	0/0/0	7/0/0
1939	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1940	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0
1941	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	0/0/0	0/0/0	0/0/0	2/0/0
1942	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	0/0/0	2/0/0	0/0/0	0/0/0	0/0/0	5/0/0
1943	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	1/0/0	0/0/0	0/0/0	3/0/0
1944	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	1/0/0	1/0/0	0/0/0	0/0/0	6/0/0
1945	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0
1946	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	3/0/0	0/0/0	0/0/0	0/0/0	0/0/0	4/0/0
1947	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0

First entry in each column is number of days with 0.25 in. of precipitation.
Second entry in each column is number of days with 1.00 in. of precipitation.
Third entry in each column is number of days with 2.00 in. of precipitation.

Fig. 3 - Mean Annual Temperature of the Research Area

B. The Subarctic Region

16. General. The subarctic region of Alaska is characterized by great extremes in temperature between summer and winter. Maximum summer temperatures frequently exceed 80° F while a record low of -76° F has been recorded in the Yukon valley. Isotherms of mean annual temperatures are shown in Fig. 3. These show rather plainly the influence of the Bering Sea and the Gulf of Alaska. In summer the effect of the cool waters of the former are noticeable for several hundred miles inland. Although the winters are cold, the cold intensity is not unbearable, as high winds with temperatures below -10° are very infrequent. There also seems to be an absence of severe local winds in the summer. In the arctic region freezing temperatures occurred in each month of the year and it was not uncommon for snow to fall in June and August, with traces sometimes in July. This condition had a decided effect on drainage design in that infiltration could not be considered. In the sub-Arctic, freezing temperatures in the summer are very rare except in the vicinity of Kotzebue and Shishmaref. These two stations are located very close to the arctic region boundary and perhaps should be included in that area for design purposes.

TABLE II

MEAN MAY TEMPERATURES FOR SELECTED STATIONS

Station	Mean May Temp. Degrees F	Airline Distance from Sea - Miles	Remarks
Nunivak	32.6	0	Island in Bering Sea
Bethel	40.2	30	550 miles south of Arctic Circle
Unalakleet	39.6	0	On Bering Sea
Aniak	41.8	140	Kuskokwim
Holy Cross	41.6	180	Yukon
McGrath	43.0	250	Kuskokwim
Tanana	44.1	390	Yukon and Tanana
Lake Minchumina	44.6	370	Kuskokwim
Nenana	44.4	500	Tanana
Fairbanks	47.0	570	Tanana and Chena
Fort Yukon	43.0	700	On Arctic Circle
Dawson	46.4	920	Yukon
Northway	47.2	840	Tanana

17. <u>The Cooling Effect of the Bering Sea in Spring Breakup</u>. During the spring breakup, the cooling effect of the Bering Sea works to a disadvantage in so far as drainage is concerned. The upper interior valleys of the Yukon, Tanana, and Kuskokwim Rivers warm up and snow and ice melt, causing runoff perceptibly in advance of thawing temperatures in the lower reaches. The consequent and expected results are ice jams and severe annual springtime floods. Mean monthly temperatures for May, the thawing month, listed in approximate order of distance from the Bering Sea, demonstrate this situation very clearly.

In the course of field investigations in May of 1948, ice-jam difficulties were encountered in the Chena River at Fairbanks on the 12th and 13th, on the Kuskokwim River at McGrath on the 15th (but not severe), at Aniak on the 16th and 17th, and at Bethel on the morning of the 18th, river ice was just beginning to move. River stages at Aniak rose more than 20 ft. It was reported that this occurrence was not unusual and that ordinarily conditions during breakup were much worse.

By way of inquiry during field investigations, it was learned that the most destructive floods of record occurred on the Kuskokwim and Yukon Rivers between May 10 and 29, 1946. It is of interest to note dates of river breakup for stations that are listed in the following table in a downstream order.

TABLE III

BREAKUP OF RIVERS, SPRING OF 1946

Yukon		Kuskokwim	
Eagle	May 8	McGrath	May 13
Coal Creek	May 12	Stoney River	May 13
Circle	May 11	Sleetmute	May 16
Fort Yukon	May 13	Napamute	May 17
Beaver	May 13	Aniak	May 24
Stevens Village	May 14	Kalskag	May 22
Tanana	May 12	Bethel	May 25
Kokrines	May 14		
Ruby	May 13		
Galena	May 16		
Koyukuk	May 15	Hamilton	May 28
Nulato	May 16	Akulurak	May 27
Anvik	May 23		
Holy Cross	May 15		

Temperature conditions as represented by the foregoing table are not peculiar to the year 1946, as it is quite general for thawing temperatures to prevail in the upper river reaches in advance of melting farther downstream. Long-time records of breakup dates for Dawson, Circle, Tanana, and Holy Cross illustrate this fact. Dawson is located the farthest upstream and Holy Cross is farthest downstream (Table IV).

18. <u>Precipitation in the Sub-Arctic</u>. Precipitation in the subarctic region of Alaska that lies to the north of the 30° F mean annual isotherm is light and not of high intensity. Figure 4, showing isohyetals of mean annual rainfall, indicates a gradual recession in magnitudes as distances increase from the Bering Sea and from the Gulf of Alaska. Near or along the coast the mean annual precipitation is close to 20 in., with Nome 19.84 in., Moses Point 22.82 in., Bethel 18.02 in., and Aniak 20.57 inches. Farther inland, 400 to 500 miles, the amount of annual rainfall has dropped appreciably with Fairbanks 11.72 in., Nenana 11.32 in., Hughes 9.68 in., and Tanana 12.47 inches. The upper Yukon receives even less, with Fort Yukon having a mean annual precipitation of 7.06 in. and Circle Hot Springs 9.87 inches. It should be noted that there is a considerable variance in mean annual precipitation among stations which are located a short distance to the south of the 30° F mean annual isotherm. In 1946, Curry had rainfall totaling 39.74 in., Ilianna 37.29 in., Kennecott 21.24 in., Talkeetna 40.04 in., Skwentna 27.42 in., and Sheep Mountain 7.63 inches. Design criteria then for areas that lie close to the southern limits of permafrost may differ considerably from those which are applicable to the remainder of the subarctic region.

Over the entire subarctic region of Alaska, most of the precipitation occurs as rain in the months of June, July, August, and September, with July and August recognized as the wettest months. Occasionally snow may occur in September, but ordinarily there is no snowfall of any consequence until October. Over most of the region snow amounts to roughly 25 per cent of the total precipitation, except in higher altitudes where all precipitation is in the form of snow.

19. <u>Intensity of Rainfall in the Sub-Arctic</u>. The intensity of rainfall in the sub-Arctic is low. Weather Bureau reports indicate from 0.11 to 0.15 in. on a rainy day. Rains in excess of 1 inch in 24 hours are infrequent and those which equal or exceed 2 inches in 24 hours are very rare. Table V, showing rainfall data for several stations, indicates the frequency with which

TABLE IV

YUKON RIVER BREAKUP DATES

Year	Dawson	Circle	Tanana	Holy Cross	Days Lag from Dawson to Holy Cross
1898	May 6	May 13		May 20	14
1899	May 17			May 13	0
1900	May 8		May 8	Apr. 29	0
1901	May 14	May 22	May 24	May 15	1
1902	May 11	May 16	May 13	May 22	11
1903	May 13	May 16	May 22	May 16	3
1904	May 17	May 17	May 7	May 15	0
1905	May 10	May 16	May 12	May 16	6
1906	May 11	May 14	May 16	May 13	2
1907	May 5	May 8	May 6	May 19	14
1908	May 7	May 13	May 22	May 18	11
1909	May 11	May 12	May 22	May 24	13
1910	May 11	May 15	May 22	May 18	7
1911	May 7	May 12	May 11	May 17	10
1912	May 9	May 15	May 3	May 20	11
1913	May 15	May 18	May 15	May 21	6
1914	May 10	May 14	May 17	May 20	10
1915	May 3	May 14	May 5	May 16	13
1916	May 3	May 12	May 10	May 22	19
1917	May 15	May 17	May 21	May 22	7
1918	May 11	May 13	May 21	May 24	13
1919	May 11		May 17	May 16	5
1920	May 18		May 21	May 25	7

Fig. 4 - Mean Annual Precipitation of the Research Area

specified magnitudes occur. For 87 station years, 0.25 in. per day was equaled or exceeded 63 times in May, 114 times in June, 227 times in July, 385 times in August, and 206 times in September. Likewise, in a study of 106 station years, 0.25 in. per day occurred 1188 times, 1.0 in. occurred 53 times, and 2 in. occurred only twice. The U. S. Weather Bureau 1921 Summary shows a 24-hr maximum of 4 in. occurring in June at Tanana. An examination of monthly June totals for the 18 years of record up to 1921 does not include a monthly total of 4 in.; therefore, this one-day record may be in error. The next highest 24-hr precipitation noted in any record is 3.01 in., a September event at Holy Cross. Then 3.01 inches in 24 hours represents a very rare event with a recurrence interval of 100 years or more, as it was observed only once in that many station years of record. Justification of this assumption is given in paragraph 7, page 4, of "First Annual Report, Arctic and Subarctic Drainage Investigations" by the War Department, Corps of Engineers, St. Paul District.

Tables VI and VII are tabulations of maximum observed intensities for rainfall durations of 5, 10, 15, 30, 60, 120, and 1440 minutes. This material was prepared by the Weather Bureau office of Anchorage. The data formed the basis for the computations leading to Fig. 6.

20. Intensity-Frequency Data. The development of frequency relations from listings of maximum observed events is ordinarily a procedure not to be recommended. Many magnitudes which are slightly smaller than the recorded figures are missing and, consequently, will not enter into the frequency computation. The error, however, is safely in favor of the larger values. Several trials using the usual methods led to inconsistent results, as well as misleading answers. A slight modification of technique brought results that appear reasonable as well as corroborative of statements made by local Alaskans who have had opportunity to view rainfall conditions for many years. There are, no doubt, many desirable deviations from the procedure which was used, yet it seems of importance in weighing eventual results to include a brief outline and discussion.

a. Arrange the basic data for each station in the order of "rainfall durations." Anticipate a family of curves for each station.

b. Arrange the values for each "duration" in a descending order of magnitude (the largest first). It is only necessary to have as many magnitudes in this listing as there are years of record. This follows because for the ultimate objective, it is the larger less frequent value that will determine design criteria, and secondly the lower but more frequent figures drop below a straight-line relation on logarithmic plotting.

c. Assign frequencies for each number in the descending order of magnitudes. The first and largest figure is, of course, the largest event of record and would be given a frequency of one in the period of record. Event number two has been equaled or exceeded twice in the same time period. Number three, three times, and so on. Now plot the actual magnitude of rainfall as ordinate and the assigned frequency as the abscissa. Ordinarily 3-cycle logarithmic paper will cover a sufficient range in each direction. Unless the period of record is very long, a wide variation of points is to be expected from this particular type of data.

d. Examine all available Weather Bureau records for maximum 24-hr rains. Information is usually not available for shorter durations. Extend the search to other nearby stations if they are influenced by similar climatological phenomena. Select the largest value and add this point to the 24-hr recordings by plotting as ordinate the magnitude and as abscissa the interval which coincides with the total number of years of station record, counting all stations at which data on rainfall were examined.

e. Draw a straight line, which by inspection fits the points that were plotted first, through the larger figure plotted in step 4. This line now represents what might be called the parent frequency curve.

f. Draw lines parallel to the parent line and of closest fit (by eye inspection) to points of other rainfall duration. Examination of the literature has not disclosed any definite precedent for this step. However, the works of investigators lead one to believe that this may very well be the case. Bernard's formula for intensity-frequency relation is a straight line on logarithmic paper, and values for various durations plot as parallel lines with surprising regularity. Values for $\underline{k}$, above certain limits shown in Meyer's formula, plot as parallel lines for four of the five regions into which the United States was divided by this author. Mr. W. E. Fuller noted that logarithmic plots of actual flood flows showed consistently common slopes. A surprisingly large number of Yarnell's data on rains of various durations and from widely separated points plot in a similar manner. Return intervals of from 5 to 50 years for the flow of the Mississippi River at Keokuk, Le

Claire, and Winona computed by the Gumbel method plot very close to three parallel straight lines on logarithmic paper.

It seems axiomatic that at least for the same station, frequency curves for various durations should be parallel. It does not appear logical to presume, for instance, that the 5-minute curve should have a steeper slope than the 24-hr curve. If this would be the case, at some long recurrence interval a like amount of rain would fall in two time periods, one of which is 288 times larger than the other. On the other hand, if it is assumed that the 5-minute curve is flatter, the very frequent events would eventually be equal.

g. Steps up to this point may well be considered of the work sheet order. The data as they are now arranged can be directly transposed into the form shown in Fig. 6. It is of passing interest to note that other investigators have observed a straight-line relationship of logarithmic plotting for the same return period of various durations from 5 minutes up to several days (E. E. Foster and M. Bernard in Bibliography). It is of more than passing interest to note that this is not possible without the assumption made in step 6.

21. Extension of Frequency Curves to Longer Durations. The curves of Fig. 5 were extended beyond the one day to an outer limit of one month. The lines thus extended agree very well with recorded high monthly rainfall for the specific stations. Probably of less significance are the extensions of lines to one year; yet in the case of four of the five stations, the projected curves agree very well with high annual rainfall recorded either at the specified station or one nearby. The Ketchikan 20-year return interval curve projects to a figure for one year that is considerably in excess of station records. It is not, however, beyond reasonable limits as this projected figure falls within a realm of actual physical possibility.

22. Duration-Frequency Relations for Nome. Duration-frequency relations for Nome are quite different from the others in that a sharp break occurs at the 2-hr duration. Whether this is of any real significance or not cannot be answered. It is thought, however, that the record did not include a period of time sufficiently long to give a real trend. In any case, especially for design considerations, it is recommended that the low duration magnitudes be determined as indicated by the dashed lines. Then most certainly any error would be too large rather than too small. Values adjusted in this manner fit the result of prior studies of rain storms at White Mountain, a village located not far from Nome and influenced by similar rain-producing factors.

23. Duration-Frequency Relations for Ketchikan and Juneau. Actually, Ketchikan and Juneau are located a considerable distance to the south of the southern limit of permafrost. These two locations are representative of areas of high seasonal and annual precipitation. Warm moisture-laden air sweeps over the warm Pacific Ocean, then has to rise as it travels northerly to the coastal mountain ranges. One might say that these areas are nearly ideally situated from a rainfall point of view. Duration-frequency curves as shown in Fig. 6, even for these areas, indicate low magnitudes and consequently light intensities for short durations. Actually 5-minute precipitation at Ketchikan is less than a rain of similar duration at Fairbanks even though the monthly total of the former is about equal to, and often exceeds, the annual total of the latter.

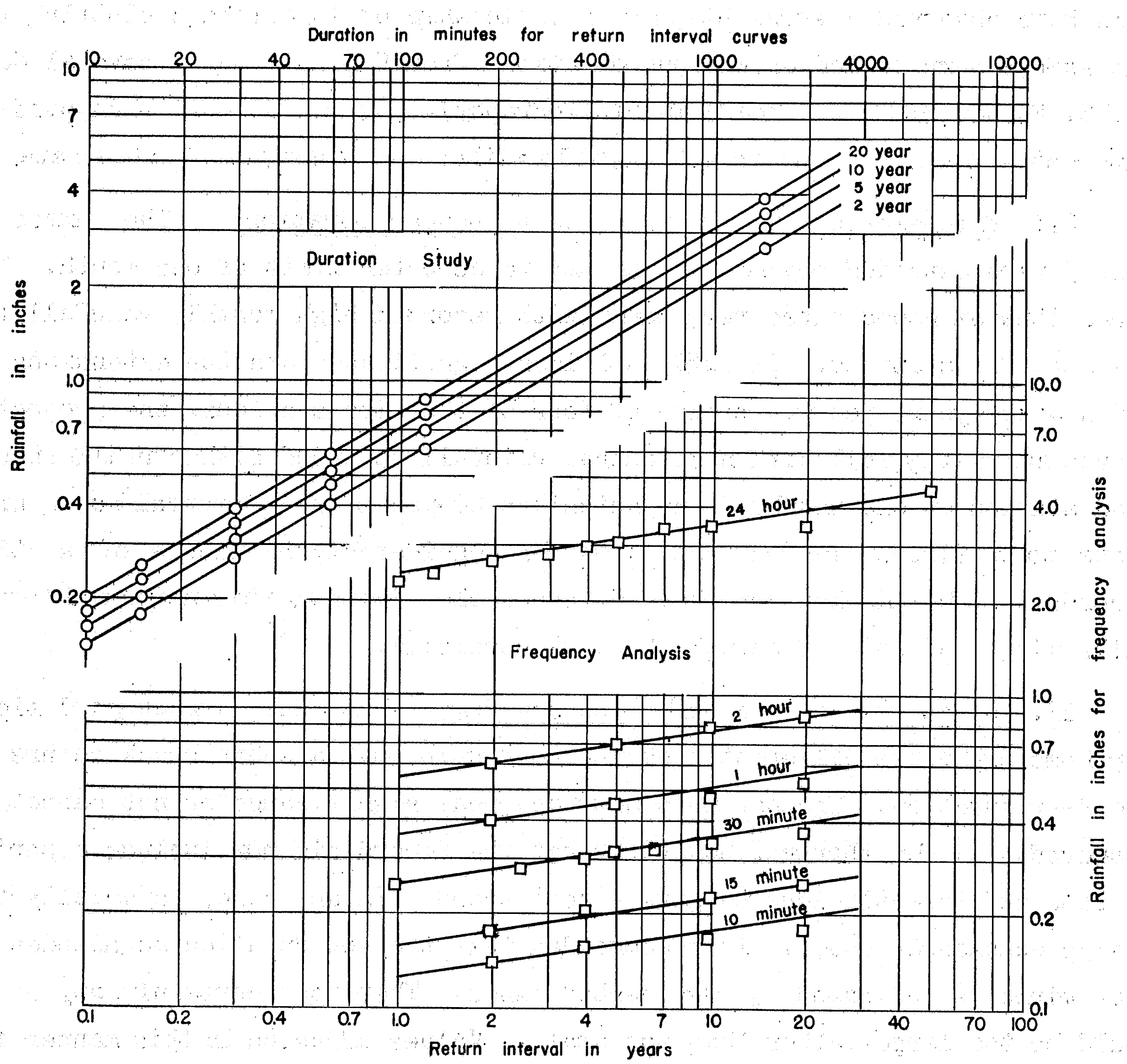


Fig. 5 - Rainfall At Juneau, Alaska

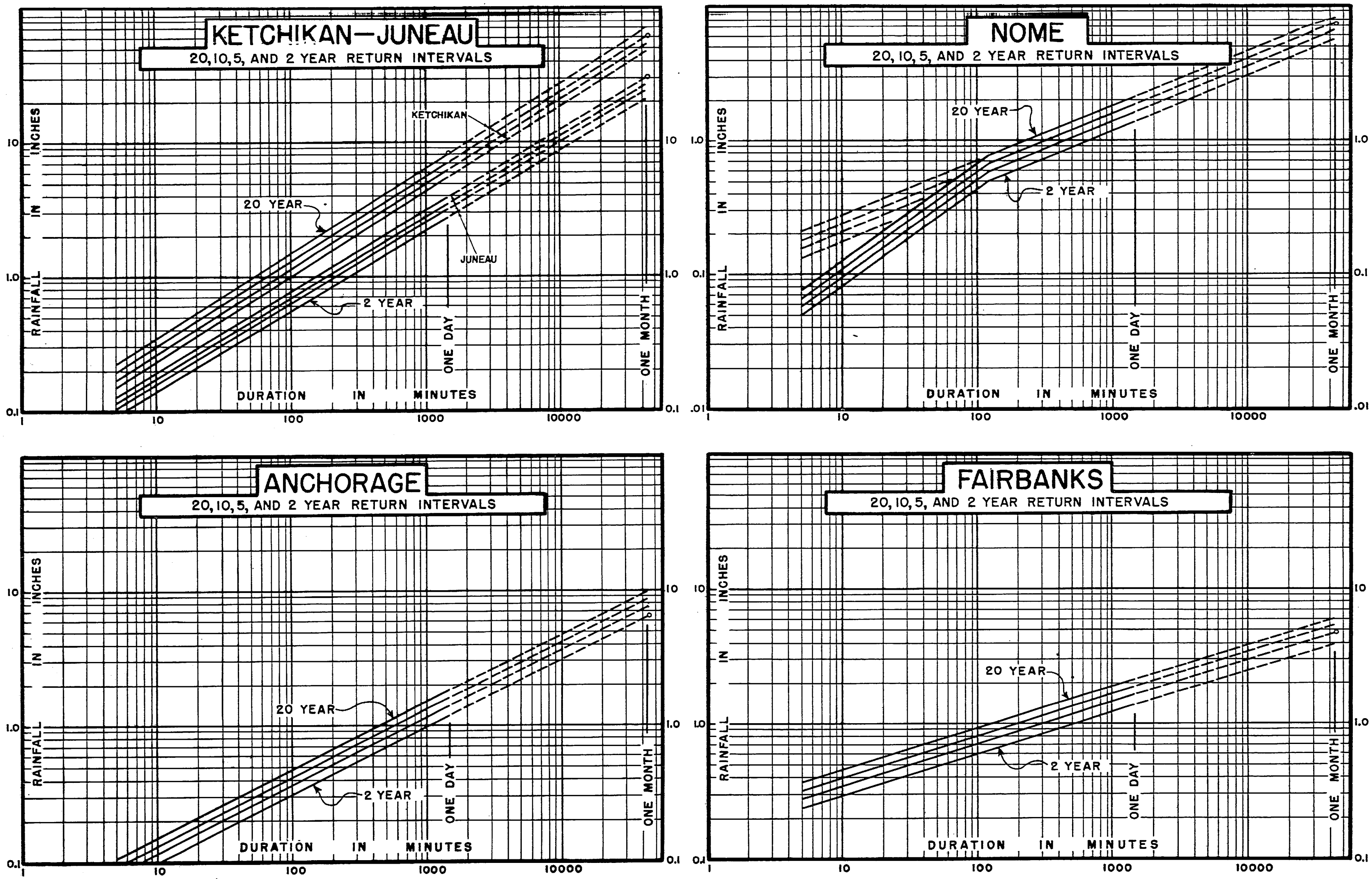
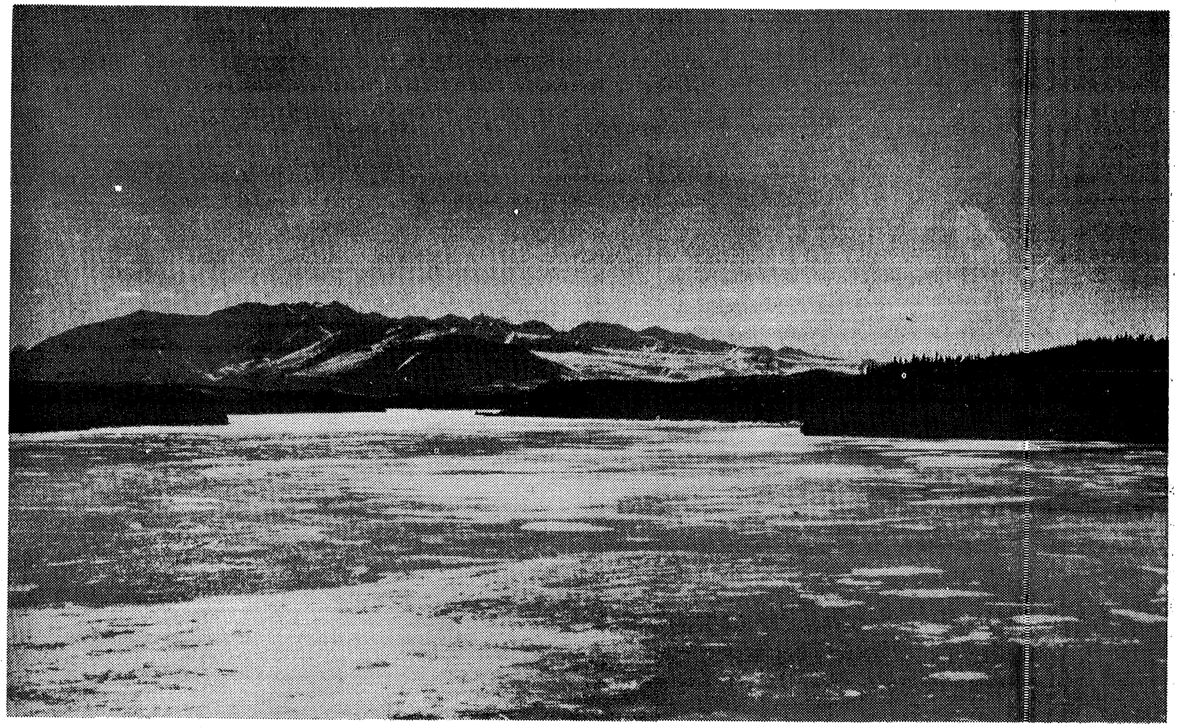
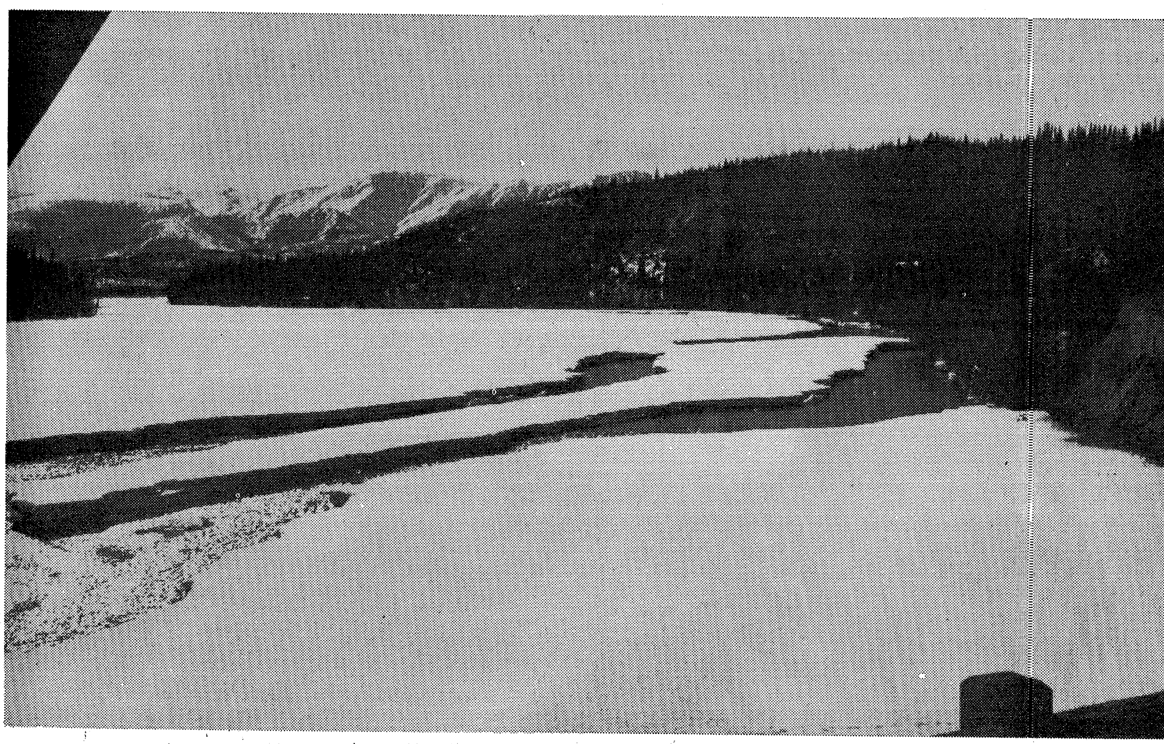


Fig. 6 - Rainfall Duration-Frequency Relations for Alaska



Robertson River, May 6, 1948



Johnson River, May 6, 1948

Plate No. 3 - River Scenery in Alaska

TABLE V

PRECIPITATION AT ANCHORAGE

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929							5/0/0	3/0/0	4/0/0	0/0/0		
1930	1/0/0	0/0/0	2/0/0	0/0/0	1/0/0	1/0/0	3/0/0	7/0/0	3/0/0	0/0/0	0/0/0	0/0/0
1931	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	3/0/0	3/0/0	2/0/0	2/0/0
1932	2/0/0	3/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	10/0/0	5/1/0	3/0/0	2/0/0	2/0/0
1933	0/0/0	1/0/0	1/0/0	0/0/0	1/0/0	1/0/0	0/0/0	2/0/0	4/1/0	3/0/0	5/0/0	0/0/0
1934	1/0/0	1/0/0	2/0/0	0/0/0	3/0/0	1/0/0	3/0/0	9/0/0	1/0/0	1/0/0	0/0/0	3/0/0
1935	1/0/0	2/0/0	0/0/0	0/0/0	1/0/0	0/0/0	3/0/0	2/0/0	0/0/0	4/0/0	3/0/0	0/0/0
1936	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	1/0/0	1/0/0	6/2/0	4/0/0	1/0/0
1937	1/0/0	0/0/0	0/0/0	3/0/0	1/0/0	0/0/0	0/0/0	4/0/0	3/0/0	6/0/0	2/0/0	0/0/0
1938	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	1/0/0	3/0/0	3/0/0	4/0/0	1/0/0	0/0/0
1939	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	2/0/0	2/0/0	5/0/0	5/0/0	6/1/0	1/0/0	2/0/0
1940	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	1/0/0	4/0/0	6/0/0	3/0/0	2/0/0	2/0/0
1941	2/0/0	1/0/0	0/0/0	2/0/0	0/0/0	4/0/0	2/0/0	0/0/0	2/0/0	3/0/0	1/0/0	0/0/0
1942	0/0/0	1/0/0	0/0/0	1/0/0	0/0/0	1/0/0	4/0/0	5/0/0	4/0/0	5/0/0	0/0/0	1/0/0
1943	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	3/0/0	6/0/0	4/1/0	0/0/0	3/0/0	1/0/0
1944	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	8/0/0	5/0/0	2/0/0	1/0/0	2/0/0
1945	1/0/0	1/0/0	0/0/0	0/0/0	1/0/0	2/0/0	2/0/0	4/0/0	4/0/0	4/0/0	0/0/0	0/0/0
1946	1/0/0	2/0/0	0/0/0	0/0/0	2/0/0	2/0/0	1/0/0	2/0/0	2/0/0	1/0/0	2/0/0	1/0/0
1947	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/1/0	5/1/0	1/0/0	1/0/0	0/0/0

First entry in each column is number of days with 0.25 in. of precipitation.

Second entry in each column is number of days with 1.00 in. of precipitation.

Third entry in each column is number of days with 2.00 in. of precipitation.

TABLE V (Continued)

PRECIPITATION AT FAIRBANKS

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929										0/0/0		
1930	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	1/1/0	9/2/0	0/0/0	0/0/0	0/0/0	0/0/0
1931	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	2/0/0	0/0/0	5/0/0	1/0/0	0/0/0	0/0/0	2/0/0
1932	2/0/0	2/0/0	0/0/0	0/0/0	0/0/0	2/0/0	3/0/0	4/1/0	0/0/0	0/0/0	0/0/0	0/0/0
1933	2/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	1/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0
1934	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	5/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1935	2/0/0	0/0/0	1/0/0	0/0/0	1/0/0	0/0/0	2/0/0	1/0/0	1/0/0	4/0/0	3/0/0	0/0/0
1936	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	4/0/0	1/0/0	3/0/0	3/0/0	1/0/0
1937	8/3/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	6/0/0	0/0/0	2/0/0	0/0/0	0/0/0
1938	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	4/0/0	4/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1939	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	3/1/0	1/0/0	0/0/0	0/0/0	1/0/0	0/0/0
1940	1/0/0	0/0/0	0/0/0	0/0/0	2/0/0	1/0/0	0/0/0	3/1/0	0/0/0	0/0/0	0/0/0	0/0/0
1941	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	1/0/0	1/0/0	1/0/0	1/0/0	1/0/0	0/0/0	0/0/0
1942	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	6/0/0	2/0/0	6/0/0	5/0/0	1/0/0	1/0/0	0/0/0
1943	1/0/0	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	1/0/0	0/0/0	0/0/0	0/0/0
1944	0/0/0	3/0/0	1/0/0	0/0/0	2/0/0	0/0/0	1/0/0	4/0/0	1/0/0	0/0/0	0/0/0	0/0/0
1945	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	2/0/0	5/1/0	1/0/0	1/0/0	1/0/0	0/0/0
1946	0/0/0	1/0/0	0/0/0	0/0/0	1/0/0	2/0/0	2/0/0	2/0/0	0/0/0	1/1/0	0/0/0	0/0/0
1947	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	1/0/0	1/0/0	4/0/0	0/0/0	0/0/0	0/0/0

TABLE V (Continued)

PRECIPITATION AT NOME

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1930								8/0/0	4/0/0	4/0/0	0/0/0	0/0/0
1931	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	3/0/0	6/0/0	6/0/0	3/0/0	3/0/0	5/1/0
1932	3/0/0	1/0/0	0/0/0	1/0/0	0/0/0	0/0/0	3/0/0	2/0/0	4/0/0	3/0/0	0/0/0	1/0/0
1933	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	0/0/0	0/0/0	2/0/0	1/0/0
1934	1/0/0	1/0/0	0/0/0	0/0/0	0/0/0	2/0/0	2/0/0	3/0/0	4/0/0	2/0/0	0/0/0	2/0/0
1935	1/0/0	0/0/0	3/0/0	0/0/0	0/0/0	1/0/0	2/0/0	4/0/0	4/0/0	12/1/0	3/0/0	1/0/0
1936	2/0/0	0/0/0	2/0/0	1/0/0	0/0/0	3/0/0	4/0/0	3/0/0	3/0/0	2/0/0	1/0/0	2/0/0
1937	6/0/0	0/0/0	0/0/0	1/0/0	1/0/0	1/0/0	1/0/0	4/0/0	9/1/0	2/0/0	2/1/0	0/0/0
1938	1/0/0	1/0/0	1/0/0	0/0/0	0/0/0	3/0/0	2/0/0	11/2/0	3/0/0	1/0/0	3/0/0	0/0/0
1939	0/0/0	1/0/0	0/0/0	1/0/0	0/0/0	0/0/0	2/0/0	2/0/0	4/0/0	1/0/0	0/0/0	0/0/0
1940	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	0/0/0	3/0/0	1/0/0	5/0/0	0/0/0	1/0/0	0/0/0
1941	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	0/0/0	1/0/0	4/0/0	0/0/0	0/0/0
1942	0/0/0	0/0/0	1/0/0	2/0/0	2/0/0	1/0/0	4/1/0	1/0/0	7/2/0	2/0/0	2/0/0	0/0/0
1943	0/0/0	3/0/0	4/0/0	0/0/0	2/0/0	0/0/0	7/0/0	6/1/0	0/0/0	0/0/0	1/1/0	0/0/0
1944	0/0/0	8/0/0	1/0/0	1/0/0	0/0/0	1/0/0	2/1/0	4/0/0	2/0/0	3/0/0	1/0/0	3/0/0
1945	0/0/0	3/0/0	1/0/0	1/0/0	0/0/0	0/0/0	2/0/0	7/0/0	5/0/0	2/1/0	2/0/0	1/0/0
1946	2/0/0	1/0/0	0/0/0	0/0/0	1/0/0	3/0/0	3/0/0	7/4/0	2/0/0	4/0/0	2/0/0	2/0/0
1947	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	7/0/0	5/0/0	2/0/0	1/0/0	2/0/0	0/0/0

TABLE V (Continued)

PRECIPITATION AT BETHEL

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
1929	3/0/0	1/0/0	1/0/0	1/0/0	1/0/0	0/0/0	4/0/0	4/0/0	4/0/0	0/0/0	1/0/0	0/0/0
1930	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	3/0/0	5/0/0	3/0/0	2/0/0	0/0/0	0/0/0
1931	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	1/0/0	0/0/0	7/0/0	4/0/0	5/0/0	1/0/0	6/1/0
1932	1/0/0	3/0/0	0/0/0	0/0/0	1/0/0	2/0/0	6/0/0	8/0/0	6/0/0	3/0/0	0/0/0	0/0/0
1933	4/0/0	0/0/0	3/0/0	0/0/0	1/0/0	0/0/0	0/0/0	4/0/0	1/0/0	0/0/0	0/0/0	0/0/0
1934	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1935	0/0/0	1/0/0	2/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	3/2/0	0/0/0
1936	0/0/0	1/0/0	5/0/0	0/0/0	0/0/0	1/0/0	3/0/0	8/0/0	5/0/0	4/0/0	1/0/0	1/0/0
1937	6/0/0	1/0/0	0/0/0	1/0/0	0/0/0	1/0/0	5/0/0	7/0/0	2/0/0	1/0/0	0/0/0	0/0/0
1938	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	2/0/0	1/0/0	11/3/0	4/0/0	2/0/0	3/0/0	0/0/0
1939	1/0/0	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	8/0/0	4/0/0	0/0/0	0/0/0	0/0/0
1940	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	1/0/0	3/0/0	4/0/0	5/1/0	1/0/0	2/1/0	1/0/0
1941	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	2/0/0	3/0/0	6/0/0	3/1/0	2/0/0	2/0/0	0/0/0
1942	0/0/0	0/0/0	1/0/0	1/0/0	2/0/0	2/0/0	2/0/0	7/0/0	5/0/0	2/0/0	2/0/0	0/0/0
1943	0/0/0	3/0/0	2/0/0	0/0/0	1/0/0	1/0/0	2/0/0	7/0/0	3/0/0	2/0/0	0/0/0	1/0/0
1944	0/0/0	5/0/0	1/0/0	1/0/0	5/0/0	1/0/0	3/0/0	9/3/0	0/0/0	3/0/0	1/0/0	1/0/0
1945	0/0/0	1/0/0	1/0/0	0/0/0	2/0/0	1/0/0	3/0/0	6/1/0	2/0/0	1/1/0	3/0/0	0/0/0
1946	0/0/0	1/0/0	0/0/0	0/0/0	2/0/0	0/0/0	2/0/0	3/0/0	2/0/0	5/0/0	0/0/0	0/0/0
1947	5/0/0	0/0/0	0/0/0	0/0/0	0/0/0	4/0/0	2/0/0	2/1/0	2/0/0	1/0/0	1/0/0	0/0/0

TABLE V (Continued)

PRECIPITATION AT TANANA

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929	3/0/0	0/0/0	1/0/0	0/0/0	2/0/0	1/0/0	4/0/0	7/0/0	2/0/0	1/0/0	0/0/0	1/0/0
1930	1/0/0	0/0/0	1/0/0	0/0/0	0/0/0	3/0/0	5/0/0	10/1/0	3/0/0	1/0/0	0/0/0	0/0/0
1931	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	6/0/0	4/0/0	2/0/0	3/1/0	2/0/0
1932	3/0/0	5/0/0	0/0/0	0/0/0	0/0/0	3/1/1	2/1/0	6/0/0	4/0/0	1/0/0	0/0/0	0/0/0
1933	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	0/0/0	2/0/0	2/0/0	1/0/0	0/0/0	0/0/0
1934	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	7/0/0	3/0/0	2/0/0	1/0/0	0/0/0	0/0/0
1935	0/0/0	0/0/0	5/0/0	0/0/0	0/0/0	1/0/0	2/0/0	5/0/0	2/0/0	5/0/0	5/1/0	0/0/0
1936	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	3/0/0	2/0/0	6/0/0	2/0/0	1/0/0	1/0/0	1/0/0
1937	7/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	7/0/0	2/0/0	0/0/0	1/0/0	0/0/0
1938	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	10/0/0	2/0/0	1/0/0	0/0/0	0/0/0
1939	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	2/0/0	1/0/0	0/0/0	0/0/0	0/0/0
1940	2/0/0	0/0/0	0/0/0	0/0/0	1/0/0	1/0/0	2/0/0	0/0/0	2/0/0	1/0/0	0/0/0	1/1/0
1941	1/0/0	0/0/0	0/0/0	0/0/0	3/0/0	0/0/0	6/0/0	3/0/0	1/0/0	3/0/0	1/0/0	0/0/0
1942	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	3/0/0	8/0/0	3/0/0	0/0/0	0/0/0	0/0/0
1943	0/0/0	0/0/0	0/0/0	0/0/0		0/0/0		3/0/0	0/0/0	1/0/0		
1944					3/0/0	0/0/0	3/1/0	8/1/0	1/0/0	1/0/0	0/0/0	0/0/0
1945	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	0/0/0	10/0/0	2/0/0	0/0/0	0/0/0	0/0/0
1946	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	5/1/0	4/0/0	0/0/0	0/0/0	1/0/0
1947	Missing for the entire year.											

TABLE V (Continued)

PRECIPITATION AT GALENA

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1942	0/0/0									1/0/0	0/0/0	0/0/0
1943	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0						
1944						1/0/0	3/0/0	5/0/0	2/0/0	0/0/0	0/0/0	0/0/0
1945	0/0/0	0/0/0	1/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	2/0/0	2/0/0		
1946						Not Available						3/0/0
1947	2/0/0	0/0/0	0/0/0	0/0/0	2/1/1	0/0/0	4/0/0	1/0/0	1/0/0	0/0/0	0/0/0	0/0/0

PRECIPITATION AT NORTHWAY

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1942										0/0/0	0/0/0	0/0/0
1943	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	7/0/0	3/0/0	1/0/0	1/0/0	1/0/0	0/0/0
1944	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	3/0/0	3/2/0	1/0/0	0/0/0	0/0/0	0/0/0
1945	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0	4/0/0	4/0/0	1/0/0	4/0/0	0/0/0	0/0/0	0/0/0
1946	0/0/0	0/0/0	0/0/0	0/0/0	2/1/0	2/0/0	6/0/0	2/0/0	1/1/0	1/0/0	0/0/0	0/0/0
1947	2/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/1/0	1/0/0	1/0/0	2/0/0	0/0/0	0/0/0	0/0/0

TABLE V (Continued)

PRECIPITATION AT BIG DELTA

Year	Number of Days with Precipitation Equal to or in Excess of 0.25, 1.00, and 2.00 Inches											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937		0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	1/0/0		3/1/0		0/0/0	
1938												
1939												
1940								1/0/0			0/0/0	0/0/0
1941	0/0/0	0/0/0	0/0/0	1/0/0	2/0/0	2/0/0	5/1/0	1/0/0	2/0/0	1/0/0	0/0/0	0/0/0
1942	0/0/0	0/0/0	0/0/0				2/1/0	0/0/0	0/0/0	0/0/0	1/0/0	0/0/0
1943	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	4/0/0	3/0/0	2/0/0	2/0/0	0/0/0	0/0/0	0/0/0
1944	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	4/1/0	5/1/0	2/0/0		0/0/0	2/0/0
1945	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	6/1/0	1/0/0	2/0/0	0/0/0	0/0/0	0/0/0
1946	0/0/0	0/0/0	0/0/0	0/0/0	1/0/0	3/0/0	2/1/0	3/0/0	0/0/0	0/0/0	0/0/0	0/0/0
1947	1/0/0	0/0/0	0/0/0	0/0/0	0/0/0	2/0/0	3/0/0	5/0/0	3/0/0	0/0/0	0/0/0	0/0/0

TABLE VI

INTENSITY OF RAINFALL

Maximum Precipitation in Inches for the Indicated Duration in Minutes

STA	YEAR	JANUARY 5	10	15	30	60	120	FEBRUARY 5	10	15	30	60	120	MARCH 5	10	15	30	60	120	APRIL 5	10	15	30	60	120	MAY 5	10	15	30	60	120	JUNE 5	10	15	30	60	120
ANCHORAGE	1942	.01	.02	.02	.04	.05	.07	.01	.02	.03	.06	.09	.11	.01	.02	.03	.05	.07	.11	.01	.02	.03	.06	.08	.13	.03	.03	.03	.03	.05	.07	.04	.07	.09	.14	.20	.26
	43	.01	.01	.02	.05	.10	.11				.13	.15	.16				.04	.06	.10				.05	.05	.08				.06	.10	.18				.09	.10	.18
	44				.07	.10	.14					.04	.07					.03	.05										.05	.05	.09			.03	.06	.09	.16
	45										.06	.11	.18			.02	.03	.06	.10	.01	.02	.03	.04	.07	.09	.01	.02	.03	.06	.07	.11	.02	.05	.07	.09	.12	.18
	46				.02	.03	.06				.02	.04	.07				.01	.02	.04				.01	.02	.04	.01	.01	.02	.04	.07	.14	.01	.01	.02	.04	.07	.13
	47			.02	.04	.08	.14			.01	.02	.02	.04				.01	.02	.04			.02	.03	.06	.09	.01	.01	.03	.04	.05	.07	.01	.03	.04	.04	.05	.06
	48			.02	.04	.04	.07			.03	.03	.04	.06			.03	.03	.08	.15			.03	.03	.04	.05	.01	.02	.02	.02	.02	.02	.01	.02	.03	.05	.06	.07
FAIRBANKS	31																									.01	.02	.03	.03	.05	.06	.32	.46	.52	.59	.63	.63
	32																									.02	.03	.04	.05	.05	.05	.04	.09	.12	.21	.32	.38
	33																									.03	.05	.06	.09	.14	.14	.07	.09	.10	.11	.16	.26
	34																									T	.01	.01	.01	.02	.04	.01	.02	.03	.06	.10	.18
	35																									.16	.18	.24	.25	.25	.27	.02	.03	.04	.08	.11	.13
	36																									.08	.11	.12	.13	.15	.17	.05	.05	.05	.06	.06	.06
	37																									.04	.07	.08	.08	.11	.11	.10	.16	.21	.28	.30	.30
	38																									.01	.01	.02	.02	.02	.02	.02	.03	.04	.08	.12	.16
	39																									.10	.16	.21	.25	.26	.26	.35	.41	.42	.42	.50	.52
	40																									.04	.06	.08	.11	.14	.22	.29	.45	.50	.59	.62	.67
	41																									.02	.03	.04	.07	.11	.14	.10	.15	.22	37	.50	.60
	42																									.04	.04	.04	.05	.06	.11	.10	.12	.16	.22	.35	.57
	43																									T	.01	.01	.03	.04	.06	.03	.04	.04	.06	.11	.16
	44																									.04	.07	.09	.14	.17	.26	.05	.08	.09	.11	.12	.14
	45																									.05	.08	.11	.17	.27	.36	.04	.05	.07	.14	.24	.39
	46																									.01	.02	.04	.06	.09	.17	.10	.16	.17	.26	.26	.26
	47																									T	T	.01	.02	.03	.05	.05	.05	.05	.05	.08	.08
	48																									.03	.05	.07	.09	.14	.20						
NOME	43	T	.01	.02	.02	.02	.03	T	.02	.03	.05	.06	.12	.02	.03	.04	.07	.12	.16	T	.01	.01	.02	.03	.04	.01	.02	.03	.06	.10	.12	.01	.02	.02	.03	.05	.08
	44			.02	.04	.05	.06			.04	.08	.15	.21			.03	.05	.08	.11			.01	.03	.04	.08			.02	.02	.04	.07			.07	.10	.14	.27
	45			.02	.02	.03	.04			.03	.05	.08	.15			.02	.05	.09	.17			.02	.04	.08	.16			.01	.02	.04	.06			.03	.05	.06	.10
	46			.03	.04	.06	.12			.02	.04	.06	.09			.05	.01	.02	.04			.01	.02	.04	.07			.02	.03	.06	.11			.04	.06	.10	.14
	47																																			.07	.11
	48					.02	.04					.04	.07					.04	.08					.06	.11		.01	.02	.03	.05	.10	.02	.03	.03	.04	.07	.10

TABLE VI
(Continued)
INTENSITY OF RAINFALL

Maximum Precipitation in Inches for the Indicated Duration in Minutes

STA	YEAR	JULY 5	10	15	30	60	120	AUGUST 5	10	15	30	60	120	SEPTEMBER 5	10	15	30	60	120
ANCHORAGE	1942	.02	.03	.04	.07	.10	.14	.07	.08	.09	.12	.21	.36	.03	.04	.05	.08	.16	.26
	43				.07	.12	.21	.06	.06	.06	.07	.11	.20	.03	.05	.09	.12	.15	.28
	44	.02	.04	.06	.10	.15	.21	.05	.09	.11	.19	.31	.38	.02	.04	.05	.10	.20	.36
	45	.02	.03	.04	.07	.13	.19	.04	.07	.10	.14	.17	.28	.04	.06	.09	.11	.13	.18
	46	.02	.02	.03	.05	.08	.09	.02	.03	.04	.07	.13	.20	.09	.17	.19	.22	.23	.23
	47	.05	.07	.09	.12	.13	.23	.04	.06	.08	.13	.23	.36	.02	.03	.05	.10	.19	.33
	48	.05	.09	.14	.18	.23	.27	.04	.08	.10	.13	.23	.47						
FAIRBANKS	31	.10	.11	.11	.11	.11	.12	.07	.08	.08	.09	.16	.28						
	32	.08	.10	.14	.19	.21	.31	.03	.04	.06	.09	.17	.28	.01	.01	.02	.03	.05	.08
	33	.01	.02	.03	.06	.09	.14	.08	.12	.13	.15	.21	.23						
	34	.21	.34	.35	.38	.39	.64	.14	.21	.25	.29	.43	.64	.01	.02	.02	.05	.06	.08
	35	.18	.32	.40	.44	.47	.52	.06	.07	.08	.09	.12	.21	.02	.03	.03	.06	.11	.20
	36	.04	.05	.06	.10	.18	.19	.10	.14	.17	.21	.32	.34	.01	.02	.02	.05	.09	.14
	37	.08	.12	.13	.15	.17	.17	.04	.08	.10	.12	.13	.16	.02	.04	.05	.08	.09	.11
	38	.05	.07	.13	.17	.21	.31	.03	.04	.07	.11	.16	.23	T	.01	.02	.03	.05	.07
	39	.22	.28	.40	.70	.99	1.06	.03	.06	.07	.10	.13	.16	.01	.02	.03	.05	.06	.09
	40	.03	.05	.07	.09	.10	.12	.10	.14	.15	.17	.28	.40	T	T	.01	.02	.04	.07
	41	.07	.10	.11	.15	.20	.21	.03	.03	.04	.07	.09	.11	.02	.03	.03	.04	.10	.17
	42	.05	.05	.06	.10	.11	.16	.15	.26	.27	.27	.28	.33	.01	.02	.03	.06	.09	.17
	43	.04	.09	.13	.23	.35	.45	.04	.05	.06	.08	.17	.25	T	.01	.01	.03	.05	.09
	44	.05	.08	.10	.13	.14	.15	.04	.08	.09	.18	.20	.26	.04	.06	.07	.10	.17	.24
	45	.13	.21	.27	.31	.34	.35	.03	.04	.06	.10	.16	.27	.02	.03	.04	.07	.10	.18
	46	.10	.20	.27	.32	.35	.35	.01	.02	.02	.05	.07	.12	.01	.01	.01	.03	.06	.10
	47	.10	.15	.16	.20	.23	.23	.01	.03	.04	.05	.09	.14			.04	.05	.07	.12
NOME	42							.01	.02	.03	.05	.09	.17	.04	.08	.10	.20	.38	.61
	43	.03	.04	.04	.06	.12	.18	.04	.08	.11	.13	.24	.45	.01	.01	.02	.02	.04	.07
	44			.06	.10	.18	.25			.09	.13	.17	.26			.10	.15	.27	.34
	45			.09	.13	.24	.40			.07	.08	.11	.15						
	46			.04	.07	.13	.22			.14	.22	.27	.53			.05	.10	.22	.36
	47	.05	.08	.10	.16	.22	.38	.04	.07	.10	.17	.32	.44	.03	.05	.05	.08	.11	.20
	48	.02	.03	.04	.07	.11	.20	.02	.04	.06	.12	.21	.27						

STA	YEAR	OCTOBER 5	10	15	30	60	120	NOVEMBER 5	10	15	30	60	120	DECEMBER 5	10	15	30	60	120
ANCHORAGE	1942	.02	.03	.04	.10	.15	.18	T	T	.01	.01	.02	.03	T	.01	.02	.03	.06	.13
	43				.09	.11	.17			.05	.06	.07	.12			.05	.06	.08	.16
	44	.01	.01	.02	.04	.08	.10					.03	.06				.04	.08	.08
	45	.02	.03	.04	.07	.11	.19			.01	.02	.03	.05				.01	.02	.04
	46			.03	.05	.06	.08			.04	.07	.13	.21			.01	.02	.04	.07
	47			.03	.04	.08	.13			.04	.05	.07	.12			.04	.04	.04	.05
	48																		
FAIRBANKS	31–47																		
NOME	42																		
	43	T	.01	.02	.03	.05	.08	.01	.01	.02	.04	.07	.14	T	.01	.01	.02	.03	.05
	44	.02	.03	.03	.06	.07	.10	.02	.04	.06	.12	.21	.40	.01	.02	.03	.05	.10	.14
	45			.05	.10	.20	.39			.01	.02	.04	.08			.04	.05	.09	.17
	46															.03	.04	.09	.40
	47			.04	.08	.12	.18			.02	.05	.10	.18			.02	.03	.07	.12
	48	.01	.02	.02	.03	.05	.08					.05	.10					.02	.04

TABLE VI
(Continued)
INTENSITY OF RAINFALL

Maximum Precipitation in Inches for the Indicated Duration in Minutes

STA	YEAR	JANUARY 5	10	15	30	60	120	FEBRUARY 5	10	15	30	60	120	MARCH 5	10	15	30	60	120
JUNEAU	1929	.04	.06	.09	.14	.28	.44	.02	.04	.05	.11	.20	.36	No Record					
	30	No Record						No Record						.02	.04	.06	.12	.22	.40
	31	.02	.03	.05	.09	.15	.27	.02	.03	.04	.07	.13	.24	.02	.03	.05	.07	.12	.19
	32	.02	.04	.06	.13	.21	.39	No Record						.02	.04	.05	.08	.14	.20
	33	.04	.06	.08	.13	.24	.29	No Record						.03	.04	.06	.08	.11	.20
	34	Bucket not in						.03	.05	.07	.12	.22	.44	.02	.03	.04	.09	.13	.25
	35	.02	.03	.05	.09	.18	.33	.01	.03	.04	.07	.13	.25	No Record					
	36	.03	.05	.07	.13	.22	.37	No Record						.03	.07	.09	.17	.31	.44
	37	.02	.03	.05	.08	.15	.30	No Record						No Record					
	38	No Record						.03	.05	.07	.14	.27	.51	.02	.04	.06	.10	.20	.33
	39	.03	.05	.07	.12	.21	.32	.03	.06	.09	.16	.28	.54	.04	.07	.11	.20	.38	.68
	40	.01	.03	.05	.09	.17	.29	.01	.02	.03	.06	.11	.17	.02	.03	.05	.11	.21	.35
	41	.02	.04	.07	.10	.17	.28	.01	.03	.05	.07	.12	.16	.02	.03	.04	.07	.13	.19
	42	.02	.04	.05	.09	.17	.32	.03	.04	.06	.10	.16	.30	.03	.04	.07	.13	.22	.40
	43	.03	.06	.08	.13	.25	.47	.02	.03	.04	.07	.11	.17	.02	.03	.04	.05	.09	.13
	44	.03	.06	.08	.12	.15	.20	.01	.02	.03	.06	.11	.20	.02	.04	.05	.10	.15	.27
	45	.02	.03	.04	.08	.12	.19	.02	.03	.05	.08	.12	.18	.02	.04	.06	.08	.12	.18
	46			.06	.11	.20	.27	.01	.02	.03	.05	.09	.14	.02	.04	.05	.08	.11	.19
	47	.05	.06	.08	.13	.20	.35	.01	.02	.03	.05	.08	.13	.03	.05	.07	.12	.18	.33
	48	.04	.07	.09	.16	.25	.42	.03	.04	.04	.05	.07	.11			.08	.13	.24	.44
KETCHIKAN	42	.05	.09	.12	.22	.36	.62	.03	.06	.09	.18	.33	.61	.08	.12	.13	.18	.27	.44
	43	.09	.12	.15	.25	.45	.80	.08	.12	.14	.25	.40	.70	.05	.08	.10	.17	.27	.38
	44			.13	.24	.51	.90			.06	.09	.16	.30			.07	.16	.32	.58
	45			.11	.18	.33	.60			.12	.19	.33	.64			.10	.17	.32	.57
	46			.46	.25	.45	.77			.10	.17	.22	.36			.14	.22	.46	.78
	47			.14	.22	.33	.56			.12	.20	.37	.69			.17	.26	.45	.86

