COMPILATION AND STUDY OF ICE THICKNESSES IN THE NORTHERN HEMISPHERE

1952-1953

(U. S. Army Corps of Engineers Contract DA-19-016-ENG-2313)

by

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I History of the Ice Thicknesses Project.

The Ice Thickness Research was commenced at the American Geographical Society upon July 21st, 1952, and the bulk of the approximately 400 titles listed in Sections I and II of the Bibliography of this Final Report was examined at the library of the Society during the ensuing ten months. Not a few references unavailable there were studied at the New York Public Library, notably the United States Weather Bureau weekly Snow and Ice Bulletins and Weekly Weather and Crop Reports, which contain lake and river ice thickness data for numerous American stations, spanning a period of more than fifty years, commencing with 1898. Another most valuable source of information is the annual Report of the Meteorological Service of Canada, 1910-1914; unfortunately ice thicknesses and snow depths were no longer recorded after the latter year. Among the periodicals most frequently consulted were the Monthly Weather Review, Geographical Journal (Royal Geographical Society), Geographical Review (American Geographical Society), American Journal of Science, Journal of Geology, Transactions of the American Geophysical Union, and Canadian Geographical Journal.

In its early months, the project benefitted from the valued counsel of Mr. William O. Field, Jr., Chief of the Society's Division of Exploration and Field Research, and in August the writer conferred one afternoon with Mr. Henry W. Stevens of the Frost Effects Laboratory, New England Division, Corps of Engineers, from Boston, on the scope of ice thicknesses research, methods of proceeding, references in the literature, and suitable individuals to interview. In November the writer talked briefly, in New York, with Mr. Angus Sherwood, of Imperial Oil Limited, concerning ice conditions on the Mackenzie River at Norman Wells, North West Territories.

During the same month, the Frost Effects Laboratory in Boston was visited, for a perusal of various references not readily available elsewhere, and for talks with Messrs. Kenneth Linell, its Director, and Mr. Henry W. Stevens, who arranged transportation for a visit to Blue Hill Observatory, in Milton, Massachusetts. Dr. Charles F. Brooks, the Director, was not present, but the Librarian, Miss Sarah Wollaston, checked the library for ice thickness references and loaned me two titles. There were almost no sources of information there as yet unexamined or not previously known to be available in New York. On the following two days Cambridge was visited, and Messrs. Palmer and Haynes, Librarian and Assistant Librarian respectively of the Harvard College Library were consulted. The Institute of Geographical Exploration and Research at Harvard was found to be closed for an indefinite term. Dr. Irving Schell, an expert on marine ice, located at the Museum of Comparative Zoology, was interviewed. In all, four days were spent in Boston and vicinity.

In December the writer journeyed to Washington, D. C. for calls at the Arctic Institute's Bibliography of Arctic Research Project at the Library of Congress, directed by Miss Marie Tremaine, and at the United States Weather Bureau Library. Few actual volumes were examined but a number of titles were added to our ever - expanding bibliography. The Air Weather Service was not visited owing to the lack of a clearance to use classified material, applied for in mid-August but which did not become available until late in May.

On March 16th, 1953 the writer departed on a three-weeks journey, primarily to Canada, although three days of the first week were spent at Hanover, New Hampshire, where the resources of the Stefansson Library were ascertained with the personal assistance of Dr. Vilhjalmur Stefansson, who offered various suggestions and recollections from his vast store of knowledge of the Arctic and sub-Arctic, and brought to my attention several useful references. Other features of the Dartmouth visit were discussions with Professor Trevor Lloyd, Chairman of the Geography Department (and first Director of the Geographical Branch, Department of Mines and Technical Surveys, at Ottawa), and Dr. Edward E. Goodale, Assistant Chief, Arctic Project, United States Weather Bureau, who expressed interest in the ice thicknesses research project. Great interest in Arctic studies generally was manifested at Dartmouth and the atmosphere prevailing there is stimulating for such investigations as that under consideration. Commander David Nutt, the Dartmouth College Museum's Arctic Specialist, was at that time in the field, on one of the annual "Blue Dolphin" expeditions to the Hamilton Inlet - Lake Melville area of Labrador.

Professor F. Kenneth Hare, Chairman of the Geography Department at McGill University, was in Washington during the writer's stay in Montreal, but calls were made upon Messrs. John B. Bird and W. F. Summers of that Department. The latter gave access to his file of several hundred Canadian Ice Distribution Survey Cards, and to his address file, for he has over a considerable interval been collecting, mainly by correspondence, data on break-up and freeze-up dates of Canadian fresh water ice. Colonel Patrick D. Baird, Director of the Arctic Institute, was then consulted, and kindly loaned Professor Hare's unpublished thesis, Climate of the Eastern Canadian Arctic and Sub-Arctic, 3 vols. (1950), which proved instructive.

In Ottawa calls were made upon Dr. Norman L. Nicholson and Mr. Keith Frazer, both of the Geographical Branch, Department of Mines and Technical Surveys, from whom the American Geographical Society later received a complete file of 1070 Canadian Ice Distrubution Survey cards; Mr. J. N. Betournay of the Department of Transport, who later forwarded data on ice thicknesses in Canadian canals; and Mr. Garnet Dunn, Chief of Administration, Defence Research Board, and the following members of the Board - Mr. Merrill, Mr. Trevor Harwood, Miss Moira Dunbar, Miss Margaret Montgomery, Miss Doreen Irwin, and Mr. Alec LaRoque. Following the return from Canada copies were received,

under signature of Mr. Ivor Bowen, Director, Joint Intelligence Bureau of the Defence Research Board, of various items of information available in some of these offices, mostly excerpts from unpublished theses on the climate of the Canadian North.

Major Andrew Taylor of Ottawa, formerly of the Corps of Engineers, Canadian Army, an authority upon the Canadian Arctic Archipelago, most kindly devoted a day to assisting the writer in several ways, notably by driving him out to the new buildings of the National Research council, some eight miles from Ottawa, where we sought the advice of Mr. John Pihlainen, whose specialty is permafrost, and of Mr. L. W. Gold, a researcher in snow and ice, and met, albeit very briefly, Dr. Robert Legget, Chief of the Building Research Division. Little information on ice thicknesses was forthcoming there. A visit was next made to Mr. James G. Wright of the North West Territories Administration, who although he possessed no ice data offered abundant suggestions on persons to contact. Major Taylor ascertained that the Dominion Hydrographer's Office relays all ice thickness information received to the Geographical Branch or to the Defence Research Board. He had previously examined the Royal Canadian Mounted Police archives (reports of patrols, explorations, etc.) and reports that a search therein for geographical information is exceedingly laborious and time-consuming, and did not seem well-advised for one whose time was limited.

Arrived in Winnipeg, there followed discussions with Mr. J. L. Johnson, the Provincial Librarian of Manitoba; Mr. Barney Stephanson, Inspector of Commercial Fisheries of the Province of Manitoba; and Mr. B. B. Hogarth, Director of the Water Resources Branch, Department of Mines and Natural Resources of Manitoba. As the result of a second call upon Mr. Hogarth, he very kindly arranged for Mr. Mudry, a hydraulic engineer of his staff, to drive the writer to Lac du Bonnet, a town on the lake of that name, some 65-70 miles northeast of Winnipeg, the headquarters of the Province of Manitoba Government Air Service, for a talk with its Director, Mr. Edward Uhlman, and to Great Falls on the Winnipeg River a few miles north of Lac du Bonnet, there to consult Mr. Ferguson, Superintendent of the powerful hydroelectric station located there, as well as of two others in the vicinity. After Mr. Bradford of the staff had conducted us through the plant, Mr. Ferguson descanted at considerable length upon the problems that ice presents to the effective operation and maintenance of hydroelectric installations, and upon the assistance rendered by ice to winter land transport in Canada. His remarks were most instructive and will be detailed more fully in a subsequent section of this Report. This seems an appropriate place to express anew the heartiest appreciation for the extraordinary efforts exerted by Mr. Hogarth as well as for the zeal of Mr. Mudry in the capacity of guide-escort. Later in April valuable ice thickness data was received from both the Water Resources Branch and the Provincial Govt. Air Service, as a direct result of these contacts personally established in Manitoba.

On the last day (of four) spent in and near Winnipeg, calls were made upon Mr. Clifford P. Wilson, Librarian of the Hudson's Bay Company and Editor of its quarterly house organ, The Beaver; Mr. E. Weber, Assistant Secretary of the Hudson Bay Mining and Smelting Co. Ltd. (with copper mines at The Pas, Manitoba, and hydroelectric plant at Island Falls, Saskatchewan, about 60 miles farther north); and Mr. Alexander Barbour, Manager of Booth Fisheries Ltd., who called attention to the interrelationship of lake ice with commercial fishing in Canada generally and Manitoba in particular, and suggested correspondents one of whom has since contributed to our accumulation of ice thickness data.

En route to New York via Minneapolis and Chicago, a visit was made to Wilmette, Illinois, where Mr. William Marshall, whose acquaintance had been made some months previously in New York, conducted the writer through the Snow, Ice, and Permafrost Research Establishment, and introduced him to Mr. James Gillis, Acting Director, and successor to Dr. A. Lincoln Washburn, who had recently resigned.

Obviously it is not practicable to recount with great minuteness the exact subjects under discussion, or the knowledge retailed and opinions expressed in all of these many interviews with Canadians and Americans, but it seems desirable to indicate in what fields of academic and economic endeavor expert advice and data was solicited. Over 33 persons were consulted in the course of the visits to Dartmouth College, Montreal, Ottawa, Winnipeg, and Wilmette, and there is no doubt that these conversations were productive of increased understanding of freshwater ice conditions in Canada, although not productive of any very formidable accessions of data. There is abundant reason to believe that such data simply do not exist except in rather modest amounts, a belief thoroughly confirmed by these Canadian quests and inquiries. Material uncovered in the course of these travels continued to arrive sporadically by mail for several weeks following the return to New York on April 5, 1953, and a correspondence conducted somewhat erratically ever since October was now intensified with generally rather satisfactory results. During the whole term of the Ice Thicknesses Research correspondence was conducted with some 35 persons of whom the vast majority responded. Correspondents are listed elsewhere in this report (see pp. 13-15).

The Canadian Ice Distribution Survey cards are the most massive reference item perused in the course of the ice thickness investigations. Unfortunately the hundreds of quotations from the published literature borne on these cards relate for the most part to marine ice. Of the latter, perhaps only one-third mentioned thicknesses, the remainder being concerned with break-up and freeze-up dates or with rather general observations. Yet thoroughness required that the entire file be examined, card by card. At this writing, word has been received that over 700 more of these cards are en route from Ottawa.

Periodically the SIPRE bibliography cards, received by the American Geographical Society in batches of 100 or more at a time, were examined to the total number of over 5700 titles, of which probably not over 5 per cent concerned ice thicknesses or ice seasons, and as a result the bibliography of titles examined and of Eurasian titles were materially expanded. By June 15th, 1953, activities leading to the acquisition of data were practically suspended in favor of those necessary for the production of this Final Report - editing the Bibliography, drawing of the 80-odd pages of ice thickness graphs and of a key map, preparation of various lists and tables, and writing the text of the Report.

II Difficulties Confronting Ice Thicknesses Research.

From chronicling the principal stages of the project operations, let us now turn to detailing certain deficiencies which impede, if they do not entirely prevent, achievement of complete success in ice thicknesses research, at least in the case of that dependent upon the literature, without benefit of made-to-order field observations.

One approaches the search for ice thickness data with the rather vague impression presently becoming an ever more firm conviction, that there exists an enormous literature on travel and exploration in the Arctic and sub-Arctic-on Alaska and the Yukon, the Polar Regions and Greenland, Mackenzie and Keewatin Districts, Baffin Land and Ellesmere Land and the rest of the Canadian Arctic Archipelago, and Hudson Bay. But once having ventured into this vast subject field, and turned over the first few dozen seemingly promising references, optimism at the abundance of scientific writing yields to astonishment that ice thickness data occurs so sparingly. In the course of correspondence this dearth was frequently mentioned by the writer, and almost invariably recognized by scientists who have had occasion to investigate ice, such as Dr. Charles F. Brooks, Director of Blue Hill Observatory, and Professor John C. Weaver of the University of Minnesota, who was instrumental in the preparation of the Ice Atlas of the Northern Hemisphere (1946). Some notion of this scarcity may be gained by an examination of the attached bibliography, in which the sections comprising useful references and those not of assistance are of approximately equal length, the latter in fact a trifle longer. And from the annotations, it is seen that very frequently the 'useful' category does not even contribute an ice thickness but instead perhaps a table of break-up - freeze-up dates, or a few references, or general remarks or theories on freshwater ice.

Granted the dearth of ice thickness data, one must then face the prospect of its frequently proving disappointing owing to its fragmentary, scattered, or very general character. The occurrence of ice

thicknesses recorded monthly at a given station over a period of a century, or fifty or twenty years, or even a decade, is so rare as to be hypothetical, at least for Canadian and Alaskan stations, though not for certain European stations. Such records exist for many stations in as many as 20 of the northern United States, spanning over a half century, beginning with 1898. Similar data of long duration cover Great Lakes and major Lawrence River ports, but are extremely scarce for the vast Canadian expanse north of Edmonton, Winnipeg, and the St. Lawrence, the area of paramount concern to this research project as originally conceived.

One of several situations, all of them more-or-less discouraging, may be found to obtain. There may occur a run of data, spanning three or four years, which upon closer examination will be found to contribute only enough points for one graph, the others being too widely scattered in time or at the end and beginning of separate seasons, as March-April-October-November, instead of in a series of consecutive or nearly consecutive months as November-January-March, or November-December-January. Or there will occur but one or two ice thicknesses for a given station during a given year, whereas at least three are required for a graph. Or, very frequently, one encounters some estimate of the average or maximum ice thickness, or the range in ice thickness, for a given body of water during the average winter. This is of course better than nothing, but of little assistance in the exact determination of freshwater ice thicknesses.

The same scarcity of ice thickness data encountered in the published literature prevails elsewhere as well. Inquiries made in person and correspondence both revealed the existence of only relatively meagre amounts of ice thickness data in the archives of Provincial government bureaux and the files of such business and commercial establishments as might reasonably be expected to notice carefully the state of freshwater ice.

How is this relative absence of ice thickness information to be accounted for? In one or more of several ways. First, even in industries or endeavors materially affected, either favorably or adversely, by the condition of lake or river ice - such as commercial fishing, tractor haulage, aircraft landings and hydroelectric power generation - the Canadians concerned are wont to measure to the ice only very infrequently, relying upon obvious simple tests of its strength and supporting capacity, or upon comparisons of its condition with that upon the same data in previous years, taking into account winds, temperatures, and snow cover. What is the objection to making actual ice thickness measurements with a certain regularity? Only that when ice attains a thickness of three feet or more, cutting through it becomes a laborious task, and one scarcely to be undertaken even in the interests of science, unless there exists some pressing practical need for an exact measurement - which it seems there usually does not, unfortunately for such a study as this one. Joseph Burr Tyrrell, eminent

Canadian veteran of many thousands of miles of exploratory journeys in the North West Territories, remarks that with an axe, the only suitable tool available in camp, one could chop through only one foot of ice, although Eskimos using their spears would cut through two feet or more in a fairly short time.*

Secondly, exact ice thicknesses have not been of much practical scientific interest until quite recently, particularly since the conclusion of the Second World War, which fact goes far to explain the virtual absence of any data of consequence. Even assuming that actual measurements were occasionally made, apparently no record of them was kept, since they were not deemed of lasting value or interest to other investigators. Formal observations of ice thickness appear not to have been recorded, as is the case so generally with such meteorological phenomena as temperature, barometric pressure, wind velocity, and precipitation.

Ice thicknesses recorded in the earlier published accounts, particularly the travel narratives of explorers of the Canadian North through the first half of the Nineteenth Century are accurate enough, but are never maximums, as Stefansson points out. Explorers like Dr. John Rae, Sir John Richardson, or Sir George Back, traveling in the region of Great Slave Lake or Great Bear Lake or the Coppermine River, were not greatly concerned to ascertain freshwater ice thicknesses, yet occasionally such a measurement occurs in their journals. Probably it could only have been learned as an incidental result of the performance of some camp task - fishing through the ice or cutting through it to secure water - chores performed of course by Indian or Eskimo guides or camp followers who were naturally enough averse to any more work than necessary, and hence for chopping through the ice would choose a spot where it was apt to be thinner, a place well covered by snow drifts, probably close to shore. Thicker ice would more likely be found farther from the shore of a sizeable lake, where the wind had prevented the accumulation of any appreciable snow cover, which is an excellent insulation and a great retarder of ice formation. So it is that although these excellent journals provide us with valuable data of a type sufficiently scarce, still they do not inform us as to the extremes of freshwater ice thickness for the bodies of water mentioned above, even though they may cite thicknesses ranging from five to eight feet.

Notice must now be taken of the several variables affecting the course of ice thickness. In addition to individual records of ice thickness, the Contract desired the inclusion of information on as many of the following as are available: 1) the location of the measurement point, with respect to the shore line, the topography, and the prevailing wind direction; 2) the extent of the ice sheet;

*Letter from J. B. Tyrrell to the author, February 5, 1953.

3) the quality or character of the ice; 4) the loading or use to which the ice has been subjected; 5) the temperatures of the air and/or the ice at the time of the thickness measurement; 6) the depth of snow on the ice at the time of measurement; 7) the depth of water at the point of measurement; 8) the break-up and freeze-up dates; and 9) the date when the area is ice free. Unquestionably it is desirable that all this allied information be brought together in one compilation, but much of it is simply not available, and its acquisition must await new and accurate field observations made to order for the purpose. Of the above enumeration, only items 5 (air temperature), 6, 8, and 9 are available with any regularity, almost never in the identical reference source, however. The foremost can be obtained, of course, from appropriate weather records, but seems never to accompany the ice thickness. References to the other items are so infrequent that one is scarcely guilty of exaggeration in saying that they never occur. Ice thickness on rivers is influenced by the velocity and stage of the water, in addition to the foregoing several factors governing ice formation on lakes.

III Average Ice Thickness Curves.

In the consideration of Plates 54 through 59, illustrative of average ice thicknesses for a number of stations on several rivers or lakes in a sizeable geographical region, it is appropriate to specifically enumerate the stations concerned and to try to account for the grouping into regions. Plate 54 shows an ice thickness average for six stations on six rivers of the Prairie Provinces of Alberta and Saskatchewan, as follows: Ranfurly and Halkirk, Alberta, body of water unkown; Battleford, on the North Saskatchewan River at the mouth of the Battle River; Swift Current, on Swift Current Creek; Moose Jaw, on Moose Jaw Creek; and Qu'Appelle, on the Qu'Appelle River, all four in Saskatchewan. These towns are all located between 50° and 54 ° of latitude, all in country very similar in character, and the streams may be considered pretty similar in size, except for the North Saskatchewan, a large river 760 miles in length, and possibly the Qu'Appelle, a trubutary of the Assiniboine, 270 miles long.

On Plate 55 there are averaged ice thicknesses for seven rivers in Manitoba: the Saskatchewan River at The Pas, the Red River of the North at Emerson, and the East Waterhen, Bloodvein, Hole, Dauphin, and Berens rivers, of which the last four all flow into Lake Winnipeg. Both the Saskatchewan, 340 miles long after the junction of its North and South branches, and the Red, 533 miles in length, are mighty rivers draining many thousands of square miles of the Northern Plains. All of the other watercourses, however, are of relatively small size. They lie within a belt of latutude 5° wide, from 49° to 54°, all of it pretty generally alike as to terrain, elevation, climate and weather.

Plate 56 covers eight stations on four Manitoba lakes: Gimli, Norway House, and the mouths of the Hole, Bloodvein, and Dauphin rivers, all on Lake Winnipeg; Lac du Bonnet on the lake of that name; Island Lake in northeastern Manitoba; and Grace Lake at The Pas. These lakes are not strictly comparable in size, Winnipeg, one of the largest of Canadian lakes, having an area of 9,398 square miles, an altitude of 713 ft. above sea level, and being 240 miles long, and 55 miles in greatest width, while Grace Lake and Lac du Bonnet classify as small lakes, the latter being 20 miles long and from one to four miles broad. Island Lake is in an intermediate category, 550 square miles in area. Again all stations lie between 50° and 54° of latitude.

Ten stations on five rivers of the Dakotas, Minnesota, and Wisconsin are represented by the curve on Plate 57. They are Williston and Bismarck, North Dakota, and Pierre and Yankton, South Dakota, all on the Missouri River; Huron, South Dakota, on the James River, a tributary of the Missouri; Moorhead, Minnesota, on the Red River of the North; Minneapolis and St. Paul, Minnesota, and La Crosse, Wisconsin, all on the Mississippi; and Wausau, Wisconsin on the Wisconsin River, a tributary of the Mississippi. Here seven of our stations are on truly immense rivers, the Mississippi and Missouri, with their lengths of 2,350 and 2,714 miles and basins of 714,650 and 529,350 square miles respectively. In length even the other three waterways are very considerable, but of course the James and Wisconsin have but very modest volumes when compared with their parent streams. For this region the range of latitude is greater, from 42° to 49°.

Eight rivers of New Brunswick, Maine, New Hampshire, Vermont, and New York are covered by the average ice thickness curve on Plate 58: the stations are Chatham on the Miramichi River, Fredericton on the St. John River, Bangor on the Penobscot, Lewiston on the Androscoggin, Gardiner on the Kennebec, Concord on the Merrimack, Brattleboro on the Connecticut, and Albany on the Hudson River. These streams range in length from about 110 miles in the case of the Merrimack to 400 miles in that of the St. John River, and are otherwise of a somewhat similar order except that the Hudson has a far greater volume than any of the others despite its not especially extensive basin of 13,370 square miles. These stations occupy a 6° expanse, latitudes 42° to 48°.

Lastly on Plate 59 appear average ice thicknesses for seven lakes of the Maritime Provinces, Ontario, and Northern New England; specifically, unidentified lakes and ponds in the vicinity of Sydney, Nova Scotia, and Point Lepreaux and Point Escuminac, New Brunswick; Barrie, Ontario, on Lake Simcoe; Gravenhurst, Ontario, on Muskoka Lake; Burlington, Vermont, on Lake Champlain; and Greenville, Maine, on Moosehead Lake. It may be safely assumed that the lakes under consideration in the Maritimes are small, probably not over one square miles in area, and certainly less than five. Muskoka Lake is 15 miles long and five miles wide. The other three are considerable bodies of water, however: Lake Champlain with its 435 square miles, 107 miles

long and from a half-mile to 14 miles in breadth; Moosehead Lake, the largest in New England, with an area of 120 square miles, 35 miles long and two to ten miles wide; and Lake Simcoe, 280 square miles, 28 miles long and 26 miles wide. So again these bodies of freshwater are not strictly comparable. Were the data more plentiful, one could afford to be more particular in averaging ice thicknesses only for rivers and lakes of quite uniform area or volume. These lakes are located between the forty-fourth and forty-eighth parallels of latitude.

Plates 56 and 59 may require a word or two of additional explanation. Data for the former covers seven fort-nightly periods, but for three of these only one measurement apiece is available, hence there remain only four points on which to base an average ice thickness curve. In the second instance the data, although comprising 92 measurements, spans but five months, and for five of the seven lakes the date given is only the month, nullifying for this operation the advantage of the more exact dates available for Greenville, Maine, and for Burlington, Vermont.

Admittedly two averages enter into each of these last six curves, Plates 54 through 59. Each point represents averaged ice thickness data, and smoothed curves were drawn representing a mean between the various points available. No claim is made that this procedure is entirely appropriate, although it might conceivably prove to be the only one practicable under the circumstances. A considerable similarity between these curves and a sine curve may be observed.

IV Suggestions for Future Conduct of Ice Thicknesses Research.

What of the future of ice thicknesses research, and in what manner might one proceed were these investigations to be resumed in the fairly near future? It seems not inappropriate to offer here at least partial answers to these queries, based on the experience of the past year as well as on some estimate of further possibilities.

Freshwater ice thicknesses of Europe and Asia have of necessity been neglected during the course of our project, which suggests that the 275 references in Section III of the attached Bibliography should be carefully scanned. There is little doubt but that this Eurasian Bibliography can be enormously expanded, for this material is as abundant as North American ice thickness data is scarce.

As for the latter, new references of value will no doubt from time to time be revealed by a careful perusal of the periodically-appearing batches of SIPRE (Snow, Ice, and Permafrost Research Establishment) bibliography cards and the Canadian Ice Distribution Survey cards.

So much for a search of the literature, which should be succeeded by the acquisition of new data from the field, since the yield of information from the former source is regrettably so sparing. For the collection and reporting of actual periodical ice thickness measurements,

a corps of volunteer observers - such persons as postmasters, missionaries, Royal Canadian Mounted Policemen, Hudson's Bay Company factors, and fishermen - should be enlisted. Scores of observers would be needed, and their reports should cover several months, November through April, at least. These would then require a careful sifting, and perhaps the discarding of the most fragmentary or those appearing to be the least trustworthy. The need for this eventual discard should be borne in mind from the first, so that abundant stations may be covered by reports. Mr. Trevor Harwood of the Defence Research Board in Ottawa suggested that unofficial interest in measuring ice thicknesses might be promoted by the offer of $15 a season for this service, and surely the expense of making this arrangement cover twenty, fifty, or even one hundred selected stations throughout Canada and Alaska is not so formidable but that it should be seriously considered. The fact is that two of our correspondents, Mr. W. Schlader, Manager of McInnes Products Corporation Ltd. of Edmonton, a commercial fishery operating on Lake Athabaska, and Mr. J. F. Dunnett, Chief Engineer of Eldorado Mining and Refining Ltd. at Port Radium on Great Bear Lake, voluntarily offered to secure data for us in future seasons, which offers should be accepted, and which leads one to believe that a number of other commercial enterprises in Northern Canada would similarly volunteer their good offices in the gathering of ice thickness data.

The author is a firm believer in the efficacy of correspondence as a method of securing data not available in published sources. Correspondence might well be extended to include observers on or near all the larger lakes of Alaska, Greenland, Canada, and the northern United States, say for all lakes of 100 squares miles or larger in area. Should it not be quite feasible thus to secure data for one season covering 35 to 40 percent of these lakes, and for many rivers as well? Naturally one of the aims is to induce correspondents to make observations in future for stations where no data is now available. In addition to the occupations already enumerated, the correspondents should be recruited from the ranks of miners and prospectors, hydroelectric plant staffs, river and lake pilots, airlines, tractor transport companies, railroads, explorers, professional geographers, trappers, oil companies, meteorologists, geologists, bush pilots, and commercial natural ice companies.

With regard to future methods of proceeding with ice thicknesses research, Dr. Charles F. Brooks, Director of the Blue Hill Meteorological Observatory, suggests that a formula be worked out by means of which the air temperature record may be converted into terms of ice-thickness. The freeze-up dates for numerous lakes are known, so that commencing on these dates one could use degree-days to the base of 32° to obtain a measure of the amount of freezing. Presumably air temperautres can be obtained for many stations for which ice thicknesses are now available, and from these a formula can be worked out to equate the degree-days to the depth of freezing. Of necessity the formula would have to be very rough owing to the uneven effect of snow cover, which on smaller lakes would insulate the ice to a considerable degree, whereas on the larger

ones the wind would be apt to sweep the snow away, drift it or wind-pack it, in any one of which cases the insulating effect of the snow would be materially reduced. The availability of a degree-day formula for ice thickness, Dr. Brooks believes, would be particularly useful for this specific study, since the winter season varies so greatly from year to year north of the 54th parallel that mean conditions of ice thickness are of little value. Knowledge of what the temperature has been up to a certain date would make possible the computation of the probable thickness of the ice. There is an important difference between a degree-day formula for ice thickness and one for the heating of of buildings, aside from the difference in the base temperatures and the existence of a set date (freeze-up date) to start from, and that is the necessity for subtracting for temperatures (degree-days) above the 32° base.

Should it prove possible in future to secure a series of daily air temperatures extending over five or six months for most or at least several of the stations for which ice thickness data are presently available, the execution of Dr. Brooks' proposed scheme would become practicable and is heartily recommended.

