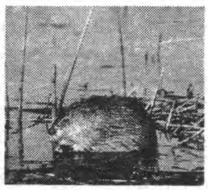
Canada Alberta Northwest Territories

Northern River Basins Study



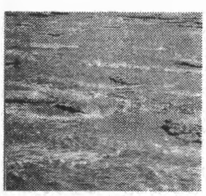






NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 124

THE CLIMATE OF THE PEACE, ATHABASCA AND SLAVE RIVER BASINS






DATE DUE

Prepared for the
Northern River Basins Study
under Project 5317-E1

by

E. Hudson
Environment Canada

NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 124

THE CLIMATE OF THE PEACE, ATHABASCA AND SLAVE RIVER BASINS

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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NORTHERN RIVER BASINS STUDY
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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona — 14 May 96

(Dr. Fred J. Wrona, Science Director) — (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin — 2 May / 96

(Dr. P. A. Larkin, Ph.D., Chair) — (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — May 29/96

(Lucille Partington, Co-chair) — (Date)

Robert McLeod. — May 21/96

(Robert McLeod, Co-chair) — (Date)

THE CLIMATE OF THE PEACE, ATHABASCA AND SLAVE RIVER BASINS

STUDY PERSPECTIVE

The Peace, Athabasca and Slave rivers are sub-basins of the Mackenzie River Basin. Their aquatic ecosystems are large, complex and subject to significant seasonal variation.

The aquatic environments contained within the Northern River Basins Study area (NRBS) are undergoing change as a result of development. The ability to predict changes likely to arise from one or more developments was a challenge presented to researchers from the onset of the Study. Weather and its prevailing set of conditions, i.e. climate, is a strong catalyst for modifying or enhancing changes brought about by development. In recent time there has been increasing discussion over the probable effects of climate change on the environment, particularly in northern latitudes. Any significant climatic change will have implications on how these areas are managed.

Related Study Questions

13a) What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?

14) What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stake holders hove the opportunity for input.

Climate within the NRBS study area varies significantly as does its influence on the aquatic environment. This report describes the climate of the study area in the context of known climate classifications. Information on weather regimes that give rise to various precipitation and temperature characteristics are described. Some discussion of the likely changes the area will see in climate and its effects on the vegetation is presented. A complementary discussion of climate changes is found in Northern River Basins Study Project Report No. 65 (*The Potential Effects of Climate Change in the Peace, Athabasca and Slave River Basins: A Discussion Paper*).

Report Summary

This climate of the Northern River Basins:

- shows where the Northern River Basins fit in various climate classifications;
- presents current climate statistics for the Northern River Basins in tables, graphs and figures;
- discusses some of the weather regimes that lead to given temperature and precipitation events across the Northern River Basins; and
- looks at climate with respect to climate based activities such as agriculture.

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1.0 INTRODUCTION

The Northern River Basins encompass most of northern Alberta, a large section of northeastern British Columbia, and a section of northwestern Saskatchewan. Figure 1 shows the Northern River Basins area relative to western Canada. The terrain across the Northern River Basins varies from mountains to valleys to plains and hills. This climate of the Northern River Basins focuses on the climate that exists across the Basins as reflected by meteorological measurements during the past 30 years in particular. A map of the meteorological stations whose data was used to make this climate annotated with the elevation of the station and a separate map annotated with the station number are in Appendix A.
The climate:

- shows where the Northern River Basins fit in various climate classifications;
- presents current climate statistics for the Northern River Basins in tables, graphs and figures;
- discusses some of the weather regimes that lead to given temperature and precipitation events across the Northern River Basins;
- touches on meteorological related topics such as permafrost; and
- looks at some aspects of climate with respect to climate based activities such as agriculture.

The climate concludes with a section on meteorological, or linked to meteorological events that made the news.

References not reviewed are given within the text in *italics* but are not listed in the Reference section.

Those seeking information on climate change and the potential effects on the Northern River Basins are referred to:

- Environment Canada, 1995, The State of Canada's Climate: Monitoring Variability and Change, SOE Report No. 95-1, 52 pp.
- Hengeveld, 1995, Understanding Atmospheric Change - A Survey of the Background Science and Implications of Climate Change and Ozone Depletion, Second Edition, Atmospheric Environment Service, SOE Report No. 95-2, 68 pp.
- Mills, P.F. 1994. The Agricultural Potential of Northwestern Canada and Alaska and the Impact of Climate Change. Arctic, Vol 47, No 2 (June 1994):115-123

2.0 CLIMATE CLASSIFICATIONS

The climate across the Northern River Basins can be classified in many ways. On a global scale, Figure 2 shows how the Northern River Basins fits onto the world classification system developed by Köppen. Köppen's climate classifications are based on a combination of temperature and precipitation and their effect on vegetation and are empirical. Table 1 outlines Köppen's climate systems descriptors and conditions. In Table 2, more detail is provided of how the climate of the Northern River Basins is classified according to Köppen's system. In Table 2, the climate of the Northern River Basins is also classified on the basis of: temperature; annual precipitation; natural vegetation; and air-mass meteorology.

For those who prefer absolute rather than 'labelled' climatology, Figures 4 and 6 provide maps of temperature and precipitation respectively for January, April, July, and October for the Northern River Basins. Figure 7 shows the mean annual precipitation for the Northern River Basins. The complete set of monthly temperature maps is given in Appendix B and the complete set of monthly precipitation maps is given in Appendix C. Figure 5 shows extreme maximum temperature and extreme minimum temperature recorded at various sites across the Northern River Basins.

Site specific climates for sites within the Northern River Basins also exist. For example, Mills, 1993, created a site specific computerized version, Climate Classification System, of the climate rating for arable agriculture in Alberta as developed by the Alberta Agrometeorology Advisory Committee in 1987. The data base for the computerized version includes data from many sites in the Northern River Basins. Mills' Climate Classification System is concerned with climate only. Mills cautions that any climatic rating, classification, or recommendation, will necessarily be interpreted in the light of separate soil and landscape limitations. The climate component in the Climate Classification System is based on the more limiting of moisture or energy component, and modified as required by excess spring moisture, excess fall moisture, fall frost factor, hail factor, day length, and aspect factor. Figure 8 is sample site-specific output from Mills' Climate Classification System and is for Grande Prairie.

Figure 1. Northern River Basins area relative to western Canada.

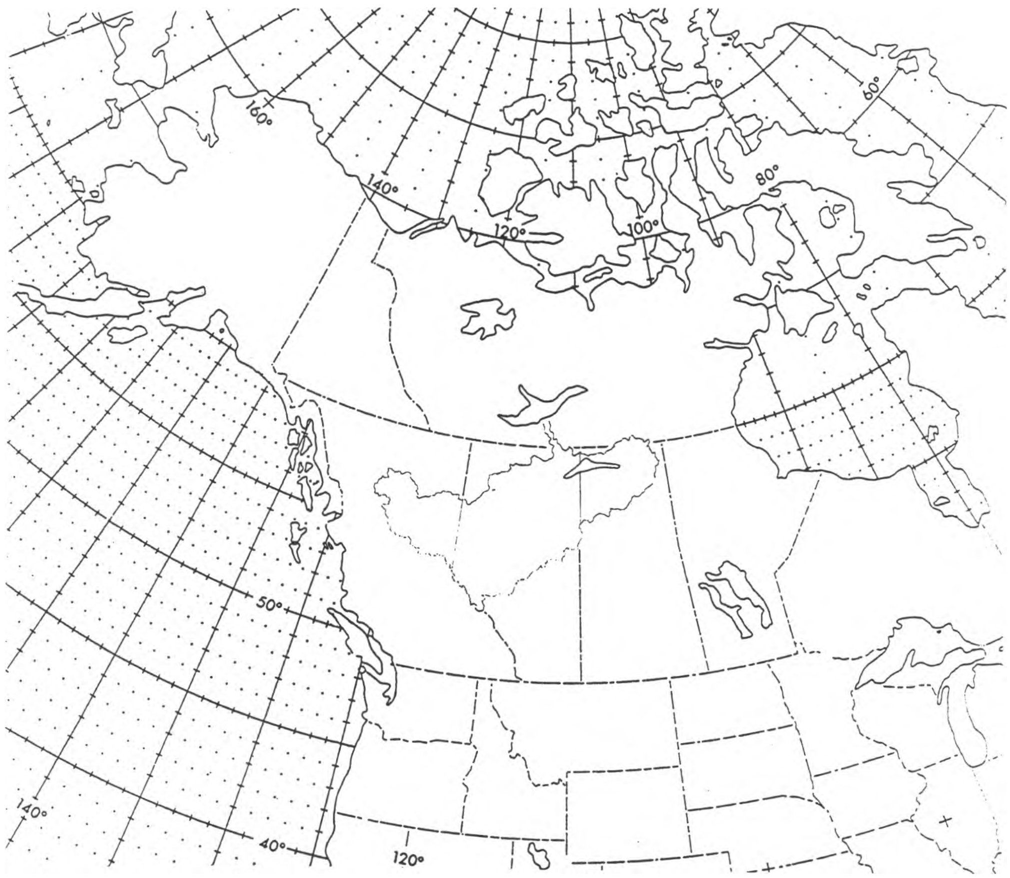
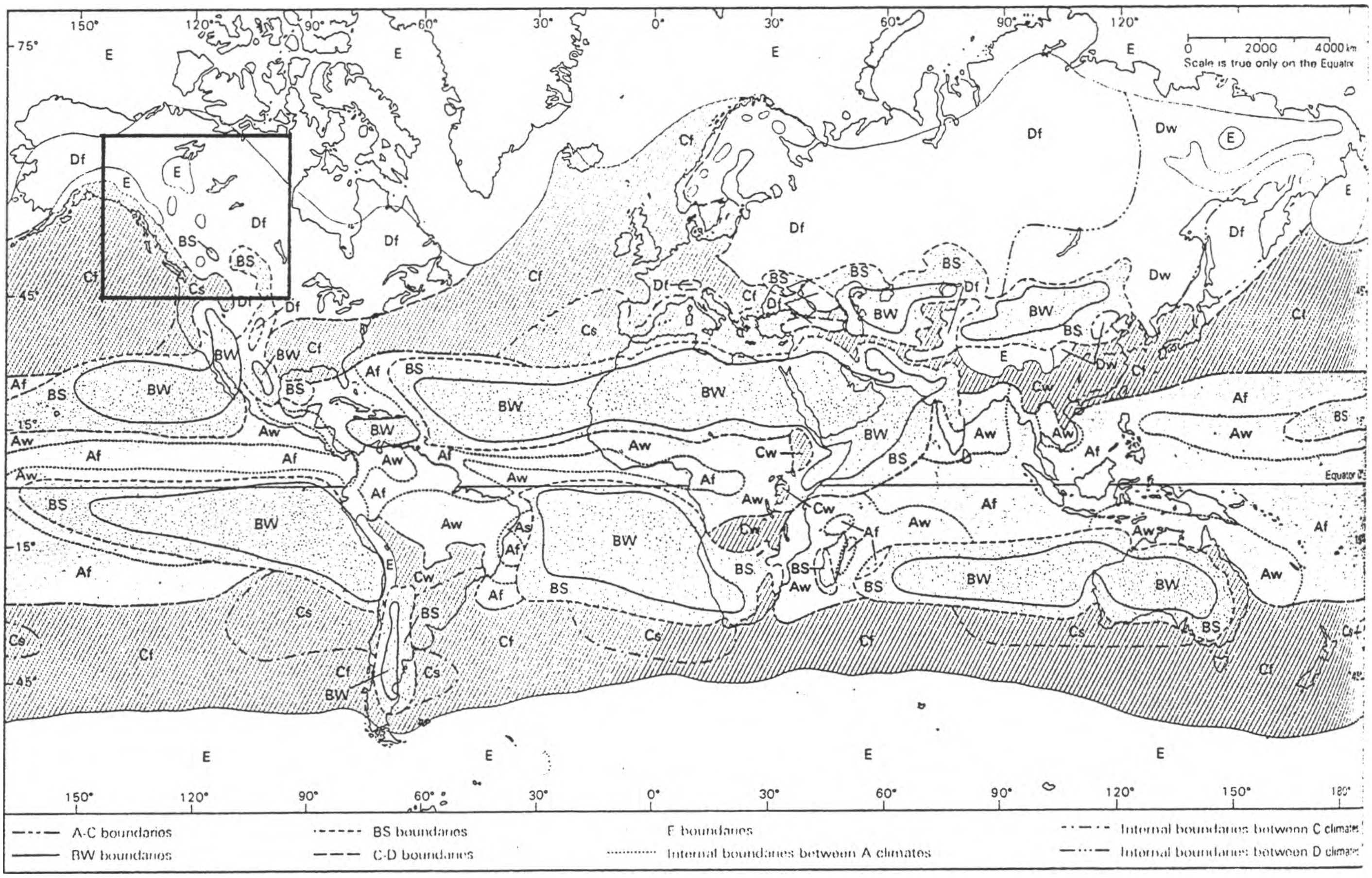


Figure 2. World distribution of climatic types according to the Köppen system. (From Encyclopedia Britannica, 1980, *from Lamb, Climate: Present Past and Future*). Outline of Northern River Basins area superimposed on blowup of western North America.



Per Köppen, the Northern River Basins is labelled as having a "Df " climate - D for colder temperate forest climate and the small "f" to show that all seasons are moist. Köppen's climate is a world climate. It is the opinion of this author that the level of detail given on the Köppen figure over the Northern River Basins is vulnerable to scrutiny. Not knowing what data were used to compile the figure, it is suggested that the detail such as the unlabelled area that covers a section of the Northern River Basins on the Alberta / British Columbia border is a reflection that there are some areas, but not necessarily this particular area, of different climate conditions which may or may not fit the BS or E categories.

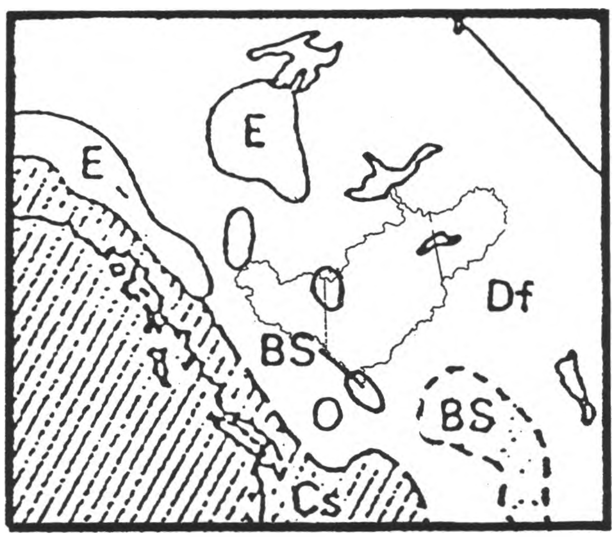


Table 1. Köppen Climate System Descriptors and Conditions.
(Collated from material in Encyclopedia Britannica, 1980)

A Equatorial and tropical rain climates Average temperature of every month above 18°C	
Af	driest month has ≥ 60 millimetres of rain produces rain forest
Aw	driest month has < 60 millimetres of rain and the year's total rainfall fails to make up for the deficiency produces savanna (grassland, some trees)
B Dry Climates of the arid zone Average annual rainfall: - where summer rainiest season: 2T + 28 centimetres (T= mean annual temperature in °C) - where rainfall fairly uniform through year: 2 T + 14 centimetres - where winter rainiest season: < 2T centimetres	
BS	Average annual rainfall: - where summer is rainiest season: >T+14 centimetres - where rainfall fairly uniform through year: between T + 7 and T + 14 - where winter rainiest season: between T and T+7 centimetre S = steppe or savanna. This climate produce grasslands or bush.
BW	Average annual rainfall: - where summer is the rainiest season: < T + 14 centimetres - where rainfall fairly uniform through year : < T + 7 centimetres - where winter rainiest season: < T **W** = desert wastes
C Temperate climates of the mainly broad-leafed forest zone Average temperature coldest month 18°C to -3 °C AND average temperature warmest month greater than 10°C	
Cs	Wettest month comes in winter and has over 3 times rainfall of driest (summer) month **Cs** climates produce broad-leafed evergreen forests
Cw	Wettest month comes in summer and has more than 10 times rainfall of driest (winter) month **Cw** climates produce evergreen forests of mountain heights in the **Aw** zone
D Colder temperate forest climates Average temperature of coldest month < -3 °C AND average temperature of warmest month greater than 10°C **D** climates are only found in the great continents of the northern hemisphere. Milder **D** climates go with deciduous, broad-leafed forests Colder **D** climates go with needle-tree forests	
Dw	Wettest month comes in summer and provides more than 10 times the water equivalent of the total rain and snow in the driest (winter) month
E Treeless polar climates Average temperature of every month below 10°C	

s dry season in summer
w dry season in winter
f all seasons moist

Figure 3. Climate regions of Alberta. (From Agroclimatic Atlas of Alberta, Dzikowski and Heywood, 1990.) Outline of Northern River Basins superimposed.

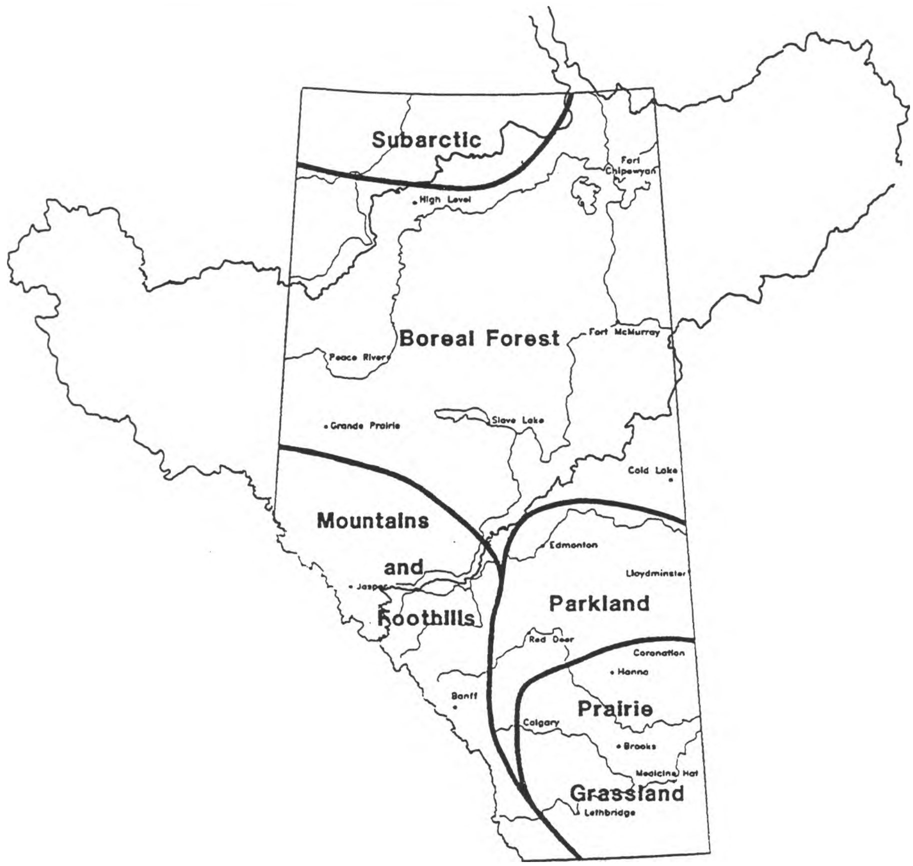


Table 2. Climate of the Northern River Basins on the basis of temperature, annual precipitation, Köppen's global classification for temperature and precipitation and their effects on vegetation, natural vegetation, and air-mass meteorology.

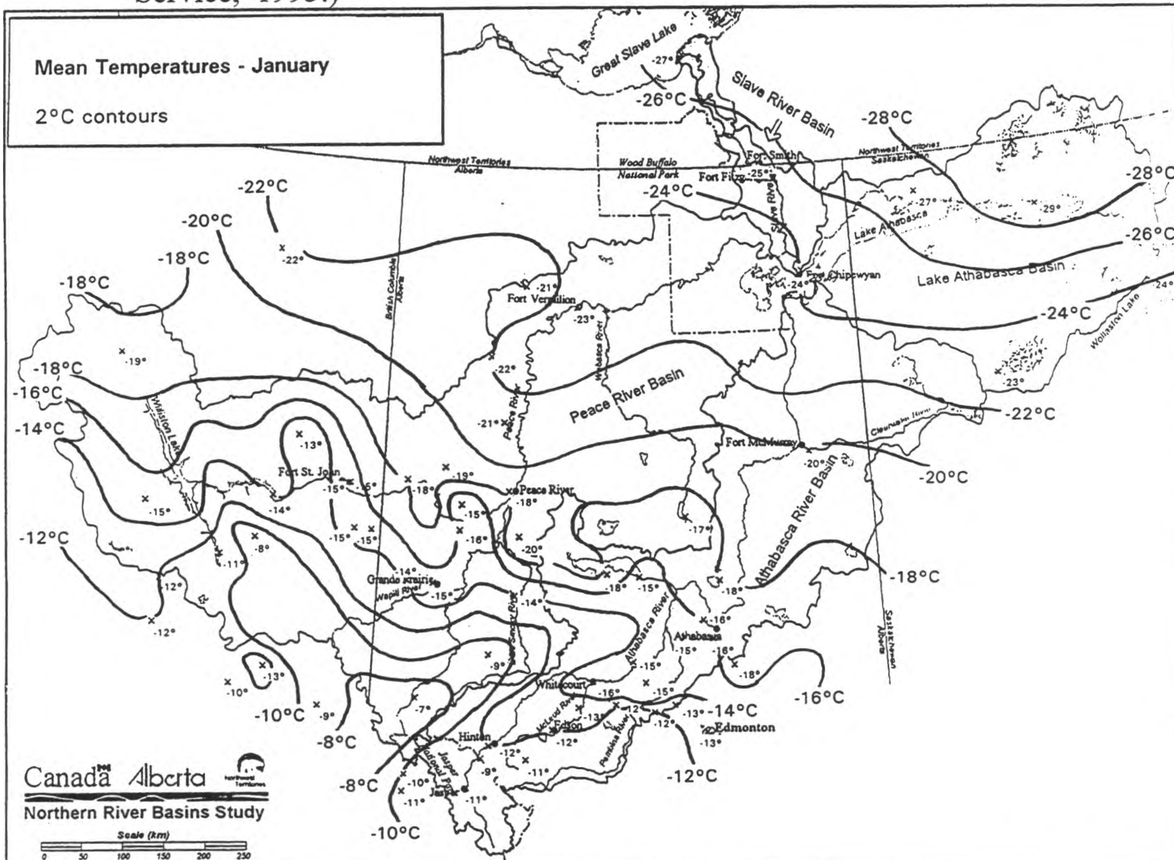
Basis	Categories Northern River Basins Category ✔'d off		Comments
Temperature	 ✔ ✔	tropical mid latitude polar	
Annual Precipitation rain plus water equivalent of snow	 ✔ ✔ 	up to 100 millimetres > 100 mm to 250 mm > 250 mm to 500 mm > 500 mm to 1000 mm > 1000 mm to 2500 mm	Recorded annual precipitation across the Northern River Basins ranges from about 300 millimetres (northern most Slave Basin) to more than 800 millimetres at one station in the British Columbia section of the Northern River Basins.
Köppen's global classification for Temperature and Precipitation and their Effects on Vegetation from Lamb as cited in Encyclopedia Britannica, 1980	D ✔ f ✔	**A**- equatorial & tropical rain climates **B** -dry climates of arid zone **C** - temporal climates of mainly broad-leafed forest zone **D** -colder temperate forest climates s dry season in summer w dry season in winter f all seasons moist	Per Figure 2 and Table 1, the Northern River Basin fits into the D, colder temperate forest climates, classification of Köppen's system. Per Köppen, the "D" category is for areas where the average temperature of the coldest month is below -3°C and the mean temperature of the warmest month is at least 10°C. February is the coldest month across the Northern River Basins with mean daily temperatures ranging from -6°C in and around the Jasper area to near -22°C across the Slave River Basin. July is the warmest month across the Northern River Basins with mean temperatures in the range 14 to 16°C The "f" subscript applies as the Northern River Basins receives moisture all year long. However, there is, for the most part, a bias to the precipitation.. 50 to 65% falls during the four month May to August 'convective' season. The higher percentages lie across the central Athabasca Basin. There are two exceptions. The first exception occurs over the extreme northeastern section of the Basin. At Fort Resolution and Uranium City, respectively, 36% and 46% of the annual precipitation occurs during the May to August period. The second exception to the majority of annual precipitation occurring during the May to August period occurs over the western half of the British Columbia section of the Northern River Basins. Here the May to August precipitation, per the available data, ranges from 30 to 42% of the annual precipitation. July is the month of greatest mean precipitation at almost all localities. Data shows September amounts to be comparable to those for May.
Natural Vegetation from Agroclimatic Atlas of Alberta, Dzikowski and Heywood, 1990 *(Rowe, J.S., 1992, Forest Regions of Canada, Environment Canada, Canadian Forest Service, Publication #1300, 172 pp + map)*	✔ ✔ ✔ ✔	boreal forest mountains and foothills parkland subarctic	Per Figure 3, boreal forest is the dominant natural vegetation type across the Northern River Basins. There is an area of parkland on the southern fringe of the basins and an area of mountains and foothills natural vegetation across the western sections of the basins near and over the Rocky Mountains. Over sections of the Peace River Basin, areas of prairie and parkland have developed within the boreal forest.. Greater incidence of cold winter temperatures gives a subarctic classification to northeastern-most section of the basin.

continued...

Table 2 Concluded. Climate of the Northern River Basins on the basis of temperature, annual precipitation, Köppen's global classification for temperature and precipitation and their effects on vegetation, natural vegetation, and air-mass meteorology.

