UNIVERSITY OF ALBERTA AT CALGARY

# THE CHINOOK AND ITS GEOGRAPHIC SIGNIFICANCE IN SOUTHERN ALBERTA

by

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ABSTRACT

The chinook is a complex meteorological phenomenon that concerns the geographer because of the varied and significant influence it has on the character and use of the landscape. To introduce the study and to outline the basic research problems involved the early references to the chinook are examined. As this study represents some of the initial information derived from the Chinook Research Project, initiated in 1963 by the Geography Department, University of Alberta, Calgary, the organisation and instrumentation of the project are considered. The theory and meteorological character of the chinook is then examined and a tentative geographic definition is proposed and discussed. Using this definition some of the varied effects of the chinook on the landscape are examined and their significance assessed. The chinook's role as a 'snow-eater' is examined in an attempt to determine the absolute and relative influence of the phenomenon on snow-melt, evaporation and hence the hydrologic cycle. Study of the chinook's influence on vegetation is confined to analysis of the causal relationship between the chinook and red belt, or winter killing of trees, and fires. To assess the chinook's importance in agriculture a farm questionnaire was prepared. The data derived is used with that from other sources in an analysis of the significance of the chinook on ranching in Alberta. In conclusion suggestions are made regarding future research on this subject.

# ACKNOWLEDGMENTS

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## CHAPTER I

## EARLY REFERENCE TO THE CHINOOK

The following discussion of early references to the chinook serves to introduce this study of a complex meteorological phenomenon and its geographic significance.

Although the chinook wind is still poorly understood it has become legendary[1] and its general character and significance were known to the Indians and quickly appreciated by all who pioneered the western prairies and Rocky Mountain foothills.

Whilst Hendry and Fidler explored in the above area it was David Thompson who first inferred that the area was subject to some special climatic phenomenon. In the fall of 1787 he records:

> At length the Rocky Mountains came in sight like shining white clouds in the horizon....Our guide told us that as we approached these mountains of snow we should find the weather became milder, this we could not believe, but it was so, and the month of November was full as mild as the month of October at the trading house we left eastward.[2] For the cold of these countries decreases as much by going westward as by going to the south.[3]

It is in the journal of Alexander Mackenzie that we find the first real account of the chinook. On reaching the Athabasca River in January 1793 he recalled:

> On the 5th in the morning the weather was calm, clear and very cold; the wind blew from the South-West and in the course of the afternoon it began to thaw.[4]

He continues:

> These warm winds come off the Pacific Ocean, which cannot, in a direct line be very far from us, the distance being so short, that though they pass over the mountains covered with snow, there is no time for them to cool.[5]

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1. Gard, R.E. 1945, p.360.
2. This refers to Buckingham House on the North Saskatchewan River.
3. Thompson, D. 1962, p.47.
4. Mackenzie, A.(Sir). 1801, pp.138-9.
5. Ibid.,p.139.

More precise references to meteorological conditions in southern Alberta are found in the journals of the Palliser Expedition, 1857-1860. Hector noted:

> ....that the average temperature during the winter months at the base of the Rocky Mountains is higher by 15° than that of the western portions of Canada and that the mean depth of snow at the same place is much less than in the prairie country.[1]

Whilst near Fort Assineboine he noted:

> In the morning the thermometer was 14°, but during the day it rose very rapidly, with a great storm of wind from the south-west. At 7 p.m. the thermometer was 40°. At about 10 p.m. the storm ceased, the sky cleared and the thermometer at once fell to 1° and the barometer rose to 27.47 inches.[2]

Whilst Hector, like Mackenzie, incorrectly concluded that chinook conditions merely reflected proximity to the Pacific, he had an amazing understanding of the Alberta climate. In a separate paper, dated 1861, he notes:

> Along the eastern base of the Rocky Mountains these changes are even more distinctly marked than in the longitude of Edmonton, and the effect they have in reducing the amount of snow is very remarkable, so that there is a narrow tract close to the mountains where there is never more than a few inches of snow on the ground, and the rivers, when rapid, remain open during the winter.[3]

Hector also commented upon the botanical repercussions of temperature change:

> So long as the vegetation remains dormant during the winter season, the sudden chnages which have been described, however great can have little influence on plant life, but when the mean temperature for the 24 hours rises above the freezing point and the powerful sun of each day, with the abundant moisture derived from the melting of snows, stimulate the ascent of sap and the germination of seeds, these sudden alternations must have a very baneful effect, and exclude from the flora of the country many plants that it would be quite fitted to sustain.... as late as the middle of May serious damage is frequently done to the vegetation by sudden variations in temperature.[4]

With expansion into the Canadian west descriptions and explanations of the chinook become more numerous. Dawson, in 1879, studied the chinook phenomenon in great detail and was forced to question the validity of

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1. Hector, J.(Sir). Journals of the Palliser Expedition, 1863, p.15.
2. Ibid., p.123.
3. Hector, J.(Sir). 1861. (Quoted in Warkentin, J. 1964, p.165)
4. Ibid. This is considered more fully in Chapter 5.

Mackenzie's explanation thus:

> It is difficult to understand how currents of air, blowing for at least 350 miles across a country which is for the most part mountainous should retain enough warmth to temper effectually the climate of the plains to the east.[1]

Dawson realised that the chinook was similar to the European foehn and drew on Hann's work on the latter to suggest an adiabatic theory that forms the basis of current theory and may be summarised thus:[2]

Warm moist air flowing eastward from the Pacific Ocean is forced to rise, condense and cool at the saturated adiabatic lapse rate of approximately 2.7°F. per 1,000 feet. Because moisture has been released when the air descends to the plains it is drier and gains heat at the dry adiabatic lapse rate of 5.5°F. per 1,000 feet. Thus, height for height, it is warmer and drier on the leeward than on the windward side of the mountains.

The 1880's were particularly fruitful years of chinook research. Hazen[3] writing in 1882 refers to eleven other papers published since 1883. There are probably three reasons for this sudden interest and prolific publication: 1. The 1880's saw the influx of numerous pioneers to Alberta and the western United States, many of whom relied upon agriculture and hence the weather for their livelihood.

2. The winter of 1886-7 was particularly severe, with a marked absence of chinooks. The loss of many cattle belonging to the new settlers emphasised the importance of the chinook.

3. The establishment of a fully equipped meteorological station at Calgary in 1883, one at Banff shortly after and the expansion of the United States meteorological network provided data for quantitative climatic analysis.

Aldous reporting, in 1881, on survey work in the Bow Valley noted:

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1. Dawson, G.M. 1881, p.77.
2. Willett, H.C. & Saunders, F. 1959, pp.305-8.
3. Hazen, H.A. 1888, pp.19-20.

On the other hand the short grass of the plains is unaffected, the snow is melted and blown off into the ravines and hollows by the prevalent south-easterly winds called chinooks.[1]

Begg in 1882 reported:

Chinook winds from the Pacific Coast rush through the Kootanie, Crow's Nest, Bow River and numerous other passes, along the headwaters of hundreds of crystal streams and around the ends of longitudinal ridges, which divide the mountain ranges, forming channels or conductors for those warm winds to increase the temperature and dissolve the snow as if by magic.[2]

The first local newspapers of the western prairies and foothills, published in the 1880's, refer frequently to the chinook and its influence on pioneer life. The Lethbridge News in March 1887 stated:

The first real live Chinook of this season struck here on Sunday morning last and continued until Monday evening and in that time, the snow, which was from 12-18 inches deep all over the prairies, disappeared as if by magic.... Cattle could be seen coming out from the bottoms from all directions and making for the open prairie where they luxuriated in the first square meal for weeks.[3]

The work of Dawson[4] and later Bowerman[5] heralded the trend toward more scientific study of the chinook. McCaul, writing in 1888, compared the early meteorological records for Calgary with his own for Fort Macleod and noted:

Indeed it would seem from the table that the common idea among stockmen and others, that the effects of the Chinook winds are not nearly so pronounced at Calgary as at Macleod and in the whole broad valley of the Belly River and its tributaries, were true; for while at Macleod the prevalence of a south-west wind, almost invariably mild and warm, is most noticeable at Calgary it would seem that the north-west wind is quite as frequent as that from the south-west and there do not appear to be the same sudden and pronounced rises in temperature that we experience in this more southerly district.[6]

Hazen, writing in 1888, compared temperature changes in Montana with synoptic conditions and thus sought to challenge the accepted adiabatic theory

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1. Aldous,M. 1881, p.38.
2. Begg, A. 1889, pp.354-5.
3. Lethbridge News, 1887, March 2.
4. Dawson, G.M. 1881, pp.B76-8.
5. Bowerman, A. 1886.
6. McCaul, C.C. 1888, pp.362-3.

of chinooks. He said:

> This explanation for the Chinook, however, will not hold for the reason that it is felt in the plains where there are no mountain ranges near.[1]

With regard to the area influenced by chinooks he said:

> Its lower limit, roughly speaking is at the forty-fourth parallel and may extend eastward to Dakota.[2]

Hazen considered chinooks resulted from the location of a low pressure centre in Alberta which induced a westerly circulation of air from the warm arid plains to the south and west, at the same time excluding colder air from the north. Had he combined his synoptic criteria with the adiabatic theory he would have been nearer the truth.

Harrington,[3] in a series of three papers in 1886 and 1887 presented the most enlightened research of any at the time. Indeed his comprehensive and accurate coverage of the subject has hardly been equalled since. By a consideration of wave theory and adiabatic processes he substantiated the foehn theory as propounded by Hann, and emphasised its applicability to the chinook phenomenon. The problem of explaining the descent of light warm air on the leeside of the mountains was discussed for the first time. He explained as have more recent writers, that the warm air is induced to descend by the low pressure occurring to the lee of the mountains as a result of wave action caused by disruption of the easterly airflow. Like Hazen, he investigated the relationship between chinooks and certain synoptic conditions. Using data from Montana he concluded that:

> When a cyclone or anticyclone passes on such a course that the air is forced over the mountains from the western to the eastern slope, chinooks may occur.[4]

Harrington also developed a quantitative method for areally delimiting a chinook. He says of chinook air:

1. Hazen, H.A. 1888, p.20.
2. Ibid., p.19.
3. Harrington, M.W. 1886, 1887.
4. Ibid.,1887,p.474.

As it descends and takes the place of the air drawn away by the cyclone a decrease of absolute humidity will result. It is, then, by noting the distance to which the decrease of absolute humidity extends that we can trace the eastern limits of the Chinooks.[1]

Having studied genetic factors and quantitatively analysed the phenomenon itself Harrington was able to appreciate and study the central problem of much future chinook research. In his second paper he asked the question: "What are the Chinooks?" and continued:

> In attempting to account for anything we must clearly define what that thing is. The Chinooks are frequently spoken of in the Northwest, but they have hardly got beyond the stage of newspaper literature and a clear definition of them is lacking.[2]

A definition of the chinook to satisfy the needs of the geographer is still lacking, and the problem is again tackled in Chapter 3.

The early references to the chinook are often vague and contradictory but their analysis serves to introduce the topic and to outline some of the problems still requiring solution. Subsequent chapters deal with the scope, methods and initial findings of the author and the Chinook Research Project at the University of Alberta, Calgary.

1. Harrington, M.W. 1887, p.517.
2. Ibid., 1887, pp.467-8.

## THE CHINOOK RESEARCH PROJECT

As this thesis represents only some of the initial findings of a long term research project of considerable scope the writer feels it desirable to place his research in context by describing the project as a whole.

The research project was initiated in the fall of 1963 by Dr. Ian Ashwell of the Geography Department, University of Alberta, Calgary. The writer and numerous other assistants have helped in the subsequent expansion and day to day operation of the project.

The research is aimed at increasing knowledge of the chinook and its geographic significance as an influence on the landscape and human activity. Meteorological analysis is being confined to the reasonably accessible area between Calgary and the Continental Divide but the influence of the phenomenon throughout southern Alberta is being studied. The research invloves the determination and analysis of the meteorological and micro-meteorological characteristics of chinook conditions. Those aspects of the landscape and human activity influenced by such conditions have then to be determined and the significance of this influence evaluated. On the basis of previous work and initial data the influence of the chinook on hydrology, vegetation and agriculture is being studied.

### Organisation

To study the meteorological characteristics of the chinook, such as areal variation, duration and intensity a comprehensive network of suitably instrumented stations was a primary requisite. Before the project began the only stations in the study area continuously recording meteorological data were those at Calgary, Banff and Kananaskis. Several other stations under various government agencies are equipped to provide continuous records but unfortunately they are not operated during the winter.

Continuously recorded data is supplemented by other meteorological records. At numerous locations various agencies, governmental and private, have made daily observations or maintained partial records of factors concerning them. For example, maximum and minimum temperatures are recorded at the installations of the Calgary Power Company Limited, the Calgary Fire Halls and Glenmore Reservoir. Summer records of temperature and humidity are maintained by many Forest Ranger Stations and evaporation data for Calgary exists for the period 1896-1900.

However, for two reasons the available and forthcoming data from the above sources was considered inadequate. Firstly, no instruments were installed to measure such factors as radiation, soil temperature, snow cover and evaporation. Secondly, the limited network of stations was inadequate for analysis of chinook development, ar.al variation and progression.

Stations

To rectify this matter new stations with more comprehensive instrumentation were established. Their location was governed by five main factors:

1. The location of existing stations.
2. The wish to analyse areal differences in the chinook and its possible eastward progression from the mountains toward Calgary.
3. Accessibility, especially in winter.
4. The topographic suitability and vegetation of the site.
5. The co-operation of landowners.

Seven new stations were established and their location and that of other stations in the research area is shown in Figure 1. The stations providing data used in this research will be described briefly below but more complete

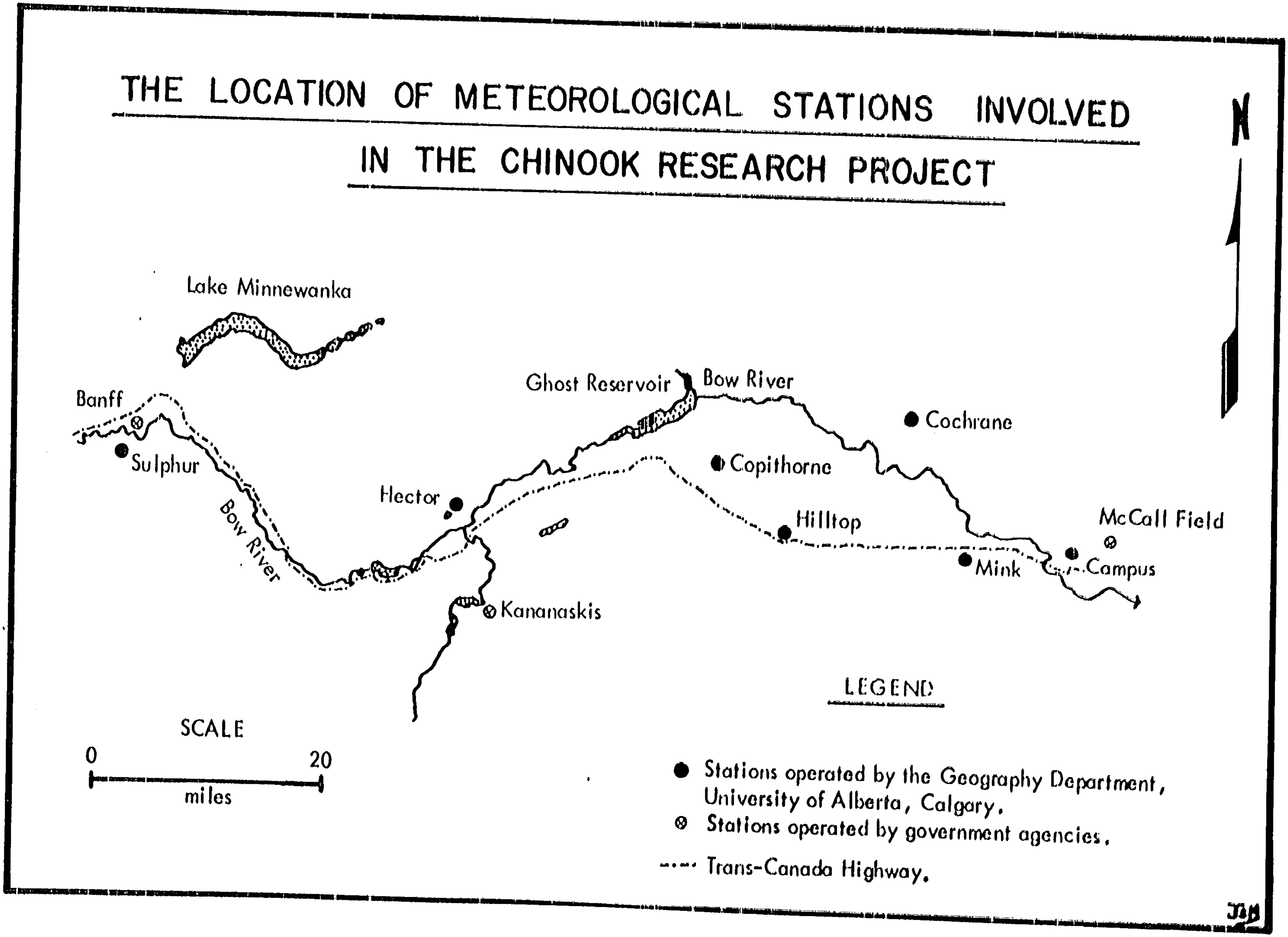
THE LOCATION OF METEOROLOGICAL STATIONS INVOLVED
IN THE CHINOOK RESEARCH PROJECT
N
Lake Minnewanka
Banff
Sulphur
Bow River
Hector
Ghost Reservoir
Bow River
Cochrane
Copithorne
Hilltop
Kananaskis
Mink
McCall Field
Campus
SCALE
0
20
miles
LEGEND
Stations operated by the Geography Department, University of Alberta, Calgary.
Stations operated by government agencies.
Trans-Canada Highway.
J&H

Figure 1

details and photographs are included in Appendix A.

Calgary: McCall Field

Organised weather observations were begun in Calgary in 1876 by the Northwest Mounted Police. Measurements were made at various downtown locations until 1931 when a station was established at the old municipal airport on North Hill. In 1938 the station was relocated at the New Municipal Airport, two and a half miles further north. In 1948 it was moved half a mile further west and in 1956 was moved 300 feet north to the present site on McCall Field Airport. The station has a comprehensive selection of instruments located on or north of the main control building, which lies somewhat lower and to the east of North Hill.[1]

Calgary: Campus

The University campus meteorological station was the first new one to be established and it began operation in October, 1963. As it is very accessible and of use in other projects and for teaching purposes it is the most fully instrumented. It is located in a flat grassed area open to the north. Buildings of various heights lie at various distances over 50 yards to the south, south-west and east. Although these may influence the site it has been inspected and approved by the Department of Transport. It is expected that the station will soon be moved to an open grass plot on the western edge of the campus, where the snow plot is located.

Mink

This station is on a mink farm seven miles west of downtown Calgary, adjacent to the old Banff Coach Road. It is situated at 3,950 feet mid-way up an open grassed hill slope that faces north-west.

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1. Government of Canada, Department of Transport, Meteorological Branch, Calgary, Alberta, Annual Meteorological Summary, 1964, pp.1-2.

Cochrane

This station is located in the grounds of the disused Glendale School some 17 miles north-west of Calgary, just north of Highway 1A. The surrounding land rises to the south and consists of arable and grass with patches of willow, poplar and occasional conifers. The small school house lies about 50 yards north of the site and contains the anemograph.

Hilltop

The small hill which this station surmounts lies some 300 yards north of Highway 1, some 25 miles west of Calgary. The surrounding area of grass and willow slopes gently down in all directions affording an excellent view, especially toward the mountains. Some of the scrub bush on the slopes was cleared during 1964.

Copithorne

This station, near the southern edge of the Stony Indian Reserve lies two miles north of Highway 1, about 29 miles west of Calgary. The site lies mid-way up the steep, grassed south-west facing slope of Parks Ridge. This hogsback ridge trends north-west to south-east and is separated from other similar ridges by shallow valleys containing sloughs.

Kananaskis

The Canada Department of Forestry keeps meteorological records at their research station located in the Kananaskis valley five miles south of Fort Chiniquay on the Rocky Mountain Forestry Road. The station lies above the valley floor which is quite wide here being occupied by Barrier Lake. The site is a relatively flat and quite extensive grass clearing surrounded by conifer forest. In connection with forest management and watershed research many other instruments are located in this vicinity, especially in the Marmot Creek basin further south.

Hector

Camp Chief Hector is located alongside Highway 1A at the western end of the Stony Indian Reserve. The site, overlooked by Mount Yamnuska, is a flat stony grassland area fringed by intermittent mixed woodland, with a small lake to the west.

Banff

Temperature and precipitation readings were begun at Banff in 1890 and a station of first class standing was established in 1894.[1] The present station operated by the Department of Transport is located in the centre of the town behind the old Fire Hall. The site is dominated by this building and further confined by a road and parking lot, all within several yards of the instruments.

Sulphur

Sulphur Mountain rises to 7,495 feet and lies four miles south of Banff, at 4,538 feet. An observatory was built on the peak in 1904 and meteorological readings have been made intermittently since then. At present the Stevenson screen, erected by the writer in 1964, is located two yards south of a small stone building on the summit. The site is not ideal but it is reasonably accessible and although snow entered the screen during the winter it was never covered. The anemometer is affixed to the roof of the Cosmic Ray Laboratory nearby. Because of difficulties in regularly servicing the instruments, especially during winter, only a limited amount of data has been secured from this station.

Instrumentation

The instruments, their accuracy and operation will now be described, but the instrumentation of each station is detailed in Appendix A.

A standard Stevenson screen was erected, usually four feet above the ground at each station. As temperature and humidity are of considerable significance a thermograph and hygrograph was placed in each screen. These instruments run for one week giving a continuous record of temperature and relative humidity respectively. Both were checked weekly by comparison with values indicated by an Assmann Psychrometer. The thermograph trace was also checked against a maximum-minimum thermometer in the screen. Where necessary the instruments were adjusted and the readings corrected. Errors for the values recorded or in timing seldom exceeded 2%. Both instruments were subject to failure during very cold weather or high and gusty winds. The clockwork drive occasionally stopped during severe cold but often restarted when the temperature rose, as during a chinook. The wind frequently blew the pens off the chart and when they stuck to the glass case several days data was often lost. However, it was seldom that all the stations were so affected and daily checks eliminated such problems at the manned stations.

To record the wind, anemometers were in operation or were installed at all stations except Mink, Hector and Banff. Those installed at the new stations were modified to run for a week but proved unreliable and have yielded virtually no data. Only at McCall Field, the Campus and Kananaskis has accurate wind data been collected continuously. A supplementary anemometer set 1'6" above the ground at the snow plot on campus has yielded useful data on daily wind passage and sensitive anemometers have been used in evaporation studies.

At the Campus several other instruments are in operation. Thermocouples, resistance thermometers with Rustrak recorders and a thermograph with mercury in lead sensing elements have been used to provide continuous records of temperatures at varying levels in the soil, on the ground and snow surface and in the soil. An actinometer provides a continuous record of solar radiation and in April 1965 a net radiometer was installed to measure solar radiation, radiation from the earth and the ground albedo.

From time to time temperature traverses between Calgary and Banff and across Calgary have been made using an Assmann Psychrometer or car mounted aircraft thermometer. Although such methods are not too accurate they have yielded some interesting results that merit closer and more accurate investigation.

Various instruments and the snow plot have been used to investigate snow melt and evaporation but these are considered fully in Chapter 4.

McCall Field has supplied a considerable amount of long term data and also synoptic and upper air information derived from pilot reports and balloon ascents. At the campus cloud and general weather conditions are noted twice daily. A partial photographic record of chinook arch clouds has been obtained for the winter 1964-5, but the operation of an all-sky camera installed in 1964 on a roof near the snow plot has not yet been perfected.

Despite instrumental failures an astounding volume of significant data has been collected since the project was initiated. Much of this data is being transferred to punch-cards as time and money permits. This will facilitate storage and, by speeding analysis, greatly enhance the usefulness of the data.

An even denser network of stations with more comprehensive and reliable instrumentation is still needed. In particular more instruments are needed in the mountain valleys and in the Calgary urban area. However, the basis has been laid for a sound study of chinook meteorology that is a necessary preliminary for an accurate analysis of the geographic significance of the phenomenon.

CHAPTER 3

## THE CHINOOK: ITS CAUSE, CHARACTER AND DEFINITION

The name chinook, meaning snow eater, was originally given to warm winds reaching Alberta, in winter, from the territory of the Chinook Indians in British Columbia.[1] Such a general definition soon led to a vague and more widespread application of the word. Cleveland noted in 1896, "The word 'chinook' is now used in Idaho to designate any warm wind"[2] and "an indiscriminate use of this word has also sprung up in the Mississippi valley."[3]

As editor of the Monthly Weather Review, Cleveland hoped that, "The term 'chinook' will only be applied to those winds that can be distinctly proven to be warm, dry, descending winds."[4] Such is the case in Alberta where the term usually signifies a warm, dry wind, particularly noticeable in the south-west of the province in winter and heralded by an abrupt change in temperature and formation of the chinook arch cloud. Unfortunately such a restricted usage of the term has not prevailed. Warm winds, wet and dry, of varying direction and frequency, occurring in such places as Fort Good Hope, Prince Albert, Manitoba, central British Columbia and Colorado have been termed 'chinooks.'

The term thus has a vague meaning and any precise geographical definition is still lacking. In an attempt to define and subsequently assess the influence of the chinook the dynamics and character of the phenomenon will now be discussed.

The true chinook, as found in Alberta, is a foehn wind differing only in degree from the type example in Europe. Such winds occur in many

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1. This is the most common and credible reason given for the name chinook.
2. Cleveland, A. 1896, p.7.
3. Ibid., p.7.
4. Ibid., p.7.

## WIND DATA FOR CALGARY

| PER CENT FREQUENCY FROM NOTED DIRECTIONS | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direction | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
| North | 18 | 18 | 17 | 16 | 17 | 19 | 17 | 19 | 18 | 13 | 16 | 15 | 17 |
| North-East | 4 | 5 | 5 | 5 | 7 | 7 | 6 | 7 | 5 | 3 | 3 | 3 | 5 |
| East | 4 | 5 | 6 | 7 | 6 | 7 | 6 | 7 | 5 | 4 | 4 | 4 | 6 |
| South-East | 7 | 10 | 16 | 18 | 15 | 14 | 15 | 13 | 12 | 12 | 8 | 7 | 12 |
| South | 14 | 17 | 17 | 15 | 11 | 10 | 13 | 12 | 14 | 18 | 17 | 19 | 15 |
| South-West | 13 | 10 | 11 | 9 | 9 | 7 | 10 | 11 | 11 | 15 | 15 | 15 | 11 |
| West | 22 | 19 | 12 | 15 | 14 | 15 | 13 | 11 | 14 | 18 | 19 | 21 | 16 |
| North-West | 15 | 11 | 13 | 14 | 20 | 19 | 19 | 18 | 19 | 14 | 15 | 13 | 16 |
| Calm | 3 | 5 | 3 | 1 | 1 | 2 | 1 | 2 | 2 | 3 | 3 | 3 | 2 |

| AVERAGE SPEED FROM NOTED DIRECTIONS (mph) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direction | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
| North | 11 | 11 | 11 | 14 | 13 | 12 | 10 | 10 | 11 | 11 | 10 | 10 | 11 |
| North-East | 6 | 7 | 8 | 9 | 9 | 9 | 9 | 8 | 7 | 7 | 6 | 6 | 8 |
| East | 6 | 6 | 7 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 6 | 5 | 7 |
| South-East | 7 | 8 | 9 | 11 | 11 | 10 | 9 | 9 | 9 | 9 | 7 | 7 | 9 |
| South | 7 | 7 | 8 | 9 | 9 | 9 | 8 | 7 | 8 | 8 | 7 | 7 | 8 |
| South-West | 9 | 8 | 8 | 9 | 8 | 7 | 7 | 7 | 8 | 9 | 8 | 9 | 8 |
| West | 16 | 16 | 14 | 15 | 13 | 13 | 12 | 10 | 13 | 14 | 15 | 16 | 14 |
| North-West | 11 | 11 | 12 | 13 | 14 | 12 | 11 | 11 | 11 | 12 | 11 | 11 | 12 |

The above figures are averages for the period 1937 - 1954 based on data derived from a recording anemometer set at 60 feet above the ground.