CORRESPONDENCE

A

Correspondence with the following proved rewarding through: receipt of ice thickness or ice season data, generally in tabular form; mention of published references and of experts or other qualified persons who should be consulted; receipt of information on the behavior and peculiarities of freshwater ice; recommendations on methods of proceeding with the ice thicknesses research; and assurances of specific data in the near future.

Mr. J. N Betournay, Designing Engineer, Department of Transport, Ottawa, Ontario.

Mr. Ivor Bowen, Director, Joint Intelligence Bureau, Defence Research Board, Ottawa, Ontario.

Dr. Charles F. Brooks, Director, Blue Hill Meteorological Observatory, Milton, Massachusetts.

Dr. Edwin H. Carpenter, Jr., bibliographer, New York Public Library, New York, New York.

Dr. Victor Conrad, Department of Geology and Geography, Harvard University, Cambridge, Massachusetts. (letter to Dr. C. F. Brooks, loaned by recipient).

Mr. J. F. Dunnett, Chief Engineer, Eldorado Mining and Refining Ltd., Port Radium, North West Territories.

Mr. Charles B. Fobes, meteorologist, U.S. Weather Bureau, Portland, Maine.

Dr. Laurence M. Gould, President, Carleton College, Northfield, Minnesota.

Dr. Numi Hjalmarson, physician, Woodlands, Manitoba.

Mr. George Jacobsen, consulting engineer, Montreal, Quebec.

Dr. W. A. Kennedy, Acting Director, Central Fisheries Research Station, Winnipeg, Manitoba.

Mr. Burt Kooyman, Fisheries Biologist, Game and Fisheries Branch, Dept of Mines and Natural Resources, Province of Manitoba, Winnipeg, Manitoba.

Dr. William Kaye Lamb, Dominion Archivist, Public Archives of Canada, Ottawa, Ontario.

Miss Margaret R. Montgomery, Operationsl Research Group, Defence Research Board, Ottawa, Ontario.

Mr. N. Mudry, Hydraulic Engineer, Water Resources Branch, Dept.of Mines and Natural Resources, Province of Manitoba, Winnipeg, Manitoba.

Dr. Paul H. Nesbitt, Chief of Arctic, Desert, Tropic Information Center, U. S. Air Force, Maxwell Field, Alabama.

Dr. Norman L. Nicholson, Geographical Branch, Dept. of Mines and Technical Surveys, Ottawa, Ontario.

Commander David C. Nutt, Arctic Specialist, Dartmouth College Museum, Hanover, New Hampshire.

Mr. John Pihlainen, Permafrost Research, National Research Council of Canada, Ottawa, and Norman Wells, North West Territories.

Professor D. S. Rawson, Head, Dept. of Biology, University of Saskatchewan, Saskatoon, Saskatchewan.

Mr. W. Schlader, Manager, McInnes Products Corporation Ltd., Edmonton, Alberta.

Mr. Angus Sherwood, Imperial Oil Ltd., Norman Well, North West Territories.

Mr. James Solmundson, commercial fisherman, Gimli, Manitoba.

Mr. Henry W. Stevens, Frost Effects Laboroatory, New England Division, Corps of Engineers, U.S. Army, Boston, Massachusetts.

Miss Marie Tremaine, Director, Bibliography of Arctic Research, Arctic Institute of North America, Library of Congress, Washington, D. C.

Dr. Joseph Burr Tyrrell, geologist, explorer, writer and editor, Toronto, Ontario.

Dr. W. Stewart Wallace, Librarian, University of Toronto, Toronto, Ontario.

Dr. J. Wreford Watson, Director, Geographical Branch, Dept. of Mines and Technical Surveys, Ottawa, Ontario.

Prof. John C. Weaver, Dept. of Geography, University of Minnesota, Minneapolis, Minnesota.

STATIONS COVERED BY

ICE THICKNESS CURVES

Plate	Station	Body of Water	Latitude	Longitude
1.	Nome, Alaska	Snake River	64°30'	165°24'
2.	Bethel, Alaska	Kuskokwim River	60°48'	161°45'
3, A.	Fairbanks, Alaska	Chena Slough	64°50'	147°45'
3, B.	Fairbanks, Alaska	Chena Slough	64°50'	147°45'
4.	Yukon Territory	Lewes River		
5.	Port Radium, North West Territories	McTavish Arm, Great Bear Lake	60°05'	118°01'
6.	Baffin Island, North West Territories	Arctic Bay (Lakes)	73°03'	85°12'
7.	Nottingham Island, North West Territories	(Lakes)	63°20'	78°00'
8.	North West Territories	Stupart's Bay (Lakes)	61°40'	71°50'
9.	Port Burwell, North West Territories	Port Burwell (Lakes)	60°22'	64°50'
10.	Halkirk, Alberta		52°17'	112°10'
11, A.	Ranfurly, Alberta		53°29'	111°38'
11, B.	Ranfurly, Alberta		53°29'	111°38'
12, A.	Battleford, Saskatchewan	North Saskatchewan River at mouth of Battle River	52°41'	108°20'
12, B.	Battleford, Saskatchewan	North Saskatchewan River at mouth of Battle River	52°41'	108°20'
13, A.	Swift Current, Saskatchewan	Swift Current Creek	50°20'	107°45'
13, B.	Swift Current, Saskatchewan	Swift Current Creek	50°20'	107°45'
14.	Moose Jaw, Saskatchewan	Moose Jaw Creek	50°21'	105°35'

Plate	Station	Body of Water	Latitude	Longitude
15, A.	Qu'Appelle, Saskatchewan	Qu'Appelle River	50°30'	103°47'
15, B.	Qu'Appelle, Saskatchewan	Qu'Appelle River	50°30'	103°47'
16, A.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
16, B.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
16, C.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
16, D.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
16, E.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
16, F.	The Pas, Manitoba	Saskatchewan River	53°49'	101°15'
17.	Minnedosa, Manitoba	Minnedosa River	50°15'	99°50'
18, A.	East Waterhen River, at the Ferry, Manitoba	East Waterhen River	51°35'	99°30'
18, B	East Waterhen River, at the Ferry, Manitoba	East Waterhen River	51°35'	99°30'
19.	Lake Winnipeg Basin, Manitoba	Bloodvein River Dauphin River Hole River	51°50' 51°55'	96°45' 98°05'
20, A.	Emerson, Manitoba	Red River of the North	49°01'	97°10'
20, B.	Emerson, Manitoba	Red River of the North	49°01'	97°10'
20, C.	Emerson, Manitoba	Red River of the North	49°01'	97°10'
20, D.	Emerson, Manitoba	Red River of the North	49°01'	97°10'
20, E.	Emerson, Manitoba	Red River of the North	49°01'	97°10'

Plate	Station	Body of Water	Latitude	Longitude
21.	Gimli, Manitoba	Lake Winnipeg	50°38'	96°57'
22.	Number assigned to Bloodvein River on key map. See Plate 19.			
23.	Lac du Bonnet, Manitoba	Lac du Bonnet	50°20'	95°59'
24.	Bruce Mines, Ontario	Lake Huron	46°18'	83°55'
25.	Cochrane, Ontario		49°04'	80°58'
26.	Barrie, Ontario	Kempenfeldt Bay, Lake Simcoe	44°23'	79°41'
27.	Gravenhurst, Ontario	Muskoka Lake	44°54'	79°20'
28.	Ottawa, Ontario	Ottawa River	45°24'	75°42'
29.	Fredericton, New Brunswick	St. John River	45°58'	66°39'
30.	Point Lepreaux, New Brunswick	(Ponds)	45°10'	66°30'
31.	Chatham, New Brunswick	Miramichi River	47°01'	65°26'
32, A.	Point Escuminac, New Brunswick	Miramichi Bay (Lakes)	47°01'	64°45'
32, B.	Point Escuminac, New Brunswick	Miramichi Bay (Lakes)	47°01'	64°45'
33, A.	Sydney, - Nova Scotia	(Lakes)	46°09'	60°11'
33, B.	Sydney, Nova Scotia	(Lakes)	46°09'	60°11'
34.	Pocatello, Idaho	Portneuf River	43°00'	112°40'
35, A.	Williston, North Dakota	Missouri River	48°09'	103°37'
35, B.	Williston, North Dakota	Missouri River	48°09'	103°37'
36, A.	Bismarck, North Dakota	Missouri River	46°48'	100°45'
36, B.	Bismarck, North Dakota	Missouri River	46°48'	100°45'

Plate	Station	Body of Water	Latitude	Longitude
37.	Pierre, South Dakota	Missouri River	44°22'	100°22'
38.	Huron, South Dakota	James River	44°22'	98°15'
39.	Yankton, South Dakota	Missouri River	42°50'	97°21'
40, A.	Moorhead, Minnesota	Red River of the North	46°52'	96°45'
40, B.	Moorhead, Minnesota	Red River of the North	46°52'	96°45'
41.	Minneapolis, Minnesota	Mississippi River	44°58'	93°16'
42.	Saint Paul, Minnesota	Mississippi River	44°56'	93°05'
43.	La Crosse, Wisconsin	Mississippi River	43°50'	91°12'
44.	Wausau, Wisconsin	Wisconsin River	44°59'	89°35'
45.	Harrisburg, Pennsylvania	Susquehanna River	40°16'	76°53'
46.	Albany, New York	Hudson River	42°39'	73°45'
47.	Burlington, Vermont	Lake Champlain	44°29'	73°13'
48.	Brattleboro, Vermont	Connecticut River	42°51'	72°36'
49.	Concord, New Hampshire	Merrimack River	43°12'	71°32'
50, A.	Greenville, Maine	Moosehead Lake	45°29'	69°39'
50, B.	Greenville, Maine	Moosehead Lake	45°29'	69°39'
50, C.	Greenville, Maine	Moosehead Lake	45°29'	69°39'
50, D.	Greenville, Maine	Moosehead Lake	45°29'	69°39'

Plate	Station	Body of Water	Latitude	Longitude
51.	Lewiston, Maine	Androscoggin River	45°29'	69°39'
52.	Gardiner, Maine	Kennebec River	44°12'	69°45'
53.	Bangor, Maine	Penobscot River	44°48'	68°46'

54. Average Ice Thicknesses, Based on Six Rivers in the Provinces of Alberta and Saskatchewan for the Years 1910-1914.

55. Average Ice Thickness, Based on Seven Rivers in the Province of Manitoba for the Years 1942-53.

56. Average Ice Thicknesses, Based on Eight Stations on Four Lakes in the Province of Manitoba for the Years 1951-1953.

57. Average Ice Thicknesses, Based on Ten Stations on Five Rivers of the States of North and South Dakota, Minnesota, and Wisconsin for the Years 1898-1934.

58. Average Ice Thicknesses, Based on Eight Rivers of the Province of New Brunswick and the States of Maine, New Hampshire, Vermont, and New York for the Years 1910-1922.

59. Average Ice Thicknesses, Based on Seven Lakes of the Provinces of New Brunswick, Nova Scotia, and Ontario, and the States of Maine and Vermont, for the Years 1910-1953.

Note: The data on which the following curves of freshwater ice thickness in North America are based are on file at the American Geographical Society of New York.

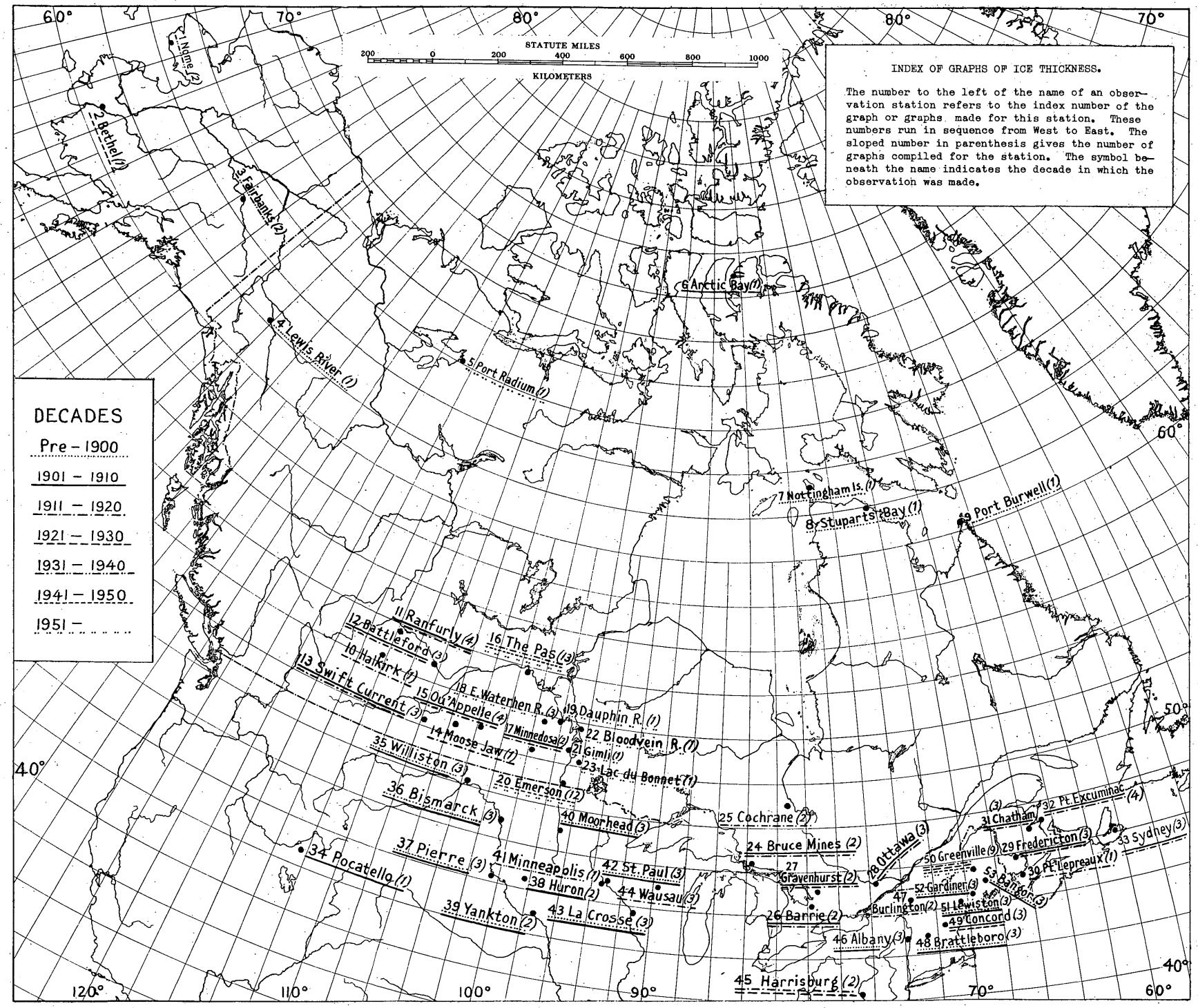

STATUTE MILES
200 0 200 400 600 800 1000
KILOMETERS
INDEX OF GRAPHS OF ICE THICKNESS.
The number to the left of the name of an observation station refers to the index number of the graph or graphs made for this station. These numbers run in sequence from West to East. The sloped number in parenthesis gives the number of graphs compiled for the station. The symbol beneath the name indicates the decade in which the observation was made.
DECADES
Pre - 1900
1901 - 1910
1911 - 1920
1921 - 1930
1931 - 1940
1941 - 1950
1951 -
1 Nome (2)
2 Bethel (1)
3 Fairbanks (2)
4 Lewis River (1)
5 Port Radium (1)
6 Arctic Bay (1)
7 Nottingham Is. (1)
8 Stuparts Bay (1)
9 Port Burwell (1)
10 Halkirk (1)
11 Ranfurly (4)
12 Battleford (3)
13 Swift Current (3)
14 Moose Jaw (1)
15 Qu'Appelle (4)
16 The Pas (3)
17 Minnedosa (2)
18 E. Waterhen R. (3)
19 Dauphin R. (1)
20 Emerson (12)
21 Gimli (1)
22 Bloodvein R. (1)
23 Lac du Bonnet (1)
24 Bruce Mines (2)
25 Cochrane (2)
26 Barrie (2)
27 Gravenhurst (2)
28 Ottawa (3)
29 Fredericton (3)
30 Pt. Lepreaux (1)
31 Chatham (3)
32 Pt. Escuminac (4)
33 Sydney (3)
34 Pocatello (1)
35 Williston (3)
36 Bismarck (3)
37 Pierre (3)
38 Huron (2)
39 Yankton (2)
40 Moorhead (3)
41 Minneapolis (1)
42 St. Paul (3)
43 La Crosse (3)
44 Wausau (3)
45 Harrisburg (2)
46 Albany (3)
47 Burlington (2)
48 Brattleboro (3)
49 Concord (3)
50 Greenville (9)
51 Lewiston (3)
52 Gardiner (3)
53 Bangor (3)
60°
70°
80°
80°
70°
60°
50°
40°
120°
110°
100°
90°
70°
60°
40°

Plate 1.
Ice Thickness Curve: Nome, Alaska, on Snake River, Lat. 64°30', Long. 165°24', Winters 1932-33 and 1933-34. Source: U.S. Weather Bureau. Weekly Weather and Crop Bulletin, 1932-33-34.

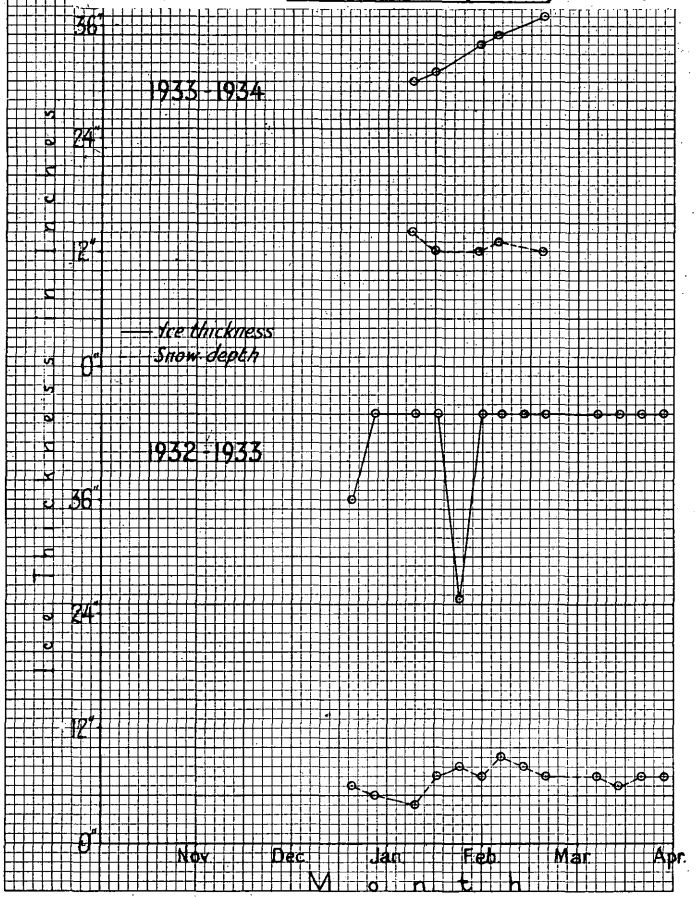


Plate 2.
Ice Thickness Curve: Bethel, Alaska, on Kuskokwim River, Lat. 60°48', Long. 161°45', Winter 1925-26. Source: Climatological Data, Alaska, 1925-26.

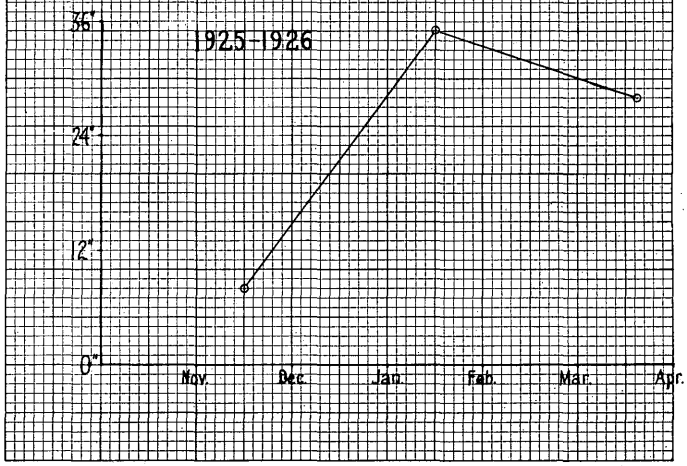


Plate 3, A.
Ice Thickness Curve: Fairbanks, Alaska, on Chena Slough, Lat. 64°50', Long. 147°45', Winter 1932-33. Source: U. S. Weather Bureau. Weekly Weather and Crop Bulletin, 1932-33; R. L. Frost, in Monthly Weather Review, Vol. 61, Nov. 1933, pp. 329-330.

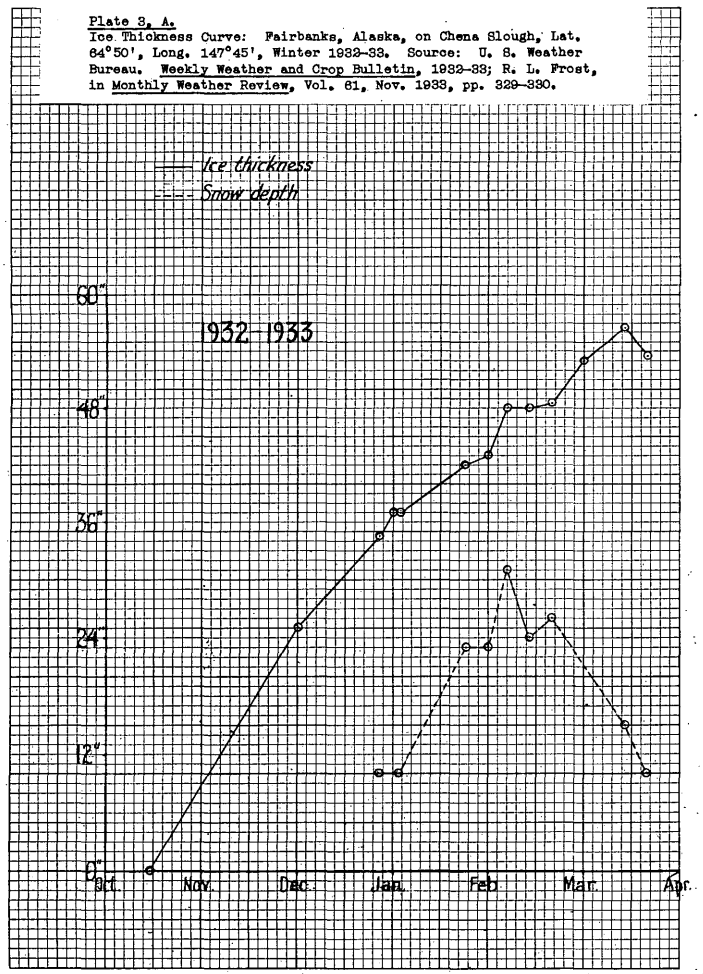


Plate 3, B.
Ice Thickness Curve: Fairbanks, Alaska, Winter 1933-34. Source: U. S. Weather Bureau. Weekly Weather and Crop Bulletin, 1934.

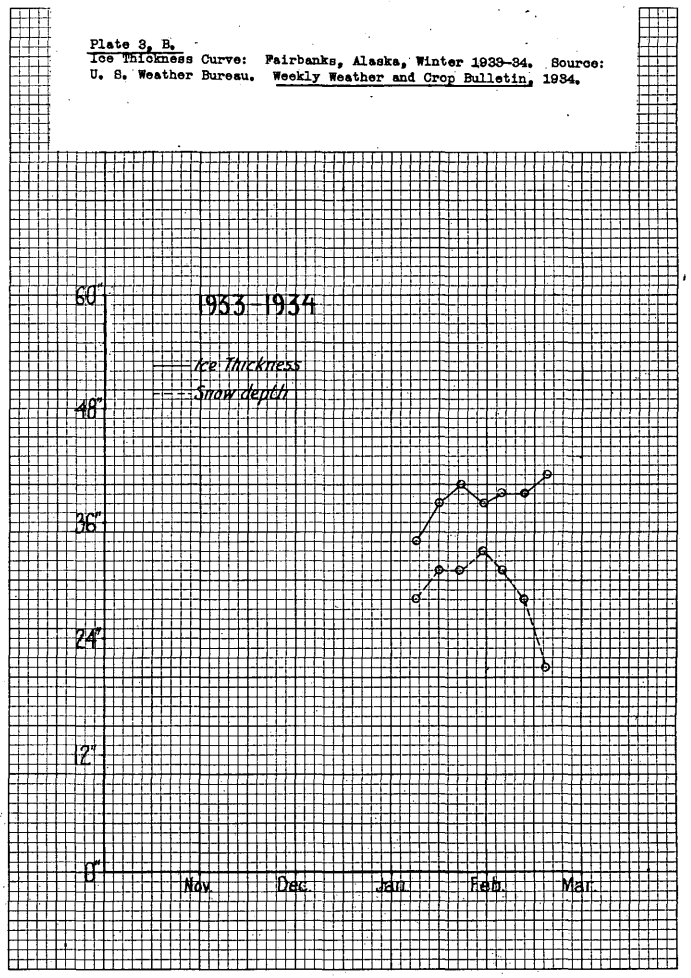


Plate 4.
Ice Thickness Curve: Lewes River, Yukon Territory, Winter 1887–88. Source: Ogilvie, William – Exploratory Survey of Part of the Lewes . . . and Mackenzie Rivers, 1887–88 (1890). Page 49.

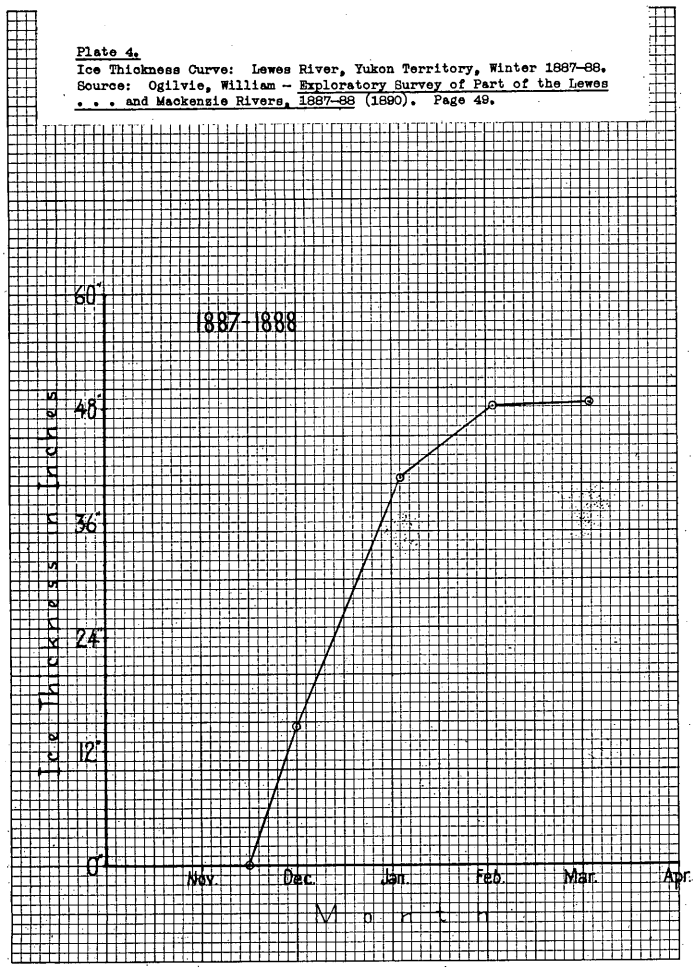


Plate 5.
Ice Thickness Curve: Port Radium, N. W. T., on McTavish Arm, Great Slave Lake, Lat. 66°05', Long. 118°01', Winter 1952–53. Source: Letter from J. F. Dunnett, Chief Engineer, Eldorado Mining and Refining Ltd., Port Radium, N. W. T., 6-18-53.