Basis	**Categories** Northern River Basins Category ✔'d off		**Comments**
Air-mass meteorology	 ✔	maritime continental	The Northern River Basins has a continental climate with warm summers and cold winters. The mountains to the west of the Northern River Basins ensure the "continental" label. Air masses with the "maritime" prefix do make their way to the Northern River Basins. However, the Rocky Mountains and other mountain ranges between the Pacific and the Northern River Basins receive much of the moisture that is available each time a Pacific (maritime) system pushes inland. In contrast, Arctic air masses have no problem dropping south from the Yukon and Northwest Territories into the Northern River Basins during winter without modification. During the summer, the Arctic air mass modifies as it drops south. It picks up moisture from lakes, swamps, and vegetation giving it a maritime flavour. Figures 11 and 12 show the air masses that affect the Northern River Basins winter and summer respectively.

Figure 4. Maps of mean temperatures for the Northern River Basins for January, April, July, and October. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)



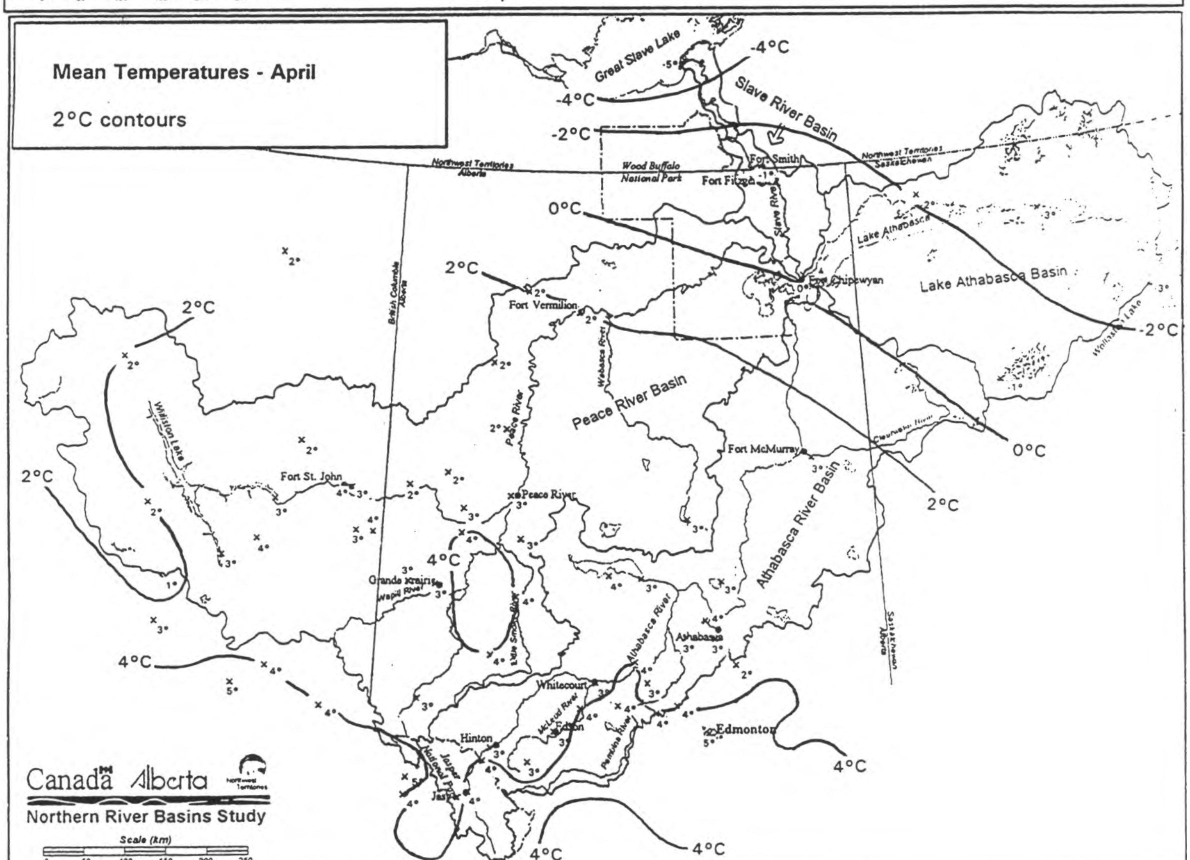
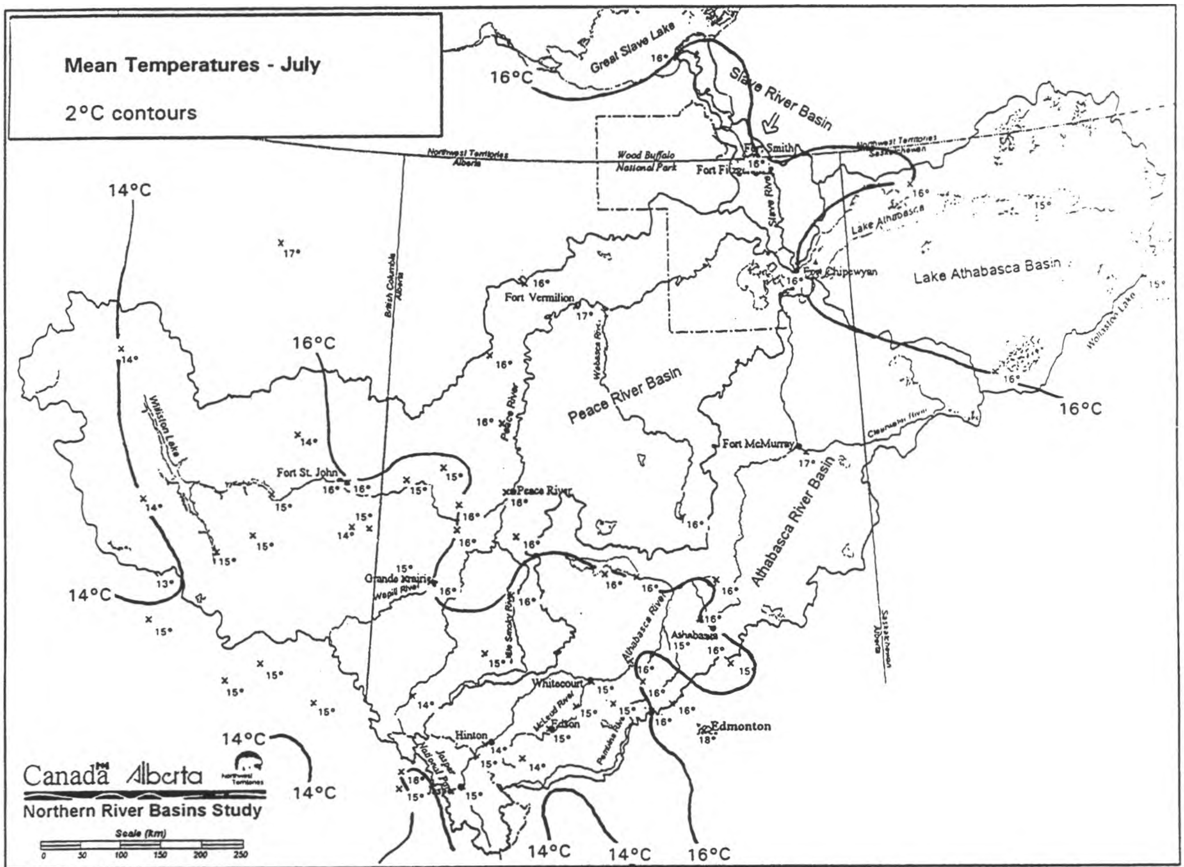
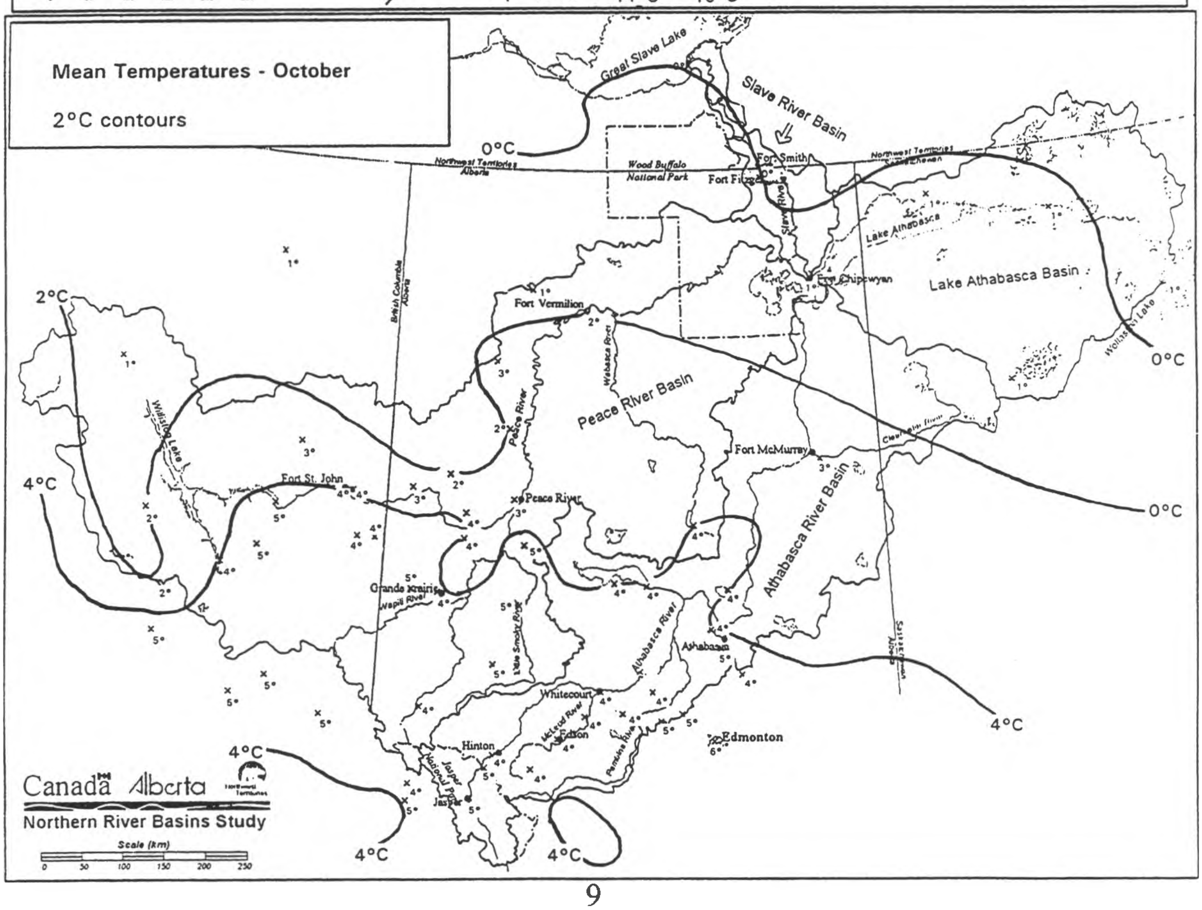


Figure 4 Concluded.





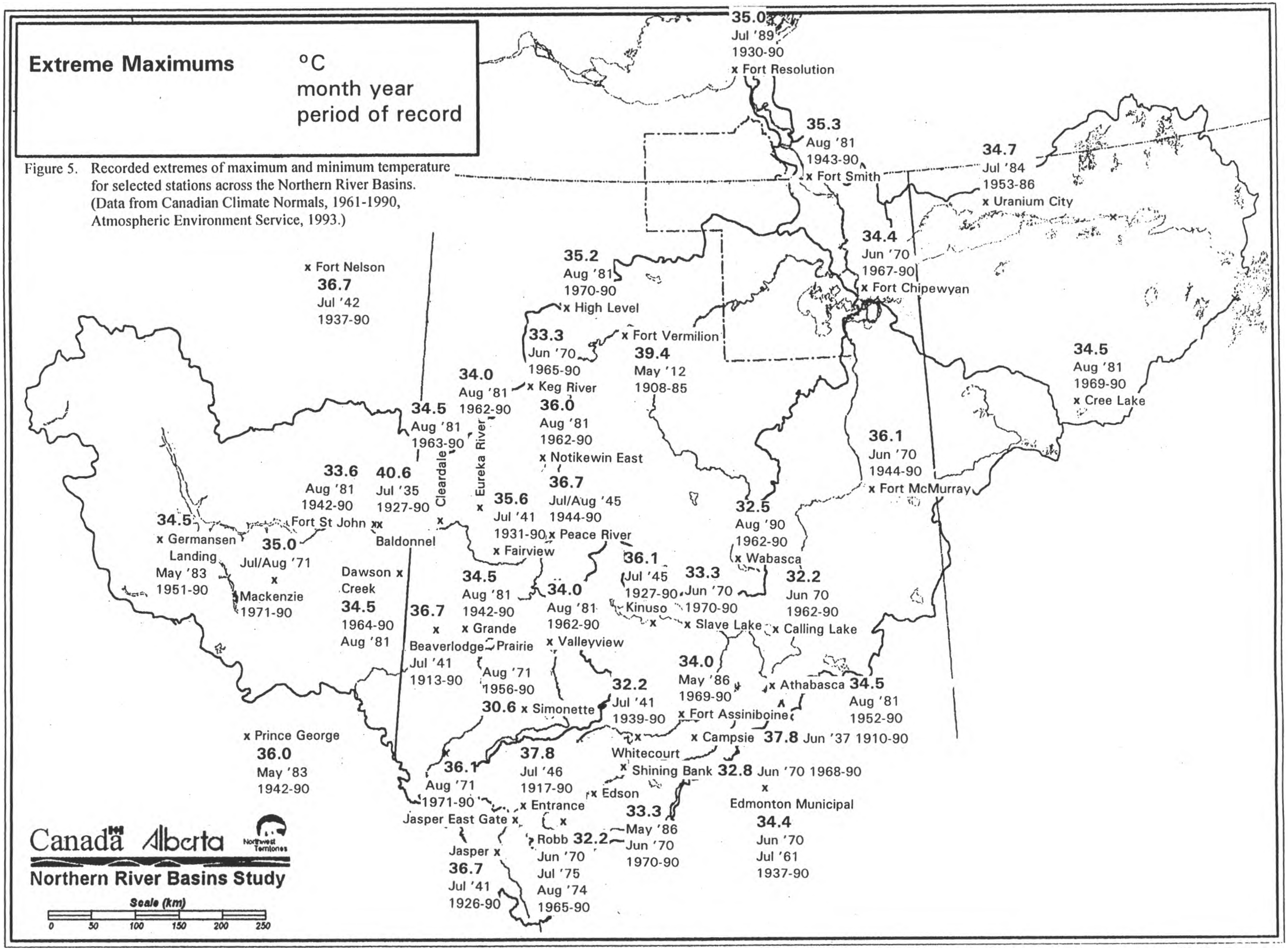


Figure 5. Recorded extremes of maximum and minimum temperature for selected stations across the Northern River Basins. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

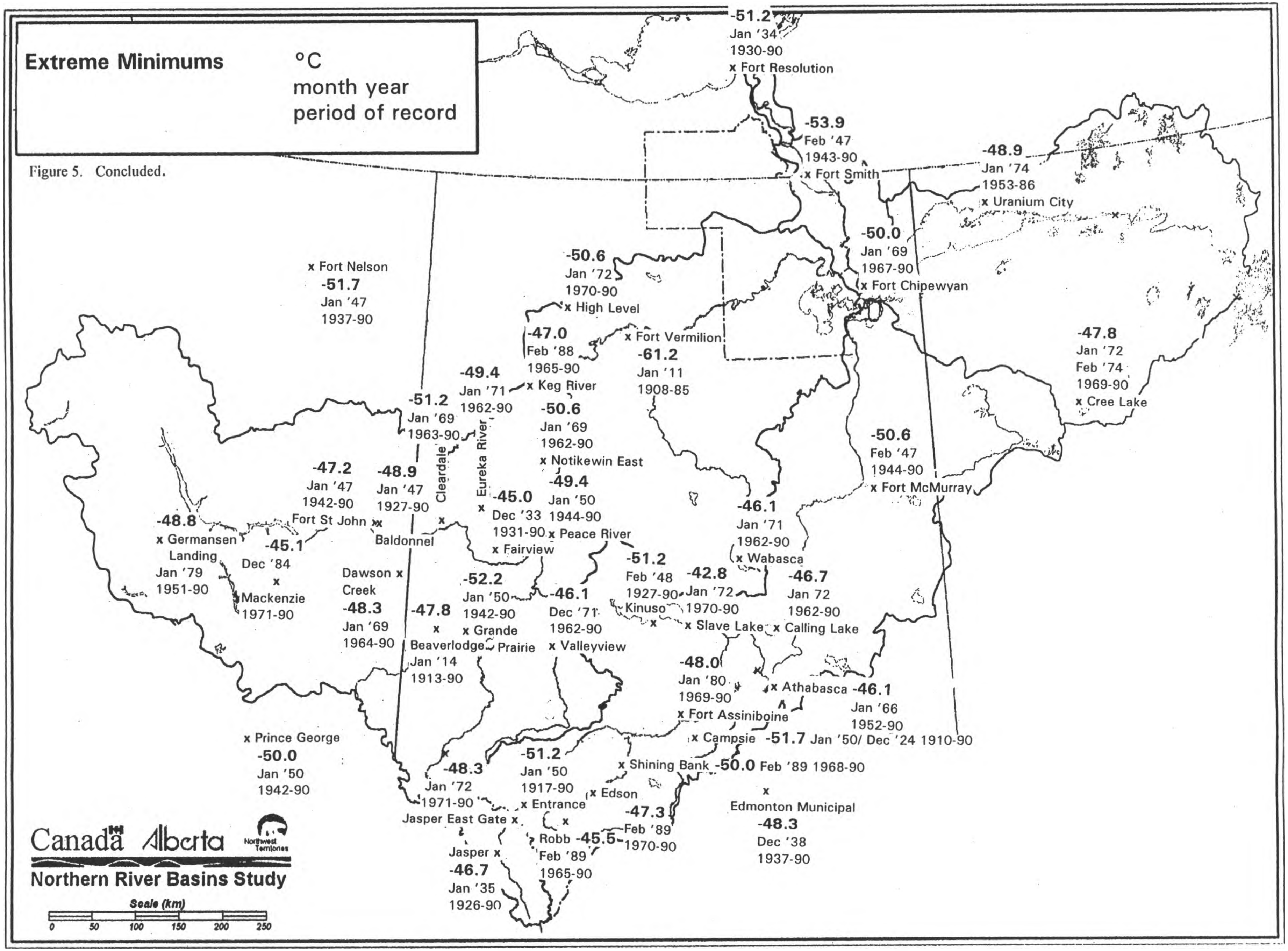
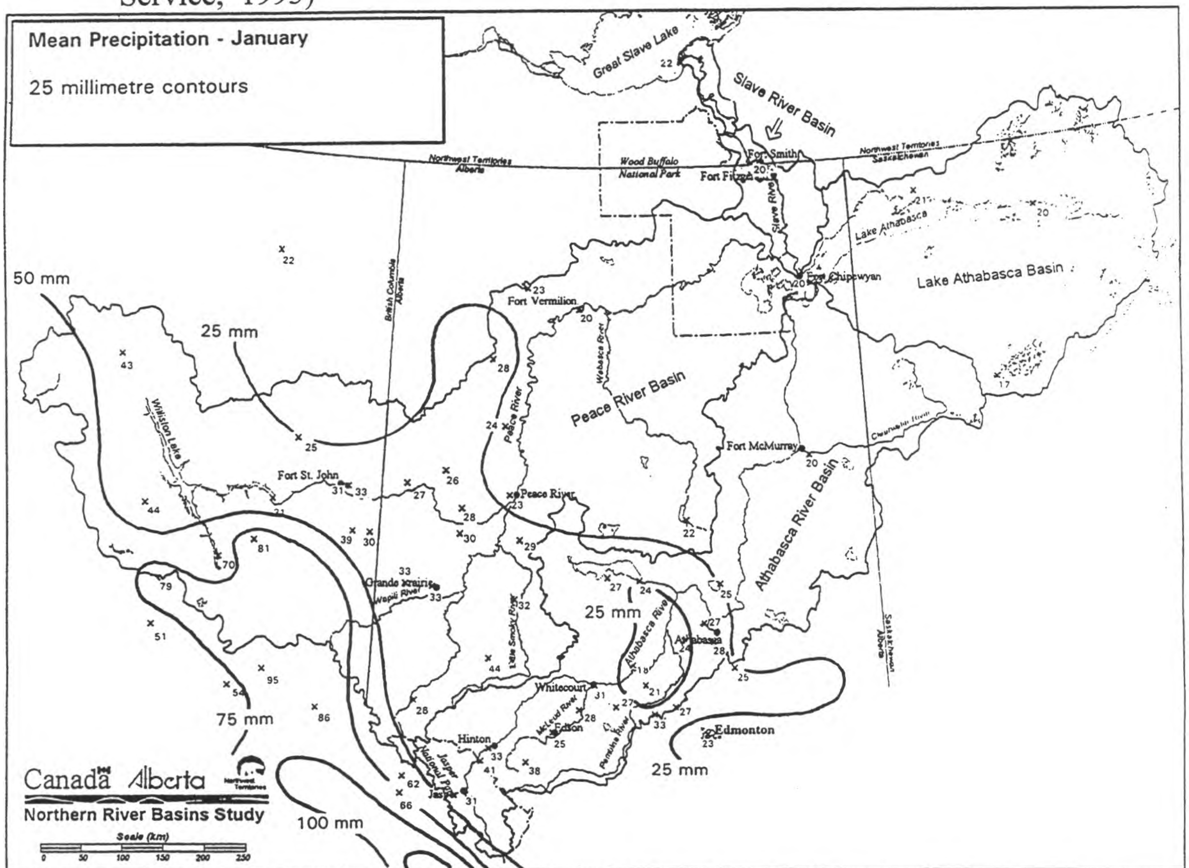


Figure 5. Concluded.