STA	YEAR	APRIL 5	10	15	30	60	120	MAY 5	10	15	30	60	120	JUNE 5	10	15	30	60	120
JUNEAU	1929	.01	.02	.04	.07	.13	.20	.06	.08	.09	.17	.28	.36	.05	.08	.13	.19	.21	.27
	30	.02	.04	.06	.10	.16	.25	.03	.06	.08	.13	.16	.27	.06	.09	.10	.12	.19	.24
	31	.04	.07	.09	.18	.29	.45	.05	.08	.10	.17	.26	.34	.03	.05	.06	.10	.20	.34
	32	.04	.06	.08	.14	.24	.27	.04	.06	.08	.12	.19	.23	.04	.06	.07	.12	.22	.39
	33	.02	.03	.04	.07	.12	.20	.02	.04	.05	.09	.18	.32	.07	.09	.09	.12	.17	.33
	34	.04	.05	.05	.07	.13	.22	.03	.05	.06	.11	.19	.31	.05	.06	.08	.11	.15	.27
	35	.02	.03	.04	.06	.13	.20	.02	.05	.07	.10	.17	.24	.05	.10	.11	.15	.21	.35
	36	.03	.04	.06	.12	.23	.44	.06	.09	.10	.13	.19	.25	.01	.02	.03	.04	.06	.10
	37	.03	.04	.06	.11	.19	.30	.03	.05	.06	.10	.18	.28	.03	.05	.07	.12	.18	.29
	38	.03	.05	.07	.14	.23	.28	.03	.06	.08	.15	.24	.41	.09	.12	.14	.19	.29	.34
	39	No Record						.03	.04	.05	.09	.14	.20	.07	.10	.14	.23	.37	.64
	40	.01	.03	.05	.07	.14	.27	.08	.14	.20	.20	.21	.22	.05	.08	11	.14	.20	.26
	41	.04	.07	.13	.17	.21	.25	.02	.03	.06	.07	.10	.18	.06	.10	.14	.21	.28	.37
	42	.03	.05	.06	.09	.18	.30	.02	.04	.06	.08	.10	.17	.05	.08	.11	.14	.25	.41
	43	.04	.05	.06	.09	.17	.34	.02	.04	.05	.09	.15	.26	.05	.08	.10	.14	.24	.32
	44	.02	.03	.04	.09	.14	.20	.02	.05	.07	.11	.13	.18	.05	.07	.09	.16	.18	.22
	45	.02	.03	.05	.08	.11	.18	.02	.04	.05	.08	.14	.24	.07	.11	.11	.14	.19	.25
	46	.02	.04	.06	.09	.11	.15	.02	.02	.03	.04	.08	.13	.02	.04	.05	.07	.07	.09
	47	.02	.04	.05	.10	.17	.26	.01	.03	.05	.07	.10	.20	.04	.06	.08	.14	.24	.46
	48			.01	.02	.04	.06	.01	.03	.04	.08	.15	.29			.10	.14	.25	.28
KETCHIKAN	42	.04	.07	.10	.15	.28	.46	.06	.06	.10	.12	.19	.34	.05	.06	.07	.09	.13	.17
	43	.05	.08	.10	.15	.28	.44	.02	.04	.10	.14	.20	.37	.01	.02	.05	.10	.15	.24
	44			.08	.14	.27	.51			.11	.20	.32	.53			.09	.15	.17	.30
	45			.08	.14	.20	.37			.08	.14	.25	.45			.13	.27	.44	.67
	46			.09	.15	.29	.51			.12	.16	.22	.38			.09	.15	.26	.41
	47			.25	.34	.65	.84			.11	.19	.33	.60			.13	.24	.36	.58

TABLE VI
(Continued)
INTENSITY OF RAINFALL

Maximum Precipitation in Inches for the Indicated Duration in Minutes

STA	YEAR	JULY 5	JULY 10	JULY 15	JULY 30	JULY 60	JULY 120	AUGUST 5	AUGUST 10	AUGUST 15	AUGUST 30	AUGUST 60	AUGUST 120	SEPTEMBER 5	SEPTEMBER 10	SEPTEMBER 15	SEPTEMBER 30	SEPTEMBER 60	SEPTEMBER 120
JUNEAU	1929	.04	.09	.11	.14	.22	.34	.05	.06	.08	.11	.16	.19	.05	.06	.10	.18	.30	.52
	30	.03	.05	.07	.12	.23	.37	.08	.14	.19	.31	.40	.60	.05	.07	.09	.12	.18	.29
	31	.06	.11	.14	.16	.25	.30	.06	.08	.09	.12	.23	.43	.04	.06	.09	.13	.21	.40
	32	.03	.04	.06	.09	.14	.23	.03	.04	.05	.08	.13	.20	.06	.08	.09	.12	.21	.34
	33	.05	.06	.09	.16	.21	.29	.06	.10	.13	.18	.26	.37	.06	.08	.11	.15	.23	.34
	34	.05	.08	.11	.12	.13	.16	.03	.05	.08	.15	.27	.49	.08	.09	.10	.11	.20	.32
	35	.02	.04	.05	.10	.17	.34	.05	.09	.12	.17	.27	.39	.06	.11	.15	.23	.36	.60
	36	.04	.06	.07	.11	.18	.29	.06	.09	.10	.17	.21	.29	.09	.17	.21	.37	.52	.70
	37	.05	.08	.10	.14	.20	.34	.07	.11	.15	.19	.32	.48	.08	.13	.16	.21	.27	.37
	38	.04	.06	.09	.12	.21	.37	.03	.05	.07	.14	.24	.39	.09	.17	.23	.34	.46	.63
	39	.05	.07	.09	.16	.28	.44	.08	.13	.15	.20	.32	.50	.03	.05	.07	.13	.23	.41
	40	.07	.13	.19	.21	.32	.33	.05	.09	.13	.14	.21	.37	.04	.06	.10	.12	.19	.35
	41	.03	.06	.11	.14	.26	.41	.03	.04	.09	.11	.18	.20	.03	.05	.07	.10	.16	.27
	42	.07	.10	.11	.13	.19	.30	.11	.16	.23	.28	.33	.42	.06	.10	.14	.18	.35	.60
	43	.05	.07	.09	.15	.20	.33	.03	.05	.06	.09	.16	.27	.06	.08	.10	.17	.28	.48
	44	.10	.15	.22	.32	.47	.52	.05	.08	.09	.14	.22	.36	.08	.11	.12	.15	.17	.21
	45	.13	.18	.25	.32	.45	.54	.05	.08	.10	.13	.22	.33	.04	.08	.12	.17	.25	.39
	46	.05	.09	.11	.21	.34	.38	.03	.05	.07	.09	.16	.25	.03	.04	.06	.11	.19	.32
	47	.03	.05	.06	.09	.10	.13	.03	.06	.08	.13	.20	.33	.04	.06	.09	.16	.28	.41
	48	.04	.06	.08	.12	.19	.32	.04	.05	.05	.07	.14	.26	No Record					
KETCHIKAN	41													.05	.09	.13	.21	.38	.70
	42	.11	.14	.16	.20	.32	.38	.10	.15	.18	.25	.34	.50	.10	.15	.17	.22	.42	.72
	43	.07	.10	.14	.18	.31	.58	.07	.09	.10	.20	.40	.60	.20	.21	.23	.30	.51	.93
	44			.12	.25	.44	.71			.20	.28	.58	.94			.24	.24	.38	.66
	45			.13	.23	.43	.79			.17	.21	.22	.39			.20	.37	.58	1.03
	46			.30	.47	.51	.59			.19	.34	.49	.73			.28	.33	.40	.76
	47			.20	.32	.58	1.03			.12	.22	.43	.75			.20	.34	.67	1.07

STA	YEAR	OCTOBER 5	OCTOBER 10	OCTOBER 15	OCTOBER 30	OCTOBER 60	OCTOBER 120	NOVEMBER 5	NOVEMBER 10	NOVEMBER 15	NOVEMBER 30	NOVEMBER 60	NOVEMBER 120	DECEMBER 5	DECEMBER 10	DECEMBER 15	DECEMBER 30	DECEMBER 60	DECEMBER 120
JUNEAU	1929	.07	.11	.13	.24	.36	.64	.04	.06	.08	.16	.31	.50	No Record					
	30	.04	.06	.09	.17	.33	.60	.03	.05	.07	.12	.21	.34	.02	.04	.06	.10	.20	.33
	31	.07	.12	.14	.18	.27	.46	.03	.05	.06	.11	.20	.32	.03	.04	.05	.08	.12	.20
	32	.03	.05	.07	.11	.19	.36	.02	.03	.04	.08	.14	.24	.02	.04	.05	.09	.14	.25
	33	.04	.07	.09	.13	.23	.40	.08	.13	.16	.21	.25	.47	Bucket not in use.					
	34	.06	.09	.11	.16	.30	.60	.03	.05	.07	.13	.21	.35	.02	.04	.05	.09	.15	.24
	35	.03	.06	.08	.14	.24	.42	.03	.05	.07	.13	.25	.49	.03	.05	.06	.11	.19	.29
	36	.05	.10	.13	.21	.32	.55	.03	.06	.09	.17	.33	.59	.04	.07	.10	.17	.32	.60
	37	.04	.07	.09	.13	.23	.44	.02	.04	.05	.10	.18	.28	.04	.07	.11	.20	.39	.70
	38	.02	.05	.07	.14	.25	.46	.11	.14	.15	.17	.21	.39	.02	.04	.06	.09	.15	.26
	39	.05	.07	.10	.16	.28	.45	.06	.10	.15	.20	.25	.38	.03	.06	.09	.14	.21	.33
	40	.05	.11	.15	.17	.30	.53	.02	.04	.07	.10	.18	.33	.03	.05	.09	.13	.21	.32
	41	.04	.06	.10	.15	.24	.38	.03	.06	.10	.13	.22	.34	.01	.02	.04	.06	.08	.15
	42	.03	.06	.12	.16	.29	.55	.02	.04	.07	.10	.18	.30	.03	.05	.07	.08	.12	.22
	43	.12	.17	.19	.25	.38	.67	.03	.05	.06	.07	.11	.21	.03	.06	.08	.12	.18	.35
	44	.05	.08	.11	.16	.23	.39	.03	.05	.08	.12	.18	.32	.03	.04	.07	.10	.17	.28
	45	.07	.13	.18	.31	.42	.66	.01	.03	.05	.07	.11	.20	.01	.02	.03	.06	.11	.14
	46	.05	.09	.13	.23	.42	.79	.05	.07	.08	.13	.21	.40	.02	.03	.04	.08	.13	.20
	47	.04	.07	.09	.11	.14	.23	.02	.04	.06	.10	.11	.19	.03	.05	.06	.08	.15	.23
	48																		
KETCHIKAN	41	.	.	.	.	.	.	.12	.18	.24	.40	.58	.97	.06	.10	.13	.20	.32	.52
	42	.08	.11	.16	.27	.44	.87	.12	.18	.25	.35	.45	.75	.10	.18	.24	.45	.73	1.18
	43	.20	.22	.25	.37	.61	.80	.13	.15	.17	.20	.36	.66	.12	.15	.20	.43	.78	1.13
	44			.25	.50	.70	1.23			.19	.35	.50	.61			.14	.20	.38	.60
	45			.27	.42	.76	1.34			.13	.19	.31	.49			.14	.19	.26	.43
	46			.17	.29	.45	.77			.14	.25	.40	.68			.10	.15	.29	.51
	47			.17	.26	.46	.74			.17	.25	.38	.64			.16	.28	.43	.73

TABLE VII

24-HOUR MAXIMUM PRECIPITATION

AT ANCHORAGE

Year	Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929							0.67	0.58	0.83			0.13
1930	0.47	0.19	0.80	0.15	0.53	0.29	0.78	0.54	0.54	0.12	0.20	0.05
1931	0.08	0.09	0.03	0.01	0.08	0.09	0.35	0.37	0.80	0.68	0.38	0.66
1932	0.37	0.51	T	0.08	0.20	0.09	0.60	0.68	1.55	0.54	0.39	0.43
1933	0.24	0.29	0.52	0.17	0.60	0.29	0.14	0.29	1.20	0.32	0.43	0.00
1934	0.28	0.27	0.39	0.17	0.80	0.25	0.49	0.86	0.48	0.34	0.04	0.70
1935	0.50	0.27	0.15	0.23	0.31	0.10	0.79	0.53	0.70	1.29	0.57	0.15
1936	0.15	0.33	0.23	0.18	0.06	0.38	0.32	0.68	0.26	1.12	0.57	0.68
1937	0.37	0.22	0.04	0.89	0.42	0.17	0.18	0.41	0.51	0.72	0.49	T
1938	0.05	0.12	0.24	T	0.50	0.75	0.50	0.25	0.50	0.60	0.34	0.19
1939	0.15	0.28	0.16	0.07	0.22	0.65	0.51	1.06	0.84	1.19	0.27	0.76
1940	0.17	0.13	0.22	0.13	0.46	0.36	0.53	0.73	1.11	1.46	0.49	0.94
1941	0.94	0.44	0.17	0.74	0.25	1.09	0.63	0.16	0.38	0.67	0.45	0.13
1942	0.25	0.36	0.19	0.30	0.12	0.36	0.63	1.00	0.94	0.80	0.07	0.45
1943	0.60	0.20	0.24	0.17	0.62	0.33	0.94	0.71	1.55	0.25	0.43	0.37
1944	0.45	0.23	0.20	0.17	0.19	0.24	0.65	0.65	0.62	0.40	0.25	0.59
1945	0.11	0.43	0.32	0.19	0.47	0.43	0.64	1.00	0.63	0.58	0.19	0.08
1946	0.25	0.39	0.17	0.10	0.50	0.31	0.31	0.65	0.42	0.26	0.50	0.30
1947	0.25	0.11	0.17	0.18	0.17	0.10	0.72	1.33	1.22	0.50	0.29	0.27
1948	0.25	0.17	0.27	0.05								

TABLE VII (Continued)

24-HOUR MAXIMUM PRECIPITATION
AT JUNEAU

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Precipitation in Inches											
1929	2.00	1.93	0.86	1.48	1.16	0.72	1.02	1.19	1.83	1.82	2.93	1.21
1930	0.74	1.42	3.13	0.84	1.12	1.00	1.85	2.21	1.39	2.49	2.13	1.17
1931	1.50	1.49	0.85	1.04	1.06	2.35	1.06	1.64	1.37	2.87	1.59	0.97
1932	2.03	1.67	0.77	0.88	0.93	1.93	1.43	0.95	1.52	2.10	1.13	1.33
1933	1.42	1.74	1.04	1.79	2.72	1.10	0.68	1.65	1.27	2.87	2.01	0.39
1934	2.48	2.39	1.37	1.12	0.76	1.08	0.88	2.72	1.26	2.45	1.45	0.93
1935	1.26	1.72	0.97	0.90	1.43	0.84	2.31	2.38	2.93	1.97	2.66	1.47
1936	1.18	1.49	1.35	2.40	0.95	0.24	1.35	0.64	2.69	2.14	3.89	3.20
1937	1.41	0.59	1.36	1.24	0.94	1.74	2.40	2.27	1.60	2.65	1.57	3.19
1938	1.39	2.41	2.23	0.82	2.40	2.86	1.91	1.12	1.83	2.04	2.07	1.81
1939	1.66	3.46	3.29	1.03	1.01	1.42	2.30	3.08	1.79	2.17	1.87	2.24
1940	1.08	0.99	1.26	0.94	1.92	0.90	1.32	1.87	1.63	3.00	1.82	1.29
1941	1.67	0.56	1.20	1.26	1.03	0.81	2.60	0.58	1.35	1.50	2.71	0.95
1942	1.62	1.30	1.21	1.01	0.47	1.15	1.90	2.24	2.53	3.23	1.44	1.54
1943	1.64	1.05	0.81	2.32	0.81	0.93	1.58	2.64	2.04	3.23	2.09	2.00
1944	1.18	0.81	1.40	0.68	0.92	1.04	0.68	1.21	1.04	2.70	1.80	1.09
1945	0.80	2.06	1.86	1.48	1.39	1.23	1.96	1.04	2.32	3.30	0.99	0.59
1946	0.91	1.15	1.30	0.96	1.19	0.28	0.95	1.22	1.98	2.31	2.40	1.18
1947	1.33	0.59	2.09	1.74	0.92	0.74	0.66	1.83	2.22	1.31	1.38	1.06

TABLE VII (Continued)

24-HOUR MAXIMUM PRECIPITATION
AT KETCHIKAN

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Precipitation in Inches											
1929	2.90	1.18	4.40	1.53	1.68	2.53	2.20	4.84	0.88	5.44	2.99	1.49
1930	0.83	2.04	2.40	2.03	1.69	2.39	2.44	0.62	4.56	7.04	2.66	3.78
1931	1.84	1.55	1.78	2.84	3.60	0.85	1.24	4.88	1.94	2.85	1.34	1.26
1932	2.60	5.36	2.31	1.20	2.18	1.18	2.78	1.73	3.08	2.28	2.74	1.61
1933	1.52	1.68	2.40	1.49	0.98	1.74	1.64	3.72	2.35	4.56	3.56	1.12
1934	4.20	1.58	2.44	2.95	1.12	2.42	1.60	1.62	2.22	1.79	2.98	2.83
1935	2.96	1.97	1.36	1.46	3.12	1.26	2.30	2.37	0.94	4.69	1.76	2.32
1936	3.12	2.36	3.38	2.40	1.38	1.59	2.64	1.78	2.23	3.80	3.94	1.44
1937	1.46	1.51	2.86	1.60	1.80	3.36	2.29	1.94	3.05	2.06	1.54	3.06
1938	2.84	3.51	1.19	2.70	2.09	2.81	1.73	1.12	3.36	4.61	3.26	2.67
1939	2.71	3.00	1.61	2.38	2.05	1.31	2.11	2.64	4.83	3.18	2.48	2.16
1940	2.23	2.73	3.57	1.52	2.48	2.21	1.70	3.13	2.13	1.82	2.44	2.56
1941	1.72	1.27	2.33	2.78	1.05	2.74	1.94	1.16	3.37	2.80	5.15	2.18
1942	3.25	2.49	2.36	2.93	1.20	0.61	0.72	1.65	3.44	6.00	6.33	3.64
1943	5.16	4.86	1.60	2.92	2.53	0.66	3.72	2.21	3.84	2.35	5.22	2.54
1944	2.63	1.16	3.66	2.50	2.47	1.23	4.87	2.40	2.99	6.77	3.07	2.82
1945	2.86	2.81	1.96	1.56	1.83	3.83	2.47	0.68	5.63	6.33	1.75	2.12
1946	3.56	2.46	2.45	2.06	1.02	0.81	2.45	2.80	3.29	5.84	2.84	2.58
1947	2.78	2.98	7.98	3.61	1.69	2.33	2.18	4.58	5.42	2.56	2.27	2.82

TABLE VII (Continued)

24-HOUR MAXIMUM PRECIPITATION

AT NOME

Year	Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929	0.43	0.16	0.15	0.33	0.17	0.09	0.59	0.90	0.80	0.17	0.40	0.31
1930			0.50	0.25	0.13	0.94	1.34	1.43	0.49	0.86	0.03	0.15
1931	0.08	0.16	0.11	0.32	0.40	0.31	0.60	0.96	0.64	0.89	0.52	1.21
1932	0.29	0.53	0.40	0.30	0.17	0.11	0.57	0.40	0.68	0.59	0.23	0.94
1933	0.22	0.16	0.12	0.07	0.19	0.18	0.42	0.55	0.23	0.16	0.47	0.28
1934	0.28	0.28	0.30	0.19	0.20	0.51	0.53	0.75	0.91	0.51	0.11	0.40
1935	0.65	0.24	0.55	0.25	0.13	0.38	0.35	0.78	0.46	1.52	1.40	0.37
1936	0.34	0.34	0.40	0.40	0.16	0.60	0.80	0.83	0.54	0.67	0.54	0.35
1937	0.69	0.22	0.18	0.91	0.63	0.46	0.54	1.02	1.15	0.72	1.14	0.19
1938	0.33	0.40	0.39	0.13	0.16	0.77	0.48	2.05	0.59	0.33	0.54	0.18
1939	0.18	0.35	0.22	0.34	0.15	0.04	0.90	0.81	0.58	0.42	0.01	0.10
1940	0.33	0.16	0.10	0.42	0.25	0.06	0.54	0.42	1.17	0.12	0.26	0.31
1941	0.08	0.29	0.12	0.15	0.07	0.27	0.50	0.21	0.30	0.59	0.22	0.17
1942	0.17	0.25	0.25	0.68	0.43	0.88	1.66	0.58	1.39	0.38	0.30	0.13
1943	0.05	0.56	0.61	0.07	0.85	0.13	0.97	1.50	0.17	0.28	1.35	0.26
1944	0.21	1.03	0.31	0.41	0.23	0.56	1.50	1.09	0.55	0.83	0.33	0.46
1945	0.23	0.72	0.74	0.74	0.17	0.17	1.16	0.79	1.04	1.05	0.69	0.40
1946	0.68	0.53	0.17	0.37	0.42	0.90	0.85	2.10	1.09	0.67	0.50	1.02
1947	0.78	0.20	0.06	0.12	0.38	0.20	0.75	1.56	0.79	0.42	0.46	0.22
1948	0.30	0.42	0.50									

TABLE VII (Continued)

24-HOUR MAXIMUM PRECIPITATION

AT FAIRBANKS

Year	Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1929											0.16	0.29
1930	0.15	0.16	0.25	0.06	0.41	0.55	1.80	2.33	0.23	0.25	0.18	0.13
1931	0.13	0.31	0.11	0.09	0.21	1.15	0.37	0.93	0.42	0.24	0.15	0.74
1932	0.48	0.78	0.10	0.06	0.07	0.48	0.57	1.63	0.34	0.18	0.07	0.11
1933	0.48	0.30	0.04	0.09	0.36	0.93	0.88	0.63	0.19	0.32	0.22	0.31
1934	0.26	0.05	0.32	0.23	0.10	0.23	0.64	0.92	0.18	0.06	0.04	0.10
1935	0.45	0.21	0.67	0.10	0.44	0.15	0.66	0.71	0.68	1.16	0.94	0.06
1936	0.06	0.10	0.20	T	0.37	0.19	0.29	0.38	0.38	0.60	0.59	0.49
1937	1.84	0.22	T	0.18	0.15	0.30	0.38	0.59	0.22	0.55	0.24	0.09
1938	0.26	0.23	0.10	0.07	0.04	0.19	0.85	0.80	0.18	0.06	0.15	0.19
1939	0.14	0.18	0.25	T	0.42	0.79	1.45	0.32	0.24	0.28	0.17	0.03
1940	0.77	0.03	0.01	0.21	0.52	0.71	0.25	1.11	0.18	0.17	0.22	0.07
1941	0.10	0.02	0.16	0.66	0.38	0.85	0.31	0.41	0.36	0.32	0.24	0.10
1942	0.11	0.14	0.12	0.03	0.36	1.16	0.49	0.70	0.57	0.29	0.82	0.03
1943	0.27	0.35	1.21	0.03	0.12	0.20	0.47	0.90	0.38	0.29	0.28	0.06
1944	0.09	0.47	0.28	0.01	0.63	0.24	0.36	1.21	0.47	0.38	0.12	0.18
1945	0.04	0.17	0.21	0.03	0.63	0.94	0.35	1.20	0.41	0.25	0.33	0.14
1946	0.24	0.29	0.13	0.11	0.79	0.61	0.96	0.40	0.22	1.17	0.13	0.11
1947	0.43	0.02	0.07	0.25	0.29	0.16	0.29	0.63	0.47	0.15	0.20	0.07

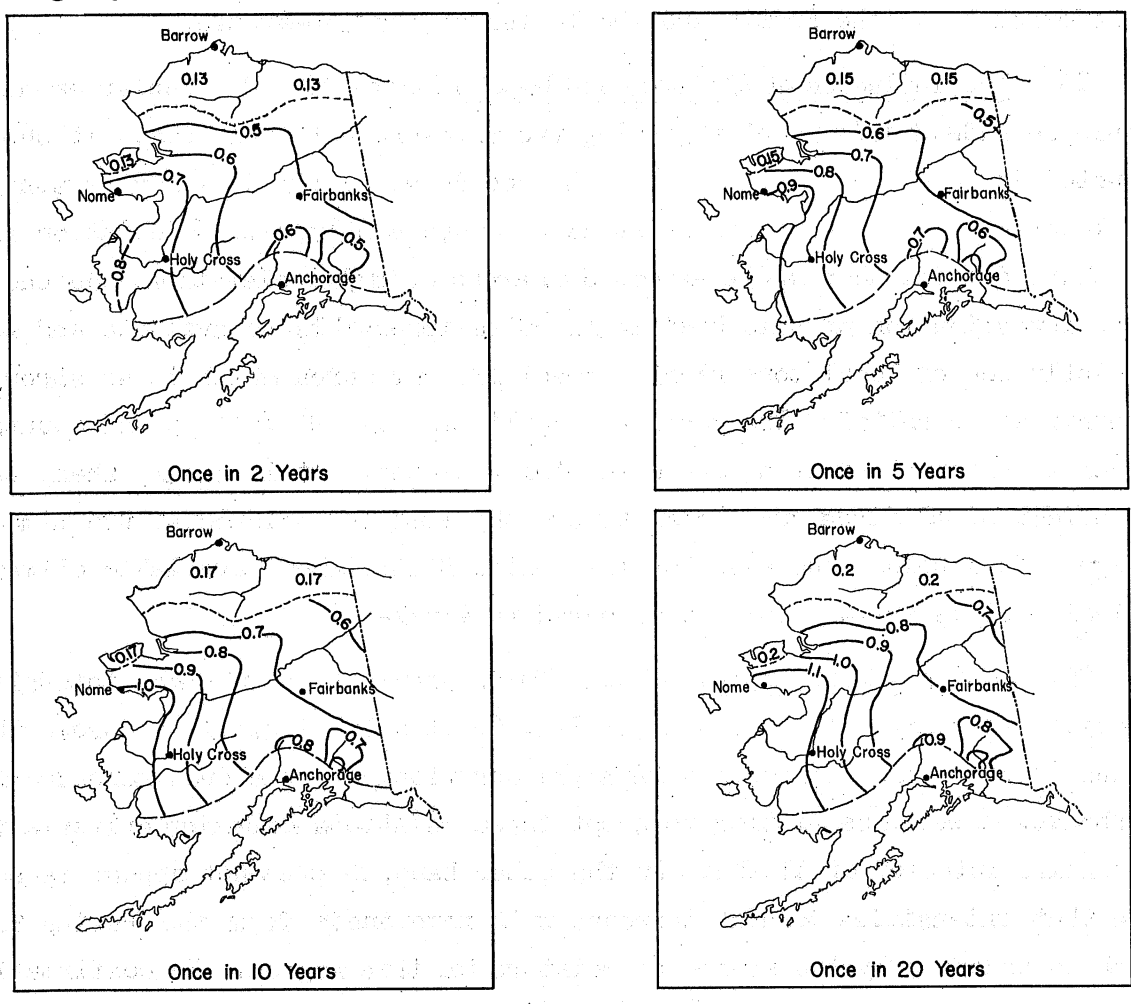
IV. DESIGN CRITERIA

24. Regions of Similar Weather-Affecting Factors. The first step in any procedure to develop hydrological design criteria for a comparatively large area is to subdivide that area into regions of similar weather-affecting factors. Preceding descriptive paragraphs were pointed in this direction. It is believed that on the basis of these descriptions, the research area of Alaska, particularly for drainage design criteria, may be divided into two specific regions as shown in Fig. 7. The first region may be described as all the area lying to the north of Brooks Range. This region also includes the northwestern part of Seward Peninsula. The second region consists of the remainder of the research area. For all practical purposes the former will be referred to as the Arctic and the latter as the sub-Arctic.

25. The Influence of Altitude and Local Topography. Particular emphasis should be made at this point regarding two rain-producing factors. It should be noted that all stations from which records of precipitation were studied are located at relatively low altitudes. Consequently, a wide deviation from the charted magnitudes can be expected in areas of higher elevation. Secondly, in an investigation of this kind it is quite impossible to evaluate and show the influence of local topography, especially in an area which is so strongly diversified in relief. The general overall pattern of valleys and mountain ranges is an actual limiting and determining factor. It is clear, then, that the effect of altitude and local topography must be weighed at the time of design. This holds true even for the United States where available climatological records are manifold as compared to Alaska.

26. Design Storm Index. Upon first examination of the intensity-duration-frequency relations shown in Fig. 6, it seems logical to assume that because the highest intensities for short durations are the ones recorded for Fairbanks, it would be fitting to adopt these relations as design criteria for the entire interior of Alaska. On the other hand, it does not appear reasonable that intensities should increase with remoteness from the Bering Sea, which is undoubtedly the source of moisture for this region. In confirmation of this latter supposition there are records of higher values for longer durations, particularly at Holy Cross and the White Mountain area. Similarly, nearness to the head of Cook Inlet seems to be a factor which determines rainfall characteristics for the Susitna River valley. Accordingly, the intensity-duration values which were charted for Fairbanks were assumed to be applicable

to the entire subarctic area of Alaska lying to the north of the southern limit of permafrost, but the figures were adjusted for such causative factors as distance from the source, proximity of main mountain ranges, and prevailing wind direction. Figure 7 shows the adjusted values for a 1-hr rainfall which can be expected to occur with a frequency of from once in 2 years to once in 20 years. Figure 8 shows the corresponding intensity-duration relations which represent supply curves for Alaska covering the range of values indicated in Fig. 7. Figures 9, 10, 11, and 12 show overland flow versus the rates of supply that are applicable for Alaska. These can be used with the procedure contained in the Engineering Manual, Part XIII, Chapter 1, for designing storm water drainage systems.



LEGEND

----- Approximate Southern Limit of the Arctic
——— Approximate Southern Limit of Permafrost

NOTES

1. Observations of rainfall at U.S. Weather Bureau stations forms the basic data for this figure. These stations are not located in the more elevated regions, consequently wide deviations from the chartered values may exist at altitudes above 2500 feet.
2. The influence of local topographic characteristics should be taken into account and evaluated at the time of drainage design.
3. The lines of equal one hour rainfall magnitudes correspond to the intensity-duration curves, which are in figure 8.

Fig. 7 - Design Storm Index for Alaska

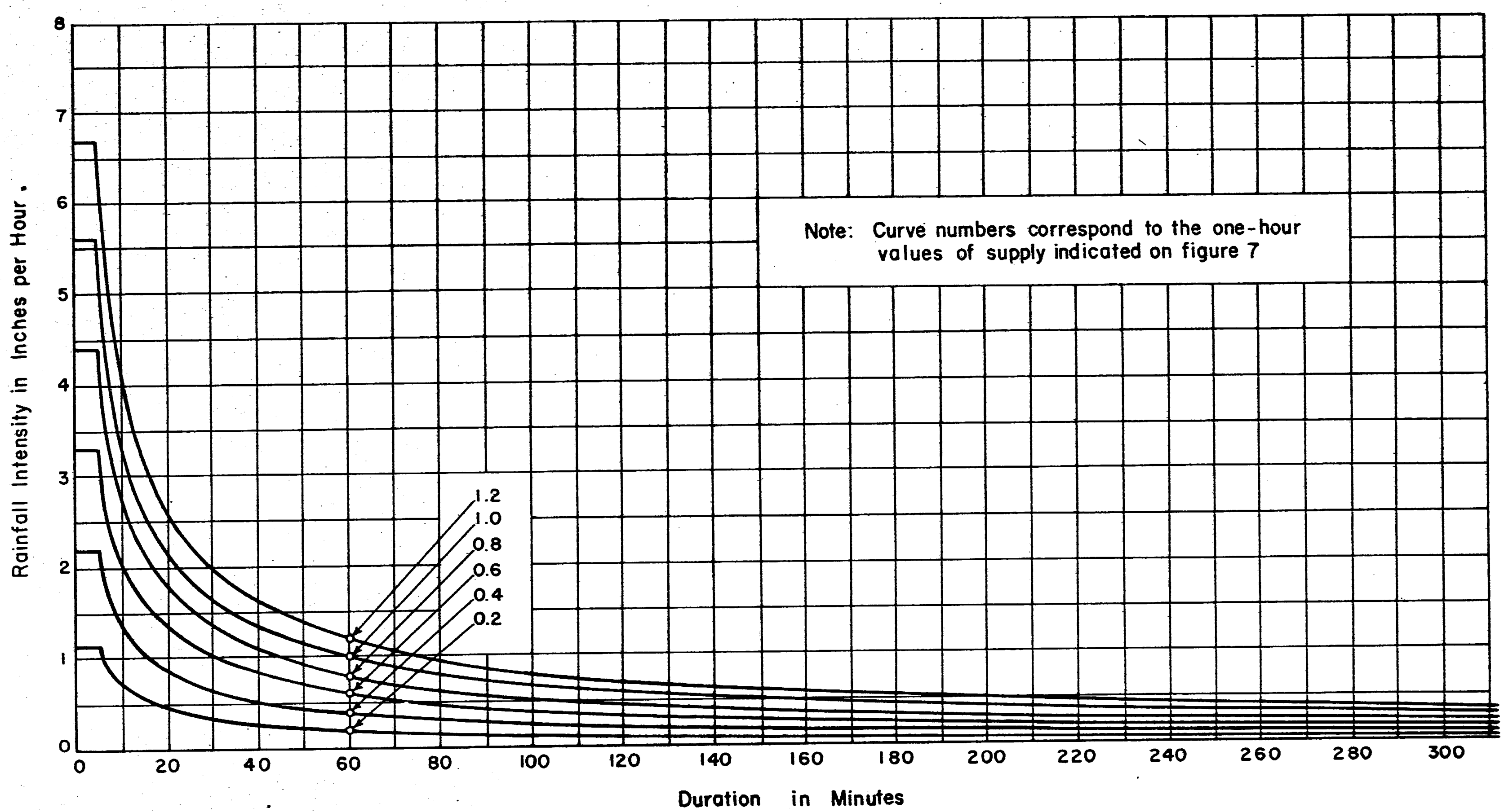
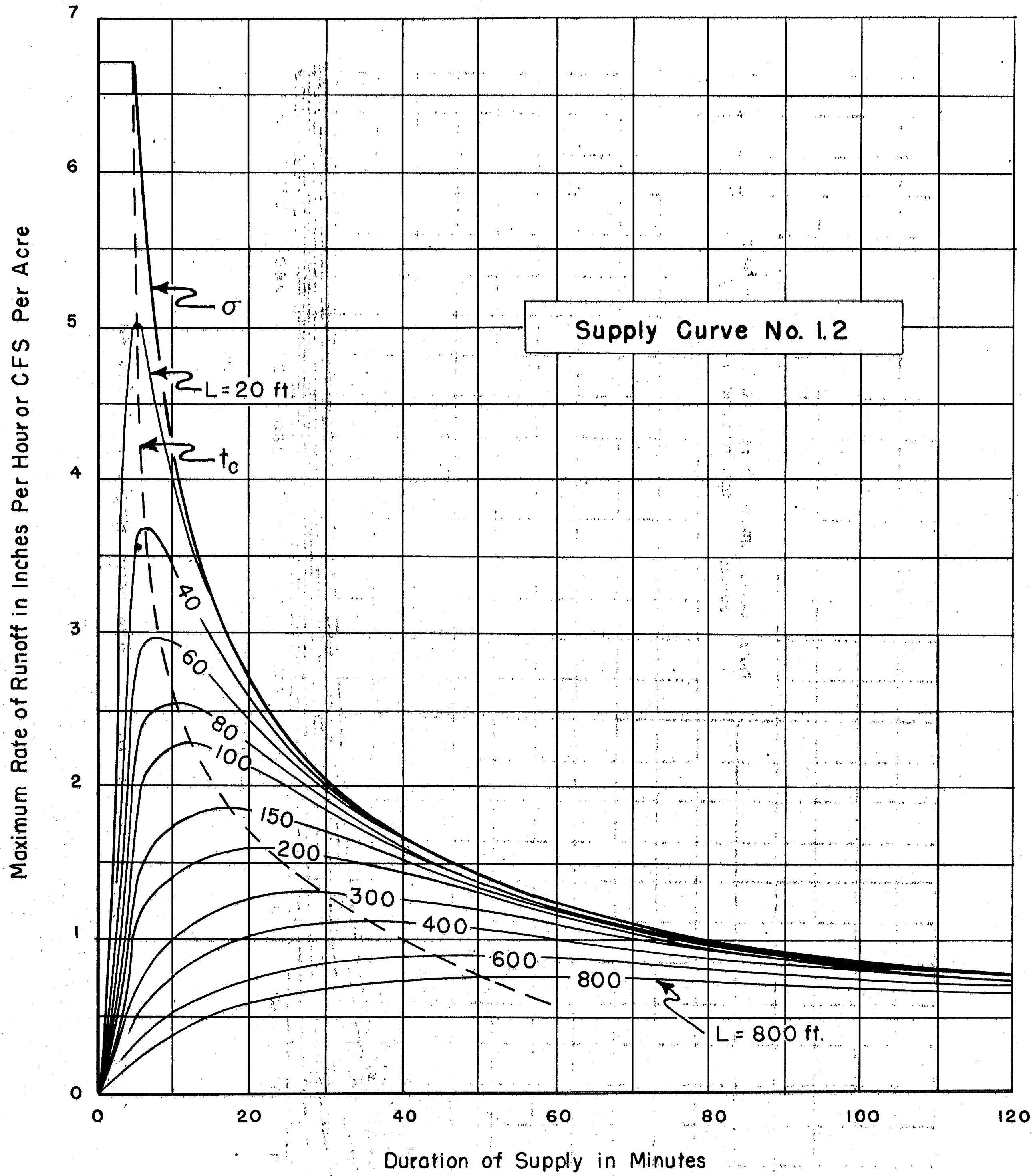


Fig. 8 – Supply Curves for Arctic and Subarctic Regions of Alaska



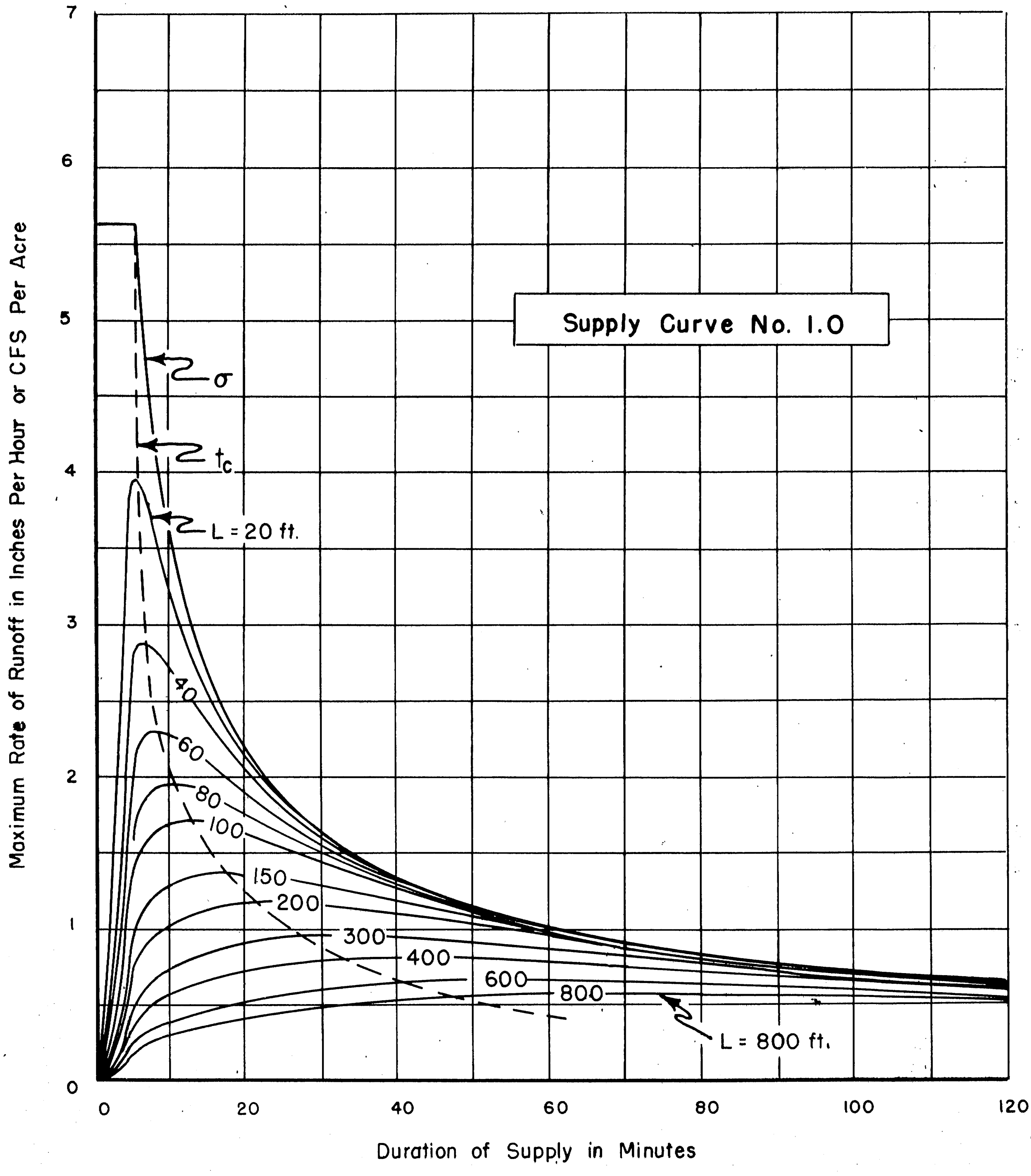
L = Effective Length in Feet

σ = Rate of Supply in Inches per Hour

t_c = Critical Time of Runoff in Minutes

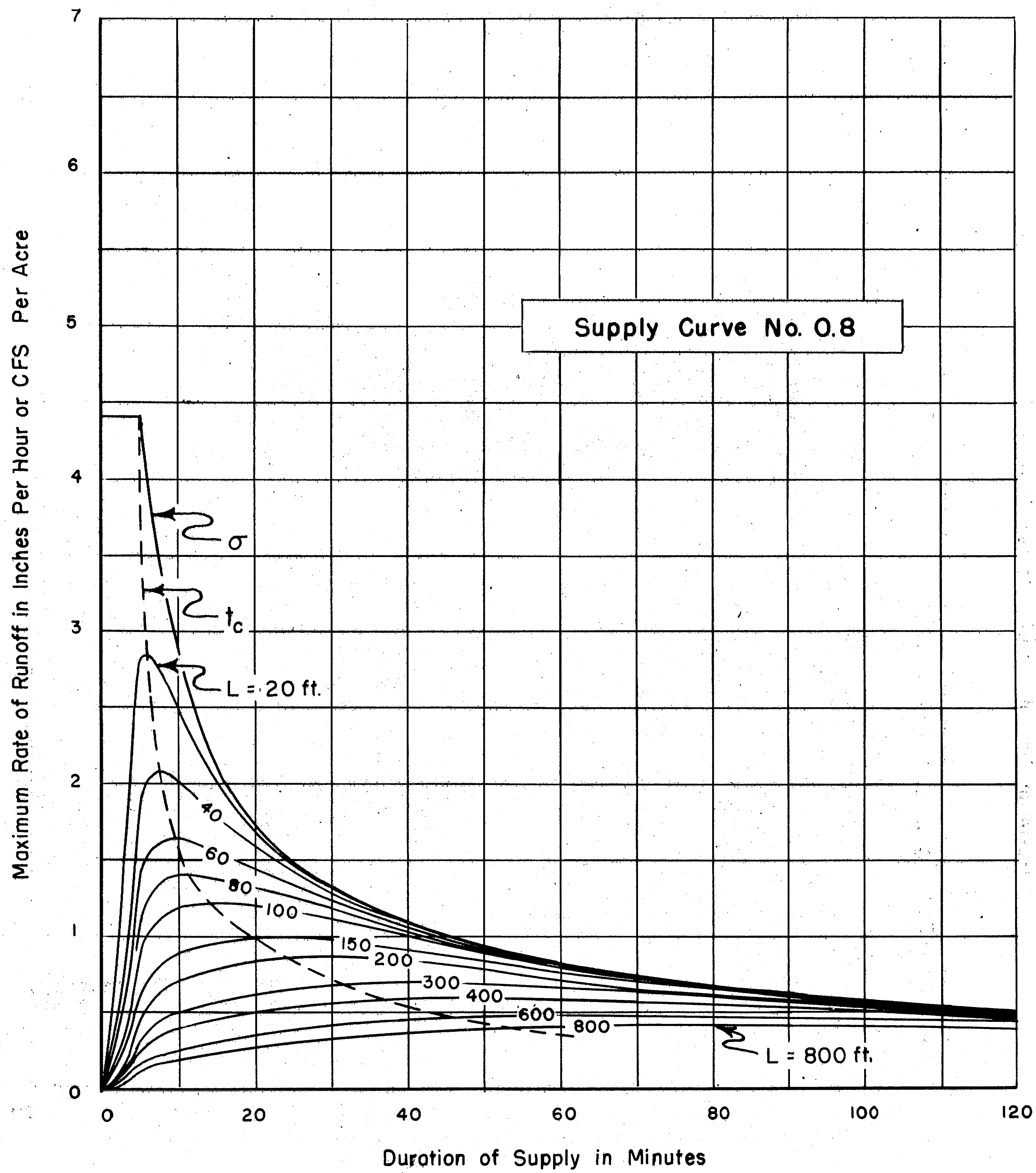
n = 0.40 S = 1%

Fig. 9 - Rates of Overland Flow for Supply Curve No. 1.2



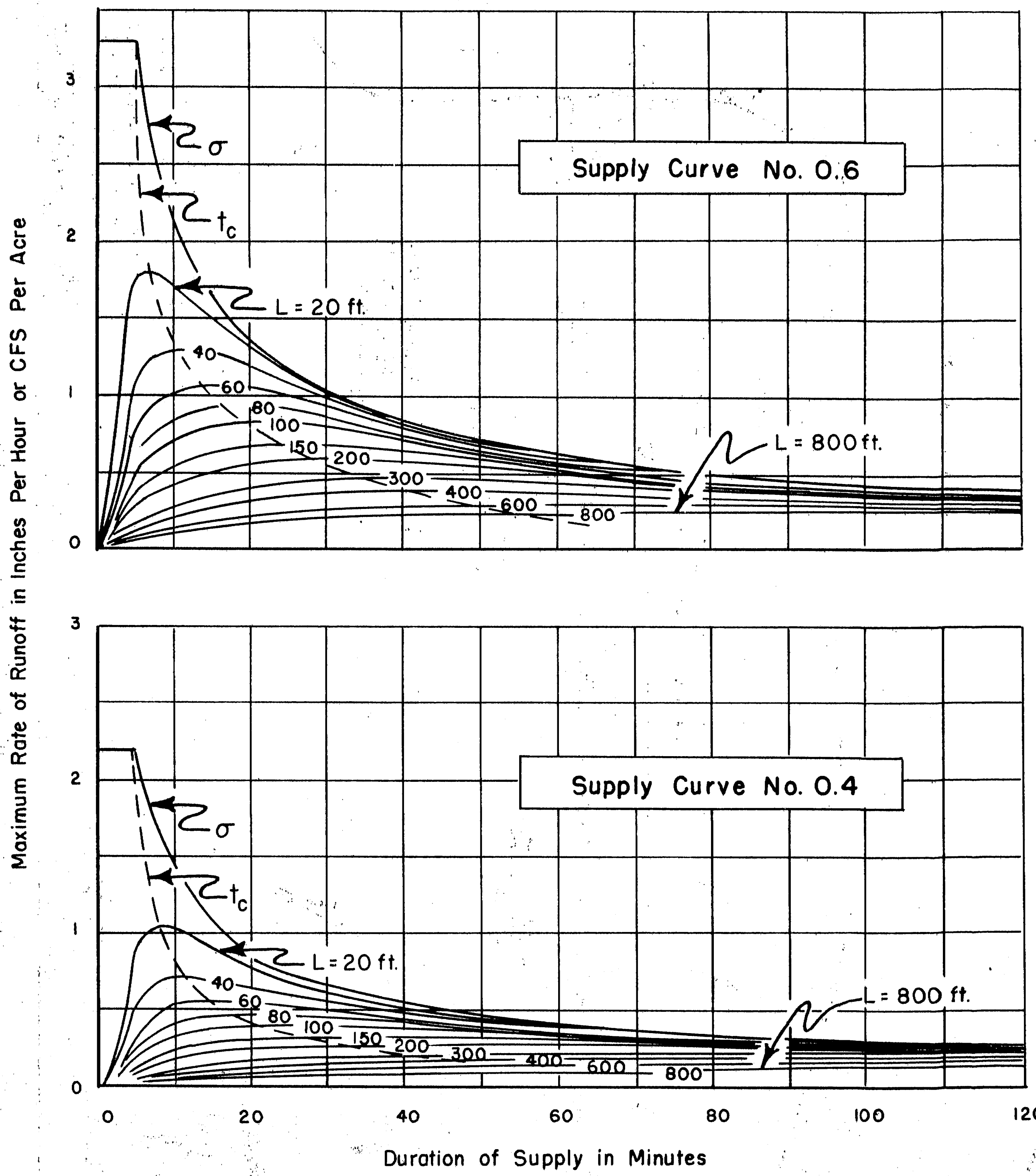
L = Effective Length in Feet
σ = Rate of Supply in Inches per Hour
t_c = Critical Time of Runoff in Minutes
n = 0.40 S = 1 %

Fig. 10 - Rates of Overland Flow for Supply Curve No. 1.0



L = Effective Length in Feet
σ = Rate of Supply in Inches per Hour
t_c = Critical Time of Runoff in Minutes
n = 0.40 S = 1 %

Fig. 11 - Rates of Overland Flow for Supply Curve No. 0.8



L = Effective Length in Feet
σ = Rate of Supply in Inches per Hour.
t_c = Critical Time of Runoff in Minutes
n = 0.40 S = 1 %

Fig. 12 - Rates of Overland Flow for Supply Curves Nos. 0.6 and 0.4

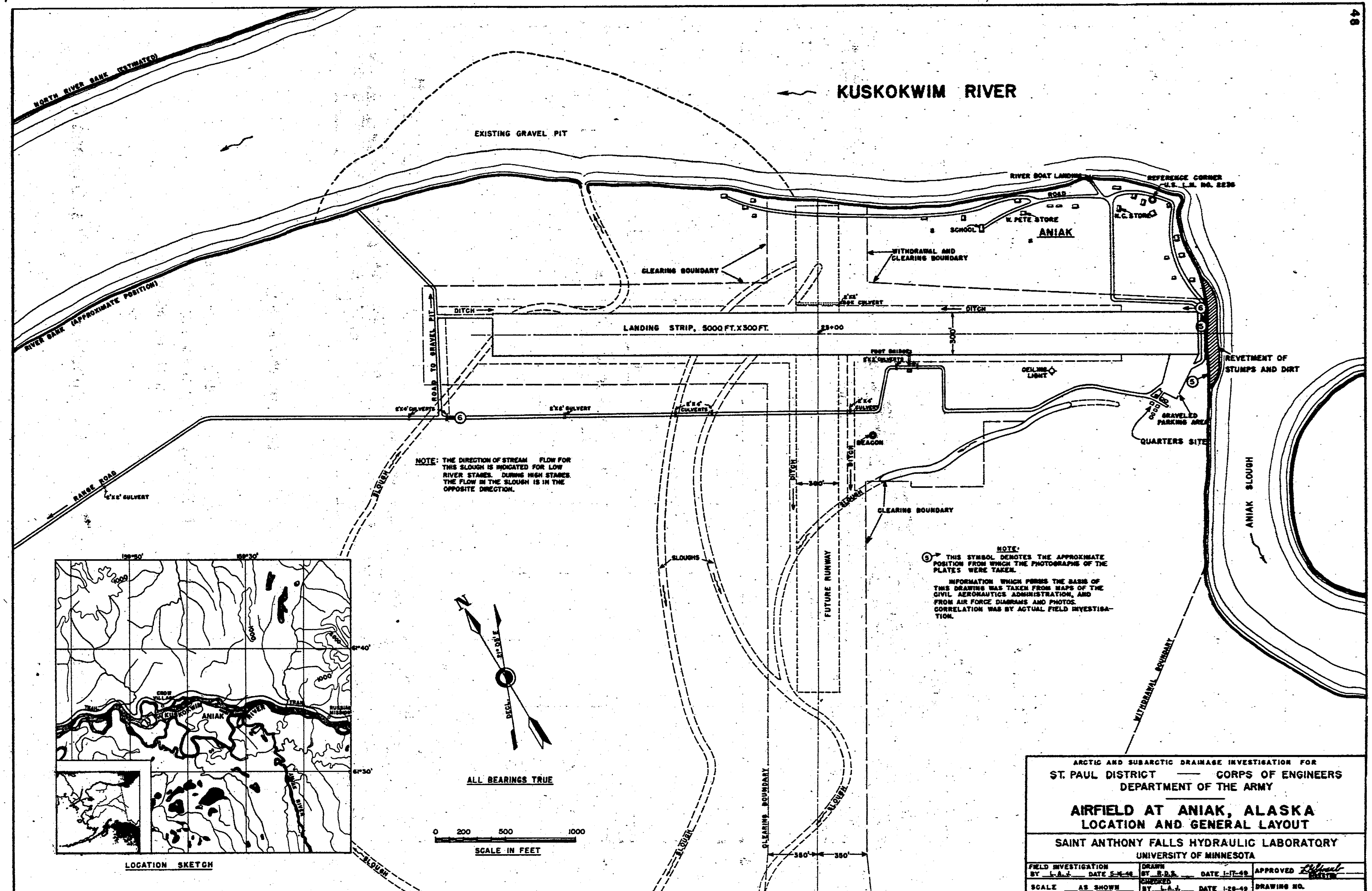


Fig. 13 — Airfield at Aniak, Alaska

V. FIELD OBSERVATIONS

27. General. The brief descriptive accounts that follow under specific name headings summarize actual observations made in the field during the month of May 1948. Included also under each heading are overall results of many discussions with employees of the Civil Aeronautics Administration and private air transport companies, as well as with local Alaskans. The investigator's views and beliefs which are made on the basis of the reconnaissance are indicated. For convenience, the investigations have been rearranged from the order of actual field work to an alphabetical arrangement.

A. Aniak (Investigation conducted May 16, 1948)

28. Description. Aniak is a small village located on the south bank of the Kuskokwim River in southwestern Alaska. Figure 13 shows general characteristics and layout at this point. Previous reports of the Corps of Engineers indicate that grass forms the predominant surface cover and this overlies about 5 ft of silt which overlies sand to depths of 20 ft or more. Photographs indicate brush and a sparse growth of trees in the vicinity. A Civil Aeronautics Administration airfield, consisting of one gravel-surfaced runway 300 ft wide and 5000 ft long is situated adjacent to and south of the village. The east end of the runway is approximately 25 ft above ordinary river stages.

29. Drainage System. The airport drainage system at Aniak for surface waters consists of shallow open ditches, one on either side of the runway. The ditch on the north side of the runway slopes to the west and discharges into a slough which is connected to the Kuskokwim River. During the time of high river stages there is considerable flow of water in the sloughs. At the time of the investigation there was evidence that the range road had been overtopped because of inadequate culvert capacity (photograph on Plate 6). Surface waters flow directly from the runway down very flat bank slopes into the shallow side ditches without the use of collecting inlets. There was no evidence of serious erosion, which indicates that rains are of light intensity.