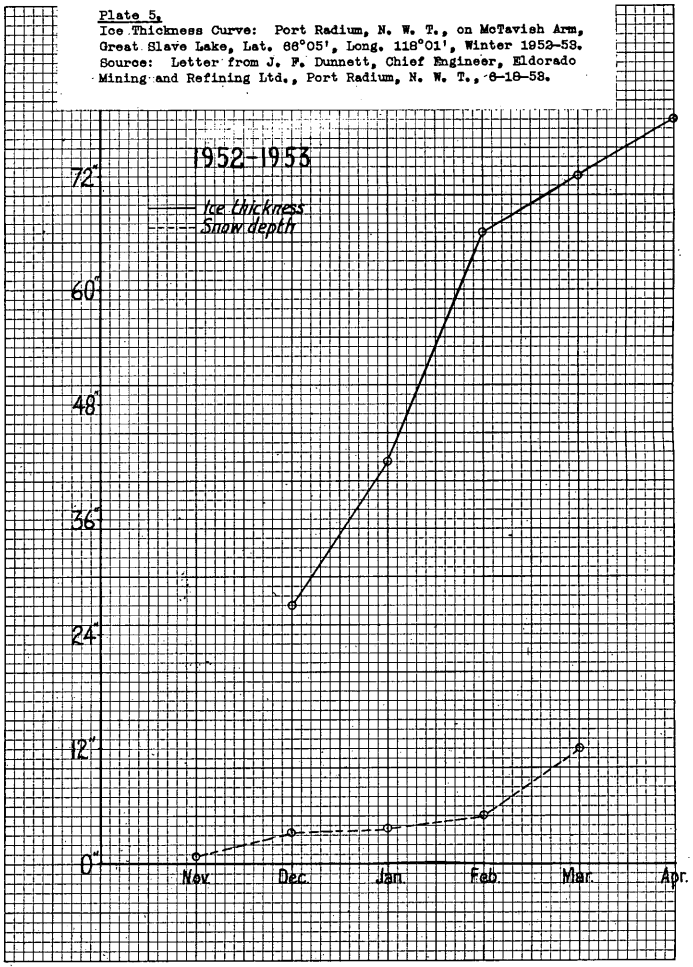


Plate 6.
Ice Thickness Curve: Arctic Bay, Baffin Island (lakes), Lat. 73°03', Long. 85°12', Winter 1910–11. Source: Report on the Dominion Government Expedition of the D. G. S. 'Arctic' in 1910 (1911).

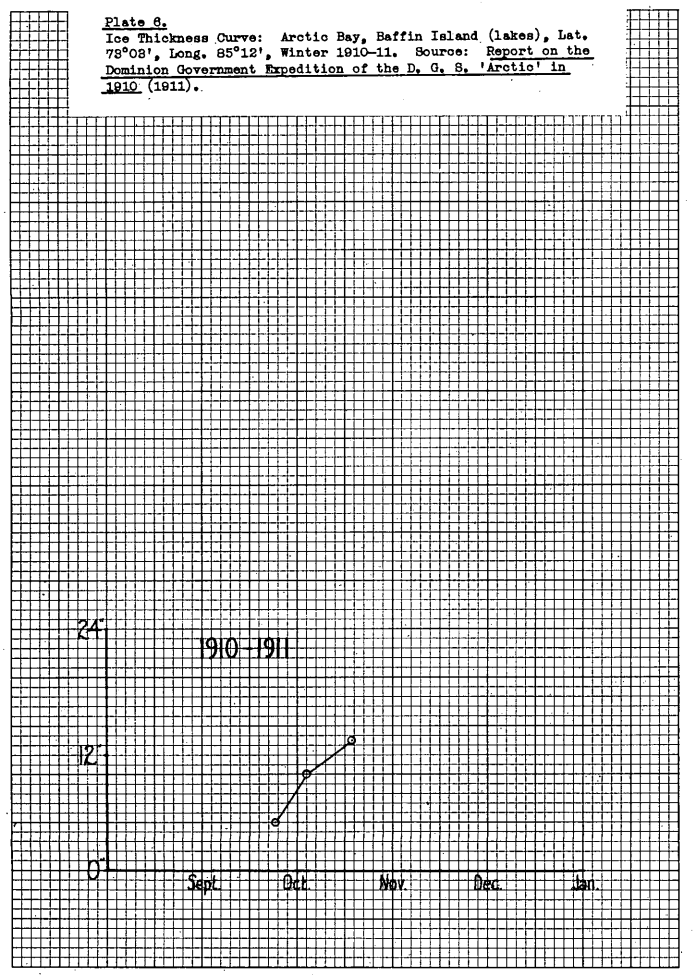


Plate 7.
Ice Thickness Curve: Lakes, Nottingham Island, Lat. 63°20', Long. 78°00', Season 1885–86. Source: Report of the Hudson's Bay Expedition of 1886 under the command of Lieut. A. R. Gordon, R. N.

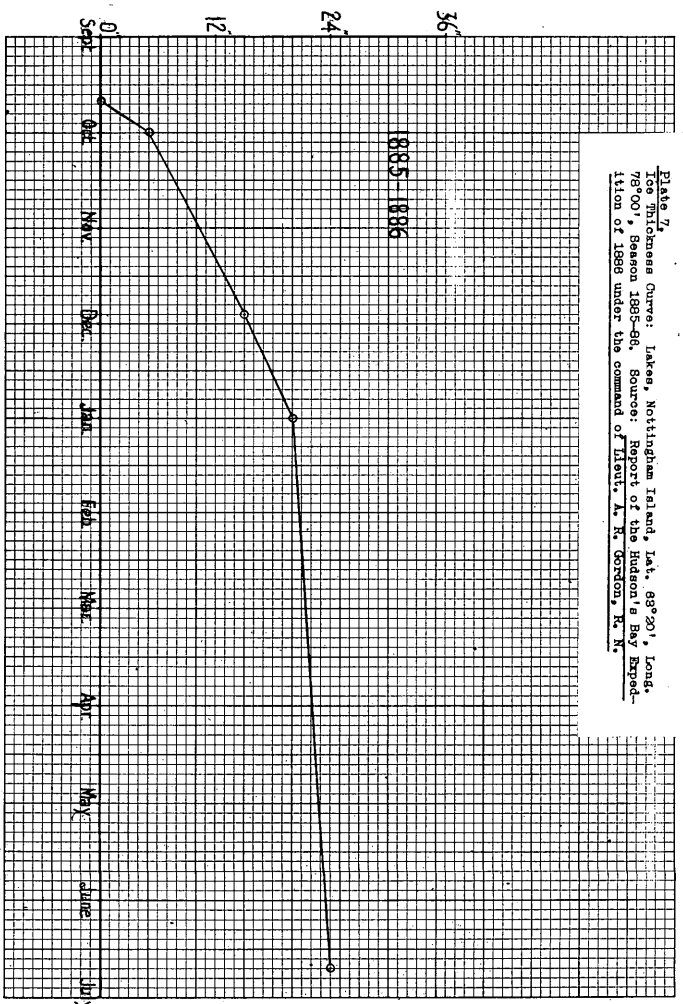


Plate 9.
Ice Thickness Curve: Port Burwell, N. W. T., (lakes), Lat. 60°22', Long. 64°50'. Source: Report of the Second Hudson's Bay Expedition under the command of Lieut. A. R. Gordon, R. N. 1885. Winter 1884-85.

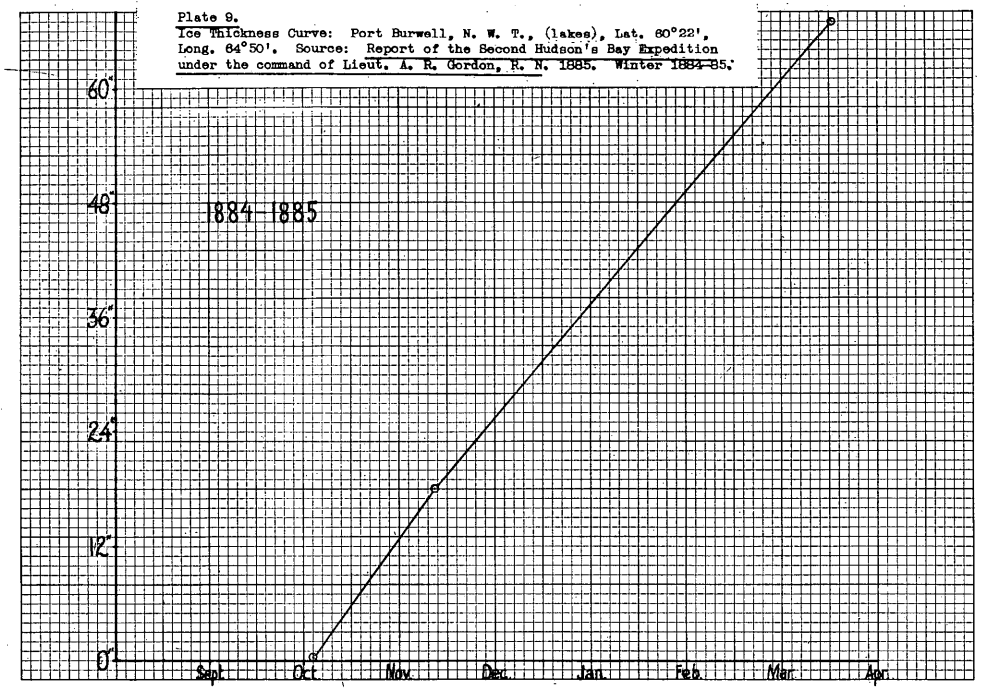


Plate 11, A.
Ice Thickness Curve: Ranfurly, Alberta, Lat. 53°29', Long. 111°58', Winters 1912-13 and 1913-14. Source: Report of the Meteorological Service of Canada, 1912-13.

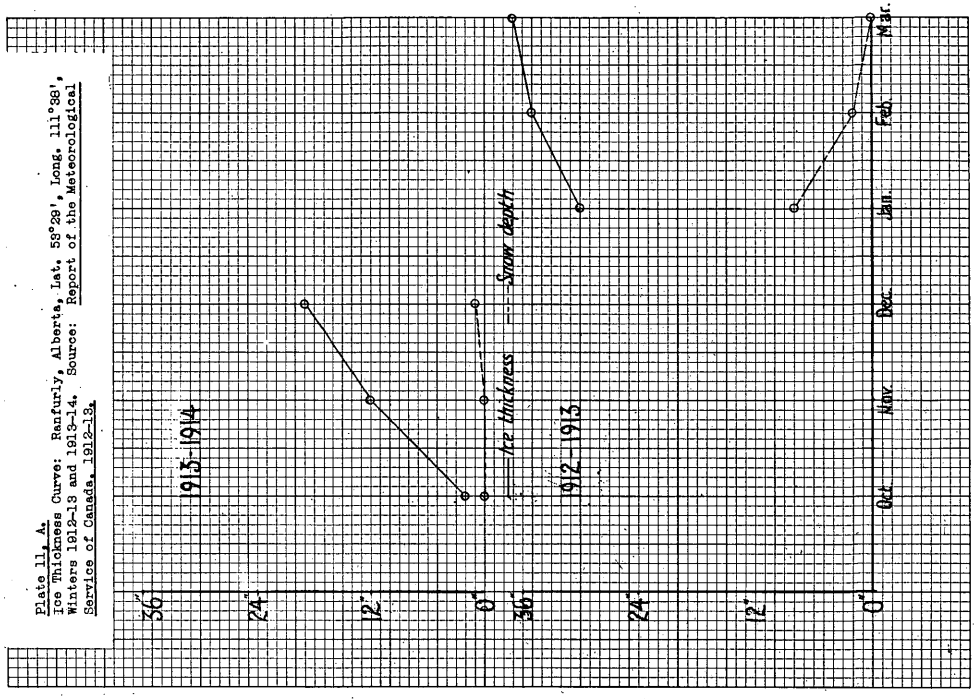


Plate 8.
Ice Thickness Curve: Lakes, Vicinity of Stu[illegible]ay, Lat. 60°22', Long. 71°50', Season 1885-86. Source: Report of the Hudson's Bay Expedition of 1886 under the comma[illegible] of Lieut. A. R. Gordon, R. N.

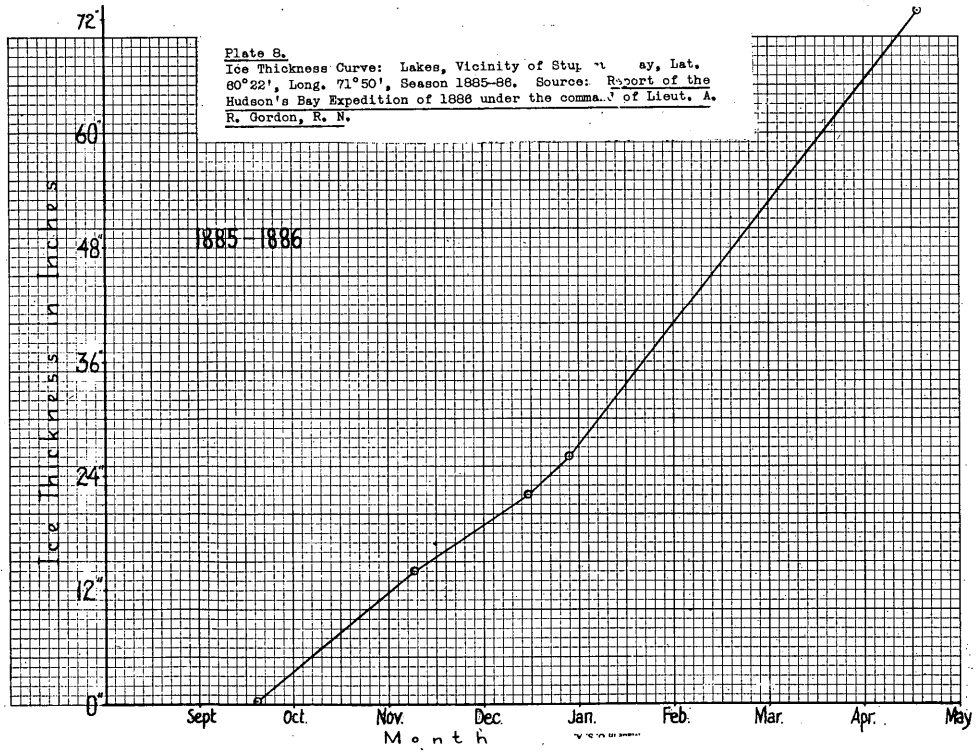


Plate 10.
Ice Thickness Curve: Halkirk, Alberta, Lat. 52°17', Long. 112°10', Winter 1912-13. Source: Report of the Meteorological Service of Canada, 1912-13.

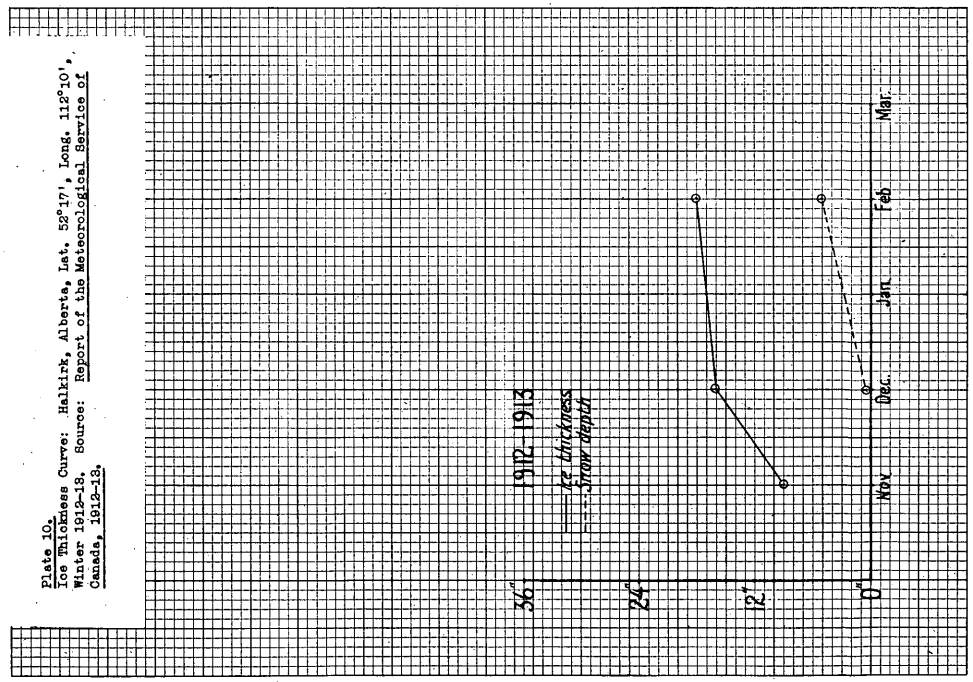


Plate 11, B.
Ice Thickness Curve: Ranfurly, Alberta, Winters 1910–11 and 1911–12.
Source: Report of the Meteorological Service of Canada, 1910–11–12.

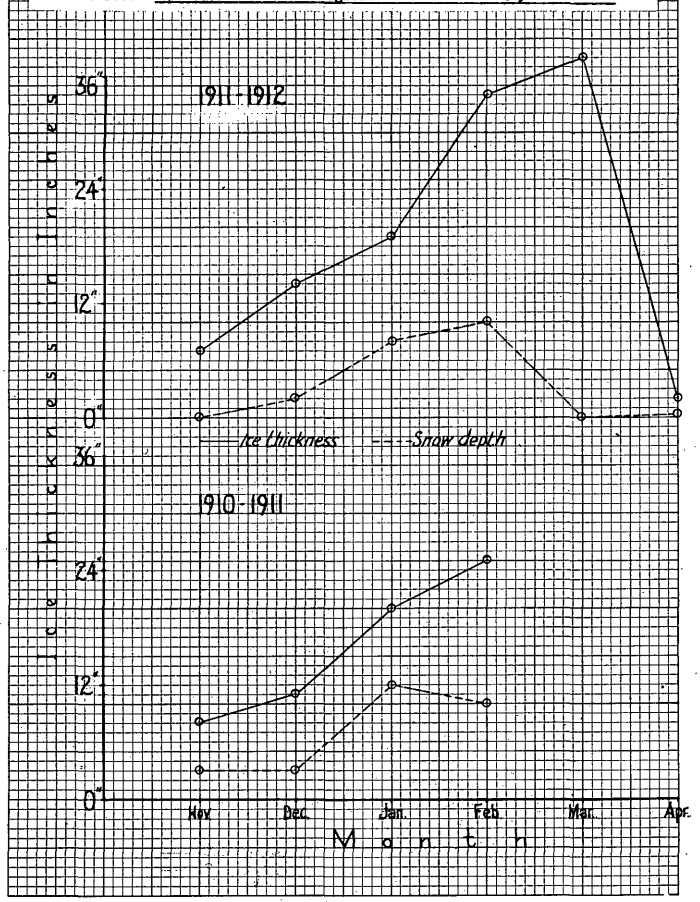


Plate 12, A.
Ice Thickness Curve: Battleford, Saskatchewan on North Saskatchewan River at mouth of Battle River, Lat. 52°41', Long. 108°20', Winters 1912–13 and 1911–12. Source: Report of the Meteorological Service of Canada, 1911–12–13.

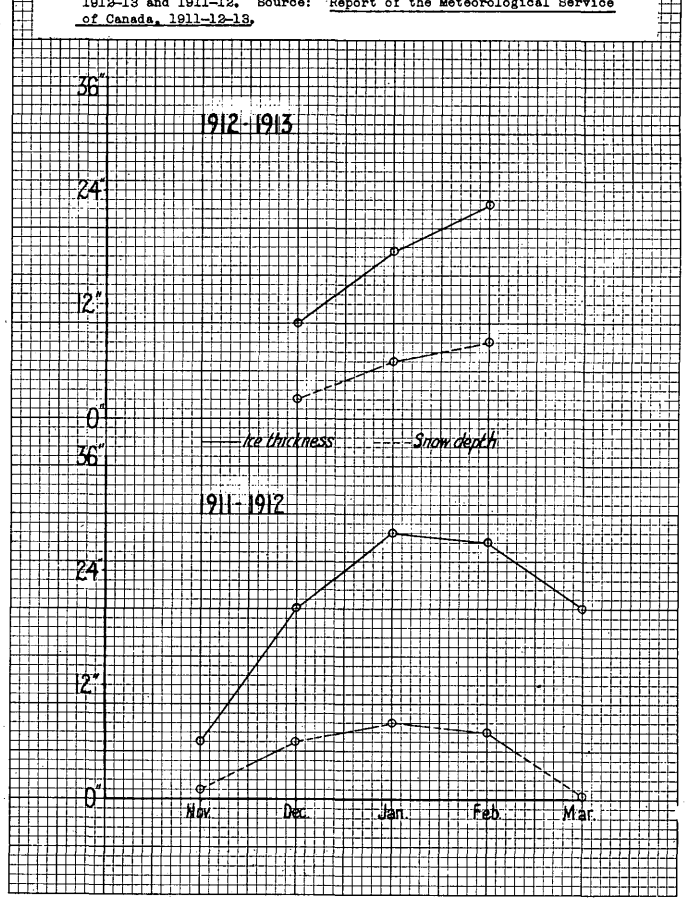


Plate 12, B.
Ice Thickness Curve: Battleford, Saskatchewan, Winter 1910–11.
Source: Report of the Meteorological Service of Canada, 1910–11.

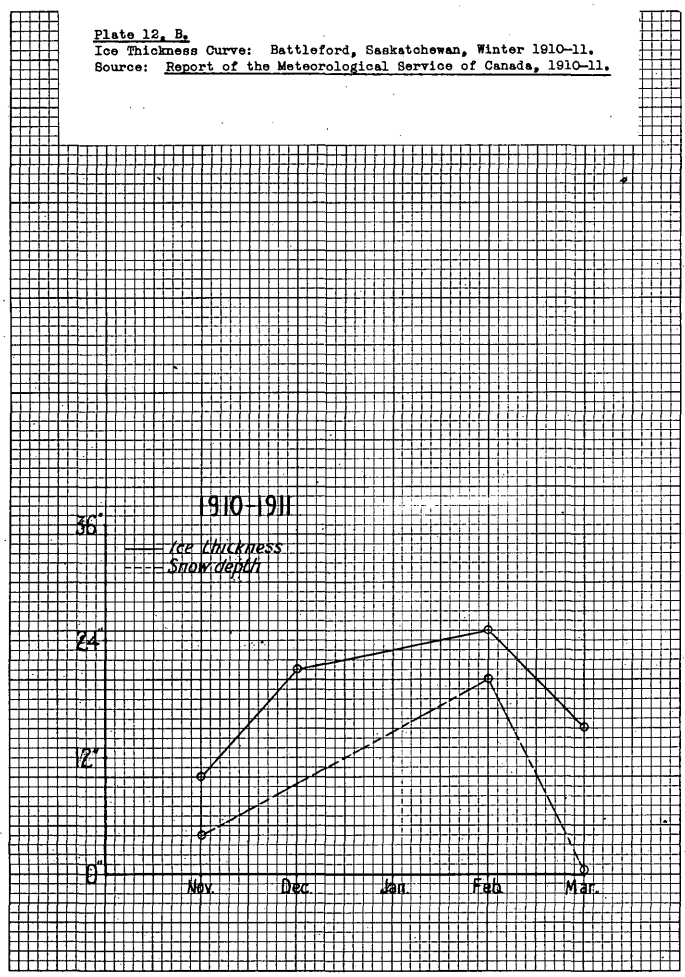


Plate 13, A.
Ice Thickness Curve: Swift Current, Saskatchewan, on Swift Current Creek, Lat. 50°20', Long. 107°45', Winters 1911–12 and 1912–13.
Source: Report of the Meteorological Service of Canada, 1911–12–13.

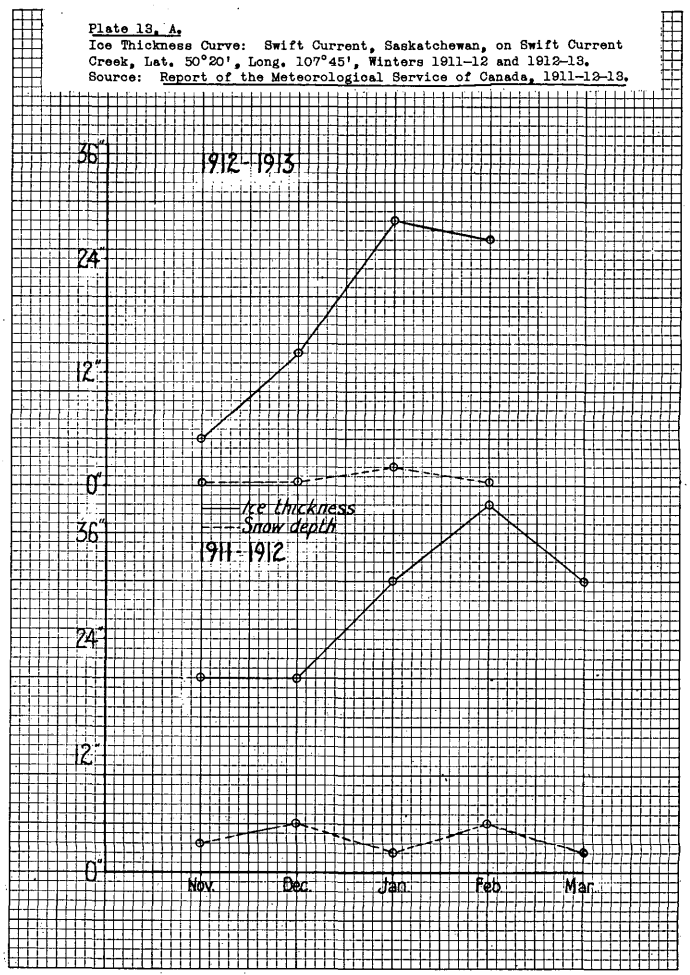


Plate 13, B.
Ice Thickness Curve: Swift Current, Saskatchewan, Winter 1910–11.
Source: Report of the Meteorological Service of Canada, 1910–11.

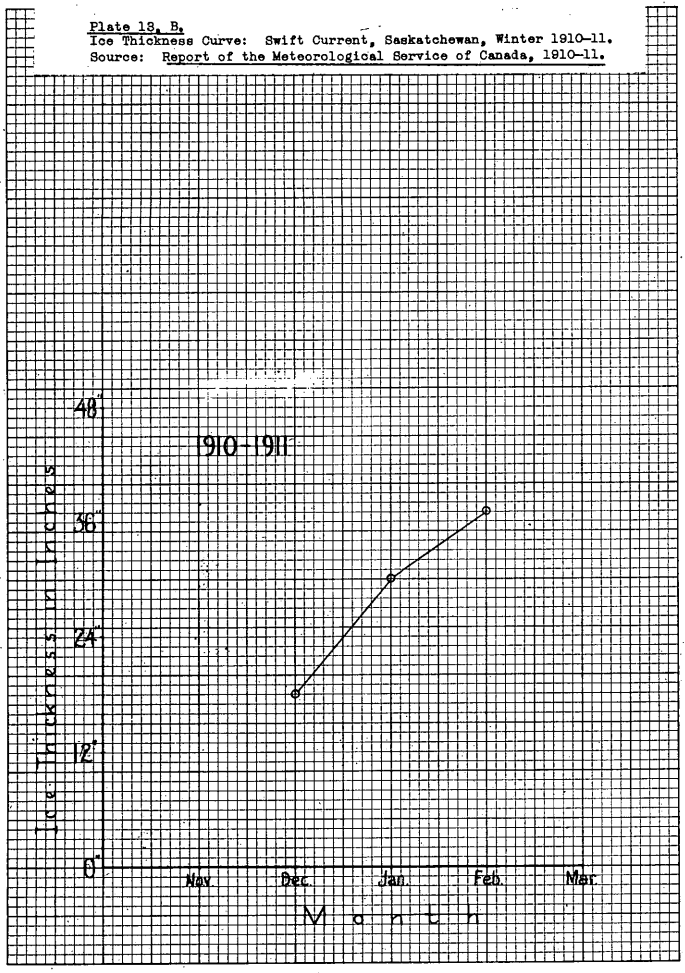


Plate 14.
Ice Thickness Curve: Moose Jaw, Saskatchewan, on Moose Jaw Creek, Lat. 50°21', Long. 105°35', Winter 1911–12. Source: Report of the Meteorological Service of Canada, 1911–12.