Figure 6. Maps of mean precipitation for the Northern River Basins for January, April, July, and October. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993)



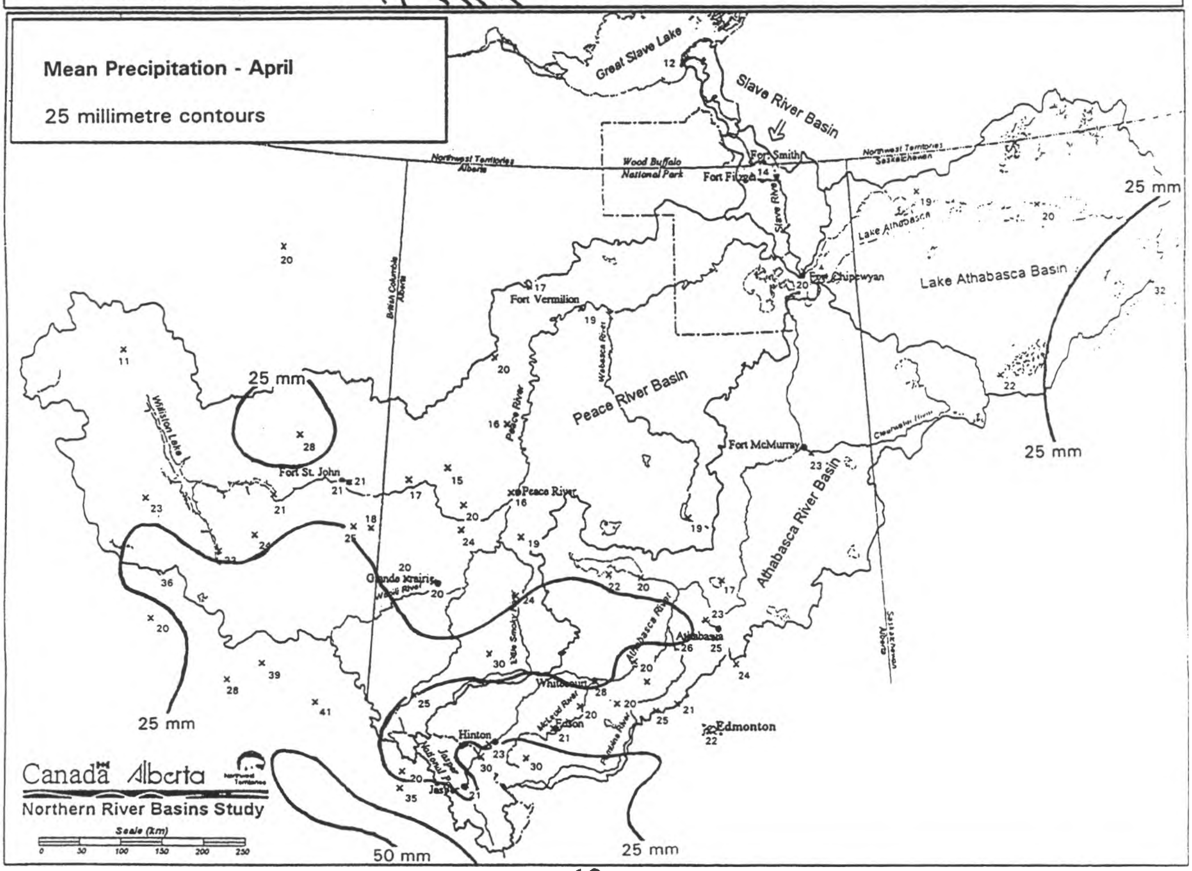
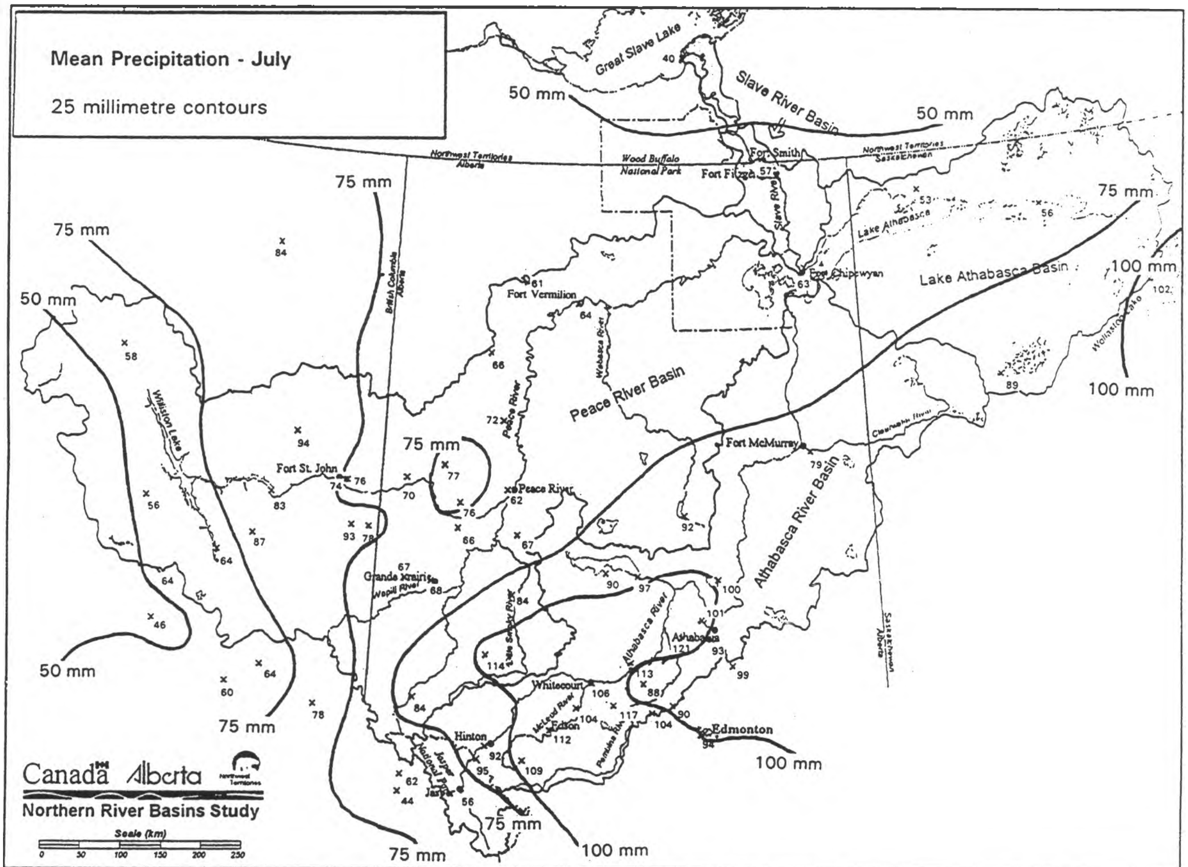
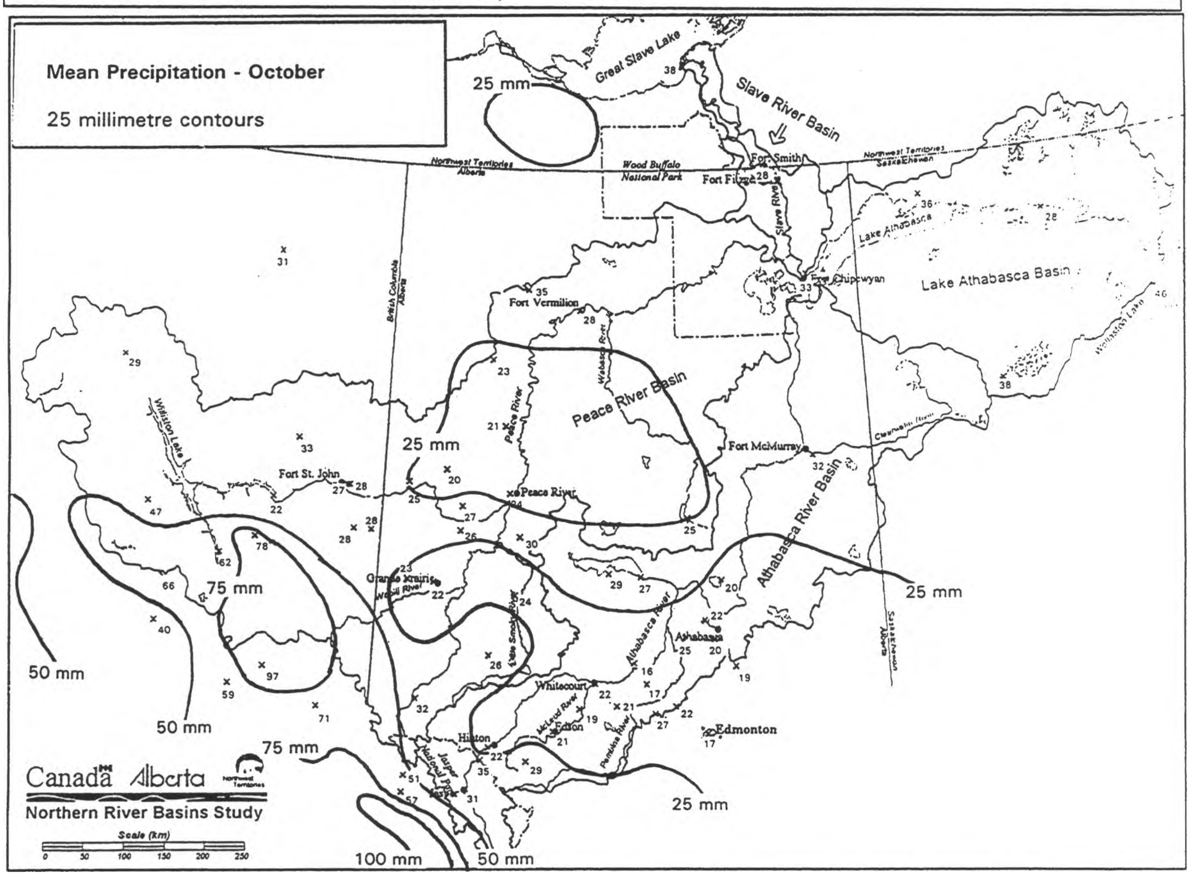
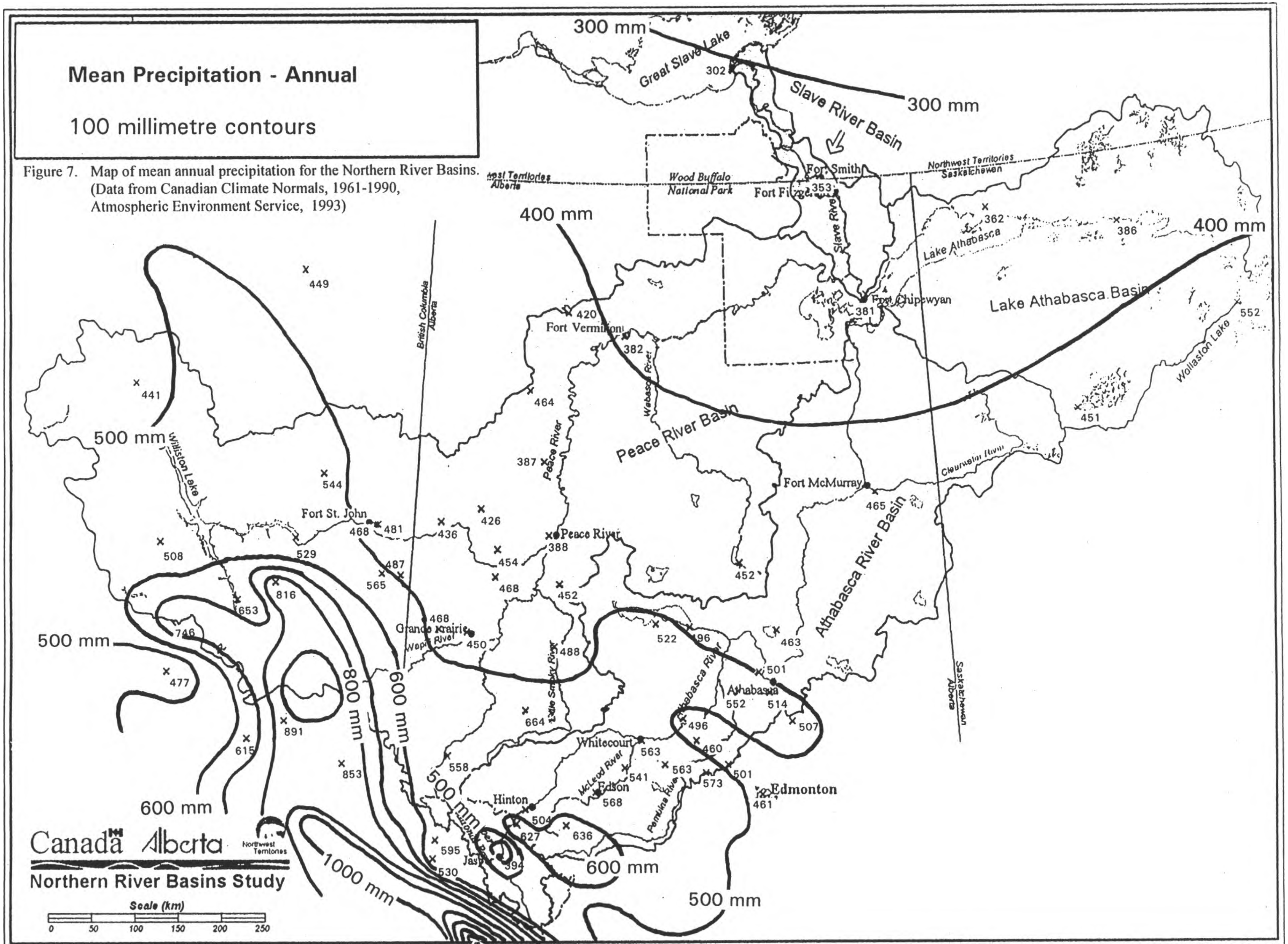


Figure 6. Concluded.







Mean Precipitation - Annual

100 millimetre contours

Figure 7. Map of mean annual precipitation for the Northern River Basins. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993)

Figure 8. Sample Climate Classification per Climate Classification System Version 2.0. (Mills and Friesen, 1993)

Agroclimatic Report for STANDARD SITE GRANDE PRAIRIE A, AB, per Climate Classification System Version 2.0
Lat: 55 deg 11 min Long: 118 deg 53 min Elev: 669 Metres Aspect: Level

Long term average Climatic Data

Season: Start: APR 27 End: SEP 8 Duration: 134 days. Hail risk : 2 Fall frost occurring 0 day(s) after regional average.

	April	May	June	July	Aug	Sept	Oct
Mean Daily Max Temp (°C)	8.4	16.4	19.9	22.1	21.1	15.9	9.9
Mean Daily Min Temp (°C)	-3.1	3.6	7.5	9.7	8.4	3.7	-1.6
Daily Mean Temp (°C)	2.6	10.0	13.7	15.9	14.8	9.8	4.1
Mean Monthly Total Precip (millimetres)	19.5	36.0	70.0	65.1	60.5	37.4	26.6

Results

Details of Calculations given in user manual. BASIC MOISTURE COMPONENT (Precip(P) minus Potential Evapotranspiration (PE)):

all units in millimetres				Cereals		Forages		Forestry	
Month	Precip	PE	P-PE	Weight	P-PE	Weight	P-PE	Weight	P-PE
April	19.5	0.0	19.5			0.5	9.8	1.0	19.5
May	36.0	96.1	-60.1	0.5	-30.1	1.0	-60.1	2.0	-120.2
June	70.0	114.8	-44.8	1.5	-67.2	1.5	-67.2	2.0	-89.7
July	65.1	119.9	-54.8	2.0	-109.6	1.5	-82.2	1.5	-82.2
Aug	60.5	93.4	-32.9	1.0	-32.9	1.5	-49.4	1.0	-32.9
Sept	37.4	36.1	1.3			0.5	0.6	0.5	0.6
Total	288.5	460.4	-171.9		-239.8		-248.6		-304.9

BASIC Growing Degree Days (GDD) of: 1099 modified by temperature range effect of: 0.994 and daylength factor of: 1.093
= Effective Growing Degree Days (EGDD) of: 1194

Indexing

		Cereals	Forages	Forestry
	Energy	39	28	14
	Moisture	28	20	34
Basic Rating	(100 minus greater of Energy or Moisture Penalties)	61	72	66
	Spring Excess Moisture	0	0	N/A
	Fall Excess Moisture	0	0	N/A
	Frost	0	0	N/A
	Hail Impact (+/-)	1	0	N/A
	Aspect Impact (+/-)	0	0	0
Net Site Rating	(Basic Rating less Modifying Variable Penalties)	62	72	66
	Class (h for heat limited and m for moisture limited)	2h	2h	2m

Limitation:			
	Cereal Crops:	Slight heat	Virtually all crop varieties are acceptable.
	Forage Crops:	Slight heat	Virtually all crop varieties are acceptable.
	Forestry:	Slight moisture	Consideration should be given to drought tolerant varieties.

3.0 TERRAIN INFLUENCES ON TEMPERATURE AND PRECIPITATION

Maps of temperature (Figures 4 and 5) and precipitation (Figure 6) are given earlier in the section. 'Caveats' apply to these figures and other figures, tables, and graphs in this climate that present temperature and precipitation data. The Northern River Basins' drainage area consists of river valleys, sloping uplands and mountains. The Caribou and Birch Mountains, for example, rise about 600 metres above the surrounding lowlands which lie at 300 metres or less. Tracing back to the Rockies, elevations rise to 2000 plus metres. Since the area is not homogeneous, climatological parameters such as temperature and precipitation measured at point locations may only be representative of a small area surrounding the location. In the mountainous drainages of the Northern River Basins, low-lying locations will usually receive less precipitation than higher elevations. Nemanishen and Cheng, 1978, show that low level stations like Kinuso and Slave Lake usually receive about 60% of the rainfall of stations above 1000 metres. Generally, temperatures will not vary as much as precipitation over a given area, or with elevation. However, during winter months low lying valleys will most often have colder temperatures than higher elevations, particularly overnight, due to radiative cooling. Figure 9 shows the relief of the Northern River Basins. Figure 10, an infrared satellite photo for 05 February, shows that there is sufficient temperature contrast between higher and lower terrain that topographic features such as the Caribou and Birch Mountains "stand out". During summer, low lying valleys can have warmer temperatures than surrounding higher elevations.

Figure 9. Relief of the Northern River Basins.

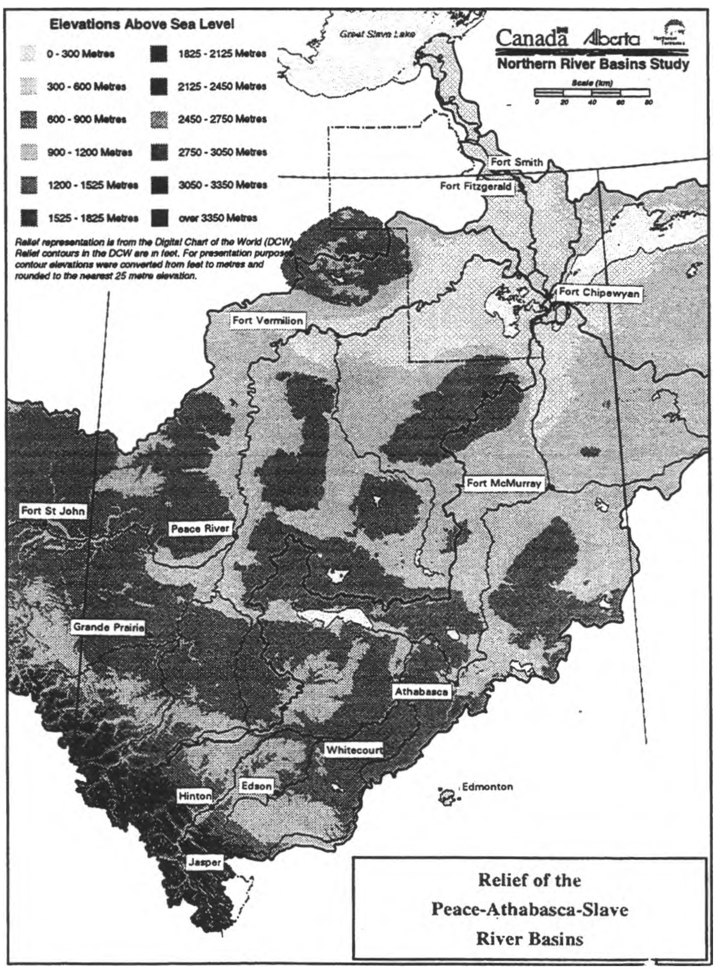
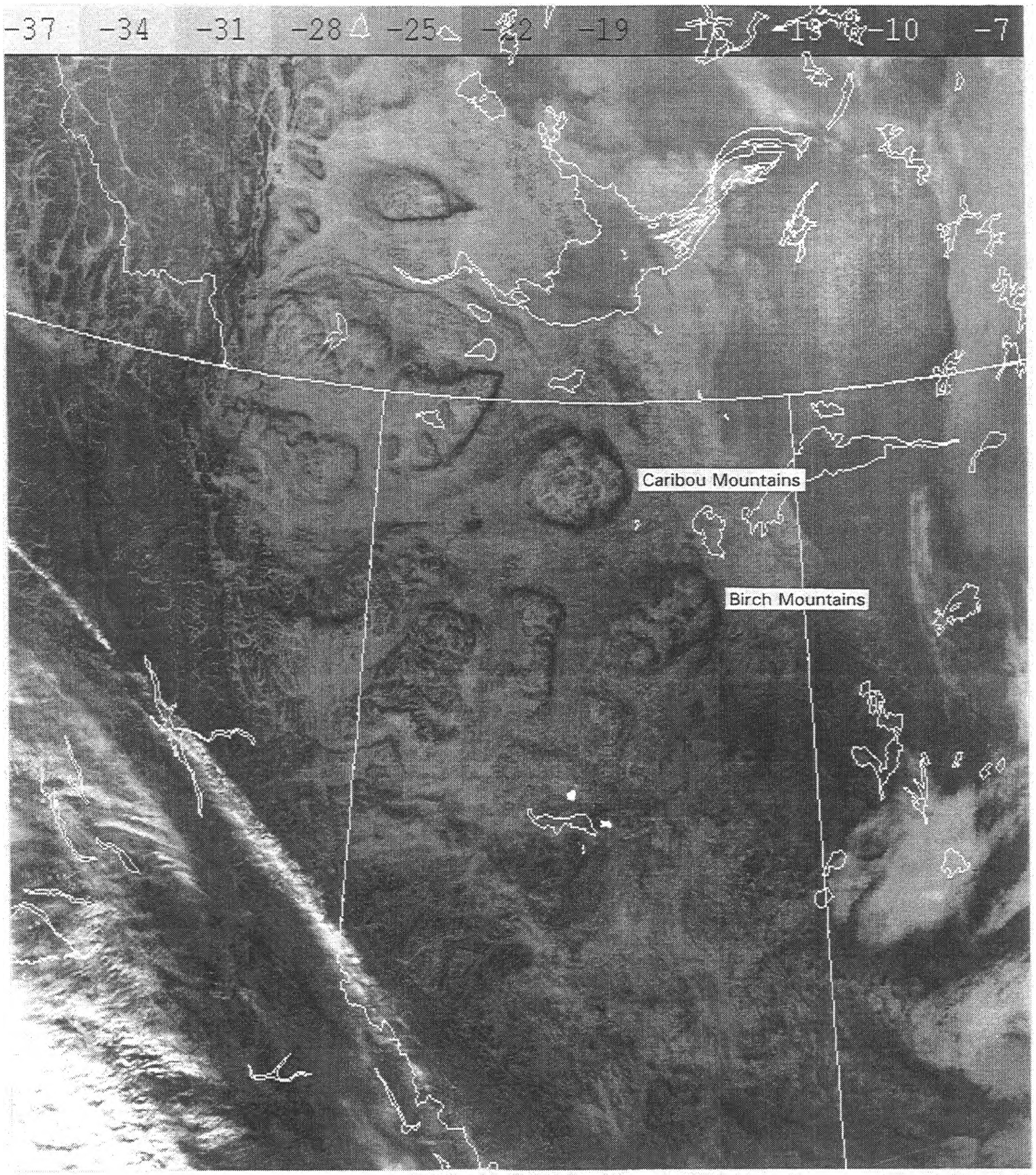


Figure 10. Infrared satellite photo 05 February 1995 showing temperature contrasts across the Northern River Basins sufficient to allow topography to stand out. (Satellite photo received by Environment Canada, Edmonton, from polar orbiting satellite NOAA-12, Channel 4, 05 February 1995, 11:10 MST)

Per the legend on the photo, warmer temperatures are dark (dark black is -7°C and warmer) and colder temperature are white. The whitest shade is -37°C and colder. The contrast between temperatures in valleys (cold and white) versus those over higher terrain (warm and dark) is particularly evident over the Yukon and southwestern Mackenzie Valley. Some relatively warm, and hence dark appearing, low cloud lies over northeastern Saskatchewan while some cold and hence grey to white coloured, mid and upper level cloud lies over central Saskatchewan and British Columbia.



4.0 AIR MASSES AND CIRCULATIONS AND THEIR EFFECTS ON TEMPERATURE AND PRECIPITATION ACROSS THE NORTHERN RIVER BASINS, BY SEASON

4.1 WINTER

Figure 11, adapted from Phillips, 1980, shows the air masses and circulations that affect the Northern River Basins during winter. In winter, the Northern River Basins experience extended periods where *continental Arctic* air - dry, very stable, pronounced temperature inversion - resides over the area. The *continental Arctic* air is driven into the area most frequently by winds aloft that are northwesterly and occasionally northerly or even northeasterly or easterly. At the surface, the *continental Arctic* air arrives when a high pressure system builds, and then settles into, the area. When the flow aloft is westerly, Gulf of Alaska disturbances with their *maritime Arctic* air (very unstable, cloud, flurries) stream from the northern Gulf of Alaska across the mountains of British Columbia into the Northern River Basins. At the surface, low pressure centres routinely lose definition as they move inland and across the mountains. However, to the lee of the mountains, redevelopment of the surface low can take place and the approach and passage of such disturbances bring precipitation events to the Northern River Basins.

When the flow aloft becomes west-southwesterly through southwesterly, the disturbances and air mass drawn from the Pacific to the Northern River Basins area get the label *maritime polar*. The *maritime polar* air mass is both milder and more stable than *maritime Arctic* air. The approach and passage of the maritime polar disturbances, like those of maritime Arctic disturbances bring precipitation.

Any system that generates winds with an easterly component across the Northern River Basins generates upslope winds because the terrain across the Northern River Basins rises, in general, from northeast to southwest. A high pressure centre building southeast from Yukon, for example, is likely to generate northeasterly and hence upslope winds across much of the Northern River Basins. Upslope winds, in turn, cause air to rise and cool so that it may no longer be able to hold its moisture. Clouds form and, depending on the amount of lift and the nature of the air mass, precipitation may develop.

When speaking about the "flow aloft", weather forecasters focus on charts for the 500 hectopascal (hPa) level. The average 500 hPa level lies at about 5500 metres but varies in height depending on how cold, or warm, the air mass below it is. Lines joining equal heights of the 500 hPa surface are essentially parallel to the winds at the 500 hPa level. The closer together the lines of equal height are, the stronger the flow. Thus, 500 hPa height charts provide meaningful indicators about underlying temperatures and the movement of weather systems.

For the Northern River Basins, the mean chart of 500 hPa heights for January (Figure 13) shows that the mean upper flow is west-northwesterly and the median height of the 500 hPa surface is about 5300 metres. The lower the height of the 500 hPa surface, the colder the air mass. Heights are even lower to the northeast so one would expect surface temperatures to be lower there. Referring back to Figure 4, the surface isotherms (lines of equal temperature) for January almost parallel the 500 hPa height contours for January having progressively lower values towards the northeast.

4.2 SPRING

The mean flow aloft, at 500 hPa during April, for example, per Figure 13, favours southwesterly from the Pacific into British Columbia and shifts to westerly across the Northern River Basins. The median height of the 500 hPa surface is about 5450 metres. This value is 150 metres higher than the January value and reflects warmer air. It is during spring that mean daily temperatures reach positive values allowing the growing season to begin. For agricultural purposes, the day that the mean daily temperature reaches 5°C is labelled as the day that the 'growing' season has begun. For natural vegetation including trees, the required mean daily temperature is lower so the growing season begins earlier. The section titled "Agriculture and Climate' provides detail on frost dates and other degree days tied to vegetation growth.

4.3 SUMMER

Figure 12 adapted from Phillips, 1990, shows summer air masses and circulations. Compared to winter, in summer the path of low pressure systems moving across the northern Pacific is further north, the disturbances are weaker and the disturbances are less frequent. Wet summer weather comes from convective events - showers and thundershowers caused by daytime heating or cooling aloft, or a combination of both. Upper cold lows with the cooling aloft that they bring, Section 5.1.3, are associated with the heaviest rains across large areas through periods of 1 to 2 days Slow moving, but severe thunderstorms bring extremes of precipitation over short time periods. The most common air mass over the Northern River Basins during the summer is the maritime Arctic air mass.

Comparing the mean 500 hPa chart for July to that for April, Figure 13, the height contours are less closely packed than those for April. Thus, in general, weather disturbances will be slower to move into and across the Northern River Basins. The direction of the flow into the Northern River Basins is much the same as that in April - southwesterly across British Columbia and westerly across the basin. The median height of the 500 hPa surface is about 5680 metres, an increase of 230 metres from the April chart indicating warm air.

