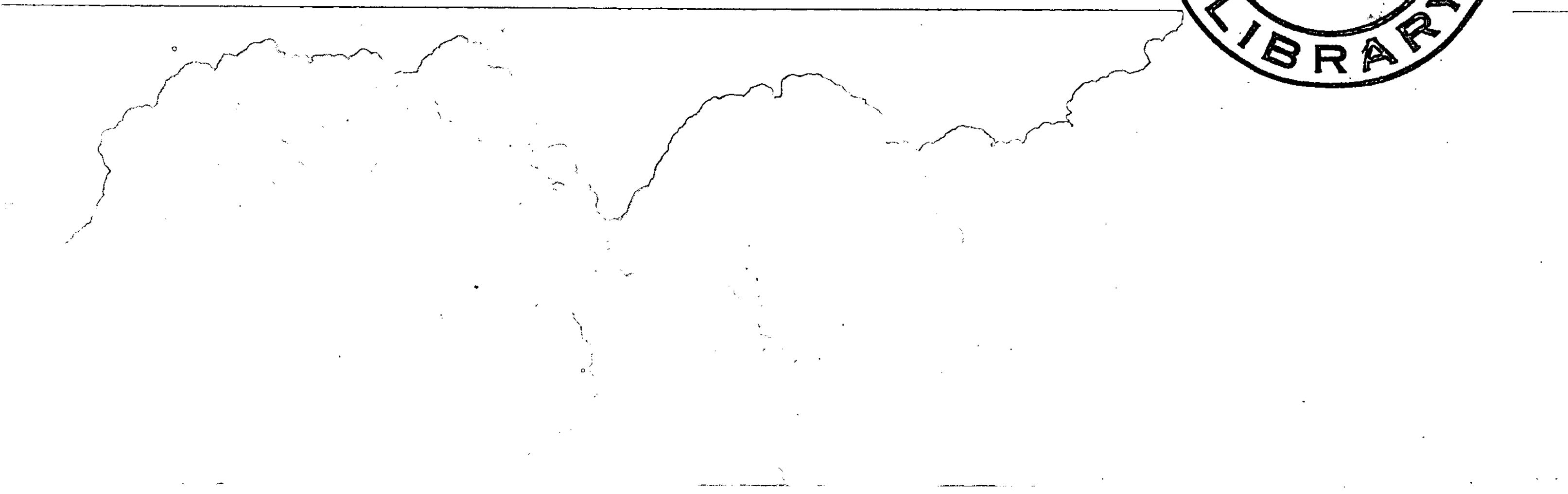
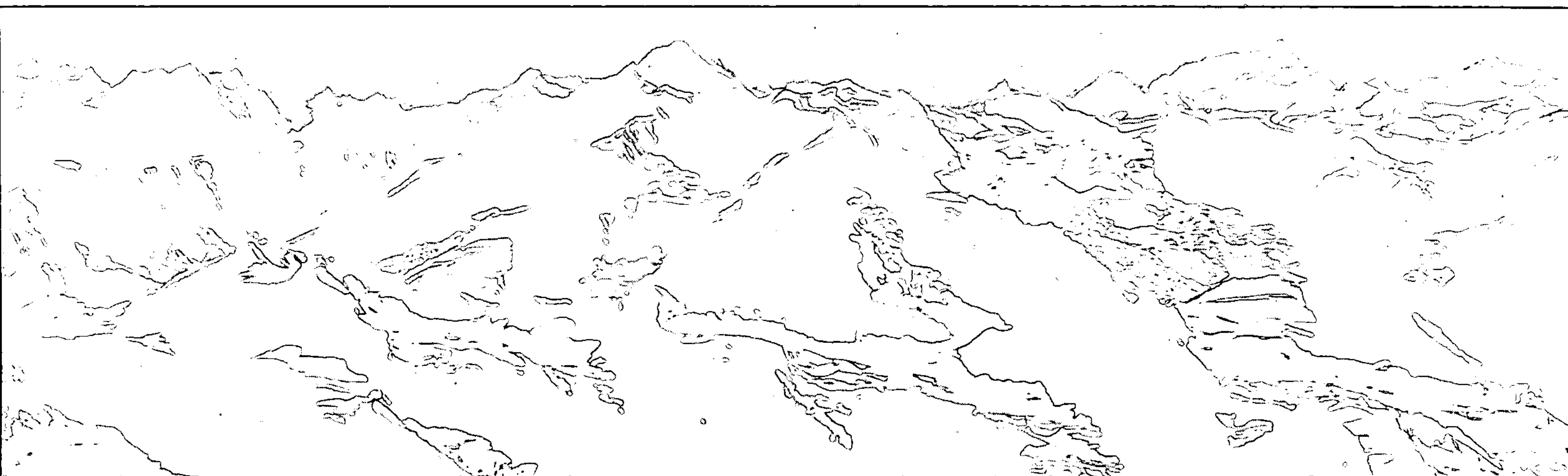
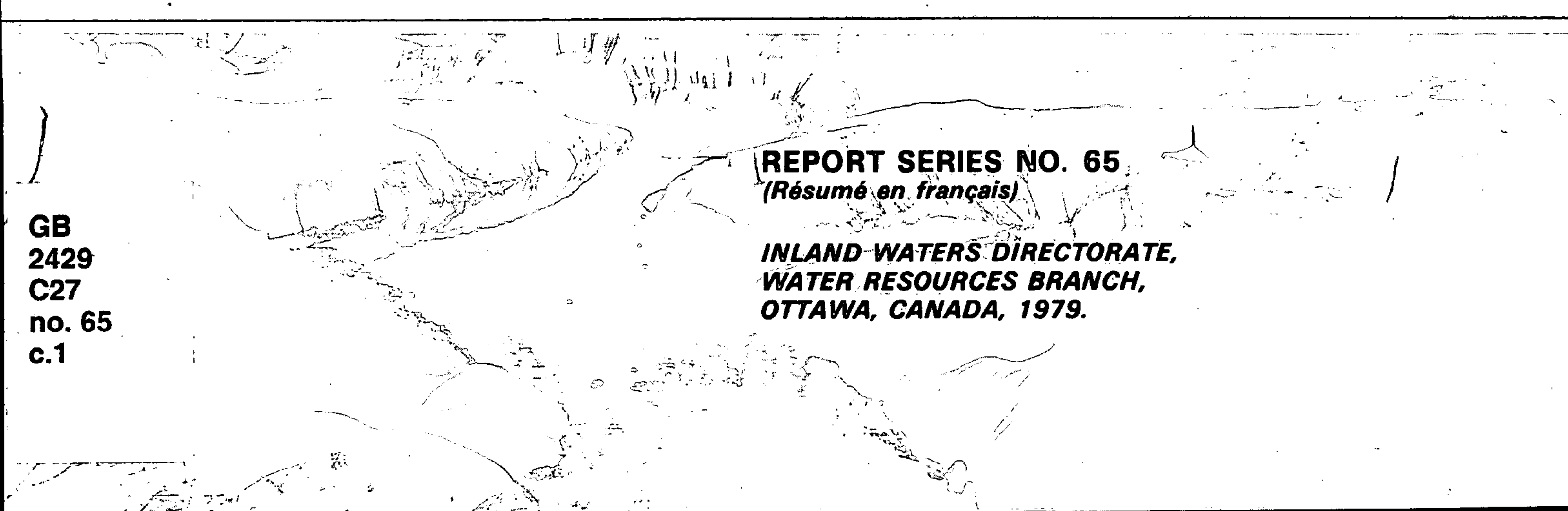
Environment Canada
Environnement Canada

Glacier Surveys in Alberta – 1977

I.A. Reid and J.O.G. Charbonneau







REPORT SERIES NO. 65
(Résumé en français)

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1979.

Environment Canada
Environnement Canada

Glacier Surveys in Alberta – 1977

I.A. Reid and J.O.G. Charbonneau

REPORT SERIES NO. 65
(Résumé en français)

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1979.

Cat. No. En 36-508/65

ISBN 0-662-10764-0

Contents

Tables

Tables (cont.)

Illustrations

Abstract

Glaciers act as natural regulators, storing water in winter and releasing it in summer. To gain some understanding of this phenomenon and the contribution which glaciers make to streamflow, the predecessors of the Water Survey of Canada began glacier surveys in 1945. The earlier surveys offered some clue to the role of the glacier, but the data collected were not sufficient to provide the overall picture. Following adoption of photogrammetric survey techniques, however, the glacier surveys have evolved to the extent that it is now feasible to produce a series of maps from which the linear, areal, directional and volumetric changes can be determined.

The surveys have revealed that the glaciers, in general, are becoming smaller in size; hence the regulating effect on streamflow is diminishing.

Résumé

Les glaciers jouent un rôle de régularisation naturelle, emmagasinant l'eau pendant l'hiver et la laissant s'écouler durant l'été. Pour arriver à comprendre quelque chose à ce phénomène et aussi à la contribution que les glaciers apportent au ruissellement, les prédécesseurs de la Division des relevés hydrologiques du Canada avaient commencé en 1945 une étude des glaciers. Ces premières études apportèrent certains indices quant au rôle des glaciers mais les observations compilées n'étaient pas suffisantes pour donner une idée d'ensemble. À la suite de l'adoption de relevés photogrammétriques, cependant, l'étude des glaciers a évolué au point qu'il est maintenant possible de produire une série de cartes à partir desquelles on peut déterminer les changements linéaires, directionnels, de superficie et de volume.

Les études ont révélé, qu'en général, le volume des glaciers diminue et que de ce fait, l'effet de régularisation sur le ruissellement est aussi diminué.

Introduction

An important function of the Water Resources Branch is the systematic collection of water resource data throughout Canada. This work is of vital importance in the development of Canada's water resources because the feasibility, safety and cost of water use or water control projects depend largely on the availability and reliability of such information.

Since glaciers form part of Canada's water resources, some glaciers are surveyed on a continuing basis by Water Survey of Canada (WSC) in an effort to determine the extent and pattern of a glacier's influence on surface water runoff. Of the large number of glaciers in Canada, however, only a few are surveyed (Fig. 1).