Source: McKay, G.A. et al. 1963. Climatic Records for the Saskatchewan River Headwaters.

Table 1

places including Greenland, New Zealand and Argentina and theoretical studies suggest that they may be expected to the leeward of any mountain range that disrupts a prevailing air flow.

Southern Alberta, occupying a mid-latitude, continental position is influenced according to the season by various air masses of Tropical, Polar, Arctic, maritime and continental origin. Cyclones from the Pacific frequently follow the 'Alberta' path and are a dominant influence on the area, especially in winter.[1] There is thus a predominantly westerly circulation over the province, as is evident in local wind data. That for Calgary, summarised in Table 1, shows that on average winds with a westerly component have a 43% frequency and that west winds have the greatest average speed. At Exshaw and Pincher Creek the mountains exert a funelling action and westerly winds are even stronger and more dominant. The Rocky Mountains fringing western Alberta rise on average to 10,000 feet, or 6,000 feet above the plains, and extend out of the province north and south. This formidable barrier lies roughly at right angles to the prevailing air flow and consequently disturbs it.

Using mathematical models several scientists, notably Queney[2] and Scorer,[3] have theorised on the flow pattern of a specific air mass over an idealised mountain barrier. The projected streamlines for air over barriers of varying width indicate that waves usually develop to the lee of the barrier.[4]

The development and amplitude of such waves depends on several factors including the shape and size of the mountain and the air speed at

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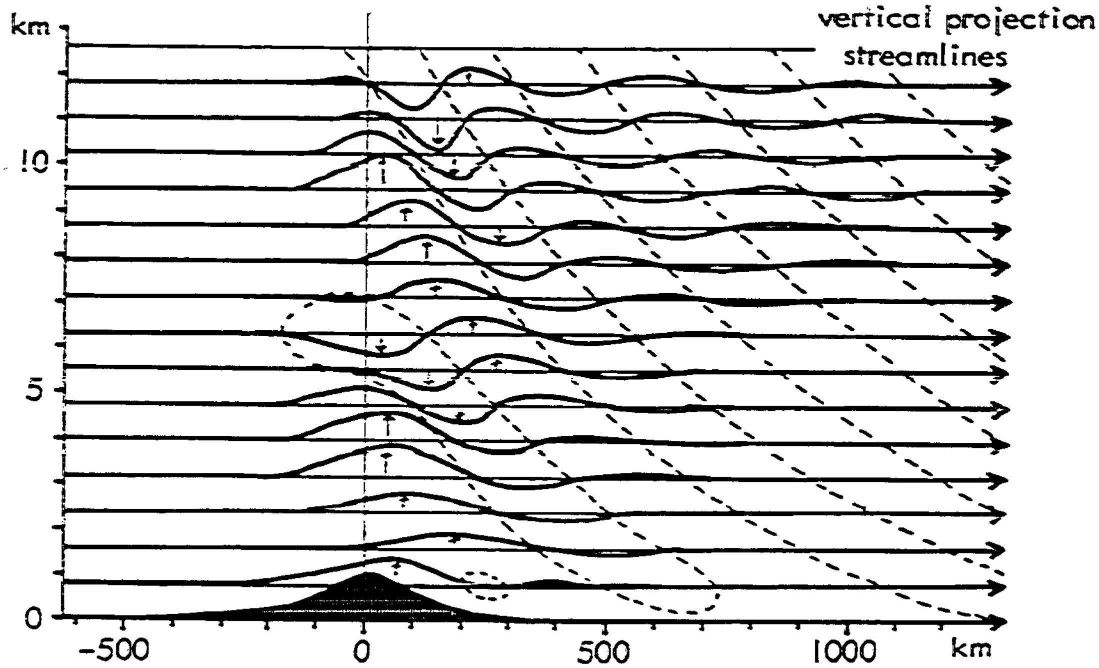
1. Borchert, J.R. 1950, pp.23-4.
2. Queney, P. 1948, pp.16-26.
3. Scorer, R.S. 1953, pp.70-83.
4. See Figure 2.

# THE THEORETICAL AIRFLOW OVER A MOUNTAIN




Perturbation by a broad typical mountain range in an unlimited uniform stratified current. This shows the vertical projection of the streamlines; displacement indicated by small arrows.

Source: Queney, P. 1948, p.22.

Figure 2

various heights. Scorer[1] suggests that steep slopes with a flat area leeward of the mountain and an increase in wind speed with height are factors conducive to wave development. A stable layer and inversion has also been considered critical in lee wave formation.[2,3] Many of these factors are found in association with the Rocky Mountains and chinook.

Even the most comprehensive mathematical model can rarely simulate the natural phenomenon where the complex character of mountains and air masses introduces more variables. However, the basic principles evolved by theory have been substantiated rather than refuted by field work.[4]

Lee waves have been detected in many places[5] by upper air measurements, cloud formations and aircraft pilots. Unfortunately radiosonde balloons are rarely used in southern Alberta.

Throughout the Rocky Mountain foothills from Alberta to Colorado distinctive cloud formations are often associated with lee waves. Under certain conditions air will condense toward the upper peak of each wave to form a lenticular or roll cloud, that may form a continuous band parallel to the mountains. When the waves are long and of short amplitude, as is often the case where they die out with height or distance from the mountains, such clouds may merge to form a more continuous alto-cumulus cover, as with the chinook arch.

This cloud formation, depicted in Figures 3 & 4, is best exemplified in southern Alberta.[6] Its occurrence, persistence and situation depend on the air mass characteristics, ground conditions and lee waves. When fully

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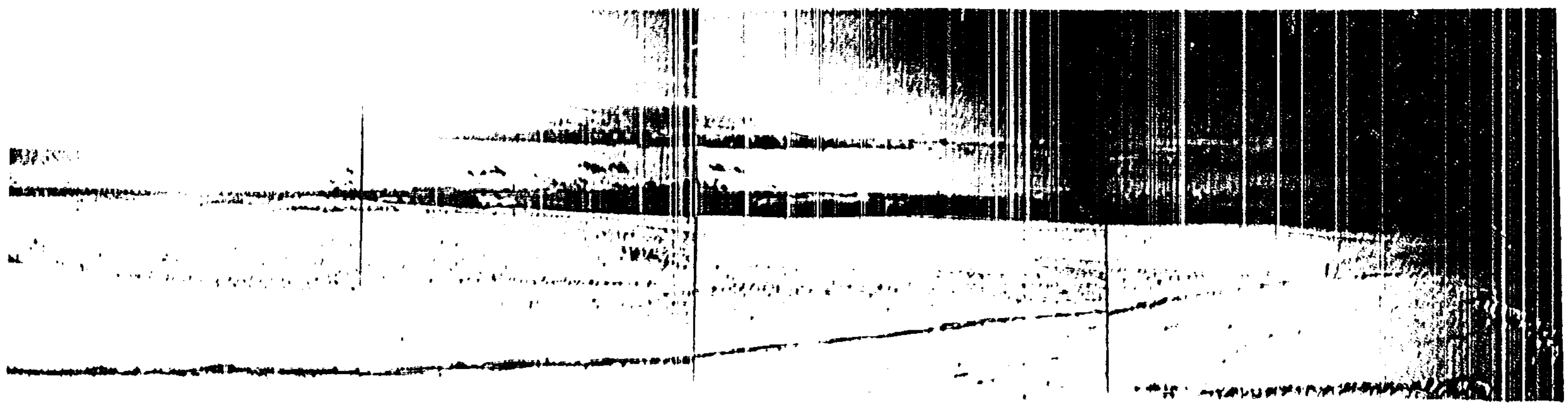
1. Scorer, R.S. 1951, pp.99-103.
2. Colson, de V. 1954, pp.363-71.
3. Yates, A.H. 1949, pp.40-4.
4. There are many examples, such as: Primeau, L.L. 1956, pp.16-21.
5. In California, Scotland, southern England, Sweden etc..
6. Thomas, T.M. 1963, pp.166-70.

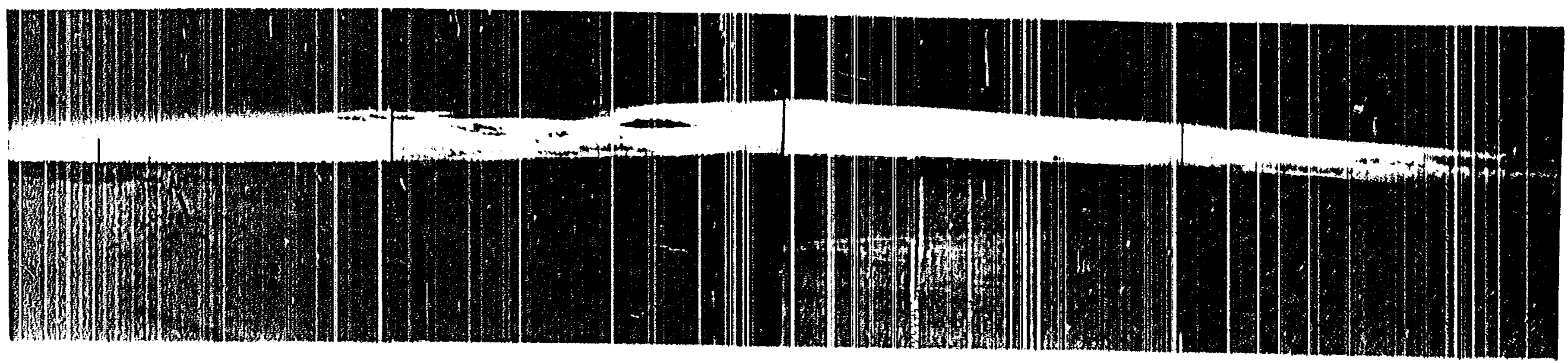
THE CHINOOK ARCH FROM CALGARY, 1.30 p.m., JANUARY 26th, 1965.



This photograph shows the remains of an arch that was better developed earlier in the day. It reformed later in the afternoon as is shown in the next photograph, Figure 4.

Figure 3

THE CHINOOK ARCH FROM CALGARY, 4.30 p.m., JANUARY 26th, 1965.



This shows the arch as it reformed toward evening, having been complete in the early morning and diffused around mid-day.

Figure 4

developed the cloud has an apparently arched edge that parallels the mountains. This edge is often silhouetted against a clear sky or one with scattered lenticular or cumulus clouds. The distance from the cloud edge to the mountains seldom exceeds fifty miles but varies with the wavelength and often changes during the day.

The cloud usually forms at a height between 10,000 and 15,000 feet, depending on the lapse rate of the air and the wave amplitude. It seldom occurs during the summer and even during winter the arch often dissipates around noon through local ground heating and turbulence, then reforms under more stable conditions toward evening. Only under certain conditions are lee waves and the chinook accompanied by the arch and it is not, therefore, a comprehensive indicator of either phenomenon.

Pilot reports, when available, are often useful indicators of lee wave development. Many of the best gliding areas are located to the leeward of mountains where the waves provide exceptional lift. Thus in 1940 a German glider climbed to 37,000 feet in a wave to the lee of the Alps.[1] However, the pilot is primarily concerned with the turbulence and dangerous downdrafts associated with such waves. Several crashes, including one at Rocky Mountain House, have been attributed to lee wave downdrafts.[2] Lee waves and turbulence are quite frequently reported by pilots flying west from Calgary.

The chinook wind consists of air that descends in a lee wave and is compressed and adiabatically heated. However, the lee wave theory seems inadequate in explaining the exceptional warmth of such winds and their descent to cooler areas. Several other factors may well stimulate the descent

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1. Yates, A.H. op.cit..
2. Government of Canada, Department of Transport, Air Services, Civil Aviation Branch, Accident Report, Serial Number 1958.

and warming of chinook air.

The pressure difference that initiates the transmontane air flow probably evacuates air from the foothills leaving a low pressure area which attracts air from above. This leeward low pressure centre may be accentuated by the passage of air over the mountains and foothills and cyclogenesis may even occur.

Local turbulence and convection due to ground heating may also cause the dispersal or mixing of the colder air at lower elevations, which enables the chinook to reach ground level. This may also be influenced in Calgary by topographic controls, air drainage and the development of an urban heat island.[1]

It has also been suggested that air traversing the mountains is subject to frictional drag that induces leeside descent. Certainly there is usually a marked increase in wind speed with height which might, by providing downward momentum, induce the chinook to descend.

Many factors in conjunction with lee waves would appear to be responsible, to a greater or lesser degree, for the descent of the chinook. Further study of these factors is warranted if more accurate forecasting of the chinook's arrival at ground level is to be achieved.

As the character of an air mass is largely determined at its source and because the chinook has been defined genetically it is necessary to consider the origin of chinook air. It is often thought that the chinook is invariably associated with air masses originating near sea level over the Pacific Ocean. Such air masses supposedly, in ascending the mountains, cool,

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1. Langemann, R.E. 1965.

condense then cool at the wet adiabatic lapse rate of about 2.7°F. per 1,000 feet. On descending the lee slope the air gains heat at the dry adiabatic lapse rate of about 5.5°F. per 1,000 feet and is thus warmer, height for height, on the lee compared with the windward side.

This infers that the chinook is always accompanied by precipitation on the windward slope and hence Ives[1] used this as a criterion for distinguishing and defining the chinook. However, even Hann[2] noted that the foehn sometimes set in prior to precipitation on the windward slope. Analysis of chinooks in Colorado has shown that they are not always accompanied or preceded by windward precipitation.[3] It has, therefore, been suggested recently by Godske[4] that chinook air is not always derived from sea level, but may originate at higher levels and have different properties. This is apparently substantiated by Borchert, who noted that:

> During the average January between the surface and 3 km. level in the United States the amount of air that moves out from the eastern base of the Rockies is about three times as great as the amount of air which moves eastward against the coast ranges and the Sierra Cascade Ranges. The divergence below the three km. level must be compensated by mean vertical descent from above the three km. level.[5]

It seems likely that the chinook, like the foehn, has a multiple origin. Hence the Meteorological Branch of Canada noted that,"Reference, however, to weather maps of many past years will show that there are several varieties of chinook."[6]

There are thus several reasons why the geographer in defining the chinook should avoid the genetic approach. Firstly the origin of the chinook

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1. Ives, R.L. 1950, pp.293-327.
2. Hann, J. 1885, pp.393-9.
3. Cook, A.W. et al. 1952, pp.42-7.
4. Godske, C.L. et al. 1957, pp.600-7.
5. Borchert, J.R. 1950, p.22.
6. Government of Canada, Department of Transport, Meteorological Branch.1939,p.146

is incompletely understood, but seems varied. Secondly, a genetic definition may include upper air chinooks, that do not reach the ground and hardly influence it. Thirdly, the geographer is primarily interested in the ground characteristics of the chinook and their influence on the landscape.

The characteristics of chinook conditions will be best appreciated by reference to a specific example of its occurrence. Chinooks were infrequent at Calgary during the severe winter of 1964-5 but the one starting February 7th, 1965 was a good example.[1]

On February 5th and 6th a weak depression passed eastwards through Montana inducing air to move south-eastwards across Alberta from the Arctic High over the Great Slave Lake. Calgary experienced bitter north-west winds and low temperatures, the maximum for February 6th being 4°F..On February 7th and 8th two high pressure areas developed over Utah and Iowa and as the Arctic High weakened pressure fell at Calgary and a depression moved across Alberta from the Pacific Ocean.[2] This westerly flow of warm Polar Maritime air produced chinook conditions.

The influx of warm air was first noted at Banff, where the temperature rose quite abruptly at noon on February 6th. At Kananaskis the temperature increase occurred later and was more pronounced. A definite chinook effect was evident here, there being a 26°F. rise in temperature between 8.0.p.m. and 9.0.p.m. and a fall in relative humidity from 70% to 40%. On February 7th chinook air extended across the foothills causing abrupt changes in temperature at the following times: Camp Chief Hector - 1.0.a.m., Copithorne and Hilltop - 1.30.a.m., Cochrane - 2.30.a.m. and Mink - 5.0.a.m.. At all these stations

1. See Appendix B.
2. This synoptic pattern is similar to that which Osmond considers necessary for a chinook.

temperature rose by at least 30°F. and relative humidity dropped at least 30% during the day.

At Calgary the chinook was heralded on February 6th by the temporary and partial formation of the chinook arch. The following day the arch developed fully and pilots reported strong westerly winds and turbulence due to subsidence.

At the campus temperature began rising at 2.30.a.m., when it was -13°F., and increased rapidly during the late morning to a maximum of 38°F. at 3.0.p.m. The relative humidity, which had continuously exceeded 70% since February 1st and 80% since the 5th, dropped swiftly from 95% at 7.0.a.m. to 53% at 3.30.p.m. As the temperature increased the vapor pressure also increased but remained relatively low. Considerable surface turbulence was indicated by the jerky trace on the thermograph and hygrograph charts. The wind, blowing from the south-west, increased markedly at 6.0.a.m. and reached a maximum of 18 m.p.h. at 3.0.p.m..

As usual winds were stronger in the Lethbridge-Pincher Creek area but temperatures were similar to those at Calgary. Warm air and west winds penetrated all of southern Alberta but temperatures decreased eastwards and the chinook was not recognisable east of Swift Current.

As the depression continued eastwards the westerly flow weakened and the chinook died out. On February 8th, at 2.0.p.m., pressure at Calgary began to increase very quickly as the Arctic High and colder air flow reasserted themselves. The wind continued to blow from the south-west but the temperature began to fall, the humidity rose abruptly to 98% and snow fell.

Chinooks are very varied but this example, if not typical, enables one to see the certain salient characteristics that are common to all. It is thus possible to formulate a qualitative or plainsmen's definition of the phenomenon. One may define the chinook as:

> A meteorological phenomenon generally characterised by lee waves and low pressure and heralded by an abrupt and considerable rise in temperature and fall in humidity, accompanied by winds having a westerly component.

The precise determination of chinook frequency, duration, intensity and distribution must await a more quantitative definition but the plainsmen's definition given above enables some discussion of these factors and the influence of the phenomenon.

The distribution, frequency and duration of the chinook is governed by the general and local atmospheric circulation and the changes thereof. Chinooks are invariably associated with the mid-latitude belt of westerly winds and depressions and hence the absolute latitudinal limits of chinook occurrence, roughly 37° and 60° north, correspond with the maximum north to south range of this belt.

In any one year or season the distribution of the chinook depends on the latitudinal position of the depression belt and storm tracks. The centre of this belt and the most common storm track often lie across southern Alberta and hence in the long term this area has the most chinooks.

The absolute east-west limits of the chinook are somewhat subjective being dependent upon the definition one accepts or the frequency considered significant. Generally speaking the chinook occurs with greatest frequency and intensity in the foothills immediately to the lee of the Rocky Mountain Front Range. East from this area chinooks decrease in intensity and in frequency, the eastward extension of any one being governed by the strength of the westerly flow and the related pressure pattern. Only occasionally do chinooks penetrate far into Saskatchewan and the phenomenon can hardly be considered significant more than a hundred miles east of the Alberta boundary.

The western limit of the chinook is generally considered more precise, being equated with the junction of the foothills and Front Range. However, the writer regards this as erroneous. West of this line, but east of and lower than the Continental Divide, is a belt of mountainous terrain about thirty miles across. This is dissected by some broad valleys, such as that of the Bow, which lie some 4,000 feet below the mountain crests to the west. It seems likely that easterly moving air will tend to descend in this area, especially into the valleys, where foehn or chinook conditions may result. Indeed the European foehn is essentially a valley feature often of little significance outside the mountains. Evidence suggests that though the chinook effect may be weaker than in the foothills it can be detected.

Wheeler noted that, "the warm dry Chinook wind (is) noticeable in all wide valleys between the ranges and in a much greater degree on the western prairies of Alberta."[1] More recently skiers have commented on the influence of the chinook on sublimation and snow conditions around Banff.[2]

Despite the lack of meteorological stations in the mountains the limited amount of data available furnishes the best evidence of valley chinooks. Records for Banff generally only show a moderate chinook effect but at Kananaskis and occasionally in the upper Red Deer valley the usual

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1. Wheeler, A.O. 1916, p.71.
2. Bradbury, R. Personal Communication, September 19th, 1964.

chinook characteristics are clearly evident. At Kananaskis chinooks of equal or lesser intensity have been recorded prior to, or contemporaneous with, their occurrence in the foothills.

Red belt or winter killing of conifers is also attributed to chinooks and being common in the Front Range valleys may offer further proof of their incidence in such places.[1] This phenomenon and its meteorological significance is considered more fully in Chapter 5.

Many variable factors may restrict and moderate the chinook in the Front Range valleys but its occasional and significant occurrence in this area cannot be overlooked.

It is thus possible to roughly delimit the area in which the chinook is meteorologically significant. This may be termed the 'chinook belt' and includes that area south of the latitude of Red Deer, extending approximately 300 miles east of the Continental Divide.[2] The belt is continued in the United States but the southern boundary has not been determined.

Even within the chinook belt there are marked variations in the season, frequency, duration and intensity of the chinook from year to year and place to place.

The chinook, as defined in the plainsmen's definition, cited previously,[3] is essentially a winter phenomenon. However, in view of the occurrence of trans-montane air currents, with lee waves and dry, westerly winds in summer the chinook has been termed a year round phenomenon.[4] In winter the chinook may differ in degree but in summer several characteristics are entirely absent and only the wind is clearly evident or significant. Because the

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1. Henson, W.R. 1952, pp.62-4.
2. See Figure 5.
3. See page 28.
4. Ives, R.L. op.cit..

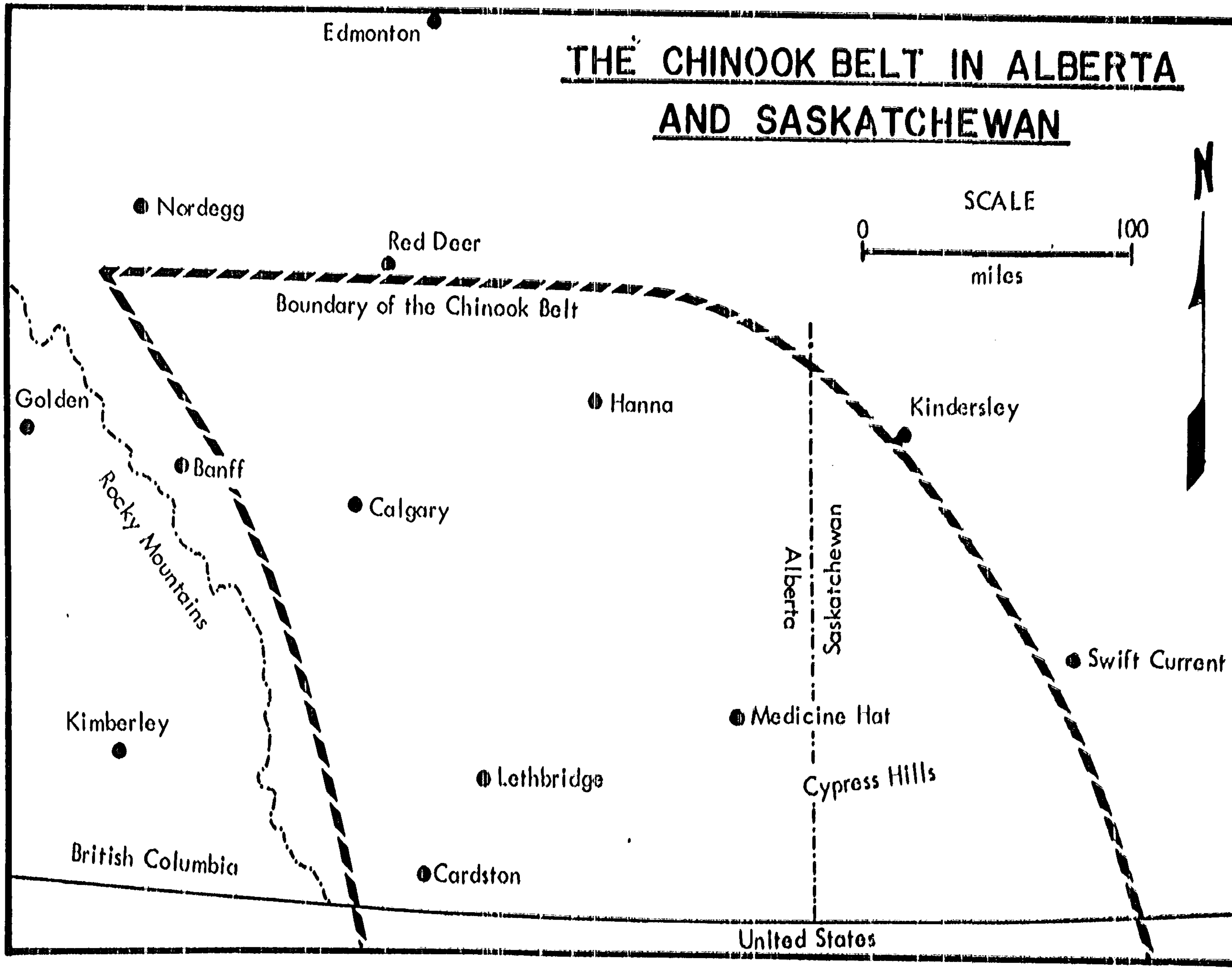
THE CHINOOK BELT IN ALBERTA
AND SASKATCHEWAN
SCALE
0
100
miles
N
Edmonton
Nordegg
Red Deer
Boundary of the Chinook Belt
Golden
Banff
Rocky Mountains
Calgary
Hanna
Kindersley
Alberta
Saskatchewan
Swift Current
Medicine Hat
Kimberley
Lethbridge
Cypress Hills
British Columbia
Cardston
United States

Figure 5

phenomenon and hence its influence is so markedly different in summer the writer feels the term chinook should be restricted to the winter phenomenon, as it is defined in the plainsmen's definition.[1]

The frequency and duration of the chinook from winter to winter depends on the strength and prevalence of the depression belt compared with other systems. If, as during February 1965, the Arctic High becomes exceptionally strong and forces the polar front far south the westerly flow may be interupted or displaced entirely for several weeks causing severe weather to prevail.

The time of arrival and the intensity of a chinook seem to depend on existing and localised conditions. Quite frequently chinook air remains aloft for hours or days and descends to the ground at any time of day or night, only when the ground or atmospheric conditions permit. The intensity of the chinook varies considerably but it is essentially a relative factor that is determined by comparing the chinook weather with that which previously prevailed.

It will be appreciated from the above remarks that the chinook is an extremely variable constituent of the southern Alberta climate. Its climatic significance and variability is reflected in the variation in the mean winter temperatures at such places as Calgary.[2]

This great and unpredictable variability of the chinook and its consequent unreliability is further reflected, as will be seen later, in the attitude of the Alberta rancher toward it.

The variability of even individual chinooks may necessitate a classification based, for example, on wind strength or temperature increase.

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1. The term winter usually includes that period from October to May.
2. See Table 2.

## WINTER TEMPERATURES AT CALGARY

| Year | Jan. | Feb. | Dec. | Annual |
|---|---|---|---|---|
| 1951 | 8.9 | 12.8 | 10.1 | 33.7 |
| 1952 | 5.1 | 19.3 | 25.5 | 38.6 |
| 1953 | 10.8 | 25.6 | 26.2 | 39.7 |
| 1954 | -2.3 | 29.8 | 29.0 | 37.4 |
| 1955 | 20.5 | 15.9 | 6.4 | 34.9 |
| 1956 | 6.4 | 11.5 | 19.6 | 37.6 |
| 1957 | 6.2 | 14.1 | 27.6 | 38.1 |
| 1958 | 27.8 | 12.8 | 23.8 | 40.0 |
| 1959 | 8.1 | 13.4 | 29.3 | 37.9 |
| 1960 | 14.6 | 17.6 | 23.6 | 39.1 |
| 1961 | 26.1 | 24.9 | 12.2 | 40.3 |
| 1962 | 17.8 | 14.6 | 23.7 | 40.0 |
| 1963 | 12.1 | 26.9 | 17.2 | 40.9 |
| 1964 | 20.6 | 32.0 | 0.8 | 38.4 |

The above monthly mean temperatures are computed from the daily average of 24 hourly temperatures.