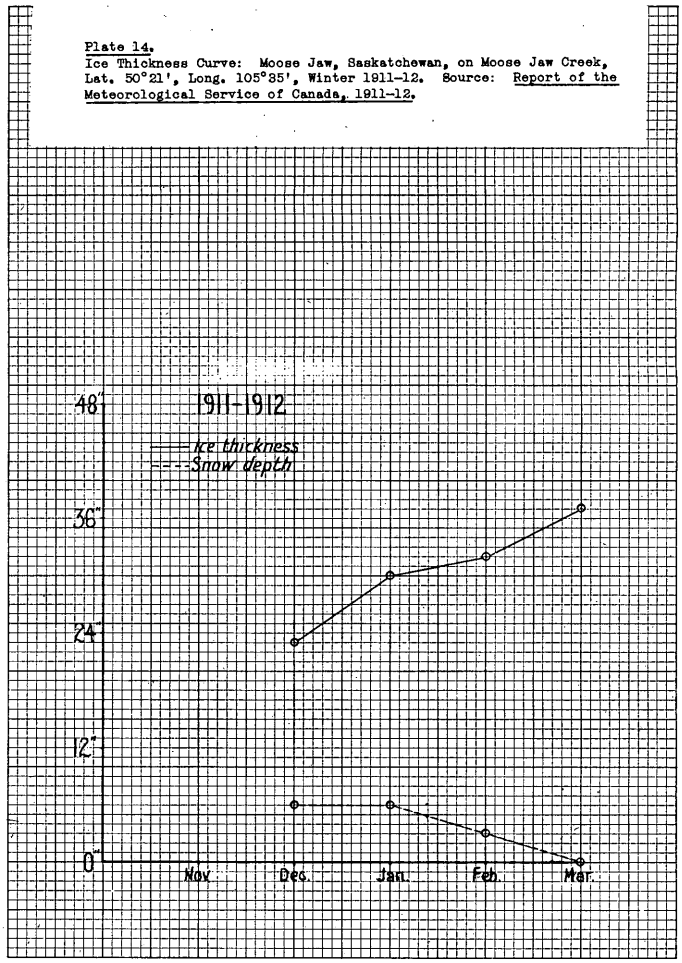


Plate 15, A.
Ice Thickness Curve: Qu'Appelle, Saskatchewan, on the Qu'Appelle River, Lat. 50°30', Long. 108°47', Winters 1912–13 and 1913–14.
Source: Report of the Meteorological Service of Canada, 1912–13.

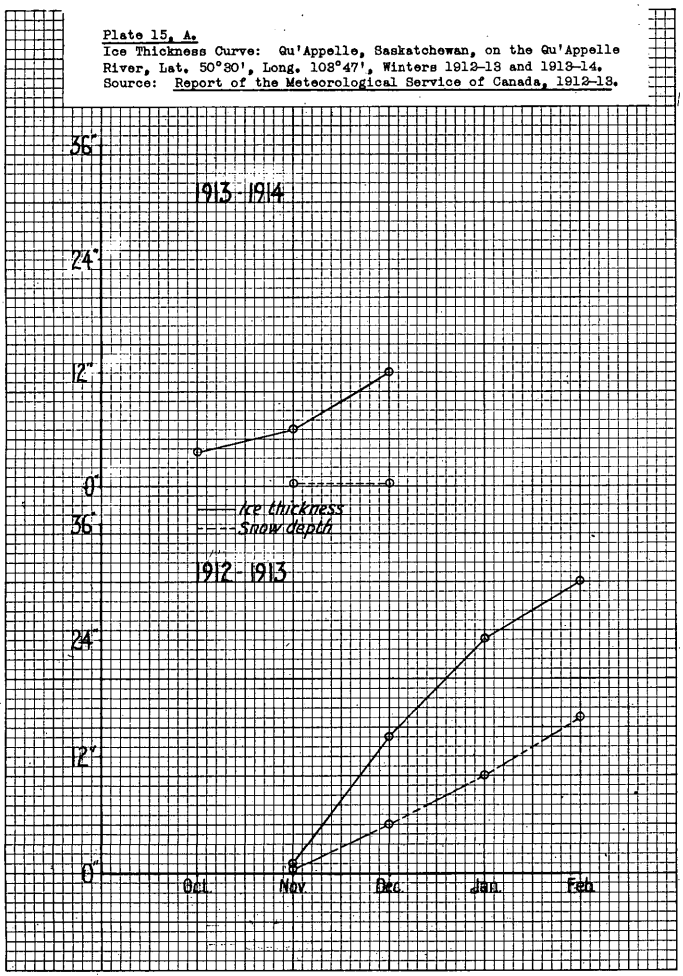


Plate 15, B.
Ice Thickness Curve: Qu'Appelle, Saskatchewan, Winters 1910–11 and 1911–12. Source: Report of the Meteorological Service of Canada, 1910–11–12.

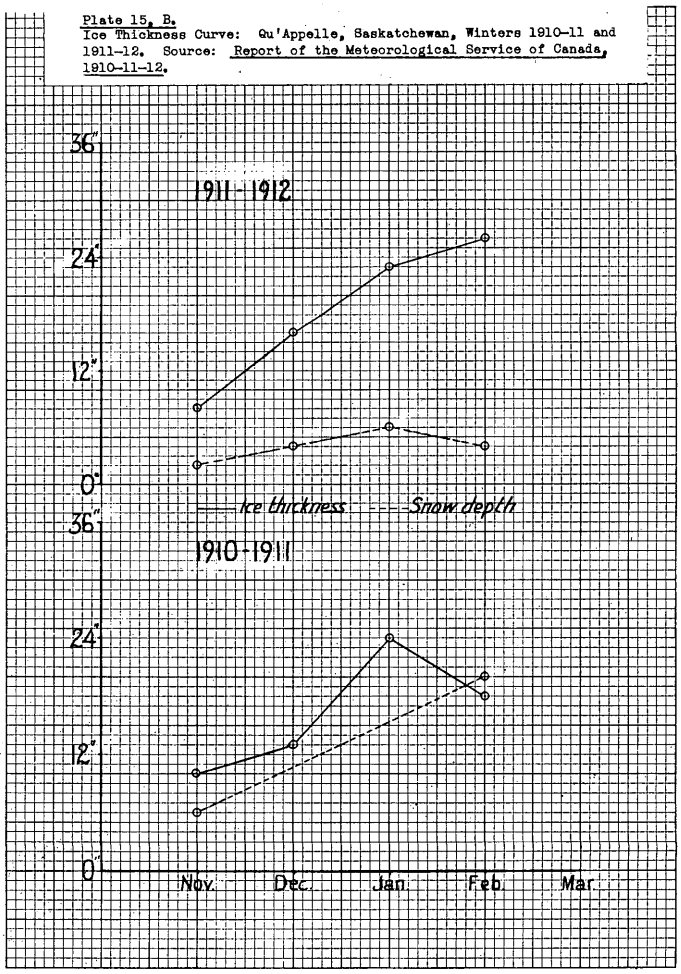


Plate 16, A.
Ice Thickness Curve: The Pas Manitoba, on Saskatchewan River, Lat. 53°49', Long. 101°15', Winters 1950-51, 1951-52, 1952-53. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Manitoba, 4-24-53.

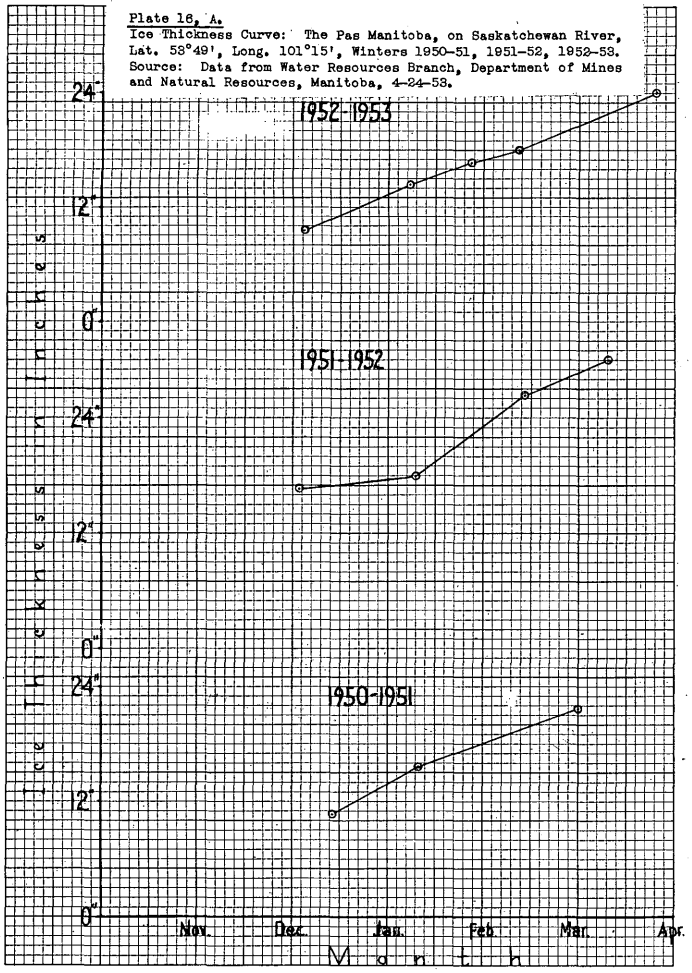


Plate 16, B.
Ice Thickness Curve: The Pas, Manitoba, Winters 1948-49 and 1949-50. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

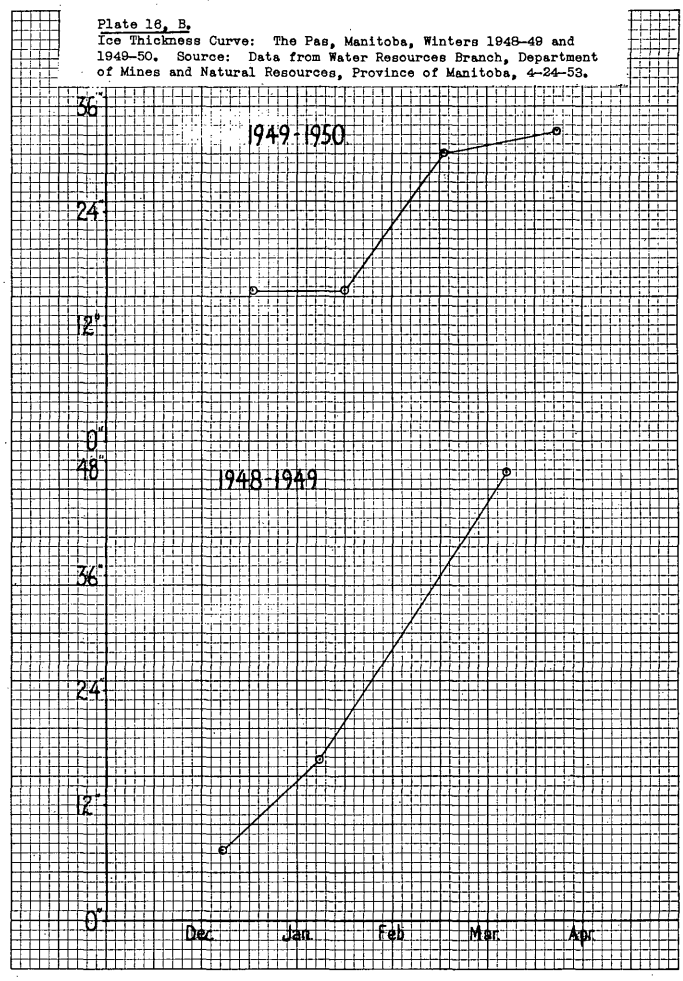


Plate 16, C.
Ice Thickness Curve: The Pas, Manitoba, Winters 1947-48 and 1948-47. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53

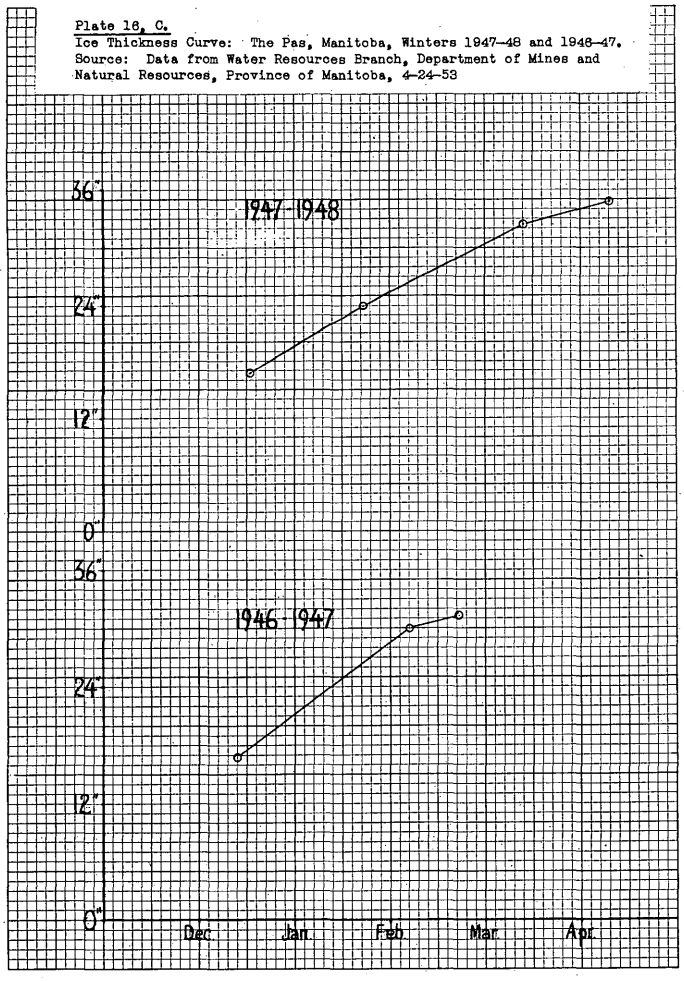


Plate 16, D.
Ice Thickness Curve: The Pas, Manitoba, Winters, 1943-44, 1944-45, and 1945-46. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

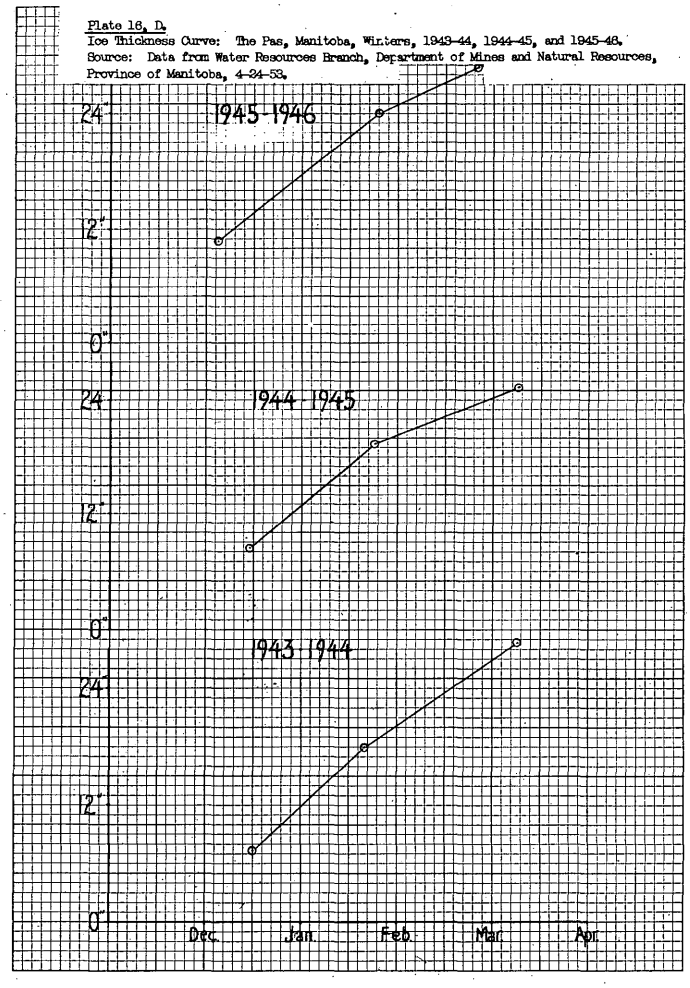


Plate 16, E.
Ice Thickness Curve: The Pas, Manitoba, on Saskatchewan River, Lat. 53°49', Long. 101°15', Winters, 1911-12 and 1912-13. Source: Report of the Meteorological Service of Canada, 1911-12-13.

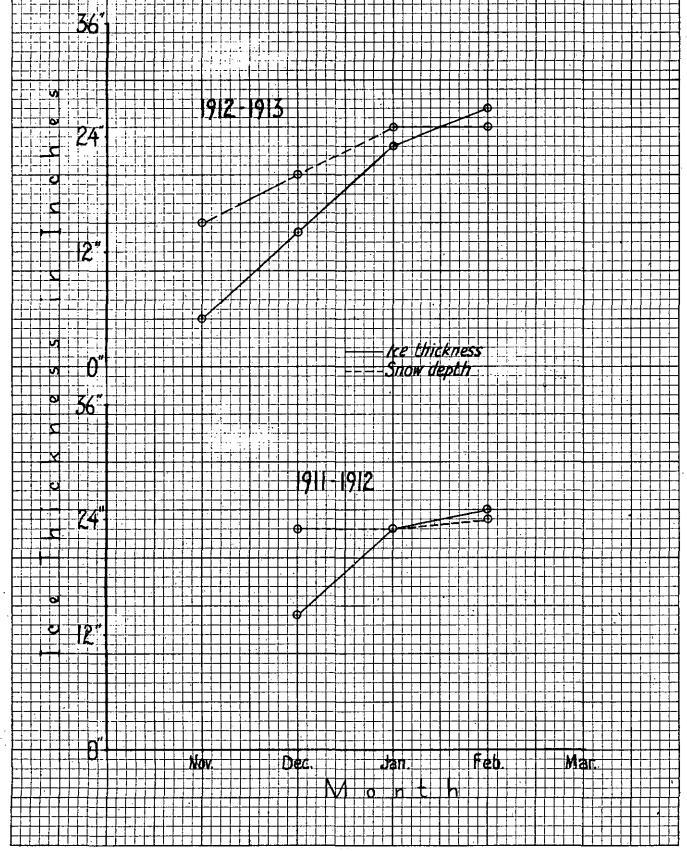


Plate 16, F.
Curve of Maximum, Minimum, and Average Ice Thicknesses: The Pas, Manitoba, Winters 1943-53. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

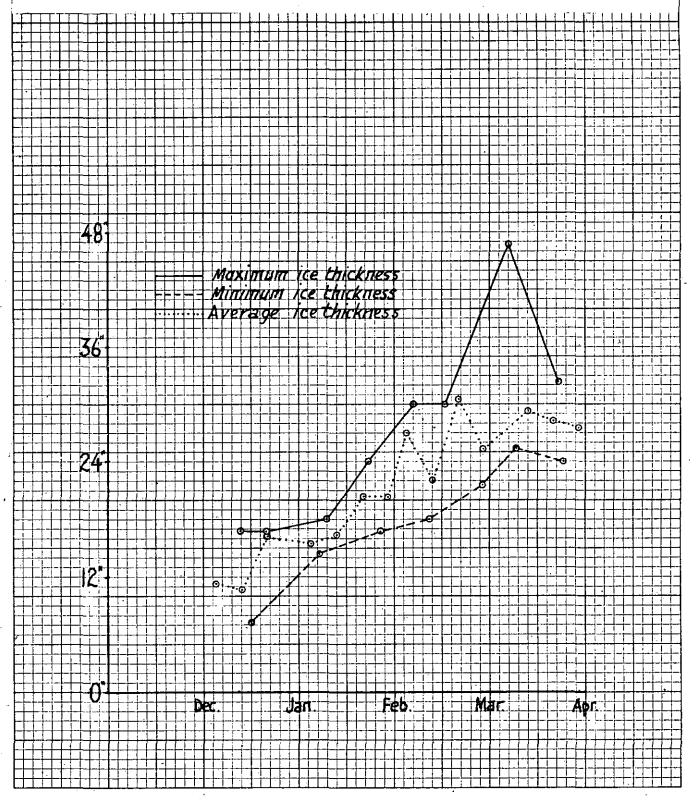


Plate 17.
Ice Thickness Curve: Minnedosa, Manitoba, on Minnedosa River, Lat. 50°15', Long. 99°50', Winters 1910-11 and 1911-12. Source: Report of the Meteorological Service of Canada, 1910-11-12.

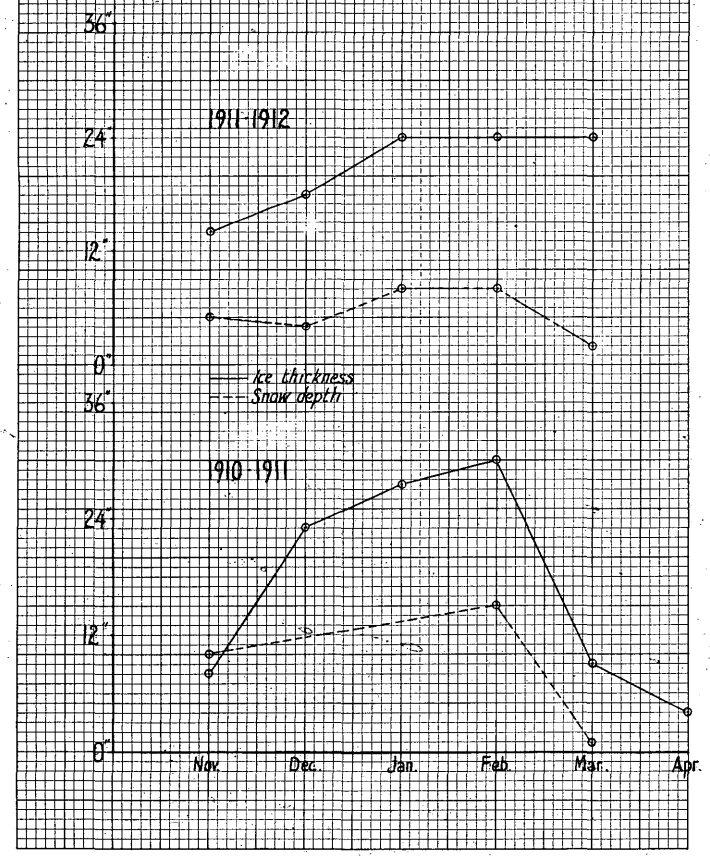


Plate 18, A.
Ice Thickness Curve: East Waterhen River, Manitoba, at the Ferry, Lat. 51°35', Long. 99°30' (approx.), Winters 1951-52 and 1952-53. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Manitoba, 4-24-53.

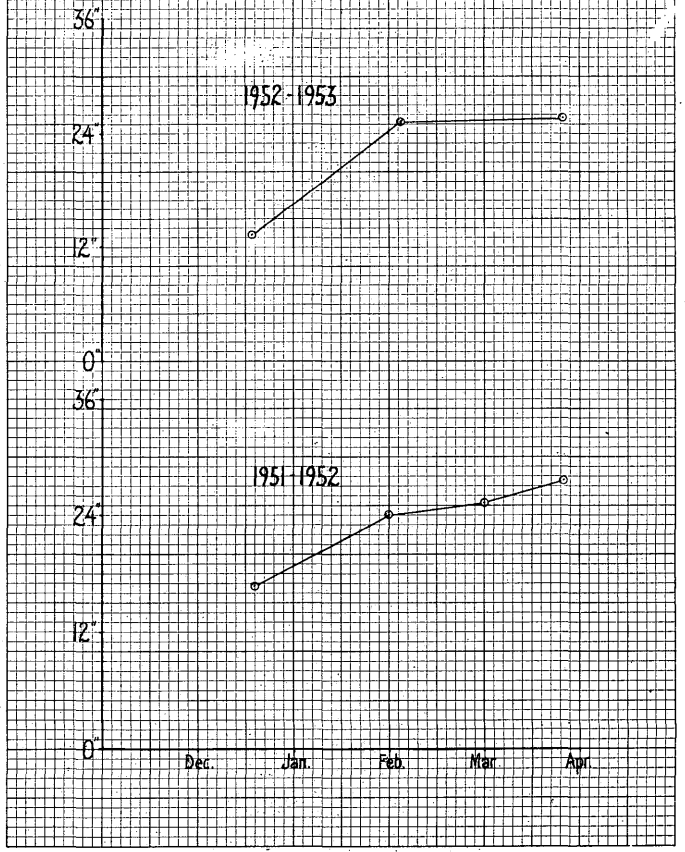


Plate 18, B.
Ice Thickness Curve: East Waterhen River, Manitoba, at the Ferry, Lat. 51°35', Long. 99°30', Winter 1950-51. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Manitoba, 4-24-53.

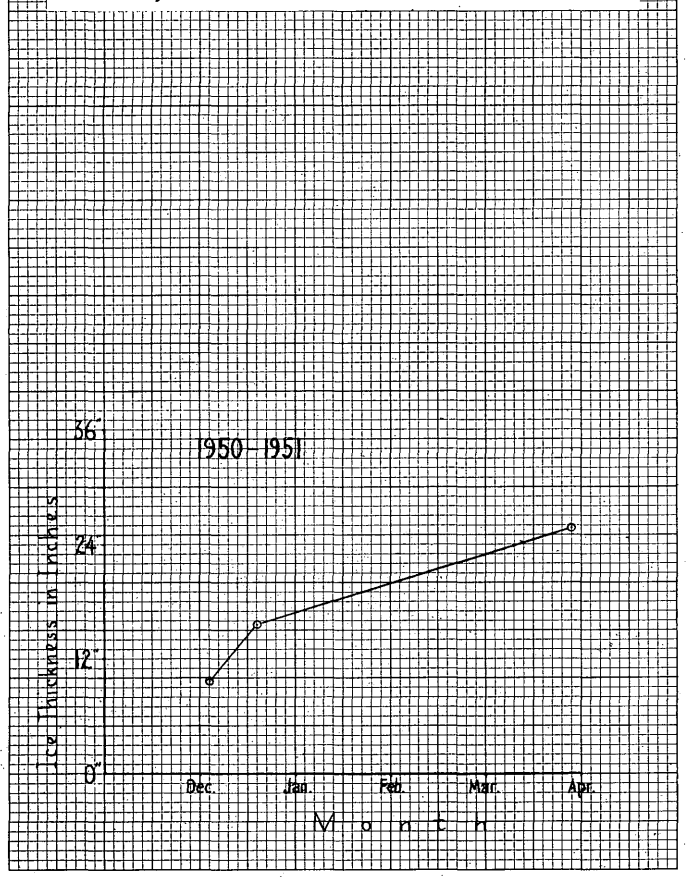


Plate 19.
Ice Thickness Curves: Three Manitoba Rivers: Bloodvein River, Lat. 51°50', Long. 96°45'; Dauphin River, Lat. 51°55', Long. 98°05'; Hole River. Winters of 1951-52 and 1952-53. Source: Data from Manitoba Government Air Service, Lac du Bonnet, Manitoba, April 1953.