30. Views of Civil Aeronautics Administration Maintenance Personnel. Mr. C. A. Crawley, Maintenance Technician in Charge of this airport for the Civil Aeronautics Administration, stated that to his knowledge capacities of existing drainage facilities were adequate and had never been overtaxed from runoff resulting from excessive rainfall. It was his belief that melting snow required the larger capacity. He strongly emphasized the hazard of springtime

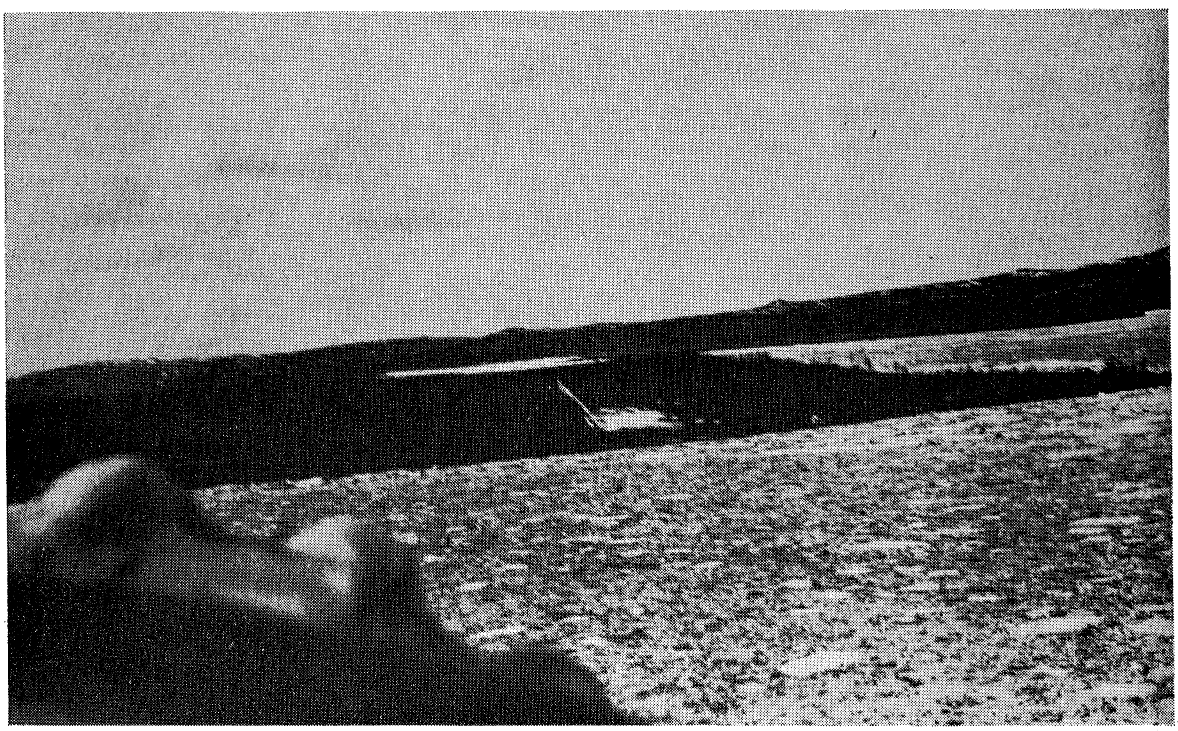
river floods caused by ice jams. It was claimed that this was an annual occurrence and that often it was necessary to evacuate women and children. Mr. Crawley pointed out that it was not uncommon for river stages to rise 25 ft or more as a result of ice jams.

31. Flood Conditions. At the time of the investigation, the river stage was within 2 ft of the runway elevation and had been higher. This is indicated by the photographs on Plate 4. At 3:30 p.m. May 16, eight P-51 fighter planes of the 57th Fighter Group bombed the ice jam with rockets. This action resulted in little relief and waters continued to rise. By 8:00 a.m. May 17, water was 2 ft deep at the Civil Aeronautics Administration control building, and overtopped the east end of the runway, causing a large discharge to the south and west across the strip. Considerable erosive damage resulted to the south bank slopes and many large cakes of ice were stranded on the runway. The Fighter Group returned equipped with 500-pound bombs with a delayed action fuse. More positive results were obtained and conditions started to improve about one hour after the bombing. At 11:00 p.m. May 17, the water level had subsided more than 6 ft.

32. Verification of Design Criteria. Calculations using the new design criteria were made to verify culvert capacity of the structure located on the north side of the runway opposite station 25 + 00. One of the photographs on Plate 6 indicates the type of drainage area which is estimated to contain 30 acres, including 9.3 acres of gravel-surfaced runway. In general, the ground surface is relatively bare, with patches of sparse grass growth occupying probably 40 per cent of the area outside the runway. The ground surface is nearly flat with no perceptible slopes in any direction. Assuming that at some future date the runway may be surfaced with an impervious layer of zero infiltration capacity, and estimating 0.2 in. per hr infiltration for the remainder of the area, computations using the new design criteria indicate a flow of less than 12 cfs at the site of the culvert. In other words, on the basis of the new design criteria this existing drainage facility is of adequate capacity, a view which was corroborated by statements of local maintenance men.

33. Subsurface Drainage. There is no drainage system for subsurface waters at Aniak. At this location the logical supposition would be that ground water was not a critical problem. It is expected that in the pervious subsoil the ground water fluctuations lag, but follow deviations in river stages. Consequently, the regulation of ground water elevations at this site is dependent on flood control of the Kuskokwim River.

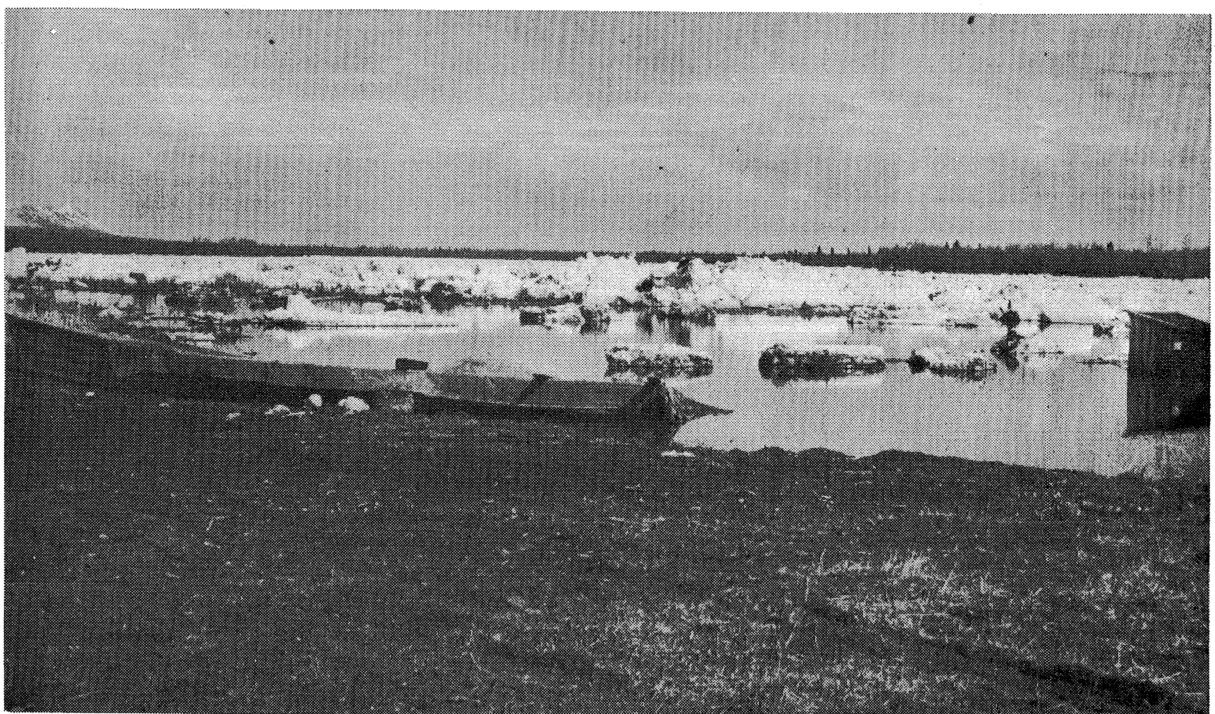
The fall from the upper to the lower end of this ice jam is about 25 ft.



Ice jams are annual springtime events near Aniak, Alaska.

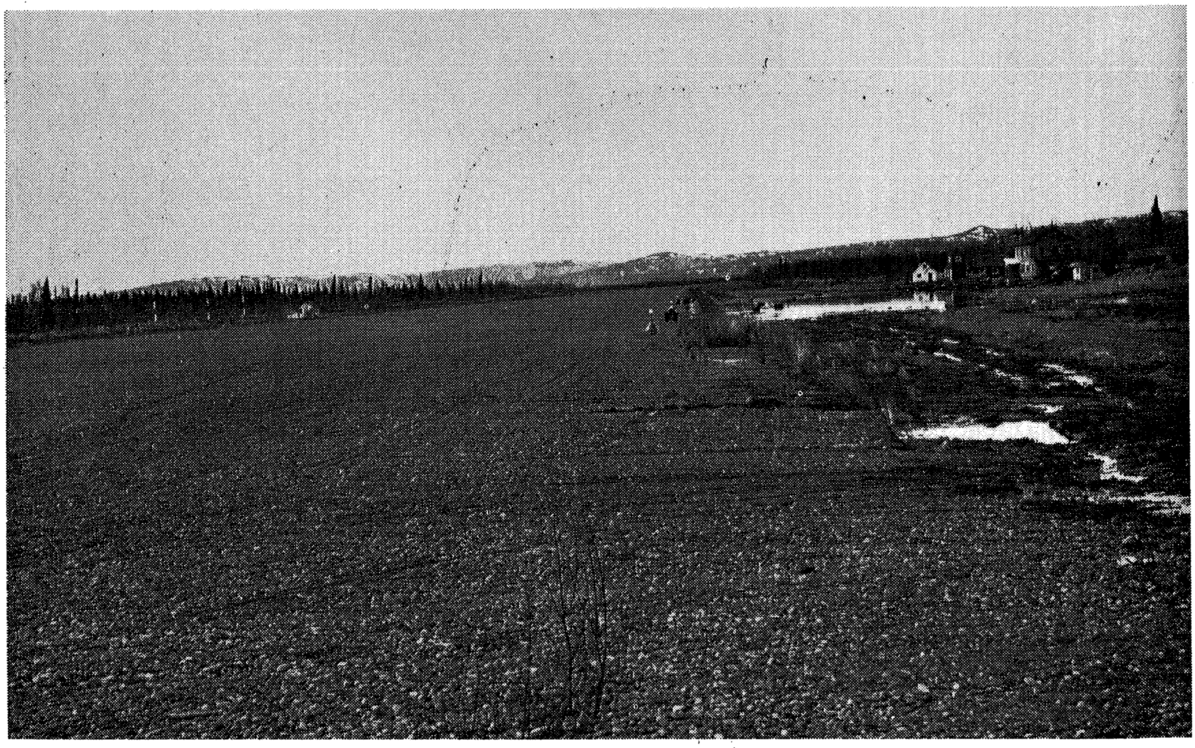
Plate No. 4 – Ice Jam in Kuskokwim River at Aniak

Large chunks of ice were noted on the east end of the runway on May 16, 1948.



The river stage on May 16, 1948 was 25 ft above the ordinary river level.

Plate No. 5 – Ice Jam in Kuskokwim River at Aniak



Looking west along the north shoulder of the runway..

High river stages of May 16, 1948 created a discharge which exceeded the culvert capacity of this site.

Plate No. 6 – Drainage Conditions at Aniak Airfield

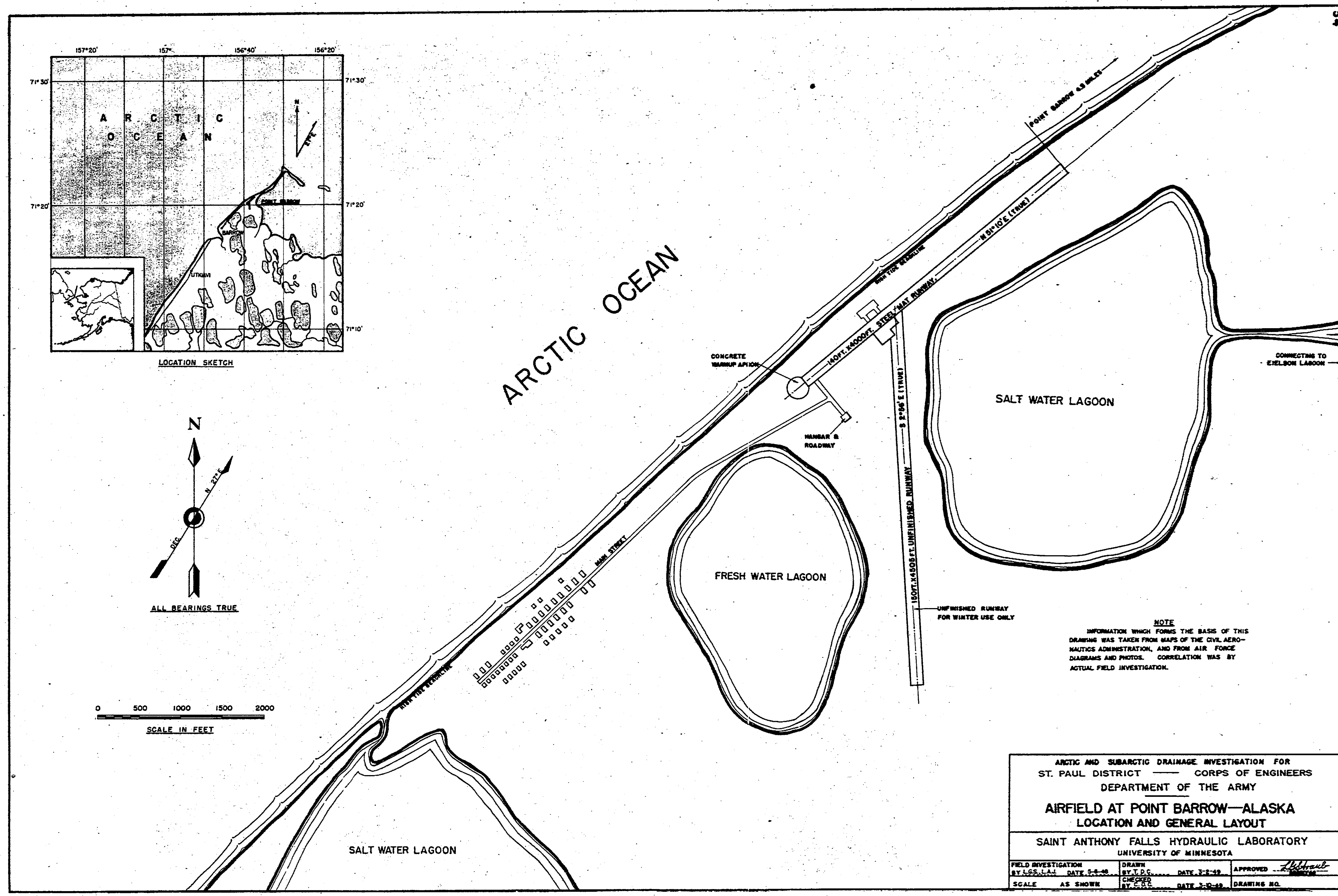


Fig. 14—Airfield at Point Barrow, Alaska

B. Barrow (Investigation conducted May 8, 1948)

34. Description. Barrow is a small village located at 71° 23' north latitude and 156° 17' west longitude. Three miles to the northeast along the Arctic Ocean coast is a Navy research establishment including an airport, the runway of which is 140 ft wide and 4000 ft long. This runway is surfaced with pierced steel plank and gravel. Four miles farther to the northeast is the northernmost tip of Alaska called Point Barrow. Figure 14 indicates general characteristics in the vicinity. This drawing is preceded by two plates of photographs.

35. Extent of Investigation. The investigation at Barrow was limited to a reconnaissance survey, along with brief conferences with Lieutenant Commander L. P. Frate of the Navy and Mr. E. D. Spaulding, Project Superintendent for the contractors, Lytle and Green.

36. Local Drainage Conditions. The establishment at Barrow is ideally situated from a drainage standpoint and is, therefore, not typical of general arctic conditions. It was pointed out that the infiltration capacity of the pervious soil was many times greater than the intensity of rainfall, and that melting snow also disappeared without causing a drainage problem. To verify this statement, Mr. Spaulding showed the investigating party that the drainage outlet from wash basins in the barracks was no more than a pipe which discharged freely onto the ground surface beneath the barracks. Water discharged via this system quickly infiltrates into the ground and has caused no trouble.

37. Local Views Regarding Design. Both Lieutenant Commander Frate and Mr. Spaulding concurred with the view that the drainage systems in the polar arctic regions should be shallow ditches with very flat side slopes. It is preferred also that these ditches be of such shape and dimension as would permit the use of heavy snow-moving machinery.

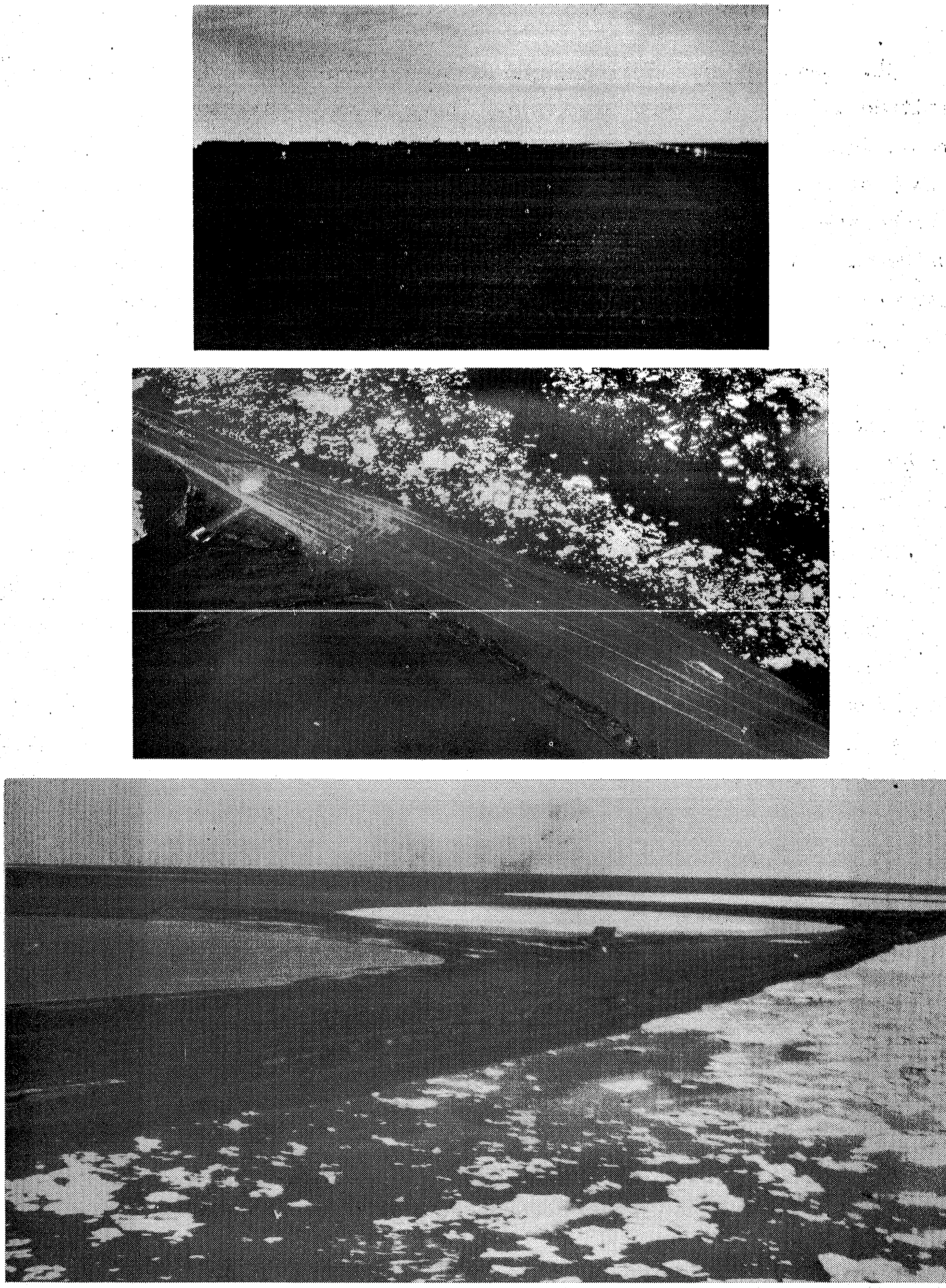


Plate No. 7 — Airfield at Barrow, Alaska

Scenes near the southwest end of the runway.

Drainage at Barrow is largely by infiltration into a pervious soil.

Plate No. 8 – Springtime Scenes at Barrow in 1948

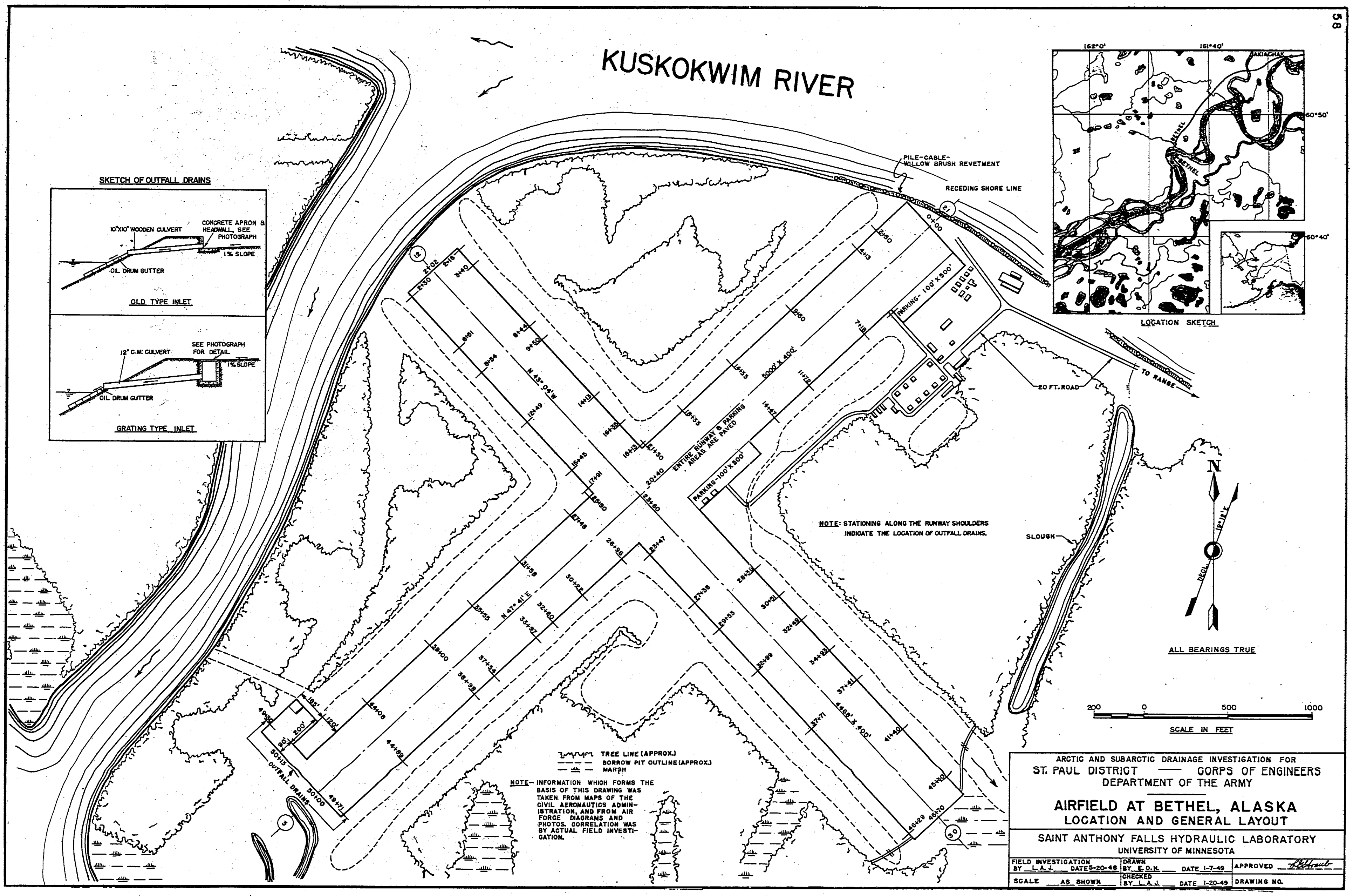


Fig. 15 — Airfield at Bethel, Alaska

C. Bethel (Investigation conducted May 15-18, 1948)

38. Description. The village of Bethel is located on the northwest bank of the Kuskokwim River in southwestern Alaska. The population which is mostly native totals about 300. Principal buildings are a government hospital, government school, several stores, a roadhouse, and a Moravian Mission. There are two airports in the vicinity, one a short landing strip just west of the village and the other a Civil Aeronautics Administration field on the opposite side of the river. Figure 15 shows general characteristics of the Civil Aeronautics Administration field. Plates 9 to 14 show photographs of several points of interest. The descriptive captions to these pictures indicate the significance of each specific scene.

The Civil Aeronautics Administration airport is located between sloughs in the alluvial deposit of the flood plain of the Kuskokwim River. It is subject to springtime river floods due to ice jams. Soil and subsoil consist of sandy silt which is extremely sensitive to erosive action of flowing water. Permafrost does not exist in this alluvial plain. In the higher and sandy terrace region, the permanently frozen soil begins within 2 or 3 ft of the ground surface. Numerous thaw sinks of varying size, some filled with water, others dry, are dispersed throughout the surface area of the terrace.

39. Outfall Drainage Structures. At the time of the investigation a project to remodel outfall drainage structures was under way. Plate 10 indicates the type of structure that is in the process of being replaced. The new design is indicated in Fig. 15 and also shown on Plate 10 by photograph 2. Mr. G. Howard, Resident Engineer for the Civil Aeronautics Administration, explained that the old type of drainage structure was unsatisfactory because of high maintenance requirements. It was reported that leakage along the outside periphery of the conduit and eventual washout could not be prevented. The resident engineer spoke in favor of the second type and pointed out that from the standpoint of discharge capacity, a structure with one-half the hydraulic dimensions would be adequate. Yet in consideration of all conditions, he thought the size indicated was a practical solution. Another maintenance difficulty has to do with actual stability of structures from a frost heaving standpoint. Mr. Howard reported that he had often observed that outlet structures do not always remain at the low point, but apparently shift in relative elevation from year to year. Sometimes this heaving and settling action is

sufficiently severe to actually create a change in grades, an increase or decrease in drainage area, and a new unprotected outlet. The result, of course, is a washout of the runway embankment. Obviously, this heaving and settling condition cannot be overcome by a change in design of drainage outlet structures. A properly planned subdrainage system if feasible from a river level standpoint, would improve the situation, as would a subgrade of coarser materials. Actual installation costs of either plan would probably be prohibitive.

40. Drainage of the Municipal Airfield. Drainage of the local strip is entirely via the surface and shallow ditches along either side of the runway. Mr. P. MacDonald, pilot for Jones Airways, stated that they experienced but little difficulty from a drainage standpoint, and that in the spring of the year. The local field is unsurfaced and located on a sand terrace in which permafrost exists from 2 to 3 ft beneath the surface. There is a considerable variance in runway elevation from one end to the other, which is no doubt one reason for adequacy of surface drainage.

41. Drainage in the Village. Drainage in the village of Bethel is entirely by a system of open ditches. The ditches vary in depth from 1 to 4 ft and are very narrow. There is much evidence of sloughing of the sides. Reverend F. Grebert of the Moravian Mission and a resident of Bethel for many years reported that extreme rains make just a trickle down the spade-width ditches. This view was confirmed by another long-time resident, Mr. Ole A. Hofseth, and also by Mr. Charles W. Guinn, owner of the Guinn General Store and resident of Bethel for the last 10 years. It was the opinion of these and other local Alaskans that melting snow would create larger surface runoff.

42. Verification of Design Criteria. Verification of design criteria was attempted by comparing the capacity of existing drainage structures with a computed discharge for the specific location. If grades and slopes can be arranged in such manner that drainage outfall structures are located near one end of the watershed area, facilities of the type indicated by the photographs on Plate 10 should have a maximum spacing of 300 ft. Existing structures have no definite spacing, as some were located to meet newly developed low points, the result of uneven heaving and settling of the grade. Mr. Howard of the Civil Aeronautics Administration stated that as far as he knew, no drainage structure had as yet been taxed to capacity, although he had noted difficulty from washouts. He attributed the cause of the washouts to leakage along the

outside periphery of the conduit. The drainage inlet with the largest watershed area is located at the west end of the eastern parking area. This structure is unlike the others as it has a larger capacity and can operate under a head, above the grating, of at least 1 ft without undue ponding. Design criteria indicate a required capacity of 7 cfs at this point. It is estimated that the existing structure would pass this amount without undesirable flooding.

As a general conclusion, it appears that application of the new design criteria at Bethel would result in structures of slightly larger capacities than can be obtained by existing facilities. Yet the agreement is good and much like what would be anticipated.

43. Floods of the Kuskokwim River. Spring floods of the Kuskokwim River at Bethel are not uncommon. Summer floods have never occurred, according to residents who have lived in the territory for as long as 50 to 60 years. The springtime high water is due to ice jams and takes place nearly every year. The most severe year was reported to be 1911, with 1946 a close second. Photographs on Plate 13 indicate the condition in 1946. At this time the water elevation was 9.7 ft higher than the river stage during the time of the investigation. The Civil Aeronautics Administration airport was entirely inundated and operating personnel were forced to evacuate.

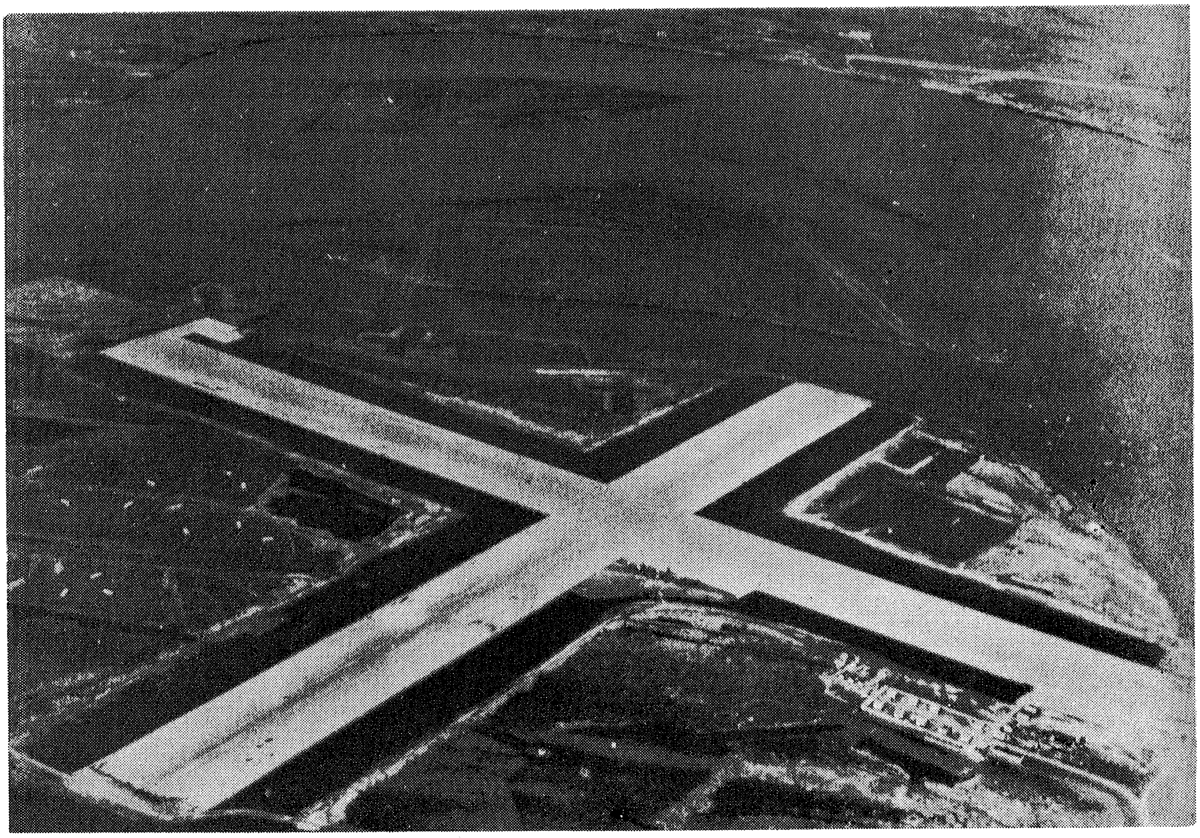
At 10:00 a.m. May 18, 1948, the 57th Fighter Group bombed an ice jam which was forming in the river just below Bethel. The river stage had risen 1.6 ft in 2 or 3 hours. This was 24 hours later than the time of river peaking at Aniak. After the bombing, Major King of the 57th Fighter Group emphasized that ice jams with consequent damaging floods could be controlled by bombing and that in his three years of experience there had never been a failure.

44. Difficulties Caused by Erosion. Floods caused by ice jams in the Kuskokwim River are looked upon with a great deal of apprehension by members of the Civil Aeronautics Administration operating staff at Bethel. They cannot help but dread the thought that the river, during flood stages, may gain access to the borrow pits and, in so doing, create by erosive action a "slough" in the existing runway areas. Bank erosion, particularly on the east side, is extremely severe. The revetment of piling, cable, and willow brush requires constant maintenance and even then does not give adequate protection.

Across the river on the village side, another form of erosion takes place. Here, by action of tides and waves, the permafrost is thawed which in turn results in sloughing of the banks. This action removes about 20 ft of bank each year and every so often all buildings must be moved back to new locations. In 1939 all buildings were moved back several hundred feet. Since that time about 300 ft of river bank has disappeared. A peninsula shown in one of the photographs on Plate 14 vanished since 1913. It is impossible to maintain any type of dock or wharf.

River bank erosion at Bethel is indirectly caused by thawing permafrost.

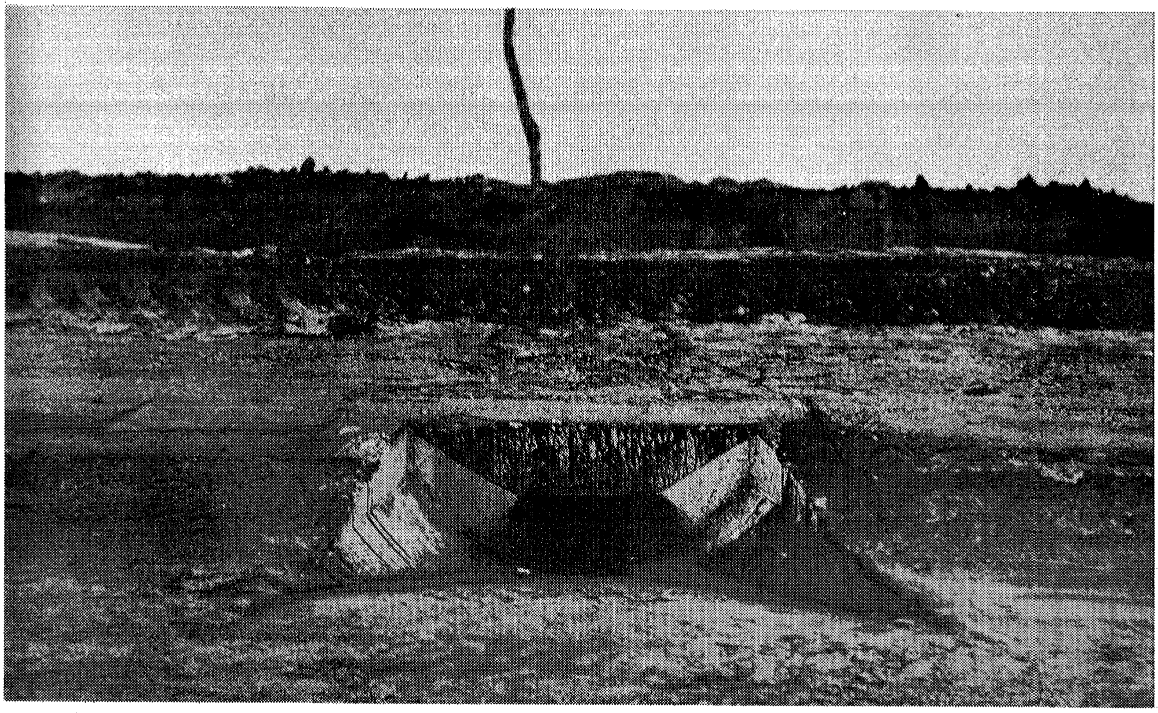
Plate No. 9—River Bank Erosion at Bethel, Alaska



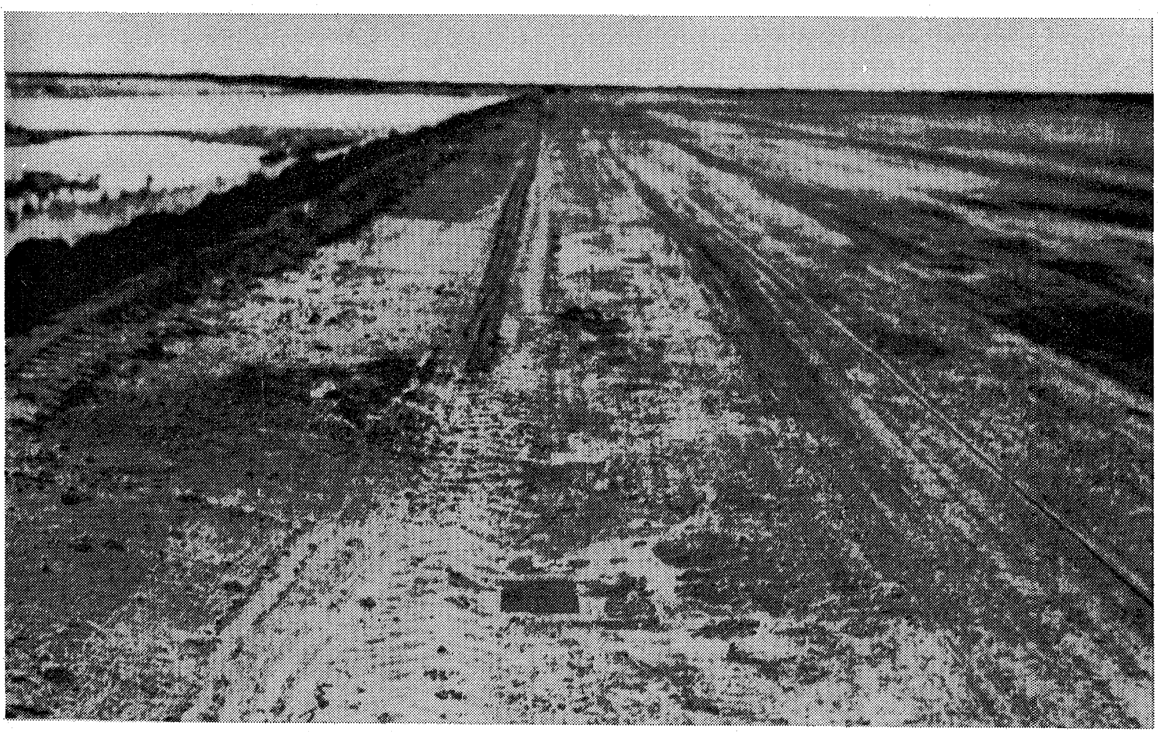
The airfield at Bethel is inundated quite often due to ice jams in the Kuskokwim River.

The area west of Bethel is studded with many cave-in lakes.

Plate No 10 - Aerial Views of Airfield and Terrain near Bethel, Alaska

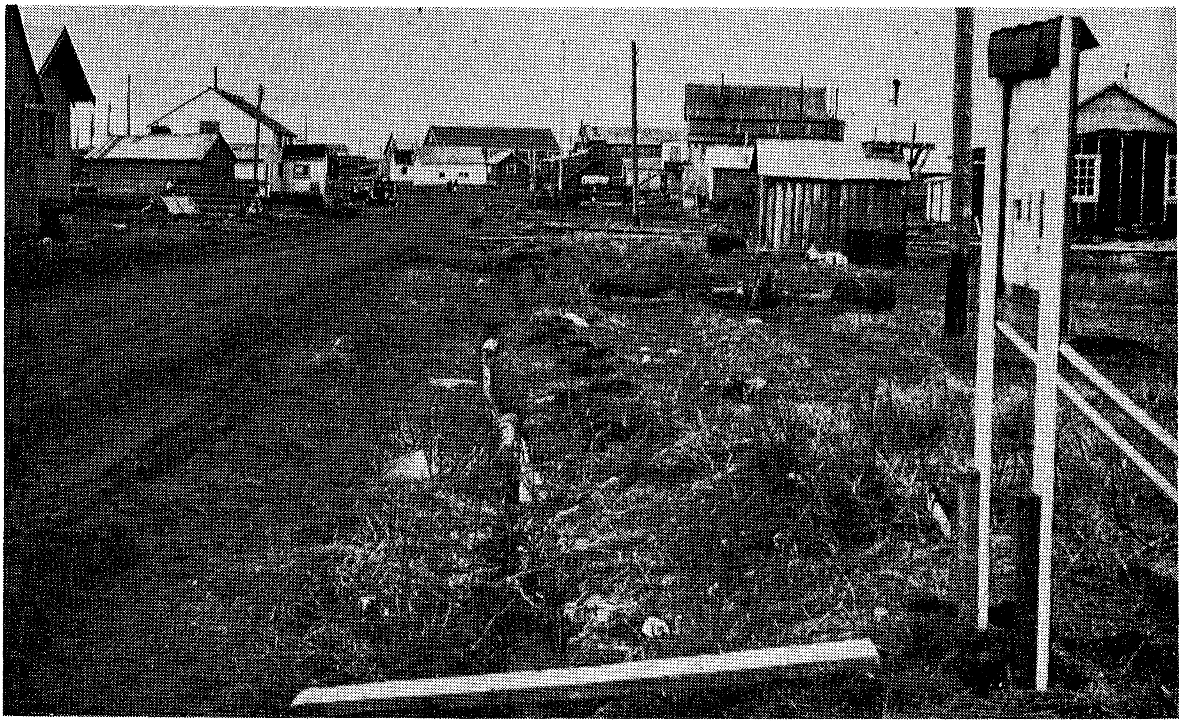


This type of drainage inlet structure has not been satisfactory.



The new type of inlet structure operates satisfactorily, according to airfield maintenance personnel.

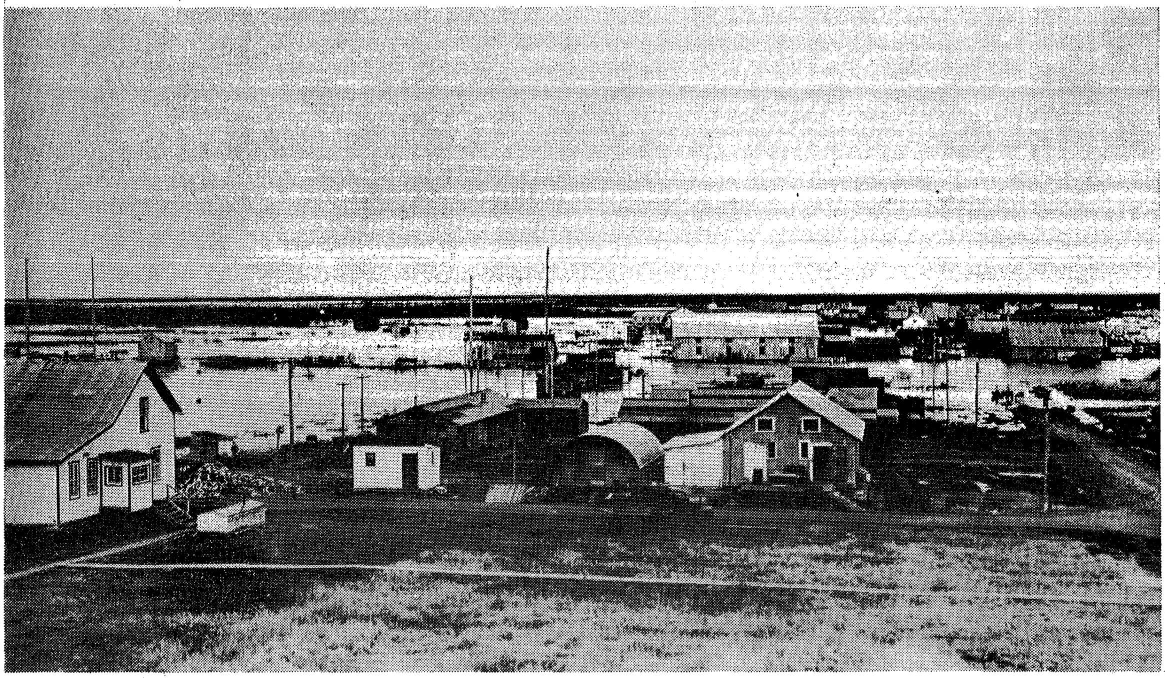
Plate No. 11 — Drainage Outfall Structures at Bethel Airfield



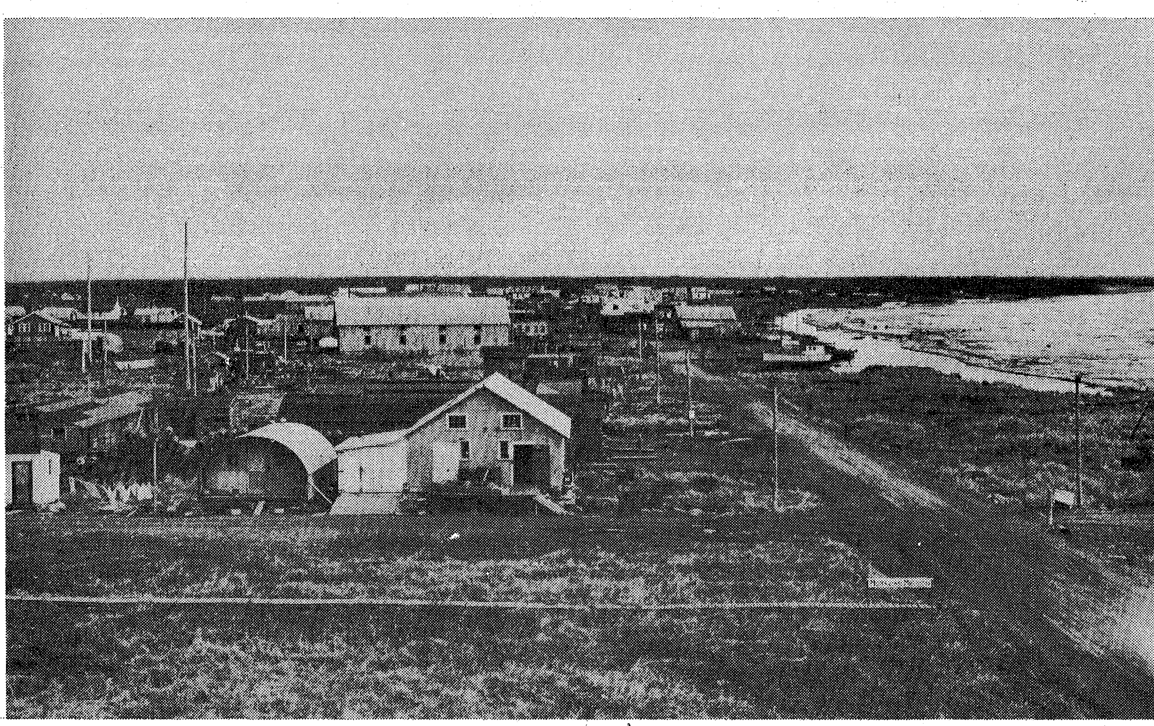
Ditches the width of a spade convey surface runoff in the village.

Narrow ditches are very difficult to maintain and are not recommended for areas where it is impossible to keep the ground frozen.

Plate No.12 — Drainage Conditions at Bethel

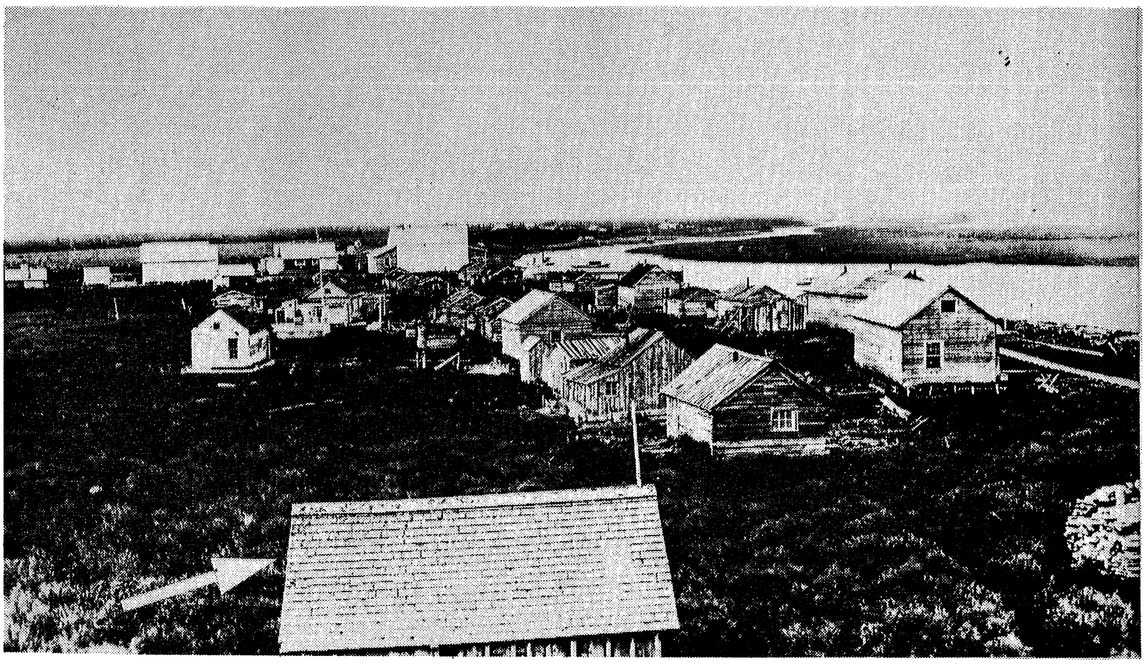


The ice-jam flood of 1946, as shown above, represents the highest river stage since 1911. The water is 9.7 ft higher than indicated in the picture below.



View of Bethel from the tower of the Moravian Church, May 17, 1948.

Plate No.13 — Flood of 1946 and Contrasting Scene at Bethel



Before 1913, the date of the above picture, river bank erosion was not serious. A large peninsula protected the north bank from prevailing winds and high waves.

This picture, taken of the same area May 17, 1948, shows a marked change in conditions. The arrows in the top and bottom photographs point to the same building.

Plate No. 14 — Contrasting River Conditions at Bethel

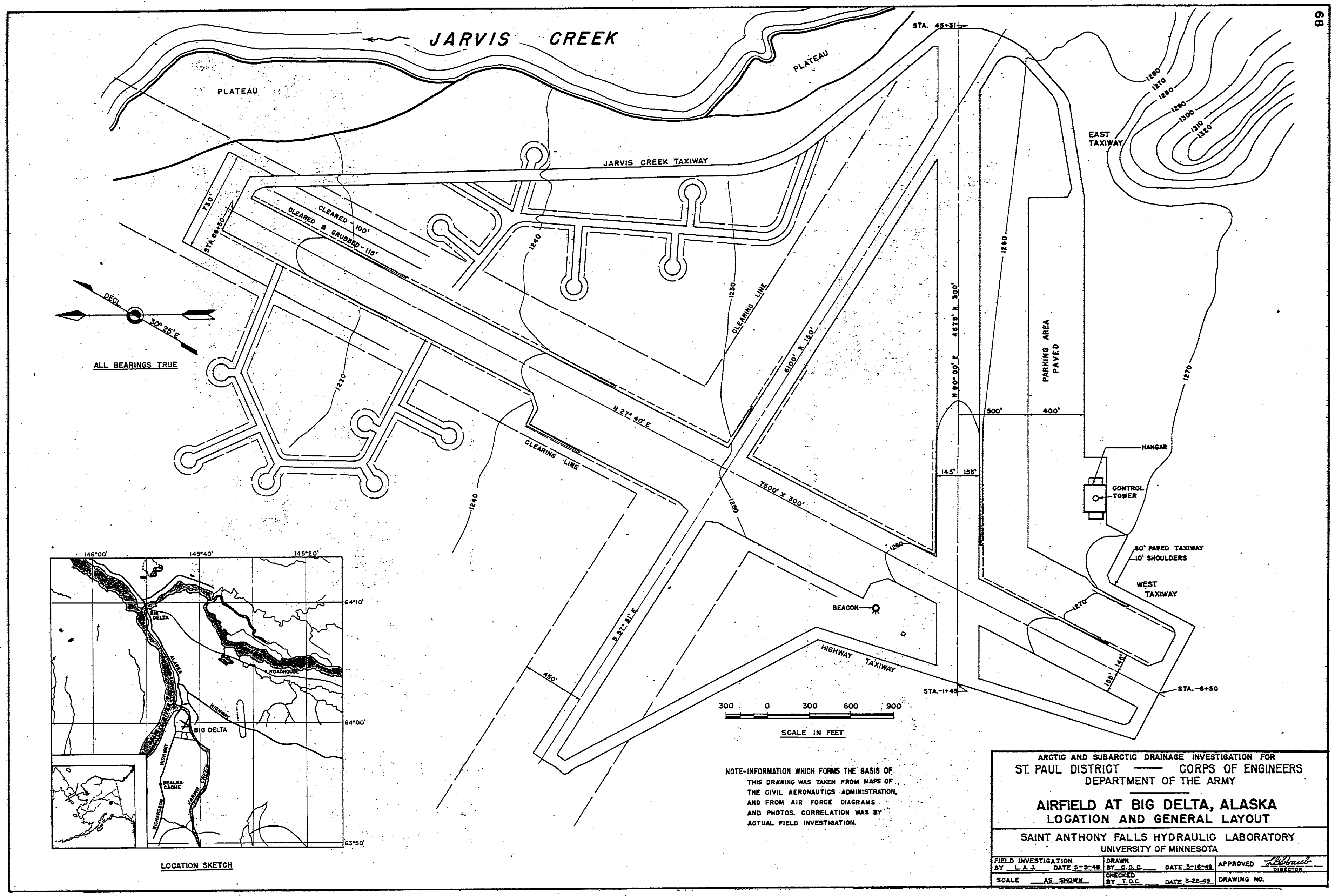


Fig. 16 — Airfield at Big Delta, Alaska

D. Big Delta (Investigation conducted May 5, 1948)

45. Description. Big Delta Airfield is located southeast of Fairbanks near the junction of the Alaska and Richardson Highways at 64° 00' north latitude and 145° 44' west longitude. Soil conditions at this site are very pervious, with borings indicating material ranging from a silty and sandy loam at the surface to sand, gravel, and boulders at greater depths. Permafrost does not exist at this location, according to Corps of Engineers' data. A short distance to the northwest, the Jarvis River flowing in a northerly and westerly direction forms a confluence with the Big Delta River. This latter river also flows in a northerly direction and is one of the largest tributaries of the Tanana River.

46. Extent of Investigation. The investigation at this site was limited to one day. It was anticipated that a more detailed survey could be made sometime later in the summer. A general perspective of layout and location of the airport is indicated in Fig. 16.