SOURCE: Government of Canada, Department of Transport, Meteorological Branch, Annual Meteorological Summary, 1964 and Long Term Records, 1885 - 1964, for Calgary, Alberta.

Table 2

However, it is first essential to formulate a quantitative definition based on the plainsmen's definition that has been proposed and utilised in this study.

CHAPTER 4

## THE CHINOOK AND THE HYDROLOGIC CYCLE

The hydrologic cycle has an important bearing on the landscape and the use man makes of it. The warm, dry chinook influences this cycle by stimulating snow-melt, run-off and evaporation. This is of particular relevance in southern Alberta which in most years is moisture defficient. Indeed such processes are of economic significance to the forester and rancher as will be seen later.[1]

It has been said that, "Untimely Chinook winds sometimes created flood hazards"[2] and also that during a chinook, "At Helena, Montana a snow cover ten inches in depth had disappeared overnight leaving a dry surface the next morning."[3] One suggests excessive run-off and the latter evaporation, which implies loss of valuable ground and plant moisture. It is clearly important to determine the absolute and relative significance of evaporation and run-off during chinook conditions. Such work was begun at the University of Alberta, Calgary in 1964 with an emphasis on winter evaporation. The methods used, problems encountered and data obtained will now be considered.

Moisture is transferred from ground to air by evaporation of water or sublimation of snow or ice. Latent heat is used in this molecular transfer from a surface of high vapor pressure to the air having a lower vapor pressure. The surface may be an open sheet of water or a medium such as vegetation or soil. The complexity of the hydrologic cycle, with numerous elusive variables makes measurement of such evaporation in nature very difficult. Therefore, one generally uses instruments having variables that can be calculated or eliminated. These may register evaporation from a

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1. See Chapters 5 & 6 respectively.
2. Sharp, P.F. 1955, p.165.
3. Ward, R. de C. 1923, p.166.

controlled water surface, as in a tank, a natural medium such as grass, or an artificial medium such as porcelain or paper. They are referred to as tanks, lysimeters and atmometers respectively and as they all use water are susceptible to freezing. Their operation in Calgary, which has on average only 109 frost free days is thus restricted. However, atmometers being portable and easily modified have yielded reliable data for limited periods of more favourable weather or chinook conditions during winter.

On campus Piché atmometers have been used. They consist of, "a graduated tube with one end closed and the other ground flat, the flat end being covered by a circular piece of filter paper pressed against it by a disc."[1] The instrument is filled with distilled water and inverted to allow evaporation from the paper and its measurement by reference to the graduated tube. The Piché atmometer is very sensitive to wind speed and in using it the following points had to be observed:

1. The results obtained are of potential evaporation and will vary with the height of the instrument.

2. Vibration may cause excessive release of water, the edge of the filter paper may dry out and rainfall may influence data.

3. Evaporation depends to a small extent on the size of the air space within the tube; there being greater evaporation with low water level because of surface tension effects.

4. Atmometers may have different external diameters and are not necessarily interchangeable.

Thornthwaite offered the following criticism of atmometers:

The porous bulb atmometer is useful to illustrate the processes of

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1. Middleton, W.E.K. 1953, p.133.

evaporation and transpiration in the class room but does not provide measurements that can be related to actual transpiration or to evaporation from a free water surface. The same is true of data secured from evaporation pans. Both instruments are supposed to supply an index of the evaporating power of the air but this theoretical evaporating power is unrelated to actual evaporation or transpiration.[1]

Thornthwaite advocated measurement of actual evaporation by determination of vertical vapor flux. This involves measurement of wind and dry and wet bulb temperatures at regular intervals at successive heights above the ground. A similar procedure was adopted at the campus during a day of chinook conditions. Results were obtained but their questionable reliability showed the need for more precise instruments and more refined techniques.[2]

To investigate snow melt and sublimation, especially during chinook conditions an experimental snow plot was laid out at the western edge of the campus. Located in an open area of gently rolling, short grassed topography the plot embraces the flat part of a slight rise. The plot, as shown in Figure 6, is approximately 50 feet square and contains 46 stakes, clearly graduated in inches. These were spaced, according to random numbers, in an area roped off to prevent disturbance of the stakes or snow. At each corner is a small standard rain gauge and a pan to measure snow meltwater. A wind recorder with cups set two feet above the ground is located on the western edge of the plot.

Readings were made from outside the plot, data from the wind recorder and snow stakes being noted daily, whilst the rain gauges and pans were inspected when necessary. A standard type of snow sampler was used in an attempt to estimate the water content of snow on the plot.

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1. Thornthwaite, C.W. 1940, p.22.
2. See Appendix C.

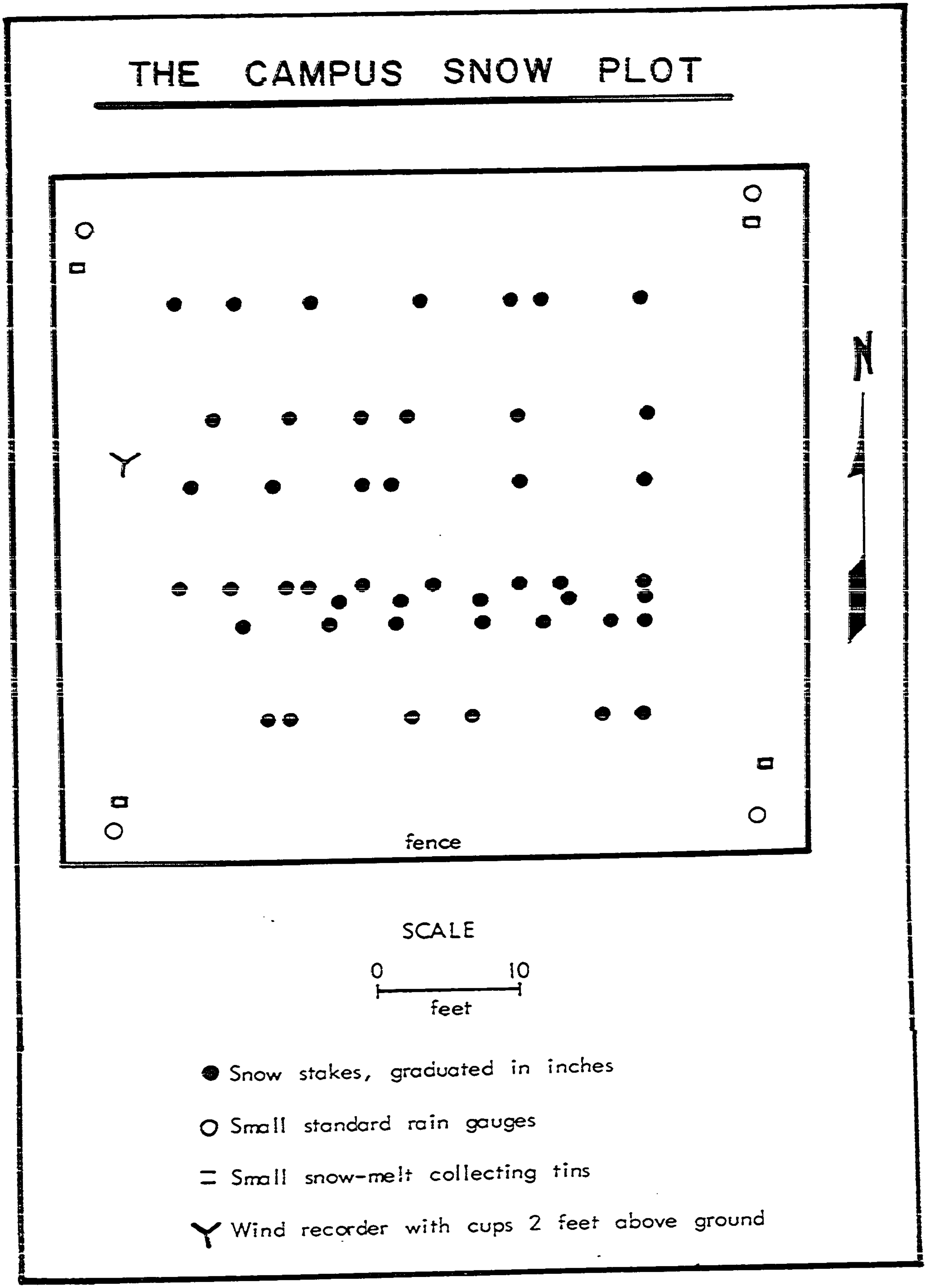
THE CAMPUS SNOW PLOT
N
fence
SCALE
0
10
feet
Snow stakes, graduated in inches
Small standard rain gauges
Small snow-melt collecting tins
Wind recorder with cups 2 feet above ground

Figure 6

To evaluate the method and to assist any future workers the operational problems encountered will be fully described. Snow stake measurement involved three main problems:

1. Drifting of snow by chinook and other winds occurred quite frequently and caused great disparity between depths recorded at individual stakes.[1] However, because of the size and location of the plot it was assumed that it was not an area of undue accumulation or deflation. Observations suggested that the average depth for the plot was generally representative of the surrounding area. However, drifting alone produced changes in depth and the initial assumption may have been erroneous and a source of error. The stakes themselves also initiated small scale drifts on their leeside, evident in Figure 8. In such cases the depth of snow on the windward side was recorded.

2. Reradiation from stakes caused localised melting. In such cases observations were made from a distance at snow surface level.

3. Inaccurate graduation and frost heaving of stakes undoubtedly produced errors but these likely counteracted each other. Estimation of ½ inches from a distance was somewhat subjective even using binoculars but checks by other observers showed a maximum discrepancy of only .22 inches for the average depth.

The rain gauges belatedly installed to collect snow for estimation of water content proved unsuitable. Heavy snowfalls overtopped them, the wind scoured them and difficulties arose over collection of snow for measurement. The pans designed to collect snow-melt all overflowed, tilted

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1. See Figure 7.

## SNOW COVER AT THE CAMPUS SNOW PLOT

This photograph, looking north, shows the stakes in the eastern part of the plot. Here the snow is relatively even but minor differences in the height at each stake can be seen.

Figure 7

MINOR SNOW DRIFTS ON THE CAMPUS SNOW PLOT

This photograph shows drifting to the lee of stakes and vegetation caused by westerly winds, typical of chinook conditions.

Figure 8

or collected dust and grass, making measurements useless. The successful use of the snow sampler depends upon modification of techniques to suit local conditions, as difficulties arose in obtaining complete cores and in weighing the small quantities of snow. Localised ice crusts and old snow also made analysis of fresh snow unreliable. The wind recorder caused least concern being subject only to occasional snow collection in the cups.

The prolonged cold spell and heavy snowfall during the 1964-1965 winter allowed extensive use of the snow plot but restricted use of atmometers. The latter only yielded reliable data when the wet bulb temperature exceeded 32°F. for several hours, usually during chinook conditions. The results, summarised in Table 3, show:

1. The variation in evaporation with height. Generally the rate of evaporation would increase with increasing height above the ground.

2. The great daily variation in the average evaporation per hour for all three instruments. On February 23rd evaporation averaged .20 millilitres per hour, whilst on March 8th it averaged 1.07 millilitres per hour.

It was noted that on December 8th and February 16, 17 & 19th, when high rates of evaporation were recorded, chinook winds prevailed. However, similar rates of evaporation were also noted on March 4, 6 & 8th when the chinook was absent though temperatures were high. Consequently correlations were sought that might indicate a causal relationship between certain meteorological variables and rates of evaporation.[1]

For the period January 13-20th a highly significant coefficient of linear correlation was found between average hourly evaporation and mean daily temperature.[1] Similar tests between average hourly evaporation and

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1. See Appendix C, pp.117-18.

EVAPORATION AT CALGARY. WINTER 1964-1965

A SUMMARY OF MEASUREMENTS MADE USING PICHE ATMOMETERS, DURING THE WINTER 1964 - 1965, AT THE CAMPUS OF THE UNIVERSITY OF ALBERTA, CALGARY.

| Date | Duration of Observation Hrs. Mins. | Total Daily Evaporation in millilitres at a height of | | | Total Evaporation per hour from all atmometers. |
|---|---|---|---|---|---|
| | | 6 feet | 3 feet | 2 inches | |
| 21.11.64 | 5.55 | 2.6 | 1.8 | 1.4 | .98 |
| 8.12.64 | 2.55 | 1.2 | 0.8 | 0.8 | .99 |
| 13. 1.65 | 6.35 | 1.9 | 1.5 | 0.6 | .64 |
| 14. 1.65 | 11.30 | 1.5 | 1.1 | 0.8 | .30 |
| 15. 1.65 | 11.40 | 1.7 | 1.2 | 0.5 | .30 |
| 16. 1.65 | 11.55 | 2.4 | 1.8 | 0.8 | .43 |
| 17. 1.65 | 9.40 | 1.7 | 1.1 | 0.3 | .33 |
| 18. 1.65 | 5.15 | 0.6 | 0.5 | 0.2 | .26 |
| 20. 1.65 | 11.45 | 3.0 | 1.8 | 1.1 | .51 |
| 8. 2.65 | 6.55 | 1.5 | 1.0 | 0.9 | .49 |
| 16. 2.65 | 9.10 | 2.8 | 3.6 | 0.8 | .79 |
| 17. 2.65 | 10.45 | 5.0 | 4.7 | 1.6 | 1.05 |
| 18. 2.65 | 11.55 | 3.3 | 2.9 | 1.3 | .63 |
| 19. 2.65 | 8.05 | 4.7 | 4.4 | 2.5 | 1.40 |
| 23. 2.65 | 2.30 | 0.2 | 0.3 | 0.0 | .20 |
| 24. 2.65 | 4.00 | 1.2 | 1.1 | 0.7 | .75 |
| 2. 3.65 | 8.30 | 1.3 | 1.2 | 0.8 | .38 |
| 3. 3.65 | 5.40 | 0.7 | 0.5 | 0.6 | .31 |
| 4. 3.65 | 11.15 | 4.2 | 3.3 | 2.2 | .86 |
| 5. 3.65 | 8.20 | 1.6 | 1.4 | 1.0 | .48 |
| 6. 3.65 | 1.30 | 0.7 | 0.5 | 0.4 | 1.07 |
| 7. 3.65 | 4.55 | 1.2 | 1.2 | 0.9 | .67 |
| 8. 3.65 | 7.50 | 5.0 | 3.8 | 3.6 | 1.50 |
| 11. 3.65 | 6.30 | 1.7 | 1.6 | 1.3 | .70 |

Table 3.

maximum daily temperature and between the daily total evaporation and the height of the instrument, however, proved significant only at the 5% level of confidence.[1] Any significant correlation between evaporation and the height of the instrument may probably be attributed to the wind which usually increases with height.

The snow plot was established too late to record the early snowfalls but data for the main period of cover from November 27th, 1964 to March 5th, 1965 was collected and analysed and is summarised in Table 4.

During this period snow lay on the ground all the time though the depth and coverage varied.[2] The average snow depth was greatest on January 22, 1965 when 8.8 inches were recorded. The snow almost vanished in mid-December but from December 22nd to January 16th the depth was at least 4 inches. The snow went completely after 6 consecutive days of higher temperatures at the beginning of March.

Decreasing snow depth was supposedly indicative of melt or evaporation but may sometimes have been due to drifting or consolidation. As accumulation and deflation due to drifting were assumed, perhaps erroneously, to balance each other on the plot no allowance was made for these factors. Consolidation usually followed a period of thaw or chinook conditions after which resumed freezing often produced an ice crust. On occasion consolidation may have been important in reducing snow depth but as investigation using the snow sampler failed it was not accounted for.

As melting and evaporation were generally considered most important in reducing snow depth attempts were made to identify those factors governing such processes and thereby assess the significance of the chinook. Significant

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1. See Appendix C, p.117.
2. See Figure 9.

## CAMPUS SNOW PLOT DATA, WINTER 1964-1965

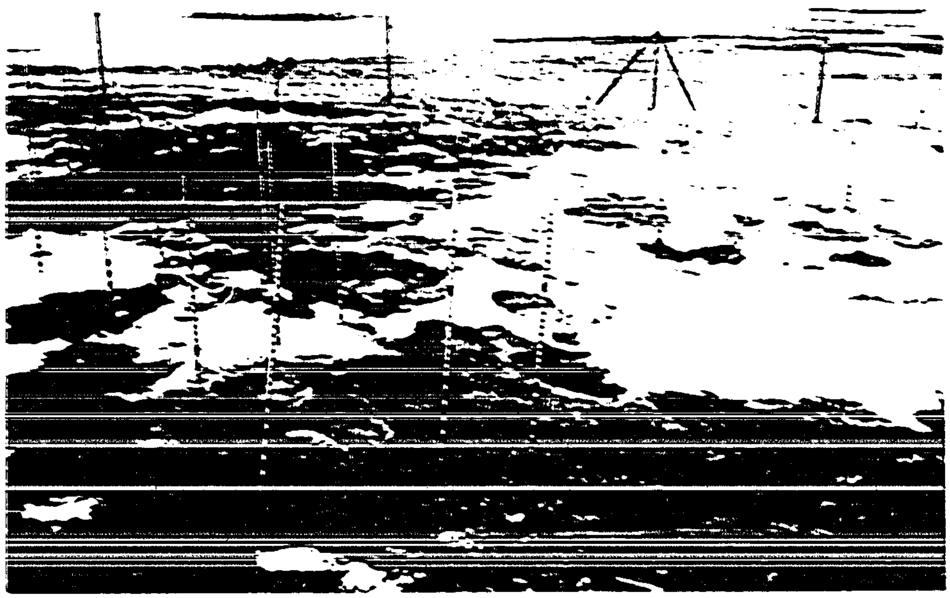
| Date | 1 | 2 | Date | 1 | 2 | Date | 1 | 2 |
|---|---|---|---|---|---|---|---|---|
| 2.12.64 | 2.3 | | 2.1.65 | 5.6 | +0.4 | 3.2.65 | 5.2 | -0.1 |
| 3.12.64 | 2.7 | +0.4 | 3.1.65 | ? | | 4.2.65 | 5.2 | 0.0 |
| 4.12.64 | 2.5 | -0.2 | 4.1.65 | 5.6 | 0.0 | 5.2.65 | 4.9 | -0.3 |
| 5.12.64 | 2.3 | -0.2 | 5.1.65 | 5.6 | 0.0 | 6.2.65 | 4.6 | -0.3 |
| 6.12.64 | 2.3 | 0.0 | 6.1.65 | 5.7 | +0.1 | 7.2.65 | 4.5 | -0.1 |
| 7.12.64 | 2.0 | -0.3 | 7.1.65 | 5.7 | 0.0 | 8.2.65 | 4.2 | -0.3 |
| 8.12.64 | 0.8 | -1.2 | 8.1.65 | 5.9 | +0.2 | 9.2.65 | 4.3 | +0.1 |
| 9.12.64 | 0.8 | 0.0 | 9.1.65 | 6.2 | +0.3 | 10.2.65 | 4.5 | -0.2 |
| 10.12.64 | 0.8 | 0.0 | 10.1.65 | 5.7 | -0.5 | 11.2.65 | 4.4 | -0.1 |
| 11.12.64 | 0.8 | 0.0 | 11.1.65 | 5.6 | -0.1 | 12.2.65 | 4.3 | -0.1 |
| 12.12.64 | 0.7 | -0.1 | 12.1.65 | 5.5 | -0.1 | 13.2.65 | 4.1 | -0.2 |
| 13.12.64 | 1.9 | +1.2 | 13.1.65 | ? | | 14.2.65 | 5.8 | +1.7 |
| 14.12.64 | 1.6 | -0.3 | 14.1.65 | 5.2 | -0.3 | 15.2.65 | 4.5 | -1.3 |
| 15.12.64 | ? | | 15.1.65 | 4.8 | -0.4 | 16.2.65 | 4.3 | -0.2 |
| 16.12.64 | 0.7 | -0.9 | 16.1.65 | 4.5 | -0.3 | 17.2.65 | 3.7 | -0.6 |
| 17.12.64 | 0.6 | -0.1 | 17.1.65 | 4.4 | -0.1 | 18.2.65 | 1.6 | -2.1 |
| 18.12.64 | 1.2 | -0.6 | 18.1.65 | 4.4 | 0.0 | 19.2.65 | 0.8 | -0.8 |
| 19.12.64 | ? | | 19.1.65 | 4.4 | 0.0 | 20.2.65 | 0.6 | -0.2 |
| 20.12.64 | ? | | 20.1.65 | 4.3 | -0.1 | 21.2.65 | 0.8 | +0.2 |
| 21.12.64 | 2.5 | +1.3 | 21.1.65 | 5.1 | +0.8 | 22.2.65 | 2.2 | +0.4 |
| 22.12.64 | 4.2 | +1.7 | 22.1.65 | 8.8 | +3.7 | 23.2.65 | 2.0 | -0.2 |
| 23.12.64 | 6.3 | +2.1 | 23.1.65 | 8.0 | -0.8 | 24.2.65 | 1.2 | -0.8 |
| 24.12.64 | 7.0 | +0.7 | 24.1.65 | 7.8 | -0.2 | 25.2.65 | 0.4 | -0.8 |
| 25.12.64 | 6.2 | -0.8 | 25.1.65 | 7.6 | -0.2 | 26.2.65 | 0.3 | -0.1 |
| 26.12.64 | 6.1 | -0.1 | 26.1.65 | 7.5 | -0.1 | 27.2.65 | 0.3 | 0.0 |
| 27.12.64 | ? | | 27.1.65 | 6.6 | -0.9 | 28.2.65 | 1.0 | -0.7 |
| 28.12.64 | 5.6 | -0.5 | 28.1.65 | 6.8 | +0.2 | 1.3.65 | 0.9 | -0.1 |
| 29.12.64 | 5.4 | -0.2 | 29.1.65 | 5.6 | -1.2 | 2.3.65 | 0.7 | -0.2 |
| 30.12.64 | 5.8 | +0.4 | 30.1.65 | 5.6 | 0.0 | 3.3.65 | 0.2 | -0.5 |
| 31.12.64 | ? | | 31.1.65 | 5.1 | -0.5 | 4.3.65 | 0.1 | -0.1 |
| 1. 1.65 | 5.2 | -0.6 | 1.2.65 | 5.2 | +0.1 | 5.3.65 | 0.1 | 0.0 |
| | | | 2.2.65 | 5.3 | +0.1 | 6.3.65 | 0.0 | -0.1 |

Column 1: Average Snow Depth in inches.

Column 2: Change in Average Snow Depth, in inches, since previous observation.

Table 4

SNOW PATCHES ON THE CAMPUS SNOW PLOT



This photograph, taken on February 25th, 1965 shows the residual patches of snow left after melting and/or evaporation. The largest snow patch, upper right, covers a small area of bare soil but the remainder of the plot is grass covered.

Figure 9

correlations were sought between depth changes and those variables, such as temperature and wind, that had been accurately measured.

For the period January 14th to March 6th, 1965 a highly significant coefficient of linear correlation was found between daily reduction in snow depth and mean daily temperature but a similar test for association between daily reduction in snow depth and daily wind passage shows significance only at the 5% level of confidence.[1] However, observation suggested that snow depth decreased most markedly on warm, windy days, as during a chinook. Hence wind, temperature and snow depth were compared. Wilcock[2] found that for 11 days in late January a highly significant correlation coefficient of .91 existed between daily reduction in snow depth, daily wind passage and the daily total of degrees in excess of 32°F each hour. Though evaporation may seem significant the temperature only exceeded 32°F on 4 of these days and as a highly significant correlation existed between snow depth reduction and wind passage, drifting may well have been most important during this period.[1]

On the assumption that snow is removed by evaporation reductions in snow depth were compared with the average hourly evaporation per day as recorded by the atmometers. For the period January 14th - March 6th, 1965 a correlation coefficient of .1 was found. This is not even significant at the 5% level of confidence. This apparent lack of association can possibly be ascribed to several factors.

Firstly, the snow plot and campus meteorological station containing the atmometers are differently located and whilst evaporation was usually computed from 8:0 a.m. to 8:0 p.m. the snow depth was observed around 1:30 p.m.. Comparisons are thus subject to areal and temporal differences in data collection.

Secondly, melting and run-off probably help to reduce the snow level.

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1. See Appendix C, p.118.
2. Wilcock, C. 1965, p.9.

Although measurement of snow-melt in pans was unsuccessful the collection of water in the pans indicated that melt as opposed to sublimation did occur. This was further evinced by the fact that meltwater, unable to permeate the frozen soil, collected on and around the plot. Such conditions were most evident on days of negligible wind and temperatures over 32°F. Prolonged spells of warm weather plus wind, as during a chinook, caused the water to vanish quickly leaving the ground dry.

Work elsewhere substantiates the view that the chinook causes considerable winter evaporation. At various times and places tanks have been installed to measure evaporation. Such tanks are commonly four feet in diameter by two feet deep, are sunk in the ground and filled with water to within two inches of the brim. Evaporation causes a fall in water level which can be measured, allowance being made for precipitation recorded in a nearby rain gauge. The evaporation may be influenced by heating due to the restricted volume of the tank and radiation from its sides. Such defects and others are recognised but considered negligible or the same at each site thus making comparisons valid.

Using such tanks a study was made of evaporation from lakes and reservoirs on the prairies.[1] Estimates of winter evaporation were made despite freezing of tanks, it being found that, "air temperatures were a good indicator of winter evaporation."[2] Maps were compiled showing evaporation isopleths for various months and seasons, that for January being included as Figure 10. This shows that evaporation is greatest in south-west Alberta and decreases north and east during January. In summer evaporation is much greater and reaches a maximum around Medicine Hat. The winter pattern would

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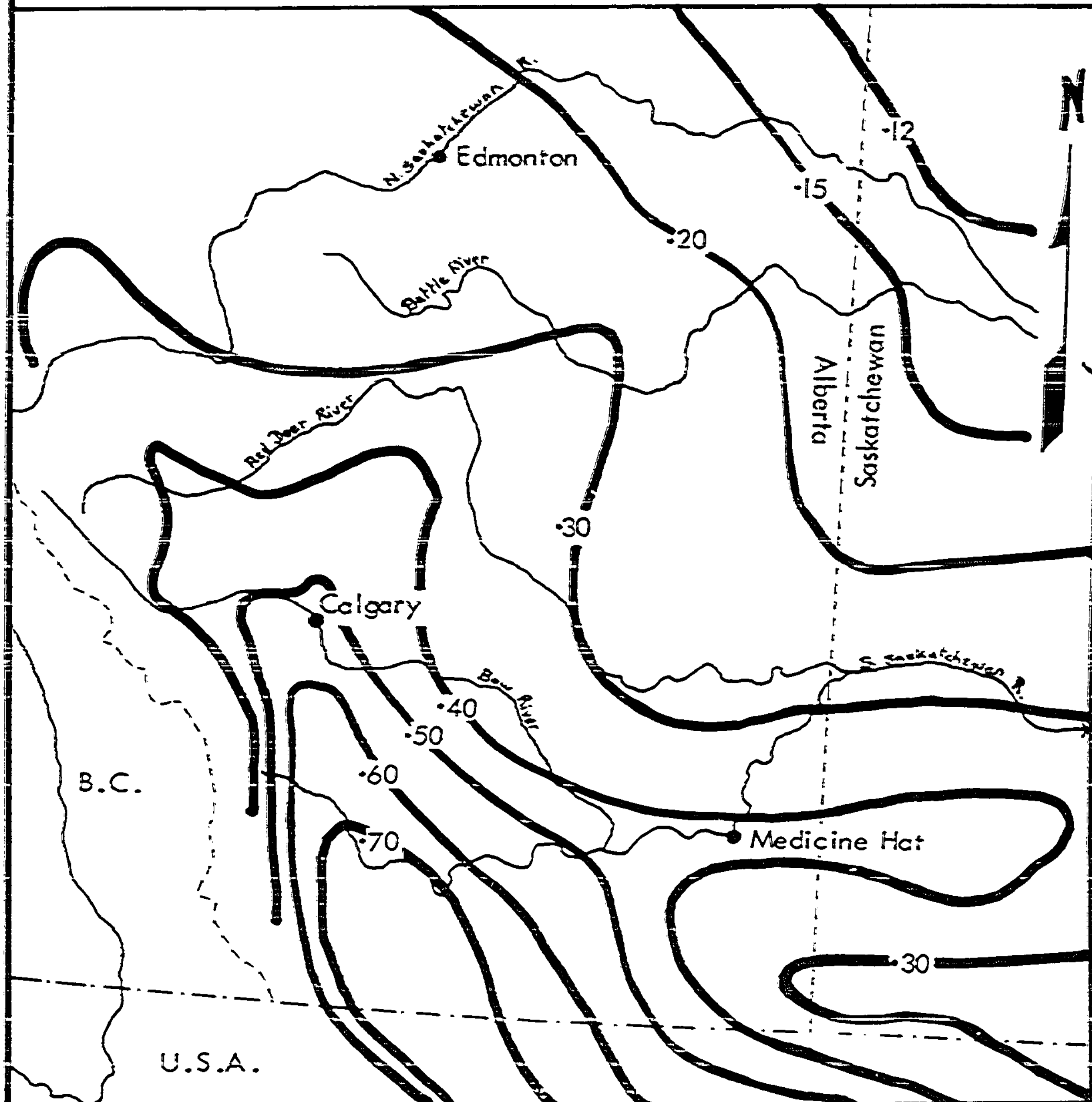
1. Berry, W.M. 1952.
2. Ibid., p.25.