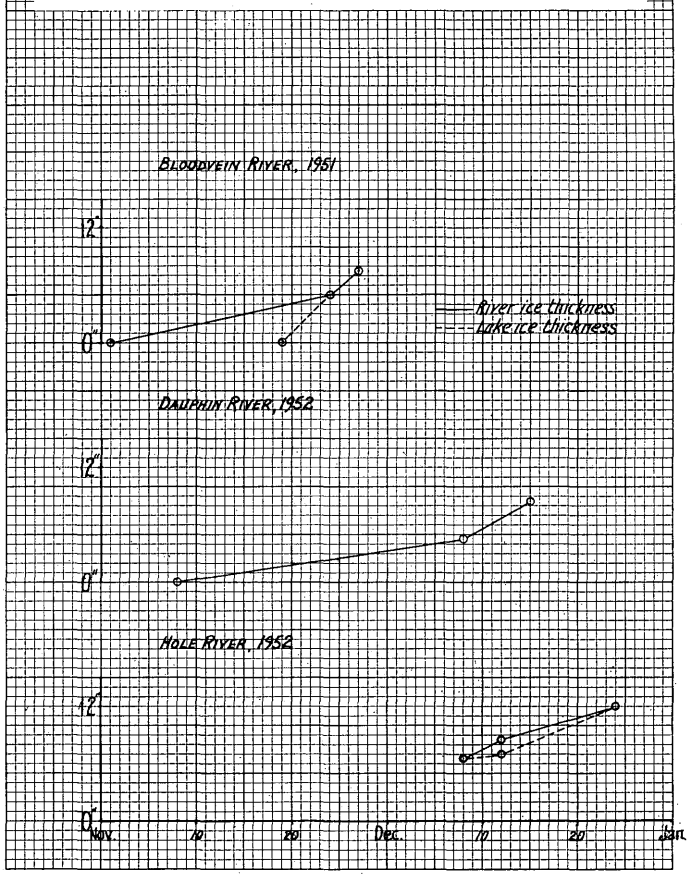


Plate 20, A.
Ice Thickness Curve: Emerson, Manitoba, on Red River, Lat. 49°01', Long. 97°10', Winters 1950-51, 1951-52, 1952-53. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

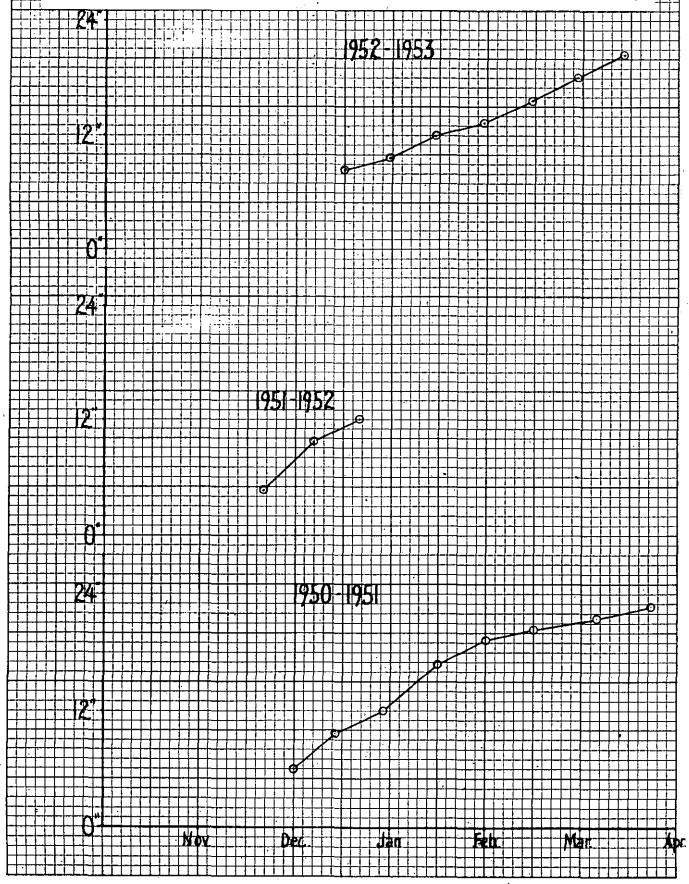


Plate 20, B.
Ice Thickness Curve: Emerson, Manitoba, Winters 1947-48, 1948-49, 1949-50. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

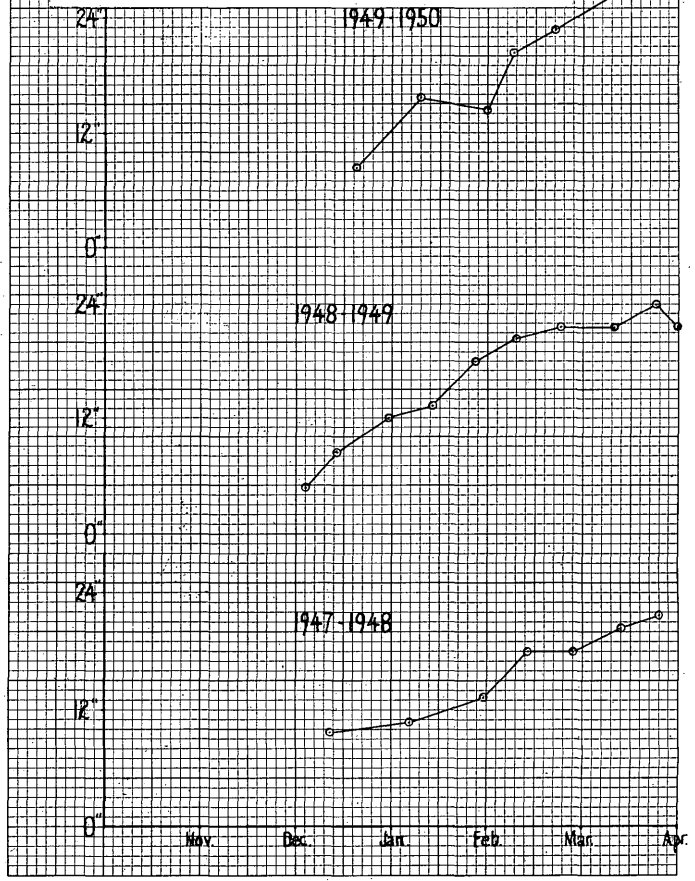


Plate 20, C.
Ice Thickness Curve: Emerson, Manitoba, Winters 1944-45, 1945-46, 1946-47. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

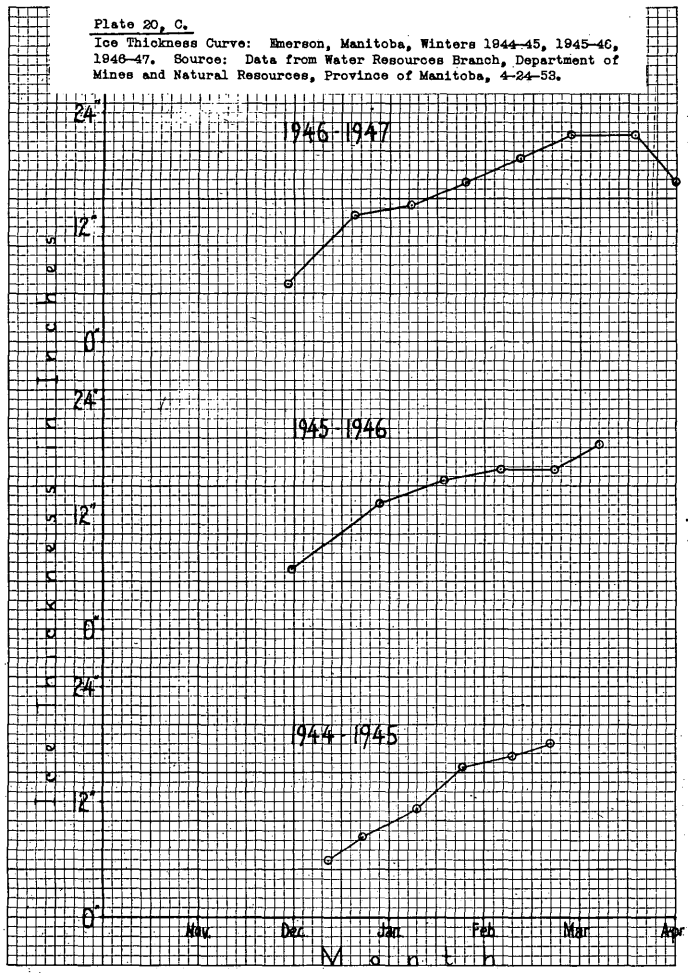


Plate 20, D.
Ice Thickness Curve: Emerson, Manitoba, on Red River, Lat. 49°01', Long. 97°10', Winters 1942-43 and 1943-44. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Manitoba, 4-24-53.

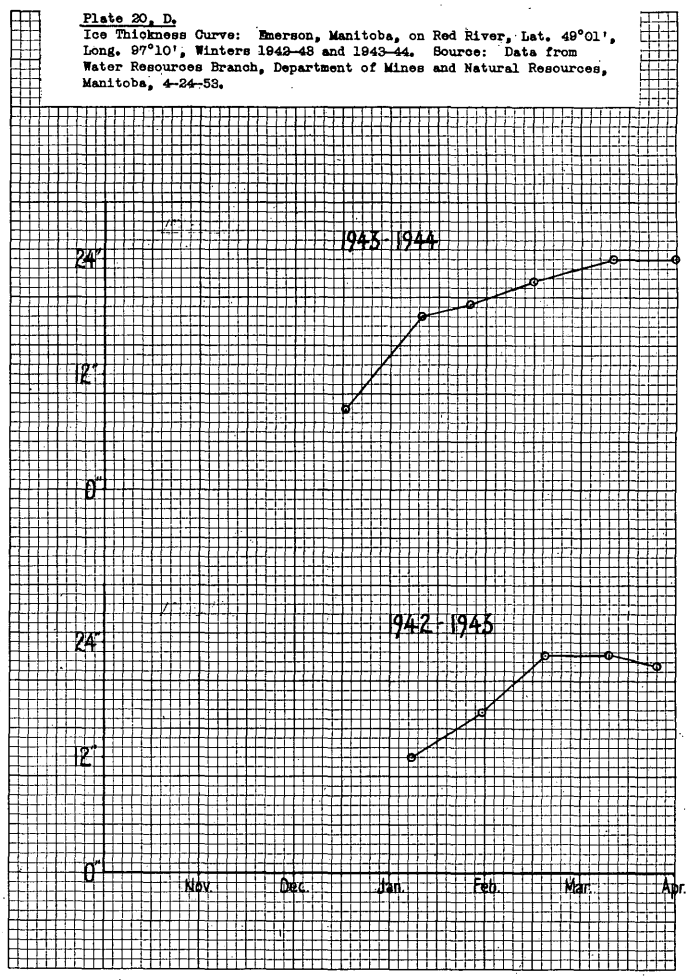


Plate 20, E.
Curve of Maximum, Minimum, and Average Ice Thicknesses: Emerson, Manitoba, Winters 1942-53. Source: Data from Water Resources Branch, Department of Mines and Natural Resources, Province of Manitoba, 4-24-53.

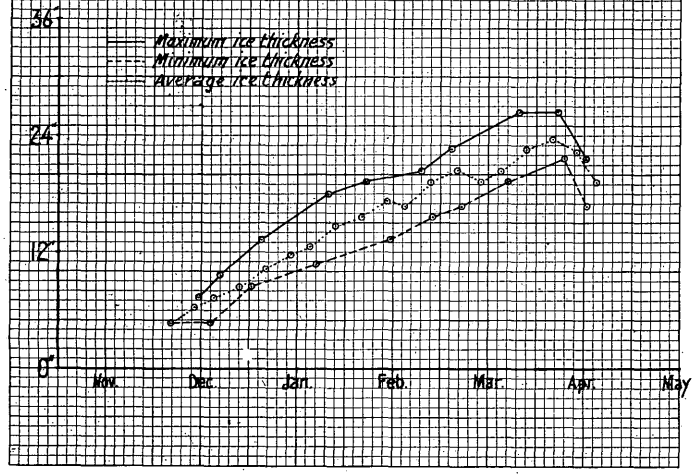


Plate 21.
Ice Thickness Curve: Gimli, Manitoba, on Lake Winnipeg, Lat. 50°38', Long. 96°57', Estimate for Average Winter. Source: Letter from James Solmundson, of Gimli, 5-4-53.

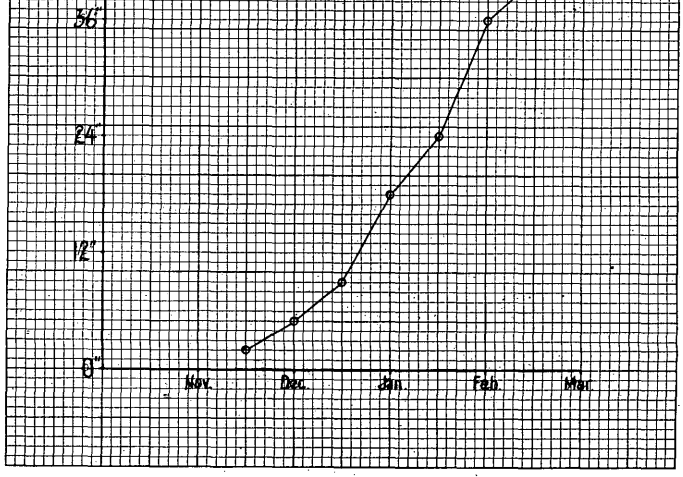


Plate 22.
Number assigned to Bloodvein River on key map. See Plate 19.

Plate 23.
Ice Thickness Curve: Lac du Bonnet, Manitoba, on Lac du Bonnet, Lat. 50°20', Long. 95°59', Winter 1952-53. Source: Journal of Hugh Smith, of Province of Manitoba Air Service.

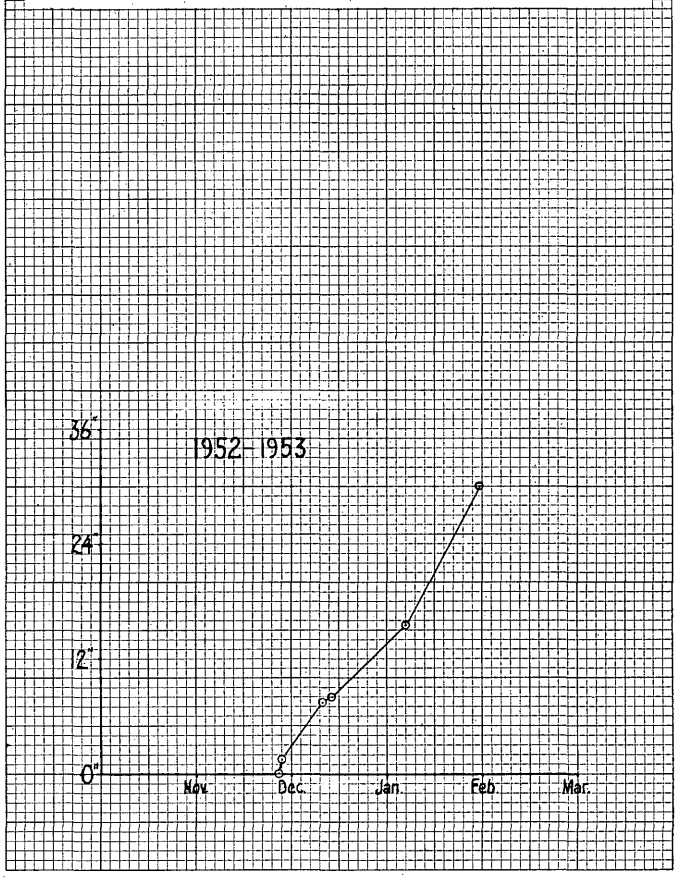


Plate 24.
Ice Thickness Curve: Bruce Mines, Ontario, on Lake Huron, Lat. 46°18', Long. 83°55', Winters 1910-11 and 1912-13. Source: Report of the Meteorological Service of Canada, 1910-11-12-13,

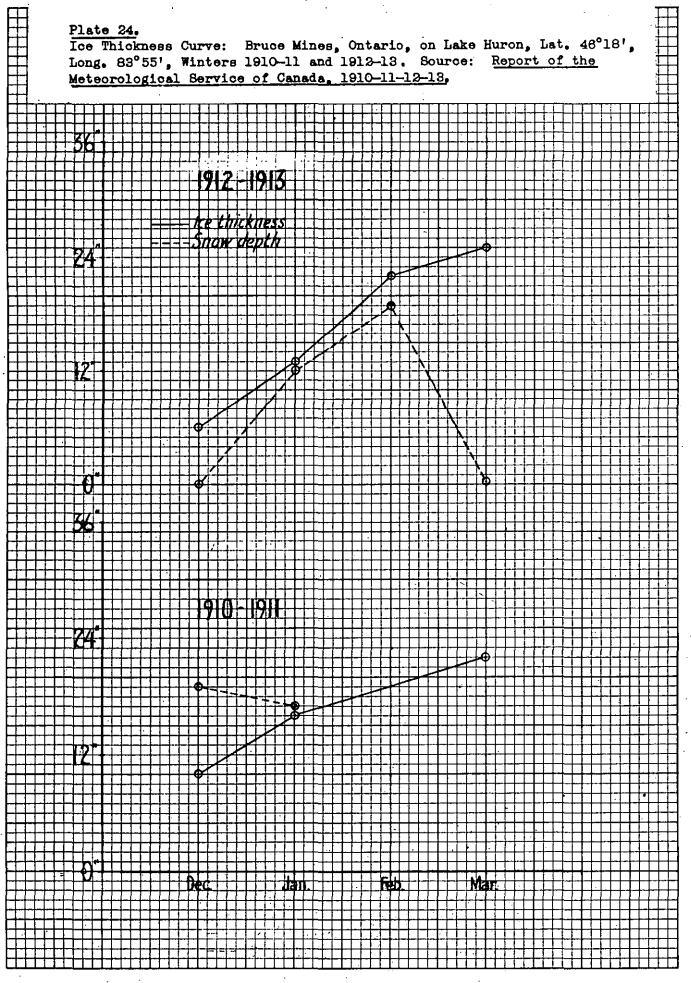


Plate 25.
Ice Thickness Curve: Cochrane, Ontario, Lat. 49°04', Long. 80°58', Winters of 1911-12 and 1912-13. Source: Report of the Meteorological Service of Canada, 1911-12-13.

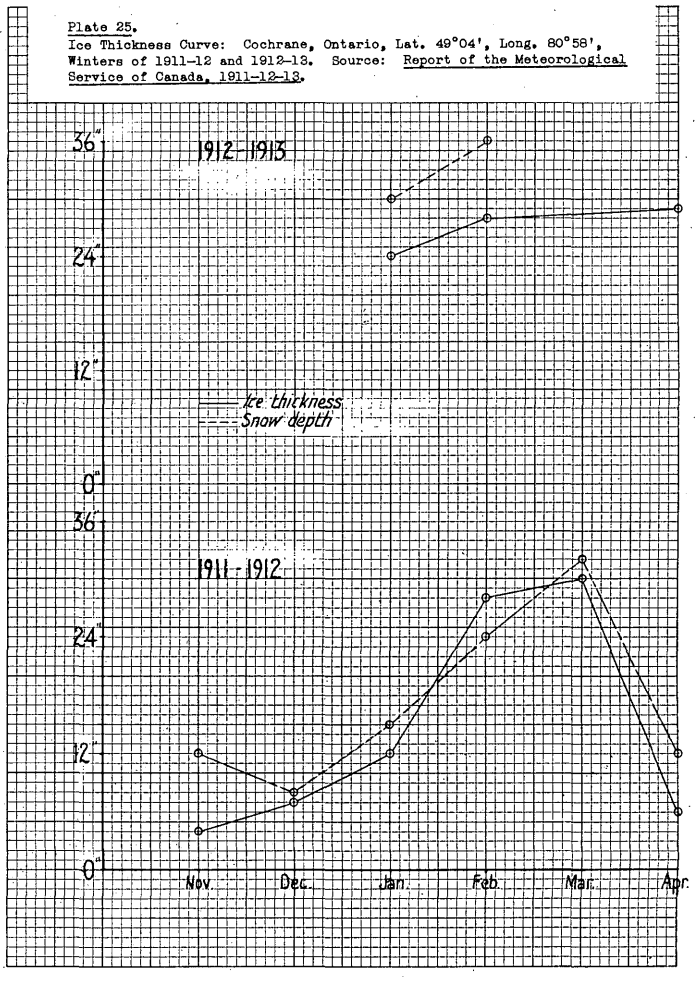


Plate 26.
Ice Thickness Curve: Barrie, Ontario, on Kempenfeldt Bay, Lake Simcoe, Lat. 44°23', Long. 79°41', Winters 1910-11 and 1911-12. Source: Report of the Meteorological Service of Canada, 1910-11-12.

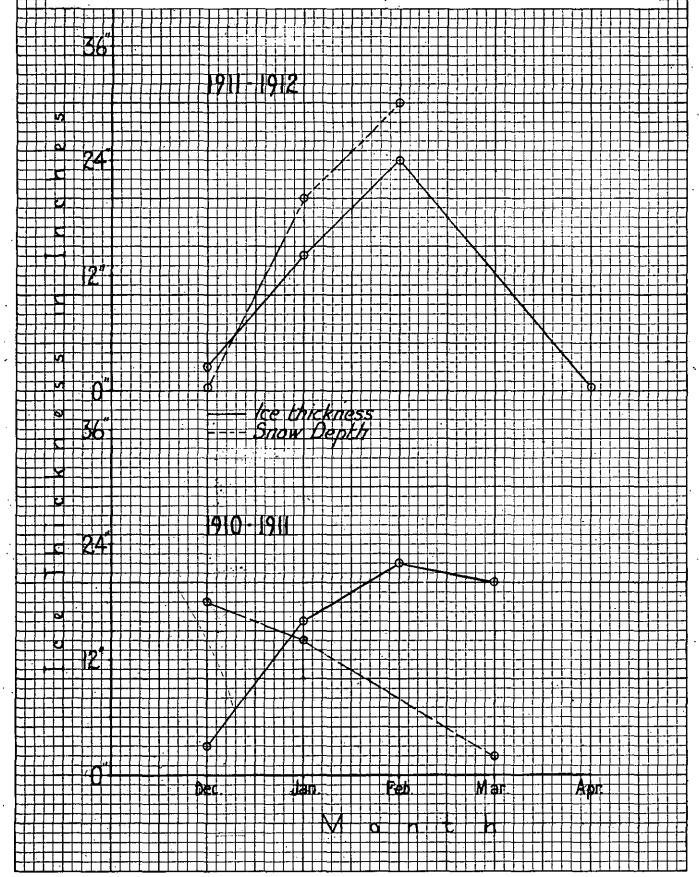


Plate 27.
Ice Thickness Curve: Gravenhurst, Ontario, on Muskoka Lake, Lat. 44°54', Long. 79°20', Winters 1910-11 and 1911-12. Source: Report of the Meteorological Service of Canada, 1911-12-13.

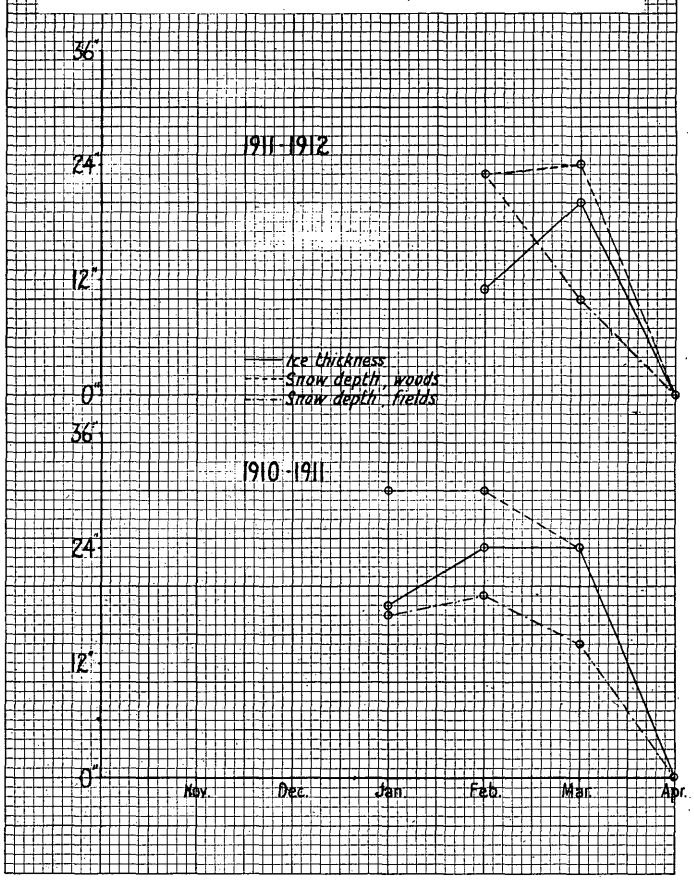


Plate 28.
Ice Thickness Curve: Ottawa, Ontario, on Ottawa River, Lat. 45°24', Long. 75°42', Winters 1910-11, 1911-12, and 1912-13. Source: Report of the Meteorological Service of Canada, 1910-11-12-13.

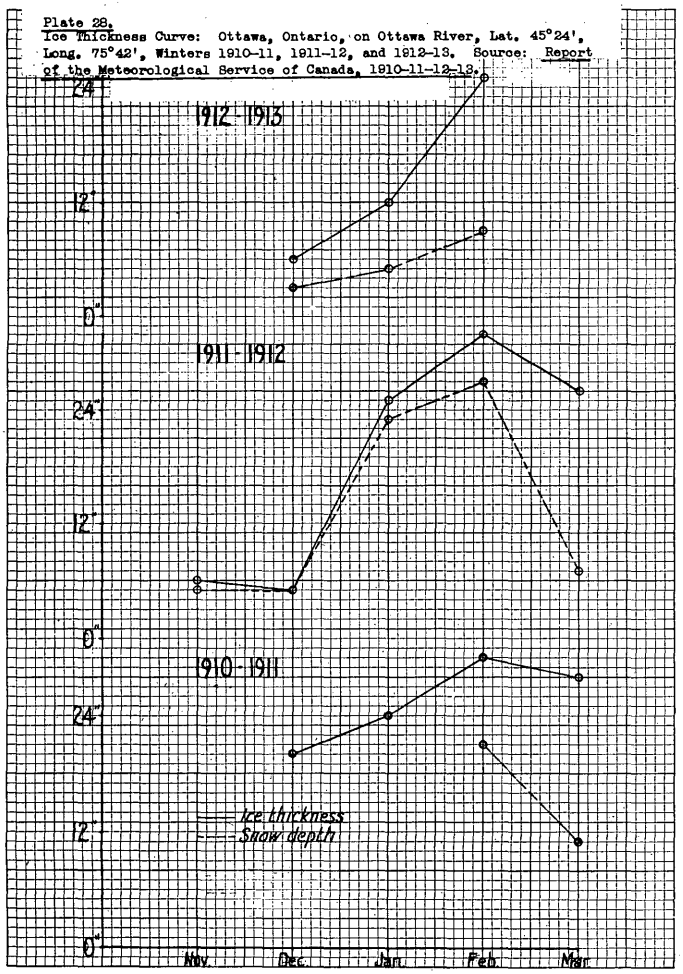


Plate 29.
Ice Thickness Curve: Fredericton, New Brunswick, on St. John River, Lat. 45°58', Long. 66°39', Winters 1910-11, 1911-12, 1912-13. Source: Report of the Meteorological Service of Canada, 1910-11-12-13.

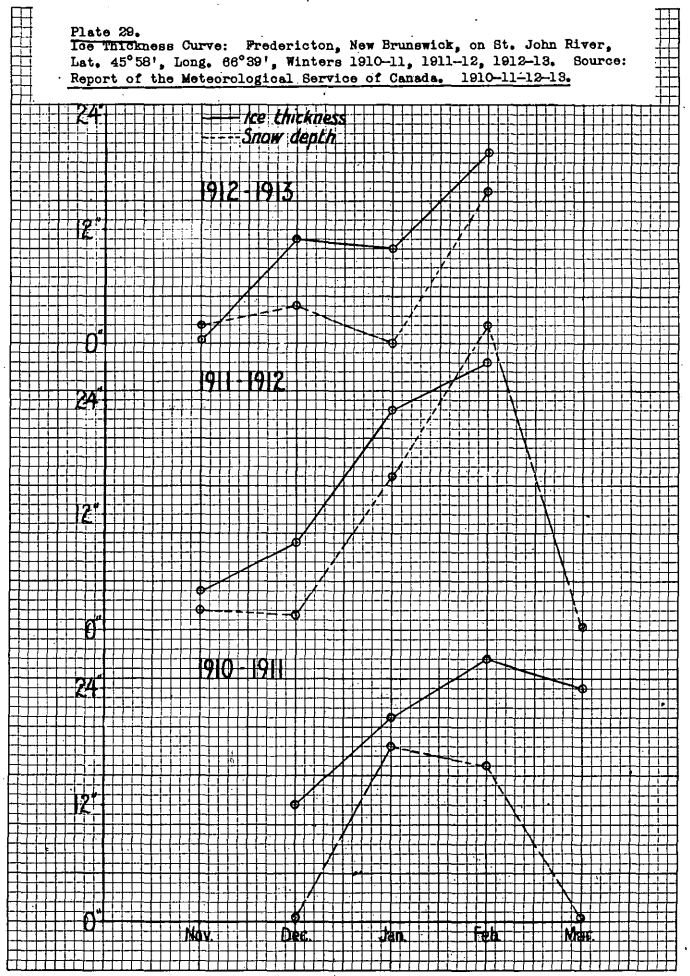


Plate 30.
Ice Thickness Curve: Point Lepreaux, New Brunswick (ponds), Lat. 45°10', Long. 66°30' (approx.), Winter 1911-12. Source: Report of the Meteorological Service of Canada, 1911-12.