4.4 FALL

The path of low pressure systems moving across the Pacific slips south from summer into fall and the disturbances become both more frequent and more intense. Comparing the mean 500 hPa chart for July to that for October in Figure 12, the contours are much closer together on the October chart and the median 500 hPa height has dropped to about 5510 metres, or a drop of 170 metres since July - an indication that the air mass over the Northern River Basins is cooler than in July.

Figures 10 and 11 depict, respectively, the winter and summer air masses that affect western North America and the Northern River Basins. Both the source air masses and the air masses that feed into the Northern River Basins change significantly from winter to summer.

Figure 11. Winter air masses and circulations.
(Adapted from Phillips, 1990, Climates of Canada)

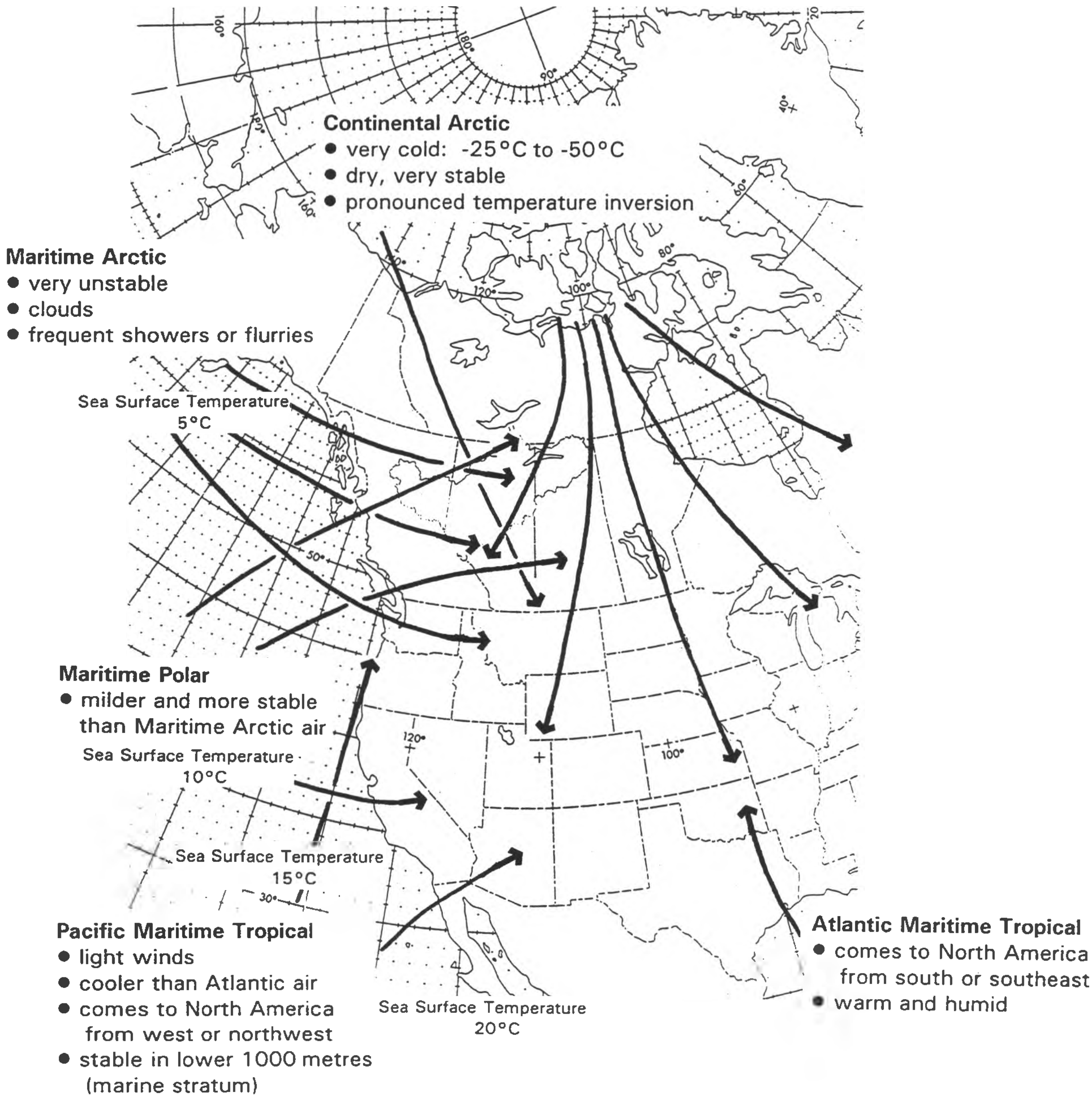


Figure 12. Summer air masses and circulations.
(Adapted from Phillips, 1990, Climates of Canada)

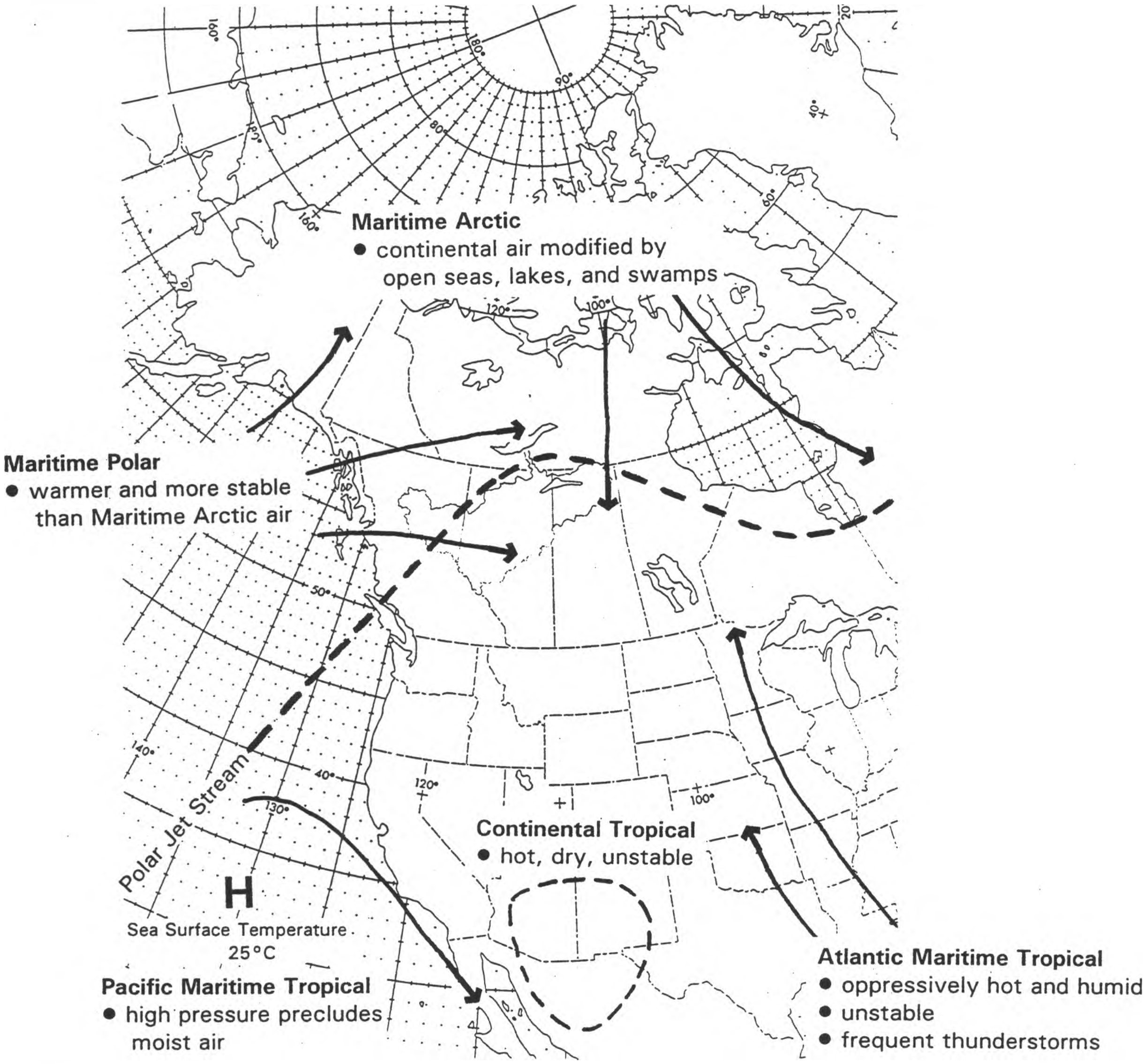
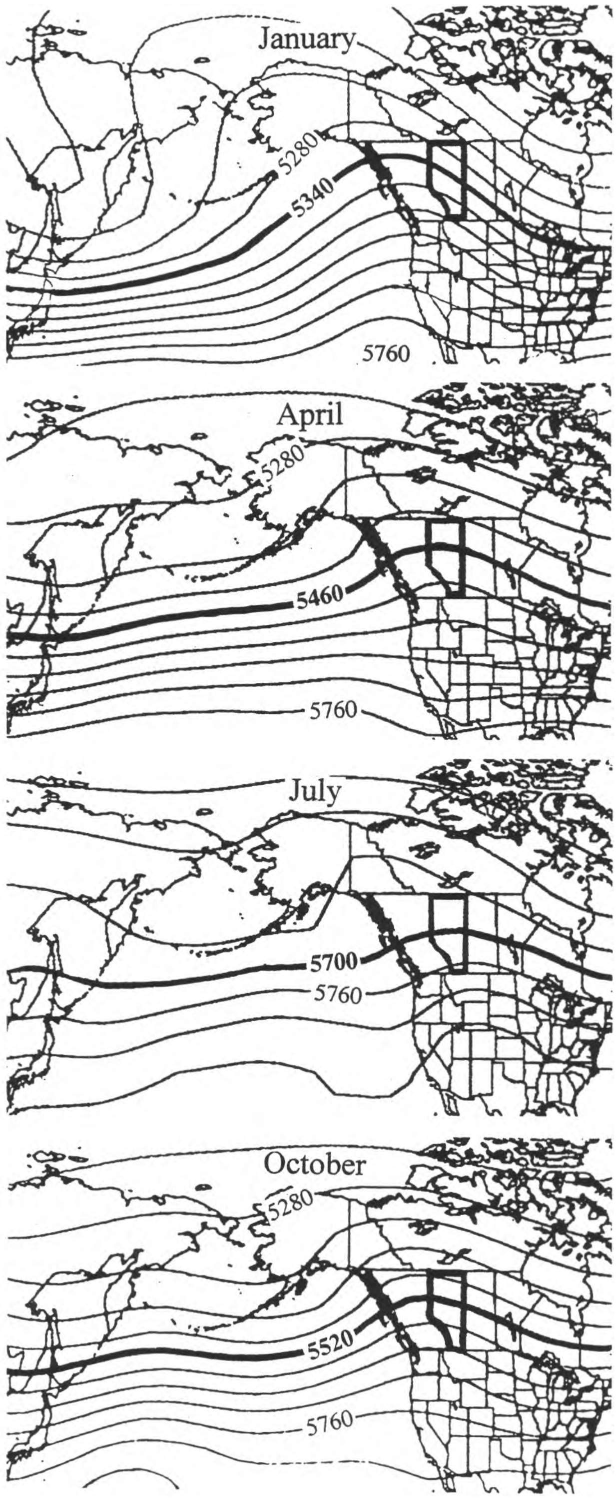


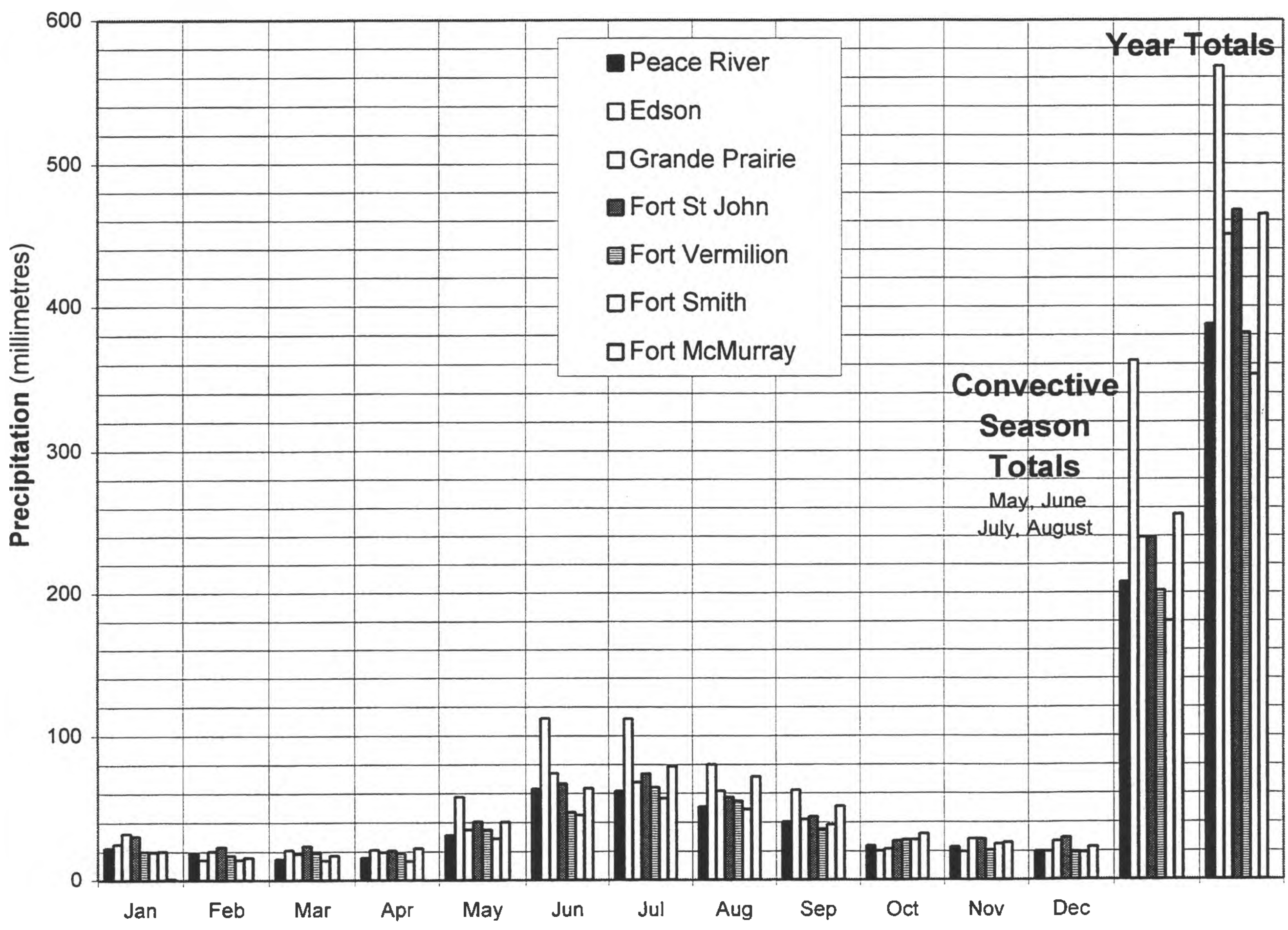
Figure 13. Mean 500 hectopascal (hPa) height contours in metres for January, April, July and October, 1956 to 1993 data. (Generated by Trudy Wohlleben, Environment Canada, from NCAR, National Center for Atmospheric Research, U.S., data)



5.0 CONVECTIVE SEASON PRECIPITATION AND CONVECTIVE WEATHER

The heaviest rainfalls, both locally and across large areas of the Northern River Basins, fall over the basin during the 'convective season' - the season where enough lift is generated in the air mass by daytime heating or cooling aloft, or a combination of both, so that clouds develop and blossom into showers and thundershowers. Thundershowers, in turn, bring 'convective weather' such as locally heavy downpours, lightning, hail, strong winds, and in the extreme, tornadoes. The 'convective season' begins about mid May and continues to the end of August and occasionally into September. Convective events, although rare, can occur during other months. The wettest months of the convective season are, on average, June and July. Figure 14 graphs precipitation for selected Northern River Basins sites by month and presents convective season and year totals. Figure 15 maps the mean convective season precipitation across the Northern River Basins. Figure 16 shows the percentage of the mean convective season (May to August inclusive) precipitation to the mean annual precipitation across the Northern Rivers Basin. Figure 17 shows the extreme daily precipitation, by month, recorded at selected Northern River Basins' stations. Table 3 gives statistical (Gumbel) return period rainfall amounts for selected stations of the Northern River Basins.

Figure 14. Mean precipitation for selected sites in the Northern River Basins by month plus convective season (May to August inclusive) and year totals. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)



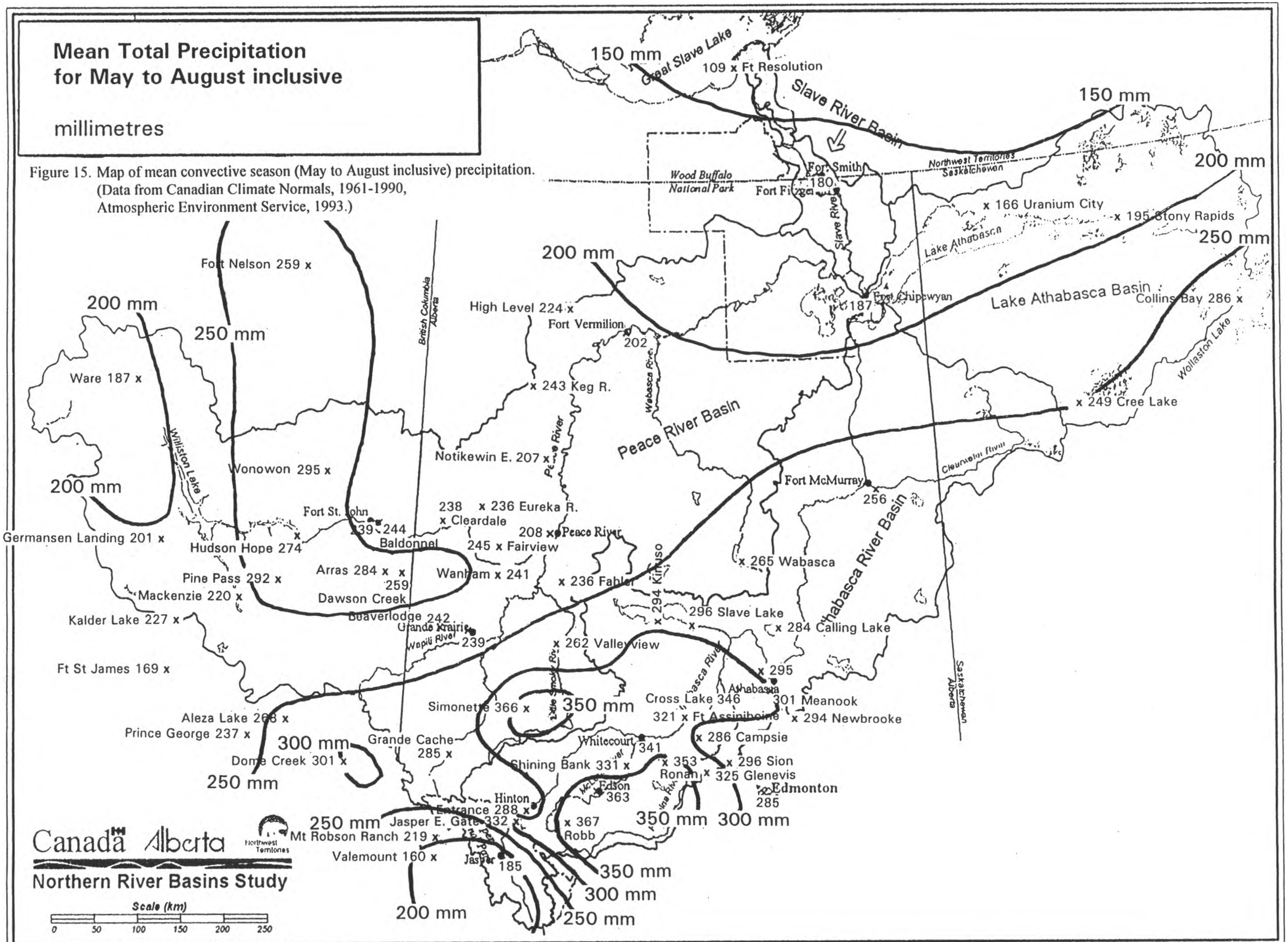


Figure 15. Map of mean convective season (May to August inclusive) precipitation. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

May to August Mean Precipitation as a Percentage of Mean Annual Precipitation

May to August is 33% of the year time-wise

Figure 16. Percentage of the mean convective season (May to August inclusive) precipitation to the mean annual precipitation. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

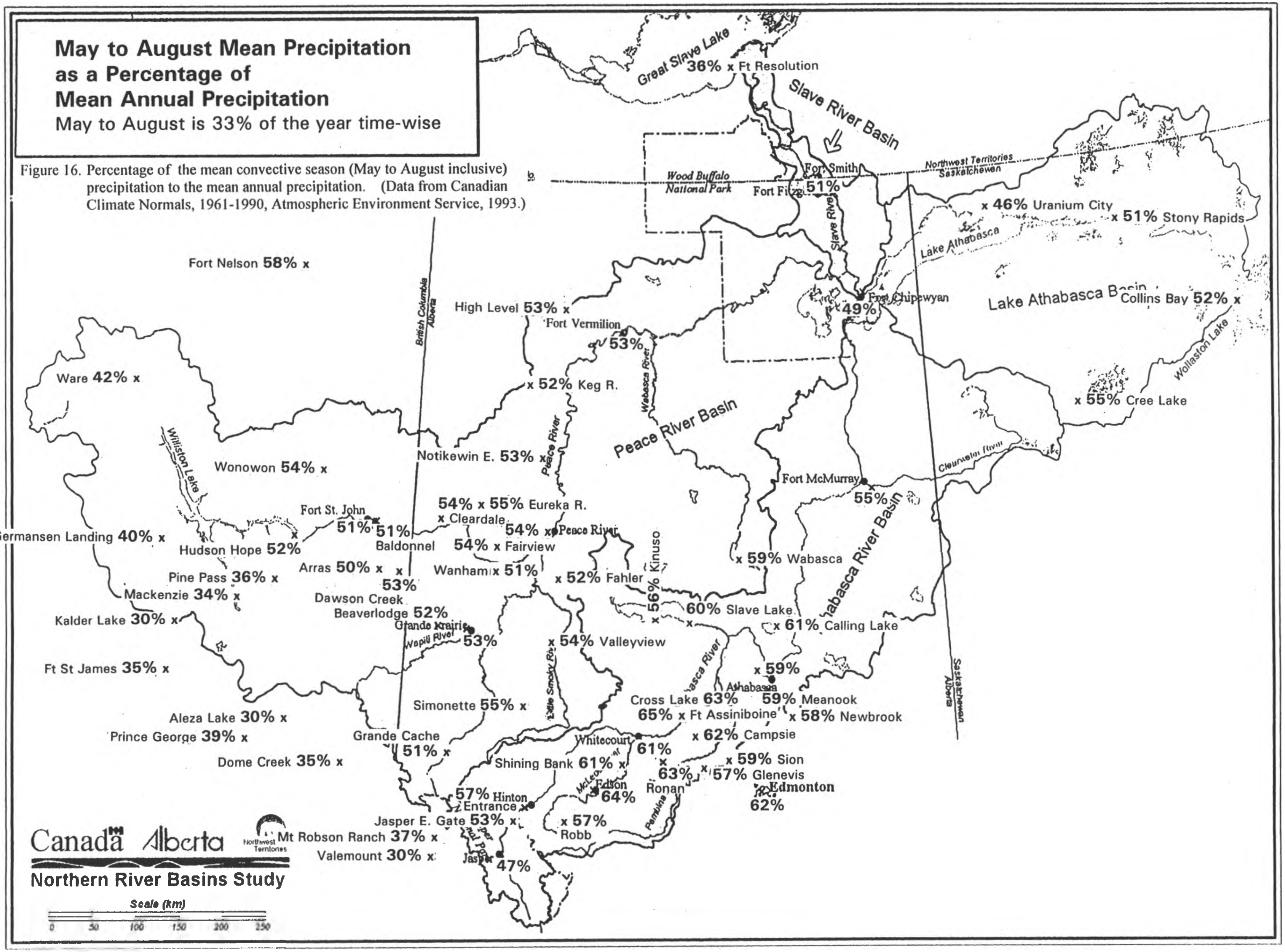


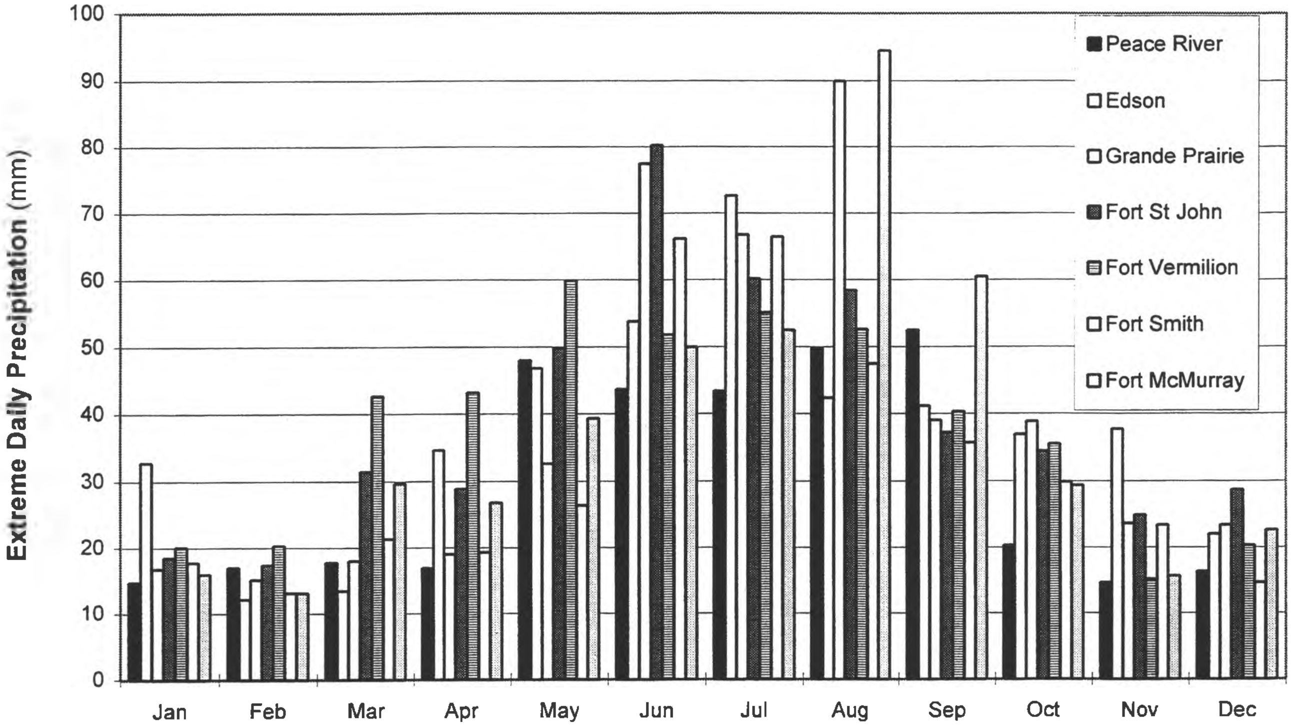
Table 3. Statistical (Gumbel) return period rainfall amounts for selected stations of the Northern River Basins. Derived from tipping bucket rain gauge data. (From Short Duration Rainfall Intensity Duration Frequency Tables and Curves - Version 91, Atmospheric Environment Service, 1991.)