# MEAN JANUARY EVAPORATION FROM LAKES AND RESERVOIRS IN SOUTHERN ALBERTA




SCALE

0 100

miles

Source: Berry, W.M. 1952, Fig.5.

NOTE

The values indicated by the isolines are in inches depth. Great local differences in topography and climate in hilly regions cause large local differences in evaporation not adequately shown here.

Figure 10

seem to reflect the influence of the chinook wind.

There is also further evidence to suggest that the chinook stimulates snow-melt and thereby increases run-off. It was noted in 1887 that:

> Sometimes when the Missouri River is frozen to the depth of a couple of feet or more this warm wave melts the snow and filling the river with water causes the ice to break up and rush down the river at a wonderful rate.[1]

More recent and substantial evidence was cited in a paper by Hoover.[2] He notes that on March 17th, 1939 chinook winds penetrated 500 miles into Saskatchewan and raised temperatures to $70^{\circ}$ at Lethbridge. Ten inches of snow were removed in two days and small prairie streams, dry all winter, suddenly assumed their maximum flow rate for the year. The chinook had thus advanced and concentrated the normal spring run-off of these prairie streams. However, Hoover admits the conditions were exceptional and as with the other cases he mentions the results were localised.

Attempts by the writer to correlate chinook conditions and increased run-off were frustrated by several factors:

1. Gauging stations are few in number and seldom operated during the winter months.

2. Those important rivers that are gauged derive most of their water from the mountains and glaciers, where the chinook is relatively insignificant or weak.

3. The flow of rivers, such as the Bow, is artificially controlled and may not reflect response to natural conditions.

However, records of the flow of Fish Creek and air temperature at Priddis, south-west of Calgary, were obtained. The data for the winters

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1. Lethbridge News. 1887, January 5th.
2. Hoover, O.H. 1948.

## RIVER DISCHARGE AND AIR TEMPERATURE AT PRIDDIS, ALBERTA

| DATE | DECEMBER | | | | JANUARY | | FEBRUARY | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1963 | | 1964 | | 1964 | | 1964 | | 1965 | |
| | D | T | D | T | D | T | D | T | D | T |
| 1 | 3.7 | 44 | 1.8 | -1 | 3.3 | 46 | 0.1 | 34 | | |
| 2 | 3.4 | 30 | 2.2 | 7 | 3.3 | 47 | 0.1 | 35 | | |
| 3 | 3.5 | 44 | 2.0 | 33 | 3.1 | 34 | 0.1 | 40 | | |
| 4 | 3.1 | 38 | 1.6 | 35 | 2.9 | 40 | 0.1 | 46 | | |
| 5 | 3.3 | 40 | 1.4 | ? | 2.5 | 30 | 0.1 | 52 | | |
| 6 | 3.6 | 35 | 1.4 | 48 | 2.2 | 35 | 0.1 | 28 | | |
| 7 | 3.9 | 27 | 1.3 | 48 | 2.0 | 30 | 0.1 | 40 | | |
| 8 | 3.6 | 17 | 1.3 | 41 | 1.8 | 22 | 0.1 | 42 | | |
| 9 | 3.6 | 17 | 2.2 | 31 | 1.4 | 15 | 0.2 | 41 | | |
| 10 | 3.3 | 10 | 1.3 | 34 | 1.4 | 28 | 0.8 | 50 | | |
| 11 | 3.1 | 16 | 2.2 | 19 | 1.1 | 22 | 0.8 | 48 | | |
| 12 | 3.3 | 35 | 3.3 | ? | 0.9 | 14 | 0.9 | 30 | | |
| 13 | 3.0 | 10 | 3.0 | 26 | 0.7 | 34 | 0.9 | 37 | | |
| 14 | 2.8 | 6 | 3.6 | 2 | 0.7 | 35 | 0.8 | 30 | | |
| 15 | 2.8 | 18 | 5.2 | -16 | 0.7 | 32 | 0.9 | 32 | | |
| 16 | 2.8 | 8 | 8.0 | -10 | 0.7 | 35 | 0.8 | 53 | | |
| 17 | 2.8 | 0 | 8.5 | 13 | 0.6 | 39 | 1.1 | 38 | | |
| 18 | 2.5 | 4 | 10.6 | 8 | 0.6 | 30 | 1.1 | 38 | | |
| 19 | 2.4 | 2 | 1.0 | ? | 0.4 | 24 | 1.2 | 44 | 1.6 | 53 |
| 20 | 2.3 | -2 | 1.2 | -13 | 0.3 | 27 | 1.1 | 34 | 25.7 | ? |
| 21 | 2.2 | 6 | 0.9 | -9 | 0.3 | 12 | 1.1 | 41 | 18.1 | ? |
| 22 | 2.2 | 17 | 5.6 | -6 | 0.2 | -3 | 1.1 | 40 | 8.0 | ? |
| 23 | 3.0 | 50 | 0.1 | -2 | 0.2 | -4 | 1.1 | 42 | 4.5 | 32 |
| 24 | 3.7 | ? | 0 | ? | 0.2 | 14 | 1.2 | 48 | 4.2 | 40 |
| 25 | 4.0 | 47 | 0 | ? | 0.1 | 22 | 1.0 | 18 | 3.6 | 53 |
| 26 | 4.2 | 42 | 0 | ? | 0.1 | 28 | 1.0 | 34 | 4.2 | 45 |
| 27 | 4.2 | 24 | 0 | -2 | 0.1 | 26 | 1.1 | 36 | 1.3 | ? |
| 28 | 4.1 | 20 | 9.5 | -5 | 0.1 | 40 | 1.1 | 46 | 1.3 | 10 |
| 29 | 4.1 | 24 | 1.4 | -7 | 0.1 | 40 | 1.1 | 40 | | |
| 30 | 3.8 | 32 | 0.9 | -14 | 0.1 | 42 | | | | |
| 31 | 3.2 | 46 | 1.4 | ? | 0.1 | 36 | | | | |

NOTE: Column D indicates discharge of Fish Creek at Priddis.
Column T indicates maximum daily temperature.
The temperature values for December 1963 and January and February 1964 were recorded at Priddis. All others were recorded at Calgary.

No data is given for January 1965 as the river was frozen.
Where the discharge is shown as 0.1 it ranged from 0 - 0.1

SOURCE: The data, which is subject to correction, was collected by the Government of Canada, Department of Northern Affairs and National Resources, Water Resources Branch, Calgary.

Table 5

1963-4 and 1964-5 is shown in Table 5. Abrupt, but generally unrelated, changes in flow and temperature are clearly evident. Only on December 23rd, 1963 was an abrupt rise in temperature, probably associated with a chinook, contemporaneous with a marked increase in stream flow. In either winter there was definitely no direct correlation between maximum temperature and daily stream flow. This may be attributed to four things:

1. Precipitation in the river basin and its influence on run-off during the two winters was not taken into account.

2. Only when snow was available for melting would the chinook influence run-off. There appeared to be no data on snow cover and its duration in this area.

3. The time lapse between temperature increase, melt and increased run-off was not known. It was found that the exceptional flow of February 20th, 1965 came one day after temperature reached a maximum during chinook conditions. However, such lags when they occurred were not consistent.

4. Increased temperatures, especially when associated with high wind velocity during a well marked chinook, may encourage evaporation rather than melt and run-off.

In a study of flooding at Calgary, King[1] attempted to assess the influence of temperature and precipitation on run-off. However, no correlation was found between precipitation and temperature at Calgary, Banff and Lake Louise and run-off or flooding at Calgary.

Temperature and wind definitely influence snow-melt and run-off but they are only two of the many variables involved. Thus except in occasional

1. King, R. 1964, p.42.

# THE DURATION OF SNOW COVER IN ALBERTA, WINTER 1963-4

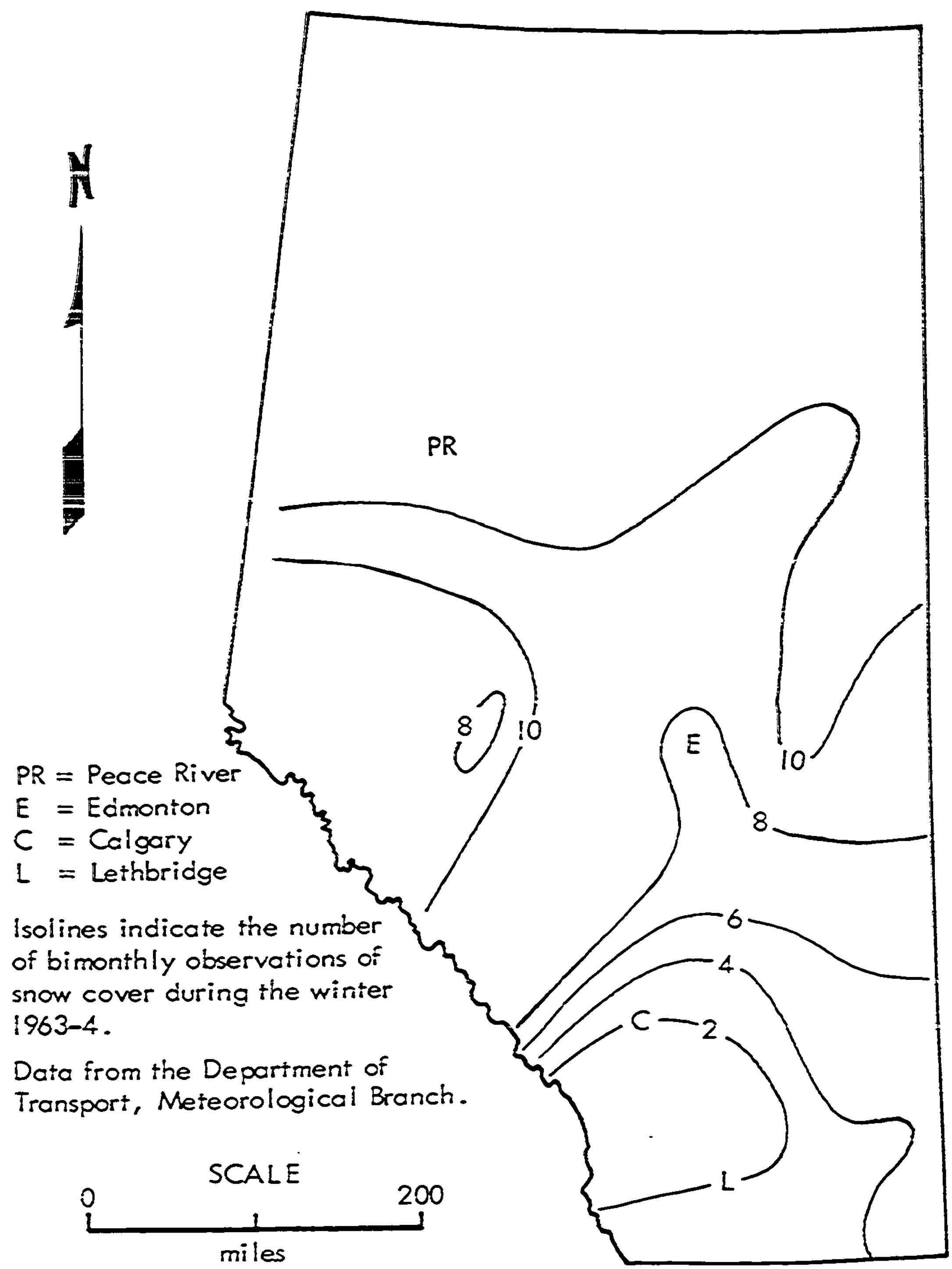


Figure 11

and localised instances no correlation between chinooks and increased run-off can be expected.

The significance of the chinook as a 'snow eater' and snow melter is reflected in the fact that although south-west Alberta has a moderate snowfall the duration of snow cover is very brief.[1] Unfortunately though the influence of the chinook on evaporation and run-off is evident it has so far been found impossible to determine the relative and absolute significance of each. It would seem that high temperatures encourage melt but when associated with wind, as during the chinook, evaporation probably predominates. The importance of evaporation may also be enhanced if meltwater is subsequently evaporated or refrozen then sublimated.

The chinook definitely removes the snow and regardless of the method is clearly of hydrologic and, as will be seen later, of economic importance.

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1.See Figure 11.

CHAPTER 5

## VEGETATION AND THE CHINOOK

The type and pattern of vegetation in any area is governed by variable, interacting physical and cultural factors. It is difficult to isolate the influence of one major factor such as climate and even harder to assess the influence of one aspect of climate like the chinook.

As noted previously[1] the area of significant chinook conditions extends from the semi-arid prairie of south-east Alberta, west and north through the parkland of the foothills into the coniferous forests of the Rocky Mountain Front Range.[2] This is climatically and ecologically a transition zone where the vegetation and perhaps climate have changed continuously. The chinook almost certainly has some influence on the broad, changing composition and pattern of vegetation. However, analysis of this complex relationship would require extensive research beyond the scope of this study. Instead attention is directed toward some of the localised and microclimatic effects of the chinook on vegetation.

Vegetation is very sensitive to fluctuations in temperature, humidity and wind. The abrupt and sustained changes in these factors associated with the chinook may be expected to exert a temporary or even permanent influence on the vegetation. Red belt and forest fires have both been ascribed or related to the chinook and will thus be considered below.

### Red belt

The terms 'red belt' or 'winter kill' are applied to conifers having a red or burnt appearance in the spring or early summer because of tissue damaged foliage. This condition is caused by winter desiccation,

1. Figure 5.
2. See Figure 12.

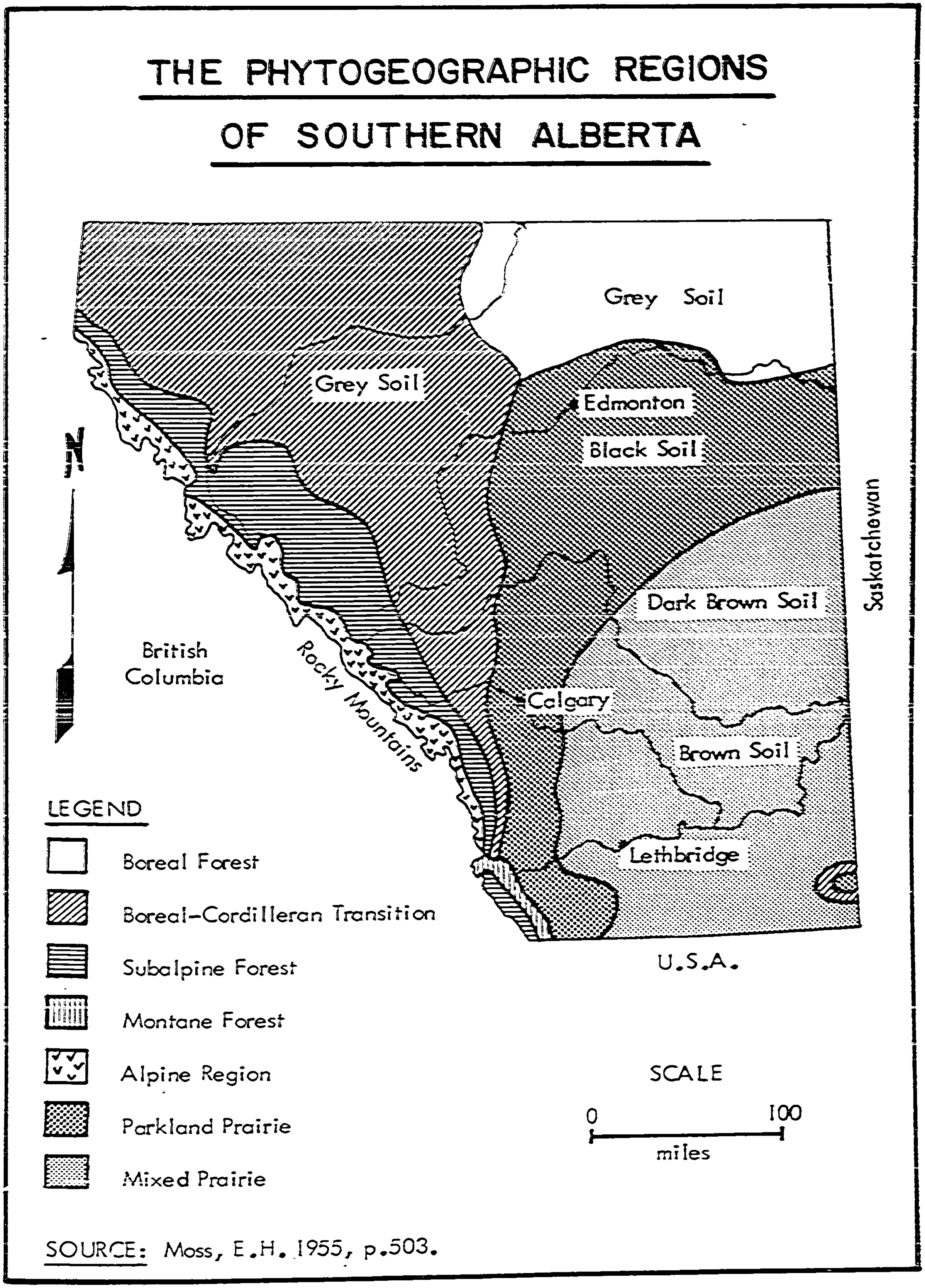
THE PHYTOGEOGRAPHIC REGIONS
OF SOUTHERN ALBERTA
Grey Soil
Grey Soil
Edmonton
Black Soil
Saskatchewan
Dark Brown Soil
British
Columbia
Rocky Mountains
Calgary
Brown Soil
Lethbridge
U.S.A.
N
LEGEND
Boreal Forest
Boreal-Cordilleran Transition
Subalpine Forest
Montane Forest
Alpine Region
Parkland Prairie
Mixed Prairie
SCALE
0
100
miles
SOURCE: Moss, E.H. 1955, p.503.

Figure 12

generally attributed to sharp increases in temperature and reduced humidity, associated with the chinook. Generally speaking, during the winter months, in Alberta, the soil is frozen to a depth of several feet and is physiologically like a dry soil. Hence if a plant transpires the moisture cannot be replaced unless the roots extend below the frozen layer or atmospheric moisture is absorbed. The low transpiration rate of conifers in winter may be increased considerably by the chinook, and if conditions prevent moisture replacement wilting and tissue damage may occur.

Whilst it appears that Lodgepole Pine is most susceptible to damage Scotch Pine, Ponderosa Pine, Douglas Fir, White Spruce and Juniper have also been afflicted in various localities. Damage usually occurs in bands, the more exposed trees and windward foliage suffering most, whilst snow covered foliage remains unharmed. Only the foliage of the preceeding year is affected and if the buds are undamaged the tree may be deformed but usually recovers. Weakening, however, leaves the tree vulnerable to other attacks, for example, by the bark beetle.

A survey[1] of Lodgepole Pine, Douglas Fir and White Spruce damaged in the Kananaskis valley in 1950 showed that dominant and co-dominant trees accounted for 95% of those afflicted. Damage was most severe in the upper portions of the crown and tree-ring analysis in 1952 showed that subsequent growth was reduced in proportion to the amount of crown afflicted. Only one tree, having 95% of its crown killed, died but 35% of the trees developed new leaders.

In 1963, on Nose Mountain, south of Grande Prairie, approximately 700 acres of mixed merchantable, pole-sized, spruce and pine was so damaged

1. Blyth, A.W. 1953.

that many trees died and others, largely defoliated, were not expected to recover.[1] Such discolouration, deformation or killing associated with red belt is quite widespread and makes it of scenic and economic importance.

As all chinooks do not cause red belt and as, in any one area, it is usually localised in bands other factors are obviously involved. The microclimate and moisture condition of the soil and tree are undoubtedly important and warrant quantitative analysis. Field measurements to investigate such factors are rendered difficult because of the size of the trees and the variables involved. Still, many scientists are studying transpiration and a few methods have been suggested for measuring the water content of conifer foliage.

The procedure usually advocated[2] involves collection and weighing of a few needles, fresh then saturated, to determine the water content as a percentage of potential capacity. The analysis of needles successively removed from the same branch should indicate changes in moisture content and perhaps transpiration. Such changes could then be compared with data from meteorological instruments around or in the tree. However, the theory and technique must be refined to yield reliable, significant data. On the advice of scientists engaged on such work the writer refrained from attempting to analyse the influence of the chinook on conifers using this procedure.

A simpler, though less accurate method of correlating chinooks and red belt was used by MacHattie[3] working in the Kananaskis valley in 1956. By comparing the lower limit of damage to trees with snow depth records he was able to decide when desiccation had occurred. This period was one of

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1. Government of Canada, Forest Biology Division, Alberta Ranger Report.1964, p.62
2. Shepherd, R.F. 1964.
3. MacHattie, L.B. 1963, pp.301-7.

chinook activity and he, therefore, concluded that:

> The red belt injury described above is thought to have resulted from sharp temperature rises during the period 21-27 December occasioned by Arctic air in the valley bottom being abruptly displaced by strong chinook winds bringing warm, dry air down to the surface and impinging with particularly sudden and lethal effect on exposed needles, trees and slopes.[1]

Henson[2] observed red belt in the Bow valley, near Castle Mountain,[3] and, like MacHattie, concluded that chinooks were responsible. He noted that, whilst there were anomalies due to topography, damage generally occurred in belts having a lower limit similar in height to the local inversion level in summer. Below this level, and on the shaded slope, he presumed that drainage of cold air protected the vegetation but higher up on the sunny slope vegetation was subjected to desiccating chinook winds.

Both writers in considering the chinook responsible assumed that it occurred in the Front Range valleys. Evidence has already been presented[4] to verify this theory but a correlation of red belt and chinook activity would further substantiate the fact. Undoubtedly ground and tree conditions together with mesoclimatic factors govern the local distribution of red belt. However, if the chinook is basically responsible one would expect to find red belt confined to all or part of the chinook belt.

Despite the lack of comprehensive long term reporting of red belt it is evident that although damaged areas are seldom extensive their occurrence is widespread. It has been observed in North Dakota, Idaho, British Columbia, the Yukon and throughout the Rocky Mountain Front Range and foothills north of the International Boundary. Outbreaks noted since records were begun in Alberta in 1950 were plotted on the map, Figure 13.

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1. Ibid., p.307.
2. Henson, W.R. 1952, pp.62-4.
3. The writer observed reoccurrence of damage in this area in May 1965.
4. See Chapter 3.

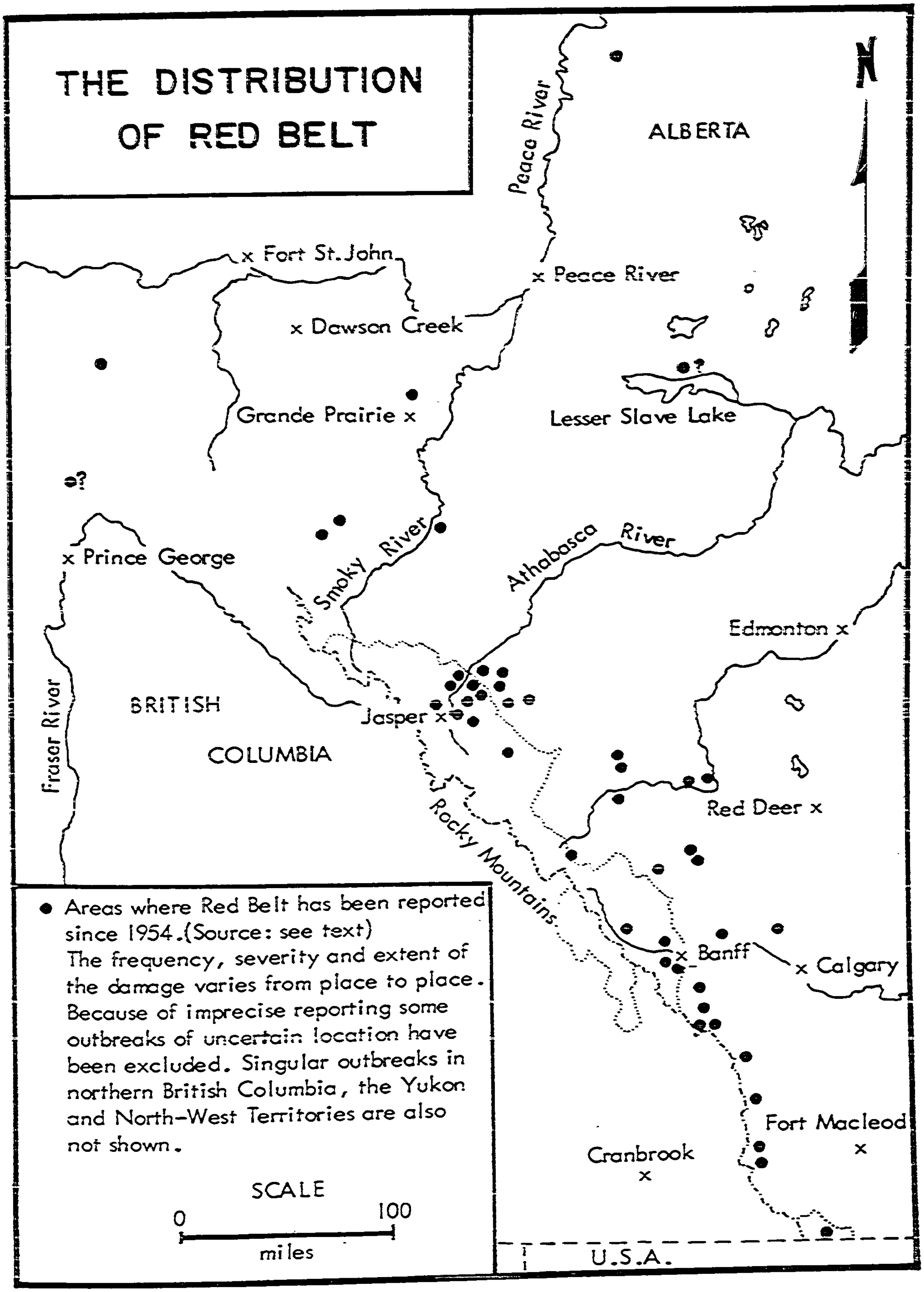
THE DISTRIBUTION OF RED BELT
ALBERTA
Peace River
x Fort St. John
x Peace River
x Dawson Creek
Grande Prairie x
Lesser Slave Lake
x Prince George
Smoky River
Athabasca River
Edmonton x
BRITISH COLUMBIA
Fraser River
Jasper x
Red Deer x
Rocky Mountains
x Banff
x Calgary
Fort Macleod x
Cranbrook x
U.S.A.
● Areas where Red Belt has been reported since 1954.(Source: see text)
The frequency, severity and extent of the damage varies from place to place. Because of imprecise reporting some outbreaks of uncertain location have been excluded. Singular outbreaks in northern British Columbia, the Yukon and North-West Territories are also not shown.
SCALE
0
100
miles

Figure 13

The overall distribution is not coincident with the area of chinook activity however, there is a high frequency of occurrence in the mountains and foothills east of the Continental Divide from Wilderness Provincial Park south to Waterton. This concentration of damage is generally attributed[1] to chinooks and implies that they are significant in the Front Range.