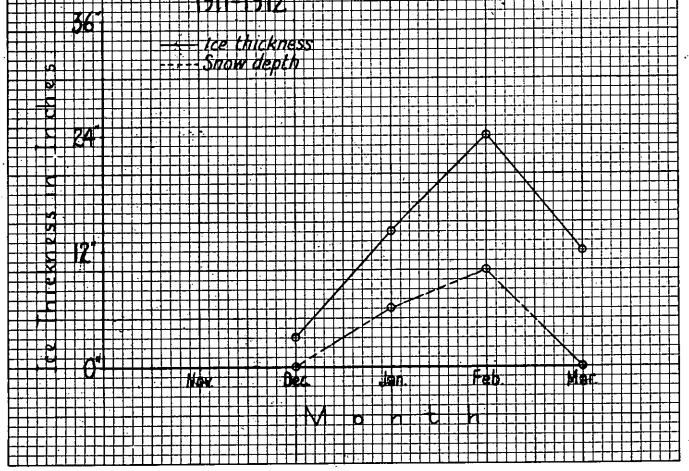


Plate 31.
Ice Thickness Curve: Chatham, New Brunswick, on Miramichi River, Lat. 47°01', Long. 65°26', Winters 1910-11, 1911-12, 1912-13. Source: Report of the Meteorological Service of Canada, 1910-11-12-13.

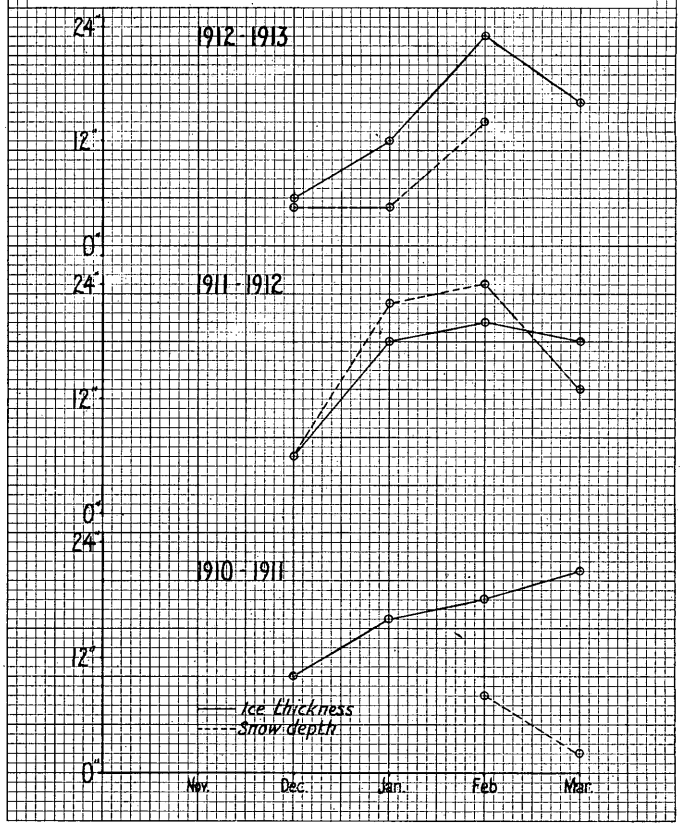


Plate 32, A.
Ice Thickness Curve: Point Escuminac, New Brunswick, on Miramichi Bay (lakes), Lat. 47°01', Long. 64°45' (approx.), Winters 1911-12 and 1912-13. Source: Report of the Meteorological Service of Canada, 1911-12-13.

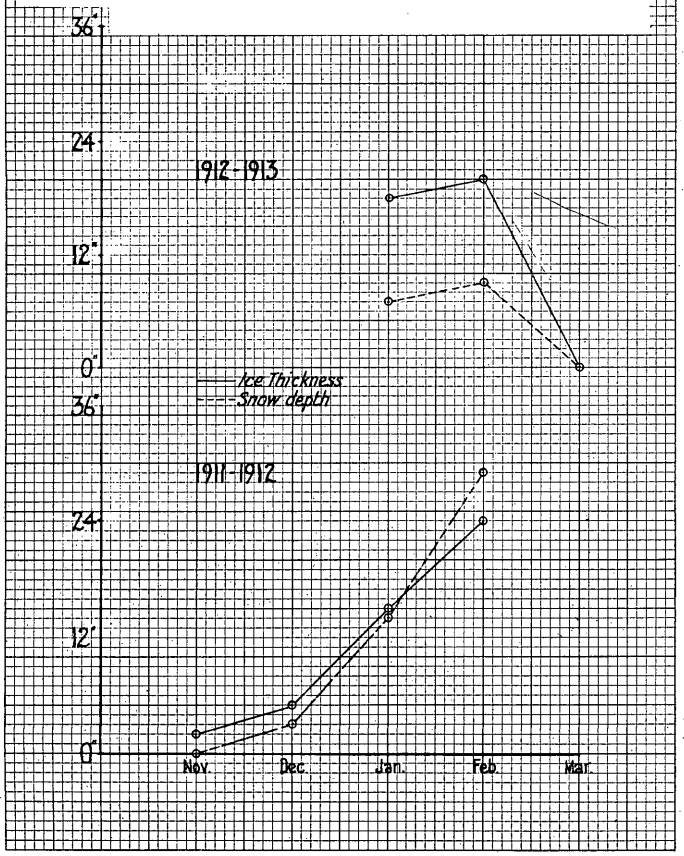


Plate 32, B.
Ice Thickness Curve: Point Escuminac, New Brunswick (lakes), Winters 1909-10 and 1910-11. Source: Report of the Meteorological Service of Canada, 1909-10-11.

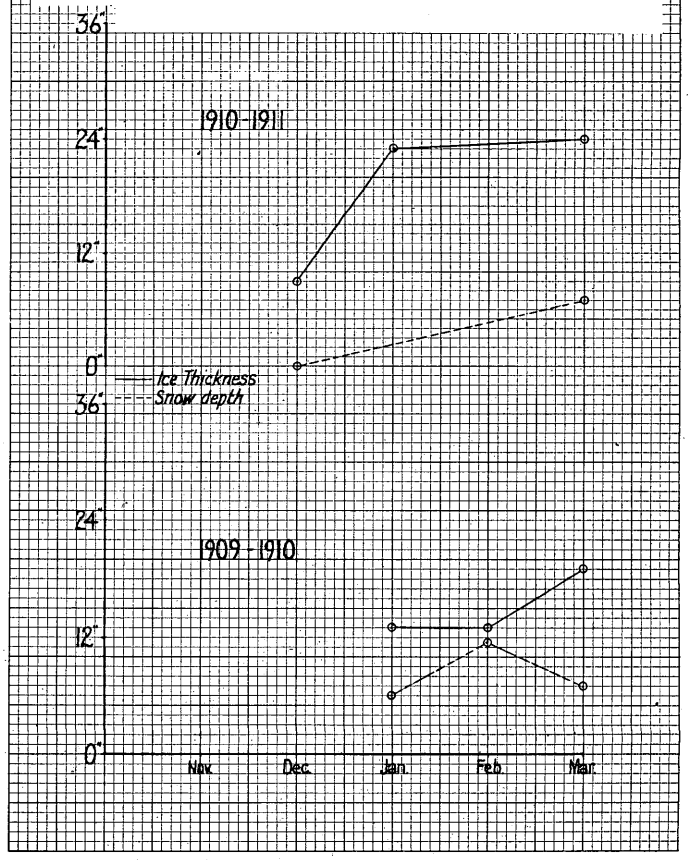


Plate 33, A.
Ice Thickness Curve: Sydney, Nova Scotia (lakes), Lat. 46°09', Long. 60°11', Winters 1911-12 and 1912-13. Source: Report of the Meteorological Service of Canada, 1911-12-13.

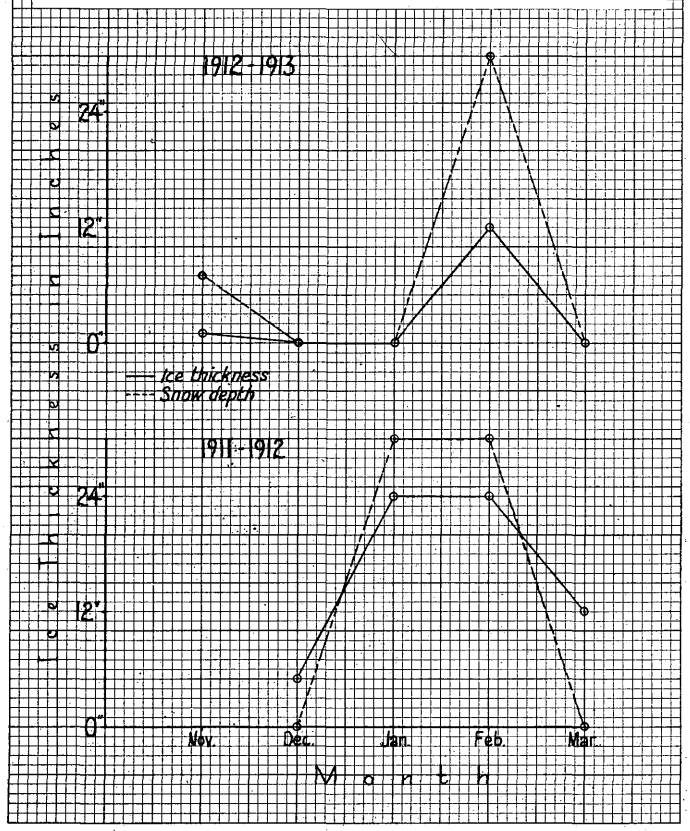


Plate 33, B.
Ice Thickness Curve: Sydney, Nova Scotia (lakes), Winter 1910-11. Source: Report of the Meteorological Service of Canada, 1910-11.

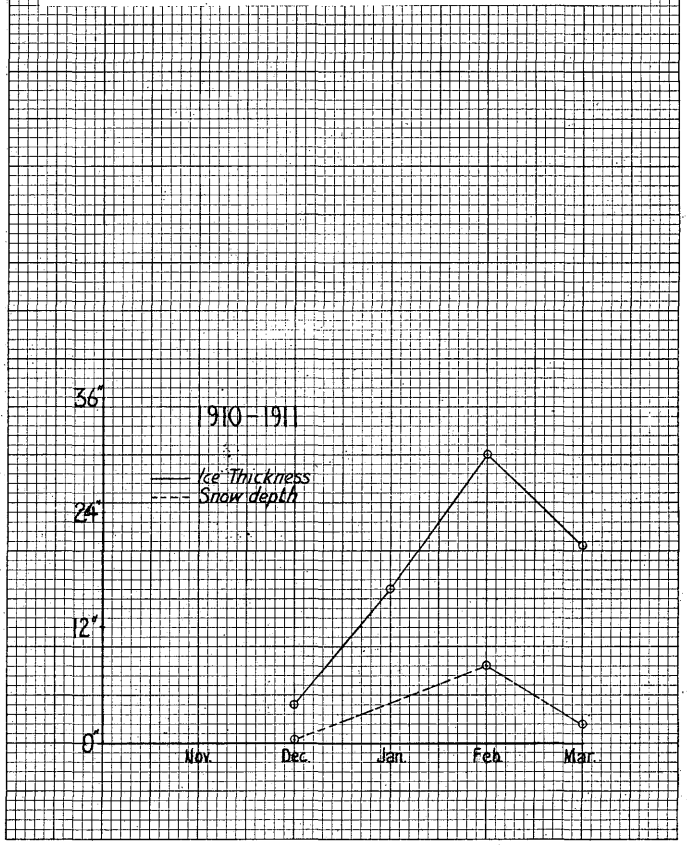


Plate 34.
Ice Thickness Curve: Pocatello, Idaho, on Portneuf River, Lat. 43°00', Long. 112°40'(approx.), Winter 1905-06. Source: U. S. Weather Bureau, Snow and Ice Bulletins (Weekly), 1905-06.

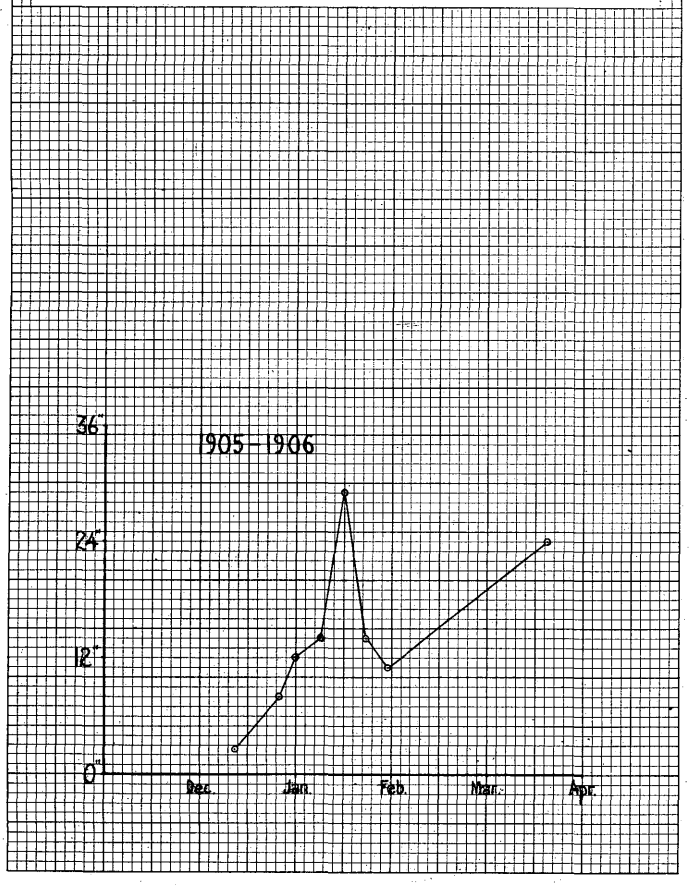


Plate 35, A.
Ice Thickness Curve: Williston, North Dakota, on Missouri River, Lat. 48°09', Long. 103°37', Winters 1905-06 and 1904-05. Source: U. S. Weather Bureau. Snow and Ice Bulletins, 1904-05-06.

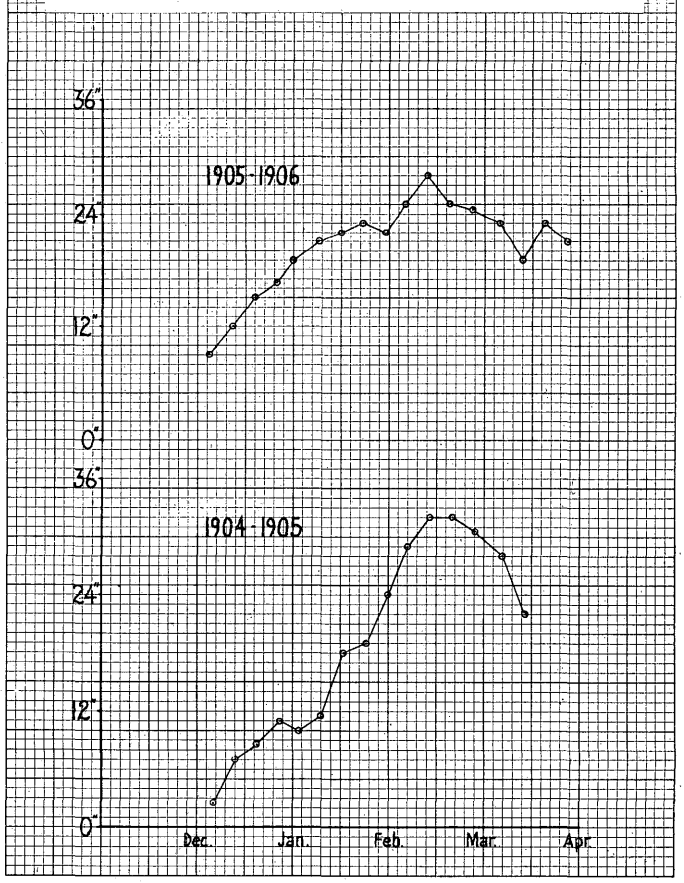


Plate 35, B.
Ice Thickness Curve: Williston, North Dakota, Winter 1898-99.
Source: U. S. Weather Bureau. Snow and Ice Bulletins, 1898-99.

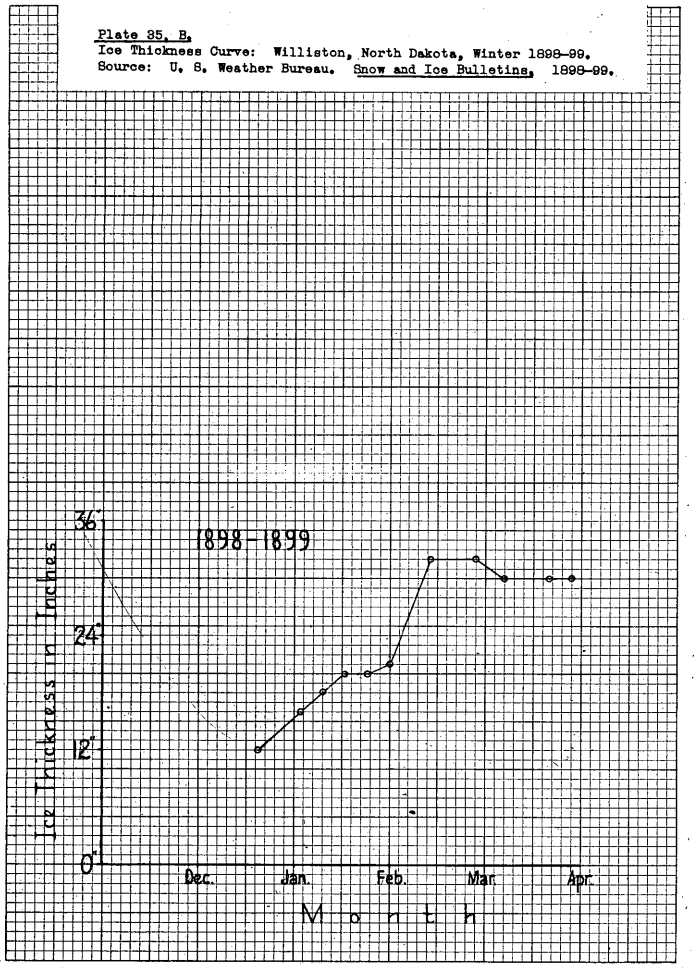


Plate 36, A.
Ice Thickness Curve: Bismarck, North Dakota, on Missouri River, Lat. 46°48', Long. 100°45', Winters 1904-05 and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1904-05-06.

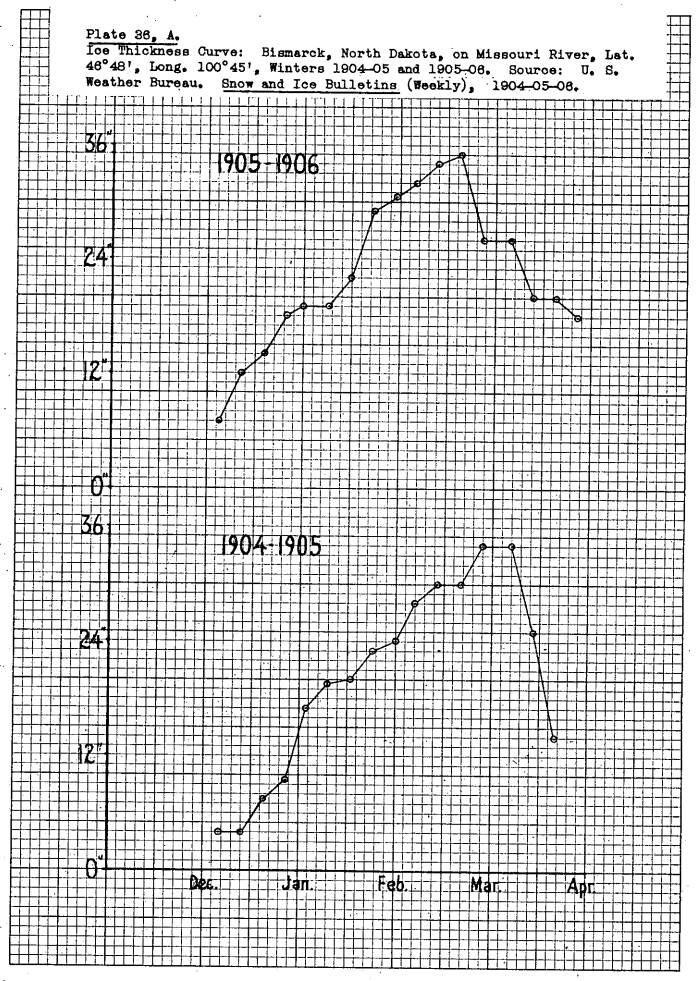


Plate 36, B.
Ice Thickness Curve: Bismarck, North Dakota, Winter 1898-99.
Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1898-99.

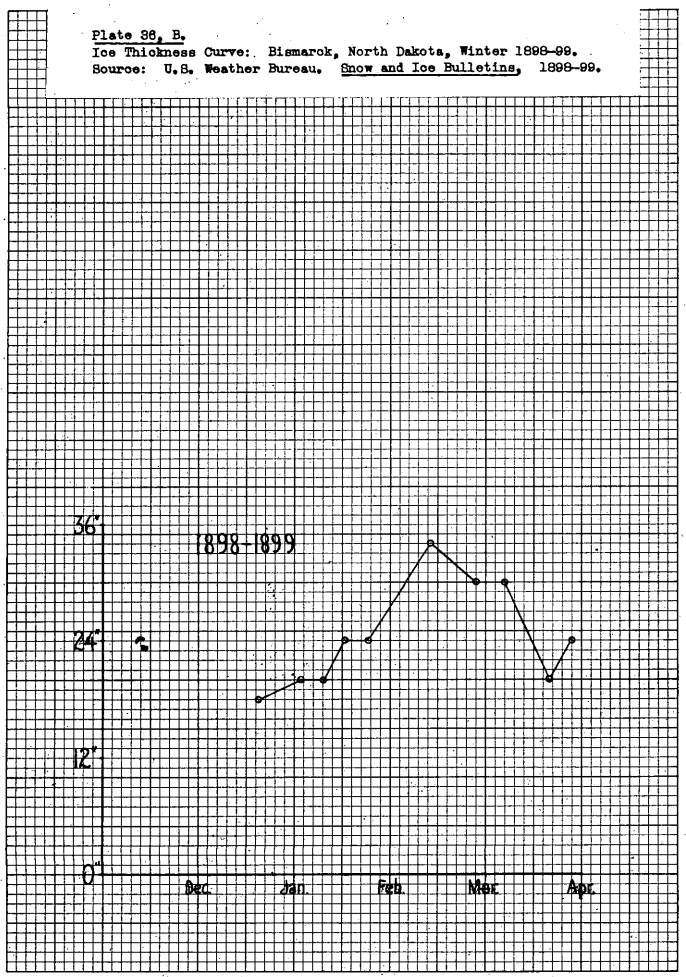


Plate 37.
Ice Thickness Curve: Pierre, South Dakota, on Missouri River, Lat. 44°22', Long. 100°22', Winters 1898-99, 1904-05, and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1904-05-06, 1898-99.

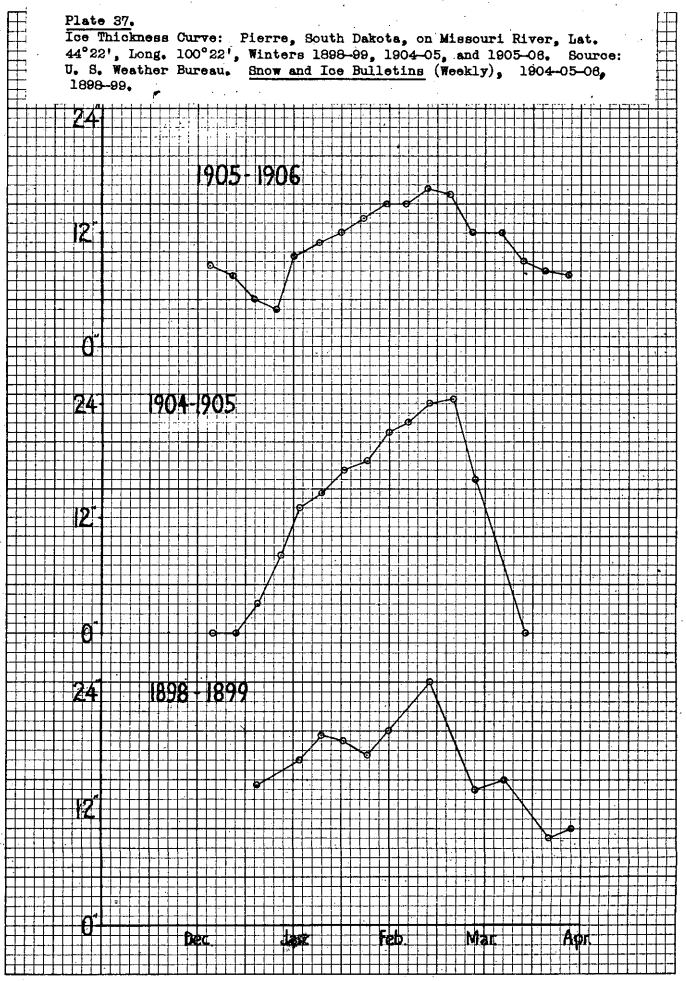


Plate 38.
Ice Thickness Curve: Huron, South Dakota, on James River, Lat. 44°22', Long. 98°15', Winters 1904-05 and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1904-05-06.

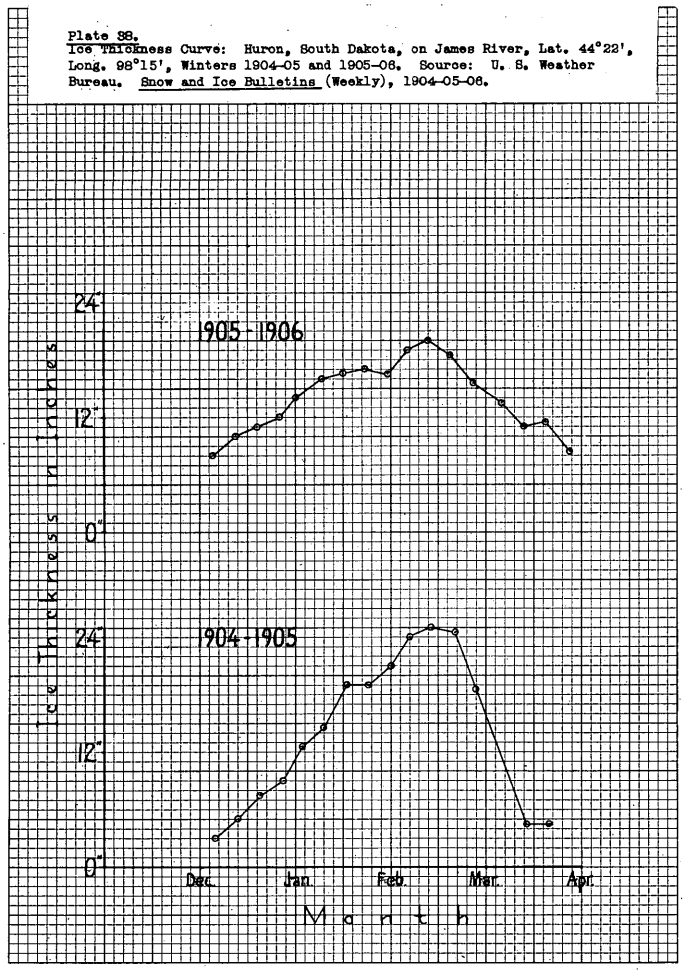


Plate 39.
Ice Thickness Curve: Yankton, South Dakota, on Missouri River, Lat. 42°50', Long. 97°21', Winters 1898-99 and 1904-05. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1898-99, 1904-05.