	Two year return period rainfall amounts (millimetres)						
Duration	**Edson** 21 years 1970-1990	**Slave Lake** 18 years 1973-1990	**Peace River** 24 years 1966-1990	**Grande Prairie** 21/22 years 1968-1990	**Fort St John** 16 years 1973-1990	**Fort McMurray** 25 years 1966-1990	**Fort Chipewyan** 22 years 1969-1990
1 hour	17	15	13	12	13	13	12
6 hours	27	29	22	24	21	25	21
24 hours	49	42	31	40	36	39	33
	Ten year return period rainfall amounts (millimetres)						
1 hour	25	26	22	18	21	21	22
6 hours	37	46	31	40	34	41	35
24 hours	68	68	47	70	50	64	55
	Twenty five year return period rainfall amounts (millimetres)						
1 hour	30	32	27	22	25	24	27
6 hours	42	54	35	48	40	49	42
24 hours	77	82	55	85	58	77	66

Figure 17. Extreme recorded daily precipitation, by month, for selected stations of the Northern River Basins. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993, updated to 1994 using data provided by Climatology Section, Prairie and Northern Region, Edmonton.)

Period of record for sites on the graph:

Grande Prairie	1942 to 1994
Fort St John	1942 to 1994
Fort Smith	1943 to 1994
Peace River	1944 to 1994
Fort McMurray	1944 to 1994
Fort Vermilion	1962 to 1985
Edson	1970 to 1994



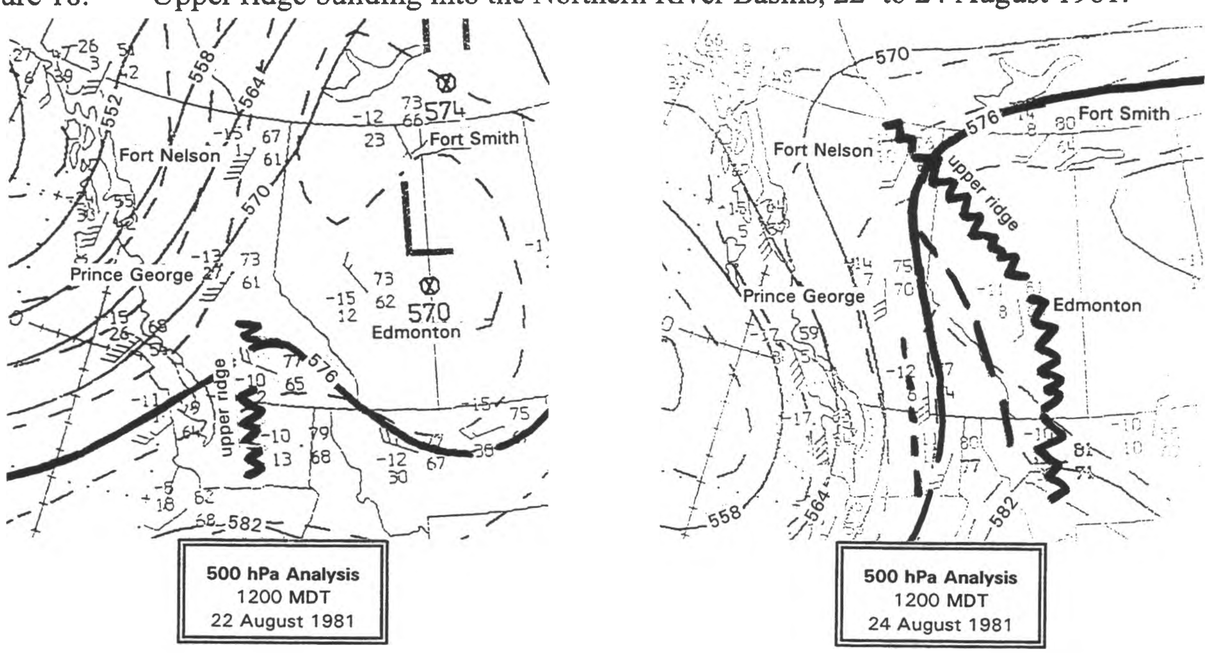
5.1 METEOROLOGICAL FEATURES DURING THE CONVECTIVE SEASON

An event that can heat the low levels of the atmosphere and make it rise, or any event that can cool the air aloft and hence make existing low level air relatively buoyant and get it to rise, has the potential to create cloud and then showers and thundershowers. Cooling aloft over the Northern River Basins happens when the flow aloft feeds cooler air over the basin. Such cooling is usually tied to the approach of an upper level disturbance or upper cold low. There are also other factors that can cause air to rise such as the lift generated when air is pushed up a slope or over a mountain. The most obvious mechanism for warming of the low levels is solar heating. Hence, a common daily cycle over the Northern River Basins is for clear morning skies to give way to cloudiness by midday and to showers/ thundershowers by mid afternoon. These usually persist until mid evening. Clearing then usually follows although some cloudiness and shower activity can linger overnight into early morning.

During the convective summer season, there are a set of meteorological features that stand out. These features are: upper ridges because of they give periods of warm (hot) temperatures and low humidities and a lack of convection, upper disturbances because they support convection (shower and thundershower activity), and upper cold lows because they bring organized areas of precipitation. Another feature of note during the convective summer season is slow moving air mass thunderstorms.

5.1.1 Upper ridges - By definition, an upper ridge is an elongation of higher heights extending from a centre of high heights. The air mass over the Northern River Basins both warms and dries as an upper ridge builds over the area. Thus, when there is an upper ridge building over the Northern River Basins, skies favour sunshine and daytime highs push to values which can approach extremes. An upper ridge can linger over the Northern River Basins for an extended period of time. The moisture content of the air mass under an upper ridge can, however, creep up as lakes and vegetation feed moisture to it. Given enough moisture, afternoon and evening showers and thundershowers develop. Figure 18 is an example of an upper ridge building into the Northern River Basins.

Figure 18. Upper ridge building into the Northern River Basins, 22 to 24 August 1981.



5.1.1.1 Upper ridge breakdown - Upper disturbances can ride along and into the west side of an upper ridge. The upper ridge may or may not rebound once the upper disturbance has moved through. Sometimes the upper ridge collapses completely and an upper cold low takes over. In such a scenario, a thundershower outbreak can be followed by a period of cool wet windy weather.

5.1.2 Upper disturbances - Upper disturbances are 'ripples' in the flow aloft that support vertical motion and hence the development of cloud and precipitation. Cooling aloft usually occurs as upper disturbances approach. With this cooling aloft, the air at low levels becomes warm relative to the air above it, and hence buoyant and rises. The rising air may cool to the temperature at which the air can hold no more moisture. Then, clouds form and ultimately, given sufficient lift, precipitation develops. If the flow aloft is strong enough, the Northern River Basins can experience the passage of an upper disturbance on a daily basis. Depending on factors such as the amount of moisture and the degree of cooling that an upper disturbance brings, and the synchronization of the upper disturbance passage with daytime heating, there will be varying amounts of shower and thundershower activity. For example, when the timing/conditions of the events is such that the relative humidity is high, daytime heating occurs, and the cooling aloft associated with the approach of an upper level disturbance's approach starts kicking in during the afternoon, significant 'outbreaks' of convective (thundershower) activity with resultant locally heavy downpours and other convective weather is likely.

5.1.3 Upper cold lows - The Northern River Basins, indeed all the river basins of Alberta, may experience one particular weather event that can generate great amounts of precipitation across a large area during the summer convective season - an upper cold low. While upper level disturbances move across the Northern River Basins usually in a matter of hours, upper cold lows, or at least the effects of an upper cold low, tend to 'arrive' and stay for at least a day. Cooling aloft occurs as the upper cold low approaches. This enhances lift generated by heating from below and scattered shower and thundershower activity merges into a general rain area. Upper cold lows have their own circulation of cloud rotating about them. When an upper cold low is to the south of the Northern River Basins, the winds over much of the Northern River Basins will be upslope northeasterly winds and upslope winds provide an added lift mechanism. Precipitation from upper cold low events is often significant. There are routinely areas of 50 to 100 millimetres of rain associated with upper cold lows and occasionally areas of 200 to 300 millimetres over 2 or 3 days. Infrequently, higher elevations may receive snow, even during summer.

Figures 19, 20 and 21 depict a cold upper low moving from off the British Columbia coast to over the Northern River Basins and an area of precipitation encompassing a large section of the Northern River Basins developing. During this particular event 234,848 square kilometres of mostly Northern River Basins country received 50 millimetres or more of rain with 264 square kilometres vicinity the Smoky Lookout (near Grande Cache) analyzed as receiving at least 300 millimetres of rain.

Figure 19.
Flow aloft (500 hPa) 6 AM MDT 31 July 1987 showing south-southwesterly flow across British Columbia and the Northern River Basins and an upper cold low off the British Columbia coast.

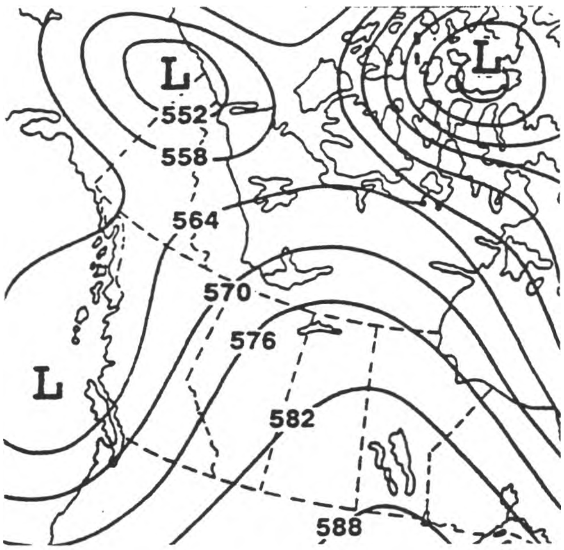


Figure 20.
Flow aloft (500 hPa) 6 AM MDT 01 August 1987 showing a cyclonic flow around an upper cold low centred vicinity Edmonton. This is the upper cold low which 24 hours earlier lay off the British Columbia coast.

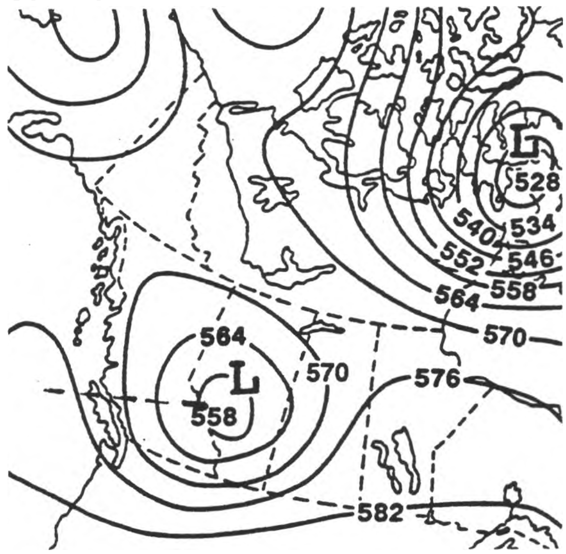
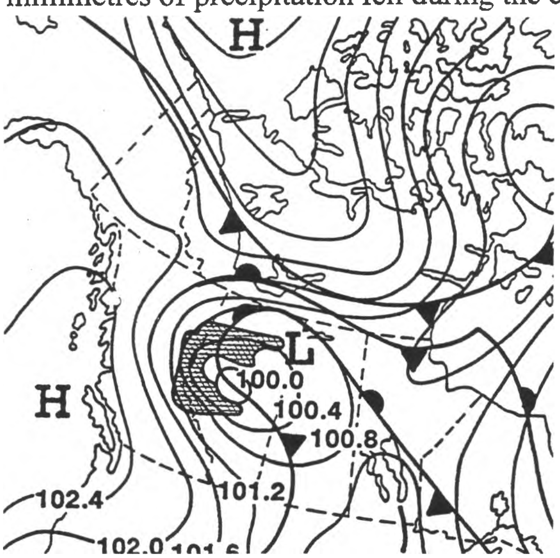


Figure 21.
Surface analysis midnight MDT 31 July 1987 showing (hatched) area where at least 50 millimetres of precipitation fell during the event.



(from Storm Rainfall in Canada Series, Alta-7-87 Event, Atmospheric Environment Service, 1987)

5.1.4 Slow moving thunderstorms, lots of precipitation locally in a hurry - A situation that can deposit a lot of precipitation in a short period of time at a given location is a slow moving thundershower. Occasionally, when the flow aloft is weak, a thundershower(s) will develop and remain resident over an area through its entire life cycle. Hence, the precipitation from the thundershower(s) gets dumped in one place. Many of the extremes of precipitation as graphed in Figure 17 came from such stationary / nearly stationary events. Thus, although Figure 17 shows the time period as being 24 hours, in many cases, most of the precipitation fell within 1 to 2 hours thereby severely testing the ability of the area where the precipitation fell to dispel it.

The following table shows precipitation amounts that were recorded at the Grande Prairie airport during the 'convective' event of 05 August 1994 (Drews, 1995). In this case, a weak, slow moving, upper level disturbance allowed a thunderstorm to develop and sit over Grande Prairie where it dumped its moisture.

Table 4. Rainfall amounts, Grande Prairie airport, tipping-bucket rain gauge (corrected amounts) (millimetres), 05 August 1994.

Duration	10 minutes	30 minutes	1 hour	2 hours	6 hours
Rainfall (millimetres)	20.1	62.3	84.0	84.3	90.0

Eighty-four of the 90 millimetres of rainfall for Grande Prairie shown in Table 4 fell in one hour.

5.1.5 Other phenomena with thundershowers - hail, damaging winds, tornadoes, lightning - In addition to heavy downpours, thundershowers can be accompanied by damaging winds, hail, lightning, and, in the extreme, tornadoes. Examples of such 'nasty' weather are listed in Section 8.0. Thunder*showers* are commonly labelled thunder**storms** when such nasty weather accompanies them. Please note that the observation and logging of such events is a function of population density. There are large tracts of the Northern River Basins where the population density is sparse. Thundershower/storm events such as hail and even tornadoes may take place unseen and those that are witnessed may not find their way into weather records. Hence, the following climate of some of the nasty weather that accompanies thundershowers/thunderstorms is meant to be illustrative rather than quantitative. Tornados have been observed in the Northern River Basins. The two tornados observed and mentioned in the Historical Meteorological Events section were both rated as F0 tornadoes. Per Ludlum, 1991, tornado researchers use a scale known as the Fujita-Pearson Tornado Intensity Scale (named after its creators) to rate tornadoes. The scale provides ratings in the areas of force or wind speed, path length, and the path width. The scale ranges from F0 to F5 and a tornado can be rated differently in each of the categories. The 'label' most frequently appended to a tornado is its rating per the wind speed scale. The maximum wind speed of a F0 tornado is 116 kph versus wind speeds in the 420 to 496 kph range for a F5 tornado (Ludlum, 1991) . The Edmonton tornado of 31 July 1987 was rated at F4.

Figure 22 maps tornadoes logged across Canada from 1916 to 1989. Figure 23, Paruk and Blackwell, 1993, shows the number of severe thunderstorm events (hail greater than 20 mm diameter (grape size) and/or wind gusts greater than 90 km/h and/or rain of more than 30 mm in one hour and/or any tornado or waterspout). There is a relative maximum of reported severe events at Peace River which could be due to either or a combination of recording diligence or the meteorology of the area is such that it is a favoured location for severe thundershower events. The majority of the severe events logged at Peace River were hail events.

Figure 22. Tornadoes across Canada, 1916 to 1989. (From Climatic Perspectives, October 1993)

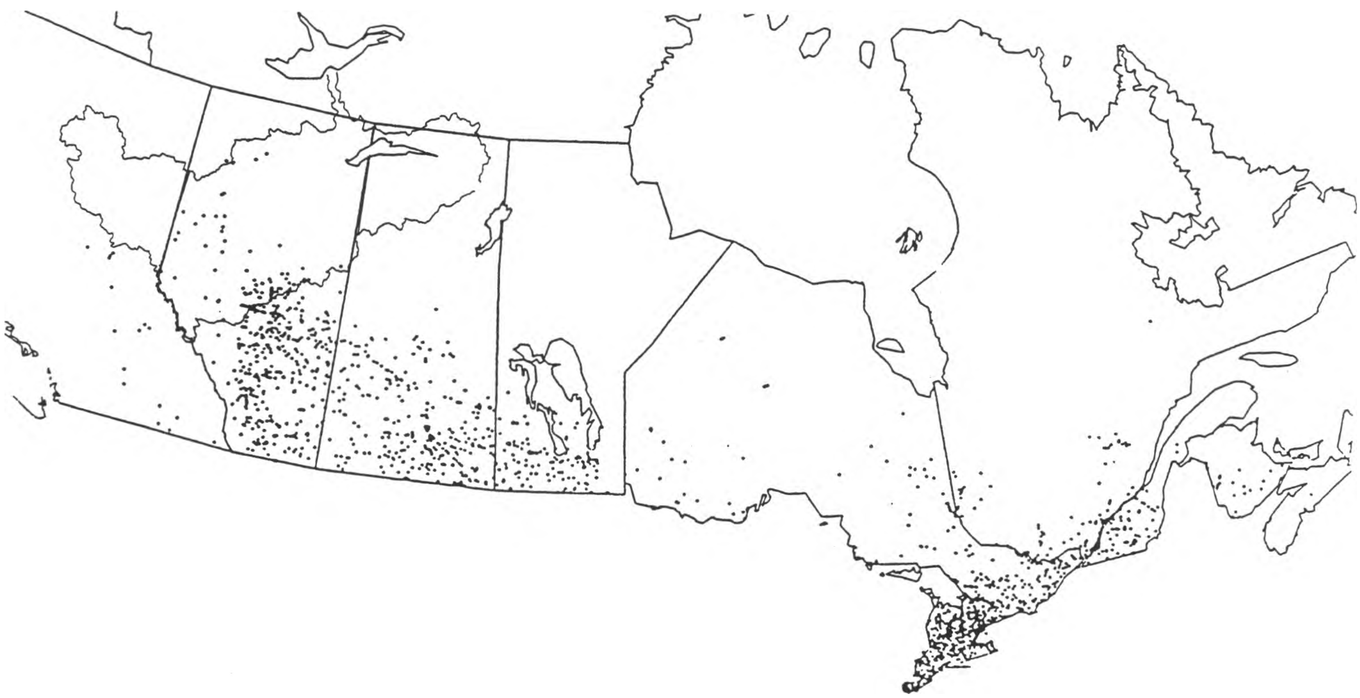
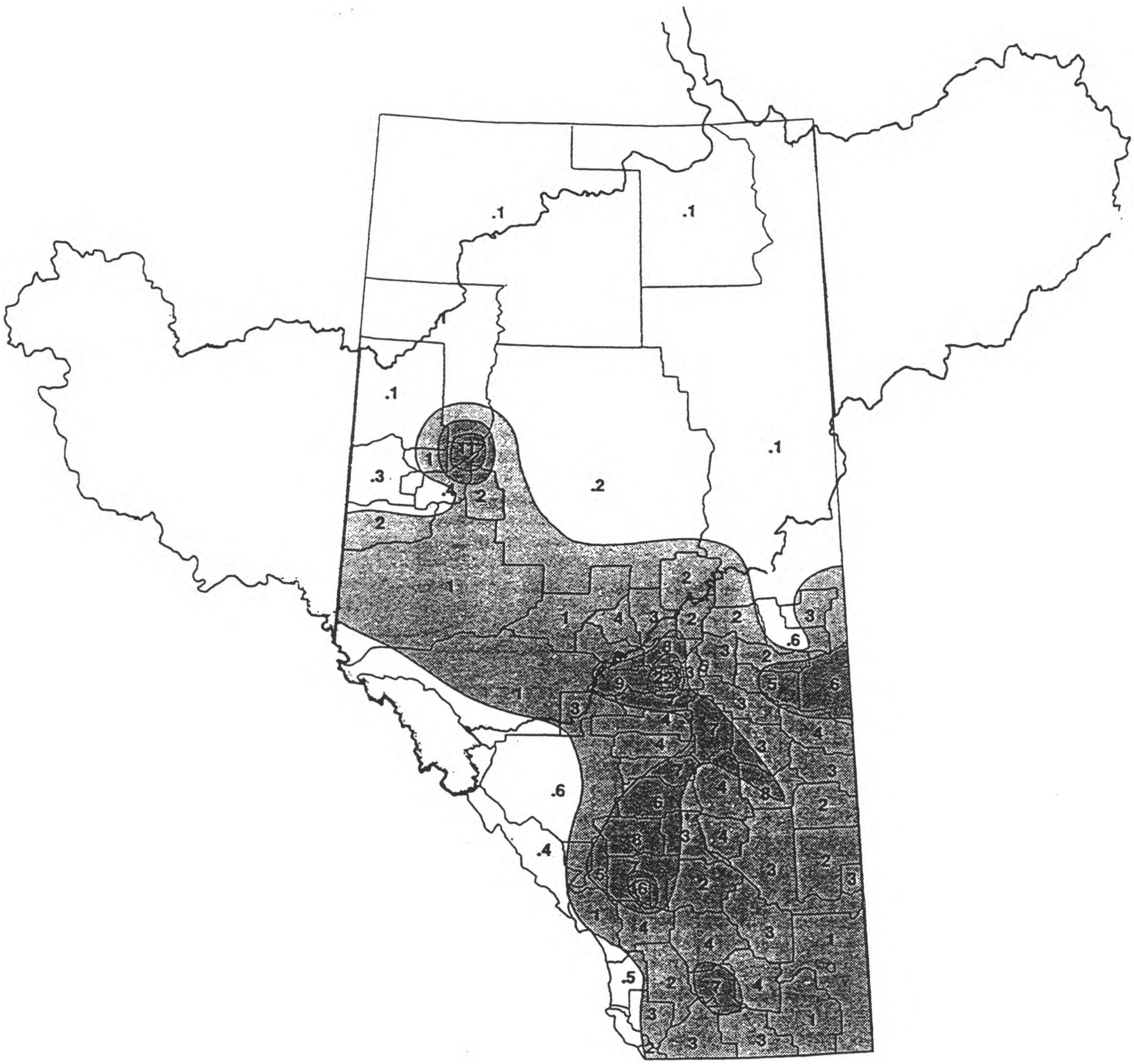


Figure 23. Severe thunderstorm events reported in each Alberta county or district per 100,000 km^2 for the period 1982 to 1991. A severe thunderstorm event is any one of, or a combination of, hail greater than 20 mm diameter (grape size), wind gusts greater than 90 km/h, rain of more than 30 mm in one hour, and any tornado or waterspout. Contours are for 1, 5, 10, and 20 events. (From Paruk and Blackwell, 1993.) Outline of Northern River Basins superimposed.



5.1.5.1 Lightning - To monitor lightning occurrence, Alberta Forestry has established a lightning detection network which also uses data from a few sensors in British Columbia. Figure 24 shows the lightning sensor network across Alberta that was in place during 1995. Figure 25, provided by Bruno Larochelle, Northern Alberta Environmental Services Centre, 1996, gives a climatology of cloud to ground lightning strikes "sensed" for Alberta sections of the Northern River Basins based on available data - 8 years spanning 1987 to 1995 but excluding 1991. The lightning network senses the electromagnetic fields radiated by lightning and is designed to respond to those fields that are characteristic of return strokes in cloud-to-ground flashes. It is estimated that each sensor in the network detects 80 to 90% of the cloud to ground strikes. The system is able to differentiate between positive and negative strikes. With negative strikes, the most common type of strike, a negative charge is lowered from the cloud to the earth. With a positive strike, a positive charge is lowered from the cloud to the earth.