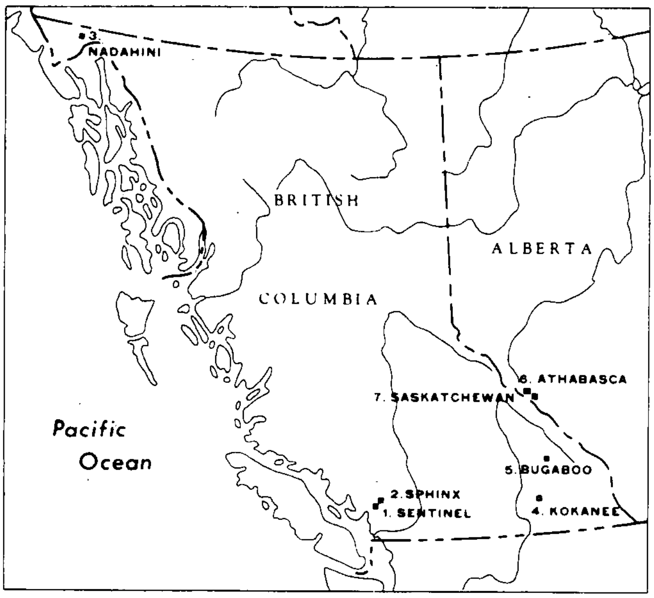


Figure 1. Key map showing location of glaciers.

This report summarizes the history of glacier surveys conducted in Canada by Water Survey of Canada and describes present glacier survey practices. Tables of results for the period of record, some interpretation of these results and the most recent glacier maps are also included. Only those surveys conducted partially by or under the supervision of WSC Headquarters Staff are described in detail; brief reference, however, is made to surveys conducted entirely by WSC Regional Office staff to make the historical summary coherent and the tables of data as complete as possible.

In response to a directive recommending greater use of the metric system, the WSC Division decided to change from English to SI units in the determination of biennial glacier variations. In 1968, the year of the changeover, it was necessary to compile separate sets of maps using both English and SI units in order that data produced prior to 1968 might be compared to data obtained after 1968.

HISTORICAL SUMMARY

Surveys of selected glaciers in the Rocky, Columbia and Coast mountains were begun in 1945. The surveys of glaciers located in the Rocky Mountains were carried out by WSC Calgary staff, and the Columbia and Coast mountain surveys were performed by the WSC Vancouver staff. These surveys, in general, were designed to determine the position of the glacier toe, to define the movement of a plaque line on the glacier's surface and to provide a transverse and a longitudinal profile for the lower portion of the glacier. Reports describing the 1945 survey and subsequent surveys conducted by the Regional Offices are available from

G. Tofte, Regional Chief,
Water Survey of Canada,
Inland Waters Directorate,
Department of the Environment,
502 - 1001 West Pender Street,
Vancouver, British Columbia.
V6E 2M9

and

G.H. Morton, Regional Chief,
Water Survey of Canada,
Inland Waters Directorate,
Department of the Environment,
Bag 2909, Postal Station M,
Calgary, Alberta.
T2P 2M7

More information concerning the evolution of the glacier surveys may be obtained from "Glacier Surveys by the Water Survey of Canada," a paper by I.A. Reid in the *Proceedings* of the Banff Symposia on "The Role of Snow and Ice in Hydrology," held in September 1972.

A glacier's contribution to the volume of runoff can be calculated if two quantities are known: (1) the change in volume of a glacier during a given period of time and (2) the amount of ice that flows from the source ice-field to the glacier during the same period of time. Surveys have been designed to measure the first quantity directly, but since no direct method of measuring the second quantity was known until recently, it has been determined only indirectly.

A paper entitled "A Simple Method of Measuring the Average Amount of Water Produced Annually by Melting of Ice on a Glacier" by I.A. Reid and W.S.B. Paterson was presented at the Symposium on "Hydrology of Glaciers" at Cambridge, England, in September 1969. The Symposium's *Proceedings* were published by the Glaciological Society, Cambridge, in 1974.

Since the information obtained for each glacier by Regional Office staff was applicable only to the lower portion of the glaciers, volumetric and linear changes could be obtained for only the lower portion. In an effort to increase the areal coverage of the glaciers surveyed, an aerial photogrammetric survey of the Athabasca Glacier was undertaken as a pilot project in July 1959 (Reid, 1961). Permanent survey plugs were established around the perimeter of the glacier and tied-in by means of a triangulation survey. From the aerial photographs, a topographic map was produced using a high-precision plotter. This was the first time that a topographical map of high quality was prepared by the Branch, and the precedent was set for later maps.

In 1963, a survey party composed of staff from the Calgary Regional Office and headquarters participated in a surveying experiment with a team from the University of New Brunswick led by Dr. G. Konecny, former Head of the Department of Survey Engineering. Optical-electronic distance measuring equipment together with standard equipment and normal triangulation procedures was used to reconfirm the location of plugs in the somewhat modified triangulation network around Athabasca Glacier and to define the coordinates of the newly established plugs around Saskatchewan Glacier. Only Saskatchewan Glacier was photographed in 1963, implementing terrestrial photogrammetry in place of aerial photogrammetry for the first time. The map was plotted under contract by the University of New Brunswick.

During the summer of 1964, high-quality maps of five selected glaciers in British Columbia were prepared by stereoscopic terrestrial photogrammetric methods. It was found by study that for the survey of glaciers, stereoscopic terrestrial survey methods have certain advantages over aerial surveys.

Since 1965 stereoscopic terrestrial photographs of the Athabasca and Saskatchewan glaciers have been taken by Calgary Regional Office and headquarters personnel in odd-numbered years. The plotting of the maps was performed by headquarters staff, using a first-order plotter located at the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.

This method is now used to map glaciers in British Columbia in even-numbered years and to map glaciers in Alberta in odd-numbered years. From the maps, linear and volumetric changes in the glaciers are determined. Results of earlier work have also been published in this *Report Series.*

The Calgary Regional staff continues to observe plaque line movements and the position of the toe of the Athabasca and Saskatchewan glaciers in even-numbered years, i.e., 1976, 1978.

The continuation of these surveys, apart from more fundamental scientific observations made by the Department's Snow and Ice Division, is an important aspect of Branch activities for two reasons: (1) the surveys provide a basis for obtaining greater knowledge of Canada's fresh-water resources and (2) they fulfil our announced commitment[1] to monitor glacial changes as part of a world-wide surveillance of glacier trends. We can only speculate on the ultimate usefulness of the information being collected. Yet it could well be that the trends of a glacier's behaviour over a period of time will prove to be a very useful prediction tool in hydrological and climatological studies of the future.

These glacier surveys are closely coordinated with other activities of the Water Resources Branch. The information contained in these survey reports is provided to individuals, scientific agencies and to various libraries throughout the world.

[1] The commitment is to the International Commission on Snow and Ice of the International Association of Hydrological Sciences and to Unesco, Paris.

Description of Glaciers

ATHABASCA GLACIER

Athabasca Glacier is located at latitude 52° 12′, longitude 117° 14′, on the eastern slopes of the Rocky Mountains in Jasper National Park (Fig. 2). This glacier was selected because of its accessibility. The Branch has made periodic surveys around the toe area since 1945. It is one of the main outlet glaciers from the Columbia Icefield, and the meltwater from the Athabasca flows into the Arctic Ocean via the Sunwapta, Athabasca and Mackenzie rivers.

SASKATCHEWAN GLACIER

Saskatchewan Glacier is located at latitude 52° 08′, longitude 117° 12′, on the eastern slopes of the Rocky Mountains in Banff National Park (Figs. 3 & 4). The glacier was selected on account of its accessibility. The Branch has made periodic surveys around the toe area since 1945. It is the major outlet glacier from the Columbia Icefield, and its meltwater flows into Hudson Bay via the North Saskatchewan, Saskatchewan and Nelson rivers.

Figure 2. Athabasca Glacier, August 13, 1977.

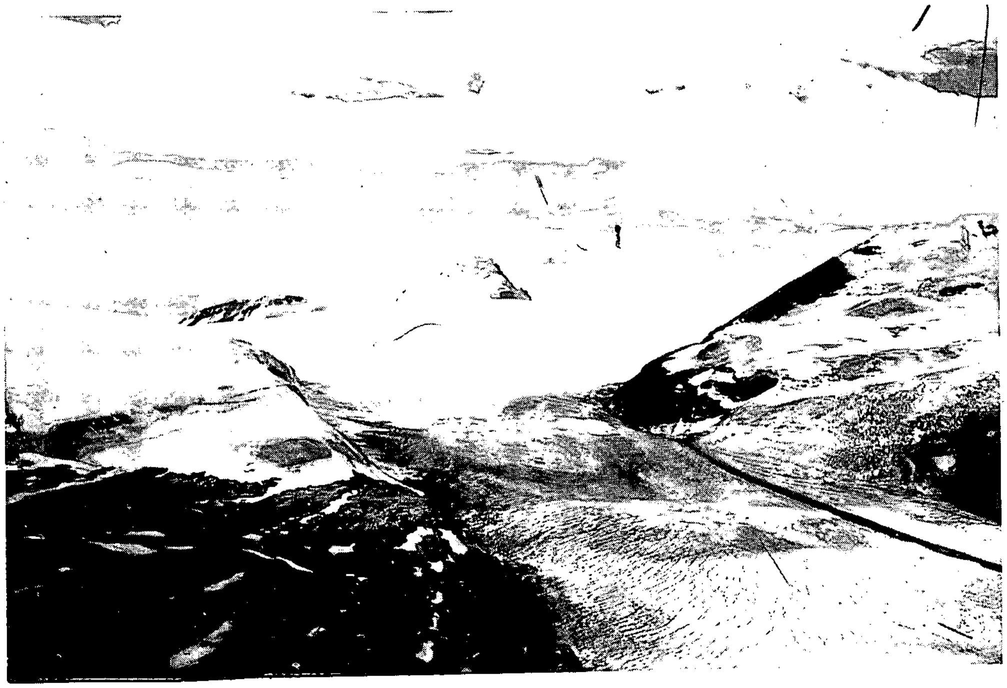


Figure 3. Saskatchewan Glacier, upper base, August 12, 1977.

Figure 4. Saskatchewan Glacier, lower base, August 14, 1977.