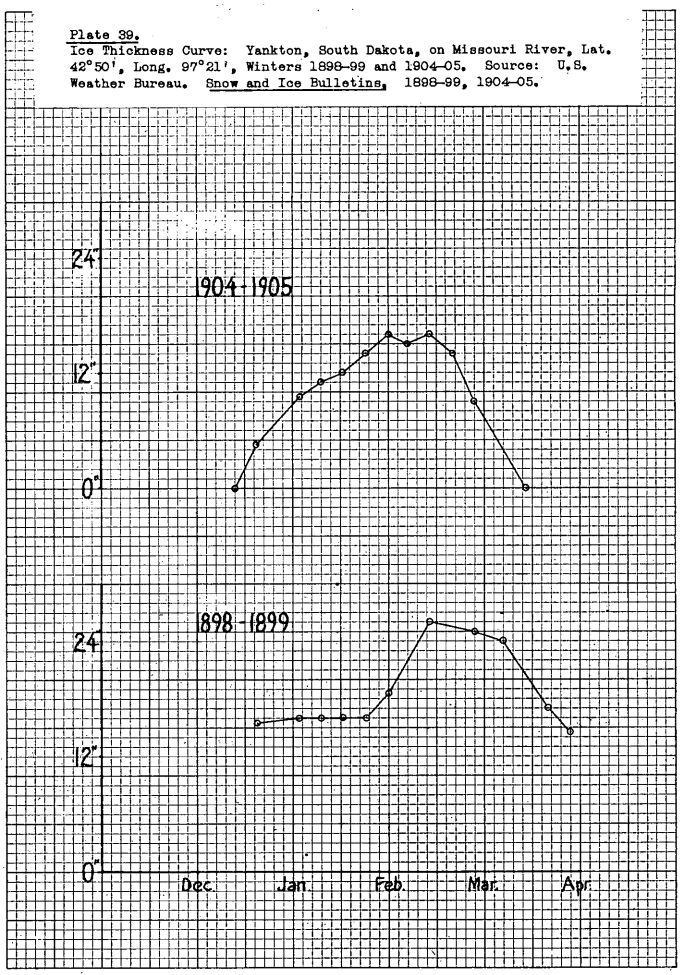


Plate 40, A.
Ice Thickness Curve: Moorhead, Minnesota, on Red River (of the North), Lat. 46°52', Long. 96°45', Winters 1904-05 and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1904-05-06.

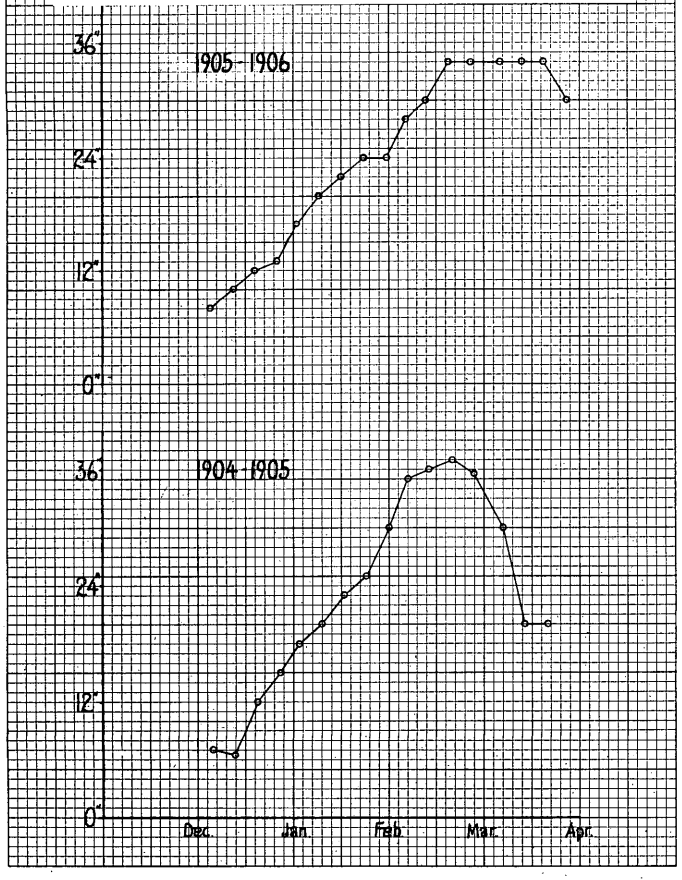


Plate 40, B.
Ice Thickness Curve: Moorhead, Minnesota, Winter 1898-99. Source: U. S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1898-99.

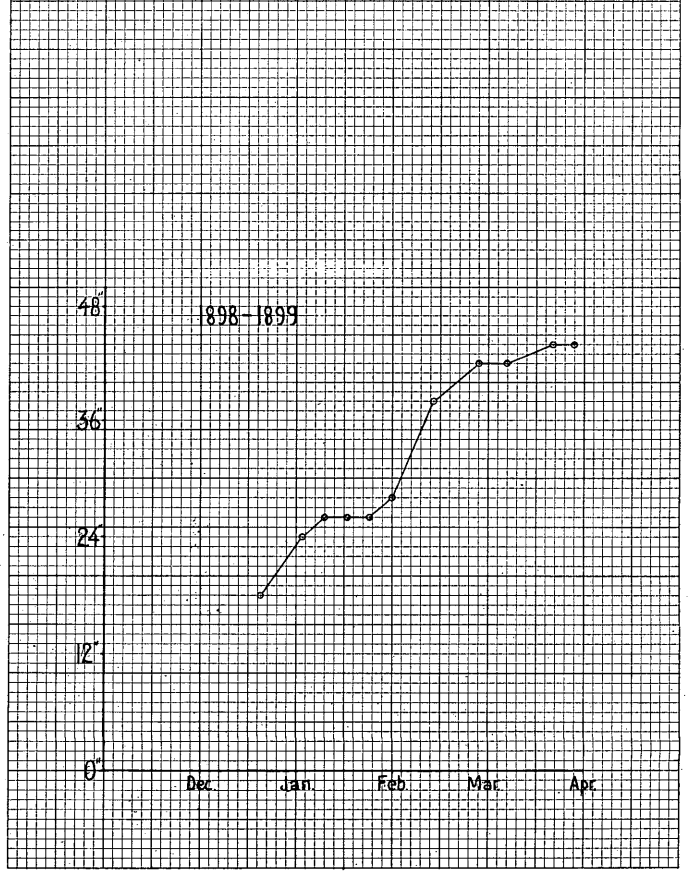


Plate 41.
Ice Thickness Curve: Minneapolis, Minnesota, on Mississippi River, Lat. 44°58', Long. 93°16', Winter 1933-34. Source: U. S. Weather Bureau. Weekly Weather and Crop Bulletin, 1933-34.

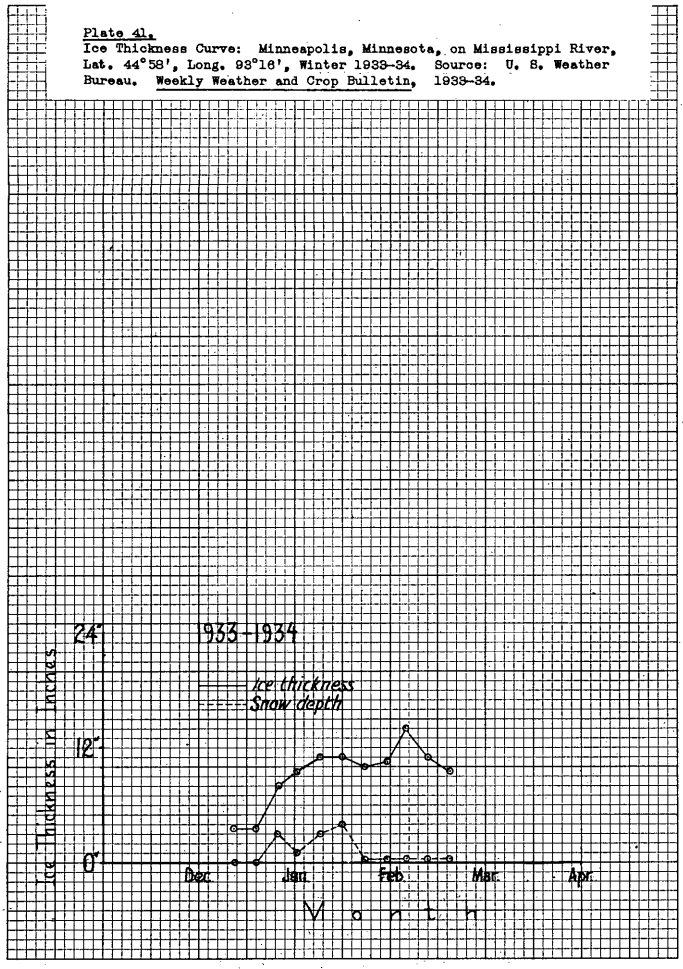


Plate 42.
Ice Thickness Curve: Saint Paul, Minnesota, on Mississippi River, Lat. 44°58', Long. 93°05', Winters 1898-99, 1904-05, and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins, 1898-99, 1904-05-06.

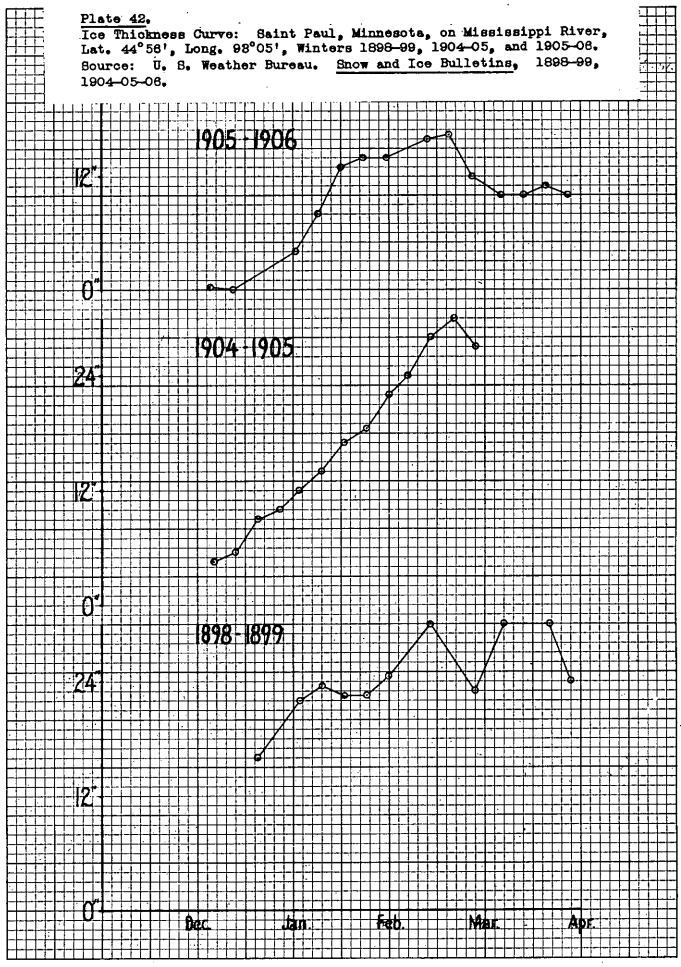


Plate 43.
Ice Thickness Curve: La Crosse, Wisconsin, on Mississippi River, Lat. 43°50', Long. 91°12', Winters 1898-99, 1904-05, and 1905-06. Source: U.S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1898-99, 1904-05-06.

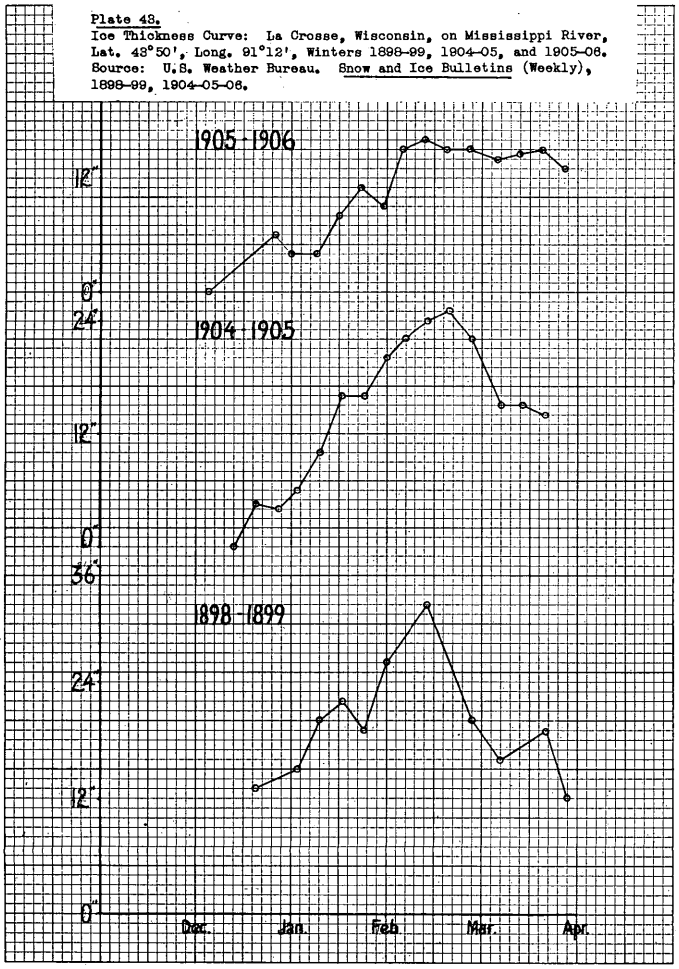


Plate 44.
Ice Thickness Curve: Wausau, Wisconsin, on Wisconsin River, Lat. 44°59', Long. 89°35', Winters 1916-17, 1917-18, and 1918-19. Source: U.S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1916-17-18-19.

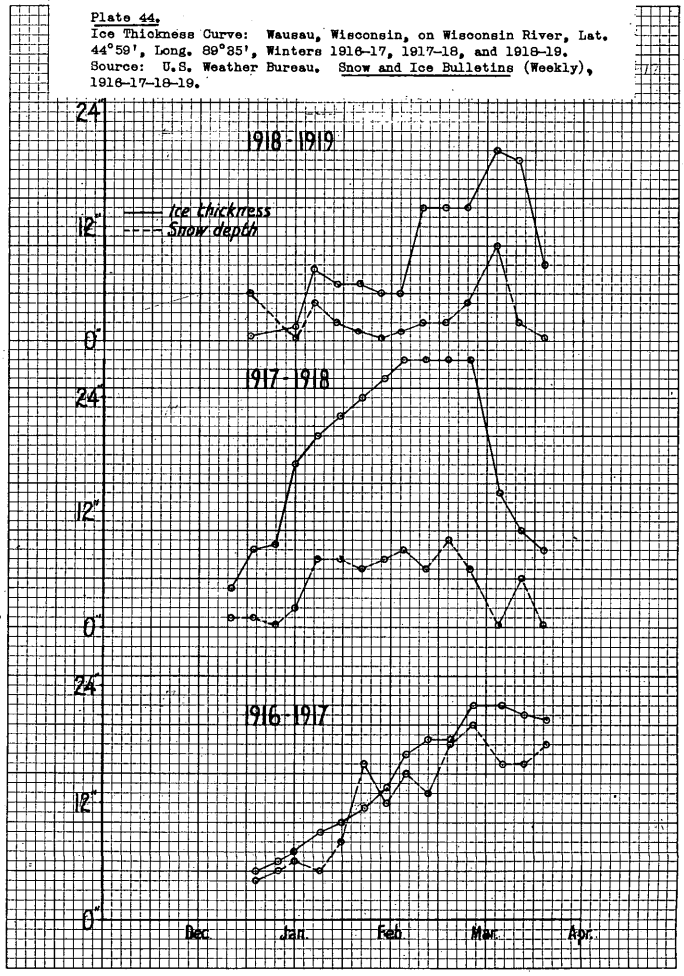


Plate 45.
Ice Thickness Curve: Harrisburg, Pennsylvania, on Susquehanna River, Lat. 40°16', Long. 76°53', Winters 1917-18 and 1924-25. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1917-18, 1924-25.

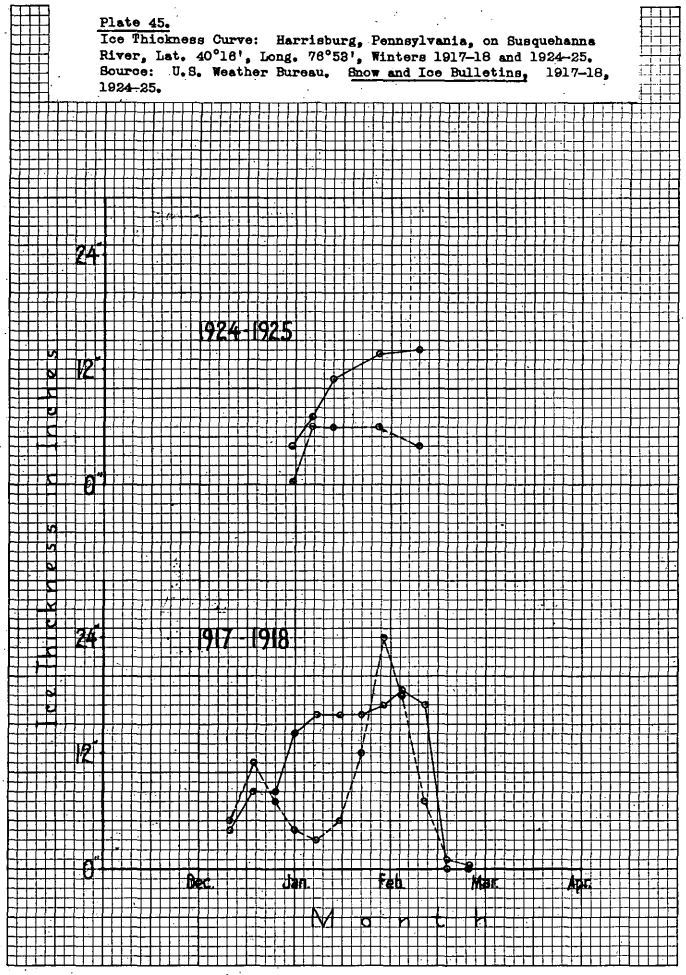


Plate 46.
Ice Thickness Curve: Albany, New York, on Hudson River, Lat. 42°39', Long. 73°45', Winters 1898-99, 1904-05, and 1905-06. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1898-99, 1904-05-06.

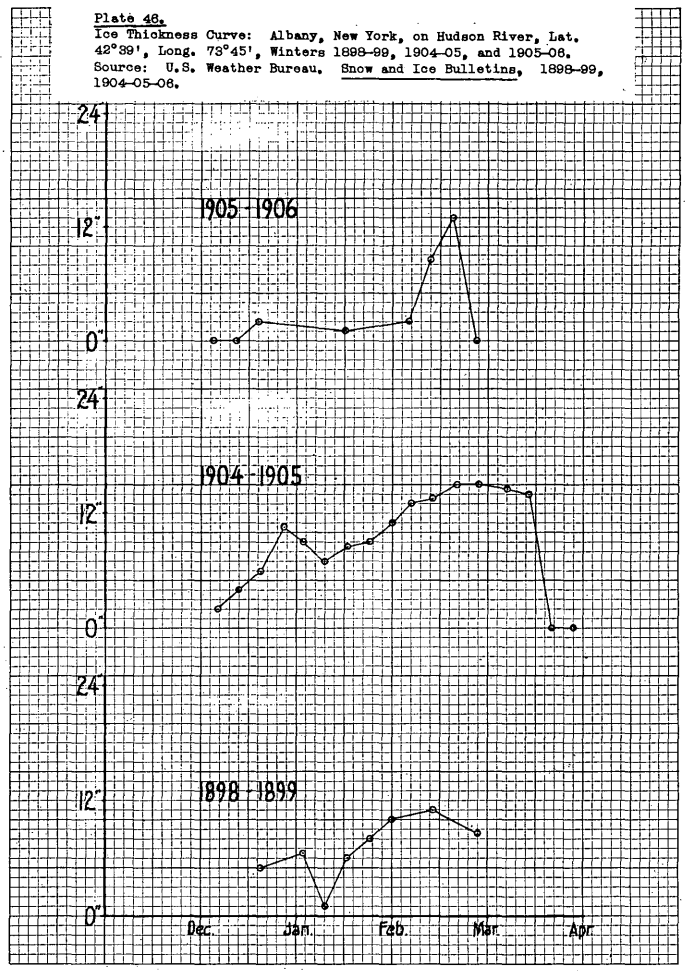


Plate 47.
Ice Thickness Curve: Burlington, Vermont, on Lake Champlain, Lat. 44°29', Long. 73°13', Winters 1916-17 and 1917-18. Source: U.S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1916-17-18.

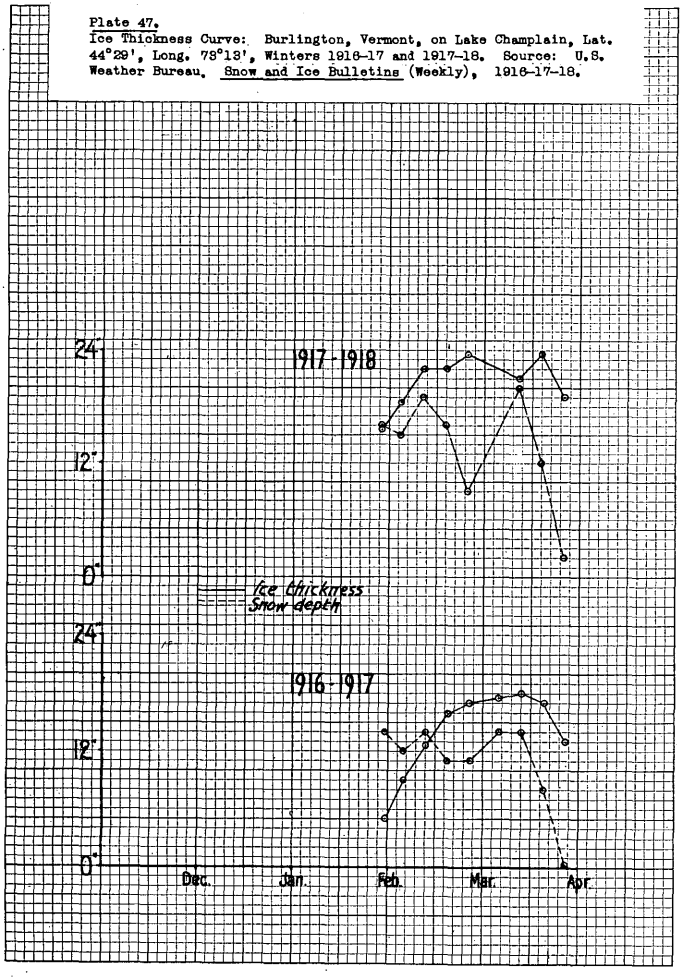


Plate 48.
Ice Thickness Curve: Brattleboro, Vermont, on Connecticut River, Lat. 42°51', Long. 72°38', Winters 1898-99, 1904-05, and 1905-06. Source: U. S. Weather Bureau. Snow and Ice Bulletins, 1898-99, 1904-05-06.

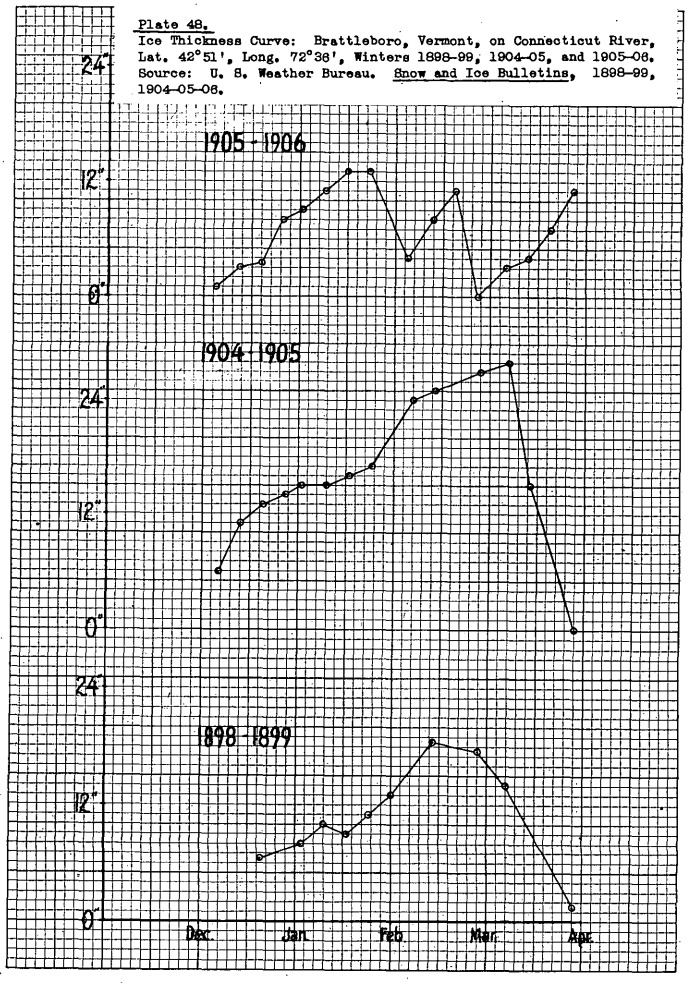


Plate 49.
Ice Thickness Curve: Concord, New Hampshire, on Merrimack River, Lat. 43°12', Long. 71°32', Winters 1904-05, 1905-06, and 1921-22. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1904-05-06, 1921-22.

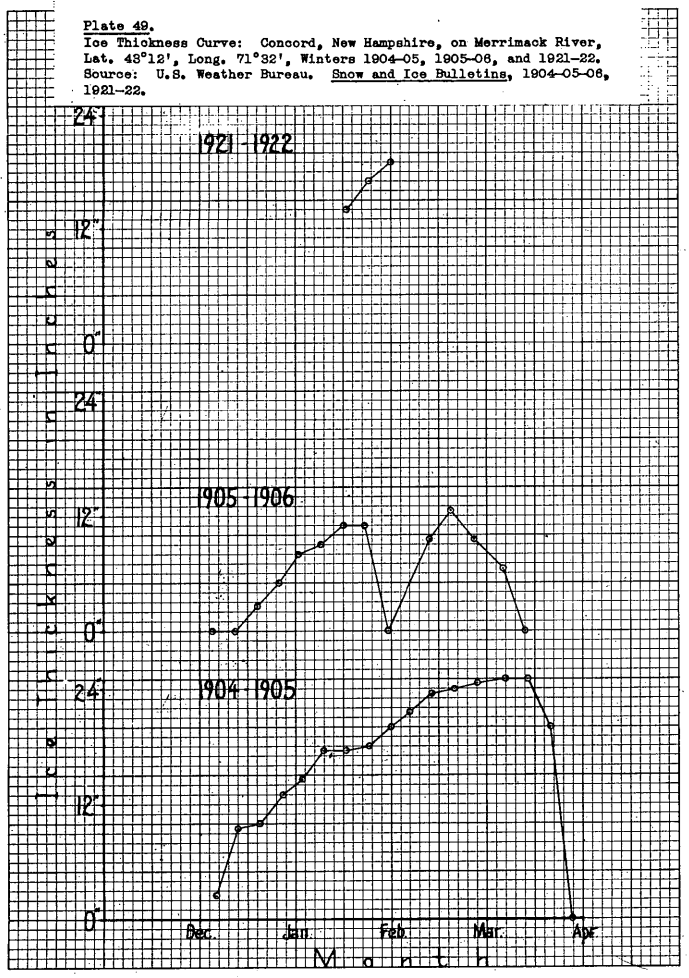


Plate 50, A.
Ice Thickness Curve: Greenville, Maine, on Moosehead Lake, Lat. 45°29', Long. 69°39', Winters 1950-51, 1951-52, and 1952-53. Source: U.S. Weather Bureau. Snow and Ice Bulletin (Weekly), 1950-51-52-53.