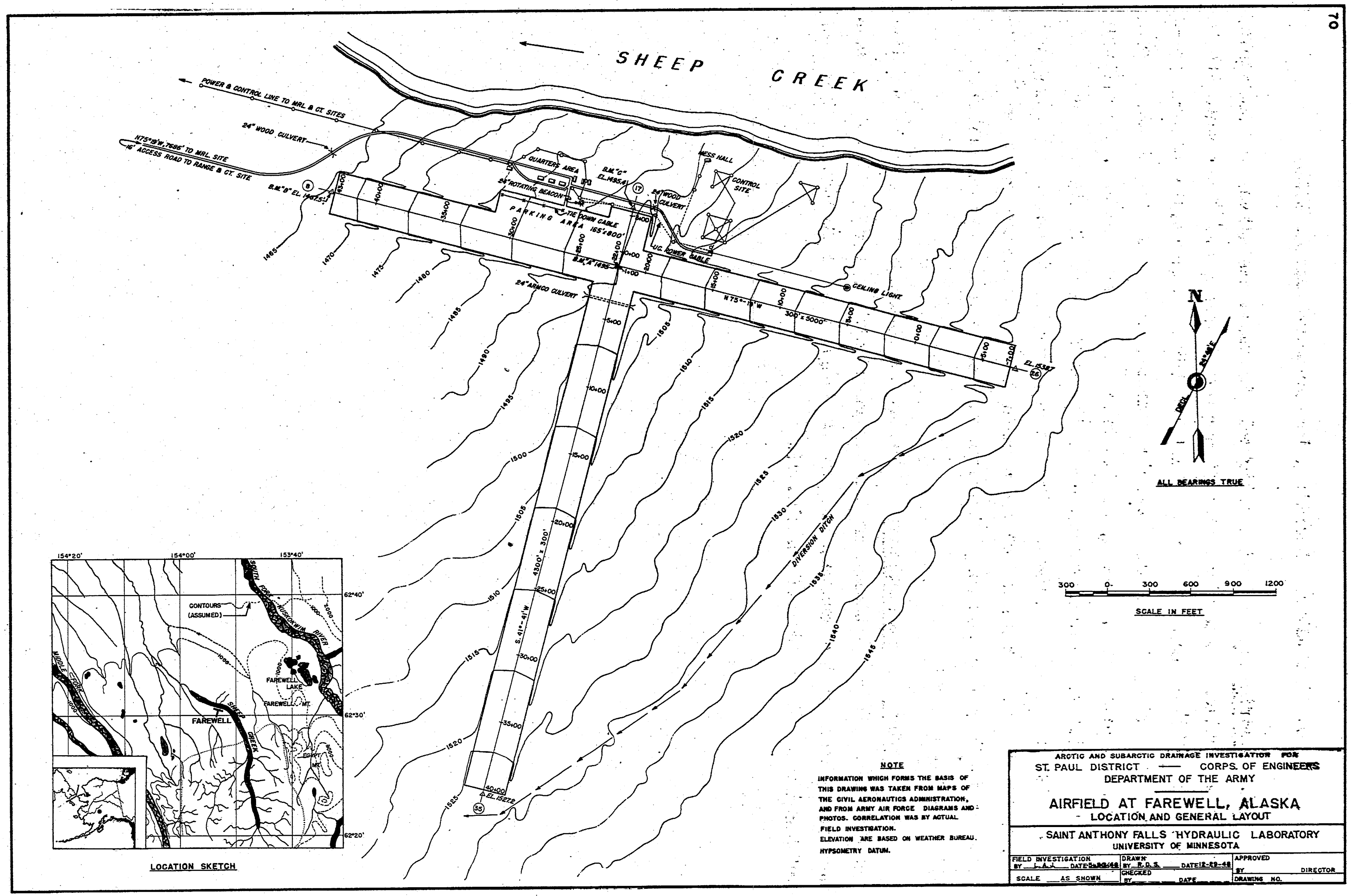


Fig. 17 — Airfield at Farewell, Alaska

E. Farewell (Investigation conducted May 19, 1948)

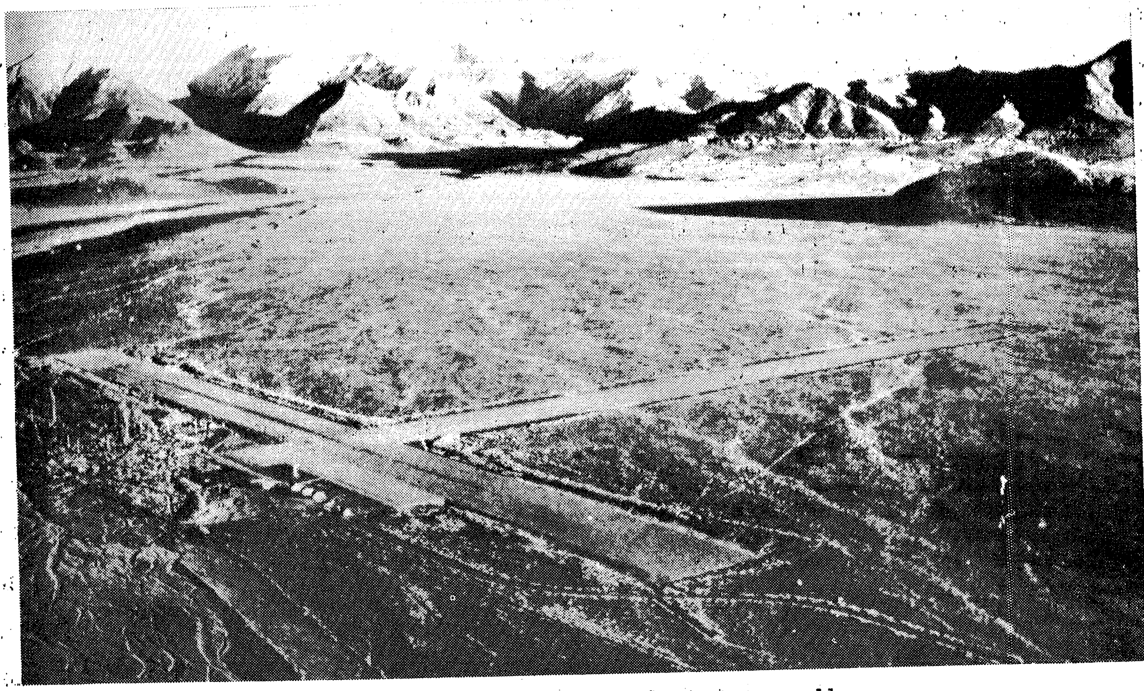
47. Description. A Civil Aeronautics Administration airport called Farewell is located on the south bank of Sheep Creek at 62° 30' north latitude and 153° 53' west longitude. The approximate altitude at this location is nearly 1600 ft above sea level. Farewell Mountain, some distance to the northeast, makes a conspicuous landmark. Figure 18 and Plates 15 and 16 indicate general layout and conditions at this location. The importance of this field is largely for emergency landings. The field consists of two gravel-surfaced runways each 300 ft wide and located at right angles to each other. One strip is 5000 ft long and the other is 4300 ft long.

The general terrain in the immediate vicinity of the field slopes sharply to the west. The east end of the east-west runway is 65 ft higher than the west end. The south end of the north-south runway is 30 ft higher than the north end. The slopes are very uniform. Surface features give the impression of an open prairie with an absence of trees and from a sparse to an average growth of grass. Soils are very coarse and appear to contain a large proportion of gravel. This does not explain a sort of soggy, spongy condition when the ground is very moist such as in the spring of the year. Mr. Robert Finn, Civil Aeronautics Administration mechanic for the airport, explained that for about one week each spring the field was too soft for a plane to land or take off.

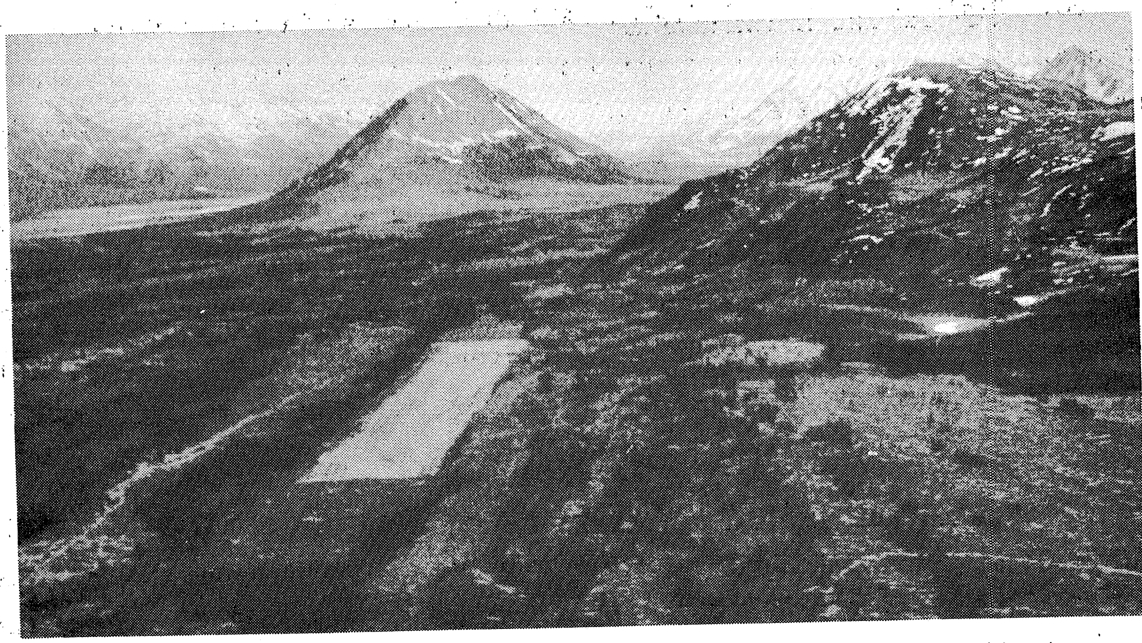
48. Drainage of the Airfield. All drainage is via the surface and open ditches. A diversion ditch intercepts surface runoff from the southeast and carries this around the south end of the north-south runway. Here the ditch terminates in a small natural swale. Surface runoff from the runways is handled by a system of shallow open ditches, one on either side of the runway. Mr. Carl Shiplett, Maintenance Technician in Charge for Civil Aeronautics Administration, and Mr. Finn stated that there was no drainage trouble from summer rains, but that each spring the culvert under the north-south runway overtopped because of water from melting snow. All other drainage facilities were of adequate size.

49. Analysis of Culvert Capacity. The culvert referred to is placed on a grade that is steeper than critical. Because of conditions at the outlet, this end of the pipe will not become submerged. Very little, if any, head can be permitted at the inlet end of the pipe because of the low runway

elevation at this point. The capacity of the 24-in. culvert under these circumstances is calculated to be 15 cfs. New design criteria indicate a required capacity of 30 cfs at this point. This assumes infiltration capacity of 0.4 in. per hr, which is not unreasonable for the pervious soil characteristics.



Looking southeast at the airfield at Farewell.



The terrain is very rugged in the vicinity of a local landing strip at Farewell Lake.

Plate No. 15 – Airfields near Farewell, Alaska

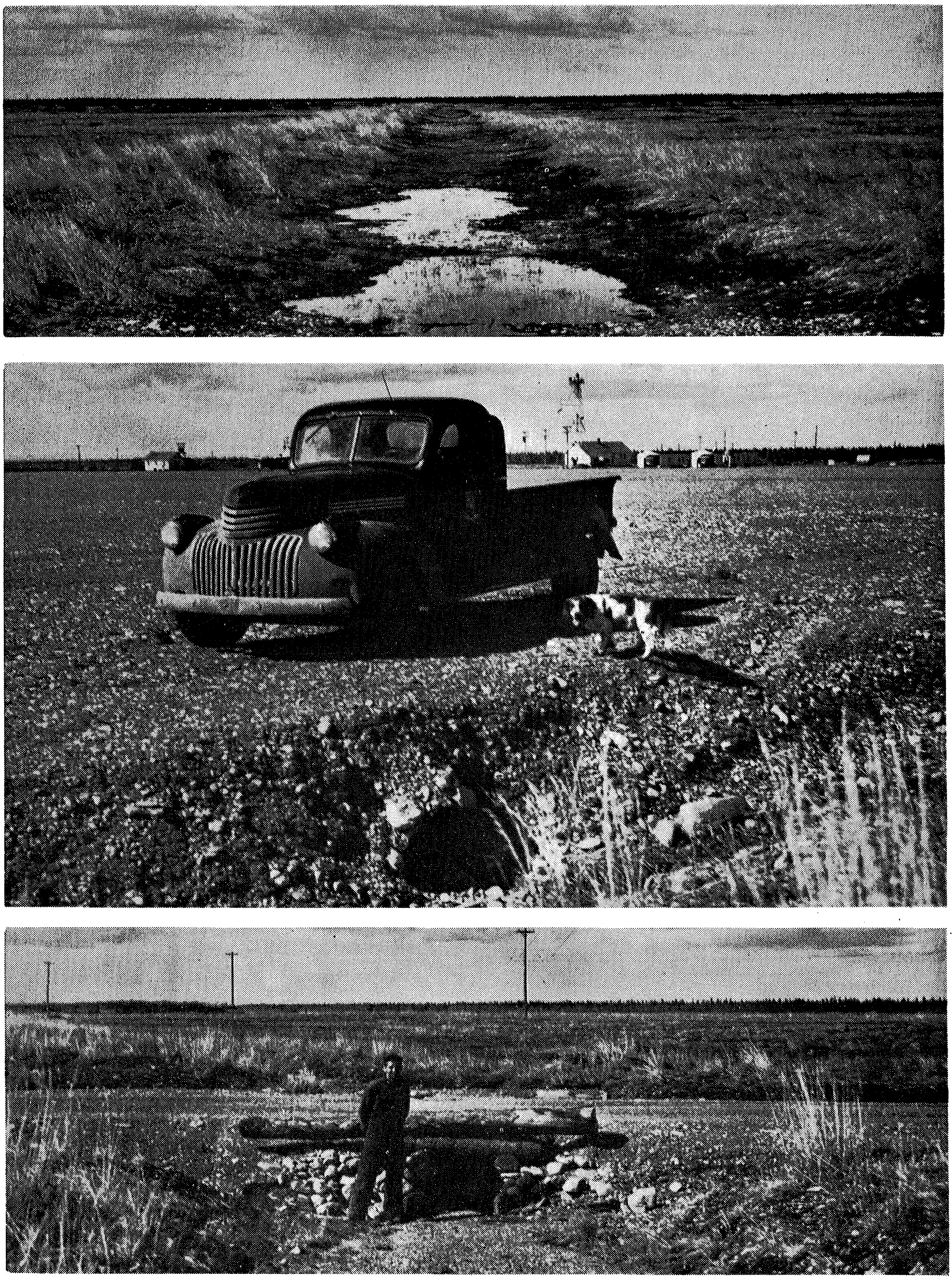


Plate No.16 – Drainage Facilities at Farewell Airfield

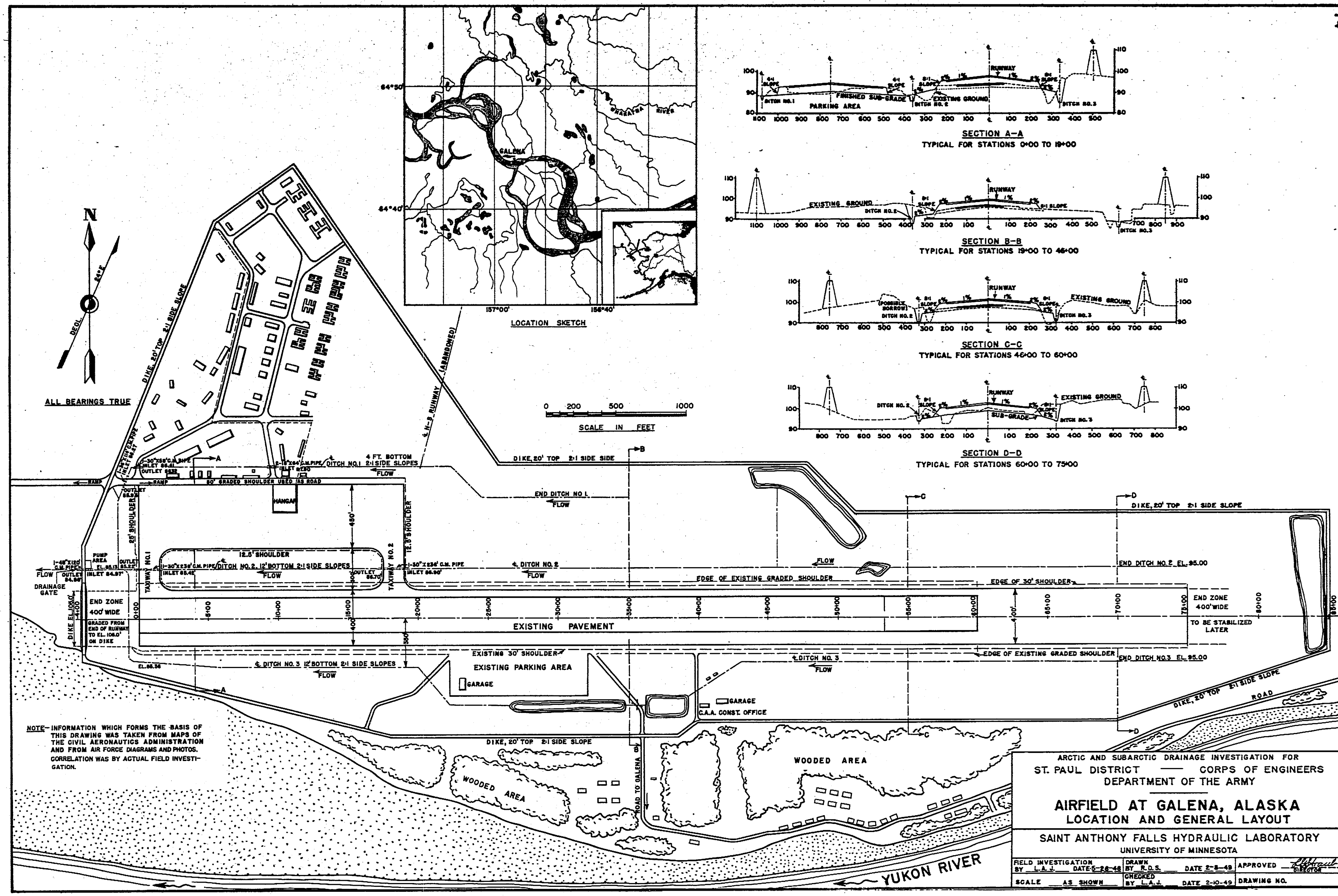


Fig. 18 — Airfield at Galena, Alaska

F. Galena (Investigation conducted May 26, 1948)

50. Description. The Civil Aeronautics Administration airfield at Galena is located on the north bank of the Yukon River at 64° 43' north latitude and 156° 41' west longitude. The asphalt-surfaced runway is 350 ft wide and can be extended in length from an existing 6000 ft to a maximum of 7500 ft. The soil and subsoil at this site are pervious and consist of sand and gravel. The airport site is entirely surrounded with a levee to prevent springtime river floods from inundating the site. Figure 18 and the photograph on Plate 17 indicate the general layout and other characteristics at this location.

51. Drainage of the Airfield. Surface drainage at the Galena airport is entirely by a system of open ditches as shown on the drawings. When Yukon River stages are high, the outlet to surface runoff from the area which is enclosed by dikes is by pumping. No pumping records were available.

52. Verification of Design Criteria. From data contained in Fig. 18, it is possible to compare the hydraulic capacities of existing drainage facilities with design capacities which are calculated on the basis of the new design criteria. The tabular data that follow indicate the results of computations. The number identification in the table refers to the facility location on Fig. 18.

TABLE VIII

CAPACITY OF CULVERTS AT GALENA

Culvert No. Shown on Fig. 18	Diameter in Inches	Length in Feet	Possible Hydraulic Grade ft/ft	Capacity cfs	Watershed Area Acres	Design* Discharge cfs
1	2 - 18	64	0.015	14.5	70	14
2	36	114	0.01	42.0	115	23
3	30	236	0.01	24.0	114	23
4	30	238	0.015	28.0	144	29
5	24	40	0.01	13.2	70	14
6	48	438	0.0016	34.0	137	27
7	48	126	0.01	85.0	410	82

*The design storm index indicates supply curve (1.0).
The soil is pervious. Assume infiltration equals 0.4 in. per hr.

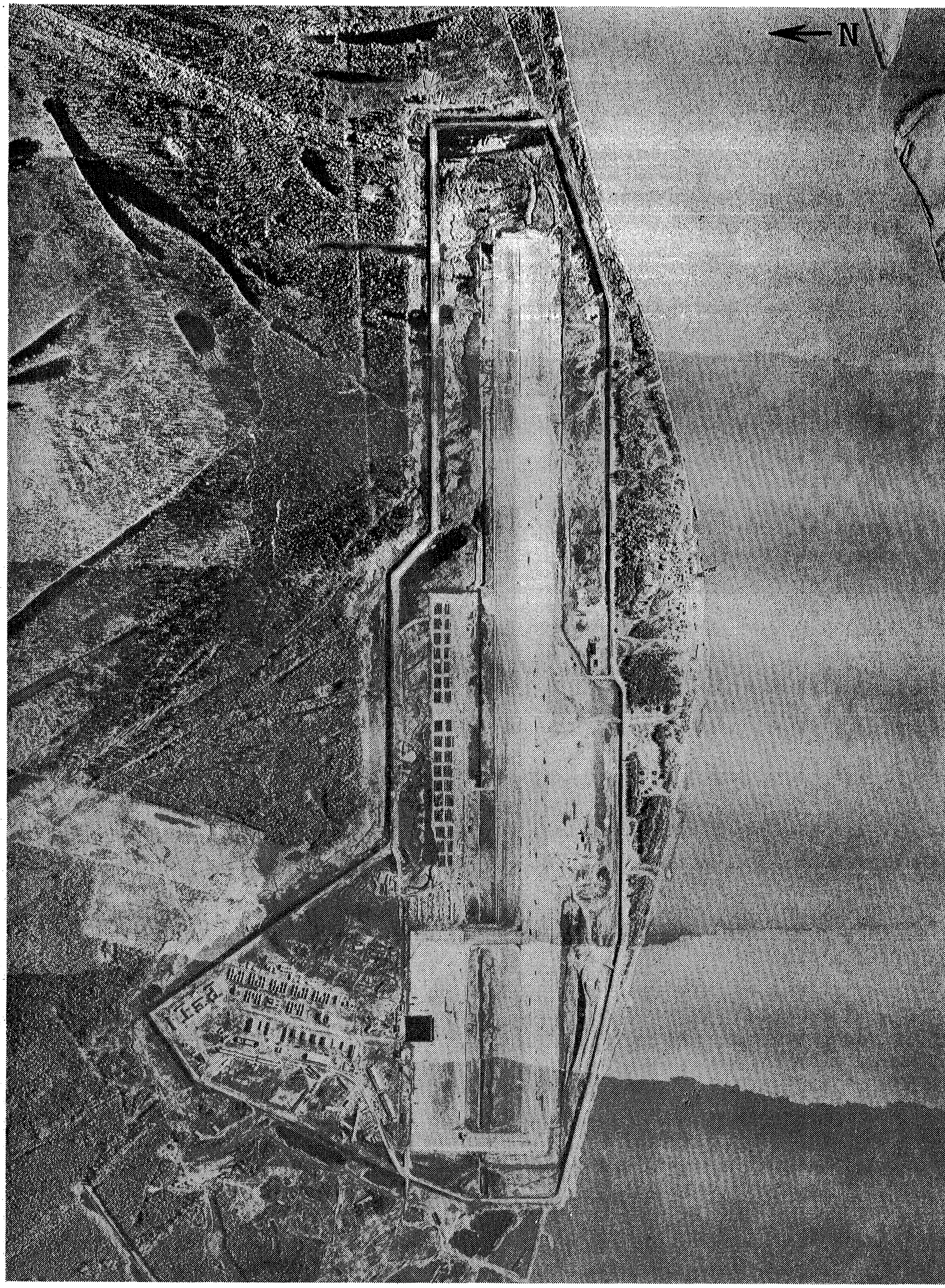


Plate No.17 — Airfield at Galena, Alaska

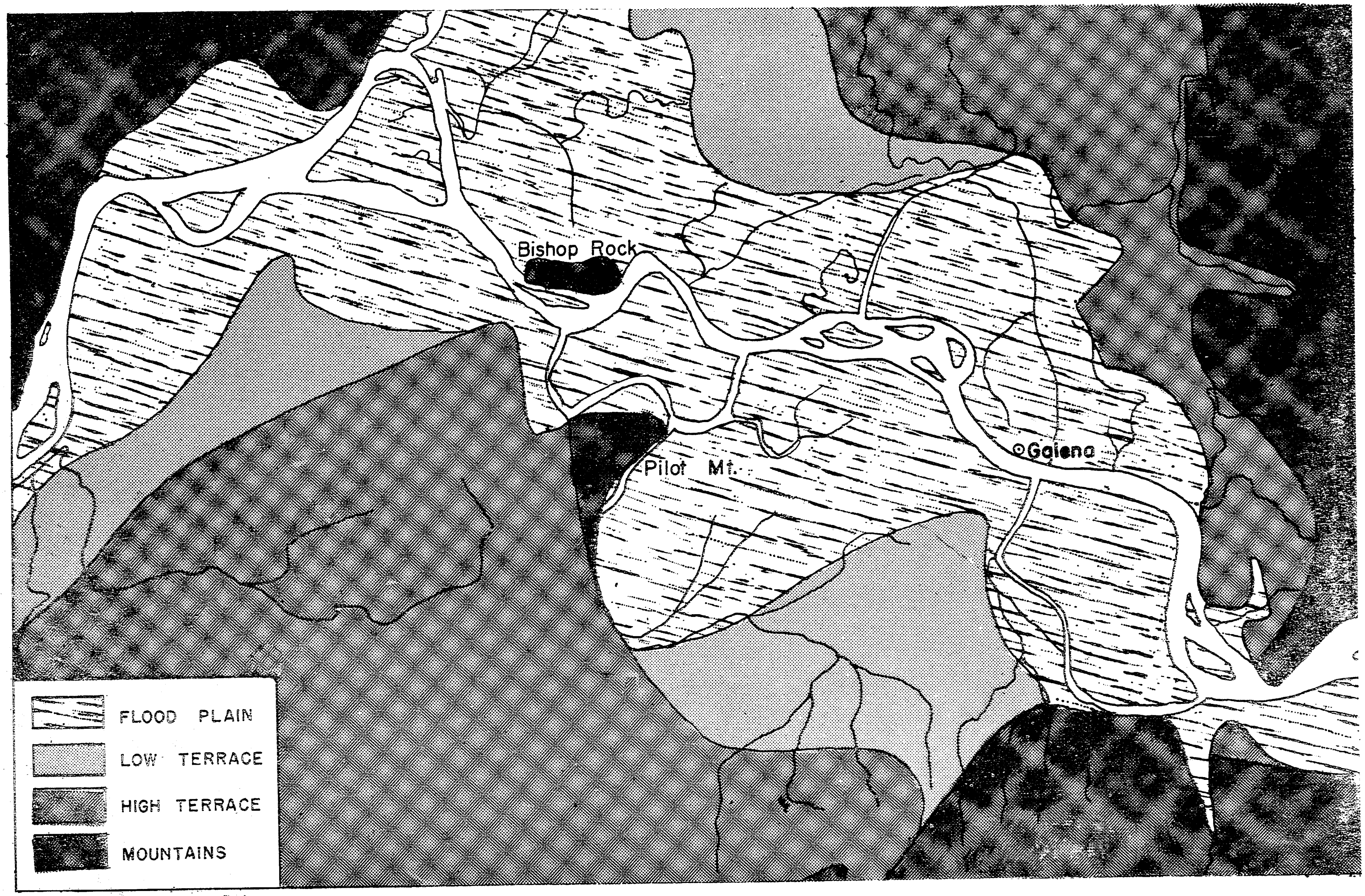


Fig. 19- Sketch Showing Terrain Near Galena, Alaska

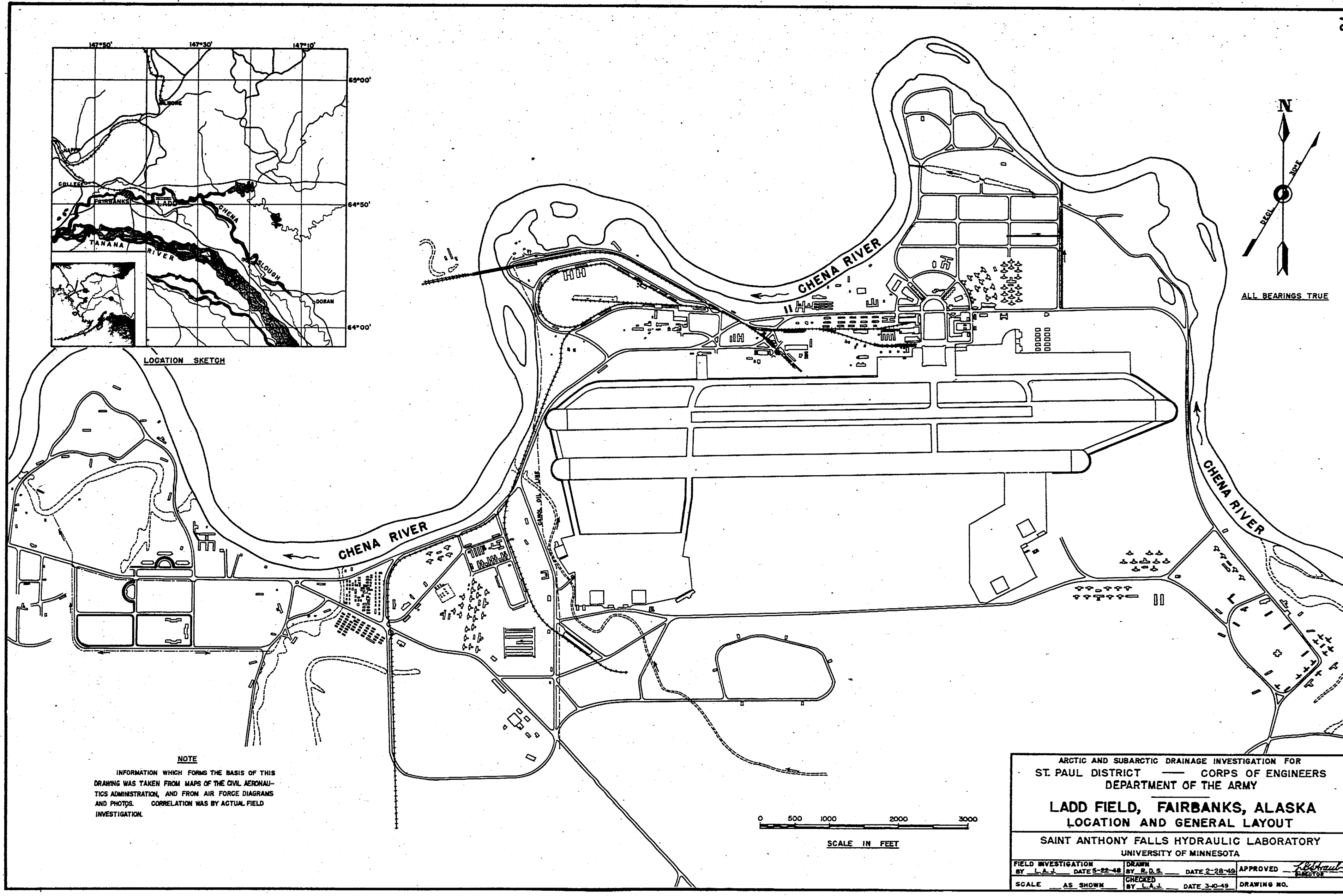


Fig. 20 — Ladd Field, Fairbanks, Alaska

G. Ladd Field at Fairbanks (Investigation conducted May 23, 1948)

53. Description. Ladd Field, a U. S. Air Force establishment, is located between bends in the Chena River about 2.5 miles east of Fairbanks at 64° 51' north latitude and 147° 37' west longitude. This airport is ideally situated with respect to transportation facilities as it has access to the Alaska Railroad, Richardson Highway, and the Tanana River. From a drainage point of view the location is not as favorable. It is subject to springtime river floods and ground elevations are low with respect to river stages. Soil and subsoil conditions are pervious, thus ground water elevations fluctuate with, but lag behind, variations in river levels. At some locations basements are not possible because of high springtime river and ground water stages. Ordinarily drainage difficulties are confined to the spring of the year when a combination of melting snow and rain causes the high river stages. Ice jams also make for high river levels. Summer discharges of flood magnitude are very rare as many long-time residents reported that they had never witnessed a summer flood on either the Chena or Tanana Rivers.

54. Floods of Chena and Tanana Rivers. Between 11:00 a.m. and 2:00 p.m. Friday, May 21, 1948, the Chena River reached a flood peak which was reported to be the second highest in history, exceeded only by an ice-jam flood of May 11, 1937. After 2:00 p.m. Friday, the stage started to fall at a rate of about 1 in. per hr. The Tanana River at Nenana reached a peak at 3:00 a.m. May 22, and by 1:30 p.m. had dropped 1 1/2 inches. The village of Nenana was reported to be inundated to depths of 4 ft and more with water up to the windows of the public school and up to the roofs of many homes. The only dry spot in town was the railroad depot. An observation flight to the south and east of Fairbanks was made to note the flooded area. Richardson Highway at many points looked like a long slender island. The Tanana River had ceased to be a recognizable river as it inundated vast areas. The dike separating the Tanana from the upper reaches of Chena Slough was still intact. The snow in the mountains was probably one-half melted, with slopes facing south nearly bare, while those facing north were still covered with snow. It is of interest to note that from 8:00 p.m. May 19 to 8:00 a.m. May 20 (a 12-hr period), the Chena River rose 6 inches. During the same period of the previous day, it rose 7 inches. The flood stage of 1948 was approximately 13 ft above ordinary winter ice levels and it is reported that the ice-jam flood of 1937 exceeded this by about 2 ft. Two feet above the 1948 peak level would have inundated large portions of the military base at Ladd Field.

55. <u>General Layout and Drainage Design</u>. Figure 20 shows a general layout of Ladd Field, along with details of drainage design for the civilian area. Figure 21 shows details of drainage design for the military area, and Plates 18 and 19 contain photographs indicating general characteristics of the vicinity. Some pictures show conditions during the 1948 flood.

56. <u>Verification of Design Criteria</u>. To verify design criteria, a comparison was made with drainage capacities calculated by Fay, Spofford and Thorndike. The area to be drained is shown in Fig. 21 and comprises an area that is occupied by existing buildings plus an additional area on which housing for military personnel is intended. The terrain is very flat with no significant variation in elevation anywhere. With the exception of one line, airfield drainage is directed toward the west. The one line designated <u>n</u> on the drawings joins the system under study at G-3. It is quite obvious that this airfield drainage line was not designed to remove runoff with sufficient rapidity to prevent ponding. Consequently, the contribution of the <u>n</u> line to the <u>G</u> series at G-3 was calculated with the assumption of ponding at the inlets. Another condition affecting the design is that bituminous pavement exists on Walseth Road, North Front Street, Ketcham Road, Freeman Road, and Northeast Street. Streets A, B, C, and D, and also 1st, 2nd, 3rd, and 4th, are intended for future construction. The tabular data that follow show the results of this design analysis. The contribution of each inlet is indicated, as well as the pipe line capacities that would be required between the inlets. The data are shown by an arrangement which progresses downstream.

The summations of Table IX were made using the method contained in Engineering Manual, Part XIII, Chapter 1, and assuming the storm index and the 0.8 supply curve to be applicable. Infiltration on turf areas was estimated as equal to 0.4 in. per hr. This infiltration rate for areas in the vicinity of Fairbanks is not unreasonable as the soils are very pervious. Capacities as calculated by the architectural and engineering firm, Fay, Spofford and Thorndike, are indicated in the last column under the heading F.S.T.

Capacities calculated by the use of the new design criteria are consistently larger than those determined by Fay, Spofford and Thorndike. The differences are not great, however, and the two values agree very well for the larger drainage areas. The actual differences would not require a change in actual size of pipe.

The Chena River which flows westerly through the city is the eventual outlet for all drainage facilities in the vicinity. High river stages in the summer are very uncommon and contrast with nearly annual springtime floods due to ice jams.

Plate No. 18 – Looking East over the City of Fairbanks, Alaska

TABLE IX

DRAINAGE CAPACITY ANALYSIS

Pipe Line Designation	Contributing Inlets																Pipe Capacity cfs	F.S.T. cfs
	14	13	12	11	10	9	8	6	5	4	3	15 to 6	L-1 to 6	N-1 to 3	M-1 to 3	2		
G-13 to G-12	0	.61															.61	.48
G-12 to G-11	0	.61	.54														1.15	.89
G-11 to G-10	.78	.61	.50	0													1.89	1.42
G-10 to G-9	.72	.59	.50	0	1.32												3.13	2.52
G-9 to G-8	.72	.59	.50	0	1.32	.66											3.79	2.94
G-8 to G-6	.72	.59	.50	0	1.32	.66	.93										4.72	3.46
G-6 to G-5	.69	.57	.47	0	1.29	.63	.92	.76				2.00	6.74				14.07	11.82
G-5 to G-4	.69	.57	.47	0	1.29	.63	.92	.76	1.84			2.00	6.74				15.91	12.26
G-4 to G-3	.69	.57	.47	0	1.29	.63	.92	.76	1.84	1.46		2.00	6.74				17.37	13.26
G-3 to G-2	.63	.53	.40	0	1.12	.55	.63	.60	1.47	1.37	.90	1.74	6.06	9.30	3.43		28.73	28.13
G-2 to G-1	.63	.53	.40	0	1.12	.55	.63	.60	1.47	1.37	.90	1.74	6.06	9.30	3.43	2.24	30.97	30.1

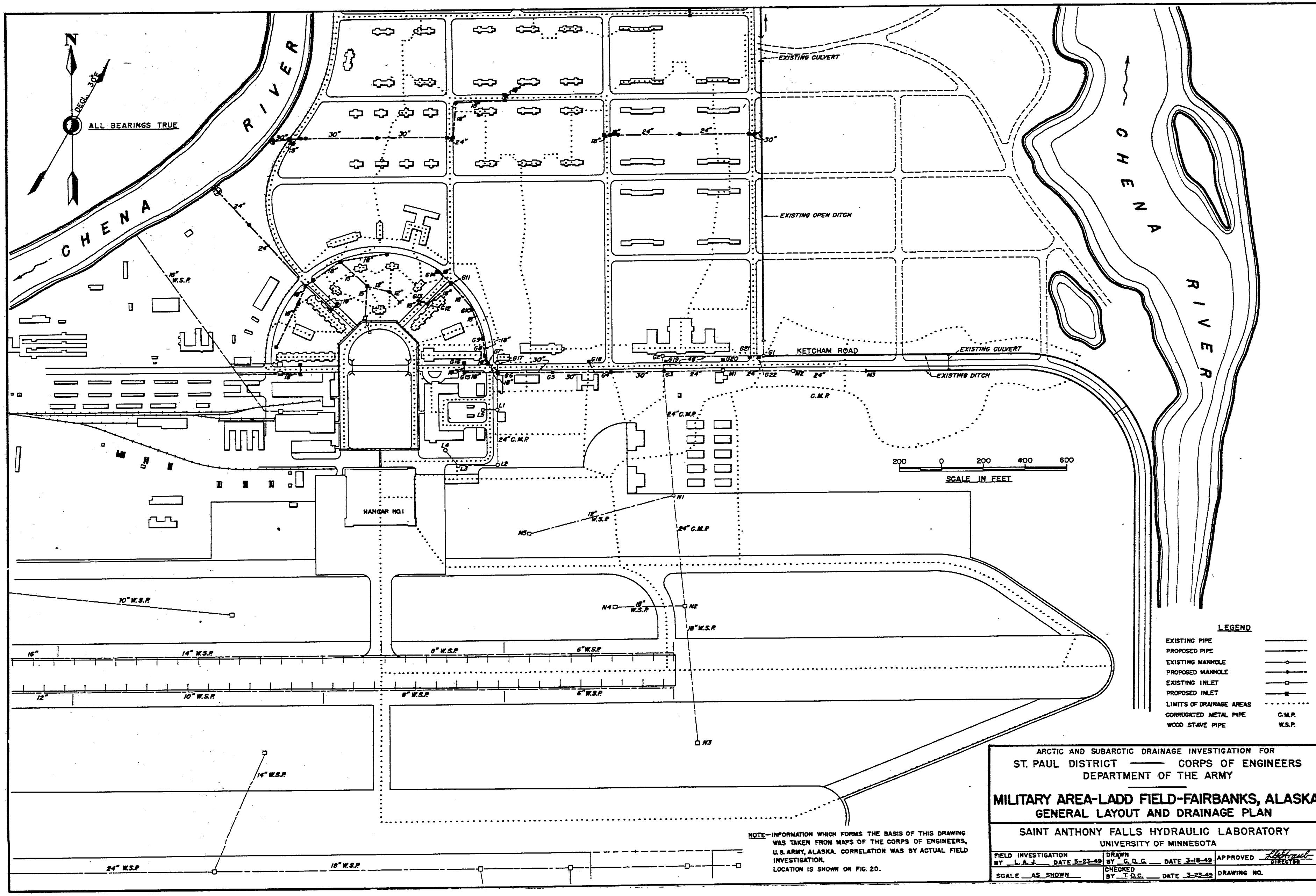
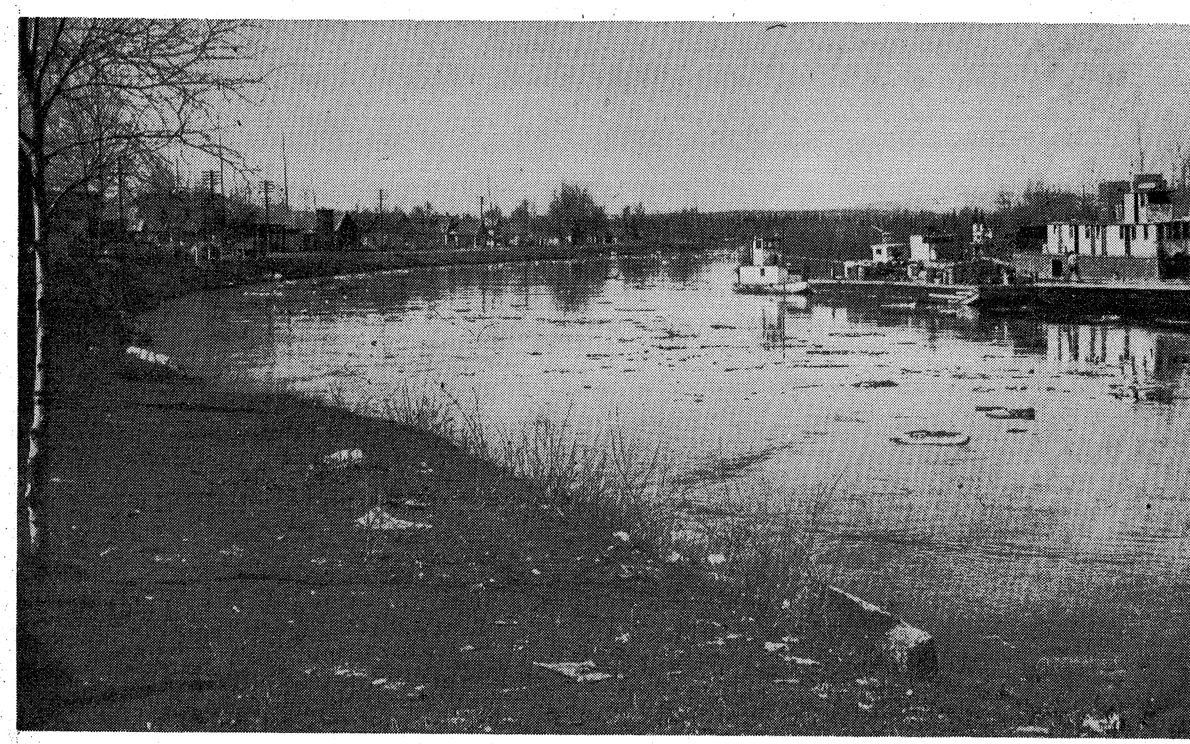


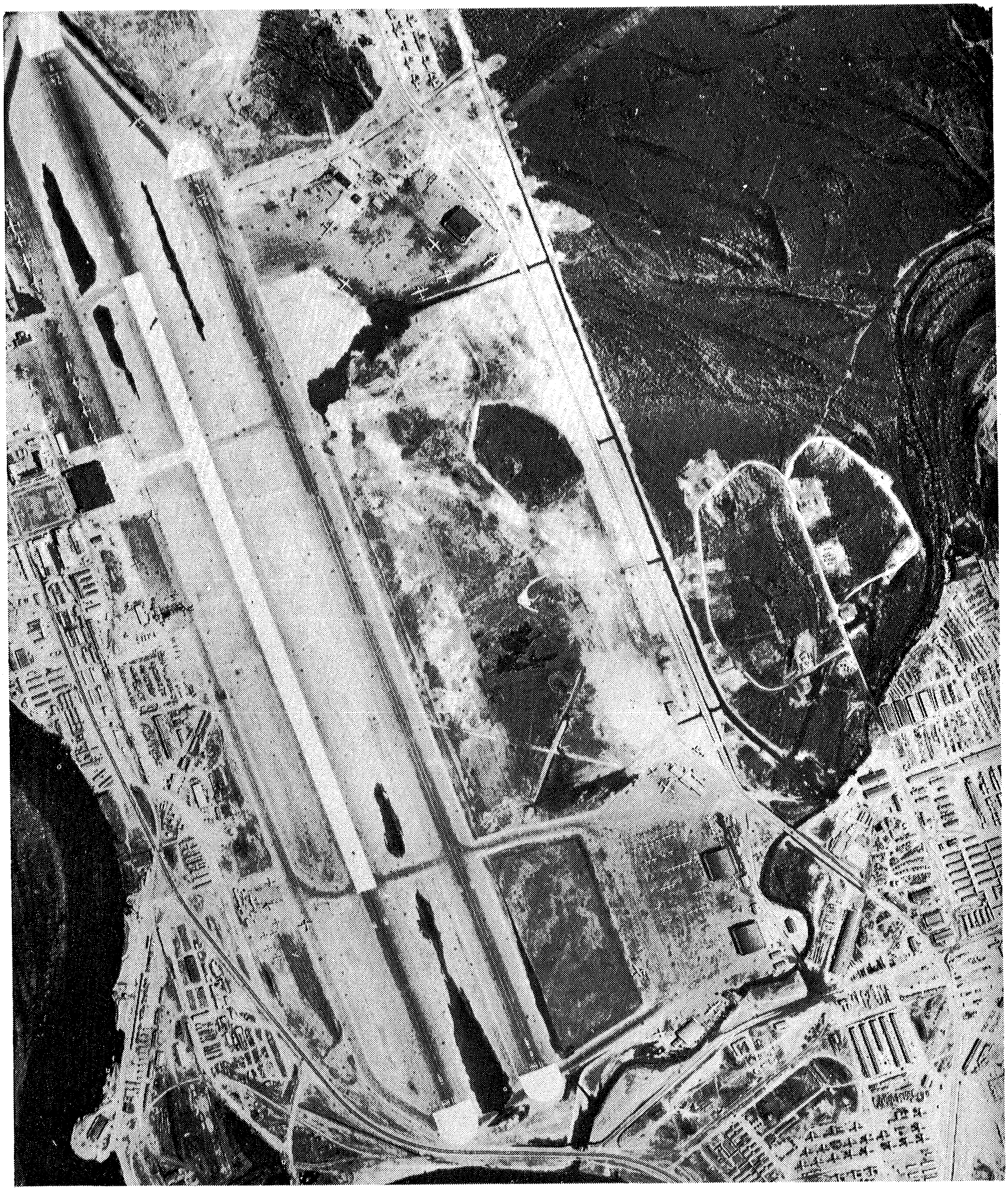
Fig. 21 — Military Area at Ladd Field, Fairbanks, Alaska

Many streets were impassable and many homes isolated during an ice-jam flood in May 1948.



A river stage as high as indicated in this photograph is an unusual summer event, but it is quite common in May of each year.

Plate No. 19 – Flood and River Scenes in Fairbanks



High Chena River stages during May 1948 caused a reversal of flow in drainage conduits and inundated large areas.

Plate No.20-Drainage Conditions at Ladd Field

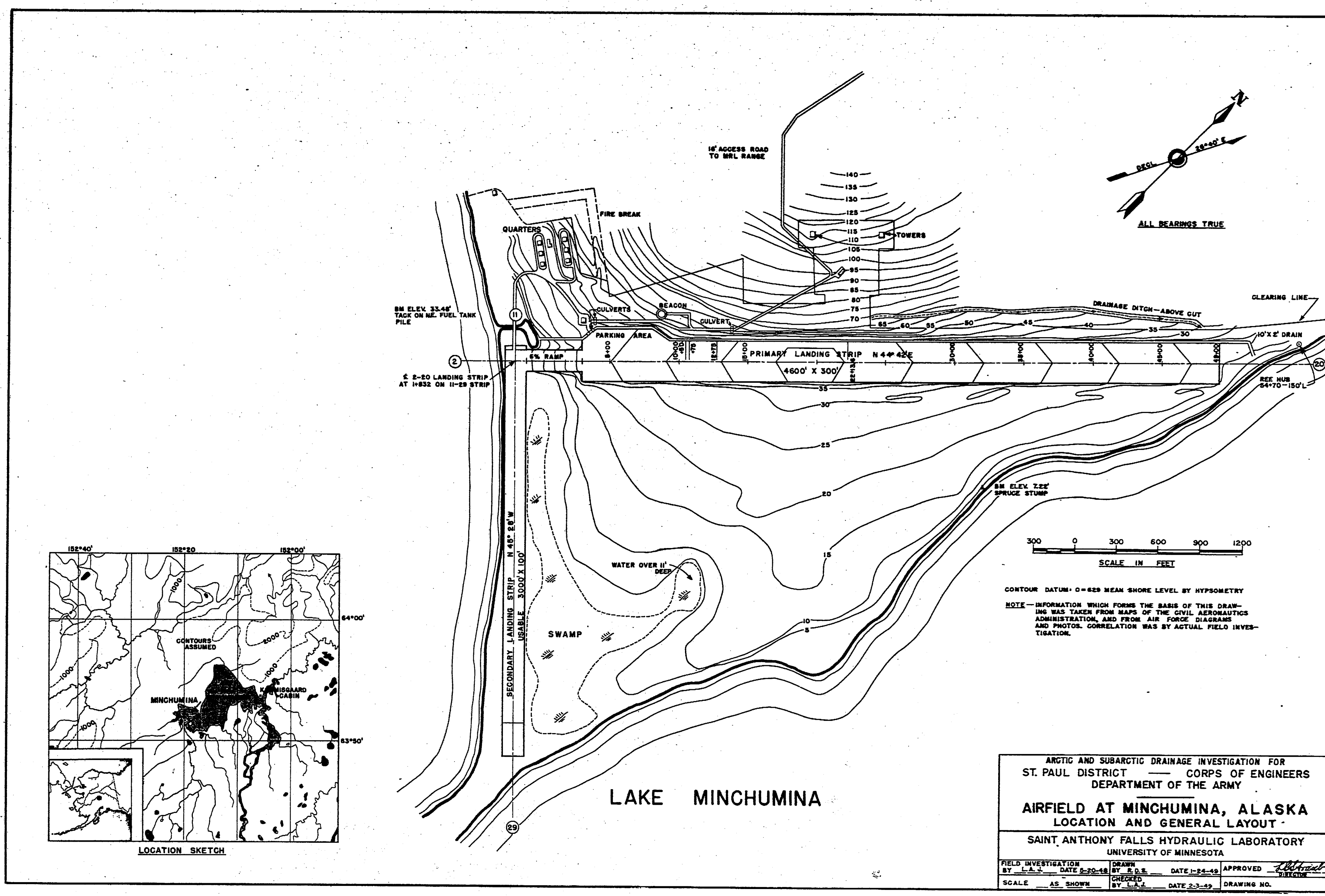


Fig. 22 — Airfield at Minchumina, Alaska

H. Lake Minchumina (Investigation conducted May 20, 1948)

57. Description. A Civil Aeronautics Administration airport is located near the apex of a peninsula of Lake Minchumina at 152° 18' west longitude and 63° 53' north latitude. The northeast-southwest runway is 300 ft wide and 4600 ft long. The northwest-southeast runway is 100 ft wide and 3000 ft long, but is not usable at all times as its surface level lies below high water stages of the lake. Figure 22 and Plates 21 to 24 show general characteristics and layout at this site. The terrain at this airport is decidedly rolling with slopes toward the lake. Uncleared areas are heavily wooded with a distinct demarcation of areas between deciduous and coniferous trees (photographs on Plates 21 and 22). The soil appeared to be of a coarse texture with a considerable portion of gravel.

58. Drainage of the Airfield. Drainage of the primary runway consists of an intercepting ditch to prevent direct runoff of a hilly wooded area from eroding the face of an excavation cut. A shallow ditch on the north side of the runway conveys drainage from the runway to the lake. Surface water drains from the runway centerline to the east, over the edge of the fill, and out into a timbered section without the benefit of outfall structures. Runoff is directed beneath road and ramp fills by culverts which are fabricated of either logs or old oil drums (photographs on Plates 23 and 24).

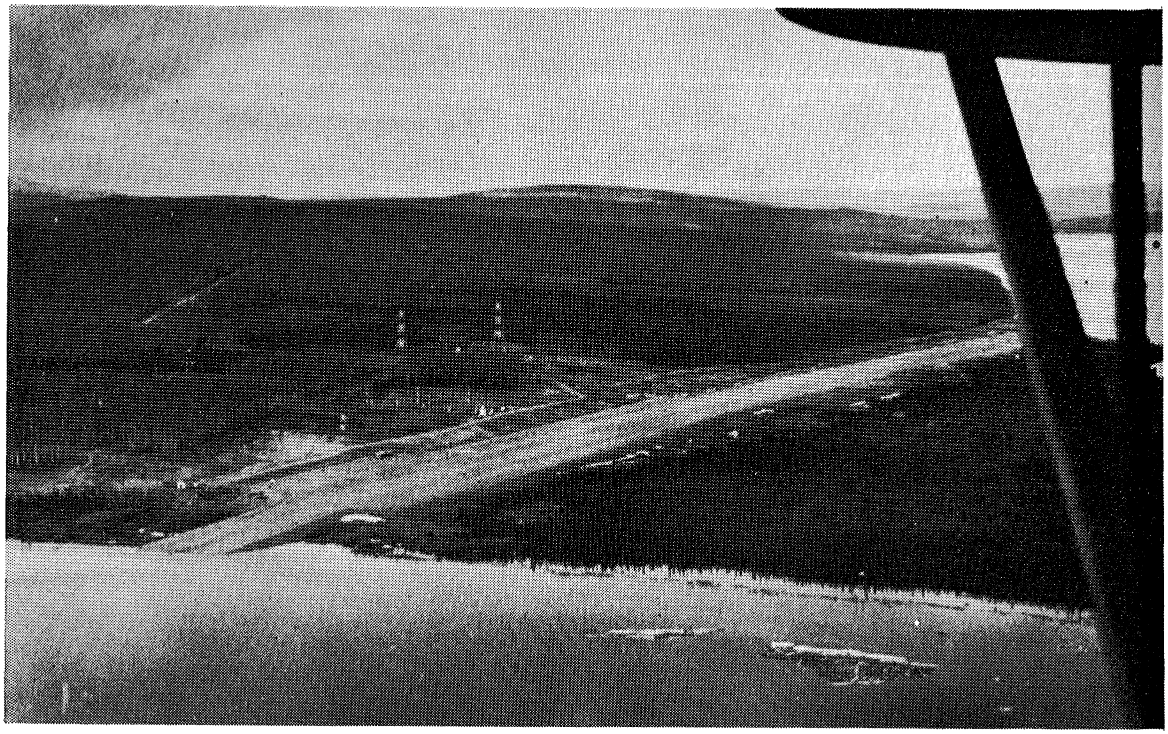
59. Observations of Local Maintenance Personnel. Mr. R. C. Jameson, Maintenance Technician in Charge for the Civil Aeronautics Administration, reported that to his knowledge there were no difficulties resulting from summer rains. It was estimated by Mr. Jameson that magnitudes of the discharges in the culverts at the time of the investigation would exceed summer high flows. He claimed that fluctuations of Lake Minchumina were particularly troublesome in the spring of the year. The range from an extreme summer low to an extreme springtime high in lake level was reported to be 7 ft.

Mr. Jameson had been stationed at Lake Minchumina for only one or two seasons. The investigator found no evidence of erosion or watermarks such as would indicate high discharges.