Field Work

During the summer of 1959, a Branch survey party established 21 control points on rock around the periphery of Athabasca Glacier. These control points were established in connection with the preparation of an aerial photogrammetric survey.

In 1963, Dr. G. Konecny, in conjunction with Branch personnel (Chapter 1), conducted a stereoscopic terrestrial photogrammetric survey of Saskatchewan Glacier.

The control established in 1959 and 1963 is used for the stereoscopic terrestrial surveys of the Athabasca and Saskatchewan glaciers.

Since the surveys of the two glaciers are basically the same, only the Athabasca Glacier is described in detail. The triangulation control network for Saskatchewan Glacier is an extension of the control for Athabasca Glacier.

CONTROL

A schematic sketch of the control net for Athabasca Glacier is shown in Figure 5.

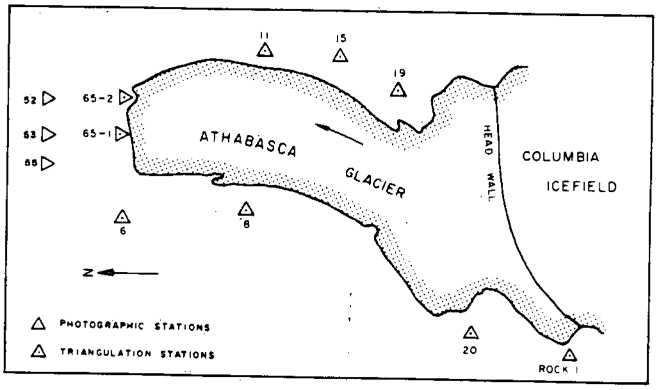


Figure 5. Sketch showing distribution of photographic and triangulation stations, Athabasca Glacier.

Triangulation stations, numbers 6, 8, 11, 15, 19, 20, 65-1, 65-2 and Rock 1, were used as the control for the terrestrial survey. The other stations, shown on the map (in pocket), were established in the 1959 aerial photogrammetric survey. These stations, with the exception of Rock 1, were marked by a standard Water Resources Branch bench-mark plug cemented in bedrock where possible (Fig. 6).

Figure 6. Standard WRB plug used to locate the photographic stations.

The photographic stations, numbers 52, 53, and 55, are located on the chalet ridge overlooking the glacier and are also marked by a standard Water Resources Branch bench-mark plug. Small rock cairns were built close to each plug for ease in locating them in the field.

INSTRUMENTS AND EQUIPMENT

A Wild T-2 theodolite and a Wild P-30 phototheodolite were used to measure all horizontal and vertical angles. All readings were to the nearest second.

A Wild P-30 phototheodolite was used to photograph the glaciers. The camera was calibrated at the National Research Council, Division of Applied Physics, before plotting the glacier maps. This calibration is necessary only once unless the camera sustains a violent shock. Kodak spectroscopic type plates were used for the photography.

BASE LINE

The base line for the Athabasca Glacier map is based on measurements made between triangulation stations 1 and 3 using 300-ft (91.44-m) invar tape.

Table 1. Sample Field Notes for Triangulation–Athabasca Glacier Survey

Transit at Station 4 H.I. = 1.22 m Overcast, cold, sunny intervals, windy

Date:
Transit:
Notes:

Stn.	Horizontal angle	Mean	Reduced mean	Vertical angle	Mean	Remarks
67-1	36° 59′ 44″ 216° 59′ 41″	36° 59′ 42.5″	00° 00′ 00″	84° 44′ 23″ 275° 16′ 09″	84° 44′ 07″	On plug
65-1	115° 30′ 36″ 295° 30′ 22″	115° 30′ 29″	78° 30′ 43.5″	91° 18′ 01″ 268° 42′ 24″	91° 17′ 48.5″	Top of transit
67-1	96° 59′ 46″ 276° 59′ 37″	96° 59′ 41.5″	00° 00′ 00″	84° 44′ 27″ 275° 16′ 14″	84° 44′ 06.5″	On plug
65-1	175° 30′ 32″ 355° 30′ 22″	175° 30′ 27″	78° 30′ 45.5″	91° 18′ 20″ 268° 42′ 24″	91° 17′ 58″	Top of transit

Table 2. Sample Field Notes for Taking Photographs with a Phototheodolite–Athabasca Glacier Survey

Phototheodolite at Station 55
Backsight on Station 53
Height of tripod = 1.30 m

Began 11:00
Finished 11:55

Date:
Transit:
Notes:

Angle	Aversion (rt.)	Inclin. (grad.)	Plate no.	Photo no.	Exp. time(s)	Remarks
270° 00′ 00″	00° 00′ 00″	+7	8	8	1/2	High overcast
270° 00′ 00″	00° 00′ 00″	+7	9	9	1/2	Light winds
270° 00′ 00″	00° 00′ 00″	+7	10	10	1/10	Light winds
263° 00′ 00″	07° 00′ 00″	0	11	11	1/10	Light winds
263° 00′ 00″	07° 00′ 00″	0	12	12	1/5	Light winds
263° 00′ 00″	07° 00′ 00″	0	13	13	1/2	Light winds

Measuring stakes about 38 mm by 90 mm by 900 mm were set along the base line at 300-ft (91.44-m) intervals. For optimum measuring accuracy, the method used by the National Research Council in calibrating the invar tape was duplicated in the field. In this method, the tape is supported at 23-m intervals along its length. Support stakes, 19 mm by 19 mm by 1200 mm, were set in line by eye at 23-m intervals between the measuring stakes, and a nail was driven horizontally on grade into each stake to support the tape. An aluminum plate, 100 mm by 100 mm, was nailed on top of each measuring stake, and a scratch was made in line-of-sight on each plate at the 300-ft (91.44-m) marks.

During the chaining operation, with the position of one end of the tape at zero, the spring balance reading and the tape alignment and grade all correct, a scratch was made on the aluminum plate perpendicular to the line-of-sight at the other end [300-ft (91.44-m) mark] of the tape. Two thermometers, one at each end of the tape, were read and all measurements were recorded.

TRIANGULATION

After reaching the glacier, the party made a reconnaissance survey of the toe area to determine the best locations for the photographic stations. The locations of photographic stations should be about the same elevation and on a high ridge facing the glacier. The ratio between the distance separating the photographic stations, and the distance to the area to be stereoscopically photographed should not be less than 1:4 nor greater than 1:20. To meet this criterion, measurements were made from the best general area for the photographic stations to the toe area of the glacier and the upper limit of the glacier. When these distances were known, the party established photographic stations on a ridge to give the best possible results.

The triangulation was carried out using a Wild T-2 theodolite and a Wild P-30 phototheodolite. Each horizontal and vertical angle was observed three times using the telescope in a direct position and three times in an inverted position. The mean angle was used in the computations for distance, positions and differences in elevation (Table 1).

PHOTOGRAPHY

The photographs taken from stations 52 and 55 (long base) were used to plot distant areas of the glacier, and the photographs taken from stations 55 and 53 (short base) were used to plot near areas. Sample field notes for taking photographs with a phototheodolite are shown in Table 2.

Photography instructions are outlined in the booklet which accompanies the phototheodolite. These instructions, as well as those contained in the *Text Book of Photogrammetry* (Zeller, 1952), were followed closely.

Office Work

Since the triangulation net for Athabasca Glacier was not connected to any existing net, it was necessary to compute geodetic positions of triangulation stations from the assumed coordinates of triangulation station No. 1 (Athabasca Glacier). The coordinates of station No. 1 were scaled from a large-scale topographic map.

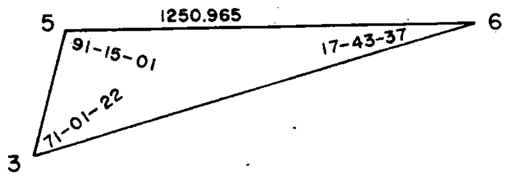
Positions of the other triangulation stations were calculated by the method outlined in *Tentative Instructions for Computation of Geodetic Positions* (United States Department of the Interior, 1951).

COMPUTATIONS

The computations of coordinates were carried out with a basic calculator using seven-place natural trigonometric functions.

BASE LINE

The distance between triangulation stations 1 and 3 was measured with a standardized invar tape. Corrections



$$\frac{5-3}{\sin\angle 6} = \frac{5-6}{\sin\angle 3}$$

$$5-3 = \frac{1250.965 \times 0.3044810}{0.9456479}$$

$$5-3 = 402.788 \text{ m}$$

Figure 7. Computations for distance using the sine law.

Table 3. Typical Calculations for Elevations–Athabasca Glacier Survey

@ Stn. 3 — Elevation of Stn. 3 = 1978.213 m

Stn.	Distance	Vertical angle from stn. 3	Diff. of elev.	Ref.*	Total diff. of elev.	Ht. of target	Ht. of inst.	Mean diff. of elev.	Elev. (Z)
BLE	530.979	-00° 29′ 00″	-4.481	+0.018	-4.463	0.15	+1.524	-3.089	1975.124
2	795.314	-00° 25′ 10″	-5.822	+0.043	-5.779	0.46	+1.524	-4.715	1973.498
4	949.665	-02° 02′ 43″	-33.912	+0.061	-33.851	0.46	+1.524	-32.787	1945.426
5	402.788	+08° 26′ 00″	+59.717	+0.012	+59.729	0.46	+1.524	+60.793	2039.006

*In the column marked Ref., corrections are obtained from *Tables of Earth's Curvature and Refraction* (Breed and Hosmer, 1947).
BLE = Base line east.

for slope and temperature were made to the measured distance. In addition, the base length was reduced to sea level by the formula $-B\frac{h}{R}$, where B is the measured length of the base, h is the altitude above sea level, and R is the radius of the sector of the earth at the location.

HORIZONTAL ANGLE

When the notes for all stations were reduced, the coordinate for triangulation station No. 1 was assigned the value, latitude 52° 13′ 12″, longitude 117° 13′ 30″. The position of station No. 1 was ascertained from a large-scale topographic map.

The azimuth of line 1 to 3 was determined from observations on the star "Polaris." The orientation of the glacier is therefore referenced to true north. Computations showing an example of the sine law to compute distances are shown in Figure 7.