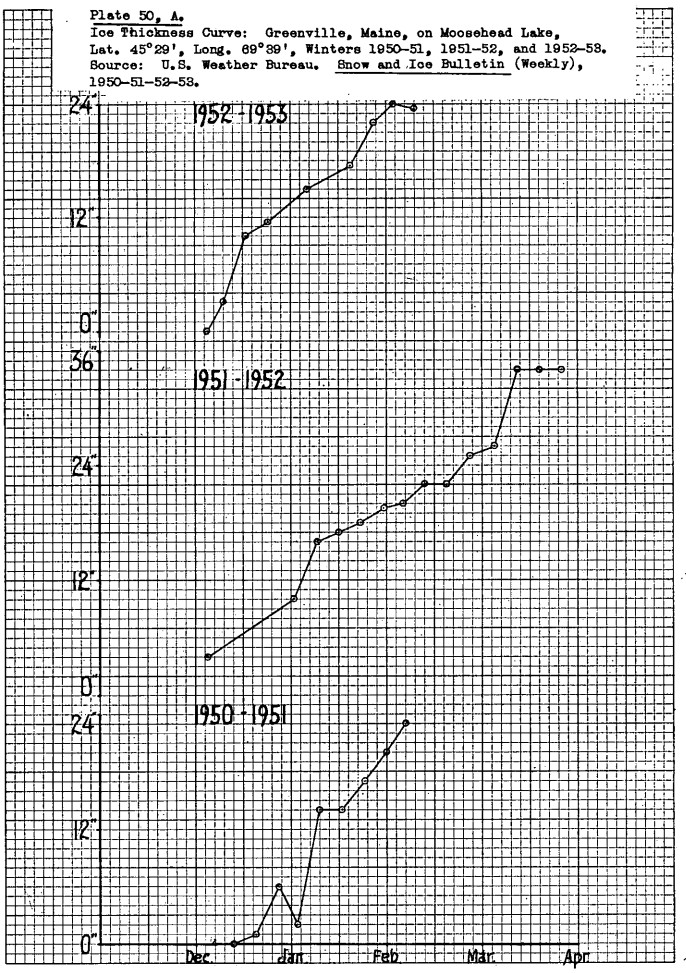


Plate 50, B.
Ice Thickness Curves: Greenville, Maine, Winters 1918-19, 1921-22, and 1949-50. Source: U. S. Weather Bureau. Weekly Snow and Ice Bulletins, 1918-19, 1921-22, 1949-50.

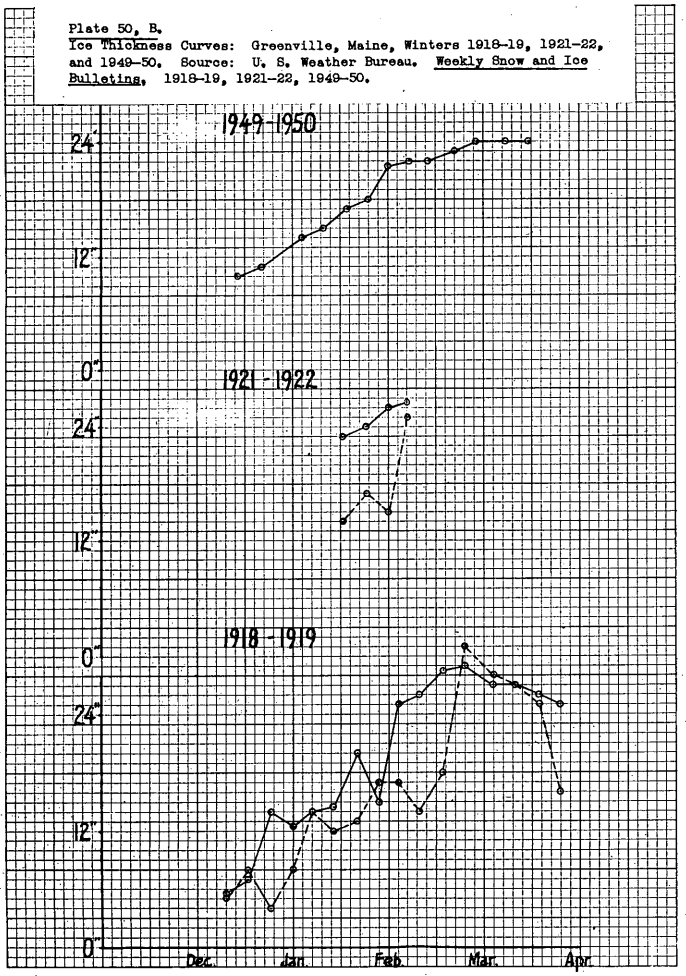


Plate 50, C.
Ice Thickness Curve: Greenville, Maine, Winters 1916-17, 1917-18. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1916-17-18.

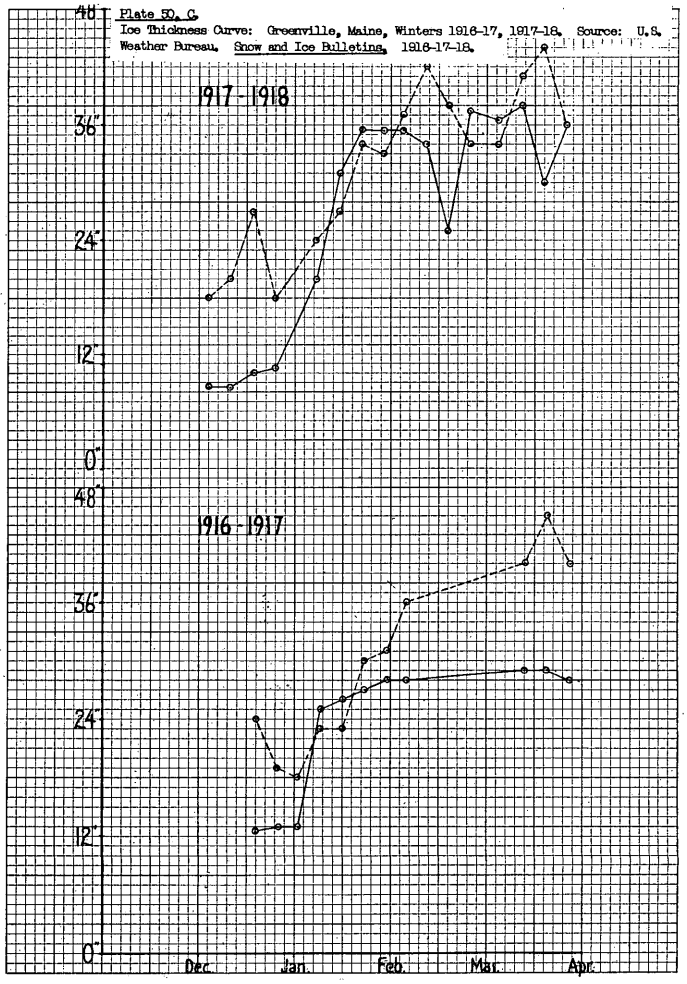


Plate 50, D.
Curve of Maximum, Minimum, and Average Ice Thicknesses: Greenville, Maine, Winters 1918-19, 1922, 1949-58. Source: U. S. Weather Bureau. Weekly Snow and Ice Bulletins, 1918-19, 1922, 1949-58.

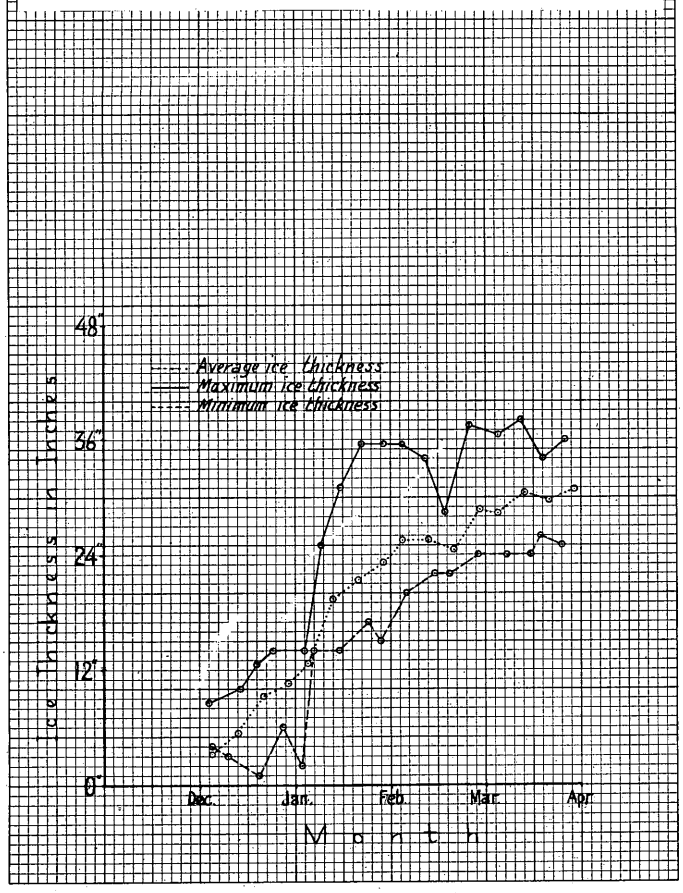


Plate 51.
Ice Thickness Curve: Lewiston, Maine, on Androscoggin River, Lat. 44°02', Long. 69°35', Winters 1898-99, 1904-05, and 1905-06. Source: U.S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1898-99, 1904-05-06.

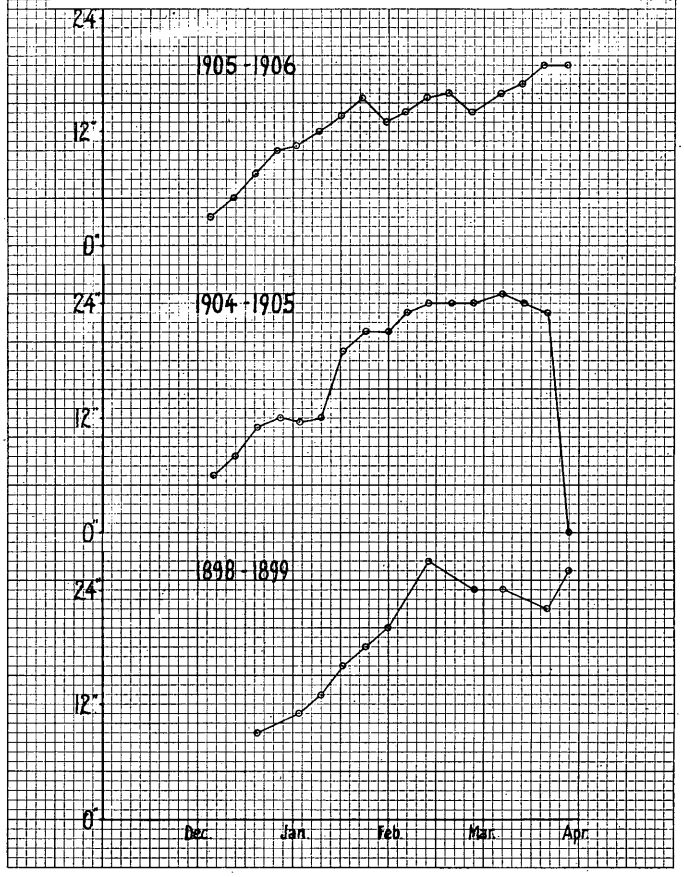


Plate 52.
Ice Thickness Curve: Gardiner, Maine, on Kennebec River, Lat. 44°12', Long. 69°45', Winters 1898-99, 1904-05, and 1905-06. Source: U.S. Weather Bureau. Snow and Ice Bulletins, 1898-99, 1904-05-06.

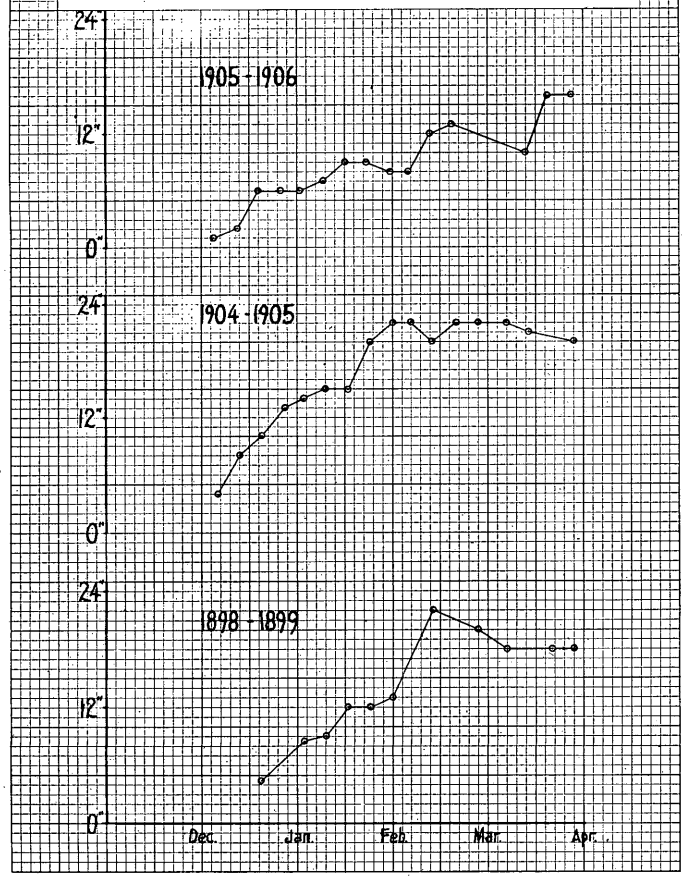


Plate 53.
Ice Thickness Curve: Bangor, Maine, on Penobscot River, Lat. 44°48', Long. 68°46', Winters 1898-99, 1904-05, and 1905-06. Source: U.S. Weather Bureau. Snow and Ice Bulletins (Weekly), 1898-99, 1904-05-06.

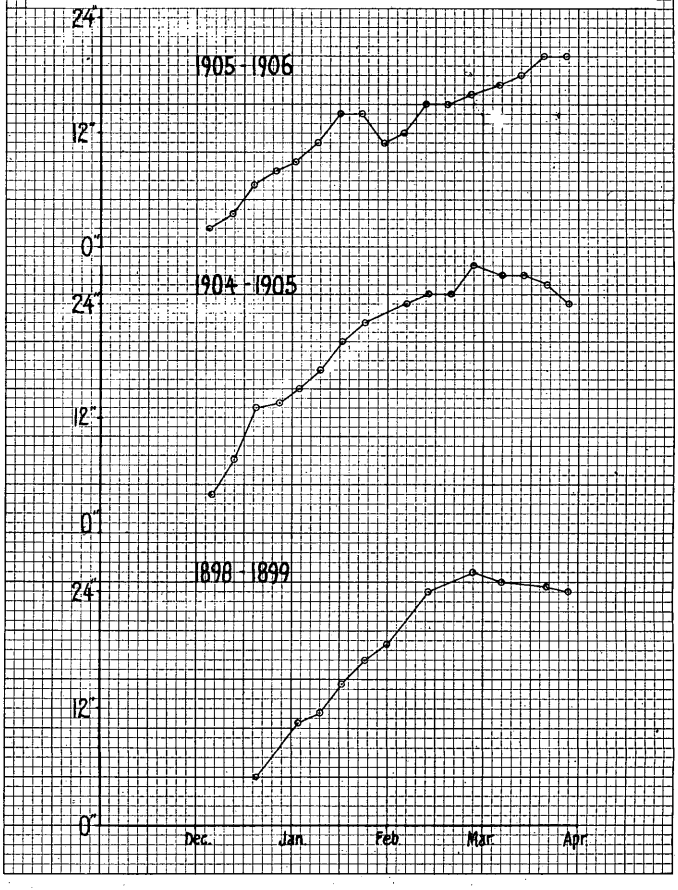


Plate 55.
Average Ice Thickness, Based on Seven Rivers in the Province of Manitoba for the Years 1942-53. (See Plates 18 A, B, C, D; 18 A, B; 19; 20, A, B, C, D).

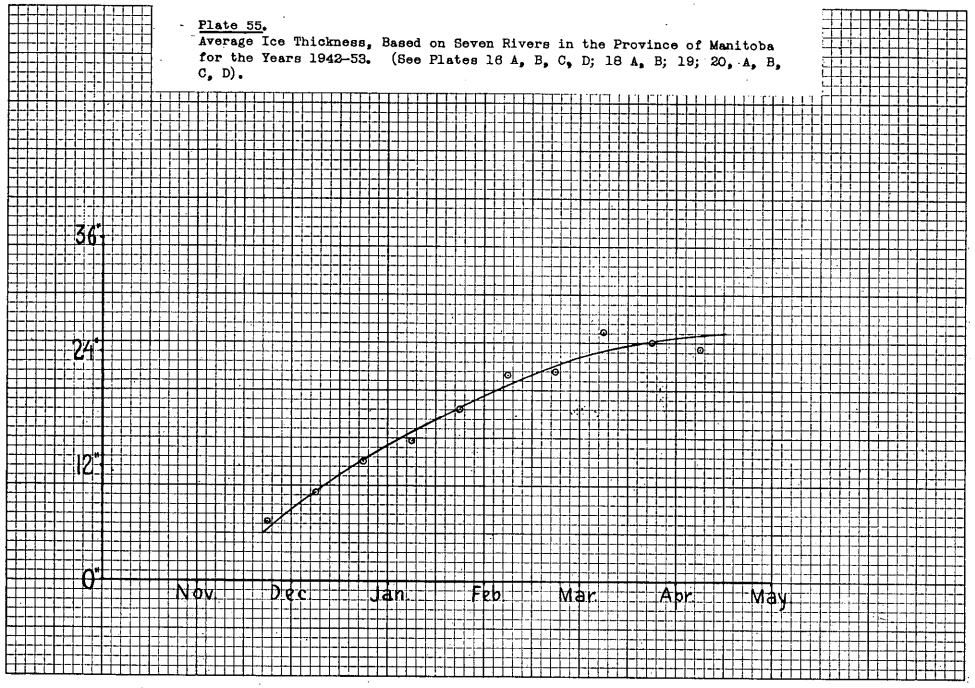


Plate 57.
Average Ice Thicknesses, Based on Ten Stations on Five Rivers of the States of North and South Dakota, Minnesota, and Wisconsin for the Years 1898-1934. (See Plates 35 A, B; 36 A, B; 37; 38; 39; 40 A, B; 41; 42; 43; 44).

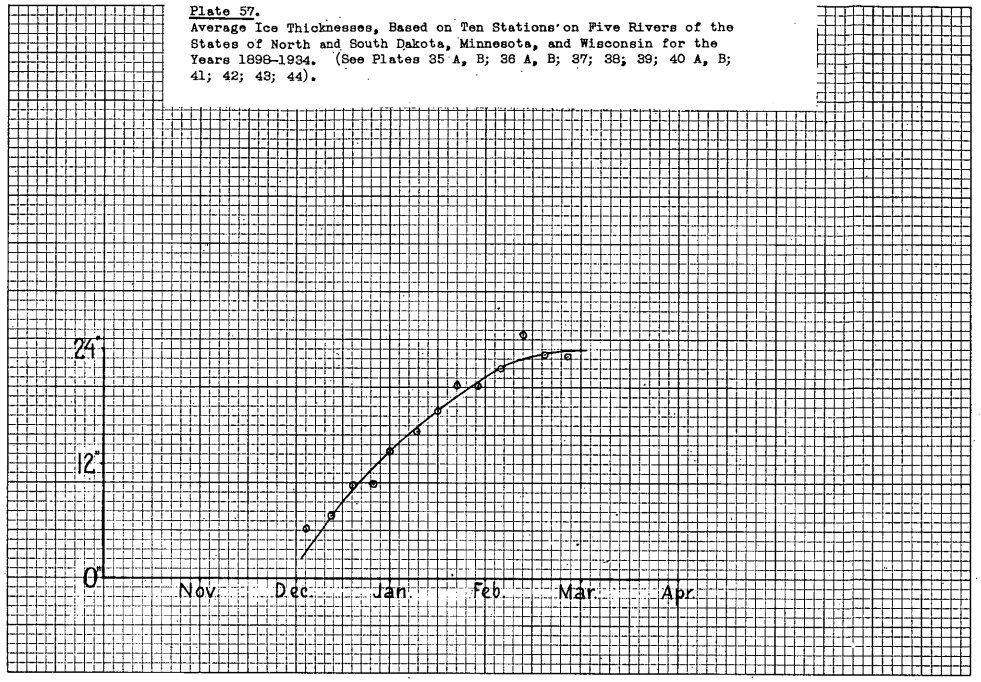


Plate 54.
Average Ice Thicknesses, Based on Six Rivers in the Provinces of Alberta and Saskatchewan for the Years 1910-1914. (See Plates 10; 11 A, B; 12 A, B; 13 A, B; 14; 15 A, B).

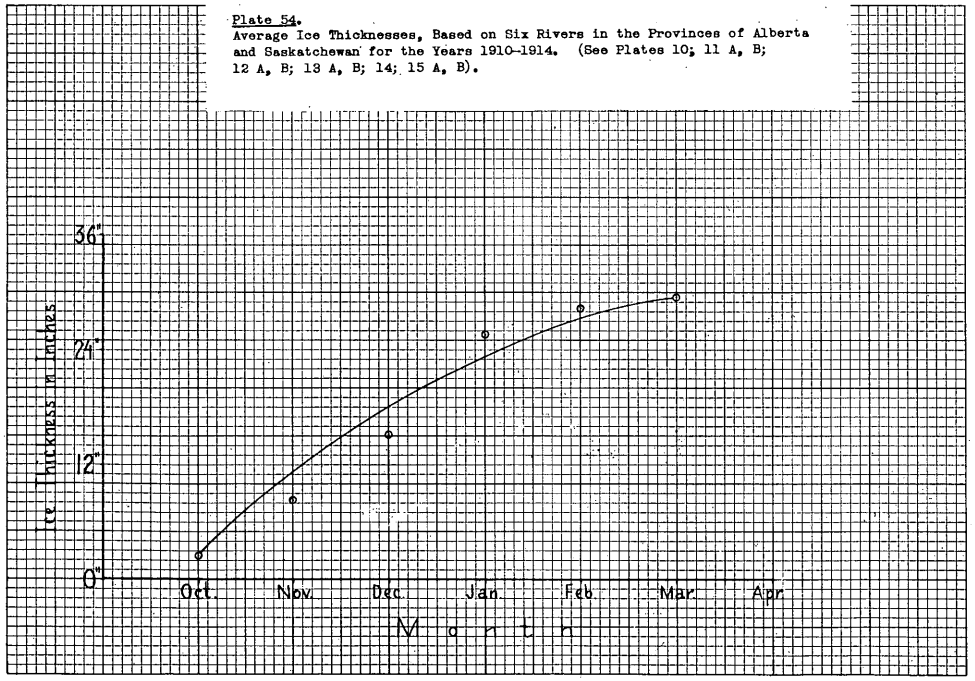


Plate 56.
Average Ice Thicknesses, Based on Eight Stations on Four Lakes in the Province of Manitoba for the Years 1951-1953. (See Plates 21, 28).

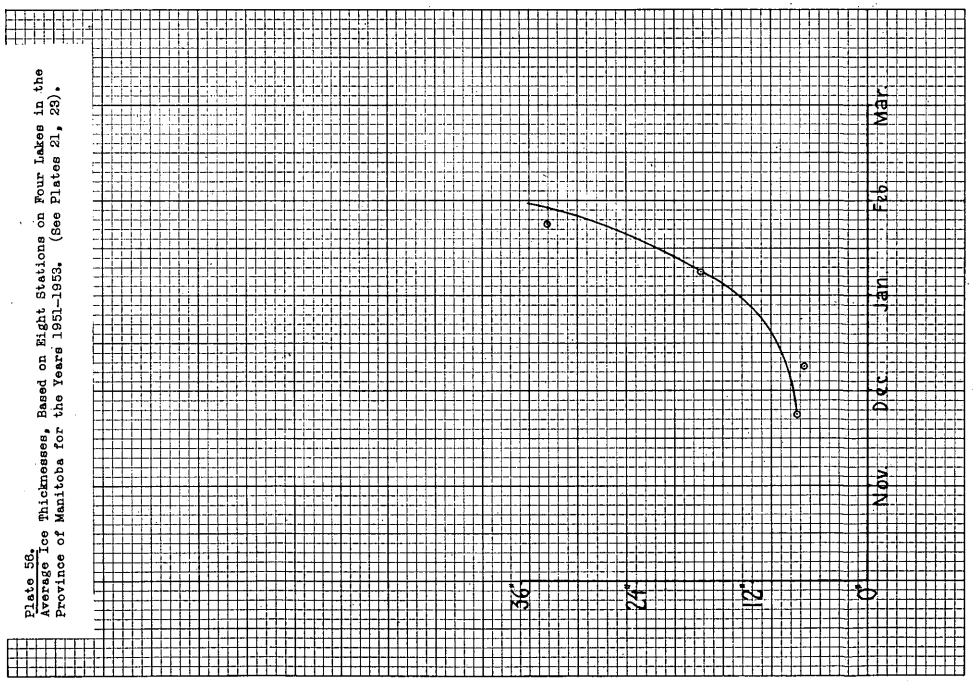


Plate 58. Average Ice Thicknesses, Based on Seven Lakes of the Provinces of New Brunswick, Nova Scotia, and Ontario, and the States of Maine and Vermont, for the Years 1910–1953. (See Plates 26; 27; 30; 32 A, B; 33 A, B; 47; 50 A, B, C).

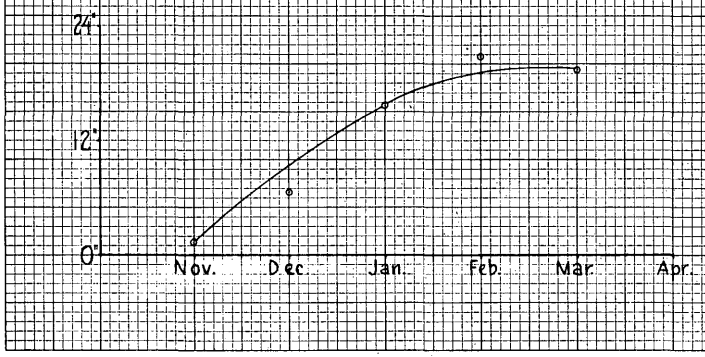
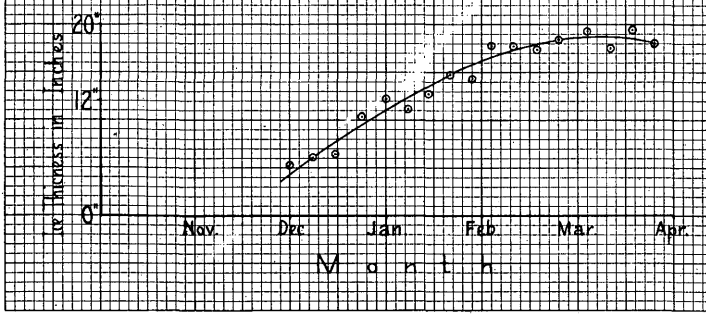


Plate 58.
Average Ice Thicknesses, Based on Eight Rivers of the Province of New Brunswick and the States of Maine, New Hampshire, Vermont, and New York for the Years 1910–1922. (See Plates 29, 31, 46, 48, 49, 51, 52, 53).



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III

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