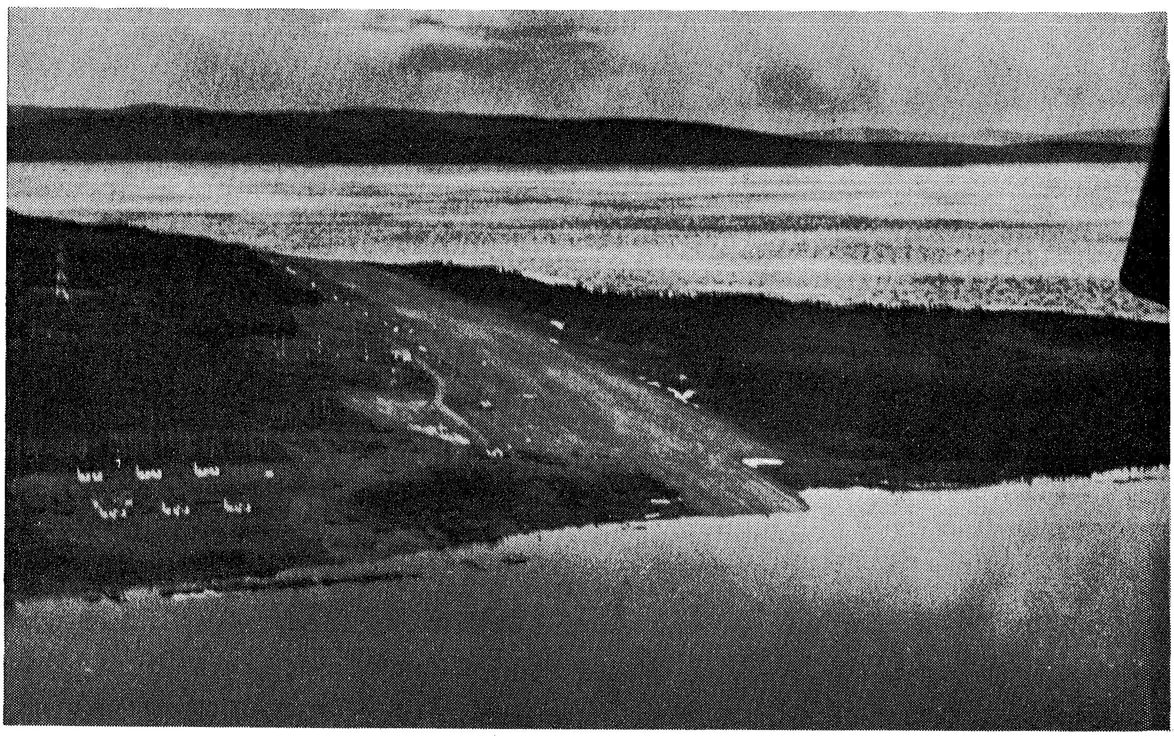
60. Verification of Design Criteria. The largest area tributary to any 2 by 2-ft timber box culvert is approximately 50 acres. About one-third of this area is timbered. Surface slopes are relatively steep ranging from 10 per cent to 1 per cent. The overall average slope is estimated to be about 5

per cent. With the exception of the wooded section, surface conditions are bare with but a sparse growth of grass which does not occupy more than 40 per cent of the area. The soil is relatively pervious. Using methods as described in the Engineering Manual and the new design criteria, calculations indicate a required capacity at the site of the culvert of 25 cfs. This does not exceed, but nearly equals, the capacity of the existing drainage structure.

Plate No. 21 – Looking Southeast over Minchumina Airfield

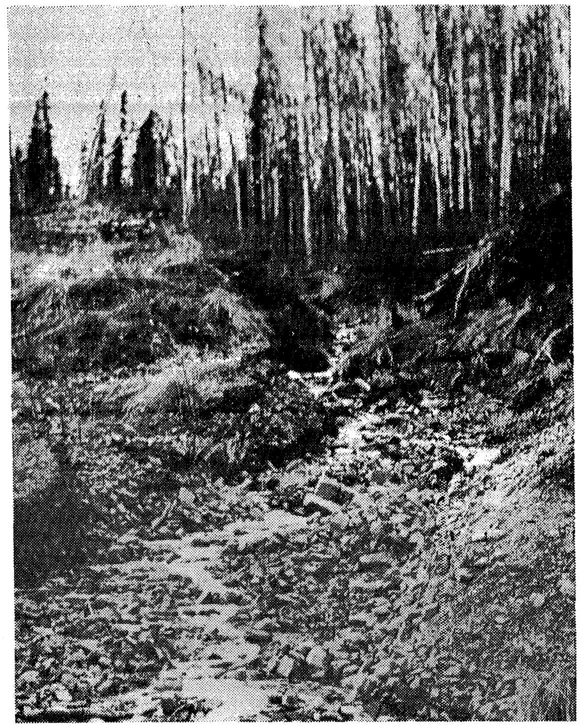


The pattern of tree growth is indicative of a variance in permafrost conditions.

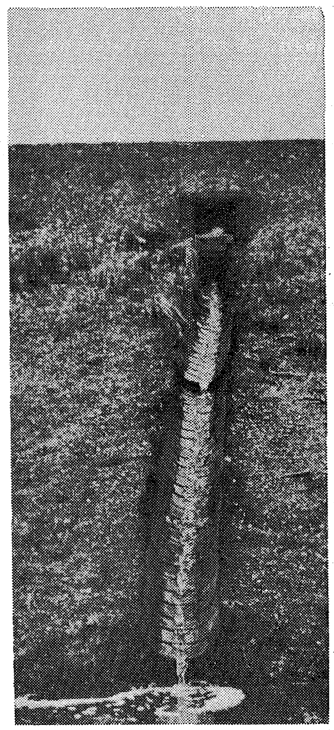


One runway of the airfield was inundated on May 20, 1948.

Plate No. 22 – Aerial Views of Minchumina Airfield



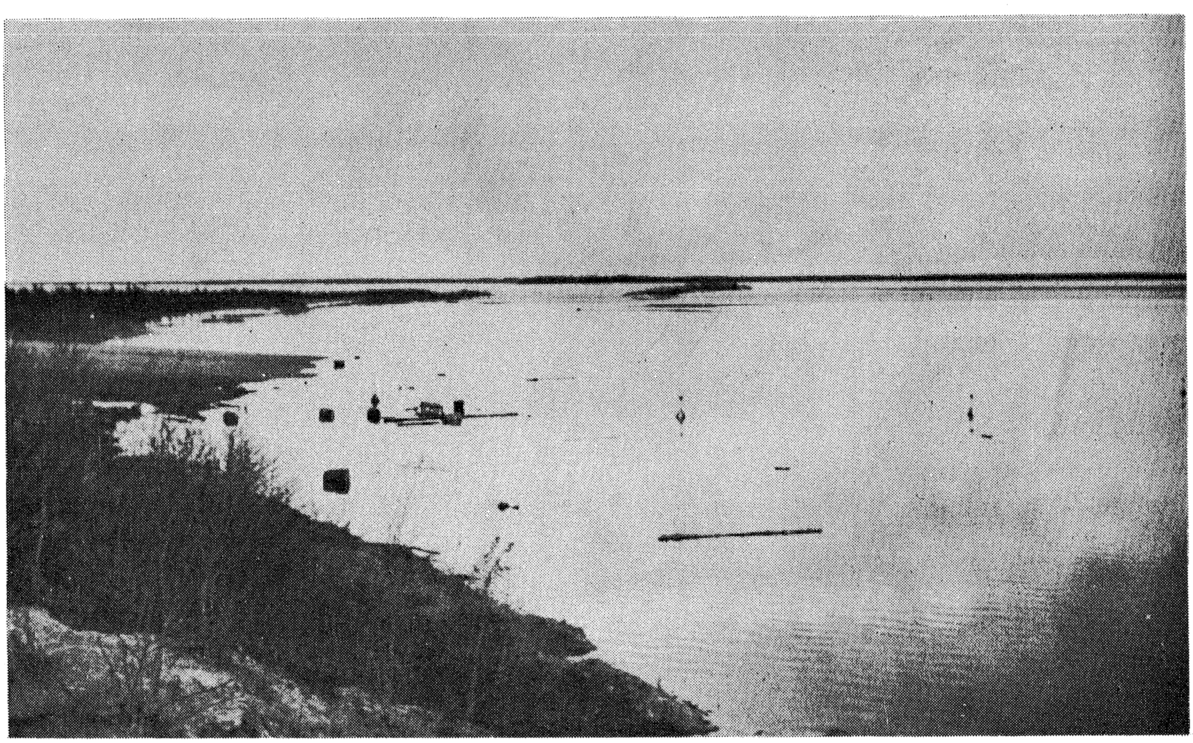
A diversion ditch conveys runoff away from the airfield.



Many materials and innovations are used to provide drainage structures.

Plate No. 23 — Drainage Facilities at Minchumina Airfield

The picture above shows the northwest end of the short runway shortly after its completion in 1946.



This picture is a view of the short runway during the flood of May 20, 1948.

Plate No 24-Contrasting Conditions of One Runway at Minchumina

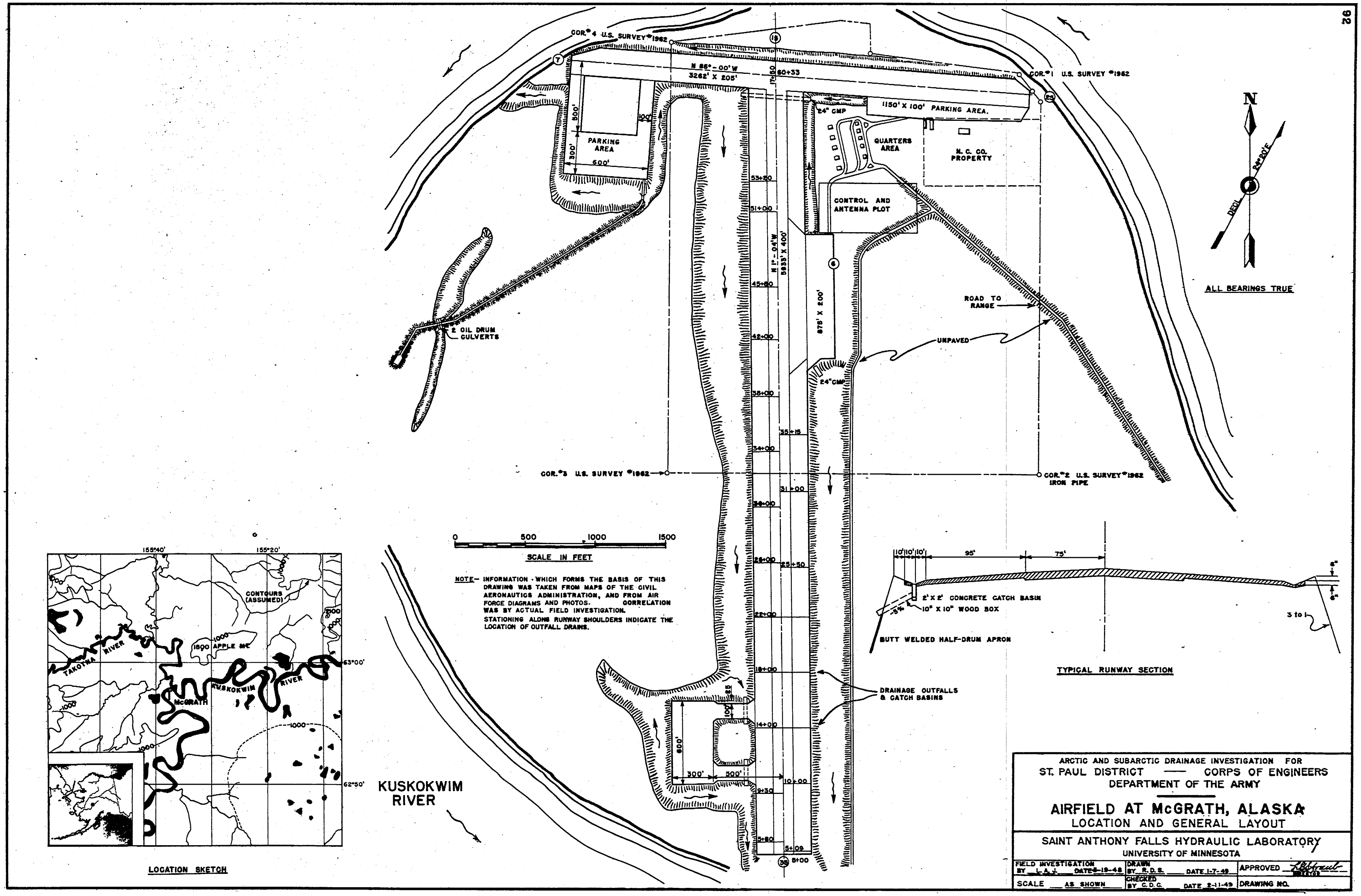


Fig. 23— Airfield at McGrath, Alaska

I. McGrath (Investigation conducted May 19-20, 1948)

61. Description. McGrath, a small village with a population of about 140, is located in southwestern Alaska on the right bank of the Kuskokwim River at 62° 58' north latitude and 155° 37' west longitude. A Civil Aeronautics Administration airport is located on the left bank of the river just opposite the village. Two roadhouses, a general store, a post office, and several other buildings are now in close proximity to the runways. Figure 23 and Plates 25 to 30 show the general layout and other characteristics of this site. The soil here is silt overlying coarser textured material to depths of 25 ft or more. Test hole drilling by the Corps of Engineers Permafrost Division indicates an absence of permafrost at the site. The airport runways and the parking aprons have bituminous-treated surfaces.

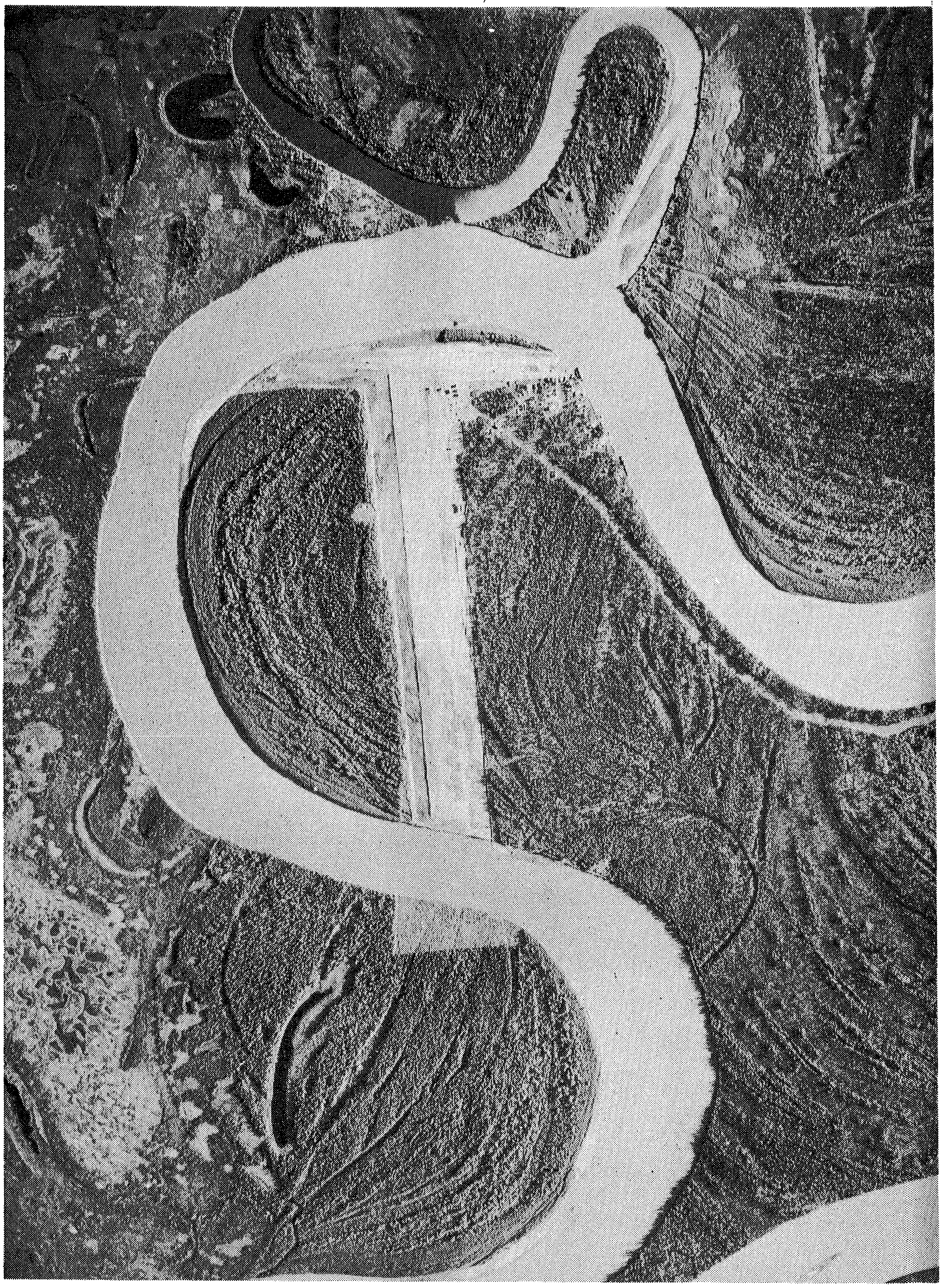
62. Drainage of the Airfield. Drainage of the runway and parking apron areas is entirely via the surface into outfall structures which convey the runoff into borrow pits. These borrow pits are located parallel to, and on either side of, the runway and are connected to the Kuskokwim River. The general layout indicates a large variance in the spacing of the outfall structures; consequently, there is a large range in the sizes of drainage areas which are tributary to the structures. The largest tributary area comprises approximately 3.2 acres of paved surface, while the average watershed is about 2 acres. On the basis of the new design criteria the capacity of the drainage structure, which is located at the outlet of the larger area, would be overtaxed. The capacities of the outfall structures, which are the outlets to the 2-acre areas, are approximately equal to the discharge determined by the new design criteria.

63. Analysis of Culvert Capacity. It is of interest to analyze conditions affecting the 24-in. culvert which is located beneath the north-south runway near its northern end. The tributary drainage area at this location is 21.6 acres of which 14.8 acres are paved. There is a sparse grass growth on the remaining area. Slopes are relatively flat and do not exceed 1 per cent except for the sections that lie adjacent to the ditches. By dividing the area into smaller segments, it is possible to apply design criteria for each segment and carry the calculations downstream to the culvert. This results in a required culvert capacity of 15 cfs. The capacity of the existing structure is 13 cfs.

64. Observations of Local Maintenance Personnel. Mr. John A. Lind, Jr., Maintenance Technician in Charge for the Civil Aeronautics Administration, reported that in so far as he knew they had not experienced drainage difficulties as a result of intense rains. He was of the further opinion that existing drainage facilities were of adequate size, as an overtaxed structure had never been observed or reported by any member of his maintenance staff. Mr. Lind had been stationed at McGrath for two years. Upon further inquiry it was learned that springtime river floods cause their gravest water problem. Sometimes the entire field becomes inundated and damage results in the way of erosion and deposition of silty material. In addition, high river stages create large flows in the sloughs with consequent washouts of the drainage structures, which cross these low serpentine areas. Two such washouts occurred in the spring of 1947.

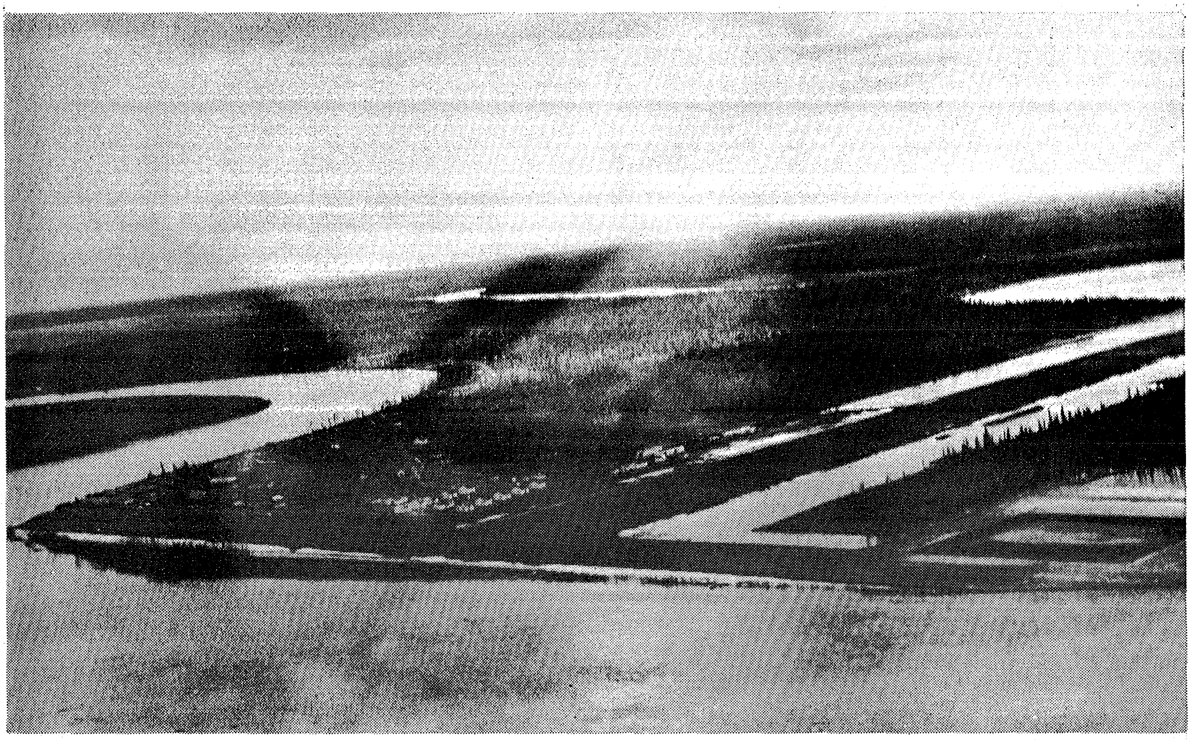
65. Conditions of Outfall Drainage Structures. The photographs on Plates 28 to 30 illustrate conditions observed during the investigation of many of the outfall structures. Evidence existed at every installation which indicated that considerable maintenance and repair had been required. Some facilities were no longer located at the low point of the drainage area, while at others the grating elevation was much lower than was necessary. In one case a large hole, into which runoff waters discharged, had developed a few feet from the inlet. Upon viewing these conditions, the writer was left with the impression that this type of inlet-outfall structure was particularly difficult to maintain.

66. Description of Alternate Site. From a drainage standpoint there is a good airfield site about 3 miles to the east of the existing airport. Observations indicate a high, level, gravel terrace, the area of which exceeds that of the present site. The low point of this terrace is all of 50 ft above river flood stages. The area is located adjacent to the river and accessible by river transportation. A glide angle from any direction would be quite flat.

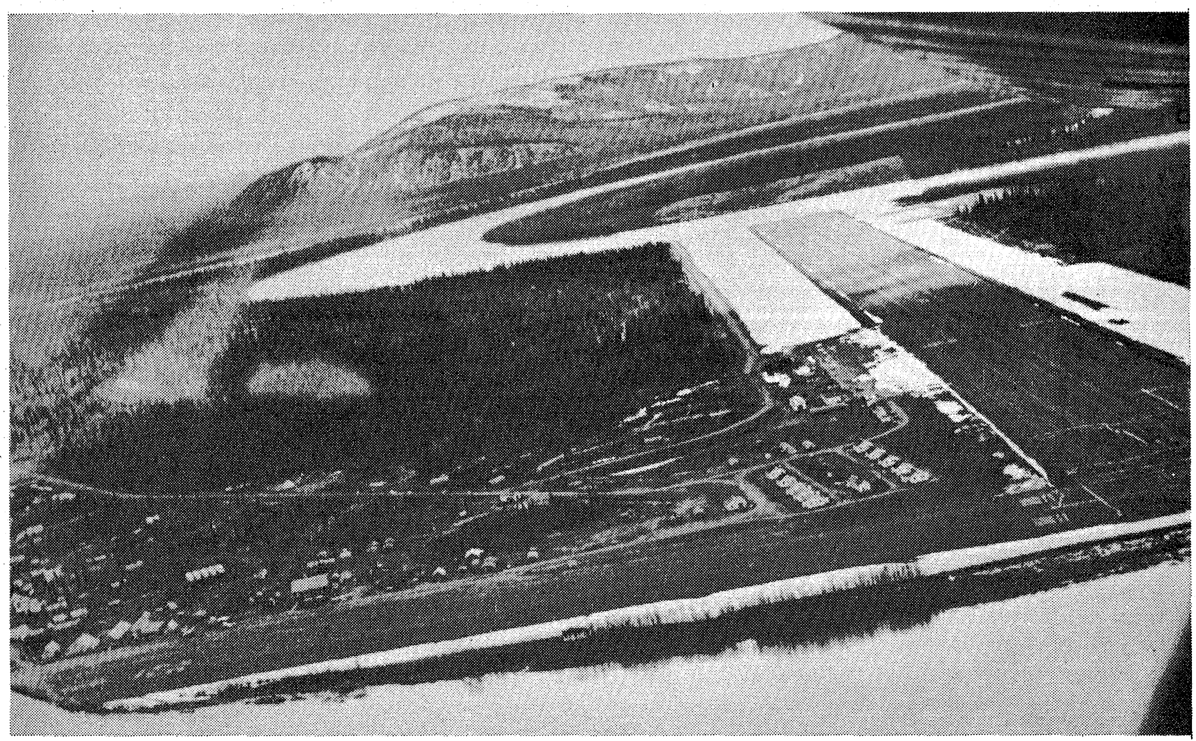


The curved, serried pattern of tree growth indicates that floods are frequent events.

Plate No. 25 — Airfield at McGrath, Alaska

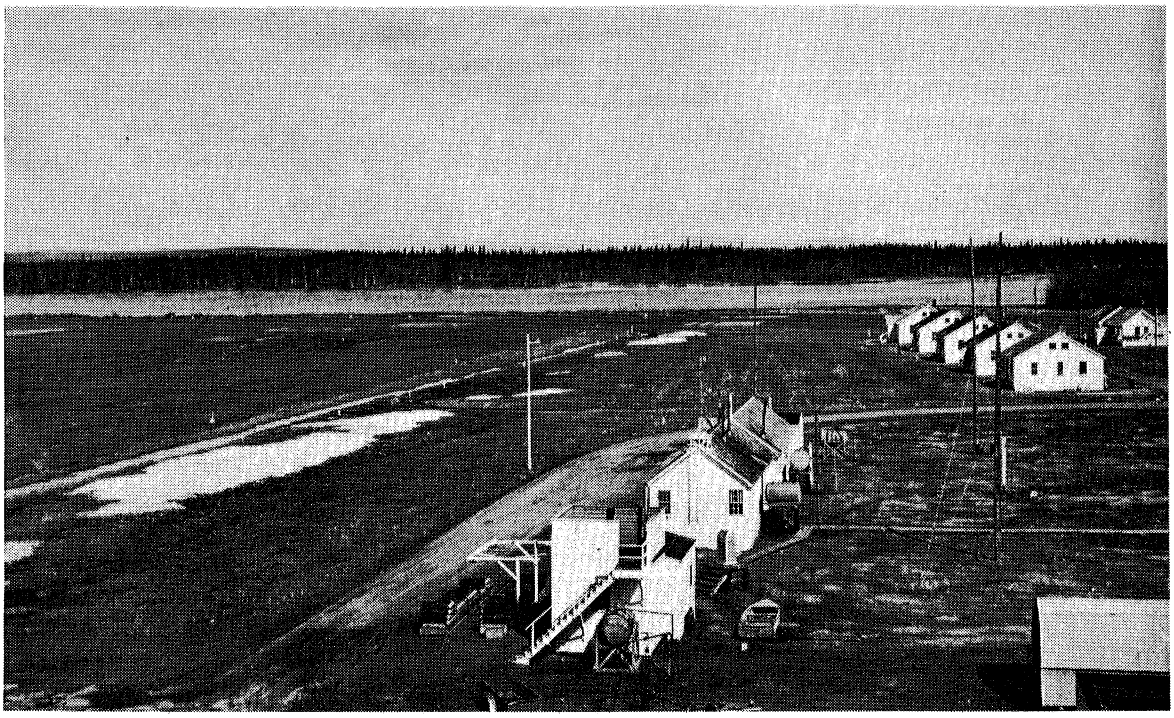


Looking southeast at the Airfield on May 19, 1948.

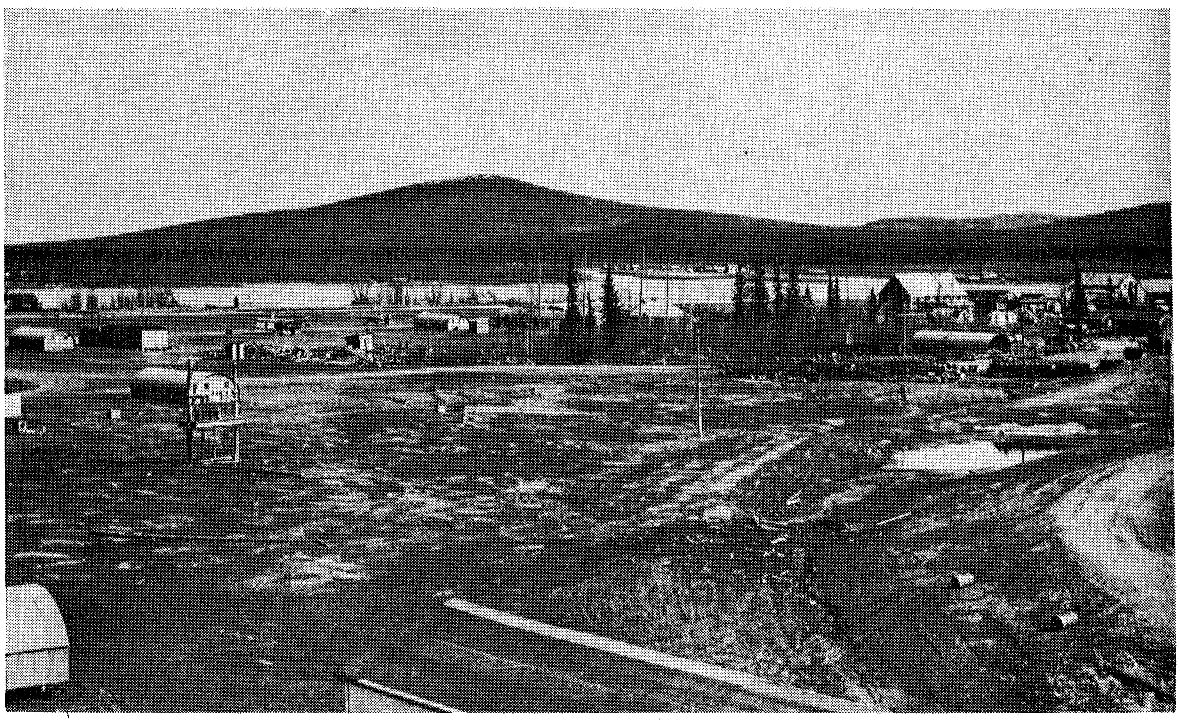


Looking south of the Airfield on May 19, 1948.

Plate No. 26 - Aerial Views of Airfield at McGrath



Looking north.



Looking northeast.

Plate No. 27 - Views from the Tower at McGrath

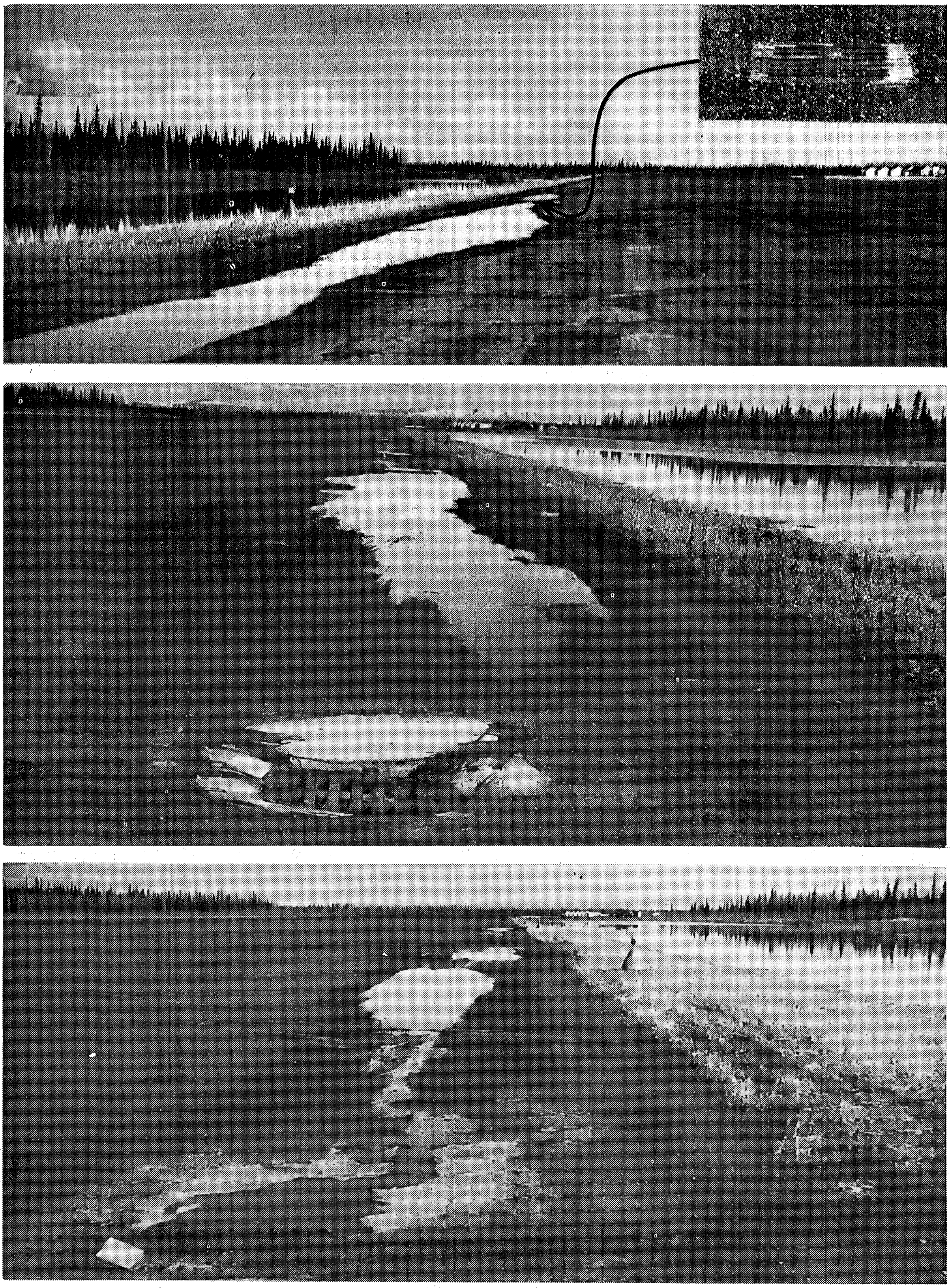


Plate No. 28 - Drainage Inlets at McGrath Airfield

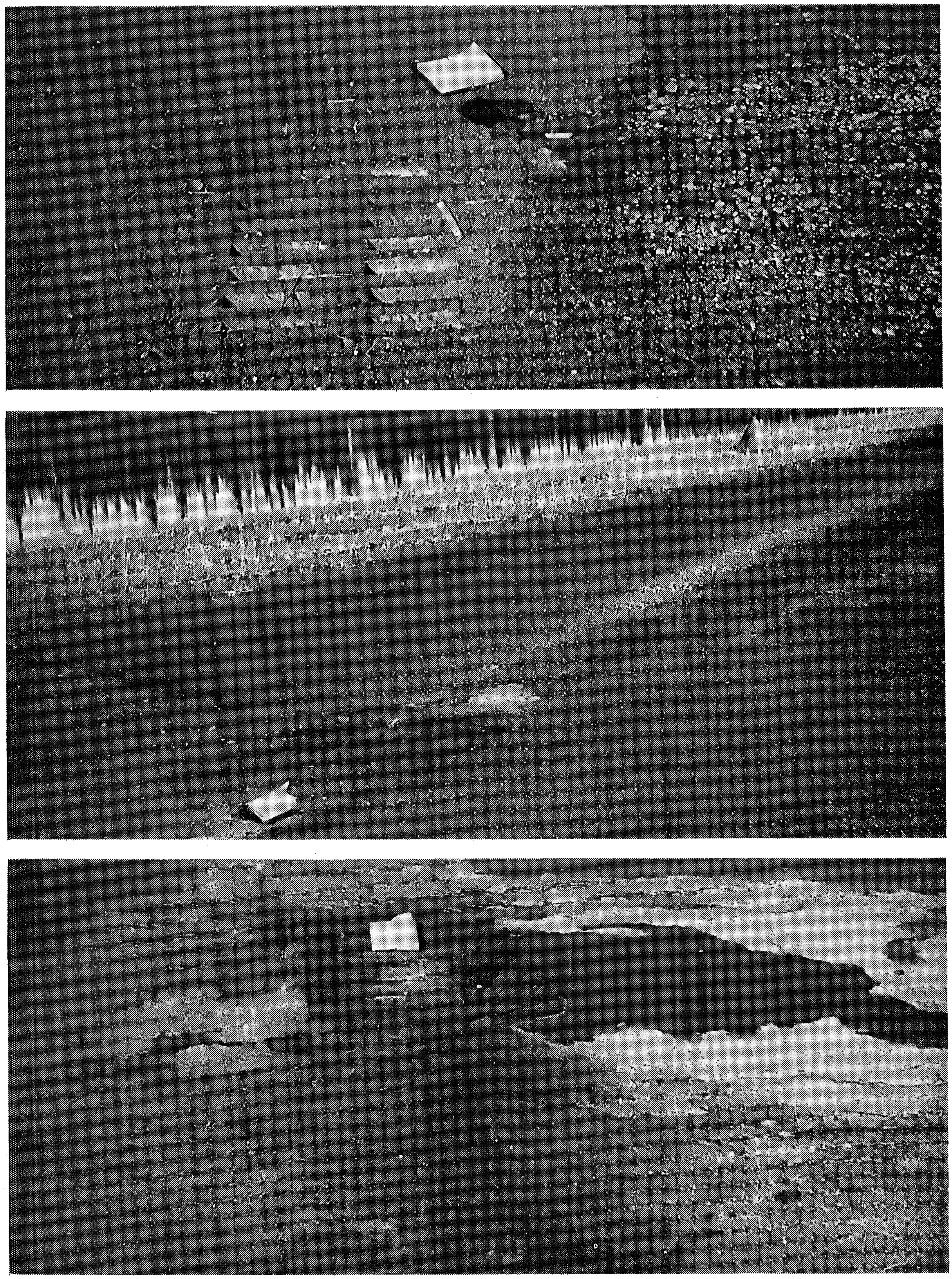
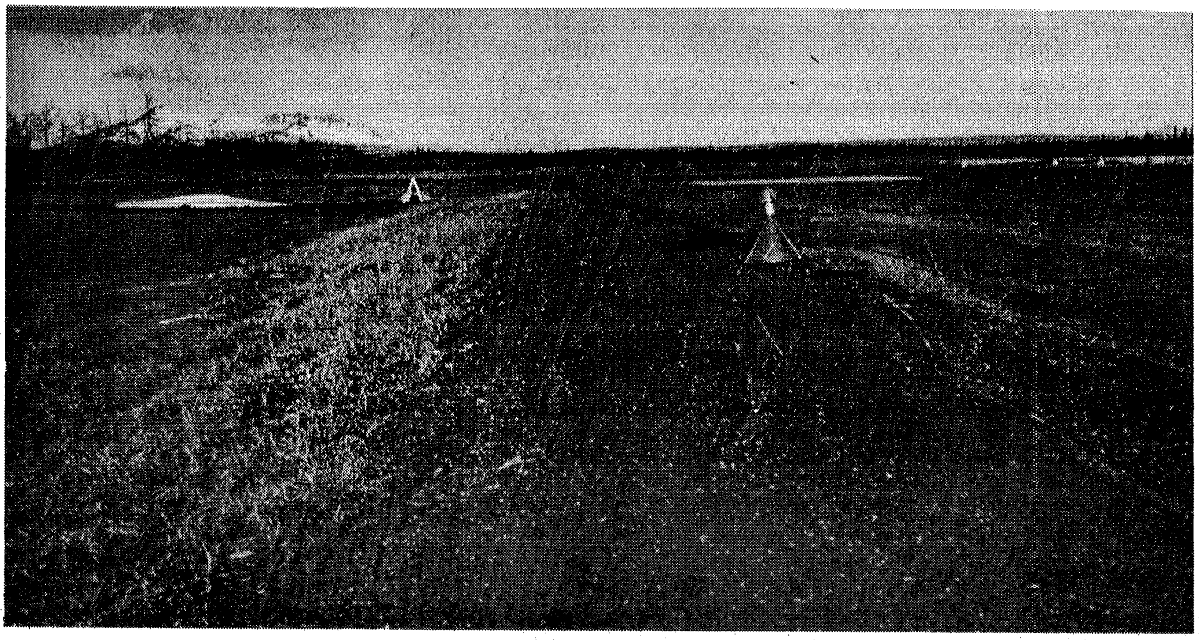


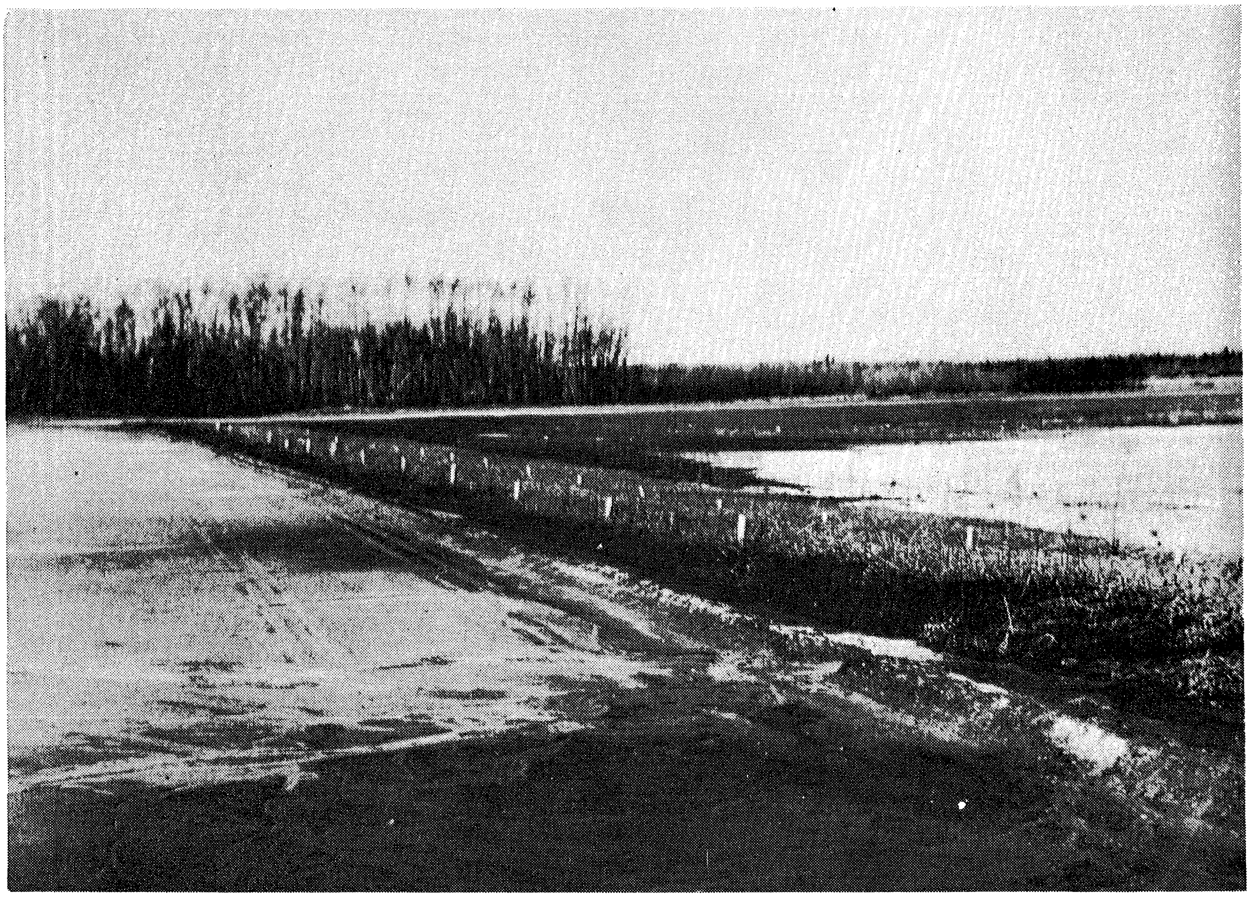
Plate No.29-Drainage Inlets at McGrath are Difficult to Maintain



At this section of the east-west runway, surface drainage flows from the paved area over sparse sod into a shallow ditch without evidence of serious erosion.

The drainage structure at this section is made of oil drums.

Plate No.30–Drainage Conditions along Runway Shoulders at McGrath



Flat, seeded, side slopes maintain their original shape quite well. This picture shows an experimental area where various factors such as plant variety and depth of planting are tested. The experimental work had not been carried on for a sufficient length of time to permit definite conclusions.

Plate No. 31–Experimental Grass Plots

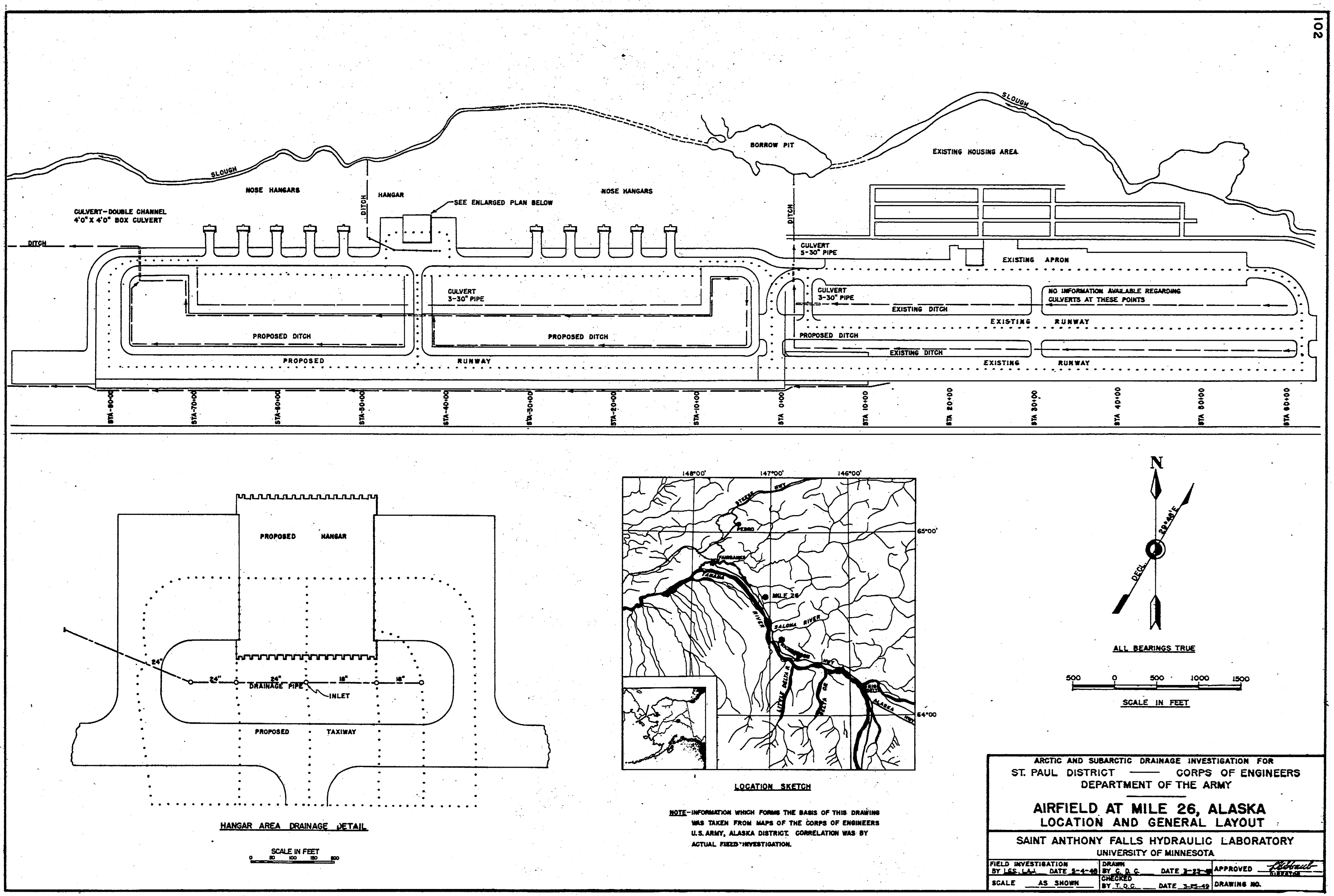


Fig. 24— Airfield at Mile 26, Alaska

J. Mile 26 (Eielson)

(Investigation conducted May 4, 1948)

67. Description. Eielson Field, at the time of the investigation, was in the process of construction. The airport site is located along the Richardson Highway approximately 25 miles southeast of Fairbanks. Soil at this location would be classified as medium or coarse textured. Permafrost exists in the area, but islands of unfrozen ground have been discovered during the process of core drilling. The site of the large hangar was selected on the basis of foundation investigations, enabling locating the entire building on unfrozen material.

68. Drainage of the Airfield. Figure 24 shows the general layout of Eielson Field and indicates important features of the drainage system. All runway drainage is via the surface to shallow open ditches. The ditches are designed with a 10-ft base width and flat (10 to 1) side slopes. The principal objective of this shape and overall section dimension is to facilitate access by heavy snow-moving equipment. It is anticipated that by reason of the design, maintenance costs of opening ditches prior to spring breakup will be reduced perceptibly. Design of the culverts and ditches for the runway drainage system, in so far as hydraulic capacity is concerned, is on the basis of the 0.8 standard supply curve and the Rational Runoff formula. It is safe to say that the new design criteria, upon application, would substantiate the selection of the culvert capacities which were computed by Fay, Spofford and Thorndike.

The inset shown in Fig. 24 indicates the general features of the drainage system for the area adjacent to and west of the 300 by 300-ft hangar. Runoff discharges, as determined by the new design criteria, are slightly larger than those computed by Fay, Spofford and Thorndike, especially for the uppermost inlets. Actual pipe line capacities, however, will not be overtaxed. For this system, as in the case of the system for runway drainage, Fay, Spofford and Thorndike used the Rational formula for computing rates or runoff.

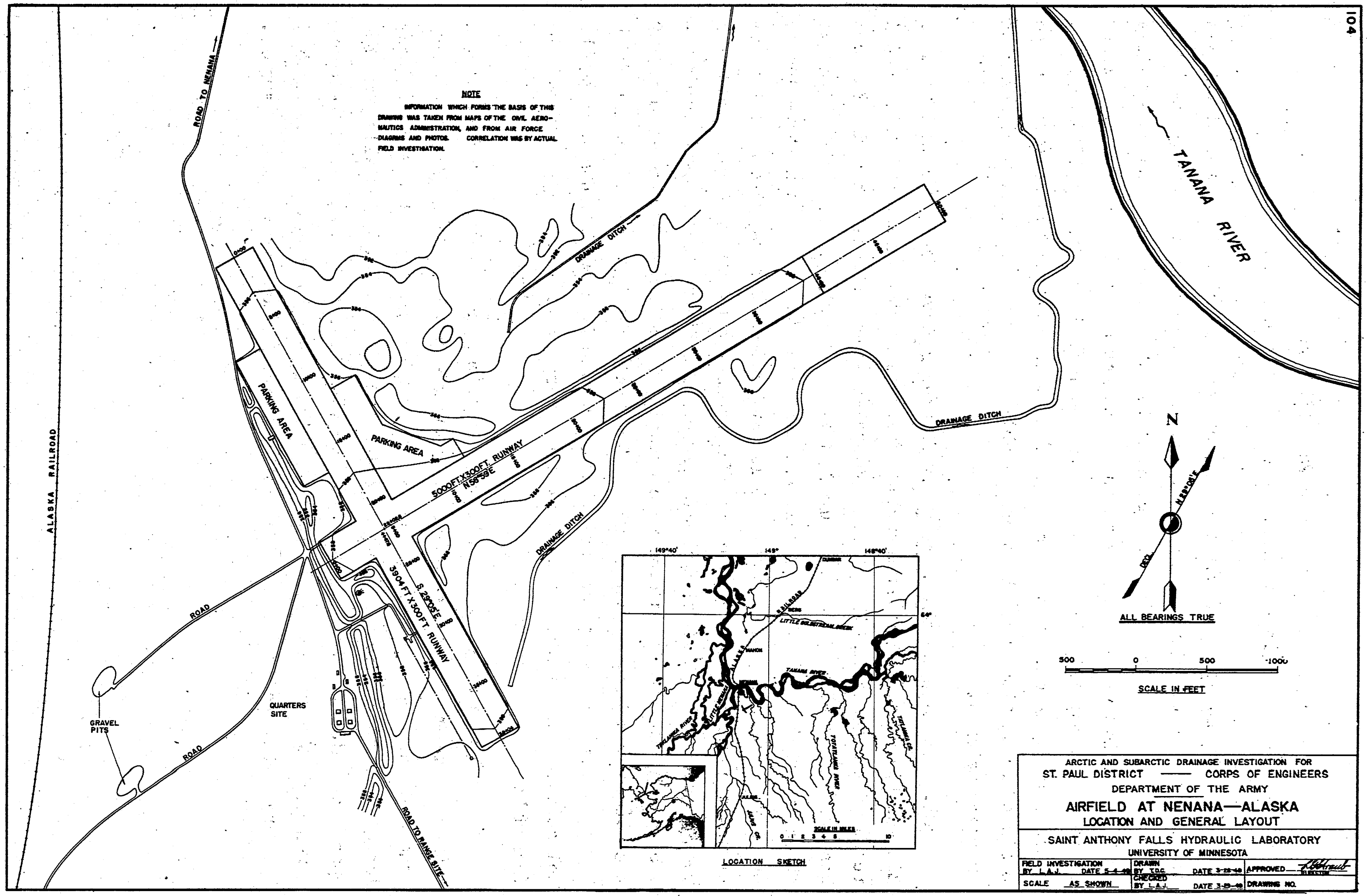


Fig. 25 — Airfield at Nenana, Alaska

K. Nenana (Investigation conducted May 20, 1948)

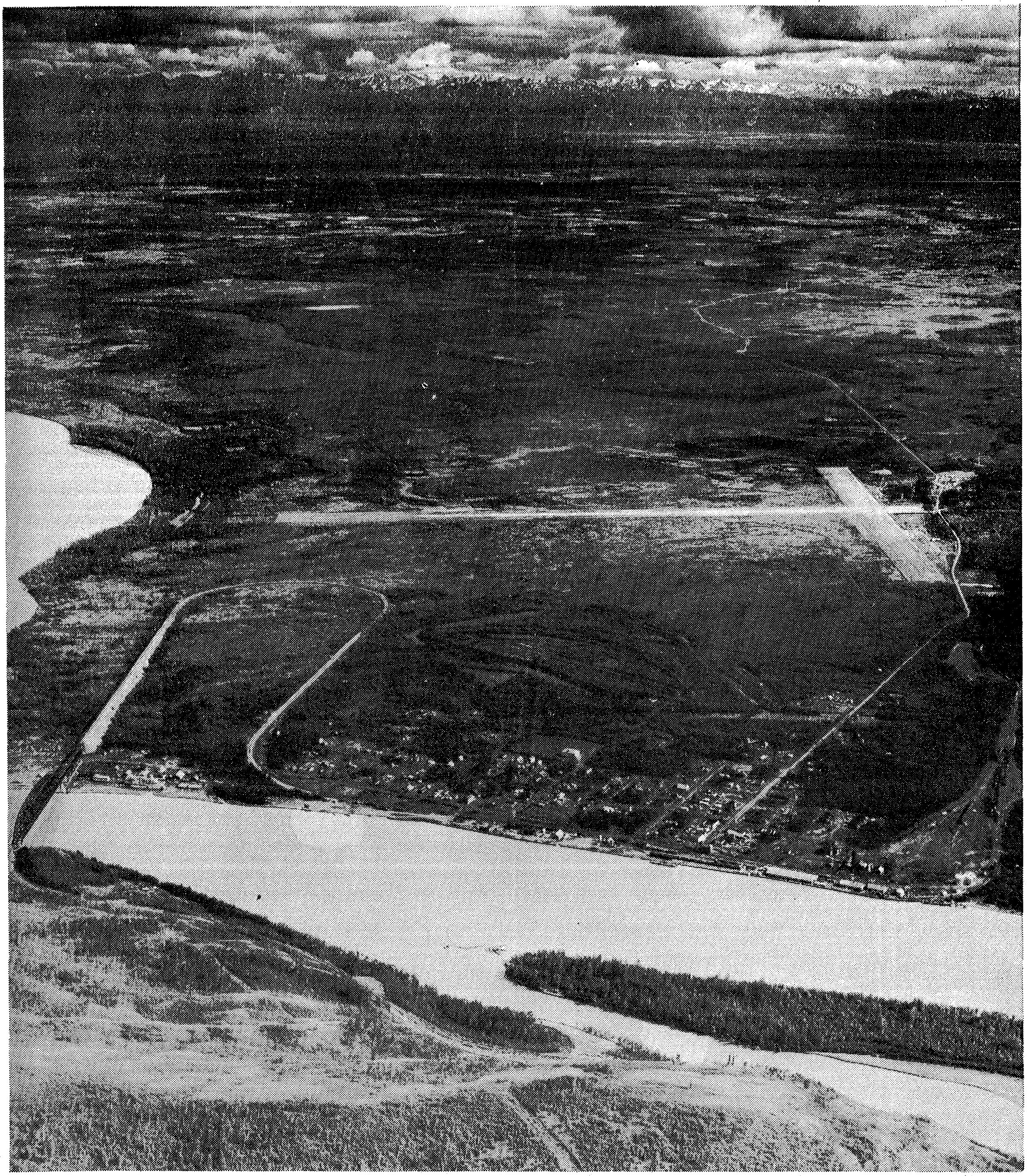
69. Description. Nenana, a small village of about 250 population, is located on the south bank of the Tanana River at 149° 05' west longitude and 64° 33' north latitude. This town has access to transportation by railroad, river, and air. A Civil Aeronautics Administration airport is located adjacent to and south of the village. The airfield consists of two gravel-surfaced runways each 300 ft in width. One strip is 3900 ft long and the other is 5000 ft long. Figure 25 shows the general layout and topography at the site of the airfield. Plates 32 to 34 contain photographs showing general and specific conditions.