The geodetic positions of the triangulation stations, with the exception of triangulation station No. 1, were calculated by the method outlined in *Tentative Instructions for Computation of Geodetic Positions.*

ELEVATIONS

The elevation of triangulation station No. 1 was obtained by running a line-of-levels from Geodetic Bench Mark 713-E. The elevations for the other stations were calculated by trigonometry using five-place trigonometric tables and the tangent law for right-angle triangles. The mean vertical angle was calculated from the field notes. Typical computations are shown in Table 3.

PLOTTING

The plotting of the Athabasca and Saskatchewan Glacier maps was carried out by using a Wild A-7 plotter located at the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.

Volumetric and Height Zone Changes

One means of determining the change in quantity of ice released or added to storage between successive surveys is by computing the volumetric change from maps. Four methods are described in the *Canadian Journal of Earth Sciences* (Brandenberger and Bull, 1966).

The previous reports in this series used the Haumann method modified by adding a grid around the glacier and computing the change between successive surveys within the grid. This system seemed to work satisfactorily for computing volumetric changes, but gave slightly lower values for height zone changes. The magnitude of change depended on where the grid was placed around the glacier. If the grid paralleled the glacier's edge, the height zone changes were correct. This case seldom, if ever, happens. Because of the slightly lower values, it was decided to use the Finsterwalder method (Finsterwalder, 1954) for computing the changes in height and the Haumann method for computing the volumetric change (Fig. 8). All the tables have been revised to reflect these changes.

The decrease in height and loss of volume of the zone have been computed from the following formulas (Haumann, 1960):

$$dh = \frac{\Delta F_1 + \Delta F_2}{F_1 + F_2} \Delta h$$

$$dV = F_m dh$$

$$\overline{dh} = \frac{dh}{n}$$

where dh = the loss of height during the observation period,
$\overline{dh}$ = the loss of height for one year,
n = the number of years,
Δh = the contour interval,
dV = the loss of volume,

$F_1 = A_2A_3B_3B_2$ = the area at the beginning of the period,
$F_2 = C_1C_2D_2D_1$ = the area at the end of the period,
$\Delta F_1 = A_2A_3C_2C_1$ the contour line displacement at the lower limit of the zone,
$\Delta F_2 = B_2B_3D_2D_1$ the contour line displacement at the upper limit of the zone,
$F_1' = A_1A_2B_2B_1 + A_3A_4B_4B_3$ the total loss of a zone,
$F_1'' = A_1A_4B_4B_1 = F_1 + F_1'$ the total area at the beginning of the period, and
$F_m = (F_2 + F_1'')/2$.

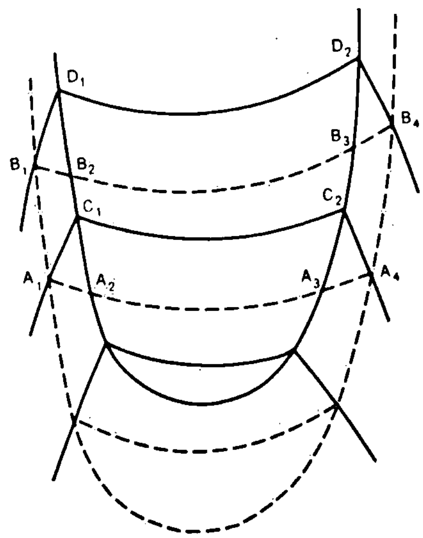


Figure 8. Sketch showing glacier at beginning and end of period (after Haumann, 1960).

ACKNOWLEDGMENTS

The authors acknowledge the services of L.A. Warner, WSC Calgary, who participated in the field work.

Table 4. Athabasca Glacier–Summary of Changes from 1959 to 1962

Height zone (ft)	dV (ft³)	Mean 59 & 62 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
6350-6400	-6 035 000	259 700	-23.24	-7.75*
6400-6450	-7 656 000	264 600	-28.94	-9.65
6450-6500	-7 270 000	277 900	-26.16	-8.72
6500-6550	-6 658 000	307 800	-21.63	-7.21
6550-6600	-6 150 000	361 700	-17.00	-5.67
6600-6650	-6 064 000	464 000	-13.07	-4.36
6650-6700	-5 405 000	551 000	-9.81	-3.27
6700-6750	-4 951 000	640 400	-7.73	-2.58
6750-6800	-4 791 000	725 600	-6.60	-2.20
6800-6850	-6 175 000	951 500	-6.49	-2.16
6850-6900	-9 085 000	1 184 000	-7.67	-2.56
6900-6950	-8 934 000	1 229 000	-7.27	-2.42
6950-7000	-6 671 000	1 006 000	-6.63	-2.21
7000-7050	-5 550 000	943 900	-5.88	-1.96
7050-7100	-4 687 000	991 000	-4.73	-1.58
7100-7150	-4 061 000	1 367 000	-2.97	-0.99
7150-7200	-2 936 000	1 737 000	-1.69	-0.56
7200-7250	+1 924 000	2 436 000	+0.79	+0.26
7250-7300	+6 148 000	2 509 000	+2.45	+0.82
7300-7350	+5 881 000	1 897 000	+3.10	+1.03
7350-7400	+3 766 000	2 014 000	+1.87	+0.62
7400-7450	+1 422 000	1 800 000	+0.79	+0.26
7450-7500	+2 339 000	1 225 000	+1.91	+0.64
7500-7550	+2 897 000	511 900	+5.66	+1.89
7550-7600	+3 431 000	598 800	+5.73	+1.91
7600-7650	+5 744 000	591 500	+9.71	+3.24
7650-7700	+6 603 000	845 400	+7.81	+2.60

*Estimated.

Table 5. Athabasca Glacier–Summary of Changes from 1962 to 1965

Height zone (ft)	dV (ft³)	Mean 62 & 65 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
6340-6350	-162 100	16 210	-10.00	-3.33*
6350-6400	-6 474 000	189 900	-34.09	-11.36
6400-6450	-5 570 000	210 700	-26.43	-8.81
6450-6500	-4 937 000	250 100	-19.74	-6.58
6500-6550	-4 710 000	282 500	-16.67	-5.56
6550-6600	-4 302 000	335 800	-12.81	-4.27
6600-6650	-3 786 000	430 800	-8.79	-2.93
6650-6700	-2 915 000	506 000	-5.76	-1.92
6700-6750	-1 977 000	601 000	-3.29	-1.10
6750-6800	-4 365 000	705 200	-6.19	-2.06
6800-6850	-4 729 000	918 300	-5.15	-1.72
6850-6900	-4 812 000	1 240 000	-3.88	-1.29
6900-6950	-4 313 000	1 123 000	-3.84	-1.28
6950-7000	-3 332 000	1 019 000	-3.27	-1.09
7000-7050	-5 126 000	925 200	-5.54	-1.85
7050-7100	-4 031 000	955 300	-4.22	-1.41
7100-7150	-6 774 000	1 423 000	-4.76	-1.59
7150-7200	-7 904 000	1 664 000	-4.75	-1.58
7200-7250	-3 829 000	2 321 000	-1.65	-0.55
7250-7300	-5 817 000	2 563 000	-2.27	-0.76
7300-7350	-4 993 000	1 816 000	-2.75	-0.92
7350-7400	-3 897 000	2 073 000	-1.88	-0.63
7400-7450	-5 273 000	1 740 000	-3.03	-1.01
7450-7500	-5 710 000	1 233 000	-4.63	-1.54

*Estimated.

Table 6. Athabasca Glacier–Summary of Changes from 1965 to 1967

Height zone (ft)	dV (ft³)	Mean 65 & 67 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
6340-6400	+353 300	166 700	+2.12	+1.06*
6400-6450	+358 900	175 900	+2.04	+1.02
6450-6500	+484 800	223 400	+2.17	+1.09
6500-6550	+1 081 000	270 800	+3.99	+2.00
6550-6600	+1 268 000	327 600	+3.87	+1.93
6600-6650	+1 454 000	414 400	+3.51	+1.76
6650-6700	+1 594 000	496 500	+3.21	+1.61
6700-6750	+2 773 000	567 200	+4.89	+2.45
6750-6800	+5 032 000	692 200	+7.27	+3.63
6800-6850	+5 001 000	894 700	+5.59	+2.80
6850-6900	+5 584 000	1 241 000	+4.50	+2.25
6900-6950	+5 989 000	1 081 000	+5.54	+2.77
6950-7000	+7 456 000	1 004 000	+7.43	+3.72
7000-7050	+11 080 000	909 800	+12.18	+6.09
7050-7100	+10 860 000	967 600	+11.22	+5.61
7100-7150	+13 580 000	1 433 000	+9.48	+4.74
7150-7200	+14 730 000	1 679 000	+8.77	+4.38
7200-7250	+9 515 000	2 367 000	+4.02	+2.01
7250-7300	+7 012 000	2 646 000	+2.65	+1.33
7300-7350	+4 001 000	1 794 000	+2.23	+1.11
7350-7400	+606 400	2 166 000	+0.28	+0.14
7400-7450	-961 900	1 718 000	-0.56	-0.28
7450-7500	+2 056 000	1 254 000	+1.64	+0.82

*Estimated.

Table 7. Athabasca Glacier–Summary of Changes from 1967 to 1969

Height zone (ft)	dV (ft³)	Mean 67 & 69 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
6340-6400	+344 200	131 900	+2.61	+1.30*
6400-6450	+546 200	170 100	+3.21	+1.61
6450-6500	+636 000	214 100	+2.97	+1.49
6500-6550	+756 000	261 600	+2.89	+1.45
6550-6600	+966 000	325 200	+2.97	+1.48
6600-6650	+1 434 000	400 500	+3.58	+1.79
6650-6700	+2 017 000	488 400	+4.13	+2.06
6700-6750	+861 700	570 600	+1.51	+0.75
6750-6800	-1 700 000	682 900	-2.49	-1.25
6800-6850	-1 952 000	909 700	-2.75	-1.38
6850-6900	-1 443 000	1 183 000	-1.22	-0.61
6900-6950	-841 800	1 108 000	-0.76	-0.38
6950-7000	-1 181 000	952 600	-1.24	-0.62
7000-7050	-1 747 000	909 800	-1.92	-0.96
7050-7100	-848 900	975 700	-0.87	-0.44
7100-7150	+1 644 000	1 359 000	+1.21	+0.61
7150-7200	+591 700	1 793 000	+0.33	+0.17
7200-7250	+3 472 000	2 346 000	+1.48	+0.74
7250-7300	+6 448 000	2 698 000	+2.39	+1.20
7300-7350	+1 983 000	1 906 000	+1.04	+0.52
7350-7400	+3 290 000	2 109 000	+1.56	+0.78
7400-7450	+6 848 000	1 747 000	+3.92	+1.96
7450-7500	+1 421 000	1 328 000	+1.07	+0.93

*Estimated.