Illustrative daily lightning maps are given in Figures 26 and 27 noting that there are days during the summer months when there are no strikes "sensed" or, there is no lightning activity to sense. Lightning plots on the originals are in colour in time steps making the originals less "busy". The map in Figure 26 was chosen as it shows the lightning detected the day Beaverlodge had a thundershower which gave a heavy downpour on the town - 06 July 1995. In addition to maps, the lightning data has also analyzed to show the number of strikes within distance "x" from a given site. Table 5 shows, for example, the number of cloud to ground strikes recorded within 20 kilometres of Grande Prairie, Slave Lake, and Whitecourt 06 July 1995. Such statistics, when generated for a month rather than a day, are expected to provide meaningful site-specific lightning statistics and in turn site-specific thundershower statistics. Output from the lightning sensor network has already prompted questions as to how representative the existing site-specific thundershowers climatologies found in the Canadian Climate Normals are - a thundershower day being a day when thunder was heard and logged. 21 August 1994 was chosen for Figure 27 as a representation of a busy lightning day. There were 47,746 strikes recorded on this day, the majority of occurred on the Northern River Basins' area. The record to date is approximately 65,000 strikes detected across the area covered by the map.

Figure 24. Alberta lightning sensor network, 1995. (Figure courtesy Nick Nimchuk, Alberta Forestry.)

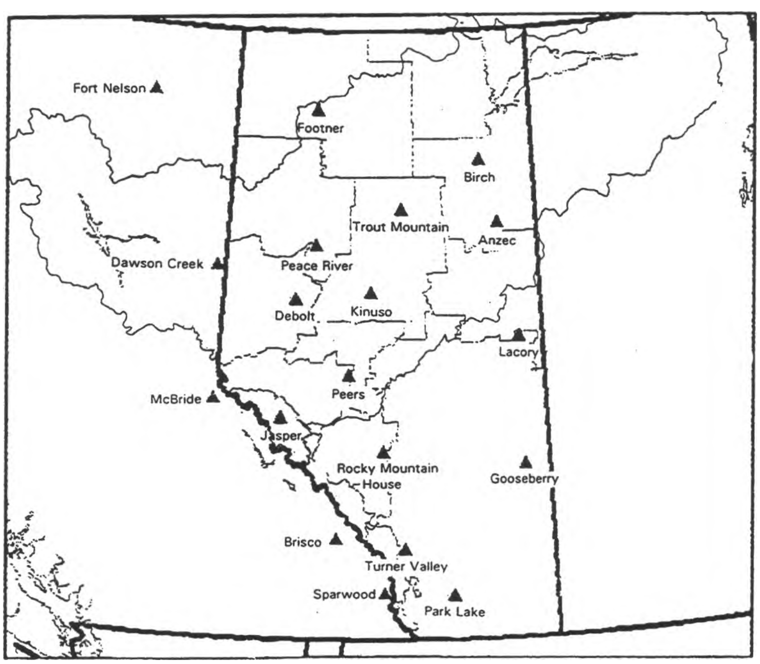


Figure 25. Average number of cloud to ground lightning strikes per year for Alberta on a 10 x 10 kilometre square based on 1987 to 1990 and 1992 to 1995 data. (Figure courtesy Bruno Larochelle, 1996, Northern Alberta Environmental Services Centre, Environment Canada.)

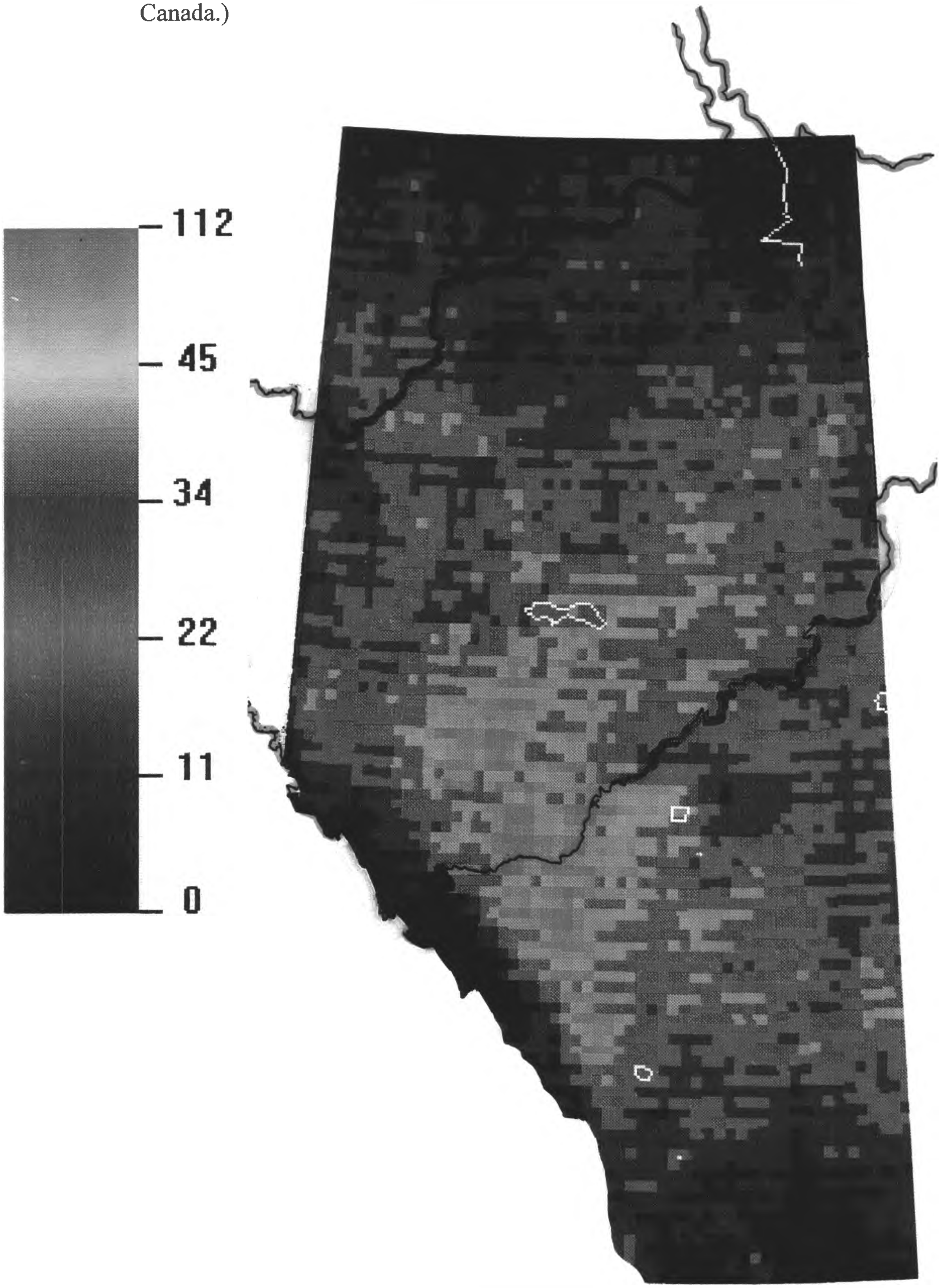


Figure 26. Cloud to ground lightning, 06 July 1995. ("+" = positive strikes, "x" = negative strikes) (From Northern Alberta Environmental Services Centre, Environment Canada)

There are routinely more negative strikes than positive strikes. Per the count on the upper right-hand side of the figure there were 10 negative strikes to every positive strike on 06 July 1995. Positive strikes tend to have a longer continuing current than negative strikes and to come from the side of a thunderstorm where there is little precipitation.

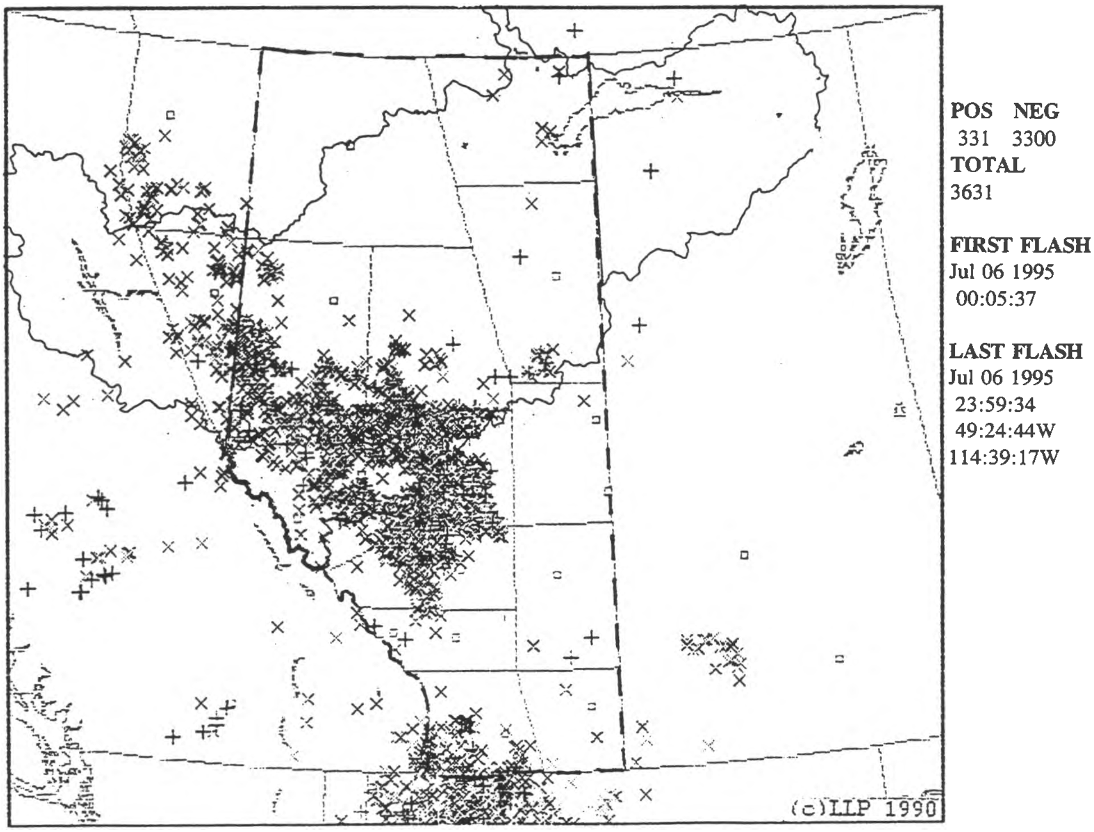
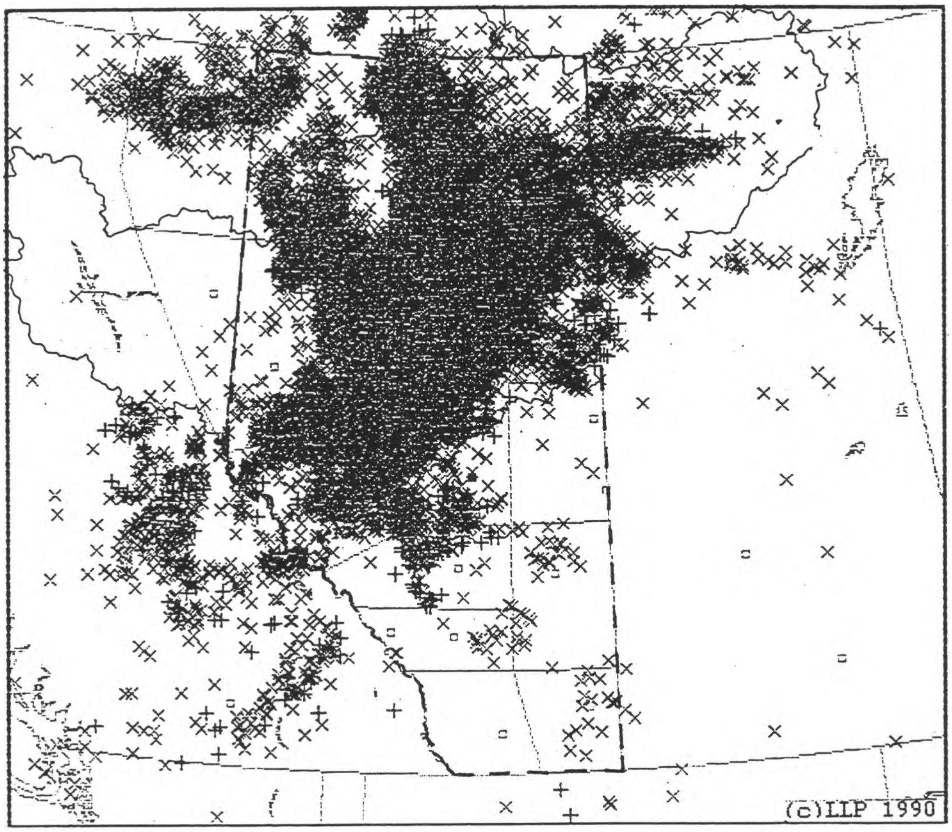


Table 5. Lightning strikes recorded within 20 kilometres of Grande Prairie, Slave Lake and Whitecourt, 06 July 1995. (From Northern Alberta Environmental Services Office, Environment Canada)

	Number of cloud to ground strikes				
	midnight to 6 AM MDT	6 AM to noon MDT	noon to 6 PM MDT	6 PM to midnight MDT	TOTAL
Grande Prairie			18		18
Slave Lake		2	3		5
Whitecourt			31		31

Figure 27. Cloud to ground lightning, 21 August 1994, a busy day with 47,746 strikes recorded within the map area. (Figure courtesy Northern Alberta Environmental Services Centre, Environment Canada.)



POS NEG
2965 44781
TOTAL
47746

FIRST FLASH
Aug 21 1994
00:00:06

LAST FLASH
Aug 21 1994
23:50:00
57:39:13W
113:48:50W

6.0 WINTER WEATHER AND PERMAFROST

6.1 SNOW

Figure 28 shows monthly snowfall and month-end snow cover for several locations across the Northern River Basins. Per the figure, maximum snowfall occurs during January and the maximum month-end snow cover occurs the end of February. Comparing the recorded measured snowfall to the water equivalent, Figure 29 shows that the driest snows, the snows with the highest ratios of snow depth to water equivalent, occur during the winter while the wettest snows occur during spring and late summer or fall.

Figure 28. Monthly snowfall and month-end snow depths for selected sites of the Northern River Basins. (Data from Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

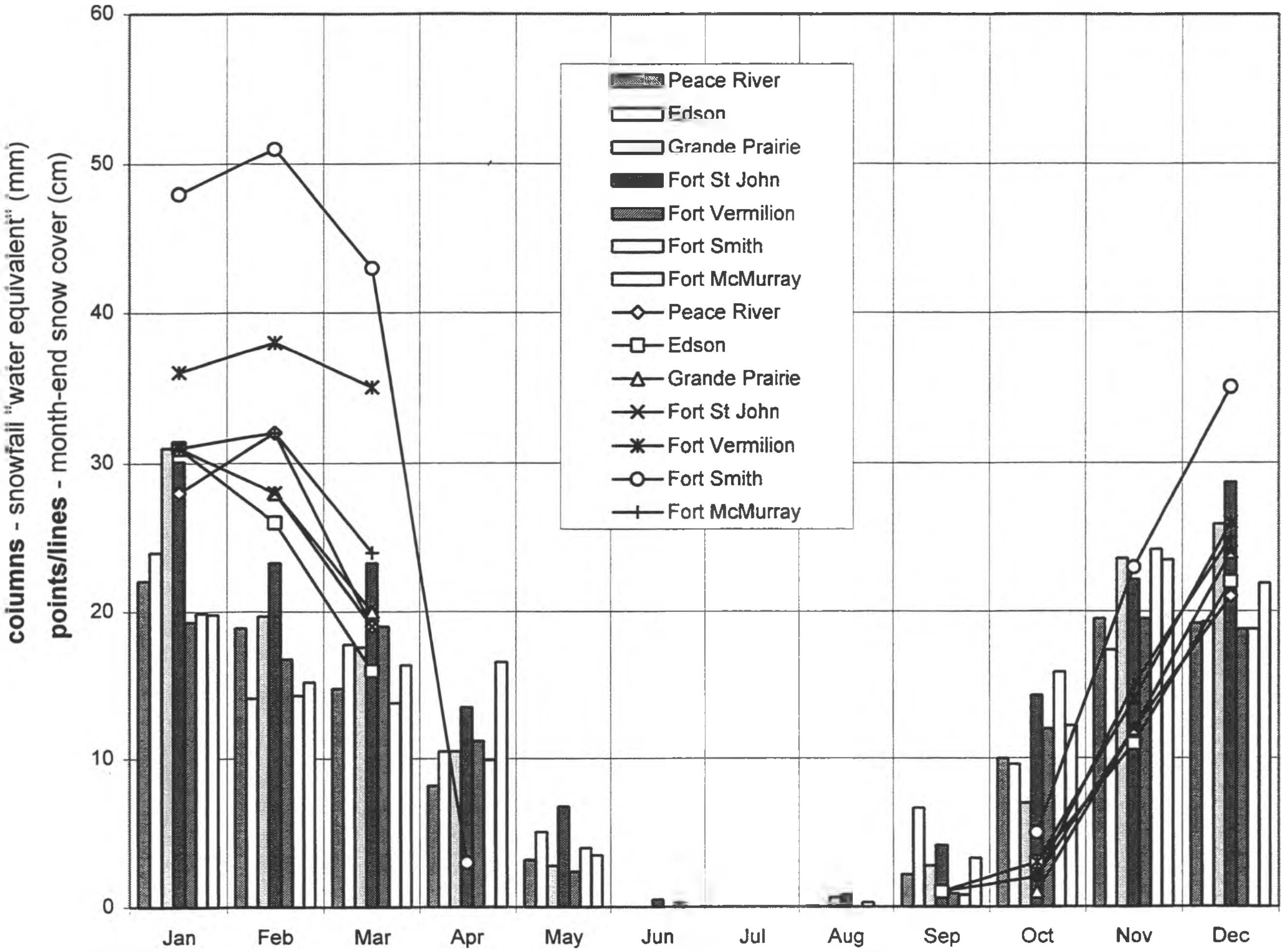
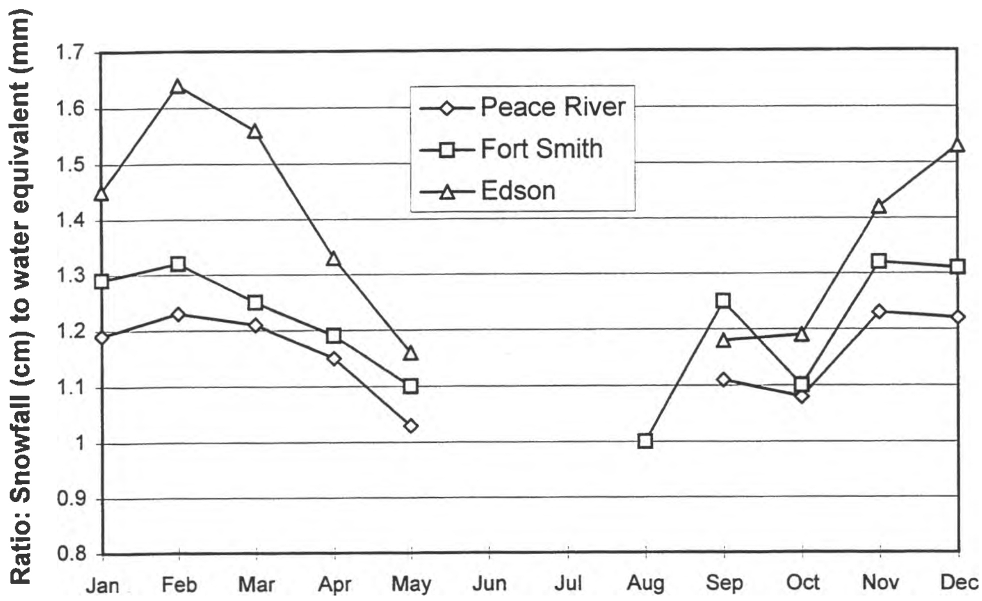


Figure 29. Mean snowfall versus water equivalent, by month, Peace River, Edson and Fort Smith. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)



6.2 ABOVE FREEZING WINTER TEMPERATURES

During the winter, the flow aloft, generally westerly, occasionally brings air with above freezing temperatures aloft over the Northern River Basins. The above freezing temperatures can make it to the surface particularly when there are strong winds to mix the warm air aloft down to the surface and flush out residual cold air. Across the east slope of the Rockies, including those of the Northern River Basins, but particulary across southwestern Alberta, above freezing surface temperatures can occur when warm dry winds descend the east side of the Rockies. Moist air on the west side of the mountains cools at it climbs and looses its moisture. The rate of warning of the now dry air on the east side if the Rockies is greater than the rate of cooling that occurred on the west side of the Rockies resulting in air "surfacing" with temperatures a little warmer than those that it started out with as it first met the British Columbia Coast. Figure 30, per Longley, and taken from the Agroclimatic Atlas of Alberta, shows the number of winter days that the daytime maximum temperature gets to at least 5°C for the Alberta section of the Northern River Basins. Table 6 shows the extreme and mean maximum temperature posted at selected Northern River Basins' stations for December, January, and February.

Figure 30. Average number of days during the winter (December, January, February) when the daytime maximum reaches at least 5°C. (From Agroclimatic Atlas of Alberta, Dzikowski and Heywood, 1990.) Outline of Northern River Basins superimposed.

Table 6. Highest maximum temperature (for period shown in table) with year recorded and average mean daily maximum temperature (for period shown in table) for December, January and February, for selected stations of the Northern River Basins. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

	Edson 1970-1990 *1970-1990*	Grande Prairie 1942-1990 *1961-1990*	Peace River 1944-1990 *1961-1990*	Fort St John 1942 - 1990 *1961-1990*	High Level 1970-1990 *1970-1990*	Fort McMurray 1944-1990 *1961-1990*	Fort Smith 1943-1990 *1961-1990*	Uranium City 1953 - 1986 *1961-1986*
Dec	**15.4** '88 *-5.4*	**13.3** '43 *-8.3*	**9.4** '60 *-10.1*	**11.4** '80 *-9.1*	**12.3** '85 *-14.8*	**10.0** '63 *-12.6*	**9.7** '84 *-17.2*	**5.9** '85 *-17.7*
Jan	**13.7** '81 *-5.3*	**11.1** '65 *-10.0*	**10.0** '45 *-12.2*	**10.6** '65 *-10.8*	**9.7** '89 *-15.8*	**11.6** '89 *-14.5*	**8.2** '81 *-20.3*	**3.3** '85 *-21.8*
Feb	**16.5** '88 *-2.5*	**11.7** '54 *-6.1*	**9.4** '54 *-7.6*	**12.8** '68 *-6.5*	**12.2** '68 *-11.4*	**15.0** '68 *-8.6*	**12.2** '86 *-15.2*	**5.9** '86 *-16.2*

	Beaverlodge 1942-1990 *1961-1990*	Fort Vermilion 1908-1985 *1961-1985*
Dec	**16.7** '30 *-7.3*	**18.3** '13 *-15.7*
Jan	**16.7** '31 *-9.0*	**11.1** '34 *-18.2*
Feb	**16.1** '54 *-5.2*	**21.1** '37 *-12.0*

6.3 FREEZING PRECIPITATION

Freezing rain can occur when there are below freezing temperatures at ground level and above freezing temperatures aloft. Then, when precipitation falls, it may melt to rain as it passes through the above freezing layer. If the precipitation remains liquid until it makes contact with objects and the ground (which have below freezing temperatures) it will freeze immediately to form a layer of ice on the objects and on the ground. The added weight of freezing rain on electrical wires, for example, may cause them to topple. Freezing rain may coat highways with enough precipitation to turn them into skating rinks making driving conditions treacherous. Table 7 shows the mean number of days of reported freezing rain occurrence at selected Northern River Basins' stations. From the table, November and December are the months when the Northern River Basins is most likely to experience freezing precipitation.

Table 7. Mean number of days with freezing precipitation for October to May inclusive for selected stations of the Northern River Basins. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

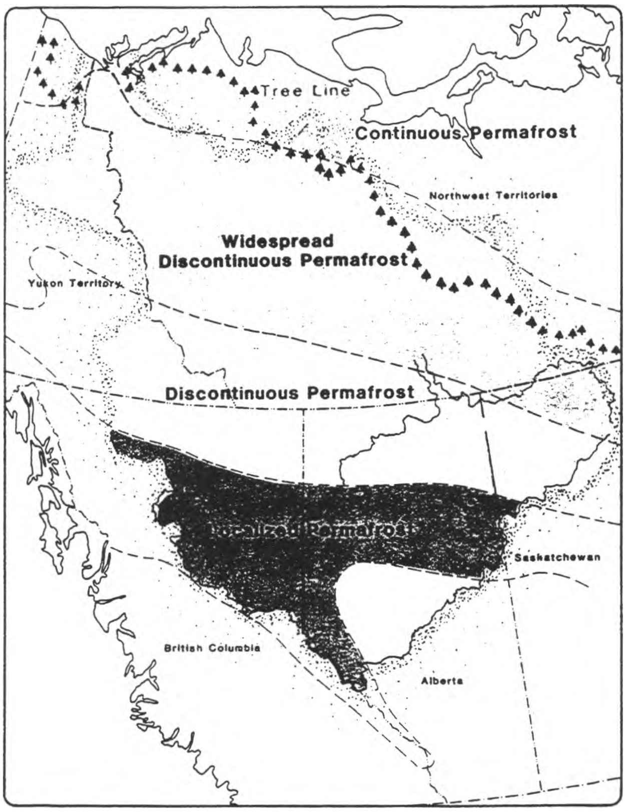
	Edson	Grande Prairie	Peace River	Fort St John	High Level	Fort McMurray	Fort Smith	Uranium City
Oct	< 1	< 1	< 1	< 1	N	< 1	**2**	2
Nov	**2**	**2**	**2**	**1**	**3**	**2**	**4**	3
Dec	< 1	**1**	**2**	< 1	**2**	**2**	**1**	2
Jan	**1**	**1**	< 1	< 1	**1**	**2**	< 1	1
Feb	< 1	**1**	< 1	< 1	< 1	**1**	**1**	< 1
Mar	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Apr	N	< 1	< 1	< 1	N	< 1	< 1	< 1
May	< 1	**0**	< 1	< 1	N	< 1	< 1	< 1

N - data exists but not enough to derive a value

6.4 PERMAFROST

Per Figure 31, there is discontinuous permafrost in sections of the Northern River Basins northward of about 56°N. Permafrost becomes widespread over extreme northeastern sections of the Northern River Basins. Between about 54°N and 56°N and across the mountainous southwestern sections of the Northern River Basins, localized permafrost exists.