70. Drainage of the Airfield. Drainage of the airport is entirely via the surface to open ditches or to excavated areas. In some cases the excavated areas or borrow pits have no surface outlets and all the water that comes into them must disappear either by evaporation or seepage. The surface of the top soil appeared coarse textured and very pervious. The general appearance, however, must not indicate proper characteristics, as in some sections the ground actually felt spongy and would not support the weight of a man without sinking an inch or two. Mr. Williams, pilot for Northern Consolidated Airlines, reported that this field was a quite hazardous one on which to land and take off because of extremely high heaving and settling action. Surface elevations could be very uneven with differences as large as 2 ft in a comparatively short distance of runway.

71. Tanana River Floods. Nenana, as most towns along the Tanana River, is subject to severe springtime river floods, which are caused by ice jams or high discharges resulting from melting snow. Summer floods have not been known to occur. On May 20, at the time of the investigation, the Tanana River was near the peak of the 1948 flood. Actually, the river stage continued to rise slowly until 3:00 a.m. May 22. The stage on May 20 was probably 6 in. below the peak level. At this time about 1000 ft of the east end of the east-west runway was inundated, while 200 ft of the north end of the north-south strip was under water. Severe damages resulted in the village with water reaching the roofs of buildings in some cases.

72. Breakup of the Tanana River. Of interest from a hydrological point of view are data showing actual time of river breakup in the spring. Table X, following, shows that the breakup has never occurred earlier than April 20 and

never later than May 16. May 5 to 12 appears to be the most likely period, as the river ice has started to move during that time in 15 years out of the period of record.



The Tanana River Valley is wide at this point. The distance to the base of the mountains in the background is about 40 miles.

Plate No. 32 - Looking South over the Tanana River at Nenana

TABLE X

BREAKUP OF TANANA RIVER AT NENANA

Year	Month	Time
1917	April 30	11:30 a.m.
1918	May 11	9:33 a.m.
1919	May 3	2:33 p.m.
1920	May 11	10:45 a.m.
1921	May 11	6:42 a.m.
1922	May 12	1:20 p.m.
1923	May 9	2:00 p.m.
1924	May 11	3:10 p.m.
1925	May 7	6:32 p.m.
1926	April 26	4:03 p.m.
1927	May 13	5:42 a.m.
1928	May 6	4:25 p.m.
1929	May 5	3:41 p.m.
1930	May 8	7:03 p.m.
1931	May 10	9:23 a.m.
1932	May 1	10:15 a.m.
1933	May 8	7:30 p.m.
1934	April 30	2:07 p.m.
1935	May 15	1:32 p.m.
1936	April 30	12:58 p.m.
1937	May 12	8:04 p.m.
1938	May 6	8:14 p.m.
1939	April 29	1:26 p.m.
1940	April 20	3:27 p.m.
1941	May 3	1:50 a.m.
1942	April 30	1:28 p.m.
1943	April 28	7:22 p.m.
1944	May 4	2:08 p.m.
1945	May 16	9:41 a.m.
1946	May 5	4:40 p.m.
1947	May 3	5:53 p.m.

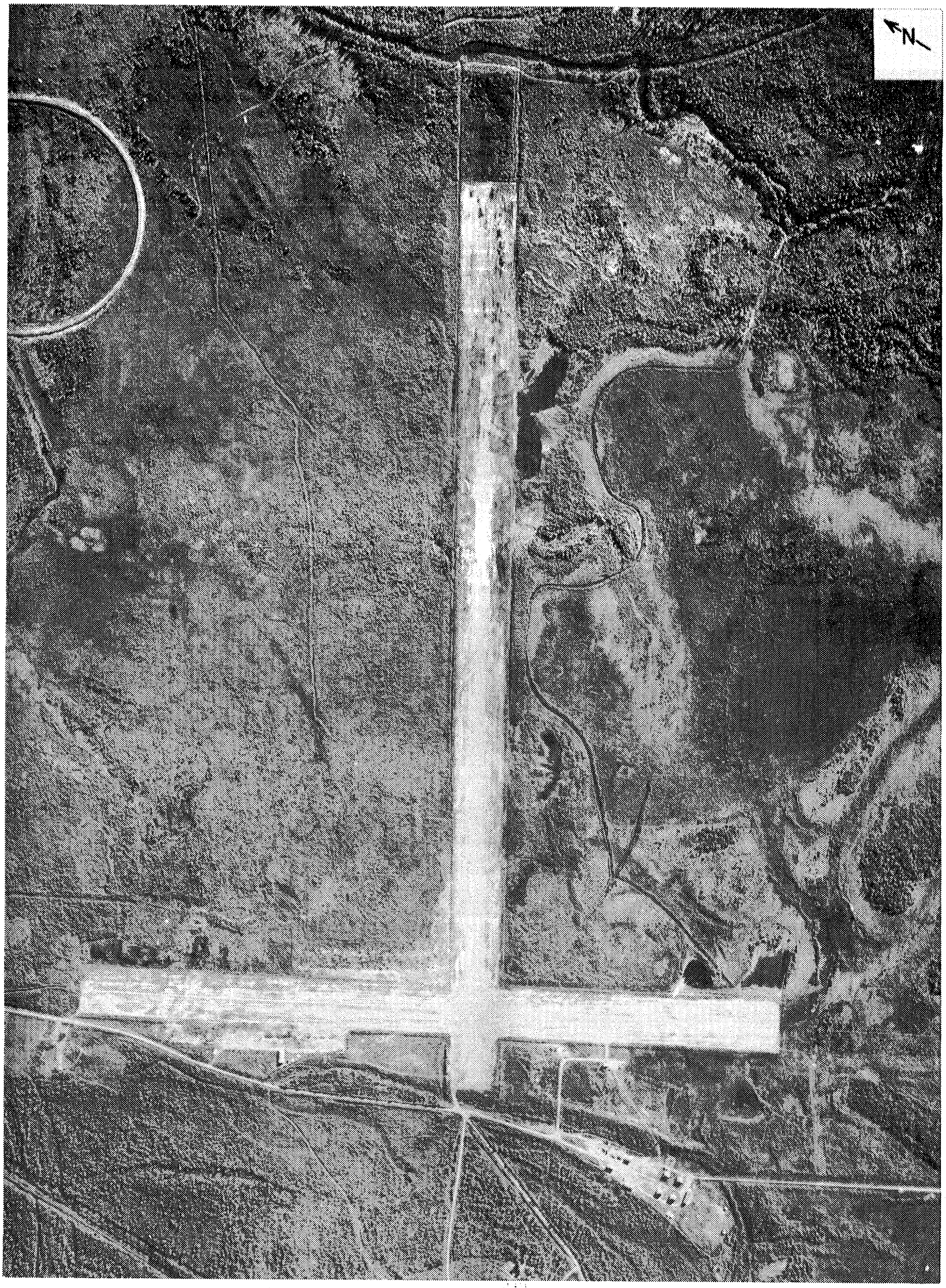


Plate No. 33 – Airfield at Nenana, Alaska

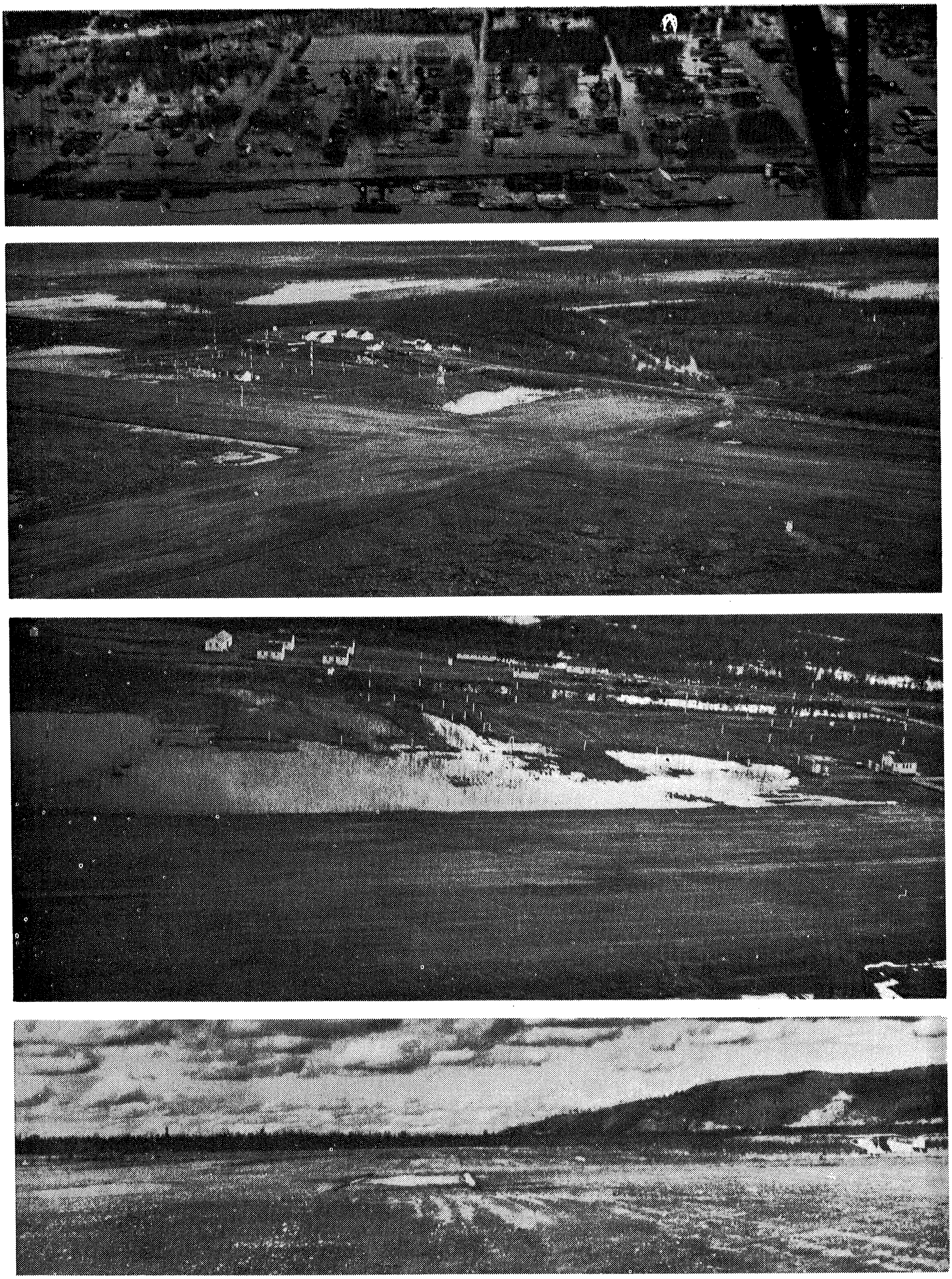


Plate No. 34-Scenes at Nenana during Flood of May 20, 1948

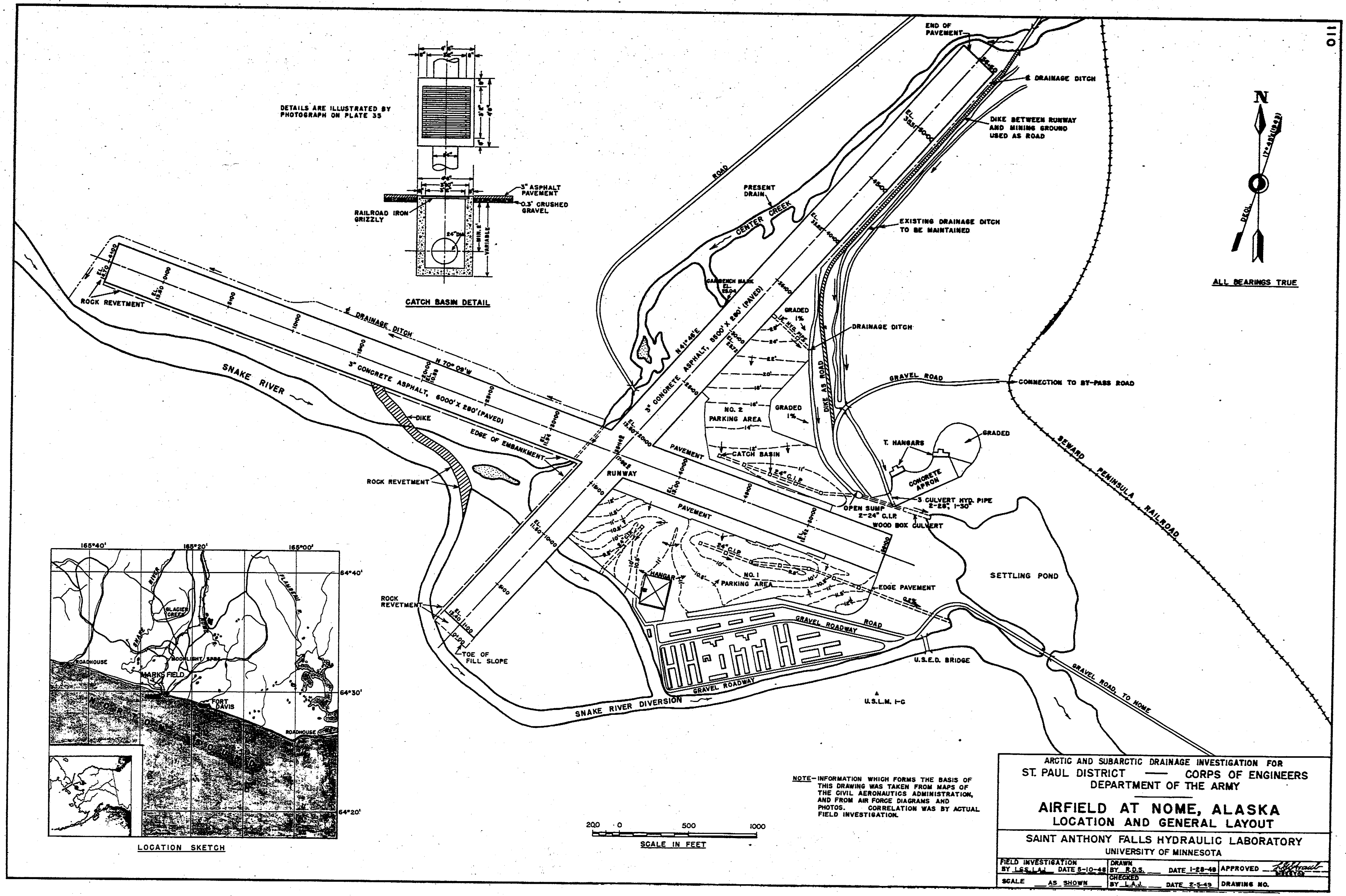


Fig. 26 — Airfield at Nome, Alaska

L. Nome (Investigation conducted May 9-10, 1948)

73. Description. Nome, one of the larger towns in the research area with an approximate population of 1600 people, is located in western Alaska on the south coast of Seward Peninsula at 165° 20' west longitude and 64° 30' north latitude. The territory is entirely devoid of trees. Tundra forms the predominant surface feature and permanently frozen ground exists at less than 3-ft depths. There are two airports at Nome. One, a local landing field, is adjacent to and north of the village. The other airport, an Air Force Base, consists of two paved runways each 280 ft in width. Location, general layout, and other details are shown in Fig. 26. Plates 35 and 36 contain photographs which illustrate local characteristics.

The Air Force Base, which is sometimes referred to as Marks Field, is situated in a northwesterly direction from the village and located on coarse tailings which resulted from gold mining operations. The infiltration capacity of this base material is very high and forms an excellent subgrade. Local field personnel report that they have observed only very slight variations in runway elevation. Heaving and settling action is at a minimum. This desirable feature, no doubt, can be attributed to the well-drained, nearly ideal subgrade.

74. Drainage of the Airfield. Drainage of the air base is, wherever possible, by systems of shallow open ditches. The two paved parking areas are drained in a different manner. The paved surfaces are sloped in the general direction of collecting inlets which convey the surface runoff into an underground conduit, which in turn discharges either into an open ditch or into Snake River. Upon checking actual conduit capacities against design criteria, it becomes obvious that the computed runoff rates exceed the rates at which the pipe lines can convey the water. Consequently, ponding can be expected to occur on the parking areas. This, however, is not serious as ponding at these locations for short durations cannot interfere with flight operations. Mr. A. C. Steinwandel, civilian employee of the Army and a long-time resident and construction superintendent in arctic regions, emphasized that the systems, even with long lengths of pipe underground, operated satisfactorily if proper maintenance precautions were taken. Inlet gratings must be covered shortly after time of freezeup in the fall and the covers removed prior to breakup in the spring. Without precautionary measures of this kind, underground pipe

lines will become filled with ice during the winter months when short periods of thawing temperatures create a small volume of runoff. This runoff, if permitted to enter the buried pipe lines, would subsequently freeze before it traversed the length of the line.

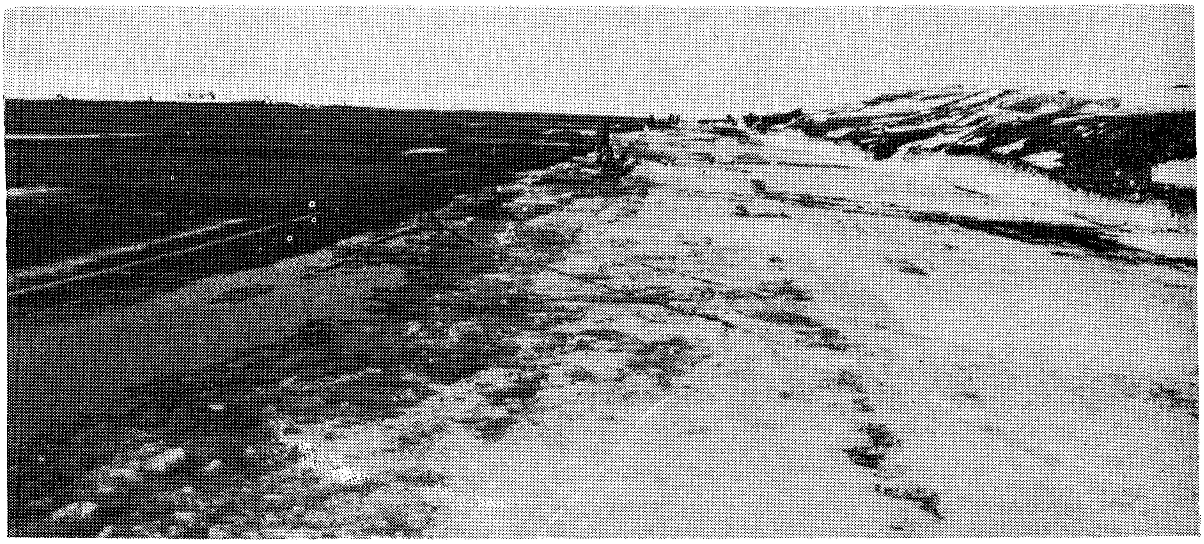
75. Flood Problems at the Airfield. The north-south runway is now located in the space which was formerly occupied by Center Creek. The creek section was filled with dredge tailings and the stream diverted to flow along the west side of the north-south runway and then along the north side of the east-west runway to Snake River. A portion of Center Creek discharge passes beneath the east-west runway through a 48-in. pipe. The watershed area is estimated at 25 sq miles and causes some flood problems, particularly in the spring if channels are not cleared of snow.

Major Whittington, Post Engineer, Nome Air Base, pointed out that high Snake River stages sometimes created a flood hazard. These high levels are not the result of intense rains and consequent high discharges, but are caused by high winds and storms on the Bering Sea. The resulting backwater effect in Snake River creates stage fluctuations, sometimes as high as 10 ft.

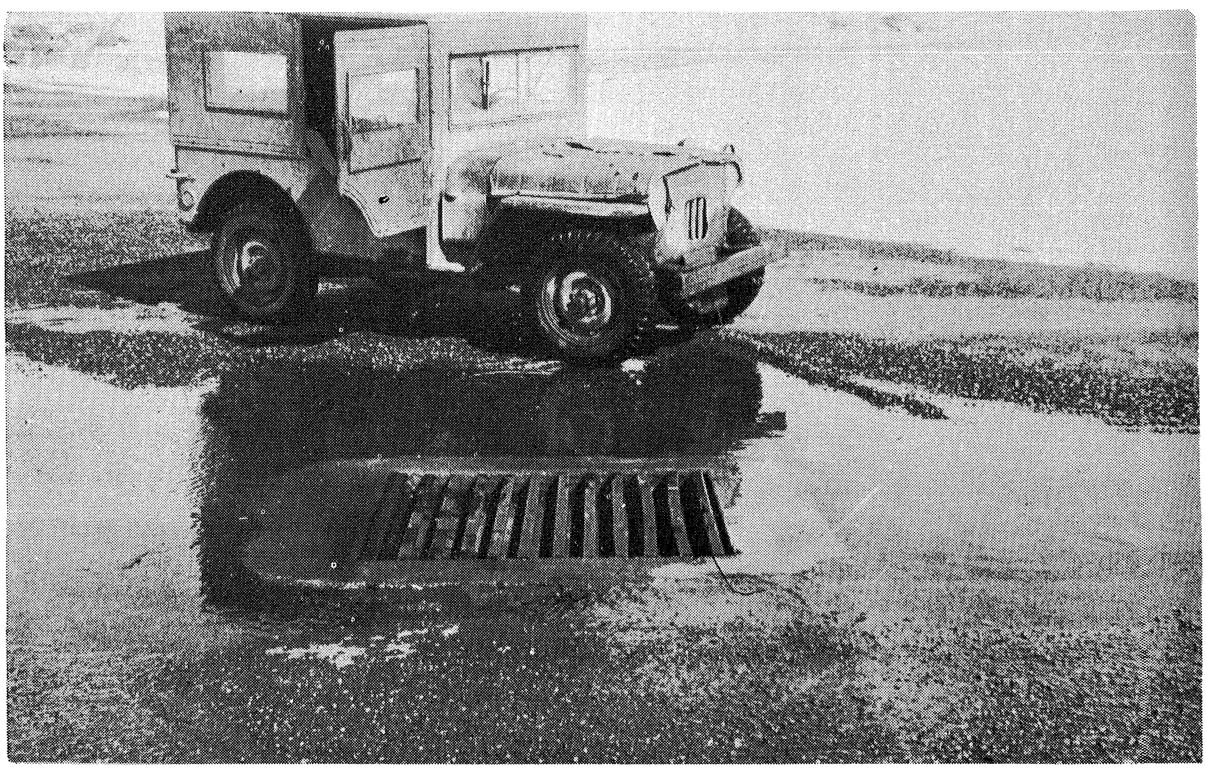
76. Removal of Snow. Removal of snow from runways, parking areas, roads, and ditches constitutes one of the larger maintenance costs. The absence of trees as protective shelter plus typical winds of high velocity contribute to a nearly continuous drifting of snow. Local field and maintenance personnel express the opinion that because of the persistent severity of drifting snow in this area, runways should be as narrow as possible in order to keep the space to be cleared of snow at a minimum size. It was further emphasized that ditches should be of such shape and dimensions as would permit the use of large snow-moving machinery. Photographs on Plates 36 and 37 illustrate maintenance work required to clear snow-filled and ice-covered drainage facilities.

77. Drainage in the Village and at the Municipal Field. There are no special facilities entailed in the drainage system for the village of Nome. Runoff from the roofs of buildings falls directly on the ground then via overland flow to shallow open ditches. Runoff from other areas is also conveyed to the eventual outlet by a crude system of shallow open channels. The local municipal airfield, a gravel-surfaced strip 190 ft wide and 3200 ft long, is located between two creeks. The land on either side of the runway slopes steeply away, a condition which provides almost an ideal system of natural

drainage. The actual runway grades are not truly uniform with consequent areas of depression. Runoff which reaches these depressions cannot escape except by evaporation or infiltration. Local Alaskans refer to this field as an all-weather strip and report that drainage difficulties are of a minor nature.

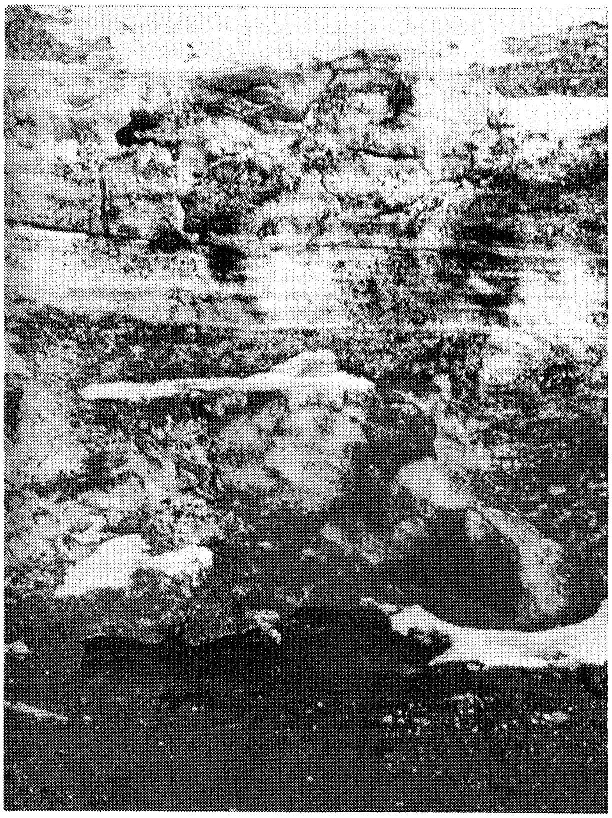


Looking west along the runway on May 10, 1948.



The grating for drainage inlet structures are made of light-weight railroad rails.

Plate No. 35 - Drainage Conditions at Nome Airfield



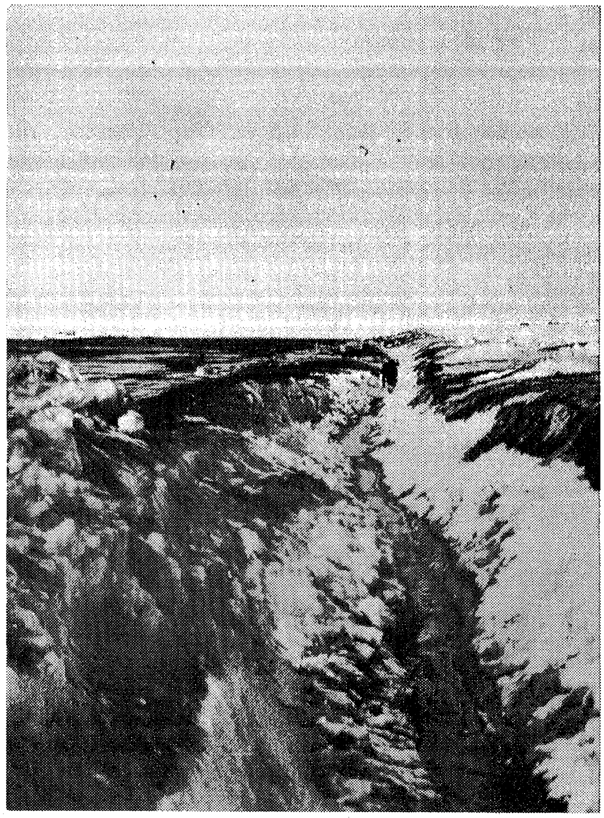


Plate No. 36 – Drainage Channels at Nome Airfield

A steam-thawing operation is in progress to free a drainage inlet structure of ice.

Considerable work was required to remove the ice and snow
that impeded drainage into this inlet.

Plate No. 37 - Steam Thawing

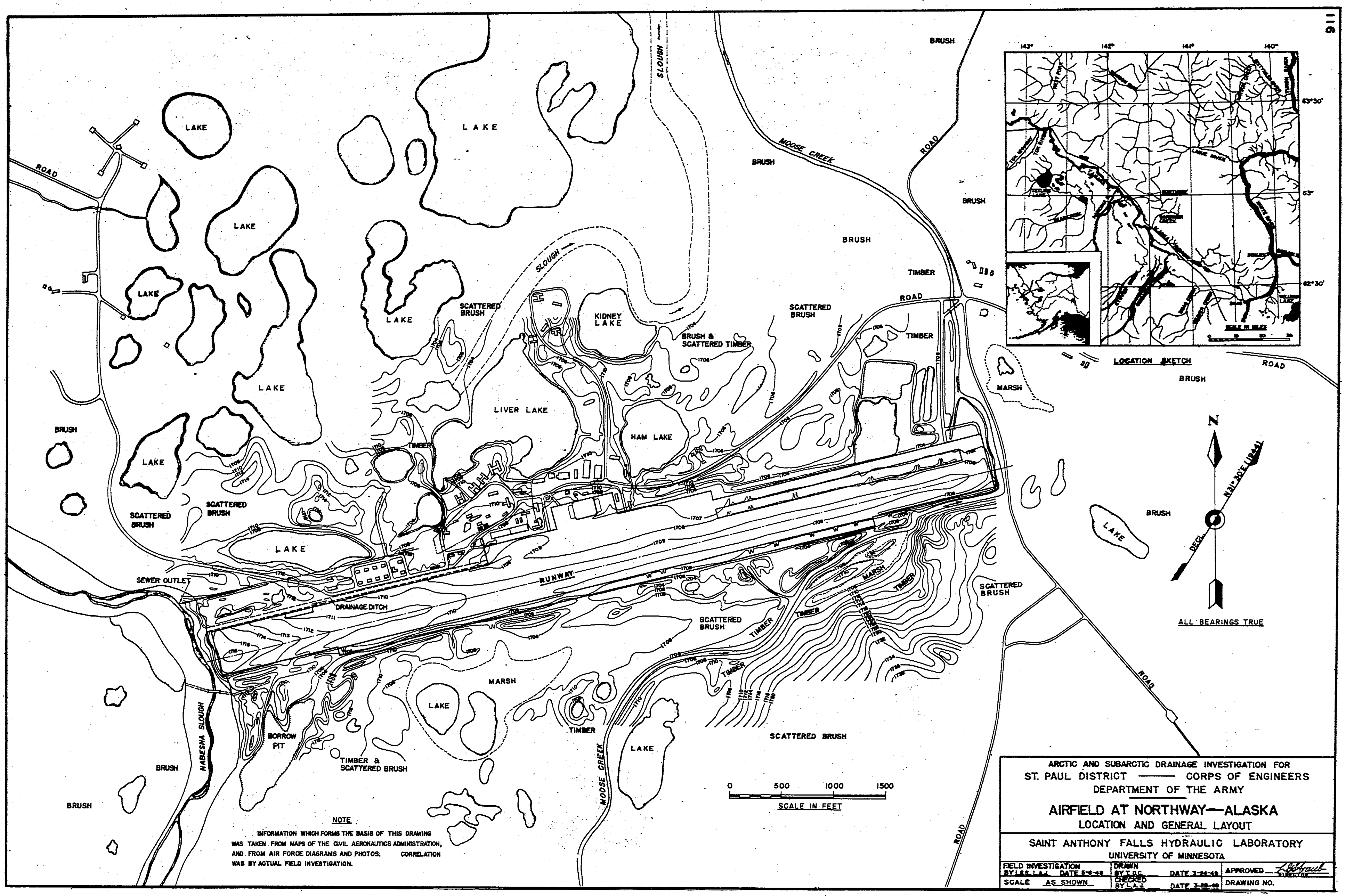


Fig. 27 — Airfield at Northway, Alaska

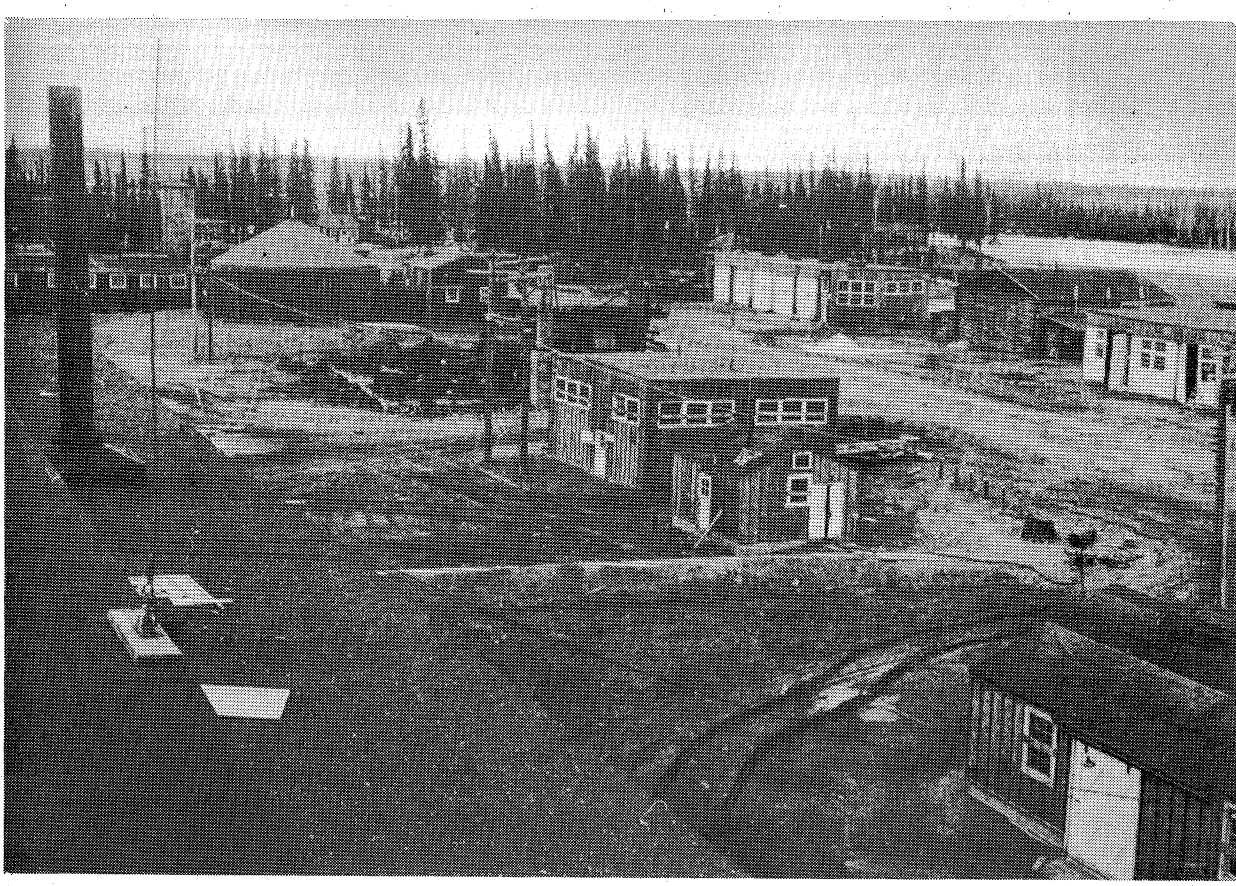
M. Northway (Investigation conducted May 6-7, 1948).

78. Description. Northway Airfield is located in the flood plain of the Nabesna River at 141° 58' west longitude and 62° 58' north latitude. Topography in the vicinity and to the north of Moose Creek is relatively flat. There are ponds, marshes, and sink lakes in close proximity to the field. Moss and peat cover the mineral soil to varying depths. Permafrost exists from 3 to 6 ft beneath the surface. The mineral soil is predominantly fine sand of a dark color. Considerable settling of building floors, as well as runway and parking apron areas, has been noted. Figure 27 and photographs on Plates 39 to 43 indicate the general layout, surface features and other characteristics at Northway airbase.

79. Drainage of the Airfield. Runway drainage is accomplished by overland flow to collecting inlets and outfall structures which discharge into open ditches that are located a short distance from and parallel to the runway shoulder. To expedite clearing of ice in the spring, small pipes arranged for steam-thawing operations are made a part of each outfall structure. Photographs on Plate 40 illustrate this feature. Settling action brought about by thawing of the permafrost adds to the difficulty of maintaining an efficient drainage system. The settling process is not uniform, resulting in large depressions which have no surface outlets. As a consequence, many pools of water are the result of comparatively little runoff. No system of subdrainage would reduce the amount of settlement. Instead, subdrainage may aggravate the situation as there would be a tendency for a deeper penetration of the thawing action. Although subdrainage would have a tendency to prevent heaving of fine-grained soils, it is not to be recommended where stability of surface elevations depends on the preservation of permanently frozen ground.

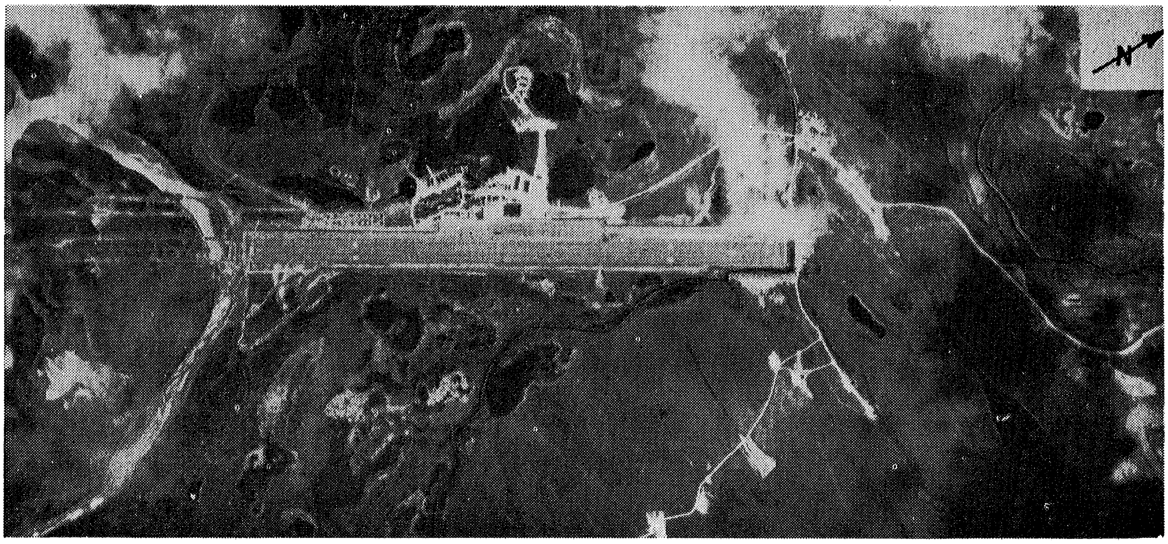
Verification of new design criteria could not be attempted as opinions relating to actual performance in past years were not available. The residents of the area at the time of the investigation had not been stationed at Northway for more than a comparatively short time. These men hesitated to make a statement as to actual operation, but expressed the view that in their opinion the capacity of existing inlets was adequate unless clogged by ice and snow. In this particular area gross inadequacy of structure capacity would be readily obvious. The soil appears to have little, if any, plastic properties; consequently, erosion would take place at the slightest provocation. Only one site of embankment was observed, indicating that the structures had not been overtaxed. It is believed that the one washout may have resulted from a clogged inlet. Extreme settlement had also occurred in the near vicinity. This may have been a contributing factor.

80. Drainage of the Camp Area. Surface water drainage in the camp area at Northway was not perfected to any marked extent. Depressions, into which watersheds of considerable size drained, existed without provision for surface outflow. According to local residents, these depressions, probably the geological beginnings of future sink lakes, were dry except for a short period following each spring breakup.

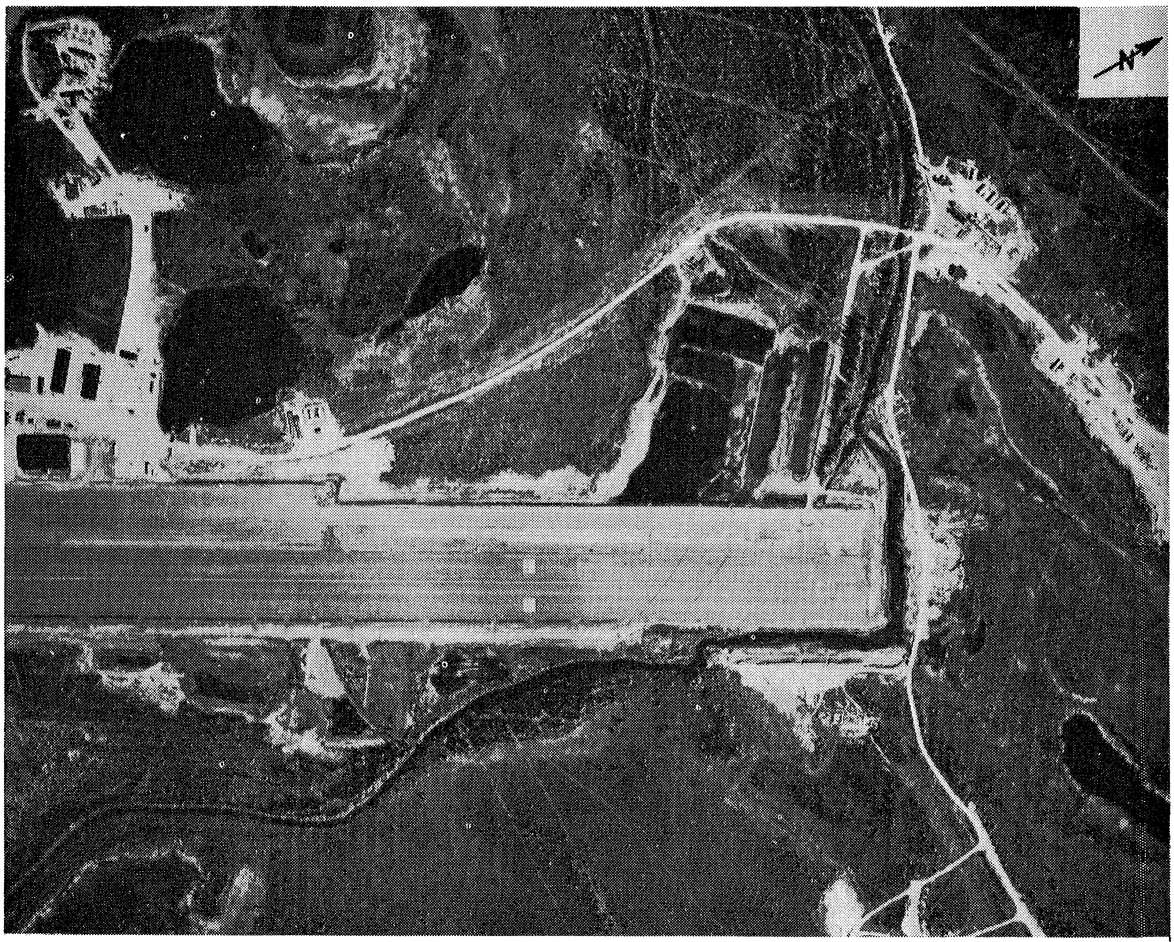


A large percentage of drainage is accomplished by proper grading. Runoff proceeds via overland flow to wide shallow ditches or to natural swales and depressions.

Plate No. 38 – Workshop Area at Northway



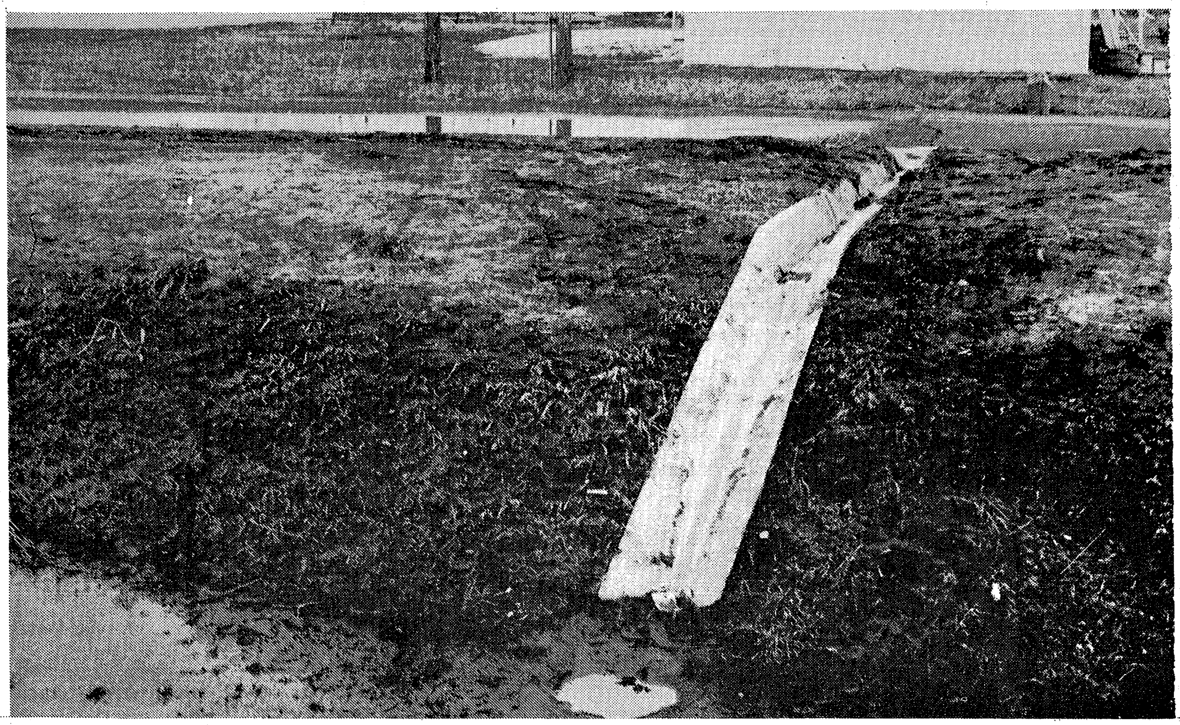
Plan view of Northway Airfield from an altitude of 15,000 ft.



Details of the northeast part of the runway indicate that a small creek had to be rerouted to provide sufficient space.

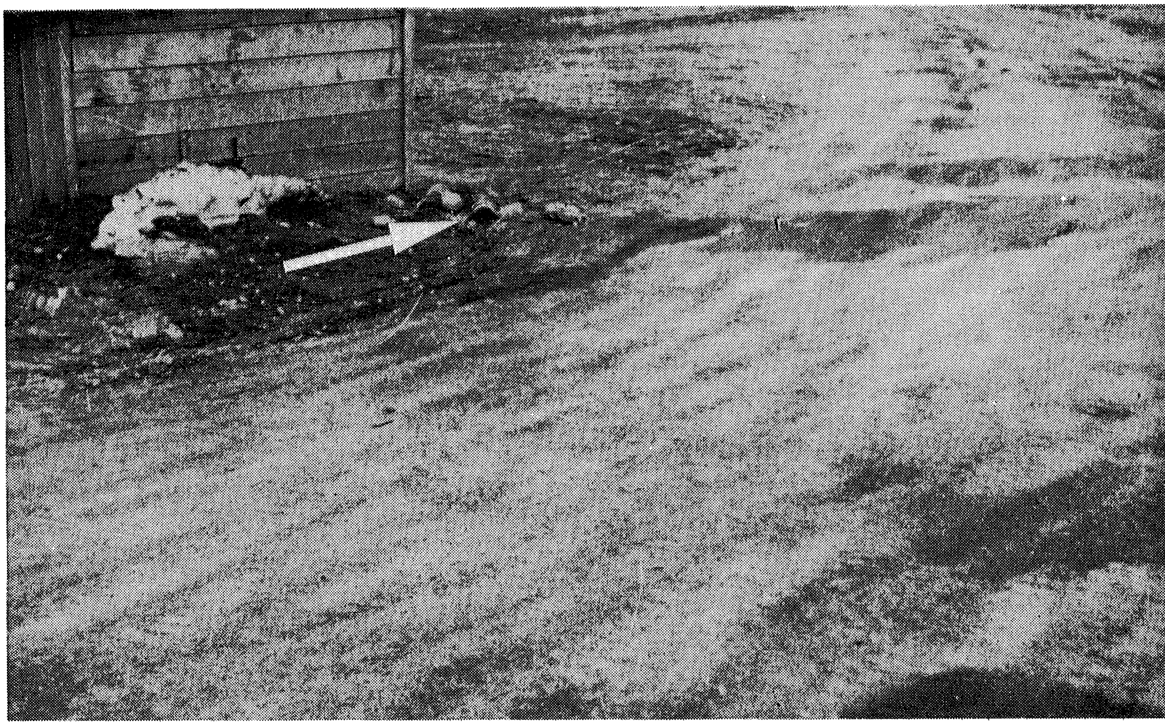
Plate No. 39 - Airfield at Northway, Alaska

Drainage outfall structures are equipped with steam pipes to facilitate thawing.

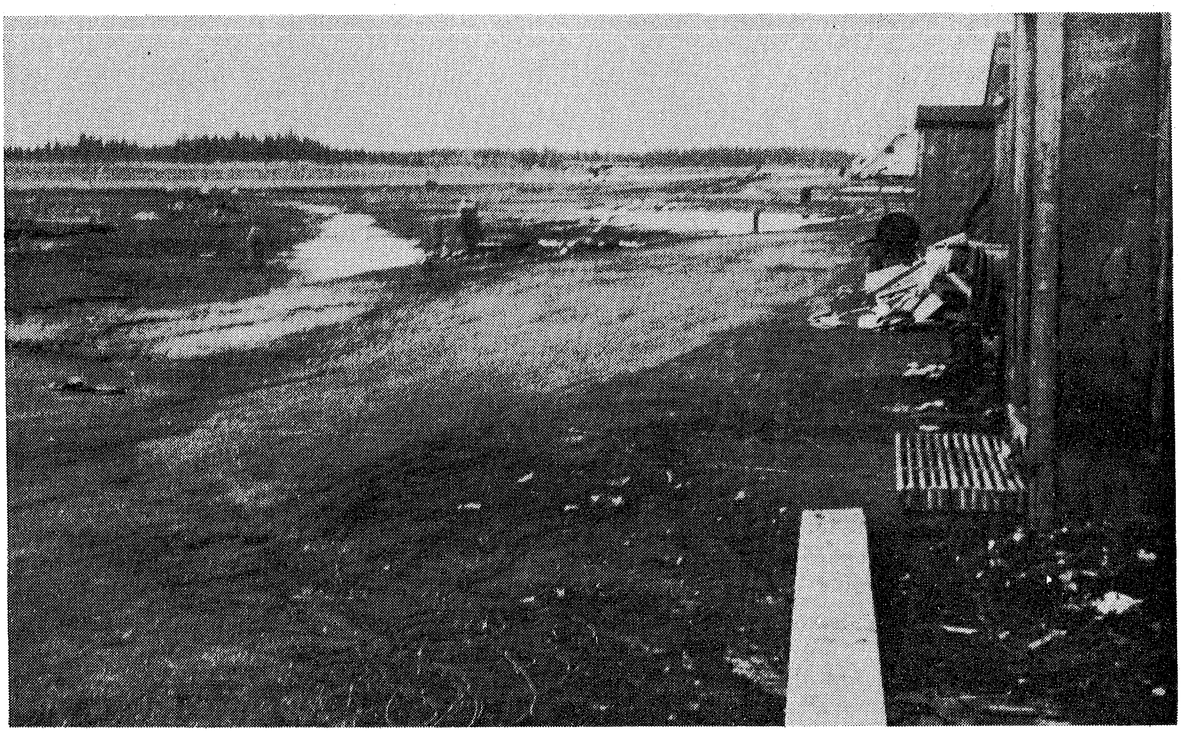


This concrete outfall structure was originally constructed sufficiently low to drain the area that is covered with water.

Plate No. 40 - Drainage Facilities at Northway



The 4-in. wooden pipe shown in the upper left part of the picture is the outlet to 10,000 sq ft of surface area.



Wide, shallow drainage ditches in which heavy snow-moving equipment can operate are preferred in this area from a maintenance standpoint.

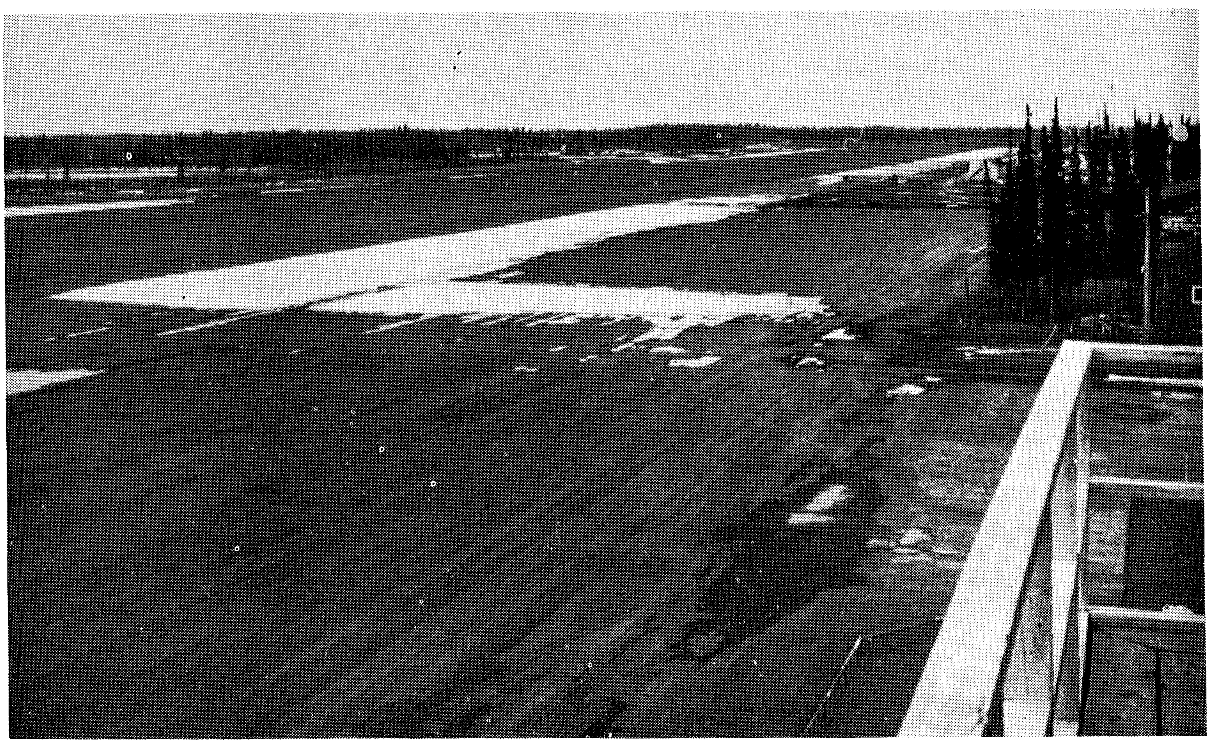
Plate No. 41 – Drainage Conditions at Northway

Areas where ponding can occur are not recommended for arctic and subarctic regions.

Looking northeast from the roof of the hangar.