Table 8. Athabasca Glacier–Summary of Changes from 1969 to 1971

Height zone (m)	dV (m^3)	Mean 69 & 71 areas (m^2)	Surface change (m)	Surface change (m/yr)
1937-1950	-57 930	8 276	-7.00	-3.50*
1950-1960	-69 700	8 812	-7.91	-3.96
1960-1970	-84 390	9 779	-8.63	-4.32
1970-1980	-103 900	12 890	-8.06	-4.03
1980-1990	-149 800	15 900	-7.42	-3.71
1990-2000	-102 600	18 260	-5.62	-2.81
2000-2010	-98 490	20 270	-4.86	-2.43
2010-2020	-108 300	23 100	-4.69	-2.34
2020-2030	-96 850	26 750	-3.62	-1.81
2030-2040	-109 600	29 220	-3.75	-1.88
2040-2050	-121 600	33 420	-3.64	-1.82
2050-2060	-118 100	38 360	-3.08	-1.54
2060-2070	-163 800	41 890	-3.91	-1.96
2070-2080	-222 600	53 500	-4.16	-2.08
2080-2090	-251 600	63 710	-3.95	-1.97
2090-2100	-309 600	67 890	-4.56	-2.28
2100-2110	-341 900	71 980	-4.75	-2.38
2110-2120	-322 200	65 750	-4.90	-2.45
2120-2130	-345 700	57 150	-6.05	-3.02
2130-2140	-371 600	58 340	-6.37	-3.18
2140-2150	-345 600	54 260	-6.37	-3.19
2150-2160	-394 500	56 920	-6.93	-3.47
2160-2170	-499 700	70 580	-7.08	-3.54
2170-2180	-627 200	105 100	-5.97	-2.98
2180-2190	-778 800	105 000	-7.42	-3.71
2190-2200	-917 500	119 800	-7.66	-3.83
2200-2210	-1 274 000	182 600	-6.98	-3.49
2210-2220	-1 452 000	156 700	-9.27	-4.63
2220-2230	-1 264 000	125 600	-10.06	-5.03
2230-2240	-1 281 000	119 100	-10.75	-5.38
2240-2250	-1 444 000	113 400	-12.73	-6.37
2250-2260	-1 508 000	123 900	-12.17	-6.08
2260-2270	-1 428 000	115 500	-12.37	-6.18

*Estimated.

Table 9. Athabasca Glacier–Summary of Changes from 1971 to 1973

Height zone (m)	dV (m^3)	Mean 71 & 73 areas (m^2)	Surface change (m)	Surface change (m/yr)
1938-1950	-9 147	5 901	-1.55	-0.78*
1950-1960	-6 780	7 618	-0.89	-0.45
1960-1970	-10 150	9 228	-1.10	-0.55
1970-1980	-19 220	12 980	-1.48	-0.74
1980-1990	-15 040	15 340	-0.98	-0.49
1990-2000	-12 000	18 460	-0.65	-0.33
2000-2010	-26 280	20 060	-1.31	-0.66
2010-2020	-28 960	21 140	-1.37	-0.69
2020-2030	-23 790	25 860	-0.92	-0.46
2030-2040	-15 810	29 830	-0.53	-0.26
2040-2050	-5 399	31 760	-0.17	-0.09
2050-2060	+10 100	36 050	+0.28	+0.14
2060-2070	+36 600	44 100	+0.83	+0.41
2070-2080	+60 950	53 000	+1.15	+0.57
2080-2090	+78 460	62 800	+1.25	+0.62
2090-2100	+90 340	71 140	+1.27	+0.64
2100-2110	+105 200	68 780	+1.53	+0.77
2110-2120	+109 800	63 090	+1.74	+0.87
2120-2130	+49 710	60 620	+0.82	+0.41
2130-2140	+93 360	55 900	+1.67	+0.84
2140-2150	+76 180	52 900	+1.44	+0.72
2150-2160	+84 250	61 050	+1.38	+0.69
2160-2170	+117 500	71 670	+1.64	+0.82
2170-2180	+297 100	103 500	+2.87	+1.08
2180-2190	+347 000	105 800	+3.28	+1.64
2190-2200	+434 600	120 400	+3.61	+1.81
2200-2210	+671 700	187 100	+3.59	+1.80
2210-2220	+755 100	150 100	+5.03	+2.52
2220-2230	+653 900	118 700	+5.51	+2.75
2230-2240	+687 800	119 200	+5.77	+2.88
2240-2250	+713 400	117 000	+6.10	+3.05
2250-2260	+639 500	120 400	+5.31	+2.65
2260-2270	+546 900	107 500	+5.09	+2.55
2270-2280	+324 000	80 410	+4.03	+2.02
2280-2290	+33 090	44 120	+0.75	+0.37
2290-2300	-111 000	31 990	-3.47	-1.73
2300-2310	-142 400	29 730	-4.79	-2.40
2310-2320	-157 000	28 440	-5.52	-2.76
2320-2330	-144 000	28 340	-5.08	-2.54
2330-2340	-128 000	34 780	-3.68	-1.84
2340-2350	+24 490	53 240	+0.46	+0.23

*Estimated.

Table 10. Athabasca Glacier–Summary of Changes from 1973 to 1975

Height zone (m)	dV (m^3)	Mean 73 & 75 areas (m^2)	Surface change (m)	Surface change (m/yr)
1940-1950	-10 400	4 094	-2.54	-1.27*
1950-1960	-14 870	6 466	-2.30	-1.15
1960-1970	-4 241	8 836	-0.48	-0.24
1970-1980	-9 185	12 940	-0.71	-0.36
1980-1990	-22 190	14 410	-1.54	-0.77
1990-2000	-15 800	17 960	-0.88	-0.44
2000-2010	-16 200	20 000	-0.81	-0.41
2010-2020	-33 380	20 860	-1.60	-0.80
2020-2030	-40 010	25 480	-1.57	-0.78
2030-2040	-40 800	29 360	-1.39	-0.69
2040-2050	-47 960	31 760	-1.51	-0.76
2050-2060	-63 490	34 890	-1.82	-0.91
2060-2070	-88 410	43 550	-2.03	-1.01
2070-2080	-121 700	52 220	-2.33	-1.17
2080-2090	-139 700	61 800	-2.26	-1.13
2090-2100	-174 100	68 800	-2.53	-1.27
2100-2110	-124 100	65 670	-1.89	-0.94
2110-2120	-120 300	62 010	-1.94	-0.97
2120-2130	-121 400	59 210	-2.05	-1.03
2130-2140	-119 800	54 480	-2.20	-1.10
2140-2150	-141 400	55 880	-2.53	-1.26
2150-2160	-186 900	60 300	-3.10	-1.55
2160-2170	-233 100	71 700	-3.26	-1.63
2170-2180	-253 200	92 060	-2.75	-1.38
2180-2190	-231 600	100 700	-2.30	-1.15
2190-2200	-233 500	1 156 000	-2.02	-1.01
2200-2210	-224 900	164 200	-1.37	-0.68
2210-2220	-144 500	152 100	-0.95	-0.48
2220-2230	-65 560	117 100	-0.56	-0.28
2230-2240	-32 390	111 700	-0.29	-0.14
2240-2250	-35 590	111 200	-0.32	-0.16
2250-2260	-6 783	113 000	-0.06	-0.03
2260-2270	+2 240	112 000	+0.02	+0.01
2270-2280	-80 390	100 500	-0.80	-0.40
2280-2290	-185 800	58 800	-3.16	-1.58
2290-2300	-276 200	36 830	-7.50	-3.75
2300-2310	-354 200	31 010	-11.42	-5.71
2310-2320	-405 300	28 320	-14.31	-7.15
2320-2330	-417 300	29 790	-14.01	-7.00
2330-2340	-408 400	29 460	-13.86	-6.93
2340-2350	-407 400	43 760	-9.31	-4.65
2350-2360	-479 000	72 150	-6.64	-3.32

* Estimated.

Table 11. Athabasca Glacier–Summary of Changes from 1975 to 1977

Height zone (m)	dV (m^3)	Mean 75 & 77 areas (m^2)	Surface change (m)	Surface change (m/yr)
1945-1950	+4 885	2 272	+2.15	+1.07*
1950-1960	+29 290	4 865	+6.02	+3.01
1960-1970	+40 940	7 458	+5.49	+2.75
1970-1980	+45 950	12 320	+2.73	+1.86
1980-1990	+52 650	14 230	+3.70	+1.85
1990-2000	+49 810	17 790	+2.80	+1.40
2000-2010	+52 810	20 080	+2.63	+1.32
2010-2020	+61 470	21 050	+2.92	+1.46
2020-2030	+63 180	25 580	+2.47	+1.24
2030-2040	+54 790	30 440	+1.80	+0.90
2040-2050	+51 420	31 740	+1.62	+0.81
2050-2060	+56 280	35 620	+1.58	+0.79
2060-2070	+51 460	43 980	+1.17	+0.58
2070-2080	+58 850	51 170	+1.15	+0.58
2080-2090	+73 280	60 560	+1.21	+0.61
2090-2100	+74 400	67 030	+1.11	+0.56
2100-2110	+53 250	65 740	+0.81	+0.40
2110-2120	+21 920	60 880	+0.36	+0.18
2120-2130	-4 715	58 940	-0.08	-0.04
2130-2140	-33 580	55 050	-0.61	-0.31
2140-2150	-40 570	56 350	-0.72	-0.36
2150-2160	-4 740	59 260	-0.08	-0.04
2160-2170	+63 540	69 070	+0.92	+0.46
2170-2180	+89 640	92 410	+0.97	+0.48
2180-2190	+8 460	105 700	+0.08	+0.04
2190-2200	-46 680	116 700	-0.40	-0.20
2200-2210	-25 380	158 600	-0.16	-0.08
2210-2220	-131 600	158 500	-0.83	-0.41
2220-2230	-271 000	115 800	-2.34	-1.17
2230-2240	-309 100	112 800	-2.74	-1.37
2240-2250	-386 000	110 600	-3.49	-1.74
2250-2260	-471 100	109 300	-4.31	-2.16
2260-2270	-656 400	118 700	-5.53	-2.77
2270-2280	-689 300	98 900	-6.97	-3.48
2280-2290	-586 800	57 640	-10.18	-5.09
2290-2300	-515 700	37 560	-13.73	-6.86
2300-2310	-483 700	31 700	-15.26	-7.63
2310-2320	-467 300	28 790	-16.23	-8.11
2320-2330	-437 900	29 390	-14.90	-7.45
2330-2340	-448 500	30 040	-14.93	-7.46
2340-2350	-512 600	41 340	-12.40	-6.20
2350-2360	-482 100	60 720	-7.94	-3.97

*Estimated.