Figure 31. Permafrost zones. (From Mackenzie River Basin Study Report, 1981.) Outline of Northern River Basins superimposed.



7.0 AGRICULTURE AND CLIMATE

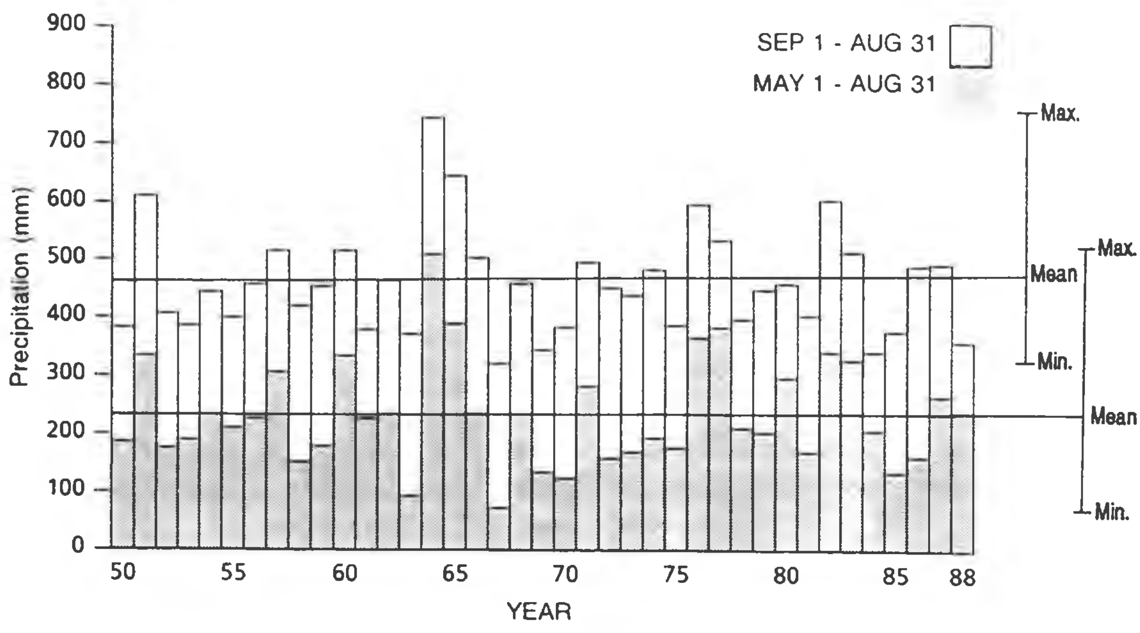
Precipitation, temperature, and sun are three key ingredients for plant growth.

7.1 PRECIPITATION

Per Figure 16 in Section 5, the percentage of precipitation that falls over the bulk of the Northern River Basins during the growing season, 01 May to 31 August, (labelled the convective season in Section 5) ranges from about 50 to 60% of the annual precipitation Most of the precipitation falls as rain. Precipitation in any month is variable and dry spells of a month or even a little longer are possible. Figure 31, from Dzikowski and Heywood, 1990, shows the variability of precipitation for the growing season 01 May to 31 August and the year long period 01 September to 31 August for Beaverlodge for the period 1950 to 1988. Dzikowski and Heywood's figure also shows the maximum, mean, and minimum recorded over the period.

The precipitation that falls on the Northern River Basins during the growing season, although 50 to 60% of the annual precipitation, is not generally enough to meet the demands of crop water use. Hence, precipitation between growing seasons is important.

Figure 32. Annual and growing season precipitation at Beaverlodge, 1950 to 1988. (Dzikowski and Heywood, 1990)



7.2 TEMPERATURE

7.2.1 FROST

At weather and climate stations, temperatures are measured 1.2 metres above the ground surface by thermometers located in louvred screens. It is these temperatures that have been used in this study. A few stations such as those at Agriculture Canada Research Stations also record temperatures 3 to 4 centimetres above a short grass surface using thermometers exposed to the sky. These temperatures are more representative of 'crop' temperatures. During the spring/fall 'frost' season, the grass minimum temperatures are lower, generally 2 to 5°C but as much as 10°C lower, than screen height temperatures. Since the seedlings of most of the field crops grown in the Northern River Basins can withstand temperatures of -4 to -6°C, and the crops themselves can withstand temperatures as low as -6°C, frost data collected at screen height remains meaningful.

Figure 33 shows the annual mean number of frost-free days for stations across the Northern River Basins. Figures 34 and 35 show respectively the mean dates for beginning and ending of the frost free season across the Northern River Basins. Values are plotted for stations with 9 or more years of data. Both the number of years of data and local topography such as differences in elevation, aspect, and slope may explain why some stations only a few kilometres apart, and in apparently similar surroundings, have frost-free periods that differ. Compare, for example Dawson Creek and Arras in Table 8. Dates for the mean beginning of the frost free period are generally late May into early June but vary considerably both across the map and within a specific area. Table 8 shows the variability in mean frost dates across the Peace River Basin. Frost data alone is potentially misleading. Per Mills, 1995, personal correspondence, Beaverlodge and Grande Prairie are only 40 kilometres apart. Frost data shows Grande Prairie having, on average 12 more frost-free days than Beaverlodge but production is similar. The 49 day frost-free period at Arras is particulary misleading as wheat, barley, and canola are all grown there. Table 9 parallels Table 8 but for middle Athabasca stations. About 50% of the last of the spring frosts occur in the week before and after the mean frost date. During the fall, about 50% of the frosts occur within one week before and one and a half weeks after the mean fall frost date. Table 10 shows variability in frost dates at Grande Prairie and Table 11 the variability at Athabasca.

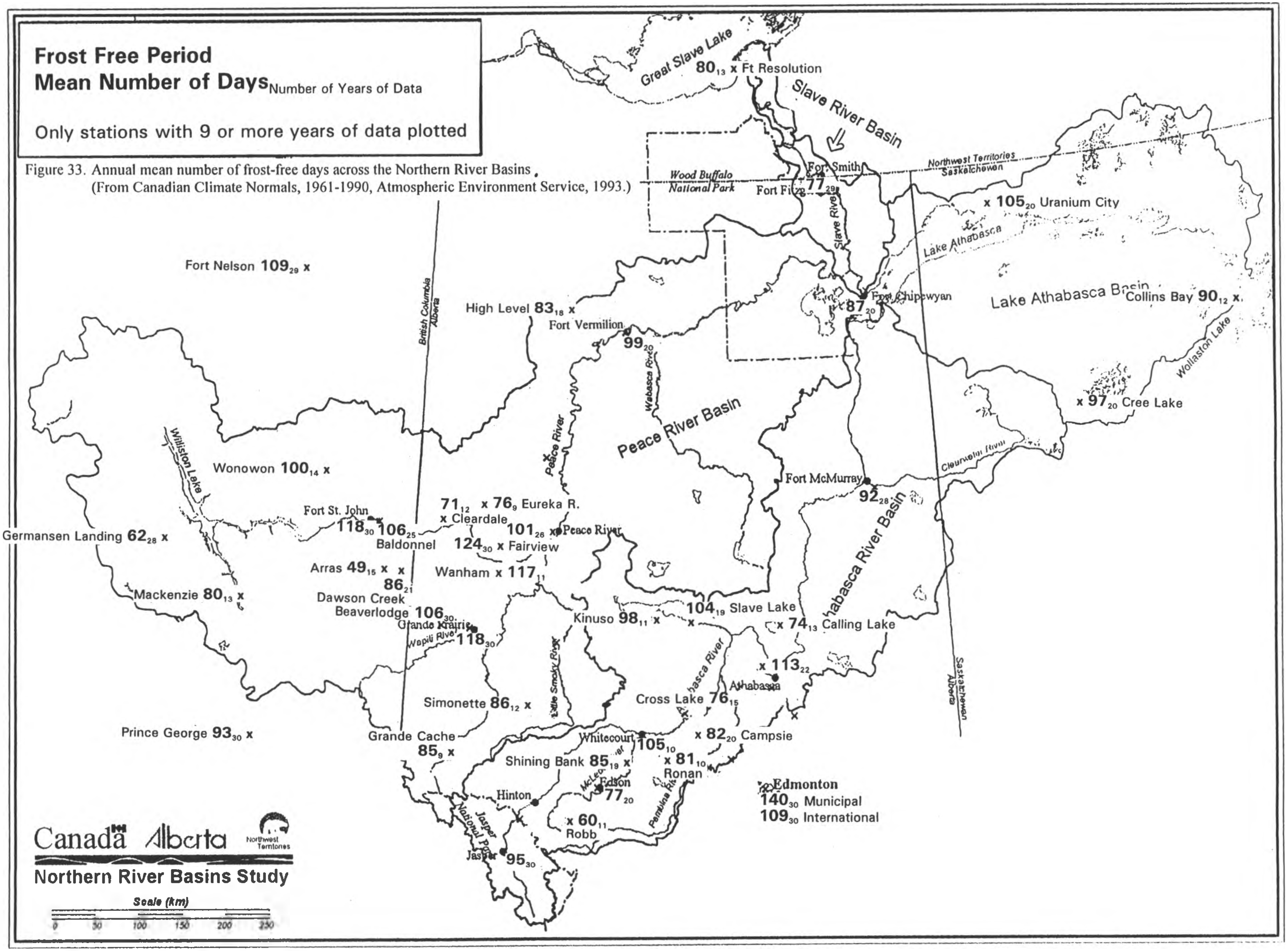


Figure 33. Annual mean number of frost-free days across the Northern River Basins. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

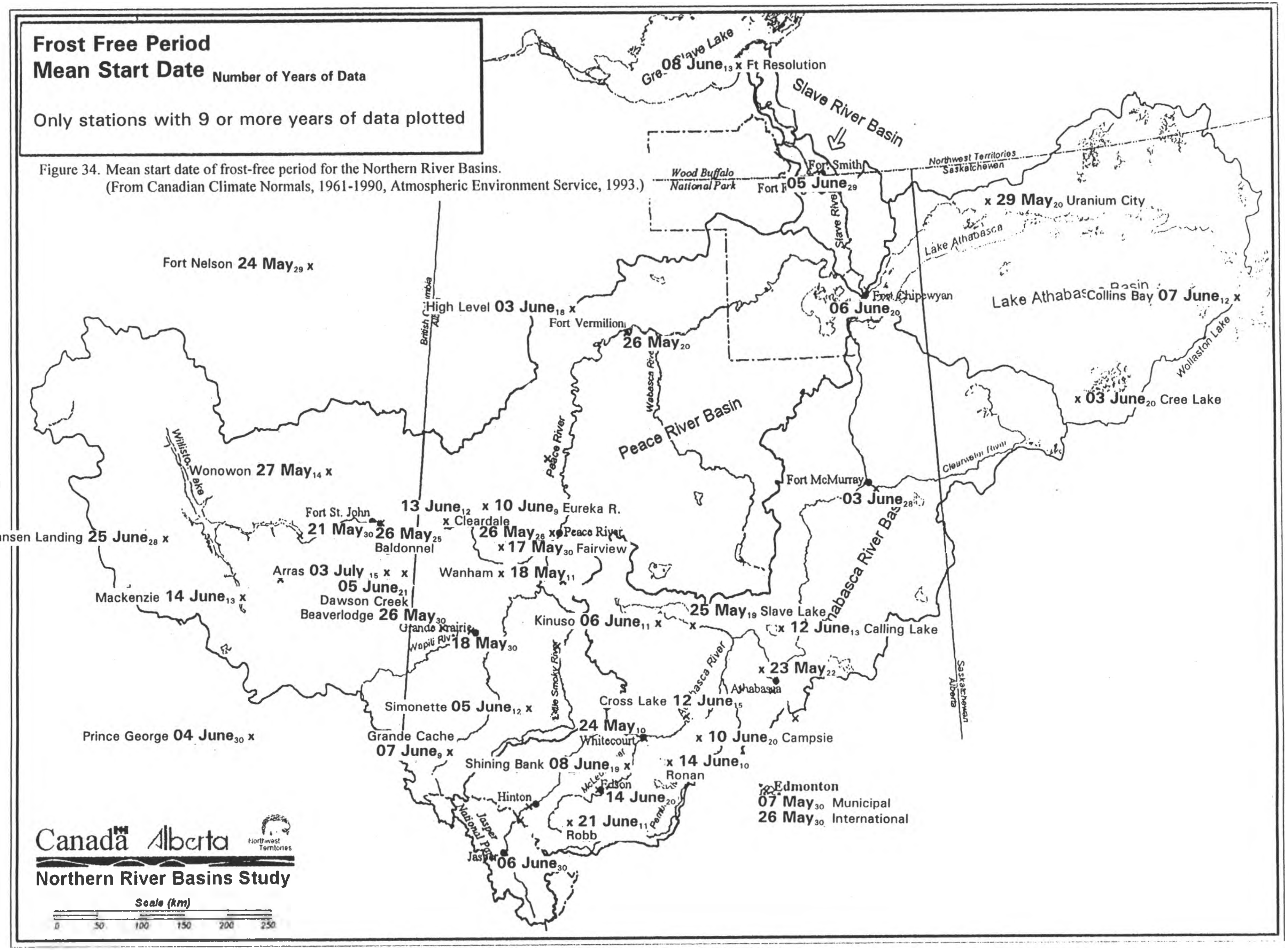


Figure 34. Mean start date of frost-free period for the Northern River Basins.
(From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

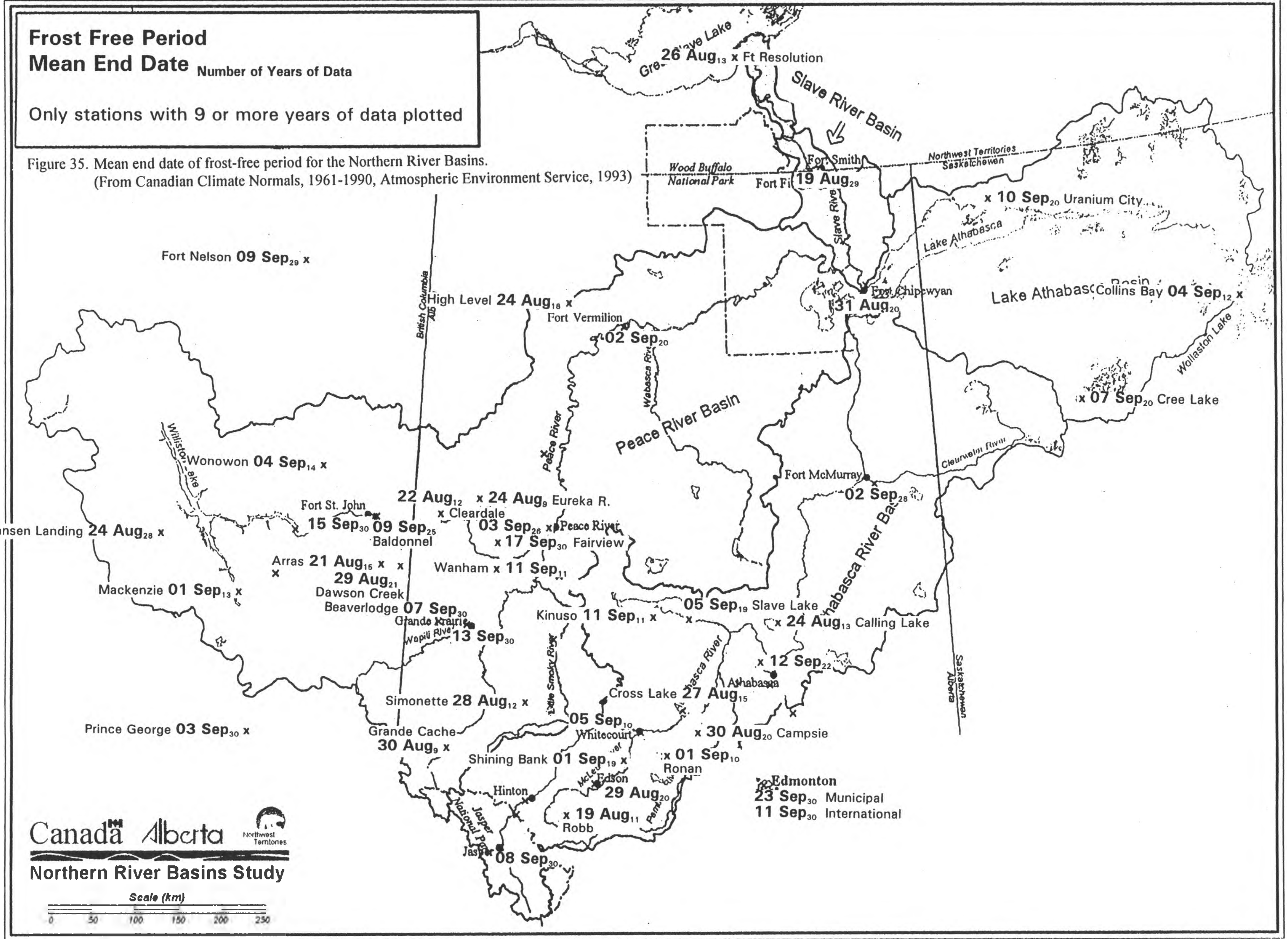


Figure 35. Mean end date of frost-free period for the Northern River Basins.
(From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993)

Table 8. Variability of beginning, ending, and length of the frost-free period for selected stations in the Peace River basin. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

	Grande Prairie	Beaverlodge	Dawson Creek	Arras	Baldonnel	Fort St. John
Period of Record.	30 years 1961-90	30 years 1961-90	21 years 1964-90	15 years 1970-88	25 years 1961-90	30 years 1961-1990
Mean 'beginning' date	18 May	26 May	05 June	03 July	26 May	21 May
	earliest of group (earliest of entire data set)			latest of group (latest of entire data set)		
Mean 'ending' date	13 Sep	07 Sep	29 Aug	21 Aug	09 Sep	15 Sep
				earliest of group (earliest of entire data set)		latest of group (17 Sep at Fairview latest of data set)
Mean length (days)	118	106	86	49	106	118
	longest (tied) in group and second longest in data set (124 at Fairview is longest in data set)			shortest		longest (tied) in group and second longest in data set (124 at Fairview is longest in data set)

Table 9. Variability of beginning, ending, and length of the frost-free period for selected stations in the middle Athabasca River basin. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

	Edson	Campsie	Athabasca
Period of Record	20 years 1970 - 1990	20 years 1961-1990	22 years 1961-1990
Mean 'beginning' date	14 June	10 June	23 May
	latest of group		earliest of group
Mean 'ending' date	29 Aug	30 Aug	12 Sep
	earliest of group		latest of group
Mean length (days)	77	82	113
	shortest of group		longest of group

Variability in frost dates at Grande Prairie. (from data through period 1942 to 1993)

Beginning	Earliest	04 May		1948
	Latest	18 June		1949
Ending	Earliest	14 Aug		1950/52
	Latest	09 Oct		1980
Longest		158 days	05 May to 09 October	1980
Shortest		75 days	02 June to 15 August	1973

Variability in frost dates at Athabasca. (from data through period 1959 to 1992)

Beginning	Earliest	05 May		1988
	Latest	24 June		1965
Ending	Earliest	21 Aug		1992
	Latest	05 Oct		1987
Longest		158 days	07 May to 02 October	1976
Shortest		72 days	24 June to 03 September	1973

7.2.2 TEMPERATURE THRESHOLDS

There are temperature thresholds other than the frost-free period that affect crop growth. Cool season crops such as wheat, barley, and oats grow well at temperatures above 5°C. At temperatures above 30°C, crops are 'stressed'. The stress threshold is moisture dependent and Mills, 1995, personal correspondence, advises that stress is often seen when temperatures reach 25°C. Following tables show frost-free and heating degree day comparisons for selected stations primarily in the Peace and Athabasca agriculture areas. For agriculture, the day in the spring that the mean daily temperature reaches 5°C is deemed to be the start date for the growing season. However, each variety and species of vegetation may require a different threshold for the beginning and ending of the growing season.

Sample degree day calculation:
If the mean temperature for the day is 19 °C (which you would have with, for example, a high of 27°C and an overnight low of 11°C for mean of (27+11)/2 = 19°C), then there would be:
19-5 = 14 degree days with respect to growing degree days (mean daily temperature above 5°C)

Table 10. Mean frost-free period, May to August and annual growing degree day comparisons, and mean number of "stress" days for selected, mainly Peace River basin, stations. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

		Peace River	Grande Prairie	Dawson Creek	Fort St John	Fort Vermilion
Mean Frost-free period		101 days	118 days	86 days	118 days	99 days
Growing degree days > 5°C	May to Aug	1066 days	1085 days	981 days	1050 days	1155 days
	Annual	*1276 days*	*1324 days*	*1212 days*	*1295 days*	*1344 days*
Mean number 'Stress' days (maximum temperature > 30°C)		< 2 days	< 2 days	< 2 days	< 1 days	3 days

Table 11. Mean frost-free period, May to August and annual growing degree day comparisons, and mean number of "stress" days for selected, mainly middle Athabasca River basin, stations. (From Canadian Climate Normals, 1961-1990, Atmospheric Environment Service, 1993.)

		Peace River	Edson	Campsie	Athabasca	Fort Smith
Mean Frost-free period		101 days	77 days	82 days	113 days	77 days
Growing degree days > 5°C	May to Aug	1066 days	922 days	1060 days	1119 days	1033 days
	Annual	*1276 days*	*1122 days*	*1279 days*	*1366 days*	1162 *days*
Mean number 'Stress' days (maximum temperature > 30°C)		< 2 days	< 1 days	< 2 days	< 2 days	3 days

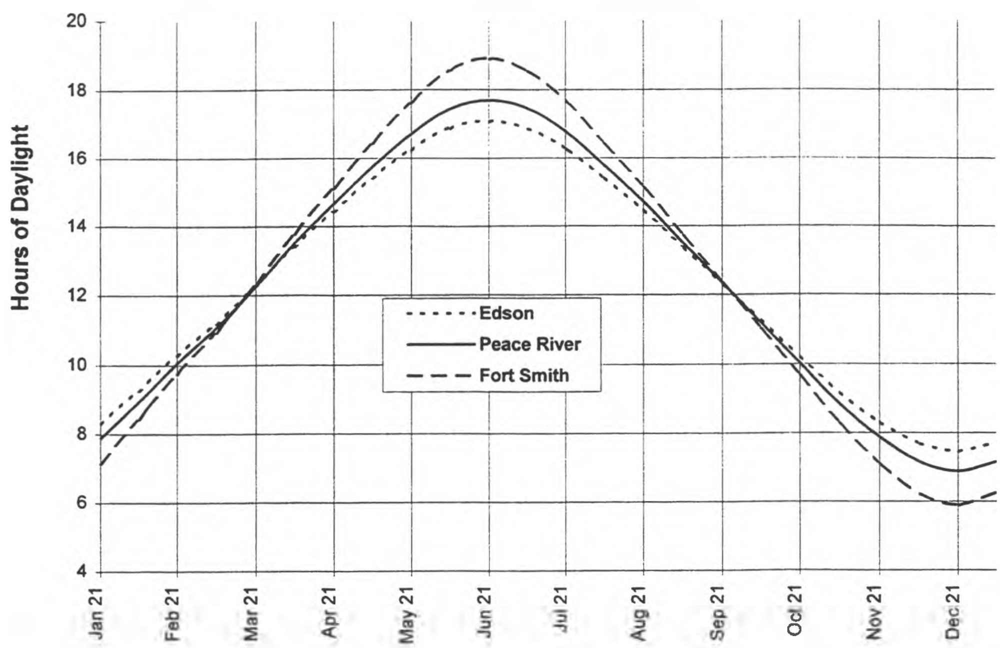
7.3 GROWING SEASON AND HOURS OF SUN

Across the Northern River Basins there are more hours of daylight, and therefore possible sunshine available, during the growing season than there are across, for example, southern Alberta, as reflected by the numbers in Table 12. It is this length rather than the brightness of the sunshine which is important for plant growth. Per Figure 36, the abundance of available daylight during the summer growing season is in sharp contrast to the lack of daylight during the winter. At Fort Smith, for example, there are, at peak, close to 19 hours of daylight available during the summer versus the minimum of close to six hours during the winter. Per Mills, 1995, personal correspondence, there are two effects of long hours of daylight: rapid growth and minimal respiratory loses at night since the period of darkness is so short. Each crop, indeed each species of a crop responds differently to the long hours of daylight.

Table 12. Comparison of maximum possible hours of daylight during the growing season for selected stations of the Northern River Basins versus Lethbridge, Alberta.

	Hours of daylight			
	Lethbridge (southern Alberta)	Peace River	Edson	Fort Smith
21 May	15.6	16.7	16.2	17.6
21 June	16.3	17.7	17.1	18.9
21 July	15.7	16.8	16.3	17.7
21 August	14.1	14.7	14.5	15.2

Figure 36. Hours of daylight for selected stations of the Northern River Basins.