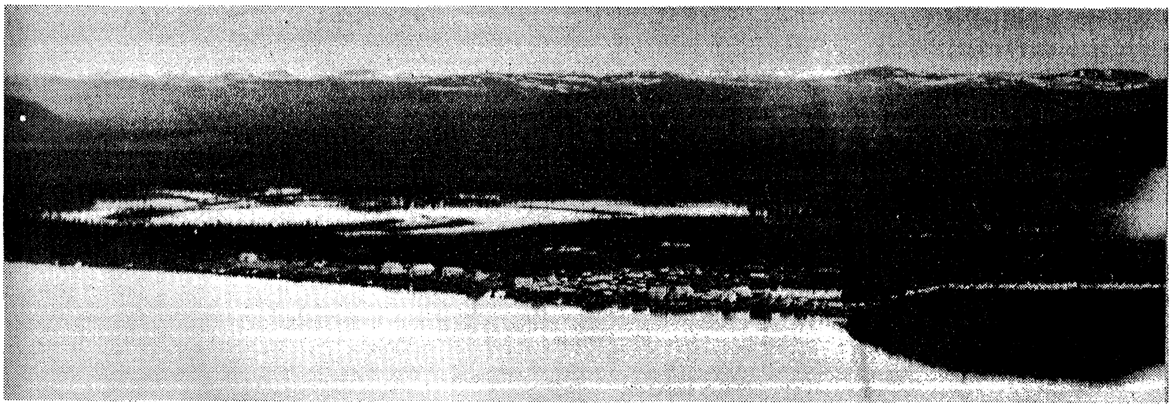
Plate No. 42 - Views from Roof of Hangar at Northway

Looking northeast.



Looking south.

Plate No. 43 - Views from the Tower at Northway



Looking northwest across the Yukon River at the Village of Nulato.

The Nulato Airfield is located in the cleared area on the hill.

An aerial view of the Village of Nulato.

Plate No. 44 – Scenes near Nulato, Alaska

N. Nulato (Investigation conducted May 26, 1948)

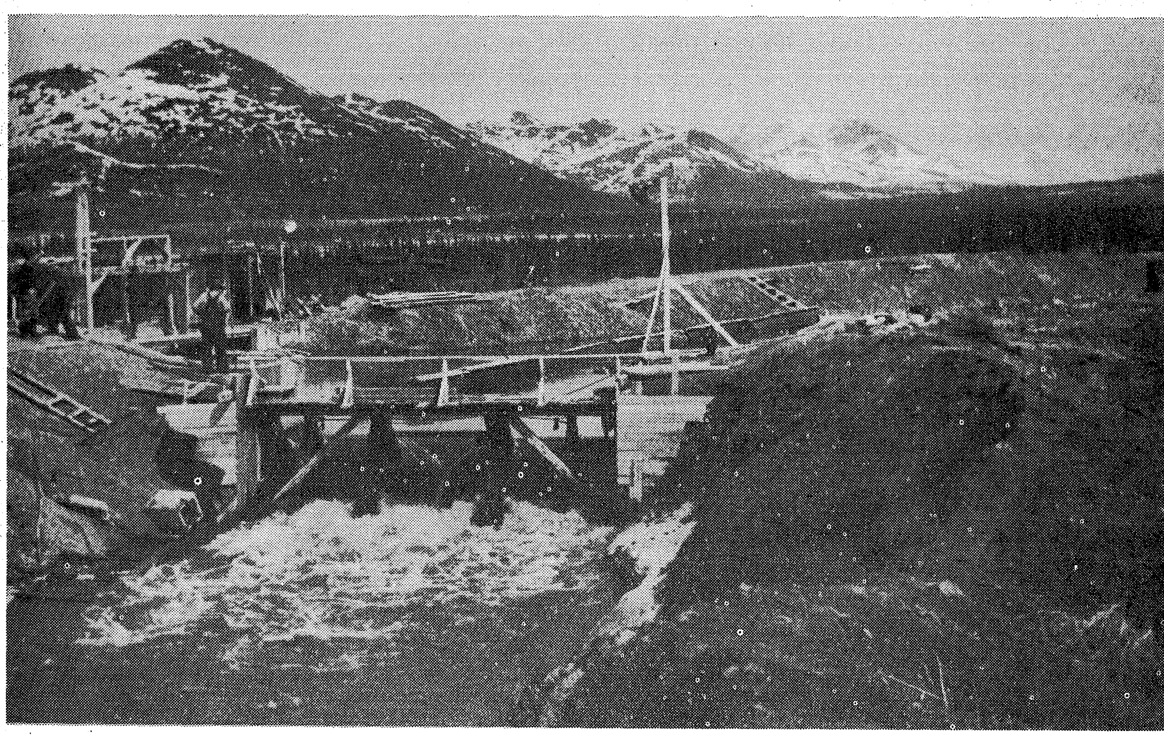
81. Description. Nulato, a small village with a population of about 120 people, is located on the north bank of the Yukon River at 158° 07' west longitude and 64° 43' north latitude. The terrain in the immediate vicinity, although not mountainous, is quite rugged. The village is located in a relatively low, flat area which is subject to springtime river floods. The local airfield is situated a short distance to the northeast of town and on the crest of a high ridge about 100 ft above the river. The strip is narrow, unsurfaced, and slopes decidedly from one end to the other. The extremity which is nearest the village is at least 100 ft lower than the opposite end. There are also prominent grades from the runway centerline in both normal directions. Natural drainage conditions are nearly ideal. The compact soil has a texture of very fine sandy loam with very small amounts of clay. The material is not plastic when wet and erodes very easily. There were no special drainage facilities with which to collect and convey runoff down the steep slopes. Even so, the investigation did not disclose gullying or other evidence of serious erosion.

82. Views of a Local Pilot. Mr. Williams (pilot for Northern Consolidated Airlines) reported that the Nulato field was accessible to small craft at all times. He stated that he had landed and taken off in rainy weather and could not recollect any particular operational difficulty. The surface of the landing strip remained firm and compact. Heaving and settling of the runway grade with resulting humps and depressions were of an insufficient magnitude to be objectionable to the flyer.

83. Results of Observations. All observations and subsequent discussions with reference to the local airport at Nulato created an impression that either the intensity of rainfall and runoff must be very low, or if the rate of rainfall is high, the duration of it must be short. Without either of these two conditions prevailing, it would not seem unreasonable to anticipate very definite evidence of erosion. This, as previously indicated, was not the case.

Photographs of Nulato and vicinity are shown on Plate 44.

In the spring of each year a dragline operating 24 hours per day is engaged to remove large cakes of floating ice from the diversion channel.



To assure proper functioning of hydraulic structures maintenance personnel are employed to keep the facilities free of ice.

Plate No.45 – Maintenance of a Diversion Channel at Nyac

O. Nyac (Investigation conducted May 16, 1948)

84. Description. Nyac, a small gold mining camp, is located in the Tuluksak River valley at 160° 05' west longitude and 60° 56' north latitude. The terrain is of rugged relief except for the valley floor which is narrow and flat in a normal direction to the course of the river. The soil is of very coarse texture with an abundance of gravel. The gold mining dredge encounters ledge rock when operating at depths of about 22 ft below the surface. A sparse growth of grass and spruce forms the predominant surface cover. The trees are not very large.

85. Drainage at a Private Airfield. In addition to the camp, the New York-Alaska Gold Dredging Corporation maintains a 4000-ft landing strip in the summer months. This strip is situated in the valley floor and parallels the course of the river. It is built of tailings, which are a waste product of the dredging operations. There is a very pronounced slope from one end of the field to the other, but slopes normal to the lengthwise direction are imperceptible. Mr. J. K. Crowdy, superintendent for the corporation, claims that he has never observed any runoff from the strip except from melting snow in the spring. He claimed that the infiltration capacity of the very coarse surface and base material was usually greater than the rate of rainfall. Observations during the time of the investigation confirmed Mr. Crowdy's statements, as it was noted that all depressions in the runway surface were dry and firm, even though some snow still remained. It was estimated that 90 per cent of the snow in the lower altitudes had melted.

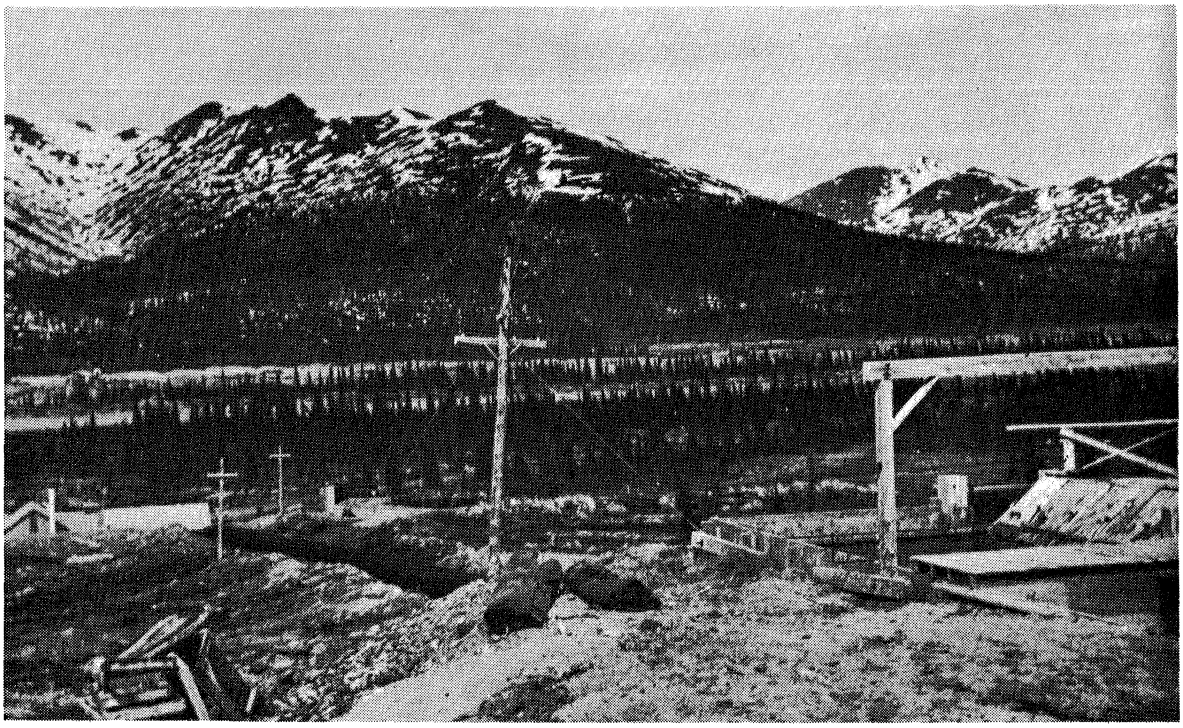
86. Special Maintenance Requirements. The maintenance requirements from a water supply standpoint of Nyac's hydroelectric power plant are of interest. The source of water supply is the Tuluksak River. In early spring and late fall, 270 cfs are diverted via a 4-mile diversion channel to control works at the intake to the penstock. Here the flow is separated and 90 cfs maximum is permitted to enter the penstock after passing beneath a gate arrangement which is supported by floating oil barrels. The object of this device is to encourage floating ice to flow by the penstock, with two-thirds of the diverted rate. A three-fourth yard crane equipped with a clam shell bucket stands by at some distance upstream from the intake, and by action of the bucket it either removes or breaks chunks of ice that are too large to pass the control works. A man stands by in the vicinity of the control works at all times to

guide large ice cakes through the gate sections or to connect a 300-amp arc welder to a specially designed grating in case clogging of it by needle or frazil ice becomes imminent (photographs of Plate 47). Mr. Crowdy pointed out that only after considerable experimentation was it possible to determine such things as rate of diversion, heating required for the intake grating, and overall maintenance technique.

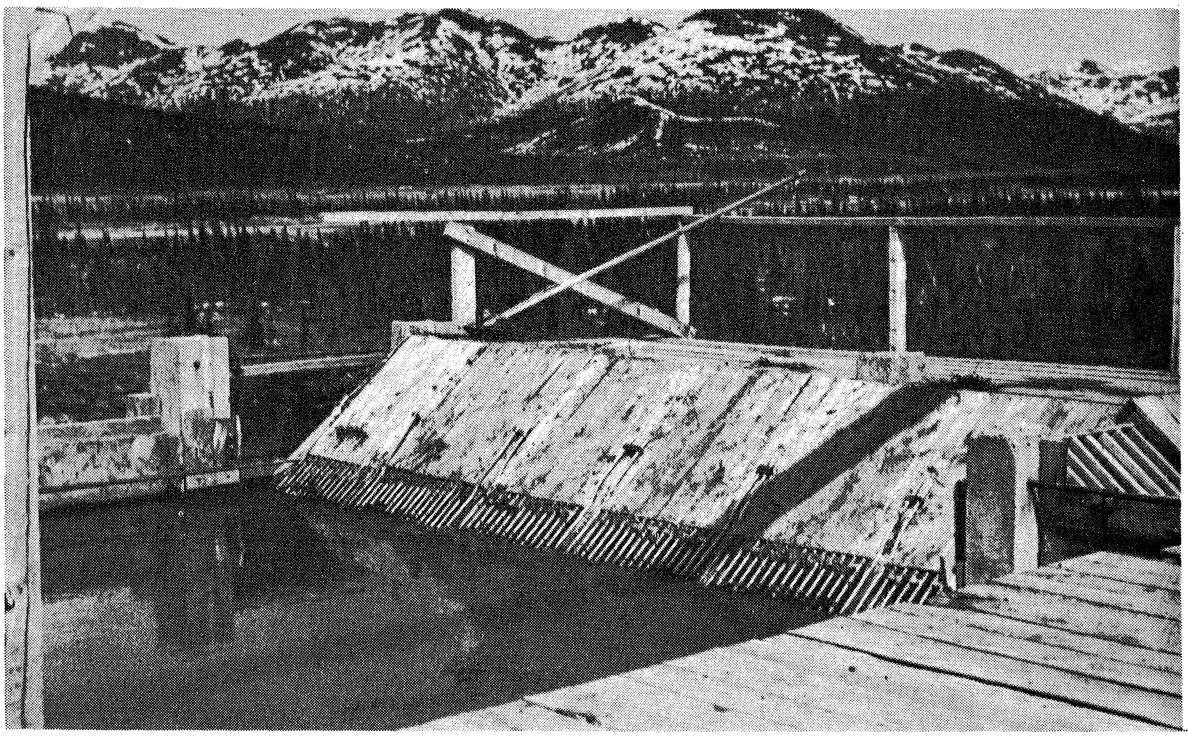
87. Analysis of Diversion Channel Capacity. The route of the diversion canal follows around the mountains at some elevation on the side slope and must of necessity intercept many small watersheds. The actual capacity of the side hill channel is estimated at about 400 cfs. The watershed area of some of the intercepted dry runs exceeds several square miles. Under these circumstances, it seems reasonable to suppose that the diversion channel, during intense rains, would be subjected to discharges which would exceed its own capacity by inflow from any one or several of these intercepted areas. It was pointed out, however, that a washout from such anticipated conditions had never occurred and that ordinarily rain was light, of low intensity and short duration. It was also pointed out that the soils in this region had a large absorptive capacity and were seldom, if ever, found in a saturated condition in the summer months.

Two-thirds of the channel flow is diverted in order to carry away large volumes of floating ice.

Plate No. 46 - Diversion Channel Outlet at Nyac



The timber structure at the right is connected to a 40-in. diameter conduit which leads to the turbines.



This heating element melts ice that would otherwise clog the inlet grating.

Plate No. 47 - Intake to the Penstock at the Nyac Power Plant

Plate No. 48 – Scenes of the Airfield at Ruby, Alaska

P. Ruby (Investigation conducted May 26, 1948)

88. Description. Ruby, a small town with a population of about 140, is located on the south bank of the Yukon River at 155° 30' west longitude and 64° 44' north latitude. The terrain in the vicinity is quite rugged. A medium to a dense stand of spruce, birch, and aspen forms the predominant type of vegetation. Grass is the form of surface cover in the open areas. The local airstrip is located one or two miles to the southeast, and occupies a position on the crest of a high ridge. The runway is not surfaced and is decidedly crescent-shaped in plan view. Landings and takeoffs, except for very light craft, must be made in a sweeping arc to follow the runway around the crest of the hill. The soil is very fine textured and compact. Actual soil composition must contain but very little clay as it is not plastic or sticky when wet.

89. Drainage of the Airfield. Natural drainage is very good because of prominent slopes. With the exception of one intercepting ditch, there are no special drainage facilities. Mr. Williams stated that he had often landed at Ruby in rainy weather and experienced no difficulty even with quite heavy loads. It was raining during the time of the investigation, yet observations did not disclose any water-filled depressions. It was pointed out that very little maintenance work is done on airports such as the one at Ruby. Nevertheless, the general condition was surprisingly good. The runway surface remains firm and compact. Heaving and settling of the grade with resulting humps and depressions are not of sufficient magnitude to be objectionable to the flyers that make regular and frequent use of the field.

All observations and subsequent discussions with reference to the local airport at Ruby created an impression similar to the one that was formed as the result of the investigation at Nulato.

Plate 48 contains photographs which show some local conditions at Ruby.

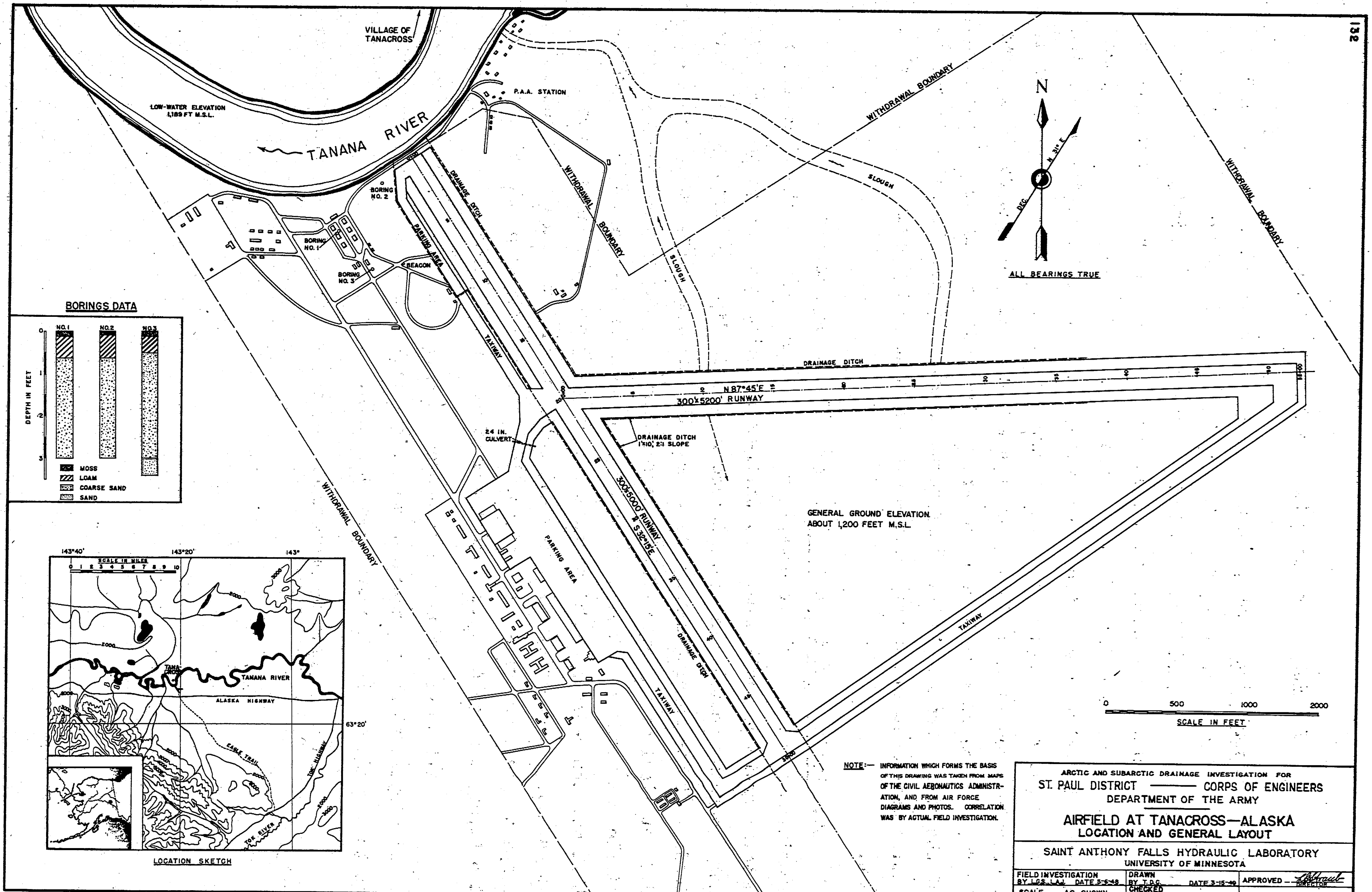


Fig. 28 — Airfield at Tanacross, Alaska

Q. Tanacross (Investigation conducted May 6, 1948)

90. Description. Tanacross, a small village with a population of about 140, is located in the upper Tanana River valley, at 143° 20' west longitude and 63° 24' north latitude. The terrain in the vicinity is flat varying in elevation from 8 to 20 ft above the low water level of the Tanana River. Mean altitude of the general ground surface is close to 1200 ft. Soil and subsoil are very pervious. Borings taken by the Civil Aeronautics Administration show moss and topsoil to a 6-in. depth, followed by coarse gravel mixed with loam to 3-ft depths and overlying sand. Photographs of the area show a striated pattern of tree growth close to the river, together with serpentine sloughs indicating the past occurrence of ice jams and river floods. Figure 28 shows the general layout of the Tanacross airport. Other characteristics are indicated photographically on Plate 49.

91. Drainage of the Airfield. Drainage of the runways and parking aprons is entirely by overland flow to shallow open ditches which are situated on either side of and parallel to the runways.

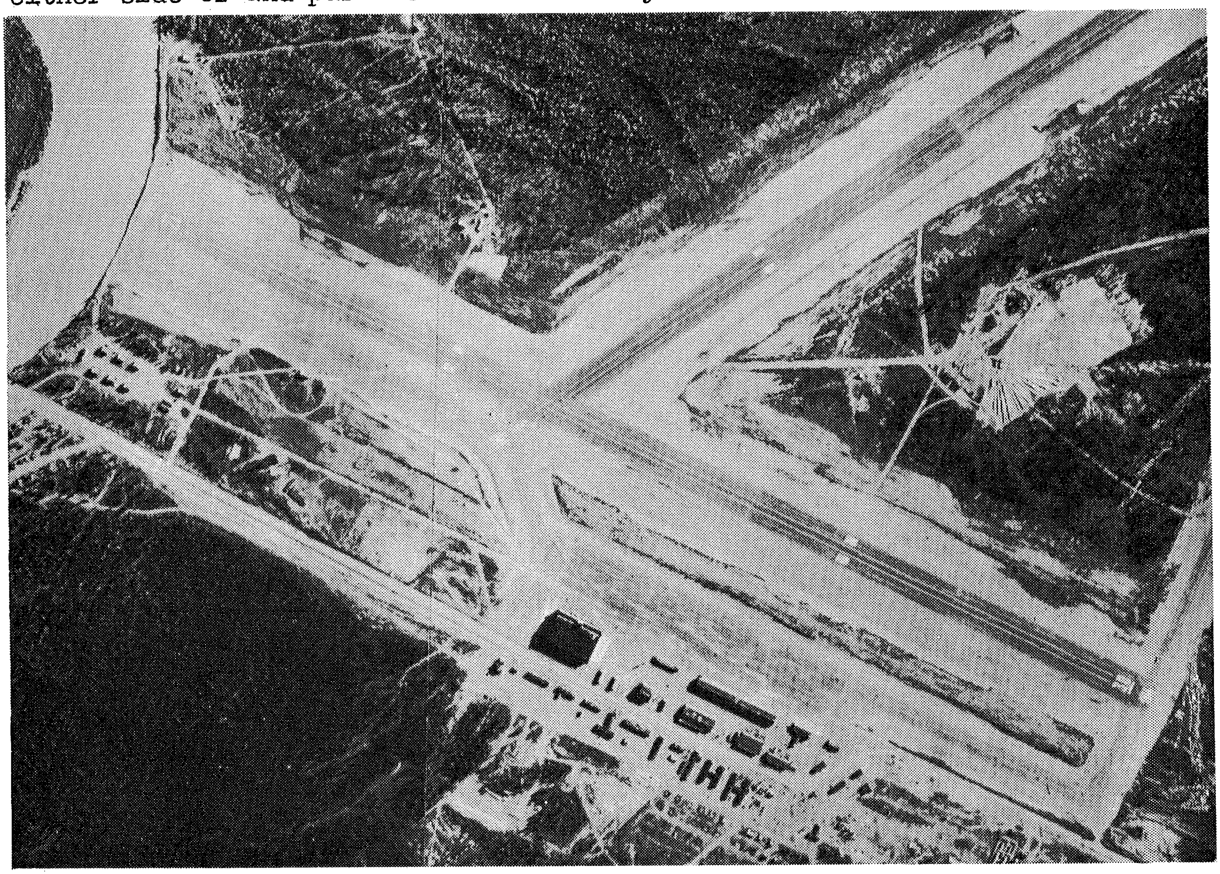


Plate No. 49 - Airfield at Tanacross, Alaska

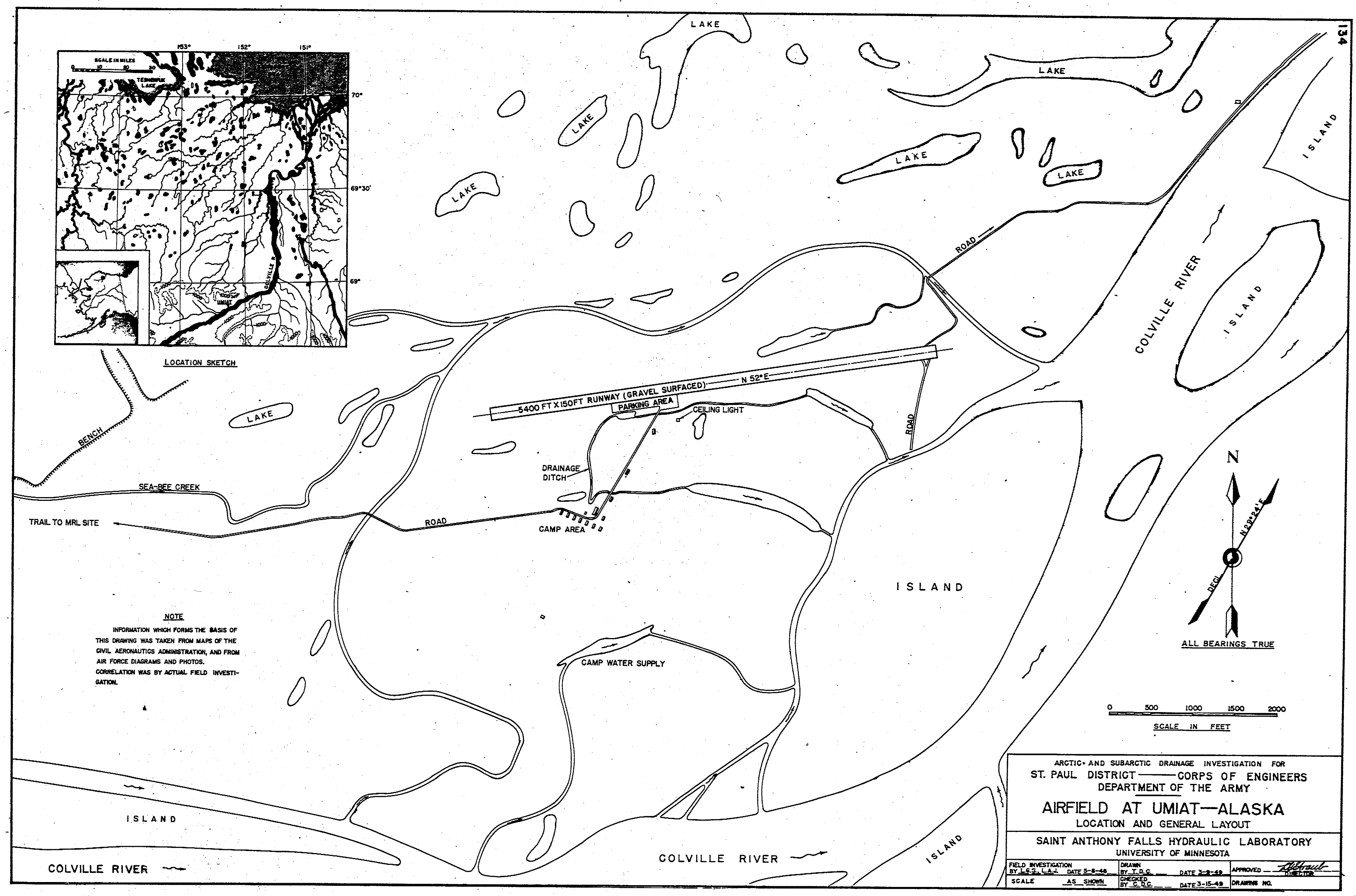


Fig. 29 — Airfield at Umiat, Alaska

R. Umiat (Investigation conducted May 8, 1948)

92. Description. The Umiat airport, an installation of the Navy Department, is located on the north bank of the Colville River at 152° 10' west longitude and 69° 23' north latitude. The airport consists of one gravel-surfaced runway which is 150 ft wide and 4000 ft long. The terrain is entirely devoid of tree growth and slopes up rather sharply to the north of the river. To the south the upward slope is more gradual to the foot of Brooks Range. In the vicinity of Umiat in the summer months, the Colville River appears in aerial view as a profusion of bars and islands, which no doubt are inundated during each breakup period. These bars and islands contain no surface vegetation whatsoever. At higher elevations approximating those of the river's primary bank, surface vegetation consists of grass and moss. Permafrost exists a short distance beneath the surface. Figure 29 shows the general layout and location. Other characteristics are shown photographically on Plates 50 and 51.

93. Drainage of the Airfield. Drainage at Umiat is entirely by overland flow to shallow open ditches. It is important that ditches be of such shape and dimensions that heavy snow-moving equipment can be used shortly before breakup to clear the channels of snow. In regions such as are represented by Umiat, drainage is of considerable more importance than would be expected by the appearance of the surface in either summer or winter. Surface configurations, although indicative of the nature of subsurface materials, are not certain criteria except in a general way. Slope and contours of the permafrost table often differ from the ground surface and may control drainage of ground water. Ice lenses and wedges may exist at various depths. Flood stages of nearby lakes or rivers may be appreciably higher than expected. The first step then in planning for drainage after selection of an airfield site is to obtain, in addition to topography, detailed information on soil, ice, and ground water. This can be accomplished only by test hole drilling and sampling. The actual conduct of acquiring test hole data should be emphasized in order that some water phenomena clues will not be unobserved. Temperatures, for instance, may indicate a probable source and should be recorded. Gas bubbles may indicate ground water from deep sources moving upward under pressure. Coloration of the soil profile is indicative of water movement.

Plate No.50 – Airfield at Umiat, Alaska

The landing field at Umiat can accommodate a plane of the size indicated in this picture.

Looking south at the Navy installation.

Plate No.51 – Scenes at Umiat, Alaska

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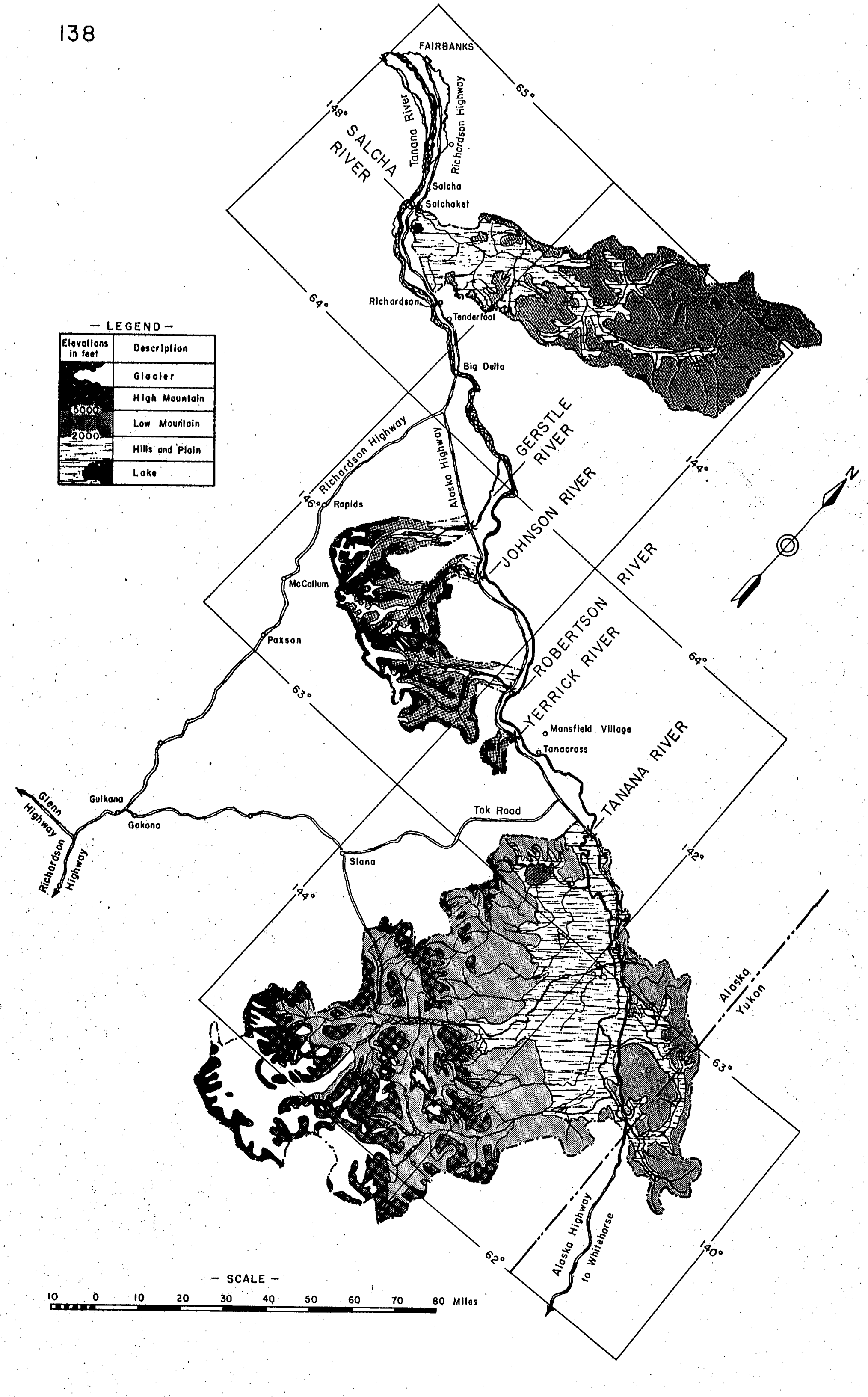


Fig. 30 - Drainage Boundaries of Selected Watersheds Along the Alaska Highway

S. Richardson-Alaska Highway (Fairbanks to Northway)
(Investigation conducted May 5 and 7, 1948)

94. Description. The Richardson Highway from Fairbanks to Big Delta traverses a distance of 91 miles. In general, it follows the wide valley of the Tanana River. It is fairly straight except for relatively short stretches where it is necessary to either climb over ridges or follow the base of some bluff. During the trip of May 5, the roadway was in good shape despite inadequate maintenance. Of the entire 91 miles, the first 20-mile stretch between Fairbanks and Eielson Air Force Base was in the poorest condition. This was due, no doubt, to the heavier and greater traffic to which it had been subjected. At one section there was evidence of icing (photographs on Plate 52). About 800 ft of highway had been covered with ice to depths of from 2 to 4 ft.

The Alaska Highway from Big Delta to Northway, a stretch of about 170 miles, was in excellent condition at the time of the investigation. In general, this highway follows the wide valley of the Tanana River. There are no sharp turns and slight grades are infrequent. The road section is about 30 ft wide and has a pronounced center crown. The grade is well above the general ground elevation and a shallow flat sloped ditch parallels both sides. The road has a gravel surface.

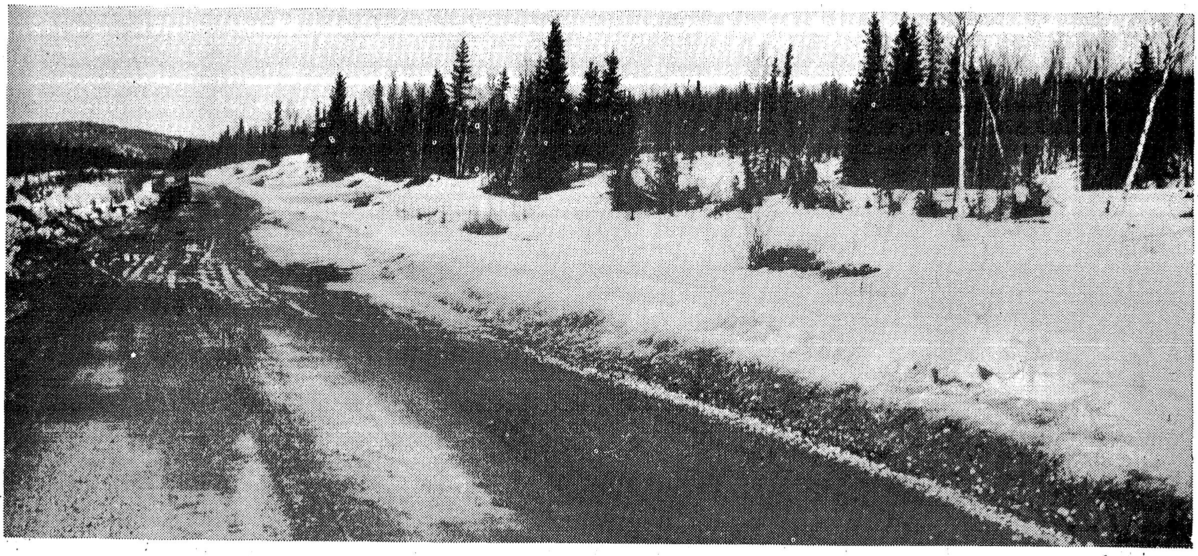
95. Selected Watersheds and Size of Bridges. Figure 30 shows general topography along the Richardson and Alaska Highways from the Salcha River to the Canadian border. Watershed areas of rivers at bridge sites are indicated. It is of interest to compare approximate bridge sizes with their respective drainage areas.

TABLE XI

BRIDGE AND WATERSHED DATA

Bridge	Watershed sq mi.	Bridge Size
Salcha River	2210	2-200' spans
Gerstle River	244	9-180' spans
Johnson River	396	4-200' and 1-160' spans
Robertson River	525	
Yerrick River	42	1-200' span
Tanana River near Tok	7630	3-160' spans

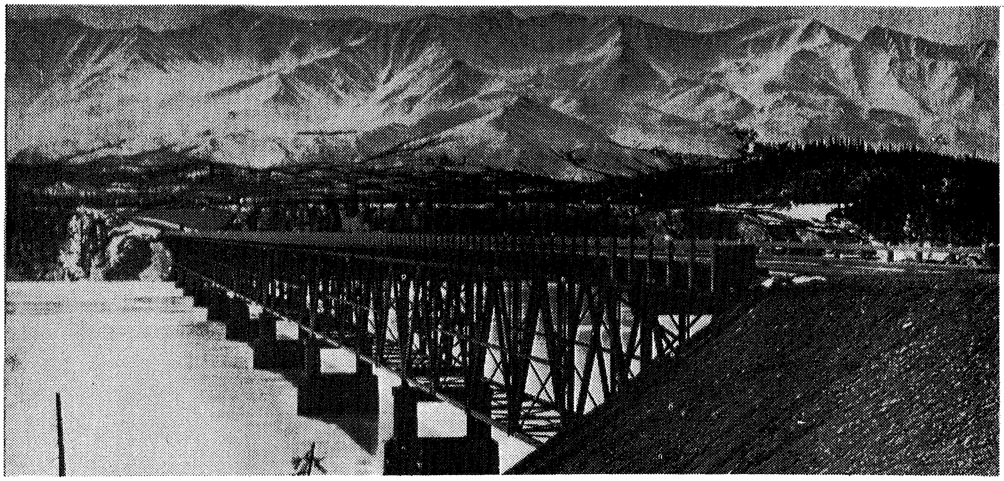
The length of a bridge is, of course, not the only factor which determines discharge capacity at the site. In each of the above cases, however, the elevation of the deck was well above any observed evidence of flood heights. It is of importance to note that there is no relation between the size of the waterway opening and the watershed area of the river over which the bridge was built. Photographs of Plates 53 to 57 show these bridges, as well as other sites of interest.

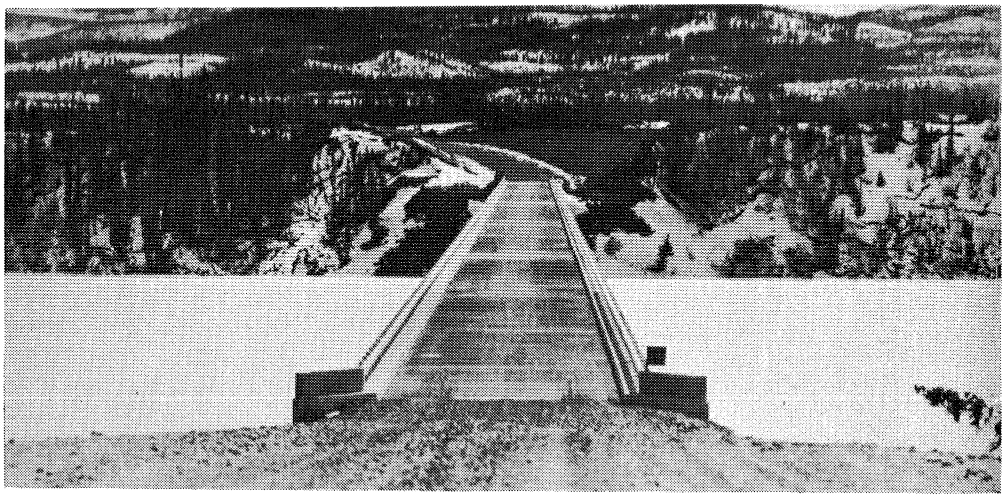


At this location surface icing had covered the road to a depth of 4 ft.

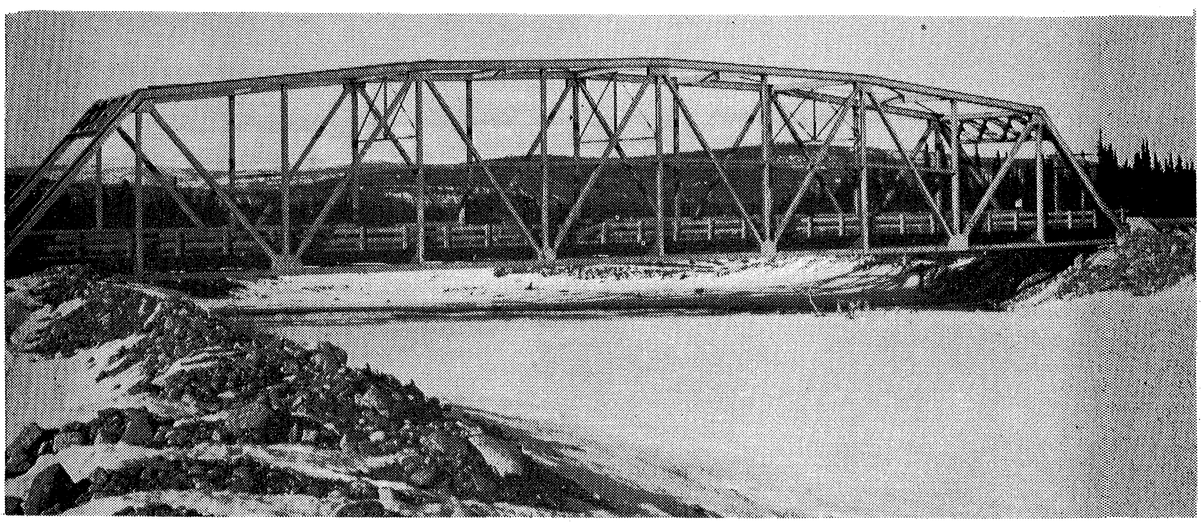
A short distance upstream from the ice-covered highway many leaning trees were noted.

Plate No.52 – Surface Icing on Richardson Highway



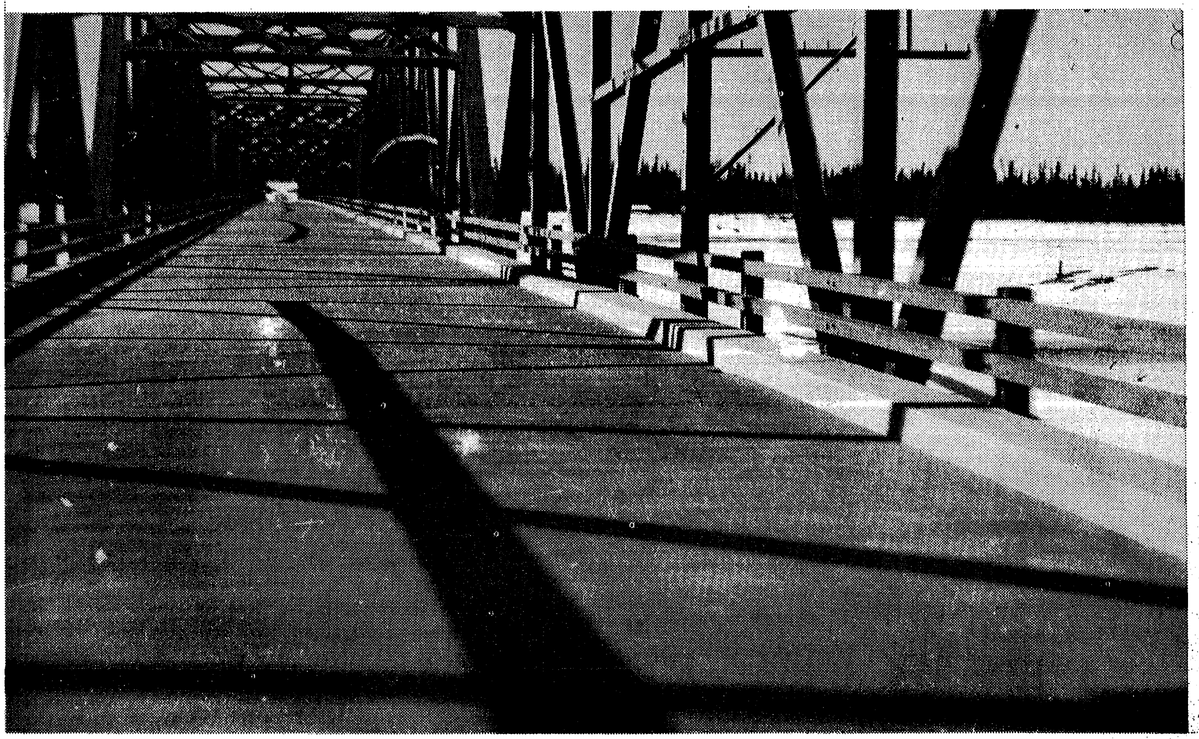


Robertson River Bridge.

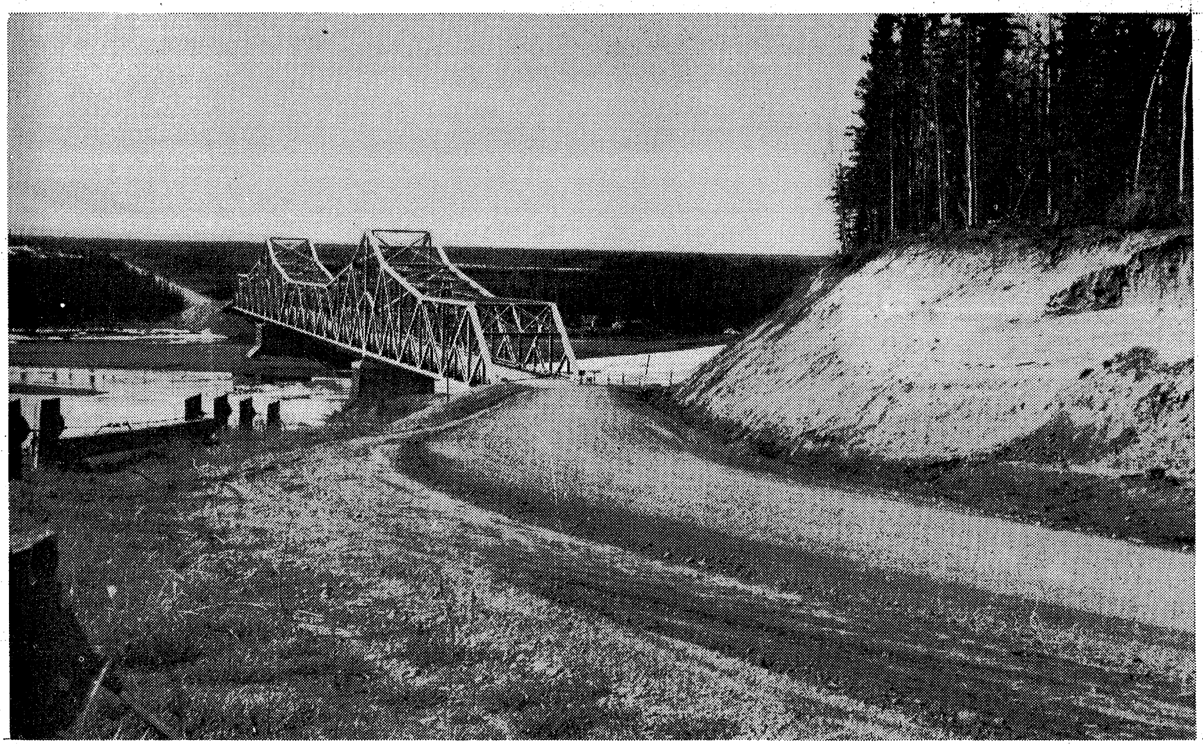


Yerrick River Bridge.

Plate No. 53 - Views of Bridges on the Alaska Highway



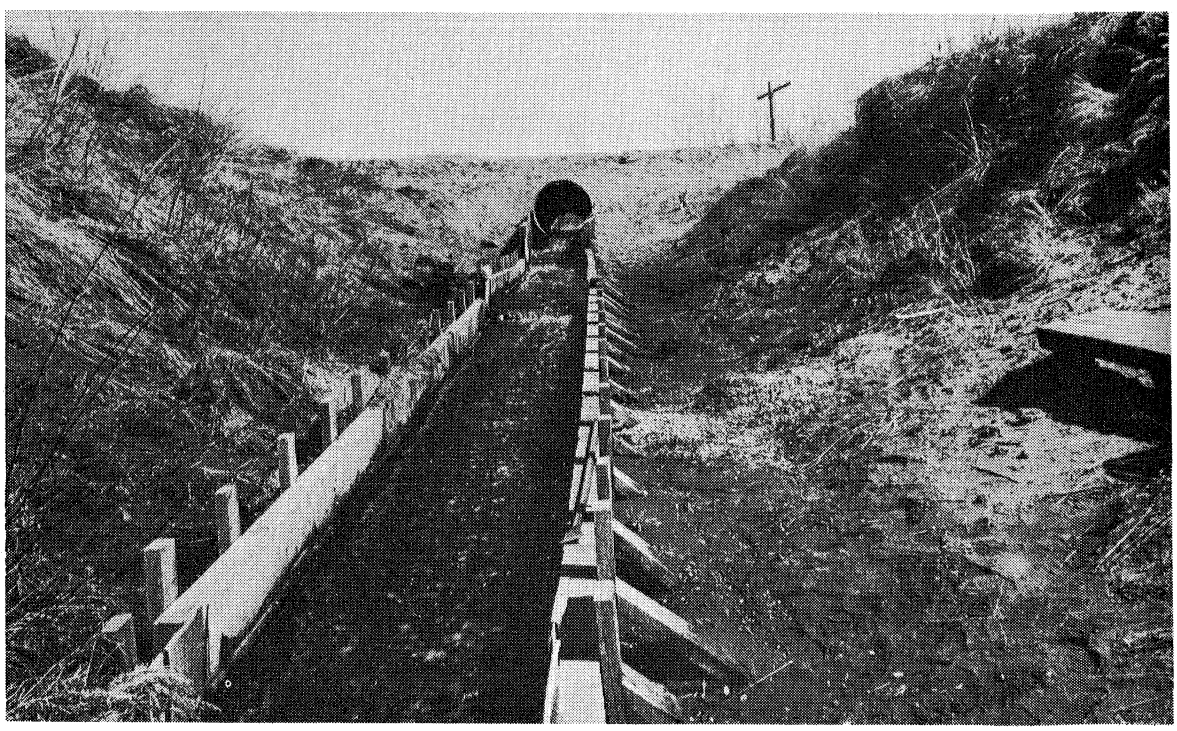
Gerstle River Bridge.



Tanana River Bridge

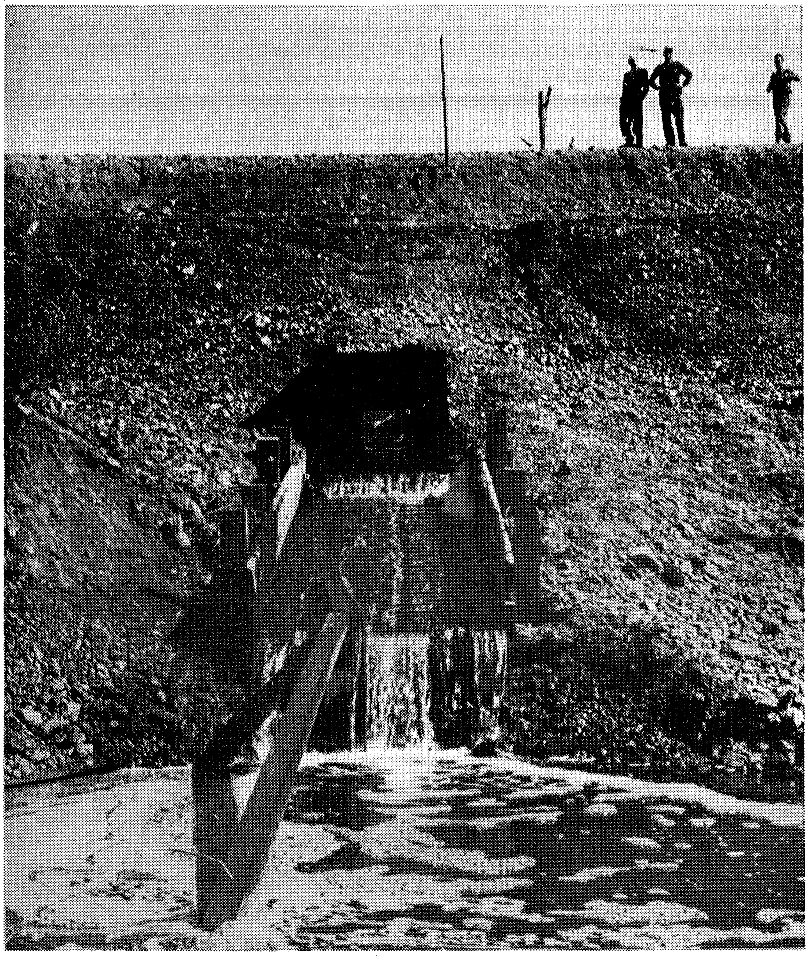
Plate No. 54 - Views of Bridges on the Alaska Highway

To stop erosion in this gully it was necessary to construct a long timber flume.



Looking upslope at the timber flume.

Plate No.55 - Gully along the Alaska Highway near Northway



Timber box culvert near Northway.

Erosion of highway ditches was quite severe in the section near Northway.

Plate No. 56 - Drainage Facilities on the Alaska Highway

Alaska Highway near Birch Creek.

Richardson Highway near Salcha River

Plate No.57 - Highway Scenes in Alaska

At this location it was necessary to provide drainage by blasting a channel through the ice.

The icing 600 ft upstream from the road was nearly 6 ft thick.

Plate No.58 - Surface Icing on Tok Highway

T. Tok Road (Tok to Mentasta Pass)

96. Description. Tok Road connects the Alaska and Richardson Highways. It was constructed during the war and follows an old trail, traversing a distance of about 140 miles. Beginning at a junction with the Alaska Highway, the route follows the valley of Tok River to Mentasta Pass, then follows the Copper River or its tributaries to the junction with the Richardson Highway.