Table 12. Athabasca Glacier–Summary of Volumetric Changes in the Period 1959-1977

Period	Total volumetric change (m^3)	Number of years	Vol. change/yr (m^3)	Surface change/yr (m)
1959-62	-1 781 000	3	-593 600	-0.23
1962-65	-3 107 000	3	-1 036 000	-0.45
1965-67	+3 139 000	2	+1 569 000	+0.69
1967-69	+666 700	2	+333 400	+0.15
1969-71	-16 810 000	2	-8 405 000	-3.87
1971-73	+6 186 000	2	+3 093 000	+1.25
1973-75	-6 130 000	2	-3 065 000	-1.22
1975-77	+1 058 000	2	+529 000	+0.21

Table 13. Saskatchewan Glacier–Summary of Changes from 1965 to 1967

Height zone (ft)	dV (ft³)	Mean 65 & 67 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
5850-5860	-520 800	52 080	-10.00	-5.00*
5860-5900	-5 764 000	272 000	-21.19	-10.60
5900-5940	-8 046 000	332 200	-24.22	-12.11
5940-5980	-10 150 000	381 900	-26.58	-13.29
5980-6020	-12 170 000	468 800	-25.96	-12.98
6020-6060	-11 110 000	596 200	-18.64	-9.32
6060-6100	-10 160 000	585 700	-17.34	-8.67
6100-6140	-10 720 000	656 300	-16.33	-8.17
6140-6180	-16 460 000	830 900	-19.81	-9.90
6180-6220	-23 960 000	1 049 000	-22.84	-11.42
6220-6260	-21 940 000	1 029 000	-21.32	-10.66
6260-6300	-17 880 000	1 062 000	-16.74	-8.37
6300-6340	-20 200 000	1 174 000	-17.21	-8.60
6340-6380	-29 670 000	1 340 000	-22.14	-11.07
6380-6420	-39 520 000	1 447 000	-27.31	-13.65
6420-6460	-38 990 000	1 522 000	-25.62	-12.81
6460-6500	-34 500 000	1 604 000	-21.51	-10.76
6500-6540	-40 320 000	1 635 000	-24.66	-12.33
6540-6580	-47 620 000	1 563 000	-30.47	-15.23
6580-6620	-48 950 000	1 944 000	-25.18	-12.59
6620-6660	-56 900 000	2 746 000	-20.72	-10.36
6660-6700	-56 810 000	2 395 000	-23.72	-11.86
6700-6740	-49 320 000	2 009 000	-24.55	-12.28
6740-6780	-51 540 000	1 833 000	-28.12	-14.06
6780-6820	-50 270 000	1 984 000	-25.34	-12.67
6820-6860	-44 940 000	2 070 000	-21.71	-10.86
6860-6900	-46 970 000	2 492 000	-18.85	-9.42
6900-6940	-53 040 000	2 094 000	-25.33	-12.66
6940-6980	-49 920 000	1 883 000	-26.51	-13.26
6980-7020	-45 550 000	1 917 000	-23.76	-11.88
7020-7060	-45 880 000	2 492 000	-18.41	-9.21
7060-7100	-47 520 000	2 563 000	-18.54	-9.27
7100-7140	-45 600 000	2 607 000	-17.49	-8.75
7140-7180	-47 840 000	2 379 000	-20.11	-10.05
7180-7220	-62 760 000	3 087 000	-20.33	-10.17
7220-7260	-61 940 000	3 663 000	-16.91	-8.45
7260-7300	-55 800 000	3 705 000	-15.06	-7.53
7300-7340	-55 290 000	2 638 000	-20.96	-10.48
7340-7380	-46 780 000	2 260 000	-20.70	-10.35
7380-7420	-45 030 000	2 281 000	-19.74	-9.87
7420-7460	-51 840 000	2 017 000	-25.70	-12.85
7460-7500	-49 920 000	1 906 000	-26.19	-13.09

*Estimated.

Table 14. Saskatchewan Glacier–Summary of Changes from 1967 to 1969

Height zone (ft)	dV (ft³)	Mean 67 & 69 areas (ft²)	Surface change (ft)	Surface change (ft/yr)
5850-5860	+289 000	28 900	+10.00	+5.00*
5860-5900	+3 881 000	257 200	+15.09	+7.54
5900-5940	+6 025 000	319 800	+18.84	+9.42
5940-5980	+7 693 000	390 500	+19.70	+9.85
5980-6020	+8 244 000	481 000	+17.14	+8.57
6020-6060	+6 241 000	577 300	+10.81	+5.40
6060-6100	+5 593 000	565 500	+9.89	+4.95
6100-6140	+5 140 000	674 600	+7.62	+3.81
6140-6180	+4 598 000	942 200	+4.88	+2.44
6180-6220	+7 129 000	994 300	+7.17	+3.59
6220-6260	+8 062 000	971 300	+8.30	+4.15
6260-6300	+2 248 000	1 153 000	+1.95	+0.97
6300-6340	-1 461 000	1 228 000	-1.19	-0.59
6340-6380	+4 617 000	1 374 000	+3.36	+1.68
6380-6420	+9 305 000	1 533 000	+6.07	+3.03
6420-6460	+4 521 000	1 559 000	+2.90	+1.45
6460-6500	+1 861 000	1 538 000	+1.21	+0.60
6500-6540	+5 974 000	1 752 000	+3.41	+1.71
6540-6580	+4 802 000	1 703 000	+2.82	+1.41
6580-6620	+3 813 000	1 916 000	+1.99	+0.99
6620-6660	+8 816 000	2 853 000	+3.09	+1.54
6660-6700	+2 685 000	2 397 000	+1.12	+0.56
6700-6740	-1 747 000	1 899 000	-0.92	-0.46
6740-6780	+6 376 000	1 786 000	+3.57	+1.78
6780-6820	+8 446 000	1 946 000	+4.34	+2.17
6820-6860	+5 268 000	2 058 000	+2.56	+1.28
6860-6900	+12 650 000	2 373 000	+5.33	+2.66
6900-6940	+19 490 000	2 207 000	+8.83	+4.41
6940-6980	+12 710 000	1 872 000	+6.79	+3.39
6980-7020	+11 520 000	1 852 000	+6.22	+3.11
7020-7060	+17 160 000	2 437 000	+7.04	+3.52
7060-7100	+17 790 000	2 659 000	+6.69	+3.35
7100-7140	+18 930 000	2 461 000	+7.69	+3.84
7140-7180	+27 150 000	2 409 000	+11.27	+5.64
7180-7220	+32 010 000	3 317 000	+9.65	+4.82
7220-7260	+26 750 000	3 515 000	+7.61	+3.80
7260-7300	+40 230 000	3 336 000	+12.06	+6.03
7300-7340	+36 080 000	3 102 000	+11.63	+5.81
7340-7380	+10 030 000	2 195 000	+4.57	+2.28
7380-7420	+10 400 000	2 291 000	+4.54	+2.27
7420-7460	+13 750 000	2 064 000	+6.66	+3.33
7460-7500	+9 690 000	1 878 000	+5.16	+2.58

*Estimated.

Table 15. Saskatchewan Glacier–Summary of Changes from 1969 to 1971

Height zone (m)	dV (m³)	Mean 69 & 71 areas (m²)	Surface change (m)	Surface change (m/yr)
1785-1790	-9 415	4 955	-1.90	-0.95*
1790-1800	-40 950	18 530	-2.21	-1.10
1800-1810	-63 280	24 340	-2.60	-1.30
1810-1820	-79 230	27 040	-2.93	-1.46
1820-1830	-119 600	34 360	-3.48	-1.74
1830-1840	-182 800	44 380	-4.12	-2.06
1840-1850	-217 600	50 730	-4.29	-2.15
1850-1860	-221 700	43 300	-5.12	-2.56
1860-1870	-249 400	53 860	-4.63	-2.31
1870-1880	-301 900	65 490	-4.61	-2.30
1880-1890	-339 900	74 860	-4.54	-2.27
1890-1900	-345 500	75 610	-4.57	-2.28
1900-1910	-367 500	80 250	-4.58	-2.29
1910-1920	-420 300	88 860	-4.73	-2.37
1920-1930	-501 100	98 450	-5.09	-2.54
1930-1940	-596 600	104 300	-5.72	-2.86
1940-1950	-675 800	107 100	-6.31	-3.16
1950-1960	-737 600	114 000	-6.47	-3.23
1960-1970	-773 000	122 700	-6.30	-3.15
1970-1980	-781 200	126 200	-6.19	-3.10
1980-1990	-804 500	126 100	-6.38	-3.19
1990-2000	-878 100	138 500	-6.34	-3.17
2000-2010	-1 081 000	152 200	-7.10	-3.55
2010-2020	-1 481 000	179 500	-8.25	-4.13
2020-2030	-1 628 000	203 700	-7.99	-3.99
2030-2040	-1 379 000	170 900	-8.07	-4.03
2040-2050	-1 143 000	143 600	-7.96	-3.98
2050-2060	-1 021 000	128 900	-7.92	-3.96
2060-2070	-1 017 000	129 900	-7.83	-3.92
2070-2080	-1 029 000	138 900	-7.41	-3.70
2080-2090	-1 079 000	158 900	-6.79	-3.39
2090-2100	-1 168 000	113 300	-6.74	-3.37
2100-2110	-1 184 000	166 300	-7.12	-3.56
2110-2120	-1 114 000	156 400	-7.12	-3.56
2120-2130	-1 042 000	143 700	-7.25	-3.62
2130-2140	-1 091 000	147 400	-7.40	-3.70
2140-2150	-1 207 000	170 200	-7.09	-3.54
2150-2160	-1 241 000	186 600	-6.65	-3.33
2160-2170	-1 402 000	218 400	-6.42	-3.21
2170-2180	-1 411 000	191 000	-7.39	-3.69
2180-2190	-1 304 000	179 900	-7.25	-3.62
2190-2200	-1 636 000	248 200	-6.59	-3.30
2200-2210	-1 987 000	287 500	-6.91	-3.46
2210-2220	-1 945 000	258 600	-7.52	-3.76
2220-2230	-1 721 000	244 400	-7.04	-3.52
2230-2240	-1 444 000	202 300	-7.14	-3.57
2240-2250	-1 288 000	181 200	-7.11	-3.56
2250-2260	-1 203 000	168 700	-7.13	-3.56
2260-2270	-1 161 000	155 400	-7.47	-3.73

*Estimated.