As red belt occurs outside the chinook belt other causal factors must be sought in explanation. Localised foehns, as noted occasionally in the Palouse, Okanagan valley and Queen Charlotte Islands, may sometimes be responsible. Likewise temperature inversions may offer a further explanation. In view of this it is questionable whether all the red belt in the area of chinook activity can be attributed to the chinook wind.

Red belt and the chinook often appear to be causally linked but without further research one cannot be certain that its occurrence in Alberta is always due to the chinook and that its occurrence in the Front Range is definitely indicative of chinook activity in that area.

Fires

Fire has been very important in Alberta's ecological development and, therefore, despite a lack of data the influence of the chinook on this factor merits attention. The increased wind velocity, higher temperatures and lower humidity associated with the chinook will, especially if sustained, tend to make the affected area more susceptible to the outbreak of fire and its subsequent spread. Although fires are mainly a summer phenomenon the chinook will tend to substantially increase the fire hazard during winter.

The increased danger of fire during periods of chinook or foehn conditions has long been recognised. The town of Glarus in Switzerland

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1. Government of Canada, Forest Biology Division, Alberta Ranger Reports.

prohibited smoking in the street when foehn conditions prevailed and ordered extra precautions regarding house fires.[1]

In southern California the Santa Ana foehn wind has been known to reduce humidity to 1% and according to a local fire danger index such winds invariably produce conditions of 'extreme fire hazard.' Sergius notes that:

> In and adjacent to the national forests of southern California the largest and most disastrous fires are associated with the Santa Ana.[2]

Though the influence of the chinook on fires in Alberta has not been studied and is poorly documented some quotes seem significant. The Lethbridge News reported in February 1886 that a chinook began one morning so that, "the whole country was dry by noon and we had a prairie fire that same evening."[3] Other references indicate that winter fires have been common in Alberta from time to time and whilst they have not been attributed to chinooks the phenomenon may have engendered favourable conditions.

In summer conditions favour fires though not the true chinook; but a warm, dry south-west wind is quite common. Thus Patterson in describing ranch life in the High River area recalls how the disastrous fire of June 1936 was rapidly and extensively spread through the foothills range and forest land by such a wind. He remarks that, "the Chinook, the friend in wintertime, but now the destroyer screamed over the foothills day and night."[4]

The chinook, regardless of how one defines the term, must certainly increase the hazard and spread of fire. However, only when it is precisely defined and more data is available on fire incidence can its absolute significance be assessed and an attempt made to correlate its occurrence

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1. Davis, W.M. 188-, p.182.
2. Sergius, L.A. 1952, p.67.
3. Lethbridge News. 1886, February 26th.
4. Patterson, R.M. 1961, p.203.

with fire frequency.

General

On a broader scale the chinook, as a significant factor in the climate of southern Alberta, must exert some influence on the general and local pattern of vegetation. It doubtless emphasises the aridity of this area and Harrington went so far as to say that:

> The Chinooks have probably played an important part in the treelessness of the western prairies and interior basins.[1]

However, the chinook is only one of many variables controlling the vegetation pattern and without further research no conclusive statement should be made regarding the significance of the phenomenon in this respect.

1.Harrington, M.W. 1887, p.521.

Roe, in his authoritative book on the buffalo, considers their distribution and notes, "Meanwhile, it may be laid down with some confidence that the available evidence furnishes no support for any theory of invariably large numbers in any one portion of the Western plains habitat than another."[1] Grazing and shelter requirements doubtless stimulated migration but reports give markedly conflicting details on the season, direction and regularity of movement. Roe concluded that, "The buffalo were highly erratic and that no statement presupposing uniformity of action in their wanderings, if in anything, can be relied upon beyond the actual observed matters of fact it may contain."[2]

Roe lived in Alberta and was certainly aware of the chinook but he found no evidence to suggest that it induced any concentration or migration of buffalo.

The chinook may have had little influence on the buffalo but with the introduction of cattle by the economically motivated pioneer rancher it assumed exceptional significance. Most of the pioneer ranchers reaching Alberta in the early 1880's came from the south. They experienced mild winters and came to rely and be dependent on the chinook. They discussed, noted and boasted about the exceptional features of the climate, and the successful establishment of ranching in these favourable years encouraged excessive climatic optimism.

Kelly noted that by 1886, "Ten years had passed since Fred Kanouse turned the first range cattle loose to rustle on the plains around Macleod,

1. Roe, F.G. 1951, p.366
2. Ibid., p.595.

## CHAPTER 6

### AGRICULTURE AND THE CHINOOK

As noted earlier[1] the true chinook is most pronounced during winter, in a belt extending two to three hundred miles east of the Rocky Mountain Front Range from southern Alberta to Colorado. This belt mainly consists of the western part of the great plains and is predominantly grassland devoted largely to the raising of cattle. Although the grassland extends east, well beyond the area of significant chinook conditions, the cattle density decreases markedly eastward from the belt. One might, therefore, wonder if the chinook is responsible for this concentration of cattle.

Economic factors in conjunction with natural conditions generally govern location but it is interesting to consider whether the chinook alone would induce cattle to concentrate in that part of the grassland which it influences.

It seems safe to assume that the habits of the wild buffalo were a response to natural rather than economic conditions. If, then, an area was climatically a more suitable buffalo habitat than others this might be reflected in movement and/or distribution of herds.

It is often assumed or implied that buffalo concentrated in the foothills because the chinook moderated the winter and, by removing the snow, prolonged the grazing period. There are, indeed, references to large herds in south-west Alberta[2] and to migrations into or through this area.[3] However, large herds were reported in many seasons and places across the plains, as were migrations. Likewise the term, 'the winter home of the buffalo' has had widespread application.

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1. In Chapter 3.
2. MacEwan, G. 1952, p.61.
3. Brodrick, R.N. 1939, p.285.

and during all that ten years there had been no heavy, general loss so the ranchmen figured there was not much likelihood of one coming."[1]

The winter of 1886-7, however, proved them wrong and as it caused a radical and sustained change in outlook and ranching operations it merits some attention.

The summer of 1886, characterised by hot, dry weather, dried up streams and extensive fires left the range in poor condition for winter usage. The first snow was removed by chinooks but after a hard fall on December 31st the Lethbridge News reported, "snow everywhere", "the cry of the stockmen just at present is for a chinook."[2] In mid-January the weather improved, but only briefly, and more snow prompted these reports: February 2nd, "The effect this weather will have on the cattle will be very serious as numbers of them have already succumbed to the cold and hunger."[3] February 9th, "Cattle are dying pretty fast in this vicinity at present."[4] The chinook arrived in late February and on March 14th it was reported, "the green grass is beginning to spring up in the river bottoms."[5]

Estimates of cattle losses vary with the source, time and area considered. The Lethbridge News, which tended to promote the area, reported, April 13th, "The loss in the Canadian territories was estimated from 6-7% among the range cattle and at the worst not more than 20% of the class known as Pilgrim cattle. In Montana, on the other hand, the losses are estimated from 40-65%."[6]

A stockman writing to the editor,[7] however, considered losses under-

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1. Kelly, L.V. 1913, p.199.
2. Lethbridge News. 1887, January 5th.
3. Ibid., February 2nd.
4. Ibid., February 9th.
5. Ibid., March 14th.
6. Ibid., April 13th.
7. Ibid., July 6th.

estimated and comments by Kelly would seem to confirm this. He notes that, "the I.G.Baker, Co., lost 60% of its beef herd that winter,"[1] and that, "twenty thousand cattle died in the country north of the Old Man's River alone."[2]

Regardless of individual losses most farmers learned a lesson; that the chinook can be advantageous but is unreliable, hence emergency hay supplies are essential to ensure against loss. A more realistic outlook was evident in the Lethbridge News which, in August 1887, noted that, "The past winter has demonstrated that while the district is capable of feeding, in summer, several millions of cattle, the area in which cattle can be safely wintered is comparatively limited so far as has yet been ascertained."[3] Hence Kelly says that by 1888, "All ranchers now cut much hay and nearly all had shelter for weak cows and calves."[4]

Subsequent consecutive mild winters induced some fresh dependence on the chinook but severe winters as in 1906-7, when losses were again sustained, once more emphasised the need for caution in exploiting such an unreliable factor.

In the last fifty years stock rearing methods have developed in response to changes in ranching economics. Chattaway[5] noted that around 1900, a ranch might lose 60-70% of its cattle during a severe winter yet restore the herd to its former size in two or three years. Such losses, often caused

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1. Kelly, L.V. 1913, p.199.
2. Ibid., p.201.
3. Lethbridge News. 1887, August 24th.
4. Kelly, L.V. op.cit., p.211.
5. Chattaway, G.D. 1942, p.139.

by undue reliance on the chinook would to-day result in a crippling financial loss or even bankruptcy. To what extent, then, can and does the Alberta rancher of to-day depend upon the chinook? To answer this question and thereby assess the significance of the chinook information on ranching methods and operating costs was required.

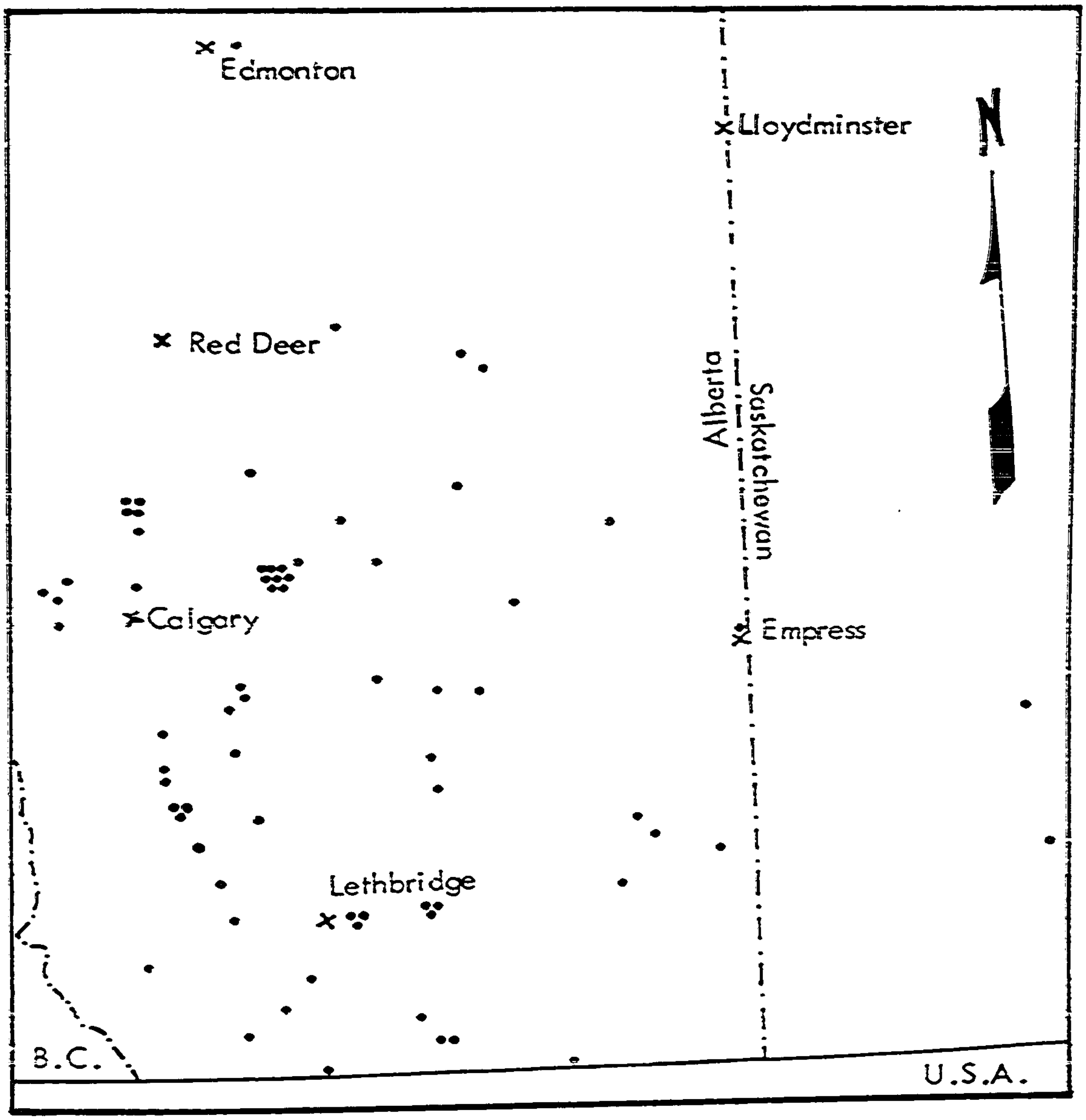
The writer has been unable to obtain reports on the two relevant surveys of Alberta ranching, conducted in 1938[1] and 1954[2] and no data has yet been derived from the grazing survey recently initiated by A.R.D.A.[3] Thus to gain up to date comprehensive data a farm questionnaire, included in Appendix D, was prepared for distribution to ranchers. Questions were asked on the acreage of farm and rangeland, the number of cattle, wintering practices, and the source and use of feed. Information was also gained on soil erosion, availability of farm weather records and the ranchers opinion as to the chinook's value.

Distribution of the questionnaire was effected by personal contact with ranchers or people who knew them. Approximately 100 were issued and 76 farms returned them completed. Despite some local concentrations the distribution of these farms through the ranching area of Alberta was reasonably good and is shown in Figure 14.

The questionnaire supplied much useful data but could have been improved had time allowed a greater distribution and a test usage to expose faults. The reliability and hence value of data from such a questionnaire is dependent upon its singular interpretation and the accuracy and comparability of the answers. This one was kept brief and general to encourage response and

1. Referred to by Chattaway, G.D. 1940, p.460.
2. By the Government of Canada, Department of Agriculture, Economic Division.
3. Referred to by Schmidt, J. The Calgary Herald, 1965, March 27, p.46.

# THE DISTRIBUTION OF FARMS RETURNING QUESTIONNAIRES




• Farms that returned questionnaires.

One was also returned from Manning and three from unspecified locations.

SCALE

0 100

miles

Figure 14

and facilitate speedy analysis. However, this produced some differences in interpretation. For example, the farm acreage sometimes includes and sometimes excludes the range area. The term winter feed is also variously interpreted, quantities being given in bales or tons, per cow or per herd, per winter or per day. Fortunately the small number of unreliable or incomparable answers does not detract greatly from the value of the questionnaire. The individual rancher's comments supplement the above data and by combining all such information with that from other sources the present significance of the chinook in Alberta ranching can be assessed.

Cattle are widespread in Alberta south and east of Entwistle. They are raised on the following types of farm: ranches and dairy farms, which are devoted to cattle but for differing purposes; mixed farms, where crops become important; and grain farms. In the Calgary and foothills region ranches predominate and of all the farm types seem most dependent on the chinook. In view of this and the scope of the questionnaire the writer has concentrated on this type of livestock enterprise.

The ranches surveyed varied considerably in operation and size. Ranging from 80-280,000 acres, 43% were under 1,000 acres, whilst the 12 that exceeded 10,000 acres all lay south of the latitude of Calgary.

In summer, given adequate water, such ranches have few problems but this is a year round business. Market conditions make it no longer economic to sell a large number of cattle before winter to the stockyards. It was thus noted on one questionnaire that, "A ranch is no better than the number of cattle it can winter."[1] Successful ranching depends upon maintaining the health and weight of cattle through the rigorous winter conditions by

1. Because information was confidential rancher's names have not been given.

the most economic methods.

The wintering of cattle on the range is normally most economic. However, the condition of the range or the weather may render it partially or totally inadequate and make it necessary to provide supplementary feed all or part of the winter. The chinook is important since, in removing snow, it increases the availability of winter range. This may only amount to a few weeks on the margin of the chinook belt but in south-west Alberta it frequently makes possible the maintenance of cattle on the range all winter.

Unfortunately the chinook, especially where weakest, may remove some snow then cease, whereupon an ice crust forms. This prevents the cattle muzzling through to graze and cuts their legs. Under such conditions or when, in the absence of chinooks, snow accumulates to great depth and low temperatures prevail, feeding becomes necessary. If the cattle are isolated or feed is inadequate a disastrous situation may develop, as in the 1964-5 winter.

In this winter chinooks were infrequent and seldom extended north or east of Claresholm. Persistent deep snow and 21 consecutive days of freezing weather caused cattle to succumb. Losses were greatest on the chinook belt margin. By January 6th 350 cattle around Oyen and 500 around Hanna were reported dead and losses for the province were put at 2,000.[1] It was also suggested that the ability of cows to bear calves and bulls to reproduce might be impaired. An estimated 70,000 cattle were expected to sell for $5,000,000 less than normal due to loss of weight and quality, whilst a further 5,000 cattle, crippled by the cold, would have to be sold early.[2]

Such losses are generally incurred when the rancher has insufficient

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1. Calgary Herald. 1965, January 6th, p.1.
2. Ibid., February 11th.

feed, cannot obtain feed at an economic price or is unable to reach the cattle. Whilst few ranchers depend entirely on the chinook most find it uneconomic to produce annually the feed required in such exceptional winters. Thus of the ranchers questioned 97% grew feed but only 48% grew all they could and most grew just sufficient for an average winter.

During a severe winter, when prolonged feeding is necessary, normal supplies become inadequate. Artificial feeds may be unlimited but the cost is often prohibitive. Hay, which is the most important feedstuff, usually becomes scarce and prices rise accordingly. Thus in December 1963 number 1 hay fetched \$15 per ton but in December 1964, due to a poor crop and hard winter, it commanded over \$25 per ton and in places reached \$40 per ton by early February.[1] Only on humanitarian grounds can such prices be afforded. Several ranchers find it cheaper to clear some of the range using a bulldozer.

Even if feed is available conditions may sometimes leave cattle inaccessible. It was reported, January 6th, 1965 that, "Few farmers have horses and drifted roads have made it impossible for them to transport hay to cattle too cold to move to the feed."[2]

Absence of the chinook may thus prove costly or disastrous and 25% of ranchers questioned had, at some time, lost cattle during severe weather. However, such losses cannot be compared with those sustained by the pioneer cattlemen, who relied almost completely on the chinook. Though complete reliance on the chinook may prove disastrous it must be, and is, regarded as a resource, neglect of which is uneconomic.

The importance of the chinook in ranching varies according to ranch

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1. Calgary Herald. 1965, February 11th.
2. Ibid., January 6th.

location and the attitude of the rancher. The chinook's areal variation is thus partially reflected in areal differences in wintering practices.

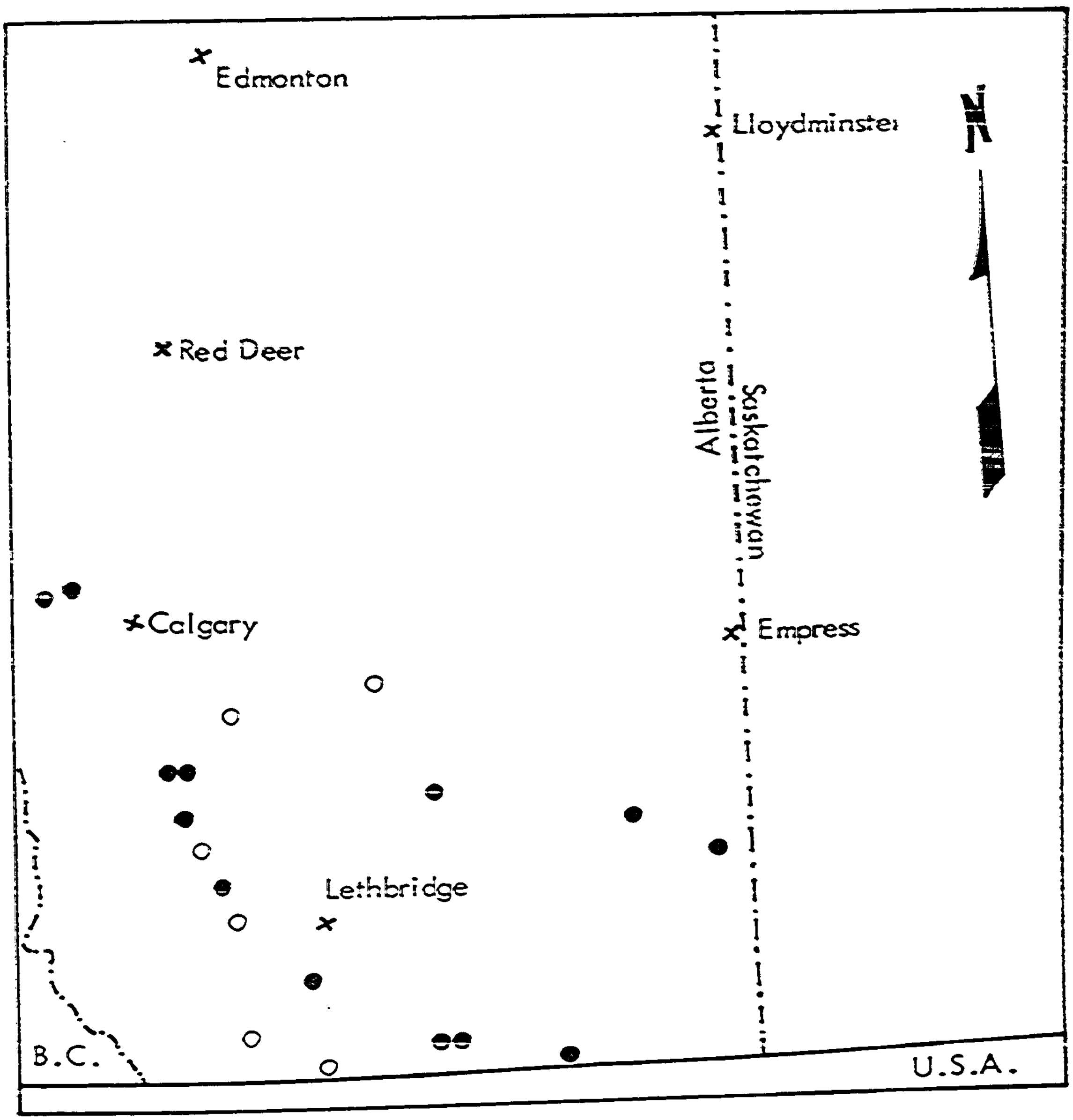
In the more favoured areas feeding may not be necessary if the range is clear, whilst elsewhere even if the chinook does not clear the snow the higher temperatures may reduce feed requirements. Thus of 67 ranches surveyed 18% leave all, and 12% some, of their cattle on the range all winter. These ranches all lie south of Calgary or in the Bow River valley, as shown in Figure 15. Elsewhere the chinook is less effective in clearing range and cattle are wintered near the ranch. Calves and bulls are usually the first to be taken off the range and the remaining cattle may only be left on the range some of the winter.

There are marked variations from ranch to ranch in the amount and type of feed used. The amount depends mainly on the severity of the winter, hence the chinook. Thus a rancher at Carstairs noted that, "Cattle in mild weather consume about one third less feed than in really cold weather."[1] It was said that in south-east Alberta, "The ranchers generally figure three quarters to one ton of hay per head for winter feeding as being a sufficient security against loss. In many cases they have gotten by with as little as ½ to ½ a ton and still maintained the cattle in weight."[2] Of the ranches surveyed some in southern Alberta had only fed twice in twelve years but of the total 64% feed all and every winter. The average amount of feed per cow ranged from ½ to 3 tons per winter.

The questionnaire revealed numerous local differences in average feed amounts which can likely be attributed to the individual attitudes of ranchers. On eight ranches around Rockyford the average feed per cow, per

1. Name not given as information supplied confidentially.
2. Longman, O.S. 1936, p.38.

# THE WINTERING OF CATTLE




● Cattle left on range all and every winter

○ Some cattle left on range all winter, or cattle left on range some of the winter

At the other ranches all cattle are taken off the range during winter

SCALE

0 — 100 miles

Figure 15

winter ranged from 1-2 tons. A rancher at Waterton noted that, "We feed somewhat more heavily than certain of our neighbours because this practice pays off, I feel, in marketing weights."[1]

Despite local variations there is a general pattern that shows feeding requirements to be clearly less in south-west Alberta. The chinook is most marked in this area and away from it the effects are less and the feed requirements consequently greater, as is shown in Figure 16.

Whilst feed requirements may be influenced by the chinook it is feed production that is economically significant. Because the chinook is unreliable few ranchers depend upon it and hence feed production usually exceeds requirements, especially during mild winters. Thus a rancher at Rockyford stated that, "We provide 3 tons of hay per cow during the winter months but most winters only feed 1½ tons."[1]

Hay production requires land, labour and time and is therefore a very important operating cost in ranching. Unless the hay surplus of a mild winter can be preserved for the next or sold uneconomic overproduction seems inevitable. The lack of reference to storage practices suggests that such a carry-over is rare, perhaps due to the initial cost of facilities. It seems likely that uneconomic waste of, or reliance upon, hay is being avoided by use of other supplementary feeds. A large and increasing number of ranchers use concentrates and grain. A Waterton rancher remarked that, "our emphasis is changing constantly from cutting range grass and volunteer timothy to cutting intensively cultivated fields, in which alfalfa plays a large part.[1] Many of the ranchers questioned reported providing oats and vitamins as well as hay and over half reported buying feed. Such methods may seem expensive

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1. Name not given as information supplied confidentially.