97. Drainage of Highway and Icing. The highway is characterized by many sharp turns and steep grades. Long stretches are suitable for only one-way traffic. There was a distinct contrast between the condition of this road and the Alaska Highway. At many sections drainage was extremely poor and runoff water from melting snow had no avenue of escape but to follow the center of the road. Deep ruts were the consequent result. Icings were observed at various locations, some of which had been partially remedied.

Appendix A of "Roads and Highways in Alaska," Part 1, 925th Engineer Aviation Group, Fort Richardson, Alaska, June 30, 1948, shows photographically the procedure with which the Alaska Road Commission combats icing difficulties.

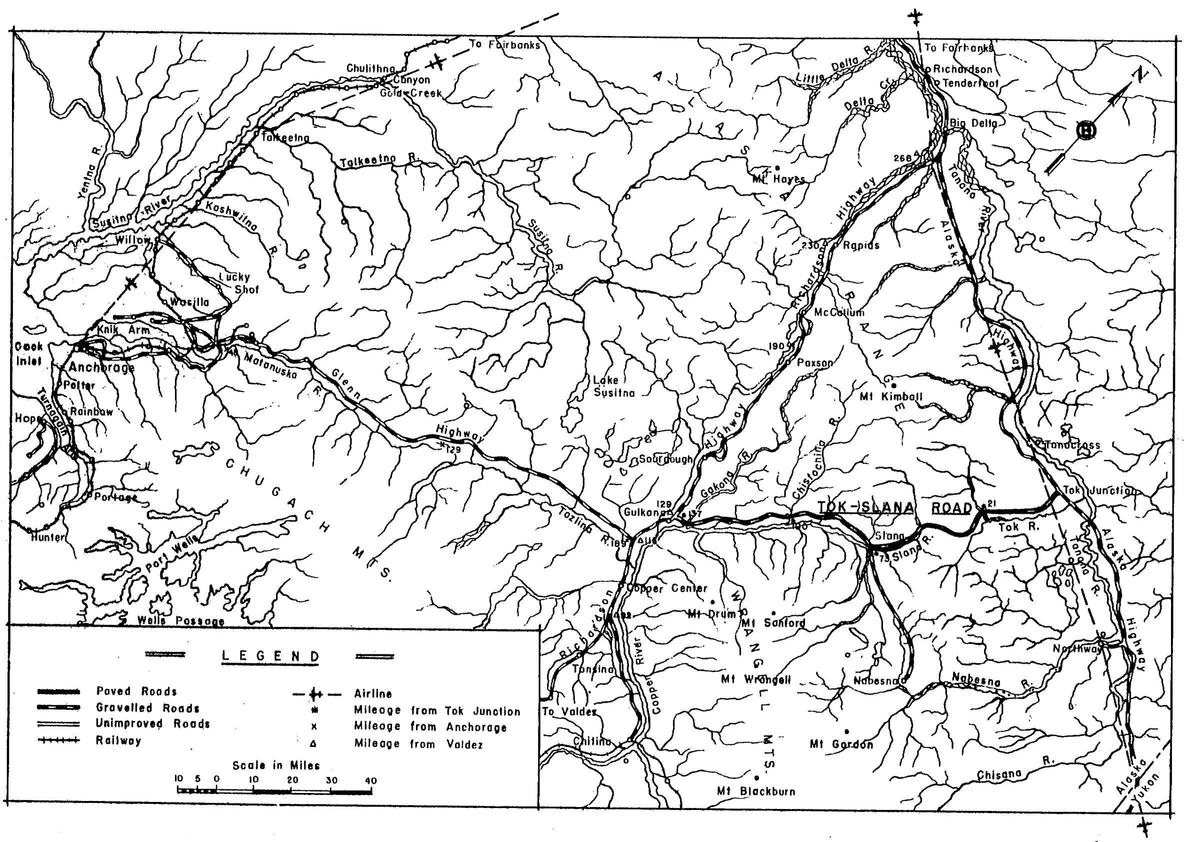
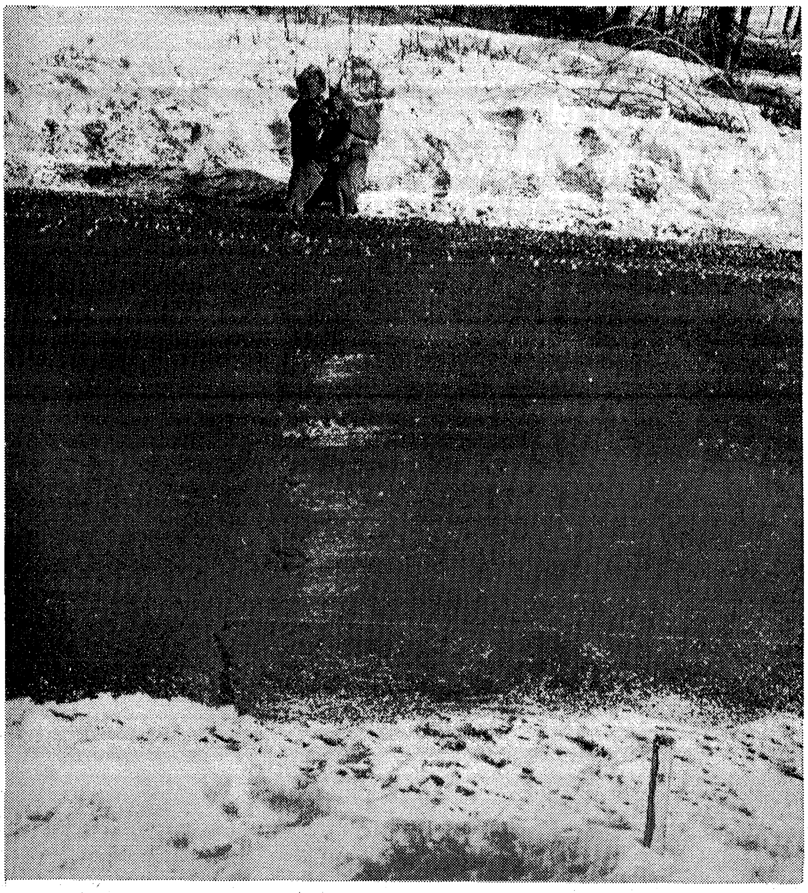
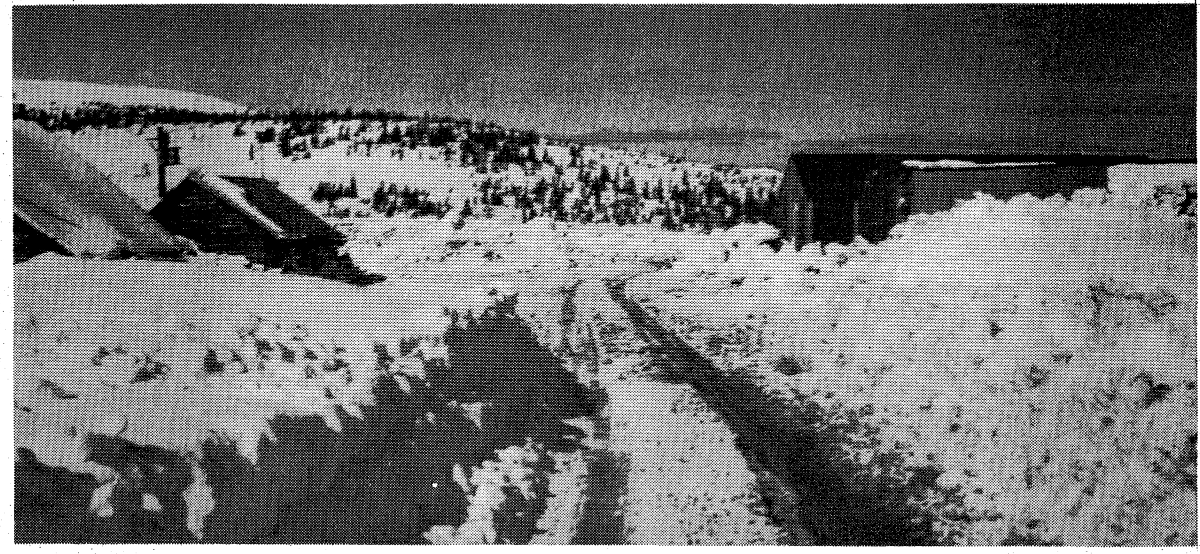


Fig. 31- Tok-Slana Road



Large transverse cracks similar to the one indicated in the photograph were noted at many culvert locations on the Steese Highway.



Alaska Road Commission maintenance station near Pedro Dome.

Plate No.59 - Scenes along Steese Highway

U. Steese Highway

98. Description. Steese Highway traverses a rugged terrain from Fairbanks to Circle, a distance of 163 miles. In general, this is a narrow, crooked road with many steep grades. It is not kept open in the winter months, and usually is passable only from the middle of June to the end of August.

99. Surface Icing and Maintenance Procedure. A reconnaissance of the section from Fairbanks to Pedro Dome was made on May 4, 1948. At that time, this stretch of highway was in fairly good shape. Maintenance crews of the Alaska Road Commission were engaged in thawing the ice out of culverts along the route. The crews were also cutting narrow open channels through surface icings which had covered the road bed to various depths and at many locations. The objective of the narrow channels was to confine early runoff to narrow widths and consequent greater depths, and thereby prevent further aggradation of the existing surface icing. Without these small ditches, runoff would continue to spread over comparatively wide frozen areas at very shallow depths and low velocities, and subsequently freeze, thereby adding another layer of ice to the many already in existence. The captions of photographs shown on Plate 59 illustrate these conditions along with other points of interest that were observed at locations along Steese Highway.

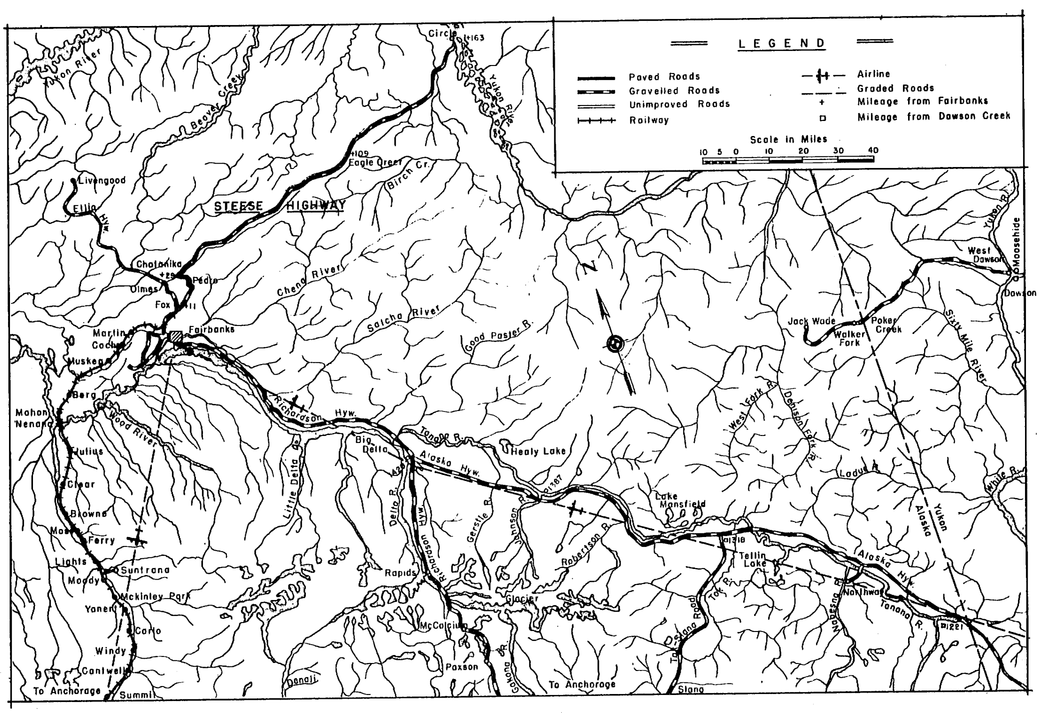


Fig. 32- Steese Highway

Highway scene near Fox, Alaska.

A soil profile at an eroded stream bank near Fox indicates many layers of varied texture.

Plate No.60 - Scenes along Elliot Highway

V. The Elliot Highway

100. Description. The Elliot Highway, sometimes referred to as the Livengood Road, forms a junction with the Steese Highway at Fox which is located about 11 miles from Fairbanks. From Fox the road traverses in a general northerly direction, over relatively rugged terrain, and terminates at Livengood, which is located about 85 miles from Fairbanks.

101. Conditions After Heavy Rain. A stretch of this road from Fox to a point beyond the Chatanika River was inspected on May 23, 1948, following a rain which lasted all of the previous night and continued until 9:00 a.m. the 23rd. For the most part, the condition of the road was good and the surface fairly smooth. Construction operations were in progress about four miles beyond the Chatanika River bridge. Here the grade was soft and did not appear to be passable. In the vicinity of the river and for a considerable distance to the south, the grade had been overtopped by river flood waters. There were numerous gullies and other evidence of erosion. Once out of the river flood plain, there was little, if any, evidence of high runoff. Even at sites of obviously large watersheds, comparatively small culverts had handled the discharge without any noticeable evidence of scour or high watermarks. Actually the culverts had not flowed full.

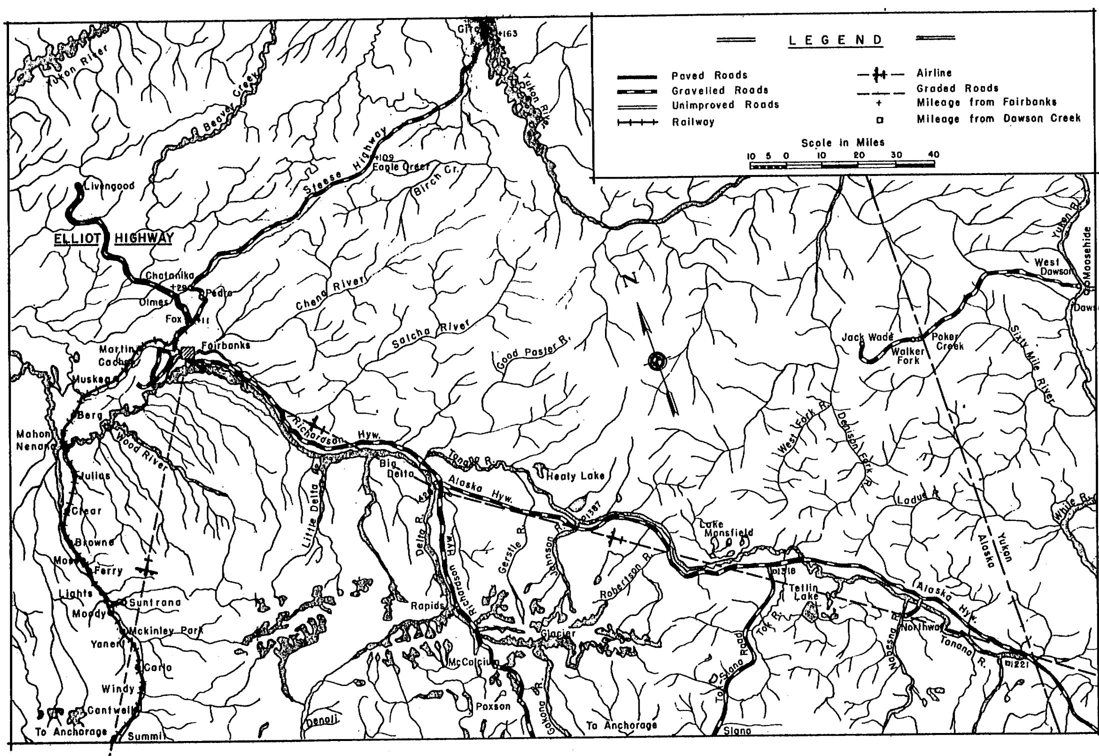
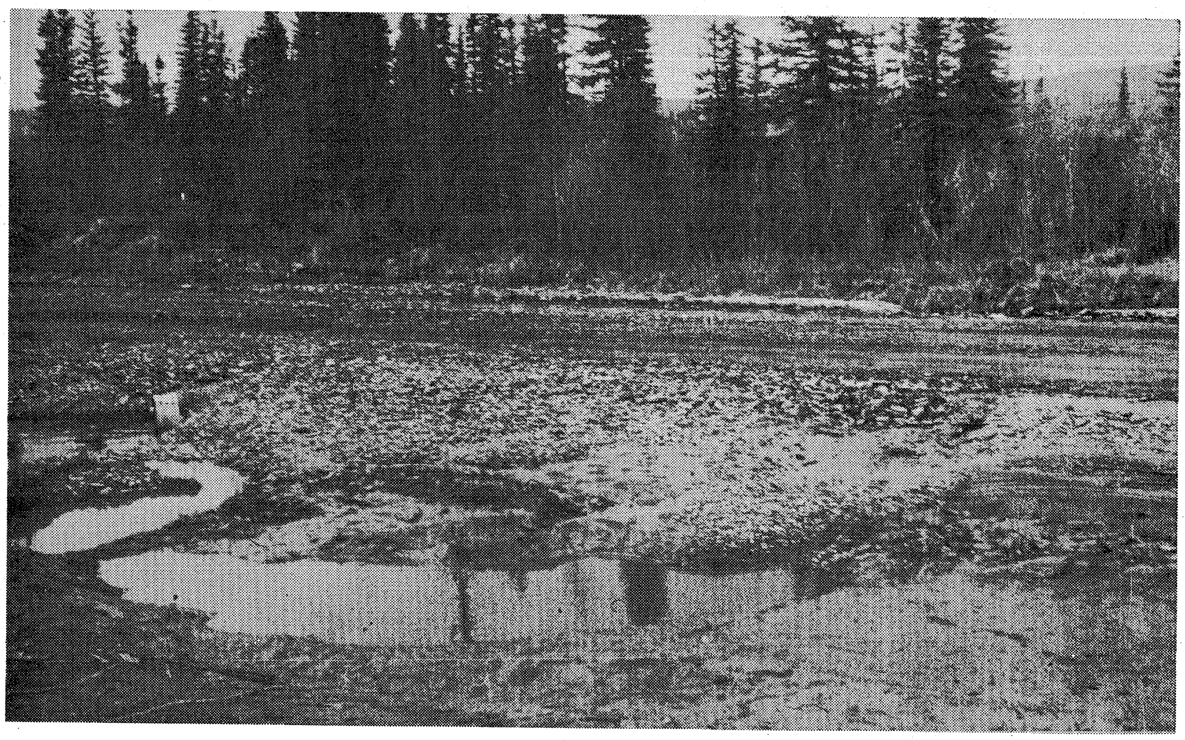


Fig. 33 - Elliot Highway

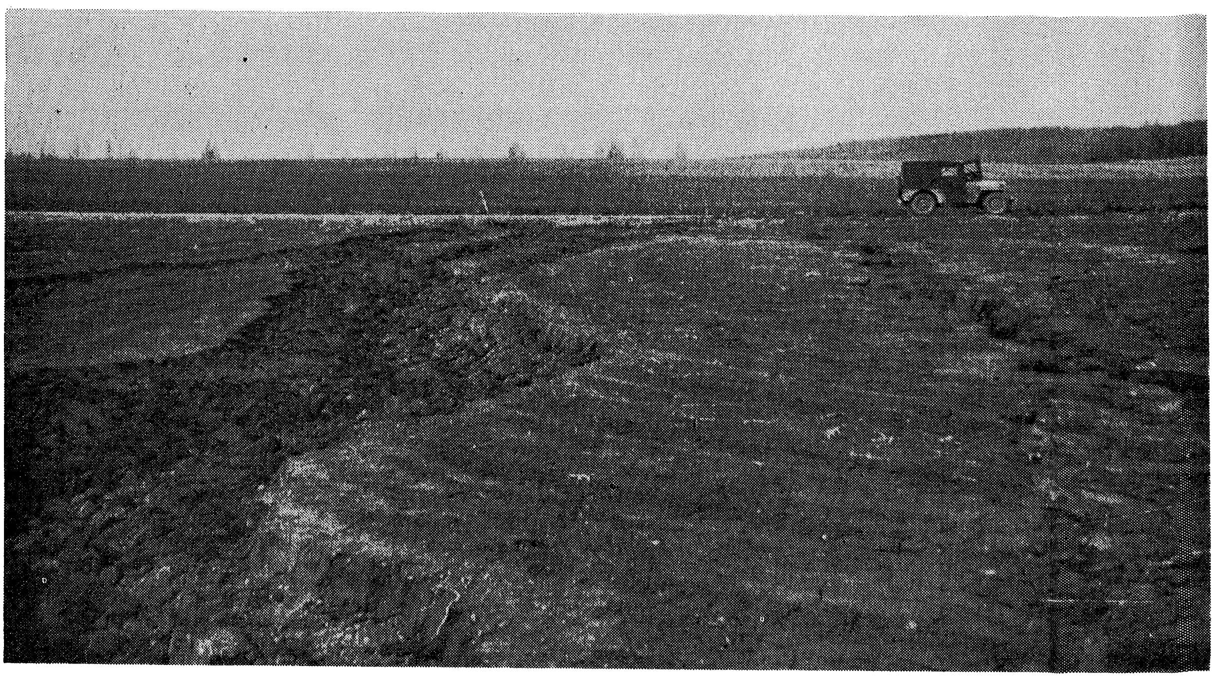
A 10-hour duration rain of May 23, 1948 resulted in considerable damage to roads.



This section of road was inundated by runoff from a relatively large drainage area.

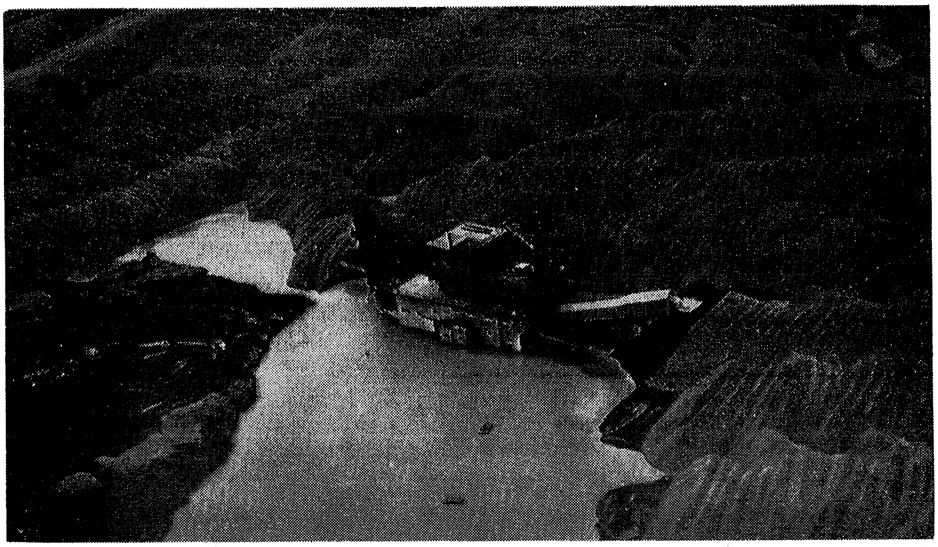
Plate No.61 – Drainage Conditions along Roads near Fairbanks

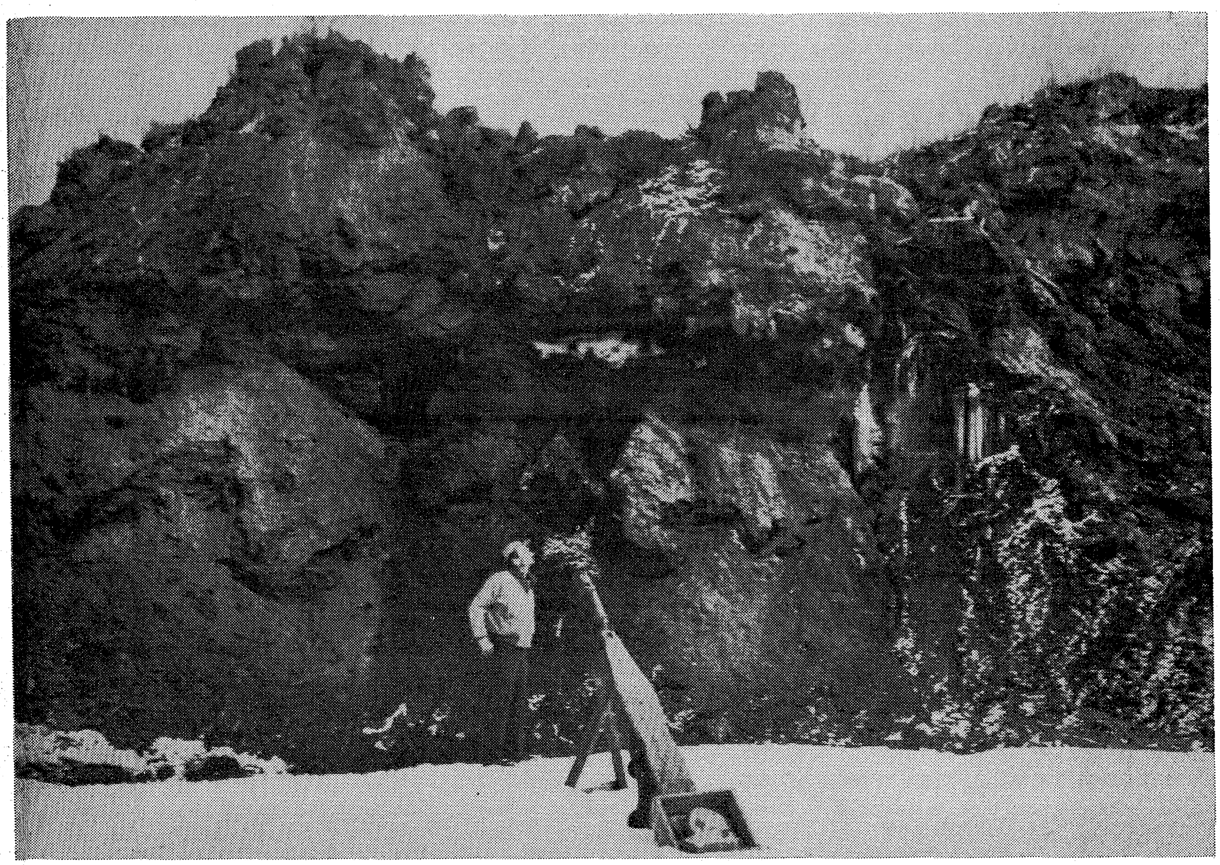
This gully resulted even though the ground was frozen.



Runoff from a small agricultural area resulted in the erosion illustrated by the above picture. The entire discharge passed through a 10 in. x 10 in. timber culvert.

Plate No.62 - Erosion near Fairbanks, Alaska





The white areas in the profile represent solid ice.

Plate No.63 - Soil Profile at Wolfe Creek Mine

VI. DISCUSSION WITH OTHER AGENCIES

A. City Engineer of Anchorage, Mr. C. W. Tryck

102. General Discussion. On Wednesday, May 12, 1948, the investigator had opportunity to spend some time with Mr. Tryck, City Engineer of Anchorage, Alaska. Various matters relating to drainage, storm sewer design and other topics of hydrological interest were discussed. In summary there appeared to be very little knowledge concerning design criteria. The city engineer pointed out that he had completed a study of the storm sewer system of Anchorage about a year ago. In the course of this study, attempts were made to correlate inlet and pipe line capacities with watershed area without any degree of success. It was Mr. Tryck's belief that in that area the capacities required for drainage facilities would depend on the size of the area and the amount of snow that could melt in a specified time. He recollected that on the basis of a "rule of thumb" criteria, of 0.2-in. runoff in 24 hours, the adequacy of drainage facilities for small areas could be judged. He emphasized that, almost without exception, rains are very light and not of the cloudburst type. It was further reported that heavier rains, when they eventually did occur, were of such short duration that the overall magnitude of water would not result in a large runoff.

B. Consulting Engineer of Anchorage, Mr. H. M. Reherd

103. General Discussion. A discussion of matters relating to drainage with Mr. Reherd resulted in conclusions similar to those which were pointed out by the city engineer. It was further illustrated that the city of Anchorage was protected from subsurface flow by a system in which the principle of the French-type drain was employed. Mr. Reherd related that these were quite popular in that territory and worked satisfactorily especially at sites of surface icing. He stated that in the layout and planning for a new village or small town, drainage systems were designed on the basis of carrying away water as fast as runoff could result from melting snow. In order to arrive at some design figure, it was assumed that the greatest blanket of snow would melt uniformly in one week. This method, Mr. Reherd said, amounted to a runoff equivalent to from 0.2 to 0.23 inches in 24 hours for small watersheds. It was thought that drainage facilities, which were judged adequate in this manner, would be suitable for conveying runoff which may occur as the result of summer rains.

Mr. Reherd's explanation of rainfall characteristics corroborated that of the city engineer. Quite similar conditions were anticipated for regions which are located to the north of the Alaska Range.

C. Consulting Engineer and Architect of Anchorage, Mr. Victor Rivers

104. General Discussion. A conference with Mr. Rivers on May 13 proved to be not only very interesting but extremely profitable. This professional engineer possessed a very keen knowledge of arctic conditions and could site engineering experiences dating back 30 years or more. His latest professional work was the design and construction of a new school at Bethel. Other activity had been with the U. S. Army Corps of Engineers in a very responsible capacity.

In general, the views of Mr. Rivers, which were illustrated by explanations of many past experiences over a wide area, corresponded closely to opinions of other local engineers. Descriptive accounts of rainfall characteristics corroborated the statements which had been made by the city engineer and by Mr. Reherd. Criteria of design would be suitable if calculated on the basis of melting snow. In addition, it was emphasized that areas which have a high water table should and could be avoided as construction sites. Drainage of surface runoff should, wherever possible, be by a system of shallow open ditches, and these should be shaped to permit removal of snow with the use of heavy equipment. Structures such as culverts, inlet gratings, and outfalls should be equipped with facilities for steam thawing.

D. Alaska Road Commission, Anchorage

105. General Discussion with Points of Design Importance. On May 13, the investigator discussed drainage conditions with Mr. M. C. Edmunds, General Superintendent for the Alaska Road Commission. The results of the discussion are summarized by the following generalized statements:

1. Rainfall is usually of light intensity and low total magnitude in regions of Alaska that are located to the north of the Alaska Range.

2. Melting snow is a greater causative factor in the creation of runoff than is rainfall.

3. Rainfall alone has never produced a river flood in the sections of Alaska which are north of the Alaska Range.

4. Ice jams in streams and rivers are almost an annual springtime occurrence. Each one causes two floods, one above the site when the jam is in the process of formation and the other below the site upon failure of the ice dam.

5. The sudden release of impounded water by melting and consequent structural failure of glaciers results in usually late summer or fall floods on many streams and rivers.

6. Proper interpretation of nature's exhibit in the form of physical features at a river or stream section affords the only procedure by which design stage and discharge relations can be estimated with any degree of accuracy. Stream flow records are practically nonexistent.

7. The main channel of rivers which are subject to flood by failure of a glacier shifts in a normal direction to the general river flow from year to year. At a specific cross section, the main channel may in one year be located close to the right bank, the next year either at the same place, at midstream, near the left bank, or someplace between these extremes. No regular progressive changes in the process of channel shifting have been observed.

106. Conditions at Knik River. Figure 34 indicates graphically the conditions noted in paragraphs 5 and 7. The cross sections are of Knik River at the intersection with Glenn Highway. The specific location is not far distant from Palmer. Here late summer and fall floods are an annual occurrence, each one changing the shape of the river bed. Flood stages represent in the neighborhood of 30,000 sq ft of channel section. The watershed area is about 1000 sq miles. During the warm climate of spring and summer months, George Lake rises in elevation as snow and ice melt forming runoff which flows into the lake. While the lake is filling, a similar process degrades an arm of Knik Glacier. This action continues until the increased pressure of the rising lake stage exceeds the structural strength of the ice dam at the outlet. Sudden collapse results in large discharges and a recession of the stage of George Lake. When high flows subside and colder weather sets in, Knik Glacier extends another arm of ice to block the outlet channel.

Examination of the river sections will disclose actual bed movement. It is of interest to note that in the year 1944 the main channel shifted from the left bank to midstream, a distance of about 1000 ft. After the flood of 1945, the main channel moved back to a position near the left bank where nearly 10 ft in depth of material was scoured away.

E. Alaska Railroad, Anchorage

107. General Discussion. On May 13 the investigator discussed drainage conditions with Mr. Antone Anderson, Assistant Chief Engineer for the Alaska Railroad with headquarters at Anchorage.

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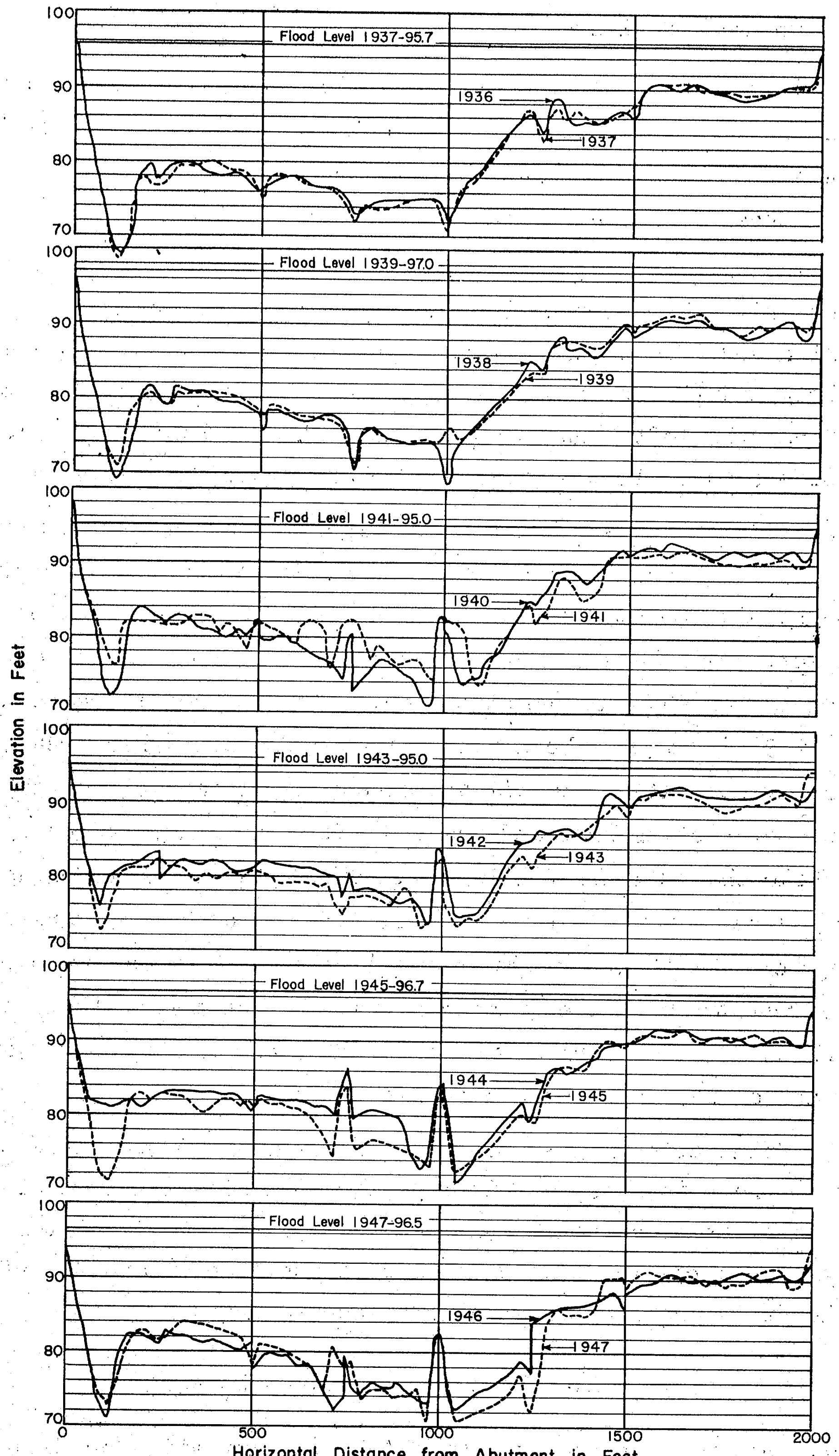

Note—The information which forms the basis for this drawing was obtained from the Alaska Road Commission. The cross sections were taken at the Glenn Highway Bridge over the Knik River. Datum is assumed. Elevations depend on the girder seat of the left abutment as 104.95 feet.

Fig. 34 - Cross Sections of Knik River

Without qualification as to size of the watershed, Mr. Anderson expressed the view that runoff caused by rainfall would exceed that caused by melting snow by at least 400 per cent. It is presumed that he was referring to very small drainage areas, otherwise this statement would be in direct contradiction to the views of other individuals who were, no doubt, thinking of something larger than just a few acres. To substantiate his opinion, Mr. Anderson explained that the railroad company, to check adequacy of drainage facilities from the standpoint of melting snow, used a "rule of thumb" figure of 3 gallons per day per sq ft of drainage area. This does not check with the figures that were pointed out by Mr. Tryck and Mr. Reherd.

Mr. Anderson was much in favor of using timber wherever possible in the construction of drainage facilities. He claimed that by proper selection of construction materials, it is possible to avoid adfreezing to some extent.

A very important point in regard to rainfall observed by Mr. Anderson was that even though the total magnitude of precipitation in subarctic regions is almost always small, intensities for very short durations and over very limited areas may be quite high.

F. Weather Bureau, Regional Office, Anchorage

108. General Discussion. The results of detailed discussions which took place on May 12 with Mr. M. A. Emerson, Assistant Regional Director, and Mr. Ottis Bobbitt, Climatological Supervisor of the Regional Office, U.S. Weather Bureau at Anchorage, are summarized in the following brief accounts:

1. Records of climatological data indicate rains of light intensity even in sections that receive as much as 200 in. of precipitation per year.

2. Present-day concepts of meteorology demonstrate that it is quite impossible for either a storm of high intensity rainfall or one of a high total magnitude to occur in the interior regions of Alaska.

3. Moisture-laden air masses from the warm Pacific Ocean are effectively blocked by a system of mountain ranges and cannot reach interior areas.

4. Extensive "lifting" of air masses in the interior is effectively curtailed by a low ceiling.

5. Thunder storms are not uncommon, but usually it is a fire rather than rain that results.

6. There has never been a river or stream flood as a result of high rainfall.

7. The Regional Office has recommended the discontinuance of automatic recording rain gages, because due to the lightness of precipitation, records are often in error and many other operational difficulties are encountered.

8. Precipitation in the region which is located north of Brooks Range is of extremely small magnitude and very low intensity.

Records of maximum precipitation for durations of 5, 10, 15, 30, 60, and 120 minutes for all stations in Alaska which operate recording rain gages were tabulated and obtained via a special arrangement with Mr. Bobbitt.

G. Civil Aeronautics Administration, Anchorage

109. General Discussion. On May 13 the investigator met with Messrs. Hooper, Knight, Ren, and Kempton of the Engineering Department of the Civil Aeronautics Administration, who furnished drawings and other pertinent engineering information with respect to many airports in Alaska. The problem which gave them the greatest amount of difficulty was one of flood control rather than drainage of surface runoff. It was agreed that by careful selection of the airport site, the trouble of ice jams and river floods could be avoided to some extent. At many existing locations, however, this was an annual springtime problem that had to be recognized. Often conditions would reach such proportions of severity that families of local field maintenance personnel would have to be evacuated until flood waters subsided.

With respect to rainfall intensity and runoff, the Civil Aeronautics Administration engineers expressed opinions which agreed closely with the views of the other men that were consulted.

VII. ANALYSES OF DESIGN PROCEDURES

A. Procedure Contained in the Engineering Manual

110. Necessity of the Analysis. A review of literature indicates that since the time of origination of the Robert E. Horton equation for overland flow, subsequent applications to hydrological computations were confronted with considerable criticism. It is especially difficult to dismiss arbitrarily from further consideration the point of error in actual derivation as pointed out by Mr. E. F. Brater. Consequently, with respect to this seemingly valid limitation further discussion seems to be in order. In the "Instructions and Outline for Arctic and Subarctic Drainage Investigation," special emphasis is made to investigate the reasonableness of applying methods contained in Engineering Manual, Part XIII, Chapter 1, for determining design of storm water drains. It follows that a recommendation to use the method, without first weighing analytically the effects of the noted implication, would be out of place.

111. Analysis of the Horton Equation. The terms of Hortons' expression are:

σ (sigma) is rate of supply in inches per hr

δ (delta) is depth of detention at the lower margin of the elemental strip in inches

q is discharge or overland flow in inches per hr

t is time in minutes

K, K_s, and m are constants for any plot.

The basically correct storage equation is

$$\sigma\, dt - q dt = d\delta_{av} \qquad (1)$$

The relationship between discharge and depth of detention is assumed to be

$$q = K_s \delta^m \qquad (2)$$

where

$$\delta = K \delta_{av} \qquad (3)$$

Then continuing the derivation by substitution and rearrangement of terms,

$$dt = \frac{1}{K} \left(\frac{d\delta}{(\sigma - K_s \delta^m)} \right) \tag{4}$$

Horton now assumed σ to be constant and selected m equal to 2 and integrated with the following result:

$$t = \frac{1}{2KK_s \sqrt{\frac{\sigma}{K_s}}} \log \left[\frac{\sqrt{\frac{\sigma}{K_s}} + \delta}{\sqrt{\frac{\sigma}{K_s}} - \delta} \right] + C \tag{5}$$

It is at this point that Brater points out a departure from theory and also from experimental results. There appears to be no reasonable explanation for the selection of $m = 2$, except to maintain simplicity. In laminar regions $m = 3$, while in turbulent flow, $m = 5/3$. Upon first thought, the obvious discrepancy creates the impression that eventual results in the use of the final expression may lead to serious errors of design. It seems of extreme importance then to explore the possibilities at greater depth and length.

Integrating expression (4) without any specific value assigned to m,

$$t = \frac{\delta}{K\sigma} \left[1 + \frac{\delta^m}{\alpha(1 + m)} + \frac{\delta^{2m}}{\alpha^2 (1 + 2m)} + \frac{\delta^{3m}}{\alpha^3 (1 + 3m)} + \ldots \right] + C \tag{6}$$

where $\alpha = \frac{\sigma}{K_s}$.

The condition for convergence is

$$\left| \frac{\left(\frac{\delta^m}{\alpha}\right)^{n+1} \frac{1}{1 + m(n+1)}}{\left(\frac{\delta^m}{\alpha}\right)^{n} \frac{1}{1 + mn}} \right| < 1$$

Consequently, Eq. (6) converges, provided

$$\delta^m < \frac{\sigma}{K_s}$$

and $m > 0$, that is, a positive value.

Now Horton's Eq. (5) can be compared with the generalized Eq. (6) in which values of m that fit conditions of either turbulent or laminar flow may be substituted. If m = 2, Eq. (6) gives a result for t identical to that obtained by the use of Horton's formula. If m = 3, Eq. (6) gives a t value which is about 5 per cent smaller than that obtained by solution of Eq. (5). If m = 5/3, t by use of Eq. (6) is less than 2 per cent larger than t obtained by use of Eq. (5). This, however, does not develop an overall generalized perspective from which to base applicability tests. Specific values of δ, K_s, σ, and K were selected at random, and although these were not altered for the set of calculations, it is not certain that the entire range or actual limiting values can be ascertained. It seems desirable to study Eq. (6) from the standpoint of the rate of change in t with respect to m. Consequently, the partial derivative of the first two terms of Eq. (6) is

$$\frac{\delta t}{\delta m} = \left[\frac{\delta^m \left(\log_e \delta - \frac{1}{1 + m}\right)}{\alpha(1 + m) + \delta^m} \right] t \qquad (7)$$

where $\alpha = \frac{\sigma}{K_s}$, and assuming that m = 2,

$$\frac{\Delta t}{t} = \left[\frac{\delta^2 \left(\log_e \delta - 1/3\right)}{3 \frac{\sigma}{K_s} + \delta^2} \right] \Delta m \qquad (8)$$

But Δm is either +1 or −1/3 to have m = 3, or 5/3.

For the values which were selected in the preceding paragraph, Eq. (8) becomes

$$\frac{\Delta t}{t} = -\frac{1}{21} \Delta m = -\frac{1}{21} \times 1 \text{ ; about } -5 \text{ per cent}$$

and

$$\frac{\Delta t}{t} = -\frac{1}{21} \Delta m = -\frac{1}{21} \times -1/3 \text{ ; less than 2 per cent}$$

If in a similar manner other values of δ, σ, and K_s are selected to fit Alaskan conditions and airfields in general, it will be observed that the error in derivation does not magnify results to a serious extent.

In order to obtain large deviations from Horton's formula in actual results, slopes must be steep and effective lengths must be short. This is a field condition to avoid in site selection, and even then answers lean toward the side of safety. The computed q will be larger than actual. Another condition for a large deviation is a large δ and a small σ. This is almost a physical impossibility, as naturally the magnitude of detention depth depends on the rate of supply.

112. Conclusion of the Analysis. Analyses of the type shown in preceding paragraphs demonstrate that although there is a basic error in theory of derivation, Horton's expression for overland flow can be used without serious error for airport drainage design. This conclusion has also been verified experimentally by the Corps of Engineers.

B. Procedure of Fay, Spofford and Thorndike

113. Procedure of the Architect Engineer. The Engineering and Architectural firm, which is employed for design and construction supervision in regions of Alaska by the Department of the Army, uses a modified form of the Rational formula to determine runoff values. Design capacities which were developed in this manner agreed substantially with the results obtained by using the procedure in the Engineering Manual (report on Ladd Field). Many Engineers would prefer this modified rational method because of its simplicity. The use of this formula, however, leads to many uncertainties and cannot be recommended as a design method. It is up to the user to choose a value for the coefficient C' with only the guides indicated on Fig. 35. This leaves too much to personal judgment and can result in considerable error. Computation for the initial time of concentration is not a precise evaluation and can result in serious error. The F.S.T. method is included in this report merely to provide a simple procedure whereby design values can be checked rapidly. It will prove useful, also, in carrying out runoff computations for comparatively large areas where "effective" lengths exceed 1000 ft.

The Fay, Spofford and Thorndike (F.S.T.) method may be briefly summarized as

$$Q = C' I A$$

where Q is discharge in cfs

C' is a coefficient

I is intensity of rainfall in inches per hour and is taken from a standard supply curve. The intensity magnitude is the ordinate value for the duration which corresponds to the time of concentration for the drainage area in question.

A is area of the watershed in acres

114. <u>Determination of Values for the Coefficient C'</u>. The coefficient C' is taken from the curves shown in Fig. 35. These were formulated by Fay, Spofford and Thorndike and are self-explanatory. The relations had been compiled in 1927 partly from field tests and experiments under the direction of Mr. Ralph Horne, partner, Fay, Spofford and Thorndike.

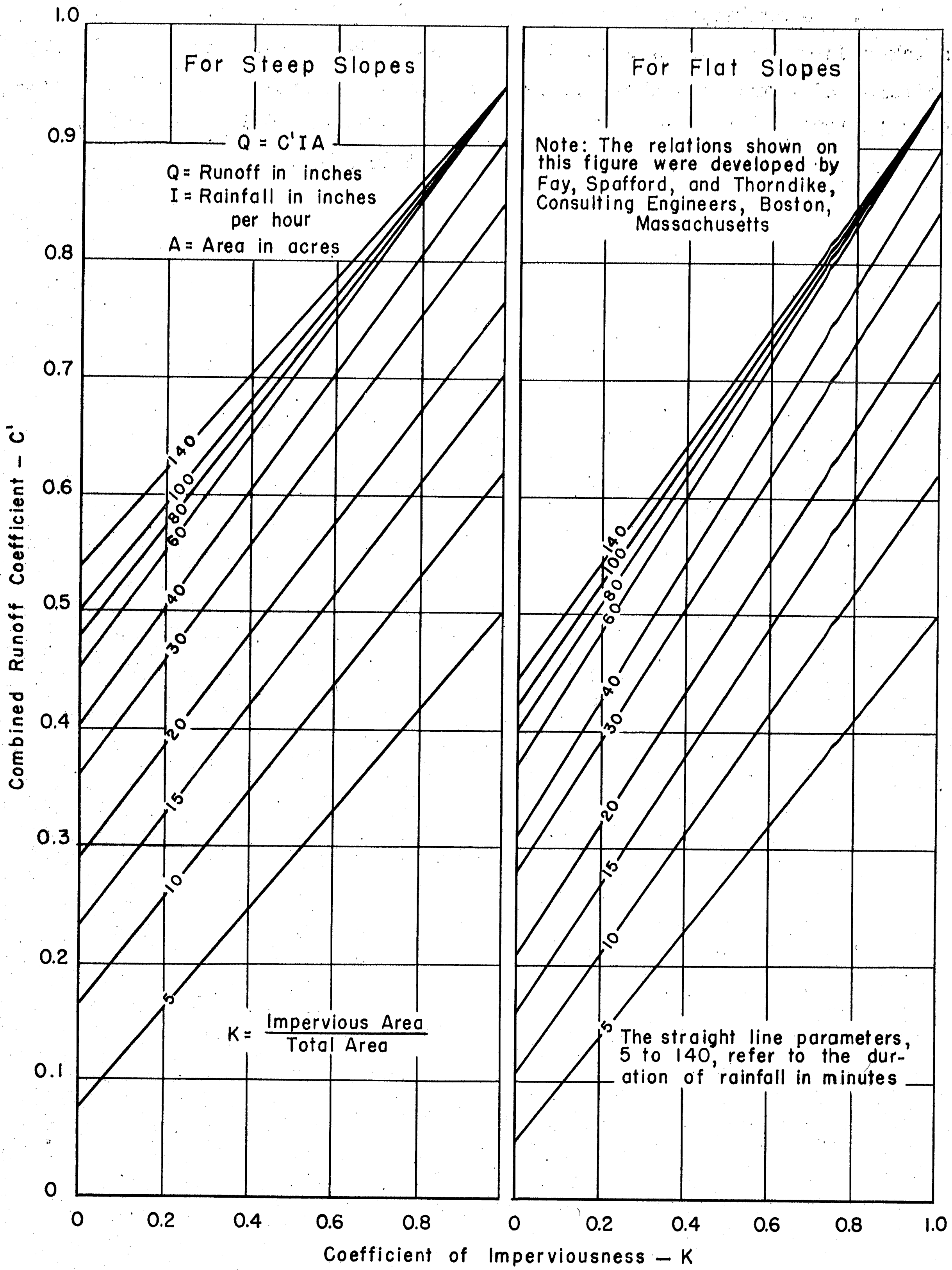

Fig. 35 - Relation Between Imperviousness and the Coefficient of Runoff

VIII. SUMMARY AND GENERAL CONCLUSIONS

115. Eighteen Points of Design Importance. The concise statements that follow are either conclusions which were reached as a direct result of the investigation or the findings of other investigators explained in greater detail in the reports that are noted in the Bibliography.

1. The methods contained in Engineering Manual, Part XIII, Chapter 1, for determining the design of storm water drains are recommended. These were found to be applicable to arctic and subarctic regions if the following specific limitations are observed:

a. The design storm index shown as Fig. 7 of this research report is used as a general guide, and if the supply curves shown as Fig. 8 are used in conjunction therewith. Figures 9, 10, 11 and 12 show overland flow versus the rates of supply that are applicable to the research area.

b. In the Arctic infiltration should be considered negligible and equal to zero.

c. In the sub-Arctic 0.4 in. per hr should be considered as a maximum infiltration rate unless specific local tests indicate a different value.

d. The upper value of n for the Arctic should be 0.1, as the surface is apt to be either frozen or covered with sleet when the rain occurs. In the sub-Arctic n may be very high, but generally should not exceed 0.3.

e. Ponding should be avoided in regions where permafrost exists. The saturation of soil and subsoil of fine texture shortly before freezeup in the fall may have a magnifying effect on subsequent heaving and swelling.

2. The study of precipitation, carried out as a part of this investigation confirms the findings of the St. Paul District office even though intensity-duration relations were developed independently and by methods that were not similar.

3. Wherever possible drainage systems for surface runoff should be of the open-ditch type and shaped to permit the removal of snow by heavy equipment. Side ditches should be located as far as possible from the edge of the runway. A transverse runway slope of $1\frac{1}{2}$ per cent is adequate. Shoulder shape

and size as well as ditch shape and size should be designed to avoid conditions which are illustrated by Fig. 16, page 74, and Fig. 27, page 80 of "Cold Weather Engineering," Chapter VIII, by the U. S. Navy Civil Engineer Corps. Further research and study are required to determine limiting dimensions.

4. Runways and taxiways should be as narrow as consistent with operational requirements. If possible, the long axis of a runway should be parallel to the direction of ground water flow.

5. Alaskan mineral soils, which usually are of medium texture and single grain structure, are especially susceptible to movement by the action of flowing water. Cognizance of this fact is very important to design of drainage systems.

6. The runoff produced as a result of melting snow from small areas is calculated to be very small and not as great as the rate of runoff which results from intense rains. The opinion of local Alaskans does not confirm this view. It is thought, however, that they are referring to watersheds which are much larger than the ones ordinarily encountered in the drainage of airfields. Further investigation with respect to this matter is needed.

7. Rainfall intensity during the melting season is very light. The 10-year frequency for the May intensity-duration relation at Fairbanks corresponds approximately to the 0.2 supply curve shown in Fig. 8. Analyses indicate that a combination of rainfall and melting snow will not yield runoff rates as large as the magnitudes which can result from summer rains. Further investigation is necessary to confirm this view.

8. If closed conduits to convey surface runoff cannot be avoided, it is recommended that a minimum diameter of 18 in. be adopted; long length pipe sections are to be preferred.

9. Although satisfactory drainage design results can be obtained with a modified rational procedure, it is not a recommended design method for arctic and subarctic regions.

10. Design criteria for subarctic and arctic regions should be on the basis of a lower frequency than generally applicable in the United States. Planning on the basis of intensities which can be expected once in 20 years would not materially increase installation costs, but would have a decided maintenance advantage.

11. Of the 18 government and private airports included in this investigation, 12 are subject to river floods. Proximity to rivers cannot be entirely

avoided as these are the only avenues of available transportation other than air. The need for research to develop methods to control ice jams and consequent floods cannot be overemphasized.

12. Drainage structures of the type which are installed at Nome and in the process of installation at Bethel were reported to function satisfactorily. Inlets to these facilities should be sealed before freezeup in the fall and opened before breakup in the spring.

13. Maintenance personnel reported that it was not essential to have drainage facilities equipped with a special arrangement of steam pipes for thawing. These special portable fixtures should be included with the boiler equipment and accessories.

14. In arctic and subarctic regions, factors in addition to those of more temperate zones, influence the behavior of rivers and streams. The watershed area, although of intrinsic importance cannot be used as a basis from which to anticipate or predict peak discharges. Stage-discharge relations are altered as a result of ice jams. High discharges may be the result of the structural failure of a glacier. The frequency of high stages may be independent of frequency of high discharges and these in turn may be independent of rainfall. Interpretation of nature's exhibit in the form of physical features at a river or stream section affords the only procedure by which design stage and discharge can be estimated. Design criteria may be determined by answers to questions such as are represented by the following: At what elevation, with respect to river stage, do iron compounds in the soil profile change from the ferrous to the ferric state? What is the lower limit of growth of the lichens, Parmelia? Gyrophora? What is the depth and meaning of organic material in sloughs? What is the meaning of the lower limit of various types of vegetation?

Field investigations to develop standards are needed.

15. Sections of roads and highways should contain a pronounced center crown and shallow, flat, sloped side ditches. Ditches should be located as far as possible from the road shoulder.

16. Road shoulders and culvert locations should be conspicuously marked to guide snow removal and thawing operations.

17. The investigation did not disclose a need for subdrainage except in conjunction with flood control of rivers. Drainage of subsurface water, even

though extensive maintenance difficulties can be anticipated, may be desirable under special circumstances to alter the thermal regime of the ground.

18. The investigation, including library research and translation of Russian literature, did not evolve any new methods for the control of icing. Methods for the control of icing are enumerated in Project Report No. 17, "Investigation of Airfield Drainage, Arctic and Subarctic Regions," Part II, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, April, 1949.

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