Table 16. Saskatchewan Glacier–Summary of Changes from 1971 to 1973

Height zone (m)	dV (m³)	Mean 71 & 73 areas (m²)	Surface change (m)	Surface change (m/yr)
1785-1790	-9 701	4 732	-2.05	-1.02*
1790-1800	-41 650	18 510	-2.25	-1.12
1800-1810	-47 680	24 300	-1.96	-0.98
1810-1820	-83 440	30 450	-2.74	-1.37
1820-1830	-142 300	37 450	-3.80	-1.90
1830-1840	-183 400	47 030	-3.90	-1.95
1840-1850	-179 100	47 380	-3.78	-1.89
1850-1860	-185 800	45 310	-4.10	-2.05
1860-1870	-252 400	58 440	-4.32	-2.16
1870-1880	-311 800	70 060	-4.45	-2.22
1880-1890	-346 600	75 020	-4.62	-2.31
1890-1900	-377 100	77 600	-4.86	-2.43
1900-1910	-455 200	87 710	-5.19	-2.59
1910-1920	-544 300	94 170	-5.78	-2.89
1920-1930	-574 700	101 700	-5.65	-2.83
1930-1940	-540 300	104 500	-5.17	-2.59
1940-1950	-489 100	106 600	-4.59	-2.30
1950-1960	-519 200	118 800	-4.37	-2.18
1960-1970	-567 700	121 300	-4.68	-2.34
1970-1980	-578 600	125 500	-4.61	-2.30
1980-1990	-705 100	136 900	-5.04	-2.52
1990-2000	-879 300	150 600	-5.84	-2.92
2000-2010	-1 058 000	173 400	-6.10	-3.05
2010-2020	-1 101 000	192 400	-5.72	-2.86
2020-2030	-908 700	172 800	-5.26	-2.63
2030-2040	-685 100	146 700	-4.67	-2.33
2040-2050	-567 600	127 000	-4.47	-2.24
2050-2060	-535 000	126 800	-4.22	-2.11
2060-2070	-594 200	133 200	-4.46	-2.23
2070-2080	-719 800	145 700	-4.94	-2.47
2080-2090	-845 100	167 300	-5.05	-2.53
2090-2100	-860 100	175 500	-4.90	-2.45
2100-2110	-809 400	167 600	-4.83	-2.41
2110-2120	-721 800	151 000	-4.78	-2.39
2120-2130	-702 500	155 100	-4.53	-2.27
2130-2140	-842 700	188 100	-4.48	-2.24
2140-2150	-1 026 000	210 700	-4.87	-2.43
2150-2160	-1 358 000	239 400	-5.67	-2.83
2160-2170	-1 504 000	302 700	-4.97	-2.48
2170-2180	-1 299 000	251 800	-5.16	-2.58
2180-2190	-1 148 000	258 100	-4.45	-2.23
2190-2200	-1 054 000	268 100	-3.93	-1.97
2200-2210	-1 011 000	284 700	-3.55	-1.77
2210-2220	-988 100	245 800	-4.02	-2.01
2220-2230	-830 700	211 900	-3.92	-1.96
2230-2240	-586 900	176 300	-3.33	-1.67
2240-2250	-449 900	172 400	-2.61	-1.31
2250-2260	-364 200	157 000	-2.32	-1.16
2260-2270	-265 500	152 600	-1.74	-0.87

*Estimated.

Table 17. Saskatchewan Glacier–Summary of Changes from 1973 to 1975

Height zone (m)	dV (m³)	Mean 73 & 75 areas (m²)	Surface change (m)	Surface change (m/yr)
1795-1810	-165 800	24 670	-6.72	-3.36*
1810-1820	-333 900	28 420	-11.75	-5.88
1820-1830	-360 900	33 410	-10.80	-5.40
1830-1840	-369 800	38 890	-9.51	-4.76
1840-1850	-390 900	43 190	-9.05	-4.52
1850-1860	-397 000	43 530	-9.12	-4.56
1860-1870	-396 300	47 810	-8.29	-4.14
1870-1880	-532 400	60 920	-8.74	-4.37
1880-1890	-553 000	64 150	-8.62	-4.31
1890-1900	-542 400	65 980	-8.22	-4.11
1900-1910	-464 400	74 780	-8.04	-4.02
1910-1920	-586 200	83 510	-7.02	-3.51
1920-1930	-549 600	82 770	-6.64	-3.32
1930-1940	-521 800	84 700	-6.16	-3.08
1940-1950	-534 600	94 120	-5.68	-2.84
1950-1960	-568 700	106 300	-5.35	-2.68
1960-1970	-549 800	102 000	-5.39	-2.69
1970-1980	-549 600	103 700	-5.30	-2.65
1980-1990	-628 300	120 600	-5.21	-2.60
1990-2000	-462 500	119 500	-3.87	-1.93
2000-2010	-264 100	162 000	-1.63	-0.81
2010-2020	-197 400	167 300	-1.18	-0.59
2020-2030	-104 200	146 800	-0.71	-0.35
2030-2040	-66 450	130 300	-0.51	-0.25
2040-2050	-90 220	120 300	-0.75	-0.37
2050-2060	-145 600	123 400	-1.18	-0.59
2060-2070	-172 500	132 700	-1.30	-0.65
2070-2080	-230 300	151 500	-1.52	-0.76
2080-2090	-276 200	164 400	-1.68	-0.84
2090-2100	-282 500	166 200	-1.70	-0.85
2100-2110	-236 300	151 500	-1.56	-0.78
2110-2120	-250 400	145 600	-1.72	-0.86
2120-2130	-308 800	154 400	-2.00	-1.00
2130-2140	-337 400	197 300	-1.71	-0.86
2140-2150	-300 100	208 400	-1.44	-0.72
2150-2160	-410 600	279 300	-1.47	-0.73
2160-2170	-524 500	283 500	-1.85	-0.93
2170-2180	-493 200	240 600	-2.05	-1.02
2180-2190	-631 500	250 600	-2.52	-1.26
2190-2200	-821 500	265 000	-3.10	-1.55
2200-2210	-715 400	259 200	-2.76	-1.38
2210-2220	+662 600	243 600	+2.72	+1.36
2220-2230	+1 786 500	197 400	+9.05	+4.52
2230-2240	+1 616 300	172 500	+9.37	+4.68
2240-2250	+1 502 600	164 400	+9.14	+4.57

*Estimated.

Table 18. Saskatchewan Glacier–Summary of Changes from 1975 to 1977

Height zone (m)	dV (m³)	Mean 75 & 77 areas (m²)	Surface change (m)	Surface change (m/yr)
1795-1800	-122 400	34 870	-3.51	-1.76*
1800-1810	-437 900	32 580	-13.44	-6.72
1810-1820	-464 900	33 590	-13.84	-6.92
1820-1830	-458 900	38 430	-11.94	-5.97
1830-1840	-424 500	38 100	-11.14	-5.57
1840-1850	-414 400	42 630	-9.72	-4.86
1850-1860	-400 700	47 420	-8.45	-4.23
1860-1870	-378 100	58 710	-6.44	-3.22
1870-1880	-337 200	53 870	-6.26	-3.13
1880-1890	-327 500	58 060	-5.64	-2.82
1890-1900	-320 900	68 710	-4.67	-2.33
1900-1910	-290 900	65 070	-4.47	-2.24
1910-1920	-245 000	66 040	-3.71	-1.86
1920-1930	-197 800	64 430	-3.07	-1.54
1930-1940	-185 300	68 620	-2.70	-1.35
1940-1950	-218 100	88 280	-2.47	-1.24
1950-1960	-257 100	90 530	-2.84	-1.42
1960-1970	-256 600	82 790	-3.10	-1.55
1970-1980	-244 700	81 830	-2.99	-1.50
1980-1990	-181 800	88 680	-2.05	-1.02
1990-2000	-73 830	90 040	-0.82	-0.41
2000-2010	-59 500	141 600	-0.42	-0.21
2010-2020	-64 990	147 700	-0.44	-0.22
2020-2030	-117 900	140 300	-0.84	-0.42
2030-2040	-166 000	120 300	-1.38	-0.69
2040-2050	-176 400	118 400	-1.49	-0.74
2050-2060	-157 200	115 600	-1.36	-0.68
2060-2070	-118 100	125 600	-0.94	-0.47
2070-2080	-90 640	146 700	-0.62	-0.31
2080-2090	-4 476	149 200	-0.03	-0.01
2090-2100	+72 500	157 600	+0.46	+0.23
2100-2110	+17 200	141 800	+0.12	+0.06
2110-2120	-2 810	140 500	-0.02	-0.01
2120-2130	+48 810	147 900	+0.33	+0.16
2130-2140	+145 800	186 900	+0.78	+0.39
2140-2150	+253 500	195 000	+1.30	+0.65
2150-2160	+708 400	251 200	+2.82	+1.41
2160-2170	+1 065 000	280 900	+3.79	+1.89
2170-2180	+954 000	239 700	+3.98	+1.99
2180-2190	+821 700	258 400	+3.18	+1.59
2190-2200	+744 100	266 700	+2.79	+1.39
2200-2210	+307 200	279 300	+1.10	+0.55
2210-2220	+235 700	250 700	-0.94	-0.47
2220-2230	-367 600	202 000	-1.82	-0.91
2230-2240	-425 400	178 000	-2.39	-1.19
2240-2250	-478 400	166 700	-2.87	-1.43

*Estimated.