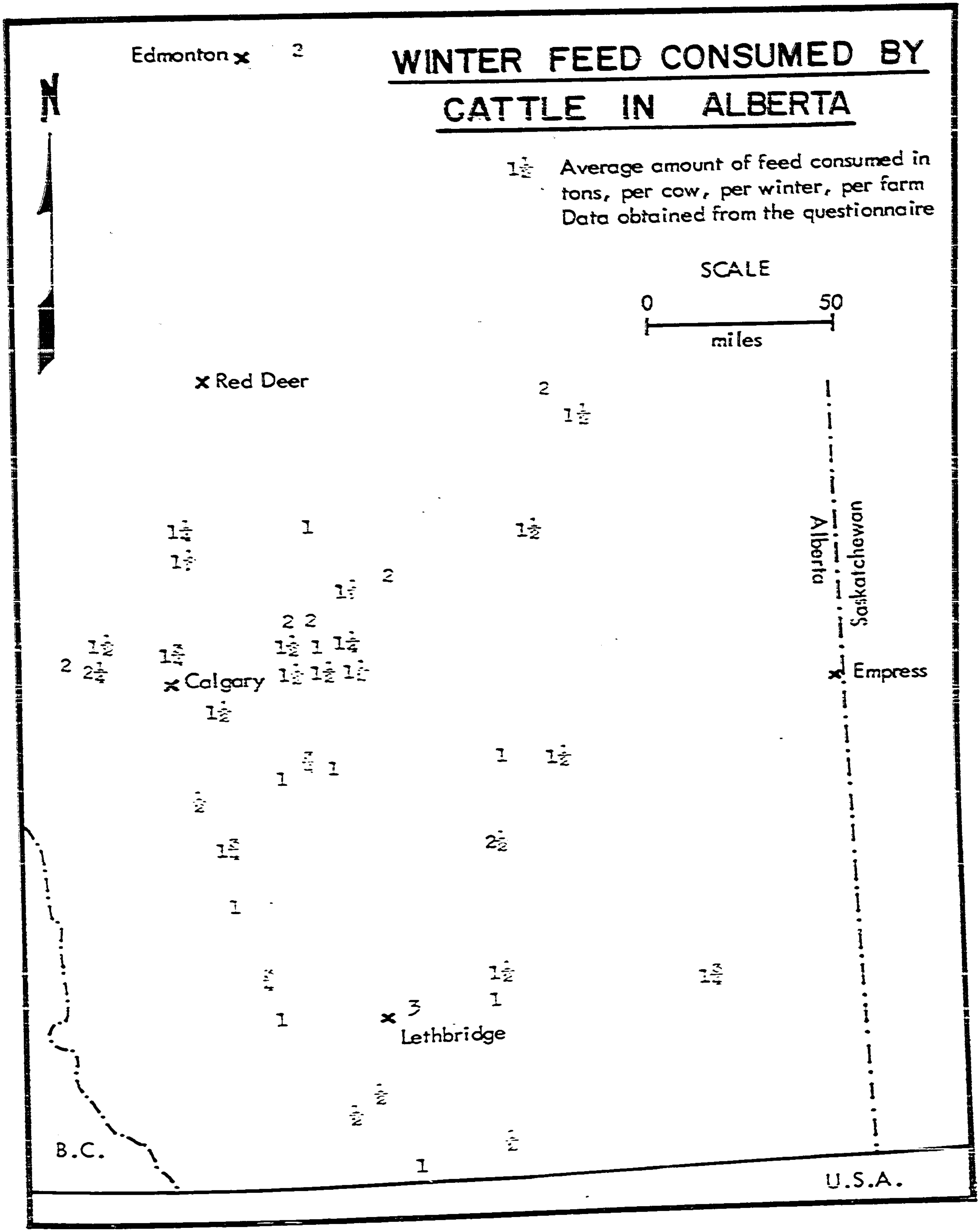

WINTER FEED CONSUMED BY CATTLE IN ALBERTA
Average amount of feed consumed in tons, per cow, per winter, per farm
Data obtained from the questionnaire
SCALE
0
50
miles
N
Edmonton
Red Deer
Calgary
Lethbridge
Empress
Alberta
Saskatchewan
B.C.
U.S.A.

Figure 16

but they insure sufficient feed in severe weather and avoid overproduction of hay in most years.

However, many ranchers still depend on hay and because the chinook is unreliable they have a surplus after a good winter or must buy expensive feed during a bad one. Thankfully severe winters are infrequent and the fact that only on such occasions is feed short shows that ranchers by no means produce what they would have to were the chinook absent. The chinook would be much more significant if it was dependable but even so it enables feeding economies that cancel out the costs of hay overproduction and the infrequent need to buy expensive feed.

Feed is a substantial operating cost in modern ranching, especially on the prairies, where long winters are normal. Thus any factor such as the chinook, that will reduce such costs, is of great significance to the rancher. In southern Alberta feeding practices vary but all clearly reflect an attempt to make the most economic use of an unreliable factor, complete dependence on which may spell ruin.

Unfortunately the beneficial effects of the chinook are to a certain extent offset by some harmful influences. The abrupt weather change associated with the chinook may on occasion adversely affect cattle and sheep. Several ranchers recalled how abrupt rises in temperature had resulted in pneumonia, though others thought this only occurred with heavy feeding. Septicemia and shipping fever in cattle and heat prostration in sheep have also been attributed to sudden temperature increases as caused by chinooks. Such outbreaks are limited and doubtless other factors are involved.

Whilst in the mountains the chinook injures the conifer on the plains it is the pasture and crops that suffer from the wind. By stimulating sublimation and evaporation the chinook depletes the limited supply of water available for growth. Then, if the ground is tilled or overgrazed it may be susceptible to soil erosion.

Even in pioneer times dust clouds were observed during chinooks but soil erosion only appears to have become significant much later. Longman considers that, "The problem of soil drifting is one of comparatively recent origin in the Province of Alberta, the first time it reached serious proportions was in 1920. The most seriously affected area at this time was immediately west of Lethbridge, where about 75,000 acres were completely destroyed."[1] Anderson of the Lethbridge Research Station recently recalled that during the 1930's, "some townships appeared to be masses of moving sand" and added that, "We don't get that now."[2] However, of the farms surveyed 50% had suffered some soil erosion due to chinook winds. One rancher at Herronton considered such erosion eliminated all the benefits of chinook winds. However, another at Crossfield noticed that other winds were just as likely to cause erosion. Grain and mixed farms that turn the soil would appear much more susceptible to soil erosion than the true ranch. Field observations and the sporadic incidence of the phenomenon suggest that soil erosion, whilst stimulated by chinooks, is a culturally induced phenomenon that can be prevented if adequate precautions are taken.

In summary the chinook is both useful and detrimental in the agriculture of southern Alberta, but it is always significant. To the rancher it seems beneficial, 76% of those questioned considered it so and 69% thought it saved them money. However, in certain ways it may be detrimental, especially in other forms of agric. enterprise.

1. Longman, O.S. op. cit. pp.25-6.
2. Anderson, T. The Calgary Herald. 1964, February 27th.

69% thought it saved them money. However, in certain ways it may be detrimental, especially in other kinds of agricultural enterprise.

CHAPTER 7

## SUMMARY AND CONCLUSION

In view of the preliminary nature of this study it seems somewhat premature to draw safely many conclusions, except regarding research methods. Indeed whilst the writer considers some general conclusions in order suggestions regarding future work in the Chinook Research Project would seem to be of more value.

When the study was begun specific references to the chinook appeared negligible and the numerous brief allusions to the phenomenon of little value. However, as the bibliography shows, subsequent research revealed that the chinook had attracted a moderate amount of scientific attention intermittently since about 1880. Such material was of varied quality but indicated some of the problems requiring solution and showed the chinook to be a more complex and variable phenomenon than the writer had realised.

The basic cause of the chinook and its similarity to the foehn is known; the significance of adiabatic processes and lee waves appreciated, but the origin and ground characteristics of chinook air are not fully understood and more research is warranted.

The initiation of the Chinook Research Project, with new stations and instruments has provided more data to aid in analysing the meteorological properties of the phenomenon. Still more instruments are needed, especially in the Calgary urban area and in the Bow Valley above Exshaw. The development of temperature traverse studies and the installation of thermocouples on a high radio transmitting tower would be particularly useful. However, first more careful and efficient use must be made of existing instruments and data and the operation of instruments such as the anemometers must be perfected.

When a greater amount of more accurate and comparable data is available and the means to analyse it are developed a much needed definition of the chinook can be formulated. To satisfy the geographer this must be developed from the plainsmen's definition and be based on a quantitative evaluation of those meteorological factors that are characteristic of chinook conditions at ground level.

This will enable one to assess numerically the frequency, intensity, duration and distribution of the chinook, thereby making it possible to compare and correlate its incidence with natural and economic changes and responses in the area it covers.

In the absence of such a definition the writer adopted a qualitative definition in gaining some insight into the influence of the chinook on some aspects of hydrology, vegetation and agriculture.

The influence of the warm, dry chinook in removing the snow cover and further depleting the supply of ground moisture has long been recognised but scarcely studied. Attempts were made to determine the influence of the chinook on snow melt and evaporation and the relative importance of each. Numerous operational problems were encountered but the work and that by other agencies definitely shows that the chinook stimulates both evaporation and melt. The relative importance of each apparently depends on the wind and hence chinook conditions would generally seem more conducive to evaporation. Clearly the study of the chinook and the hydrologic cycle is a project in itself requiring the collection of more data, improvement of existing techniques and the devlopment of new ones. In using the snow plot more frequent observation of more accurately graduated stakes is called for. There is also a need to locate thermographs, hygrographs, atmometers and the net radiometer at this site and to develop means for measuring the amount of drifting that occurs and for measuring the water content of the snow.

The significance of the chinook as a factor influencing the vegetation pattern was not assessed because of the variables involved, however, consideration was given to the relationship between the chinook and red belt and fires. Bearing in mind the character of the chinook and the cause of red belt the chinook appears responsible, but the occurrence of red belt outside the chinook belt indicates that other factors, possibly even in the chinook area, may be responsible. The chinook seems likely to increase fire hazard and spread but only more data on fires and a precise definition of the chinook will enable one to correlate fire and chinooks.

The research into the influence of the chinook on agriculture appears to be unique and was restricted largely to the effects on ranching, data being obtained mainly from a questionnaire. By depleting soil moisture, encouraging soil erosion and causing some ill health among animals the chinook can be unwelcome. However, the chinook generally benefits the rancher by clearing the snow in winter, though its unreliability and the consequent need to maintain feed supplies detracts somewhat from its value. As this aspect of the research is perhaps of more practical significance and of interest to farmers it warrants more detailed examination.

Probably most important of all is the need to realise that the influence of the chinook is much greater than this study suggests. Only time has prevented investigation of the chinook's influence on geomorphology, wildlife, fuel consumption, air pollution, road and rail snow clearance, aviation, recreation and human physiology.

The chinook is a complex phenomenon that has a varied and variable influence on the landscape that merits the attention of the geographer. The writer hopes that this preliminary study will stimulate and provide a basis for more accurate and specific research into the chinook and its influence.

## BIBLIOGRAPHY


Abbe, C. 1896. "A footnote concerning the use of the term 'chinook' in an article by Berry, J." Monthly Weather Review, V. 24, (1), p. 7.

Abbe, C. 1907. "The Wet and Dry Chinooks." Monthly Weather Review, V. 35, (4), pp 176-177.

Ackerman, E. A. 1941. "The Koeppen Classification of Climates in North America." Geographical Review, V. 31, p. 105.

Adhav, R. S. 1963. "A Thermograph for use in the Arctic." Arctic, V. 16, (3), pp 201-202.

Albertson, F.W., and J. E. Weaver. 1945. "Injury and death or recovery of trees in Prairie Climate." Ecological Monographs, No. 15 (4), pp 395-432.

Aldous, M. 1881. "Extract from a Report by Mr. Montague Aldous, D.T.S. on the Survey of the Block Outlines in the Bow River District." Government of Canada, Department of Interior, Annual Report, Part 1.

Allbright, W. D. 1922. "Some Climatic Characteristics of Central Alberta." Bulletin of the American Meteorological Society, V. 3, p. 171.

Alty, T. 1939. "Evaporation in Agricultural Meteorology." Canadian Journal of Research, V. 17, Sec. C, (1), pp 1-3.

American Meteorological Society. Meteorological and Geastrophysical Abstracts, 1951 - 1965.

Anderson, H.W. 1946. "The Effect of Freezing on Soil Moisture and on Evaporation from a Bare Soil." Transactions of the American Geophysical Union, V. 27, (6), pp 863-870.

Arthur, I.P. 1955. "An Evapotranspirometer." Australian Journal of Agricultural Research, V. 6, (5), pp 707-712.

Ashwell, I. Y. 1964. The Geography of Fohn-Type Winds. Unpublished paper presented at the annual meeting of the Canadian Association of Geographers, London, Ontario, May 1964.

Ashwell, I. Y. A., and F. G. Hannell. 1958. "Notes on a Fohn Wind in Iceland." Weather, V. 13, (9), pp 295-297.

Askin, T. 1951. "The Cattle Enterprise in Relation to Farm Organization in Alberta." The Economic Annalist, V. 21, (6), pp 133-135.

Austin, A. R. L. 1952. "Wave clouds over southern England." Weather, V. 7, (2), p. 50.

Baker, F. S. 1918. "Some Field Experiments on Evaporation from Snow Surfaces." Monthly Weather Review, V. 45, (7), pp 363-366.

Bates, C. G. August 1921. "Breaking the Power of Prairie Winds." Illustrated Canadian Forestry Magazine, p. 336.

Bates, C. G. 1923. "Physiological requirements of Rocky Mountain trees." Journal of Agricultural Research, pp 97-164.

Bavendick, F. J. 1920. "Blizzards and Chinooks of the North Dakota Plains." Monthly Weather Review, V. 48, (2), pp 82-83.

Begg, A. 1882. Chapter 16 in: Macoun, J., Manitoba and the Great North West.

Begg, A. 1889. "Early Exploration in North West Canada." Scottish Geographical Magazine, V. 15, pp 351-356.

Bellaire, F. R., and L. J. Anderson. 1951. "Thermocouple Psychrometer for Field Measurements." Bulletin of the American Meteorological Society, V. 32, (6), pp 217-220.

Bemis, A. C. 1947. "Weather Radar Research at M.I.T." Bulletin of American Meteorological Society, V. 28, (3), pp 115-198.

Berry, W. M. 1952. "Evaporation from Lakes and Reservoirs on the Canadian Prairies." Prairie Provinces Water Board, Report No. 15, p. 27.

Bethlahmy, N. 1952. "Why do plants wilt in cold weather?" Ecology, V. 33, pp 301-303.

Birrell, J. 1965. Aspects of Chinook Arch as a Wave. Unpublished manuscript prepared for Geography Course 305, University of Alberta, Calgary.

Blair, R. V., and R. A. Terzi. 1963. Bow River Snow Survey, 27th Annual Report. Government of Canada, Department of Northern Affairs and National Resources, Water Resources Branch, Calgary.

Blyth, A. W. 1953. Reduction of Growth in Conifers caused by Red Belt in the Subalpine Region of Alberta. Government of Canada, Department of Resources and Development, Division of Forest Research, Silvicultural Leaflet, No. 79. 3 pp.

Bolin, B. 1950. "On the Influence of the Earth's Orography on the General Character of the Westerlies." Tellus, V. 3, p. 192.

Borchert, J. R. 1950. "The Climate of the Central North American Grassland." Annals of the Association of American Geographers, V. 40, (1), pp 1-39.

Bowerman, A. 1886. "The Chinook Winds and Other Climatic Conditions of the North West." The Historical and Scientific Society of Manitoba, Transaction N. 22, 6 pp.

Bradbury, T. A. M. 1965. "Wave Clouds over Berkshire." Weather, V. 20, (1), pp 16-17.

Bradbury, T. J. 1965. "Wave Clouds over Sutherland." Weather, V. 20, (2), pp 56-57.

Bradley, R. 1963. Snowcraft and Ski Mountaineering for Amateurs. A privately produced booklet of 21 pages. Calgary.

Brodrick, R. N. 1939. "The Great Buffalo Migration." Canadian Cattlemen, V. 2, (3), p. 285.

Brown, A. H. 1946. "Americans Stand Guard in Greenland." National Geographical Magazine, V. 90, No. 4, pp 457-500.

Brunger, A. 1965. Development of Clouds in the Calgary Area. Unpublished manuscript, prepared for Geography Course 305, the University of Alberta, Calgary.

Brunt, D. 1934. Physical and Dynamical Meteorology. Cambridge University Press, 411 pp.

Bryson, R. A. 1955. "Convective Heat Transfer with Light Winds." Transactions of American Geophysical Union, V. 36, pp 209-212.

Buckingham, H. 1907. "The 'Southwest' or 'Wet' Chinook." Monthly Weather Review, V. 35, (4), pp 175-176.

Bulletin of the American Meteorological Society. 1938. A review of the paper, "Chinook Winds in Northern Colorado" by R. L. Ives in the American Journal of Science, Feb. 1938, pp 138-142. Bulletin of the American Meteorological Society, V. 19, p. 409.

Bulletin of the American Meteorological Society. 1938. A comment on and reprint of a remark on a chinook on December 28, 1937. Taken from The Calgary Herald, Dec. 29, 1937. Bulletin of the American Meteorological Society, V. 19, pp 408-409.

Burgess, A. M. 1885. Report of the Deputy Head on his visit to the North West. Government of Canada, Department of Interior, Annual Report, 1884.

Burkell, S. R. 1953. "Cattle Production in Western Saskatchewan and Eastern Alberta." The Economic Annalist, V. 23, (3), pp 65-69.

Burkell, S. R. 1954. "Marketing Practices of Cattle Ranchers in Southwestern Saskatchewan." The Economic Annalist, V. 24, (5), pp 108-111.

Burkell, S. R. 1956. "Organization and Management Practices of Cattle Ranchers in Southwestern Saskatchewan." The Economic Annalist, V. 26, (2), pp 34-37.

Burkell, S. R. 1958. "Recent changes in cattle production in Alberta and Saskatchewan." Economic Annalist, V. 28, (1), pp 19-23.

Burpee, L. J. (Ed.) 1907. "York Factory to the Blackfeet Country - The Journal of Anthony Hendry 1754-1755." Transactions of the Royal Society of Canada, 3rd Series, V. 1, Section 2.

Burrows, A. T. 1903. "The Chinook Winds." The Journal of Geography, V. 2, pp 124-136.

Burton, G. L. 1941. "The Early Development of Cattle Ranching in Alberta." The Economic Annalist, V. 11 (3), pp 41-46.

Butler, P. F., and J. A. Prescott. 1955. "Evaporation from Wheat and Pasture in Relation to Available Moisture." Australian Journal of Agricultural Research, V. 6, pp 52-61.

Byrne, A. R. 1964. Man and Landscape Change in the Banff National Park Area before 1911. Unpublished M.A. thesis, Geography Department, University of Alberta, Calgary.

C.O.P.A. "Beware of the Mountain Wave." C.O.P.A. Safety Bulletin, Ottawa.

Caborn, J. M. 1958. "Some observations of snow drifting near barriers." Weather, V. 13, (8), pp 264-267.

Calgary Herald. Calgary Herald, 1885 - present.

Calgary Tribune. Calgary Tribune, 1885-1895. Later the Albertan.

Campbell, J. A., and J. B. Campbell. 1942. "Grassland Investigations in Alberta, Saskatchewan, and Manitoba. Canadian Cattlemen, V. 5, (2) p. 53.

Campbell, J. B., R. W. Lodge, A. Johnston, and S. Smoliak. 1962. Range Management of Grasslands and Adjacent Parklands in the Prairie Provinces. Government of Canada, Department of Agriculture, Research Branch, Publication No. 1133.

Chambers, E. J. 1914. The Unexploited West. Government of Canada, Department of Interior, Ottawa.

Chapline, W. R. 1929. "Erosion on range land." Journal of the American Society of Agronomy, V. 21, pp 423-429.

Chattaway, G. D. 1940. "Economic Survey of Cattle Ranching." Canadian Cattlemen, V. 3, (3), p. 460.

Chattaway, G. D. 1942. "Views on cattle ranching." Canadian Cattlemen, V. 4, (4), p. 139.

Childs, E. C. 1964. "The Movement of Soil Water." Endeavour, V. 23, (89), pp 81-84.

Church, J. E. 1933. "Snow Surveying: Its principles and possibilities." Geographical Review, V. 23, pp 529-563.

Clarke, S. E. 1930. "Pasture investigations on the short-grass plains of Saskatchewan and Alberta." Scientific Agriculture, V. 10, pp 732-749.

Clarke, S. E., E. W. Tisdale, and N. A. Skoglund. 1947. The Effects of Climate and Grazing Practices on Short-Grass Prairie Vegetation in Southern Alberta and Southwestern Saskatchewan. Government of Canada, Ministry of Agriculture, Publication No. 747, 54 pp.

Coe, A. 1896. "How the Chinook came in 1896." Monthly Weather Review, V. 24, (11), p. 413.

Colson, de Ver. 1952. "Result of Double Theodolite Observations at Bishop, California in connection with the "Bishop Wave" phenomena." Bulletin of the American Meteorological Society, V. 33, pp 107-116.

Colson, de Ver. 1954. "Meteorological Problems in Forecasting Mountain Waves." Bulletin of the American Meteorological Society, V. 35, (8), pp 363-371.

Cook, A. W., and A. G. Topil. 1952. "Some examples of Chinooks east of the mountains in Colorado." Bulletin of the American Meteorological Society, V. 33, pp 42-47.

Cornish, V. 1902. "On Snow Waves and Snow Drifts in Canada." Geographical Journal, V. 20, p. 158.

Coupland, R. T. 1950. "Ecology of Mixed Prairie in Canada." Ecological Monographs, V. 20, (4).

Coupland, R. T. 1958. "The Effects of Fluctuations in Weather upon the Grasslands of the Great Plains." Botanical Review, V. 24, (5), p. 273.

Crag and Canyon. Crag and Canyon, 1900 to present. Banff Weekly Newspaper.

Craig, J. 1903. Ranching with Lords and Commons.

Critchfield, H. J. 1949. "Climatic Aspects of Soil Erosion in the Palouse Region." Bulletin of the American Meteorological Society, V. 30, (3), p. 106.

Croft, A. R. 1944. "Evaporation from Snow." Bulletin of the American Meteorological Society, V. 25, pp 334-347.

Cumberland, K. 1944. "Contrasting Regional Morphology of Soil Erosion in New Zealand." Geographical Review, V. 34.

Currie, B. W. 1955. Wind and Storms. The Prairie Provinces and North West Territories, Climatic Studies, Part 6. Physics Department, University of Saskatchewan, Saskatoon. 28 pp.

Currie, B. W. 1953. Precipitation and Snowfall. Prairie Provinces and North West Territories Climatic Studies. Physics Department, University of Saskatchewan, Saskatoon.

Currie, B. W. 1953. Temperature. Prairie Provinces and North West Territories Climatic Studies. Physics Department, University of Saskatchewan, Saskatoon.

Curry, L. 1960. "Atmospheric Circulation in the Southern South Pacific." New Zealand Geographer, V. 16, p. 73.

Darcovich, W. 1957. "Beef Production Farms in Alberta." The Economic Annalist, V. 27, (6), pp 132-138.

Davis, W. M. 1887. "The Foehn." American Meteorological Journal, V. 6, (4), pp 182-191; V. 6, (5), pp 224-227.

Davis, W. M. 1887. "The Foehn in New Zealand." American Meteorological Journal, V. 3, (10), pp 442-443.

Dawson, G. M. 1881. Report of Progress for 1879-1880. Government of Canada, Geological and Natural History Survey of Canada.

Deppermann, E. E. 1948. "Notes on 35 mm. Cloud Photography at Manilla." Bulletin of American Meteorological Society, V. 29, No. 3, pp 133-136.

Dionne, J. L., G. W. Robertson, and R. M. Holmes. 1956. Agricultural Meteorology. A brief literature review and bibliography. Government of Canada, Department of Agriculture.

Dordick, I. 1958. "The influence of variations in atmospheric pressure upon human beings." Weather, V. 13, (11), pp 359-364.

Doughty, A. G. (Ed.) 1929. The Kelsey Papers. Published by the Public Archives of Canada and the Public Record Office of Northern Ireland. Ottawa.

Douglas, C. K. M. 1936. "Fohn Wind in the Alps." Meteorological Magazine, London, V. 71, pp 72-73.

Dowling, D. B. 1917. The Southern Plains of Alberta. Government of Canada, Geological Survey, Memoir 93.

Duckworth, F. S., and J. S. Sandber. 1954. "The effect of cities upon horizontal and vertical temperature gradients." Bulletin of American Meteorological Society, V. 35, (5).

Economic Annalist. 1944. "Cattle Ranching in Western Canada." The Economic Annalist, V. 14, (2), p. 45.

Fisher, C. A. 1923. "Some factors affecting the evaporation of water from soil." Journal of Agricultural Science, V. 13, pp 121-143.

Fletcher, R. D. 1951. "Hydrometeorology in the United States." In the 'Compendium of Meteorology,' American Meteorological Society, Boston, 1951, pp 1033-1047.

Forbes, L. M. 1964. "Drought on the Range." Land, Forest, Wildlife, V. 7, No.2 p. 4-19.

Formozov, A. N. Snow Cover as an Integral Factor of the Environment and its Importance in the Ecology of Mammals and Birds. Translated from the Russian by W. Prychodko and W. O. Pruitt. University of Alberta, Edmonton, Boreal Institute, Occasional Paper No. 1, 176 pp.

French, G. M. 1951. "Mountain Waves and Their Effects on Flight." Civil Aeronautics Board, Bureau of Safety Investigation, Safety Bulletin 186-51, Washington, D.C., U.S.A. 14 pp.

Frey, K. 1957. " Diagnose der Fohns." Meteorologische Rundschau. Berlin V. 10, (6), pp 181-185. Abstract in: Meteorological and Geastro-Physical Abstracts, 1959.

Friedrich, C. A. 1961. "Factors that determine spring runoff in the Northern Rocky Mountains." Journal of Soil and Water Conservation, V. 9, pp 86-89.

Fruh, J. 1901. "Foehn in Fort Good Hope." Meteorologische Zeitschrift, V. 18 p. 36. (File of a summary and translation only)

Gard, R. E. 1945. Johnny Chinook, 360 pp.

Geiger, R. 1965. The Climate Near the Ground. Revised Edition, Harvard University Press, 611 pp.

Geisler, C. B. 1963. The Survey of Snow and Skiing Conditions in the Lake Louise Ski Area, 1962-1963. Unpublished manuscript, prepared for the Calgary Olympic Development Association.

Glenn, C. L. 1961. "The Chinook." Weatherwise, V. 14, (5), pp 175-182.

Gloyne, R. W. 1955. "Some Effects of Shelterbelts upon Local and Microclimate." Forestry, V. 27, pp 85-95.

Godman, R. M. 1959. "Winter Sunscald of Yellow Birch." Journal of Forestry, V. 57, (5), pp 368-369.

Godske, C. L., T. Bergeron, J. Bjerknes, and R. C. Bundgaard. 1957. Dynamic Meteorology and Weather Forecasting. Published by American Meteorological Society and the Carnegie Institution.

Government of Alberta, Bureau of Provincial Information, Bulletin No. 25. 1928. Peace River Country.

Government of Canada, Department of Agriculture. 1936. A Report on the Rehabilitation of the Dry Areas of Alberta and Crop Insurance, 1935-1936.

Government of Alberta, Department of Agriculture, Farm Economics Branch. 1963. 1963. Alberta Farm Business Reports.

Government of Canada, Department of Agriculture, Edmonton. 1941. "Cattle Survey in Alberta, December 1940. Canadian Cattlemen, V. 3, (4), p. 536.

Government of Canada, Department of Agriculture, Range Experimental Station, Mannyberries, Alberta. 1941. "Feed Requirements for Wintering Cattle." Canadian Cattlemen, V. 4, (3), p. 117.

Government of Canada, Department of Agriculture, Forest Biology Division. Alberta Ranger Reports, 1954-1964.

Government of Canada, Department of Mines and Technical Surveys, Geographical Branch, Ottawa. 1957. The Atlas of Canada.

Government of Canada, Department of Northern Affairs and National Resources, Water Resources Branch, Calgary District. 1964. Snow Surveying Operations. A paper presented at the Conference on Snow Research, University of Alberta, Calgary, 19 September, 1964.

Government of Canada, Department of Transport, Air Services, Civil Aviation Branch, 1963. Accident Report, Serial No. 1958. 2 pp.

Government of Canada, Department of Transport, Meteorological Branch. Daily Weather Maps.

Government of Canada, Department of Transport, Meteorological Branch. Monthly Record of Meteorological Observations in Canada.

Government of Canada, Department of Transport, Meteorological Branch. 1963. Annual Summary of 'Snow Cover Data.'

Government of Canada, Department of Transport, Meteorological Branch. 1964. Monthly Meteorological Summaries, of Observations taken at Calgary Municipal Airport, Alberta.

Government of Canada, Department of Transport, Meteorological Branch. 1964. Calgary, Alberta: Annual Meteorological Summary, Long Term Records 1885 - present.

Government of Canada, Department of Transport, Meteorological Division. Climatic Summaries for Selected Meteorological Stations in the Dominion of Canada, V. 1. Toronto.

Government of Canada, Department of Transport, Meteorological Division. 1939. "Origin of the Chinook." Canadian Cattlemen, V. 1, (4), p. 146.

Government of Canada and Alberta. 1963. East Slopes (Alberta) Watershed Research Program. First Annual Report, 1963. Prepared by Technical Co-ordinating Committee.

Government of the United States, The Air Force, Cambridge Research Centre. 1954. "Flight Aspects of the Mountain Wave." Flying Safety, Jan. 1954, pp 21-28.