Table 19. Saskatchewan Glacier–Summary of Volumetric Changes in the Period 1963-1977

Period	Total volumetric change (m³)	Number of years	Vol. change/yr (m³)	Surface change/yr (m)
1963-65	-52 030 000	2	-26 010 000	-3.03
1965-67	-44 460 000	2	-22 230 000	-3.31
1967-69	+13 560 000	2	+6 297 000	+0.93
1969-71	-44 110 000	2	-22 060 000	-3.39
1971-73	-30 850 000	2	-15 430 000	-2.26
1973-75	-16 550 000	2	-8 275 000	-1.36
1975-77	-3 566 000	2	-1 783 000	-0.31

References

Brandenberger, A.J. and C. Bull. 1966. "Glacier Surveying and Mapping Program of the Ohio State University," *Can. J. Earth Sci.*, Vol. 3, pp. 849-861.

Breed, C.B. and G.L. Hosmer. 1947. *The Principles and Practice of Surveying.* Vol. 2, Higher Surveying. New York: John Wiley & Sons, Inc.

Finsterwalder, R. 1954. "Photogrammetry and Glacier Research with Special Reference to Glacier Retreat in the Eastern Alps," *J. Glaciol.*, Vol. 2, No. 15, April 1954, pp. 306-315.

Haumann, Dieter. 1960. "Photogrammetric and Glaciological Studies of Salmon Glacier," *Arctic*, Vol. 13, No. 2, pp. 74-110.

Reid, I.A. 1961. Triangulation Survey of the Athabasca Glacier, July 1959. Water Resources Branch, Department of Northern Affairs and National Resources, Ottawa.

Reid, I.A. 1972. "Glacier Surveys by the Water Survey of Canada," *Proceedings* of the Banff Symposia "The Role of Snow and Ice in Hydrology," September 1972, Unesco-WMO-IAHS, Vol. 2.

Reid, I.A. and W.S.B. Paterson. 1974. "A Simple Method of Measuring the Average Amount of Water Produced Annually by Melting of Ice on a Glacier," *Proceedings* of the Symposium on "Hydrology of Glaciers," September 1969, Cambridge, England.

United States Department of the Interior. June 1951. *Tentative Instructions for Computation of Geodetic Positions.* Geological Survey, Topographical Division, Research and Technical Control Branch.

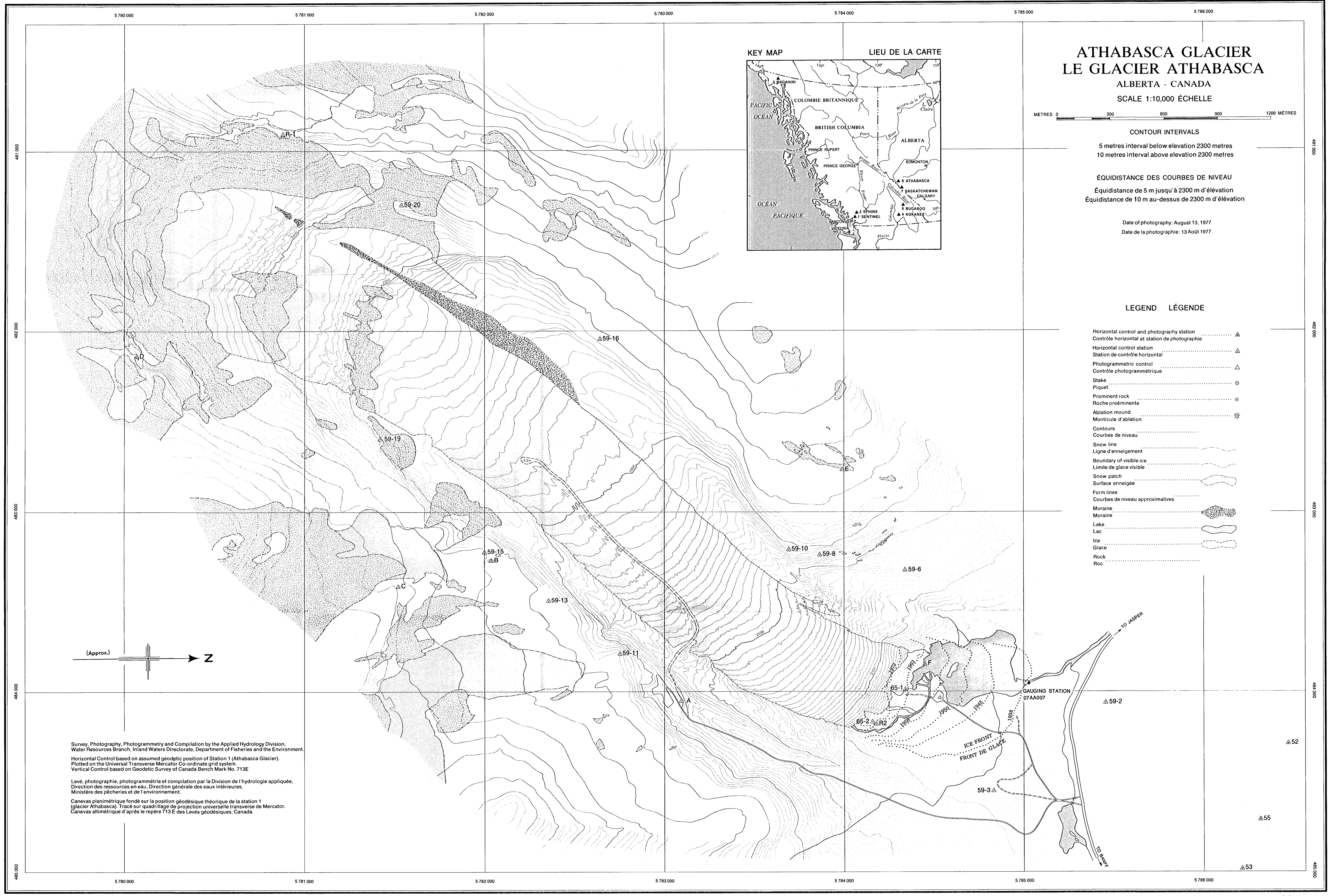
Zeller, M. 1952. *Text Book of Photogrammetry.* London: H.K. Lewis & Co. Ltd.

Fisheries and Environment Canada

Inland Waters Directorate

Pêches et Environnement Canada

Direction générale des eaux intérieures



PRODUCED BY THE INLAND WATERS DIRECTORATE.
PRINTED BY THE SURVEYS AND MAPPING BRANCH,
DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA, 1978.

COPIES MAY BE OBTAINED FROM THE INLAND WATERS DIRECTORATE,
DEPARTMENT OF FISHERIES AND THE ENVIRONMENT,
OTTAWA, ONTARIO, CANADA. K1A 0E7

CARTE PRODUITE PAR LA DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES, ET IMPRIMÉE PAR LA DIRECTION DES LEVES ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE DES MINES ET DES RESSOURCES, OTTAWA, 1978.

DES EXEMPLAIRES DE CETTE CARTE PEUVENT ÊTRE OBTENUS À LA DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES, MINISTÈRE DES PÊCHERIES ET DE L'ENVIRONNEMENT, OTTAWA, ONTARIO, CANADA. K1A 0E7

Fisheries and Environment Canada

Inland Waters Directorate

Pêches et Environnement Canada

Direction générale des eaux intérieures

SASKATCHEWAN GLACIER - LE GLACIER SASKATCHEWAN

ALBERTA - CANADA

SCALE 1:10,000 ÉCHELLE

METRES 0 300 600 900 1200 MÈTRES

CONTOUR INTERVALS - ÉQUIDISTANCE DES COURBES DE NIVEAU

10 metres interval below elevation 2500 metres — Équidistance de 10 mètres au dessous de 2500 mètres d'élévation

50 metres interval above elevation 2500 metres — Équidistance de 50 mètres au dessus de 2500 mètres d'élévation

Date of photography August 14, 1977. Date de la photographie 14 Août 1977

Survey, Photography, Photogrammetry and Compilation by the Applied Hydrology Division, Water Resources Branch, Inland Waters Directorate, Department of Fisheries and the Environment.

Horizontal Control based on assumed geodetic position of Station 1 (Athabasca Glacier). Plotted on the Universal Transverse Mercator Co-ordinate grid system. Vertical Control based on Geodetic Survey of Canada Bench Mark No. 713E

Levé, photographie, photogrammétrie et compilation par la Division de l'hydrologie appliquée, Direction des ressources en eau, Direction générale des eaux intérieures, Ministère des pêcheries et de l'environnement.

Canevas planimétrique fondé sur la position géodésique théorique de la station 1 (glacier Athabasca). Tracé sur quadrillage de projection universelle transverse de Mercator. Canevas altimétrique d'après le repère 713 E des Levés géodésiques, Canada.

PRODUCED BY THE INLAND WATERS DIRECTORATE.
PRINTED BY THE SURVEYS AND MAPPING BRANCH,
DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA, 1978

COPIES MAY BE OBTAINED FROM THE INLAND WATERS DIRECTORATE,
DEPARTMENT OF FISHERIES AND THE ENVIRONMENT,
OTTAWA, ONTARIO, CANADA. K1A 0E7

CARTE PRODUITE PAR LA DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES, ET IMPRIMÉE PAR LA DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE DES MINES ET DES RESSOURCES, OTTAWA, 1978.

DES EXEMPLAIRES DE CETTE CARTE PEUVENT ÊTRE OBTENUS A LA DIRECTION GÉNÉRALE DES EAUX INTÉRIEURES, MINISTÈRE DES PÊCHERIES ET DE L'ENVIRONNEMENT, OTTAWA, ONTARIO, CANADA. K1A 0E7