Government of the United States, Department of Agriculture, Soil Conservation Service, Agriculture Handbook No. 169. 1959. Snow Survey Sampling Guide.

Grassham, R. T. 1907. "The 'Dry' Chinook in British Columbia." Monthly Weather Review, V. 35, (4), p. 176.

Grogan, S. A. 1919. "Hot Winds at Tampico, Mexico, April 6 and 7, 1919." Monthly Weather Review, V. 47, (4), p. 234.

Halstead, M.H., & Covey, W. 1957. "Some meteorological Aspects of Evapotranspiration." Proceedings of the Soil Science Society of America, V. 21, pp 461-464.

Hann, J. 1885. "Einge Bemerkungen zur Entwicklungs-Geschichte der Ansichten uber den Ursprung des Fohn." Meteorologische Zeitschrift, V. 2, (2), pp 393-399.

Hanson, W. R. 1953. "The Range Resource of Alberta Foothills and Mountains." Canadian Cattlemen, V. 16, (10), pp 26-27.

Hargrave, H. J. 1939. "The Chinook as a factor in the Ranching Business." Canadian Cattlemen, V. 1, (4), p. 162.

Harney, P. J. 1948. "A note on the reporting of temperatures from aircraft." Bulletin of American Meteorological Society, V. 29, (4), pp 198-201.

Harrington, L. 1953. "The XIT in the Cypress Hills." Canadian Cattlemen, V. 16, (11), p. 15.

Harrington, M. W. 1886-1887. "The Chinook Winds." American Meteorological Journal, V. 3, (7), pp 330-338; V. 3, (10), pp 467-475; V. 3, (11), pp 516-523.

Harris, E. C. R. 1939. "From My Diary." Canadian Cattlemen, V. 2, (1), p. 195.

Hazen, H. A. 1888. "Chinook Winds." Monthly Weather Review, V. 16, pp 19-20.

Henson, W. R. 1952. "Chinook Winds and Red Belt Injury to Lodgepole Pine in the Rocky Mountain Park Area of Canada." Forestry Chronicle, V. 28, pp 62-64.

Heusser, C. J. 1963. "Prairie-Forest Boundary in Western Canada." Geographical Review, V. 53, No. 2, pp 309-310.

Hewson, E. W., and R. W. Langley. 1944. Meteorology Theoretical and Applied.

Holmes, R. M., and G. W. Robertson. 1958. "Note on a Portable Field Growth Chamber for Winter Injury Studies." Canadian Journal of Plant Science, V. 38, pp 377-379.

Hoover, O. H. 1948. Effects of Chinook (Foehn) Winds on Snow Cover and Run-off. A paper presented at the General Assembly of the International Union on Geodesy and Geophysics, 1948.

Horton, R. E., and H. R. Leach. 1930. "Snow Surface Temperature." Monthly Weather Review, V. 68, pp 128-130.

Hughes, F. I. B. 1942. "Let's Brag About Our Weather." Canadian Cattlemen, V. 2, (4), pp 146-147.

Humphrys, C. R. "Evapotranspiration Bibliography." Michigan State University, Water Publication No. 7.

Ing, R. W. 1943. "Tales from the Midway Ranch (Installment 12)." Canadian Cattlemen, V. 6, (4), p. 139.

Ives, R. L. 1938. "Chinook Winds in Northern Colorado." American Journal of Science, Series 5, V. 35. (206), pp 138-142.

Ives, R. L. 1941. "Colorado Front Range Crest Clouds and Related Phenomena." Geographical Review, V. 31, pp 23-45.

Ives, R. L. 1950. "Frequency and Physical Effects of Chinook Winds in the Colorado High Plains Region." Annals of the Association of American Geographers, V. 40, (4), pp 293-327.

Ives, R. L. 1952. "Snow Eaters of the High Plains." Weatherwise, V. 5, pp 32-34.

Johnson, H. N. 1936. "The Dry Chinook Wind. Bulletin of the American Meteorological Society, V. 17, (1), pp 23-27.

Johnstone, D., and W. P. Cross. 1949. Elements of Applied Hydrology. 276 pp.

Jones, R. 1928. "Some Physical Controls on the Economic Development of the Prairie Provinces." Geography, V. 14, pp 284-302.

Jones, S. B. 1934. Human Occurance of the Bow-Kicking Horse Region, Canadian Rocky Mountains. Unpublished Ph.D. thesis, Harvard University.

Kelly, L. V. 1913. The Range Men.

Kendrew, W. G., and B. W. Currie. 1955. The Climate of Central Canada. Queen's Printer, Ottawa, 194 pp.

Kidson, E. 1932. "The Canterbury 'Northwester'." The New Zealand Journal of Science and Technology, V. 14, (2), pp 65-75.

Kincer, J. B. 1923. "The Climate of the Great Plains as a factor in their Utilization." Annals Association of American Geographers, V. 13, pp 67-80.

King, R. 1964. Flooding of the Bow River at Calgary. Unpublished term paper prepared for Geography Course 407, at the University of Alberta, Calgary.

Kitto, F. H. 1919. The Peace River District, Canada. Government of Canada, Department of Interior.

Klein, G. J. 1947. "Snow Cover Measurements. Supplement to Report No. MM-192." National Research Council of Canada, Report No. MM-202. Ottawa.

Kline, C. M. 1950. "Livestock Feeding in Alberta." The Economic Annalist, V. 20, (4), pp 86-91.

Koeppe, C. E. 1931. The Canadian Climate. McKnight and McKnight, 280 pp.

Koldovsky, M. 1964. "Lee Waves behind Krknose." Weather, V. 19, (5), p. 153.

Krick, I. P. 1933. "Foehn Winds in Southern California." Beitrage zur Geophysik, V. 39, (4), pp 399-407.

Krick, I. P. 1934. "Foehn-Wind Cyclo-genesis." Beitrage zur Geophysik, V. 42, (1), pp 56-69.

Krug-Genthe, M. 1903. "Der Chinook." Geographische Zeitschrift, V. 9, (10), pp 575-578.

Langemann, R. E. 1965. Report on Temperature Variations within the City of Calgary. Unpublished manuscript prepared for Geography Course 305, at the University of Alberta, Calgary.

Larsen, J. A. 1930. "Forest Types of the Northern Rocky Mountains and Their Climatic Controls." Ecology, V. 11, pp 631-672.

Larson, F. 1940. "The Role of Bison in Maintaining the Short-Grass Plains." Ecology, V. 21, (2), pp 113-121.

Larsson, L. 1954. "Observations of Lee Wave Clouds in the Jamtland Mountains, Sweden." Tellus, V. 6, No. 2, pp 124-138.

Lawrence, E. N. 1953. "Fohn Temperature in Scotland." Meteorological Magazine, London, V. 82, (969), p 74-79.

Laycock, A. H. 1957. Precipitation and Streamflow in the Mountain and Foothill Region of the Saskatchewan River Basin. Government of Canada, Prairie Provinces Water Board, Report No. 6.

Lethbridge News. Lethbridge News, 1885-1887. Southern Alberta Newspaper.

Livingston, B. E., and F. W. Haasis. 1929. "The Measurement of Evaporation in Freezing Weather." Journal of Ecology, V. 17, pp 315-328.

Lockwood, J. G. 1962. "Occurence of Fohn Winds in the British Isles. Meteorological Magazine, London, V. 91, pp 57-65.

Loewe, F. 1950. "Foehn effects near the Balleny Island, Antarctica." Weather, V. 5, No. 5, pp 152-154.

Loewe, E., and U. Radok. 1955. "A Wave Cloud at Heard Island." Weather, V. 10, (3), pp 78-80.

Longman, O. S. 1936. Government of Canada, Department of Agriculture, 1936.

Lull, H. W. (Ed.) 1953. "Evapotranspiration: Excerpts from Selected References." Government of the United States, Department of Agriculture, Forest Service, Occasional Paper No. 131. Washington.

Mackenzie, A. (Sir) 1801. Voyages from Montreal, on the River St. Lawrence, through the Continent of North America to the Frozen and Pacific Oceans in the Years 1789 and 1793 with a Preliminary Account of the Rise, Progress, and Present State of the Fur Trade of that Country. London, T. Cadell.

Macoun, J. 1880. "Extract from a Report of Exploration by Professor John Macoun." Government of Canada, Department of Interior, Annual Report, 1880, Part I, p. 15.

Macoun, J. 1882. Manitoba and the Great North West. Guelph, Ontario.

Marsh, J. S. 1965. Winter Evaporation at Calgary. Unpublished Manuscript prepared for Geography Course 305, the University of Alberta, Calgary.

Martin, E. V. 1943. "Studies of Evaporation and Transpiration under Controlled Conditions." Carnegie Institution of Washington, Publication No. 550, 48 pp.

Math, F. A. 1934. "Battle of the Chinook Wind at Havre, Montana." Monthly Weather Review, V. 62, (2), pp 54-58.

Mellor, M. 1959. "Gauging Antaractic Drift Snow." Proceedings of a Symposium on Antaractic Meteorology, Melbourne, 1959. pp 347-354.

Middleton, W. E. K., and A. F. Spilhaus. 1953. Meteorological Instruments. 286 pp.

Miralles, V. G., and J. Catala. 1955. "A Spanish Chinook." Weather, V. 10, (12), p. 425; V. 10, (5), p. 173.

Monteith, J. L. 1956. "The Effect of Grass-Length on Snow Melting." Weather, V. 11, (1), pp 8-9.

Monteith, J. L. 1958. "Lee Waves in Wester Ross." Weather, V. 13, (7), pp 227-230.

Monthly Weather Review. 1896. "The Chinook in Oregon." A part of, and comment on, the forecast of B. S. Pague of Portland for Dec. 3, 1896 . Monthly Weather Review, V. 24, (12), p. 460.

Moss, E. H. 1955. "The Vegetation of Alberta." The Botanical Review, V. 21 No. 9, pp 493-567.

Mysak, S. 1950. "Farm Business in the Warner-Milk River District of Southern Alberta." The Economic Annalist, V. 20, (2), pp 34-38.

McBain, B. J. 1963. An Evaluation of Feed Costs for a Cow-Calf Operation in Alberta. Unpublished Manuscript, Government of Alberta, Department of Agriculture, Farm Economics Branch.

McCabe, H. J. A New Look At Chinooks. Unpublished Manuscript, 4 pp.

McCaffery, W. D. S. 1952. "Fohn effect over Scotland." Meteorological Magazine, London, V. 81, pp 151-152.

McCaul, C. C. 1888. "South Alberta and the Climatic Effects of the Chinook Wind." American Meteorological Journal, V. 5, (4), pp 145-159.

McClain, E. P. 1952. "Synoptic Investigation of a Typical Chinook Situation in Montana." Bulletin of the American Meteorological Society, V. 33, (3), pp 87-94.

MacEwan, G. 1952. Between the Red and the Rockies. University of Toronto, 300 pp.

MacHattie, L. B. 1962. Some Comments on the Meteorology of Forest Fire Control and Forest Regeneration in Canada. A paper presented at Symposia on Water Balance of the Soil and Forest Meteorology, at a scientific session of W.M.O. Technical Commission for Agricultural Meteorology, pp 81-91.

MacHattie, L. B. 1963. "Winter Injury of Lodgepole Pine Foliage." Weather, V. 18, (10), pp 301-307.

MacInnes, C. M. 1930. In the Shadow of the Rockies.

McKay, G. A., G. E. Curry, and A. S. Mann. 1963. Climatic Records for the Saskatchewan River Headwaters. Canada Dept. of Agriculture, Prairie Farm Rehabilitation Administration, Engineering Branch.

McKinnon, L. 1948. Lachlin McKinnon, Pioneer. 130 pp.

MacLeay,G. M. 1940. "Cattle Losses on Western Ranches." Canadian Cattlemen, V. 3, (1), p. 378.

Macleod Gazette. Macleod Gazette. Southern Alberta Newspaper, 1882-1886.

Nelson, S. E. 1940. "Large Scale Prairie Fire in December." Canadian Cattlemen. V. 2, (11), p. 329.

Nix, J. E. 1960. Mission Among the Buffalo. Toronto.

Ogilvie, W. 1891. Report on the Peace River and Tributaries in 1891. Government of Canada, Department of Interior.

Osgood, E. S. 1929. The Day of the Cattleman, p. 220.

Osmond, H. W. 1941. "The Chinook Wind East of the Canadian Rockies." Canadian Journal of Research, V. 19, Section A, (4), pp 57-66.

Palliser, J. et al. 1863. The Journals, Detailed Reports, and Observations Relative to the Exploration by Captain Palliser of that Portion of British North America, which in Latitude, lies Between the British Boundary Line and the Height of Land or Watershed of the Northern or Frozen Ocean Respectively, and in Longitude, Between the Western Shore of Lake Superior and the Pacific Ocean During the Years 1857, 1858, 1859, and 1860. Eyre and Spottiswoode, London.

Panofsky, H. A., and G. W. Brier. 1963. Some Applications of Statistics to Meteorology. 224 pp.

Patterson, R. M. 1961. The Buffalo Head. MacMillan.

Petterssen, S. 1958. Introduction to Meteorology. McGraw-Hill, 327 pp.

Picard, A. 1958. "Connaissance du Foehn." L'Information Geographique, Paris, V. 22, (5), pp 209-220.

Pollak, L. W. 1946. "Further Remarks on Early Uses of Punched Cards in Meteorology and Climatology." Bulletin of the American Meteorological Society, V. 27, (5), pp 195-199.

Potter, G. J. 1961. "Changes in Seasonal Snowfall in Cities." The Canadian Geographer, V. 5, No. 1.

Primeau, L. L. 1956. "Mountain Waves." Flight Comment, March-April 1956, pp 16-21.

Queney, P. 1948. "The Problem of Air Flow Over Mountains: A Summary of Theoretical Studies." Bulletin of the American Meteorological Society, V. 29, (1), pp 16-26.

Queney, P. 1955. "Rotor Phenomena in the Lee of Mountains." Tellus, V. 7, Part 3.

Ramaley, F. 1908. "Climatology of the Mesas near Boulder, Colorado." University of Colorado Studies, 1908, pp 19-31.

Rigby, M. (Ed.) 1951. "Meteorological and Geastrophysical Abstracts, V. 2." Bibliography on Special Winds. American Meteorological Society.

Rigby, M. (Ed.) 1962. "Meteorological Abstracts and Bibliography, V. 10, Supplement 3." Agricultural Meteorology. Pub. American Meteorological Society.

Roe, F. G. 1951. The North American Buffalo. Toronto.

Roe, F. G. 1957. "Western Penetration of the Historic Buffalo in the Upper Bow River Valley." Alberta Historical Review, V. 5, (1), pp 21-24.

Rood, J. L. 1961. "DC-8 Incident Report - High Altitude Turbulence." Trans-Canada Airlines' Report.

van Rooy, M. P. 1936. "Influence of Berg Winds on the Temperatures along the West Coast of South Africa." Quarterly Journal of the Royal Meteorological Society, V. 62, (267), pp 528-537.

Runciman, D. 1954. "Seventy Years of Progress." Canadian Cattlemen, V. 17, (7), p. 22.

Sanderson, M. 1948. "Drought in the Canadian Northwest." Geographical Review, V. 38, pp 289-299.

Sanson, N. B. 1919. "Snow in the Rocky Mountains Park." Canadian Alpine Journal, V. 10, p. 38.

Schneider, L. R. 1930. "Greenland, West Coast Foehns; A Discussion Based on the Foehns of January, 1929." Monthly Weather Review, V. 58, (4), pp 135-138.

Scorer, R. S. 1951. "Forecasting the Occurrence of Lee Waves." Weather, V. 6, pp 99-103.

Scorer, R. S. 1953. "Theory of Air-flow Over Mountains." Quarterly Journal of the Royal Meteorological Society, V. 79, pp 70-83.

Scorer, R. S. 1954. "Observing Waves." The Aeroplane, Oct. 15, 1954.

Sergius, L. A. 1952. "The Santa Ana." Weatherwise, V. 5, (3), pp 66-68.

Shantz, H. L. 1923. "The Natural Vegetation of the Great Plains Region." Annals of the Association of American Geographers, V. 13, pp 81-107.

Sharp, P. F. 1955. Whoop-up Country. The Canadian American West, 1865-1885.

Shepherd, R. F. 1964. Problems in Measuring Needle Moisture Deficits of Forest Trees. Unpublished Manuscript, Government of Canada, Department of Forestry, Forest Entomology and Pathology Branch, Calgary.

Sherman, L. A. 1885. "A Theory of the Chinook." American Meteorological Journal, V. 2, (1), pp 18-22.

Sherzer, W. H. 1907. "Glaciers of the Canadian Rockies and Selkirks." Part of: The Smithsonian Contributions to Knowledge, V. 34.

Simaluk, V. 1965. Pattern of Cyclone Movement over Calgary. Unpublished manuscript, prepared for Geography Course 305, the University of Alberta, Calgary.

Slatyer, R. O., and I. C. McIlroy. 1961. Practical Microclimatology. UNESCO.

Smoliak, S. 1956. "Influence of Climatic Conditions on Forage Production of Shortgrass Rangeland." Journal of Range Management, V. 9, pp 89-91.

Southern California Soaring Association. 1952. Mountain Wave Project, Reports 2 & 3.

Steele, C. F. 1961. Prairie Editor. Ryerson Press, Toronto, 196 pp.

Stewart, J. B. 1964. "Wave Clouds in Austria. (Photograph)" Weather, V. 19, (9), p 284.

Stoeckeler, J. H., and P. O. Rudolf. 1949. Winter Injury and Recovery of Conifers in the Upper Midwest. U.S. Department of Agriculture, Lake States Forest Experiment Station, Minnesota, Station Paper No. 18.

Stupart, R. F. 1910. "The Chinook in Southern Alberta and Temperature Inversions at Sulphur Mountain, Banff." Proceedings of the Royal Society of Canada, Series 3, (4), 3, pp 51-52.

Stupart, R. F. 1914. "The Climate of Southwestern Alberta." Transactions of the American Climatological Association, V. 30, pp 9-15.

Sullivan, B. E. 1965. An Areal Survey of Winter Temperature Conditions in the Calgary Area. Unpublished Manuscript prepared for Geography Course 305, at the University of Alberta, Calgary.

Symons, R. F. 1965. "Sierra Wave." Weather, V. 20, (5), p. 162.

Thambyahpillay, G. 1958. "The Kachchan - Fohn Wind in Ceylon." Weather, V. 13, (4), pp 107-114.

Thomas, M. K. 1953. Climatological Atlas of Canada. Government of Canada, Department of Transport, Meteorological Branch.

Thomas, M. K. 1961. A Bibliography of Canadian Climate, 1763-1957. Government of Canada, Department of Transport, Meteorological Branch. 114 pp.

Thomas, T. M. 1963. "Some Observations on the Chinook 'Arch' in Western Alberta and North Western Montana. Weather, V. 28, (6), pp 166-170.

Thompson, D. 1962. "David Thompson's Narrative, 1784-1812." Edited by R. Glover. The Publications of the Champlain Society, V. 40, Toronto.

Thomson, L. B. 1938. "Costs of Beef Cattle Production." Canadian Cattlemen, V. 1, p. 42.

Thornthwaite, C. W. 1931. "The Climates of North America According to a New Classification." Geographical Review, V. 21, pp 633-655.

Thornthwaite, C. W. 1940. "Atmospheric Moisture in Relation to Ecological Problems." Ecology, V. 21, (1), pp 17-29.

Tyrrell, J. B. 1914. "Peter Fidler, Trader and Surveyor 1769-1822." Transactions of the Royal Society of Canada, V. 7, Section 2, pp 117-127.

Tyson, P. D. 1964. "Berg Winds of South Africa." Weather, V. 19, (1), pp 7-12.

Tyson, P. D. 1965. "Berg Wind over Durban." Weather, V. 20, (4), pp 115-116.

Veihmeyer, F. J., and A. H. Hendrickson. 1955. "Does Transpiration decrease as the soil moisture decreases?" Transactions of the American Geophysical Union, V. 36, (3), pp 425-448.

Verge, R. W. 1958. Chinooks and Mountain Waves. Unpublished M.Sc. thesis, Department of Physics (Meteorology), University of Toronto.

Villmow, J. R. 1956. "The Nature and Origin of the Canadian Dry Belt." Annals of the Association of American Geographers, V. 46, pp 211-

Ward, R. C. 1963. "Measuring Potential Evapotranspiration." Geography, V. 48, (1), p. 49.

Ward, R. C. 1923. "Hot Waves, Hot Winds and Chinook Winds in the United States." Scientific Monthly, V. 17, (2), pp 146-167.

Warkentin, J. 1964. The Western Interior of Canada. A Record of Geographical Discovery, 1612-1917. McClelland and Stewart Ltd., Toronto.

Watt, R. F. 1956. Severe Winter Damage to Conifers Noted in Portions of North Dakota, 1955-1956. U.S. Department of Agriculture, Lake States Forest Experiment Station, Minnesota, Technical Note, No. 466.

Wheeler, A. O. 1916. "Some Meteorological Phenomena of the Canadian Rockies." Canadian Alpine Journal, V. 7, p. 71.

Wilcock, C. 1965. Statistical Results of Snowfall Measurement. Unpublished manuscript, prepared for Geography Course 305, University of Alberta, Calgary.

Willett, H. C., and F. Saunders. 1959. Descriptive Meteorology. 2nd Edition, Academic Press Inc. 355 pp.

Wills, P. 1956. "Upcurrents in the Mackenzie Country." Weather, V. 11, (4), pp 101-103.

World Meteorological Organization. 1958. Aviation Aspects of Mountain Waves. Technical Note No. 18.

World Meteorological Organization. 1960. The Airflow over Mountains. Technical Note No. 34.

Yates, A. H. 1949. "Standing Wave Exploration by Sail Plane." Weather, V. 4, (2), pp 40-44.

## APPENDIX A

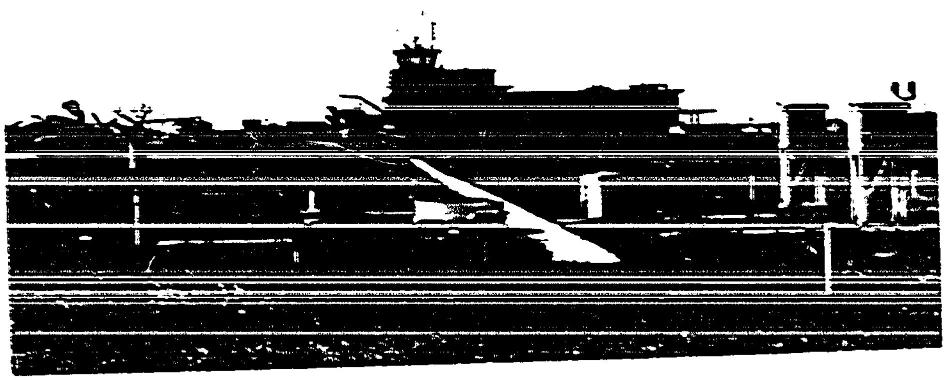
## CHINOOK RESEARCH PROJECT, GEOGRAPHY DEPARTMENT, UNIVERSITY OF ALBERTA, CALGARY.

## METEOROLOGICAL STATIONS AND INSTRUMENTATION

The following pages contain photographs and details of each station involved in the project. The instrumentation of each station is indicated in a Table.

A map showing the location of meteorological stations in the Rocky Mountain Front Range and foothills area of Alberta is included in:'Climatic Records for the Saskatchewan River Headwaters', a summary prepared for the East Slopes (Alberta) Watershed Research Programme by the Canada Department of Agriculture, Prairie Farm Rehabilitation Administration, Engineering Branch, June 1963.

# CALGARY McCALL FIELD

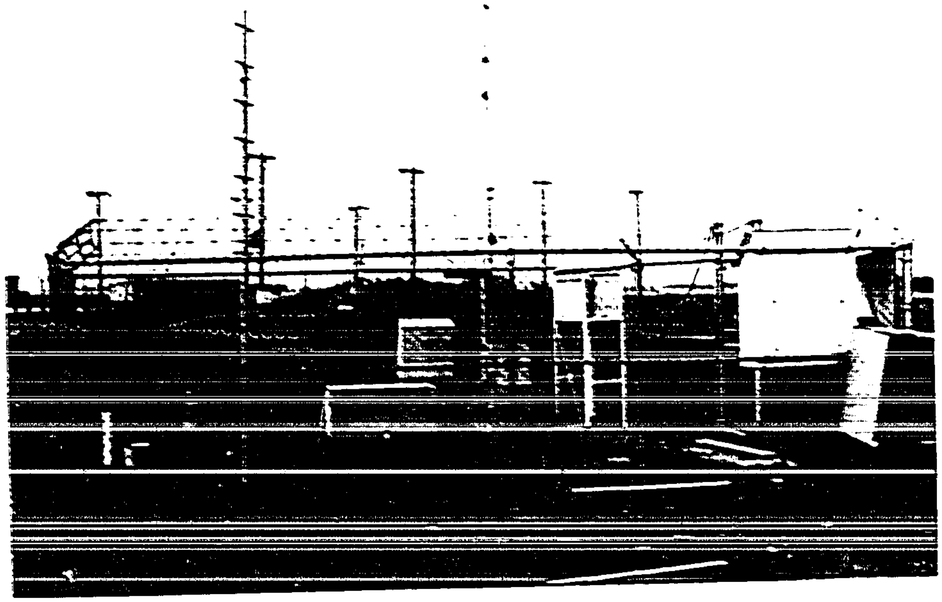


Location: Township 25, Range 1, Section 36.

Established: At McCall Field 1938.
At present site 1956.

Comment: This is a synoptic station and is the most comprehensively instrumented station in the project area.
Some instruments, eg.the anemometer, are located on the control building roof.
A tank is used to measure evaporation.

## CALGARY CAMPUS



Location: Township 24, Range 1, Section 6.

Established: 1963.

Comment: As this site is small and has been restricted by buildings since first established it is to be moved about ½ mile west to the snow plot area.
Part of the site is kept snow free to compare the soil and surface temperatures with those for the covered area.

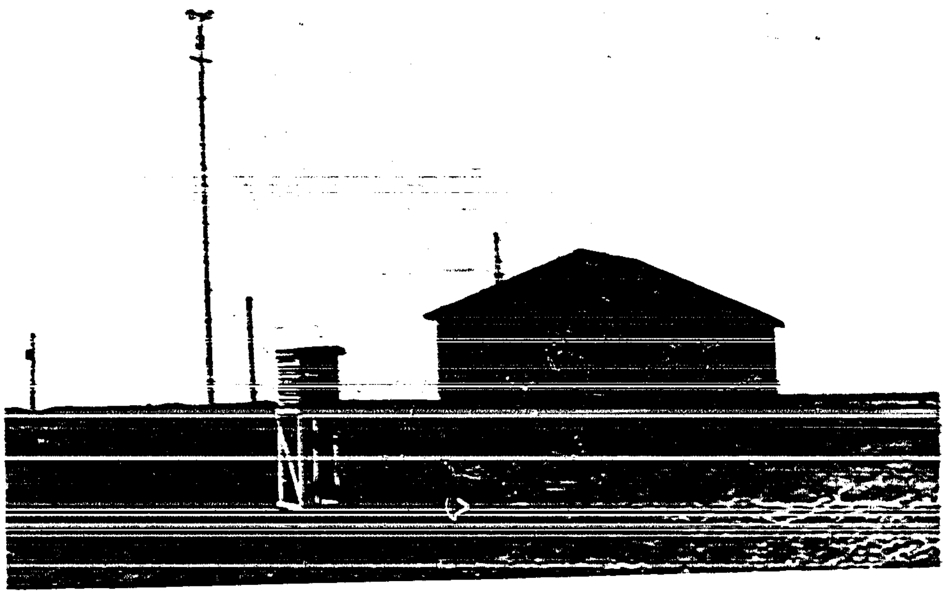
# MINK

Location: Township 24, Range 3, Section 1.

Established: 1963.

Comment: The screen was moved about 10 yards west in 1964.

# COCHRANE

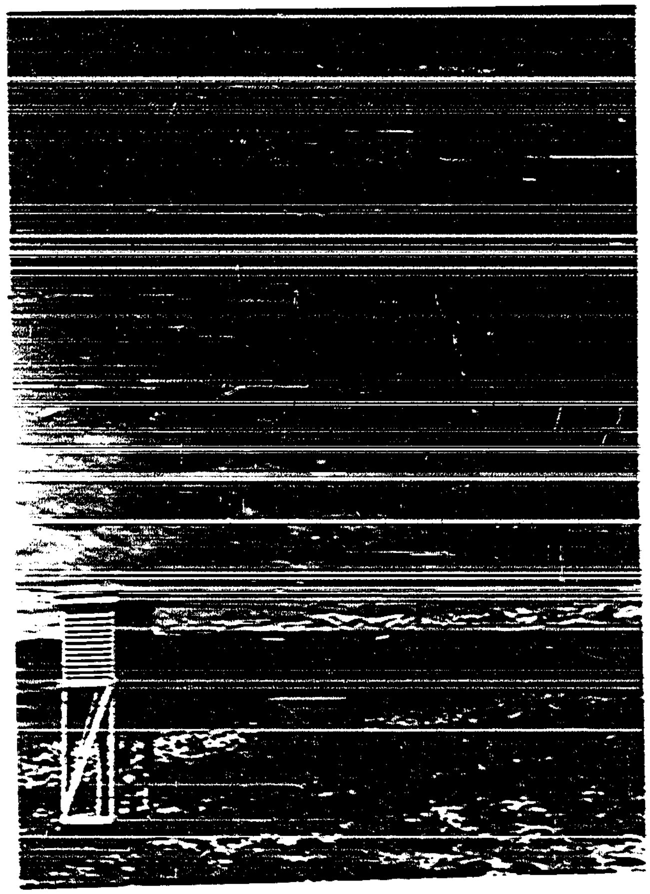


Location: Township 26, Range 5, Section 36.

Established: 1963.

Comment: Anemometer installed in 1964.
Screen moved several feet north
in June, 1965.

HILLTOP



Location: Township 25, Range 5, Section 36.

Established: 1963.

Comment: Anemometer installed 1964.
Brush cleared on hill slopes
during 1964.

COPITHORNE

Location: Township 25, Range 5, Section 8.

Established: 1963.

Comment: Anemometer and bent-stem soil thermometers installed 1964.

KANANASKIS

Location: Township 24, Range 8, Section 27.

Established: 1939.

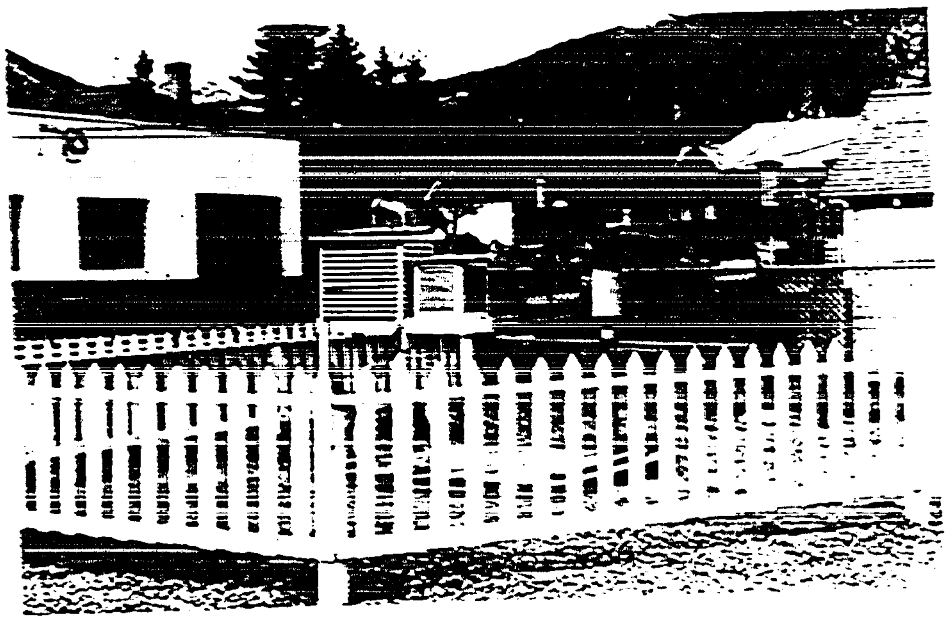
Comment: Wind, temperature and relative humidity data is forwarded to the University.

## HECTOR

Location: Stony Indian Reserve.
Township 25, Range 8.

Established: 1964.

## BANFF

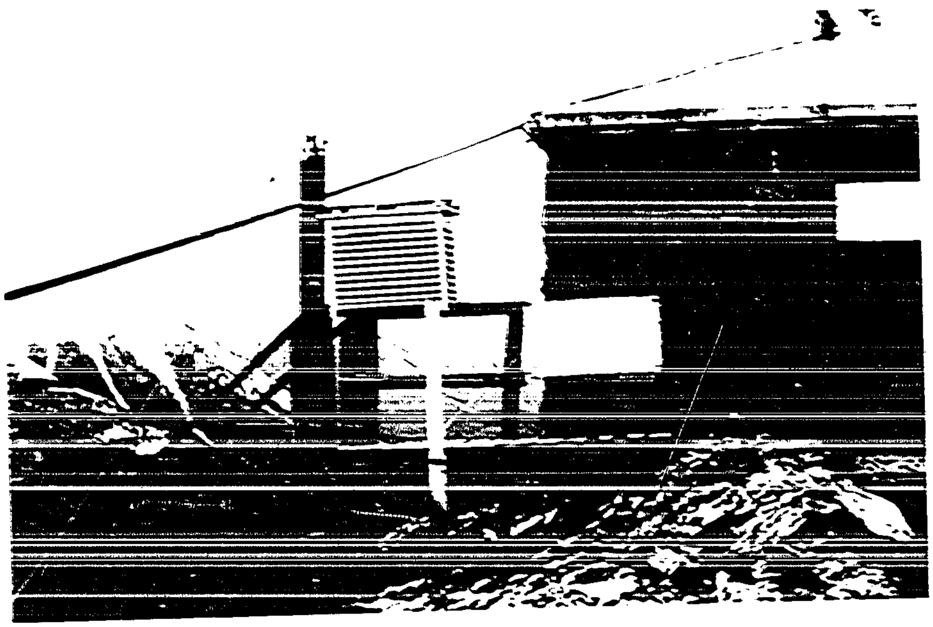


Location: Township 25, Range 12, Section 2.

Established: 1890.

Comment: The photograph shows the new site. The old site, behind the Fire Hall, (centre, right) was evacuated early in 1965. The new site is gravel covered.

SULPHUR



Location: Sulphur Mountain Peak.
Township 25, Range 12.

Established: Present Station, 1964.

Comment: Operation limited by lack of personnel to service it.
The wind equipment, located on the Cosmic Ray Laboratory roof, is operated by the Physics Department and has been changed several times.

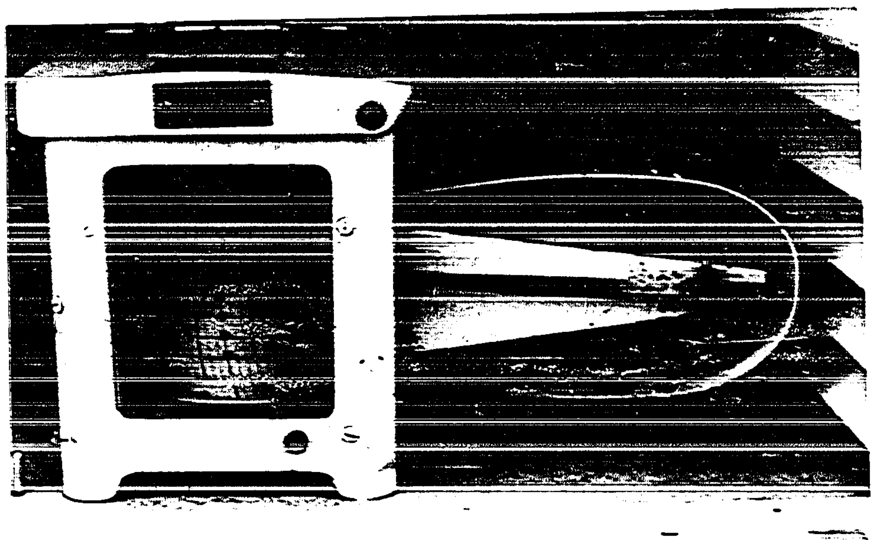
## INSTRUMENTATION OF STATIONS WHEN FULLY OPERATIVE

| Instruments Recording: | McCall Field | Campus | Mink | Cochrane | Hilltop | Copithorne | Kananaskis | Hector | Banff | Sulphur |
|---|---|---|---|---|---|---|---|---|---|---|
| Pressure | X | X | | | | | X | | X | X |
| Air Temperature | X | X | X | X | X | X | X | X | X | X |
| Soil Temperature | | X | | | | | | | | |
| Maximum & Minimum Temperature | X | X | X | X | X | X | X | X | X | X |
| Relative Humidity | X | X | X | X | X | X | X | X | X | X |
| Wind | X | X | | X | X | X | X | | | X |
| Radiation | | X | | | | | | | | |
| Sunshine | X | | | | | | | | | |
| Rain | X | X | | | | | X | | X | |
| Snow | X | X | | | | | X | | X | |
| Evaporation | X | X | | | | | | | | |
| Evapo-transpiration | | X | | | | | | | | |
| Upper Air factors | X | | | | | | | | | |
| Daily Observations | X | X | | | | | X | | X | |

Note

1. Except at the campus, where a plot is used, snow is recorded using snow gauges.
2. For Kananaskis only those instruments actually at the Research Station are indicated; many more are located nearby, as in Marmot Basin.
3. Soil Temperature: only instruments recording continuously are shown.

A THERMOGRAPH



Instruments similar to this one, made by C.F.Casella Co.Ltd. London, are installed in the screens at all the stations to measure temperature.

## APPENDIX B

## A SUMMARY OF METEOROLOGICAL DATA RECORDED DURING A PERIOD OF CHINOOK CONDITIONS AT CALGARY, FEBRUARY 7,8 & 9, 1965

| Time | Pressure m.b. | Temperature °F. | Relative Humidity % | Vapor Pressure m.b. | Wind Dir. | Wind Speed mph |
|---|---|---|---|---|---|---|
| 7.2.65. | | | | | | |
| a.m. | | | | | | |
| 12.0 | 1006 | -10 | 95 | .70 | S | 4 |
| 1.0 | 1005 | -10 | 95 | .70 | SW | 2 |
| 2.0 | 1005 | -12 | 95 | .63 | S | 5 |
| 3.0 | 1004 | -11 | 95 | .63 | SW | 7 |
| 4.0 | 1004 | -11 | 95 | .66 | ? | 6 |
| 5.0 | 1004 | -04 | 95 | .87 | ? | 6 |
| 6.0 | 1004 | -04 | 95 | 1.49 | S | 9 |
| 7.0 | 1004 | 14 | 95 | 2.44 | S | 10 |
| 8.0 | 1004 | 17 | 90 | 2.71 | SW | 10 |
| 9.0 | 1004 | 23 | 82 | 3.30 | S | 13 |
| 10.0 | 1004 | 26 | 75 | 3.47 | ? | ? |
| 11.0 | 1004 | 29 | 66 | 3.46 | W | ? |
| 12.0 | 1004 | 30 | 65 | 3.71 | SW | 11 |
| p.m. | | | | | | |
| 1.0 | 1004 | 34 | 70 | 4.37 | SW | 12 |
| 2.0 | 1004 | 35 | 62 | 4.20 | SW | 13 |
| 3.0 | 1003 | 38 | 58 | 4.49 | SW | 18 |
| 4.0 | 1003 | 37 | 55 | 4.10 | SW | 15 |
| 5.0 | 1003 | 35 | 63 | 4.24 | SW | 15 |
| 6.0 | 1004 | 34 | 64 | 4.07 | SW | 16 |
| 7.0 | 1004 | 31 | 65 | 3.79 | SW | 12 |
| 8.0 | 1004 | 28 | 65 | 3.30 | SW | 10 |
| 9.0 | 1003 | 29 | 70 | 3.72 | SW | 10 |
| 10.0 | 1003 | 23 | 65 | 2.74 | W | 9 |
| 11.0 | 1002 | 27 | 67 | 3.25 | W | 9 |

NOTE:

1. The steady decrease in pressure throughout the day.
2. The abrupt and sustained increase in temperature at 7.0 a.m.
3. The abrupt decrease in relative humidity at 8.0 a.m.
4. The abrupt increase in vapor pressure at 6.0 a.m.
5. The abrupt and sustained increase in wind velocity at 6.0 a.m.

## METEOROLOGICAL DATA RECORDED DURING CHINOOK CONDITIONS (CONTINUED)

| Time | Pressure m.b. | Temperature °F. | Relative Humidity % | Wind Dir. | Wind Speed mph |
|---|---|---|---|---|---|
| **8.2.65.** | | | | | |
| a.m. | | | | | |
| 12.0 | 1002 | 33 | 76 | W | 21 |
| 1.0 | 1002 | 33 | 70 | W | 20 |
| 2.0 | 1001 | 33 | 70 | W | 20 |
| 3.0 | 1001 | 34 | 59 | W | 22 |
| 4.0 | 1001 | 33 | 59 | W | 20 |
| 5.0 | 1001 | 30 | 61 | W | 13 |
| 6.0 | 1000 | 28 | 64 | W | 11 |
| 7.0 | 999 | 24 | 70 | W | 11 |
| 8.0 | 999 | 22 | 84 | W | 9 |
| 9.0 | 999 | 26 | 87 | W | 5 |
| 10.0 | 998 | 24 | 78 | SW | 2 |
| 11.0 | 998 | 29 | 80 | SW | 1 |
| 12.0 | 998 | 29 | 79 | SW | 2 |
| p.m. | | | | | |
| 1.0 | 997 | 32 | 80 | W | 5 |
| 2.0 | 998 | 26 | 97 | W | 20 |
| 3.0 | 998 | 27 | 97 | ? | 23 |
| 4.0 | 999 | 27 | 96 | ? | 21 |
| 5.0 | 1000 | 27 | 97 | ? | 14 |
| 6.0 | 1001 | 26 | 98 | ? | 13 |
| 7.0 | 1002 | 25 | 98 | W | 12 |
| 8.0 | 1003 | 24 | 98 | W | 10 |
| 9.0 | 1004 | 24 | 97 | SW | 13 |
| 10.0 | 1005 | 24 | 97 | SW | 13 |
| 11.0 | 1006 | 23 | 97 | SW | 13 |
| **9.2.65.** | | | | | |
| a.m. | | | | | |
| 12.0 | 1006 | 22 | 98 | SW | 10 |
| 1.0 | 1007 | 24 | 96 | W | 10 |
| 2.0 | 1008 | 24 | 96 | ? | 9 |
| 3.0 | 1010 | 22 | 96 | ? | 19 |
| 4.0 | 1011 | 14 | 97 | ? | 21 |
| 5.0 | 1012 | 11 | 96 | SW | 13 |
| 6.0 | 1014 | 10 | 96 | W | 9 |
| 7.0 | 1015 | 8 | 96 | W | 7 |
| 8.0 | 1016 | 8 | 95 | W | 9 |
| 9.0 | 1016 | 6 | 93 | W | 4 |
| 10.0 | 1016 | 8 | 92 | ? | 0 |
| 11.0 | 1016 | 12 | 82 | S | 2 |

NOTE:

1. As pressure began to increase again on 8.2.65 the chinook died out. The temperature decreased quite slowly but the relative humidity assumed a sustained value in excess of 90% quite quickly.

## APPENDIX C

### MEASUREMENT OF EVAPORATION BY VAPOR FLUX ANALYSIS

The vapor flux between successive heights above ground was determined at the campus using the following instruments located at ground level, 2 feet, 6 feet and 12 feet:

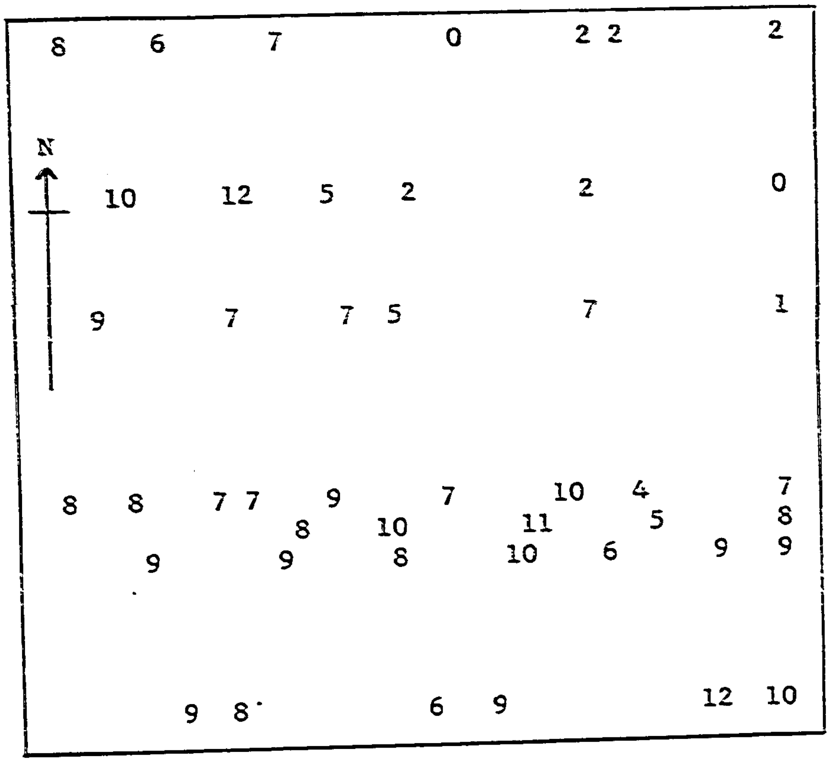
1. To measure temperature - thermocouples.
2. To measure relative humidity - Assmann psychrometer.
3. To measure wind velocity - sensitive anemometers.
4. To account for eddy diffusion the Austausch Coefficient was used.

$$\text{The vapor flux} = \frac{\text{Austausch value X difference in R.H. between heights}}{\text{Height difference between instruments, in cm}}$$

The data gained on vapor flux is given below:-

| Time | Vapor Flux in $gm^2/cm^2/m^3/sec^2$ between heights | | | Austausch Value |
|---|---|---|---|---|
| | 0 - 2 feet | 2 - 6 feet | 6 - 12 feet | |
| a.m. | | | | |
| 10.00 | 0.139 | 0.0159 | 0.0074 | 5 |
| 11.30 | 0.666 | 0.0226 | -0.0076 | 18 |
| p.m. | | | | |
| 4.45 | 1.050 | 0.1160 | -0.0131 | 30 |
| 8.00 | 0.141 | 0.0221 | 0.0044 | 5 |

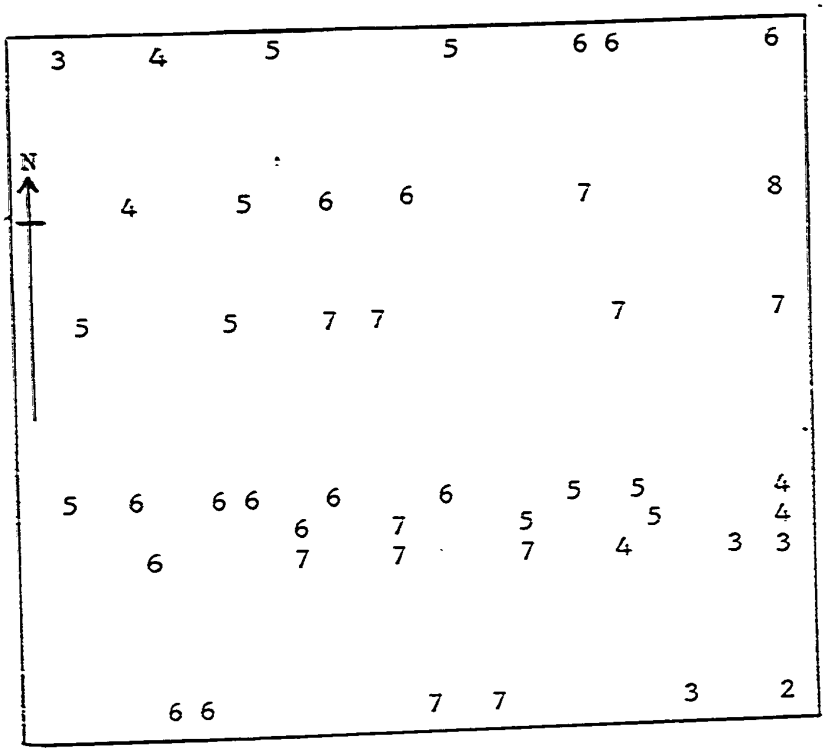
THE CAMPUS SNOW PLOT




(1)

The figures indicate the number of days the ground was clear of snow at each stake during the period 2/12/64 - 6/3/65.

Note the variation in duration of cover and the greater duration of cover in the north-east where grass was sparse.




(2)

The figures indicate measurements made at 4/50 p.m. January 1, 1965.

Figures are given to the nearest inch and show drifts in various places. The chinook was blowing from the west.

## STATISTICAL ANALYSIS OF EVAPORATION, TEMPERATURE, WIND AND SNOW PLOT DATA COLLECTED AT THE UNIVERSITY CAMPUS, WINTER 1964-1965

The correlation coefficients and significance values referred to in Chapter 4 are given below in the order they appear in the text.

In determining the Coefficient of Correlation the following formulae were used: 1. For simple linear correlation: $r = \frac{xy}{\sqrt{x^2 \quad y^2}}$

2. For multiple correlation: $R_{x(yz)} = \frac{(r_{xy})^2 + (r_{xz})^2 - 2r_{xy}\, r_{yz}\, r_{xz}}{1 - (r_{yz})^2}$

1. Where X = Average hourly evaporation per day.

   Y = Mean daily temperature.

   <u>r = .93</u>

   The least highly significant (1%) value for 'r', where n = 7 and m = 2 is .874.

2. Where X = Average hourly evaporation per day.

   Y = Maximum daily temperature.

   <u>r = .76</u>

   The least highly significant (1%) value for 'r' where n = 7 and m = 2 is .874.

   The least highly significant (5%) value for 'r', where n = 7 and m = 2 is .754.

3. Where X = Daily total of evaporation for each atmometer.

   Y = The height of the atmometer.

   <u>r = .87</u>

   The least highly significant (1%) value for 'r', where n = 6 and m = 2 is .917.

   The least highly significant (5%) value for 'r', where n = 6 and m = 2 is .811.

4. Where X = Daily reduction in snow depth.

Y = Mean daily temperature.

<u>r = .7</u>

The least highly significant (1%) value for 'r', where n = 15 and m = 2 is .641.

5. Where X = Daily reduction in snow depth.

Y = Daily wind passage.

<u>r = .4</u>

The least highly significant (1%) value for 'r', where n = 40 and m = 2 is .403.

The least highly significant (5%) value for 'r', where n = 40 and m = 2 is .313.

6. Where X = Daily reduction in snow depth.

Y = Daily number of degrees above 32°F at each hour.

Z = Daily wind passage.

<u>R = .913</u>

The least highly significant (1%) value for 'r', where n = 11 and m = 3 is .827.

7. Where X = Daily reduction in snow depth.

Y = Daily wind passage.

<u>r = .93</u>

The least highly significant (1%) value for 'r', where n = 11 and m = 2 is .735.

8. Where X = Daily reduction in snow depth.

Y = Average hourly evaporation per day.

<u>r = .1</u>

The least highly significant (1%) value for 'r', where n = 18 and m = 2 is .590. The least highly significant (5%) value for 'r', where n = 18 and m = 2 is .468.

## APPENDIX D

A COPY OF THE QUESTIONNAIRE DISTRIBUTED TO FARMERS

Geography Department,
University of Alberta,
Calgary.

Dear Sir,

The Geography Department of your local university in Calgary is conducting reasearch into the Chinook wind and its influence in Alberta. Our work is described in the enclosed press cutting.[1] We hope you will be interested in the work and help us by completing the attached questionnaire. If you do not want to provide details about your farm a few general comments, on the importance of the Chinook to you, would be appreciated. All information provided will be kept confidential.

Questions.

Do you keep any weather records for your farm? __________

What is the acreage of your farm? __________

What is the acreage of rangeland? __________

Cattle:

How many have you? __________

Are they left on the range all winter? __________

Are they given supplementary feed all through the winter? __________

Are they only given supplementary feed when the weather is bad? __________

Have you ever lost any cattle due to long periods of snow without Chinooks? __________

Feed:

Do you grow any supplementary feed i.e. hay for cattle in winter? __________

Do you buy winter feed for cattle? __________

Approximately how much feed do you provide each cow in winter? __________

Do you grow as much feed as you possibly can on your farm? __________

General:

Have you suffered soil erosion due to Chinook winds? __________

Do you think that Chinooks save you money? __________

Do you think that Chinooks are beneficial? __________

Comments:

Yours sincerely,

John S. Marsh.

1. Schmidt, J. Calgary Herald. 1964, November 12th, p.58.

## SUMMARY OF QUESTIONNAIRE DATA

### FARMS:

Number in sample - 70.

Maximum size - 280,000 acres.

Minimum size - 80 acres. (2 farms)

Mean size - 9,281 acres.

Distribution of farms according to size

| acres | number of farms |
|---|---|
| 0 - 499 | 12 ) 43% |
| 500 - 999 | 17 ) |
| 1,000 - 1,999 | 16 |
| 2,000 - 2,999 | 5 |
| 3,000 - 3,999 | 2 |
| 4,000 - 4,999 | 2 |
| 5,000 - 5,999 | 1 |
| 6,000 - 6,999 | 4 |
| 7,000 - 7,999 | 2 |
| 8,000 - 8,999 | 2 |
| 9,000 - 9,999 | 0 |
| 10,000 - 24,999 | 6 |
| 25,000 - 49,999 | 4 |
| 50,000 - 999,999 | 1 |
| 100,000 + | 1 |

### CATTLE:

Number of farms in sample - 72.

Distribution of farms according to cattle numbers

| cattle | number of farms |
|---|---|
| 0 - 99 | 24 ) 55% |
| 100 - 199 | 16 ) |
| 200 - 299 | 9 |
| 300 - 399 | 3 |
| 400 - 499 | 5 |
| 500 - 599 | 2 |
| 600 - 699 | 1 |
| 700 - 799 | 2 |
| 800 - 899 | 1 |
| 900 - 999 | 1 |
| 1,000 - 4,999 | 7 |
| 5,000 + | 1 |

There was no correlation between the size of the farm and the number of cattle maintained.

## SUMMARY OF QUESTIONNAIRE REPLIES

### CATTLE

| | |
| --- | --- |
| Are they left on the range all winter? | 18% - Yes<br>69% - No<br>12% - Some<br>1% - Occasionally |
| Are they given supplementary feed all through the winter? | 64% - Yes<br>25% - No<br>11% - Some |
| Have you ever lost any cattle due to long periods of snow without chinooks? | 25% - Yes<br>75% - No |

### FEED

| | |
| --- | --- |
| Do you grow any supplementary feed? | 97% - Yes<br>3% - No |
| Do you grow as much feed as you possibly can on your farm? | 65% - Yes<br>35% - No |
| Do you buy winter feed for cattle? | 50% - Yes<br>45% - No<br>5% - Occasionally |

### GENERAL

| | |
| --- | --- |
| Have you suffered soil erosion due to chinook winds? | 50% - Yes<br>50% - No |
| Do you think that chinooks save you money? | 69% - Yes<br>19% - No<br>2% - Occasionally<br>10% - ? |
| Do you think that chinooks are beneficial? | 76% - Yes<br>12% - No<br>4% - Occasionally<br>8% - ? |