8.0 HISTORICAL METEOROLOGICAL EVENTS, NORTHERN RIVER BASINS

This section provides examples of meteorological, or meteorological induced events that have occurred across the Northern River Basins. Events cited are from a number of different sources; among them the 1988 Weather Calendar produced by Dave Phillips, Atmospheric Environment Service, Downsview; personal files of Brian Mottus, Environment Canada, Grande Prairie; and various hydrological reports focused on flood events. The "Lesser Slave Lake Flood Study", Nemanishen and Meeres, 1980, was particularly useful as a source for material on heavy rains/flooding for the Lesser Slave Lake area.

8.1 TEMPERATURES

8.1.1 Cold temperatures

24 July 1918
Coldest July period on record occurred throughout the western Prairies. Temperatures of -3°C to -10°C resulted in crop and garden losses. (Phillips, 1988.)

11 January 1911
Fort Vermilion recorded a record low of -61.2°C, the lowest temperature ever recorded in Canada outside of the Yukon. (Phillips, 1988) (Canadian Climate Normals 1961-1990, Atmospheric Environment Service, 1993.)

8.1.2 Warm temperatures and changes to cold temperatures

10 October 1986
Indian Summer began across Alberta. Fort McMurray posted a high of 25°C on the 16th. It was not until 26 October that the daytime maximum fell from values in either the teens or twenties. (Phillips, 1988.)

8 to 31 October 1984
The weather at Fort McMurray during October 1984 illustrates the variability in weather that can occur across the Northern River Basins over the course of a few days. On 8 October 1984, a high of 26°C was posted at Fort McMurray. 38 millimetres of rain fell in the period 12 to 14 October with highs of 7 , 7, and 3 respectively. 17 centimetres of snow fell on the 16 with a high just above zero. By 27 October 1984, daytime highs were -10°C or lower and overnight lows were -19°C or lower. (Climate Records, Environment Canada.)

8.2 LARGE SCALE PRECIPITATION / FLOODING

11/12 June 1990
Heavy rain at Grande Prairie, 96 millimetres, and up to 200 millimetres in the West County. West County schools closed due to flooding, the first time schools had closed in June due to weather.(personal correspondence, Mottus, 1995.)

06 July 1988
On 06 July 1988, the Town of Slave Lake experienced severe flooding from Sawridge Creek. The flooding resulted from heavy precipitation that accompanied an upper cold low passage. Up to 160 millimetres of rain fell in the upper Sawridge Creek Basin over an 18 hour period 06 July. (Drury and Garner, 1989.)

16 to 18 July 1986
A storm caused heavy precipitation over west-central Alberta watersheds. Heavy snowfalls occurred over higher elevations with Grave Flats reporting nearly 75 centimetres. Although the precipitation accumulations were below record levels, significant rainfalls during the previous two weeks had saturated the soils. The combined rainfall and snow melt from the 16 to 18 July event resulted in several rivers reaching flood levels. Extensive flooding was reported on the Athabasca, McLeod, Pembina, and Paddle rivers, all Northern River Basins rivers, and on the North Saskatchewan and Red Deer rivers. (Warner and Paruk, 1988.)

14/15 July 1982
Heavy rain in the foothills south and southwest of Grande Prairie resulted in flooding on the Wapiti and Smoky Rivers. Among other damage, the city water supply was knocked out for 10 days due to the flooding. Meteorologically, the event shared components common to the majority of the storms that occur during the summer across the Northern River Basins: an upper cold low (500 hPa); a surface low; a combined upslope flow, influx of low level moisture, low level convergence, and instability. (Drews, 1983, and MacCulloch and Drews, 1988.)

04 June 1980
Washouts and mud slides near Edson due to heavy rain across west-central Alberta. (Phillips, 1988.)

30 April 1979
Heavy precipitation and late melting snow caused ice-clogged rivers of Clearwater, Athabasca, and Peace to flood 1530 square kilometres of Alberta farmland. 7000 residents evacuated their homes. (Phillips, 1988.)

26 to 29 June 1975
50 to 100 millimetres of rain on the Swan Hills and on the Pelican Mountains to the east of Lesser Slave Lake. On 27 through to the morning of 29 June 1975, an additional 25 to 50 millimetres fell on the Swan Hills. (Kuhnke and Barnaby, 1975.)

11 to 13 June 1972
Heavy rains in the Peace River basin southwest of Grande Prairie resulted in record flows in nearly all streams in that area. 11/12 June, an upper cold low led to over 150 millimetres of rain in a 36 hour period. Nose Mountain lookout reported approximately 200 millimetres of rain in 40 hours. Flood waters of the Wapiti River at Grande Prairie, for example, inundated the water treatment plant and damaged or destroyed bridges and bridge approaches. Flood waters of the Smoky River washed out the main power supply for Grande Cache. The Alberta Resource Railway was a major victim of the flood and the Northern Alberta Railway bridge at Watino was destroyed. (Warner and Thompson, 1974.)

01 June to 15 July 1971

During the period 01 June to 15 July 1971, the Swan Hills area of the Northern River Basins measured total precipitation which at some locations exceeded 450 millimetres. The heavy precipitation resulted in heavy runoffs. Two major storms, 13 to 17 June and 01 to 07 July, each gave about 150 millimetres of rain. The remaining 150 millimetres of rain was divided among several other storms. (Buckler and Meeres, 1972.)

27 June to 01 July 1970

During the period 27 June to 01 July 1970, there was heavy precipitation in the areas around the Pelican Mountains (east of Lesser Slave Lake) from 2 separate storms causing water levels on Calling and North and South Wabasca Lakes to rise. The first storm occurred 27, 28, and 29 June and the second 30 June and 01 July. Table 13 shows rainfalls, lake water level increases and estimates of the amount of runoff. (Mustapha, 1970.)

Table 13. Average 5-day rainfall across the Pelican Mountains area, 27 June to 01 July 1970.

Drainage basin	Average 5-day rainfall	Comments
Marten Creek	140 millimetres	
Wabasca Lakes	137 millimetres	North and South Wabasca Lakes water level rose at least 1.2 metres. Some residents estimated that the lakes rose twice that much! North and South Wabasca lakes became one lake. Runoff using a 1.2 metres rise was estimated at 76 millimetres or 54% of the 5-day rainfall. About 5 kilometres of the road to Wabasca was under water and consequently the residents of Wabasca and Desmarais were cutoff by road from the outside.
Main inflow channel to Calling Lake	228 millimetres	Calling Lake water level rose 1.2 metres. Runoff was estimated at 152 millimetres or 67% of the 5-day rainfall. Area bridges and culverts were washed out on the forestry road north of Calling Lake. A few boat docks were blown down by strong winds and high waves on Calling Lake.
Wandering River	180 millimetres	
Sawridge Creek	114 millimetres	
Driftwood River	188 millimetres	Direct runoff 81 millimetres or 43% of the 5-day rainfall

spring/summer 1935
The hydrometeorlogical factors contributing to the 1935 flood began two years earlier. The 1933 September to October precipitation at Grouard, Kinuso, and Slave Lake were record amounts up to at least the end of 1979. Winter snowfall at Slave Lake, for example, exceeded quartile values. In 1934, high snow melt runoff and summer rainfall combined to raise Lesser Slave Lake to a level only exceeded in the 1920 flood. At the spring of 1935, before spring runoff began, lake water levels were still high and there was record winter snowfall waiting to melt. Spring runoff and May rainfall brought lake water levels to just above those posted in the 1920 flood. June through July frequent precipitation events maintained high water levels. The flood crest surpassed all former and subsequent crests to at least 1979 by 2 feet. (Nemanishen and Meeres, 1980.)

June/July 1920
Series of weather systems including some that could be labelled as upper cold lows gave precipitation to the basins around Lesser Slave Lake. 04 July the water level on the lake peaked to its highest level since observations started 5 years earlier. The 04 July 1920 level was not exceeded until 1935. The high waters of 1920 brought flooding to the Town of Sawridge and highlands. (Nemanishen and Meeres, 1980.)

June/July 1914
Series of storms gave heavy rains to the basins feeding Lesser Slave Lake resulting in high water levels to the lake and flooding of rivers such as the Lesser Slave River which feeds into the lake. (Nemanishen and Meeres, 1980.)

August 1913
Above normal precipitation gave flooding on the Lesser Slave River. (Nemanishen and Meeres, 1980.)

8.3 THUNDERSTORMS - LOCAL HEAVY DOWNPOURS, WIND, HAIL, TORNADOES

06 July 1995 - local heavy downpour
Beaverlodge town flooded by a slow moving thundershower - 83 millimetres of rain in one hour. (Personal correspondence, Mottus, 1995.)

27 August 1991 - tornado
Severe thundershower with small F0 tornado at Grande Prairie. Some roofs in city lose shingles and a farm grain bin is moved about 1 kilometre. (Personal correspondence, Mottus, 1995.)

09 August 1991 - tornado
"F0" short duration tornado at Sturgeon Lake thrashes trees and causes some damage in the campground but no injuries. (Personal correspondence, Mottus, 1995.)

17 August 1984 - local heavy downpour, wind, hail
Severe thunderstorm struck High Prairie. Rain was accompanied by walnut-size hail and strong winds. Crops were destroyed and several cars were damaged. (Phillips, 1988.)

07 August 1971 - hail, wind
Vicious hailstorm did incredible damage to the Town of Whitecourt. Hardball-size hail fell for 15 minutes and was driven by 80 km/h winds at a 45° angle. Every roof required repairs and every window required replacement. Hailstones penetrated aluminum roofs and sidings, 6 airplanes were write-offs, and all neon signs were destroyed. The hail lay in 20 centimetre drifts for 2 days. (Phillips, 1988.)

8.4 FOREST FIRES

May/ June 1995
Forest fires were off to a fast start in 1995. Per Figure 37, there were several fires as of 30 May within the Northern River Basins. The two fires given the larger dots grew to 100,00 hectares by mid-June.

Figure 37. Forest fire areas up to 30 May 1995. Fire positions are approximate and the dot size is not a reflection of the fire size. Both "large dot" fires reached 100,000 hectares by mid June. (Nick Nimchuk, Alberta Forestry, 1995.)

1983 to 1994
Quiet years forest fire-wise across the Northern River Basins. (Nimchuk, 1995)

mid June to 01 July 1982
Large, lightning ignited, fires occurred north of Lesser Slave Lake and consumed 688,000 hectares. (Nimchuk, 1995)

August/September 1981
An example of an upper ridge over the Northern River Basins giving hot dry weather and upper ridge breakdown giving forest fire activity is the period August into September 1981. Per Nimchuk, 1983, "Wildfire Behaviour Associated with Upper Ridge Breakdown", an upper ridge began to build over the Northern River Basins / Alberta 04 August 1981 and remained until 26 August 1981. At times during this period, daytime highs across the Basins peaked in the 30 to 35°C range and afternoon/evening relative humidities dropped to the 25 to 35% range. The high temperatures and low relative humidities left the forests of the Northern River Basins vulnerable to fire and to lightning outbreaks that would ignite them. Through the period 10 to 20 August 1981, a series of fast-moving upper disturbances travelled through an upper ridge lying over the Northern River Basins. The upper disturbances prompted thundershower activity with lightning but sparse precipitation. The lightning ignited 165 fires.

The upper ridge rebuilt 22 to 24 August 1981. However, there was an upper cold low off the British Columbia coast. The upper low pushed northeast breaking down the upper ridge and a vigorous upper disturbance rotating about the upper centre supported the development and deepening of a low pressure centre over northwestern Alberta. The surface map for 1200 MDT 27 August 1981 showed strong southeasterly winds and temperatures of 30°C across the forests of the eastern section of the Northern River Basins and strong northwesterly winds and temperatures near 20°C over the western section of the Northern River Basins. Several of the fire areas over the western section of the Northern River Basins experienced a shift of winds from southeasterly to northwesterly. The total forest area burned 27 August was extensive.

The upper ridge returned mid September resulting in another period of extensive forest burn.

Figure 38 shows the locations of major fires during the 1981 forest fire season. Footner Lake and Athabasca forests suffered 92% of the 1981 season burn and 84% of the burn occurred during the periods 25 to 27 August and 15 to 19 September.

Figure 38. Major forest fire areas during 1981 (not to scale). (From Nimchuk, 1983.)

25 May 1968

Forest fires devastated vast areas of central Alberta. Early season records up to that time were established for the greatest number of outbreaks and the largest area ever incinerated. (Phillips, 1988.)

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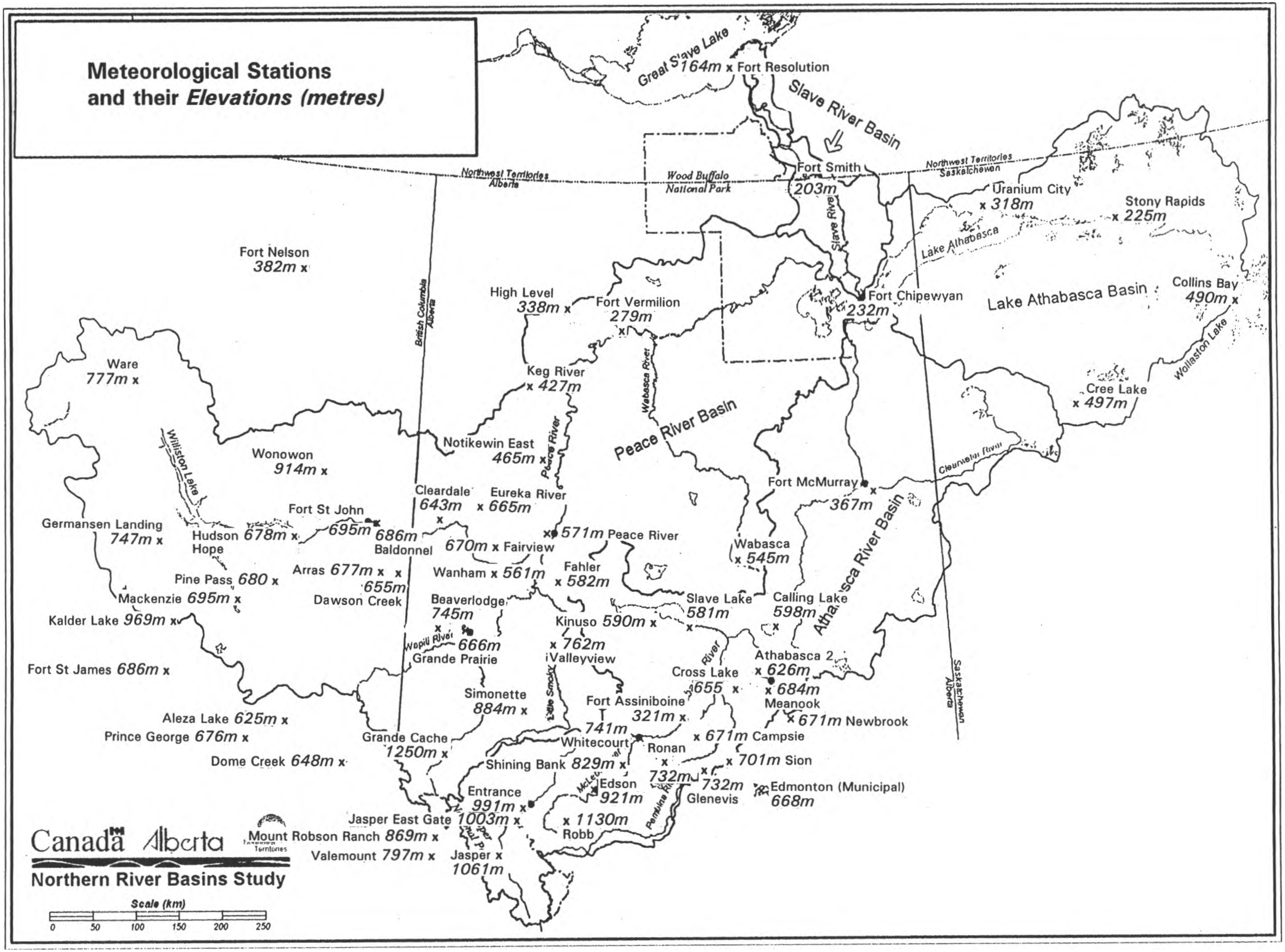
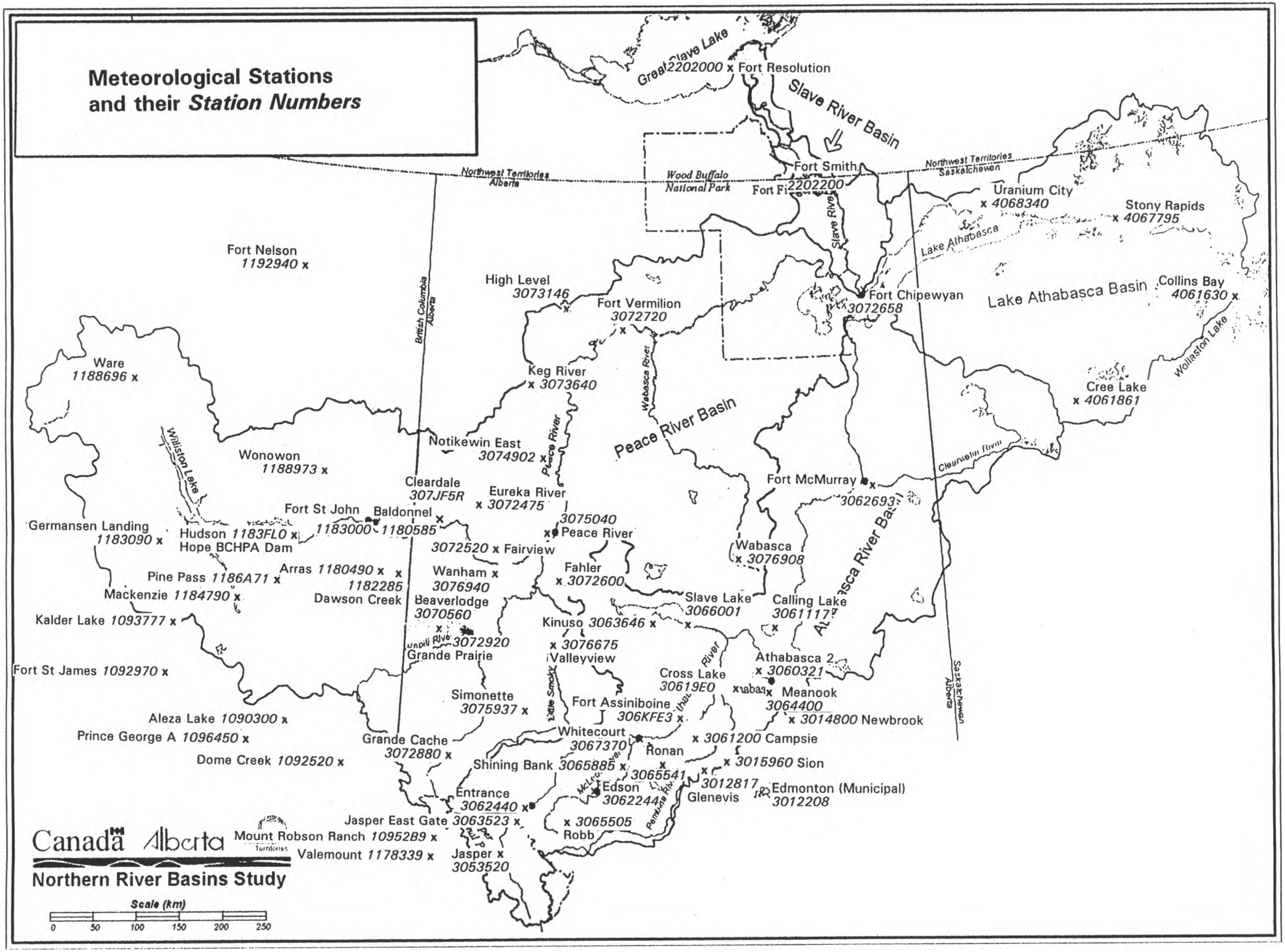
APPENDIX A:

MAP OF METEOROLOGICAL STATIONS AND THEIR ELEVATIONS
MAP OF METEOROLOGICAL STATIONS AND THEIR STATION NUMBERS



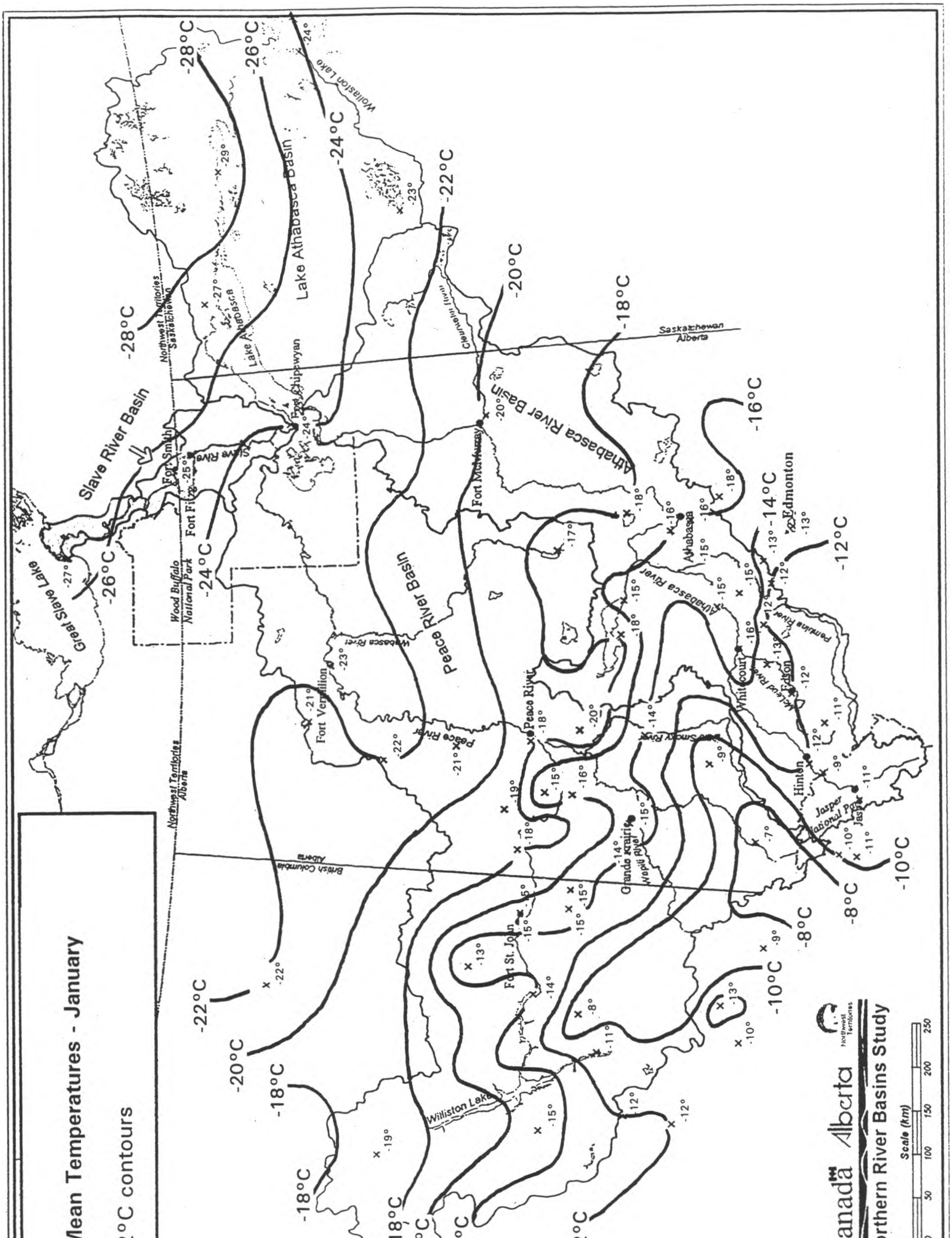
Meteorological Stations
and their Elevations (metres)
Great Slave Lake
164m x Fort Resolution
Slave River Basin
Fort Smith
203m
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
Uranium City
x 318m
Stony Rapids
x 225m
Lake Athabasca
Slave River
Fort Nelson
382m x
High Level
338m x
Fort Vermilion
279m
Fort Chipewyan
232m
Lake Athabasca Basin
Collins Bay
490m x
Wollaston Lake
British Columbia
Alberta
Ware
777m x
Keg River
x 427m
Wabasca River
Peace River Basin
Cree Lake
x 497m
Williston Lake
Wonowon
914m x
Notikewin East
465m x
Peace River
Clearwater River
Fort McMurray
367m
Cleardale
643m
Eureka River
x 665m
Fort St John
695m
686m
Baldonnel
Germansen Landing
747m x
Hudson Hope
678m x
x 571m Peace River
670m x Fairview
Wabasca
x 545m
Athabasca River Basin
Pine Pass 680 x
Arras 677m x
655m
Dawson Creek
Wanham x 561m
Fahler
x 582m
Mackenzie 695m x
Beaverlodge
745m
Slave Lake
581m
Calling Lake
598m
Kalder Lake 969m x
Kinuso 590m x
Wapiti River
666m
Grande Prairie
x 762m
Valleyview
Athabasca 2
x 626m
Fort St James 686m x
Cross Lake
655
x 684m
Meanook
Simonette
884m x
Little Smoky
Fort Assiniboine
321m x
Saskatchewan
Alberta
Aleza Lake 625m x
741m
x 671m Newbrook
Prince George 676m x
Grande Cache
1250m x
Whitecourt
Ronan
x 671m Campsie
Dome Creek 648m x
Shining Bank 829m x
732m
x 701m Sion
McLeod River
Edson
921m
732m
Glenevis
Edmonton (Municipal)
668m
Entrance
991m x
Pembina River
Jasper East Gate 1003m x
x 1130m
Robb
Mount Robson Ranch 869m x
Jasper National Park
Valemount 797m x
Jasper x
1061m
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

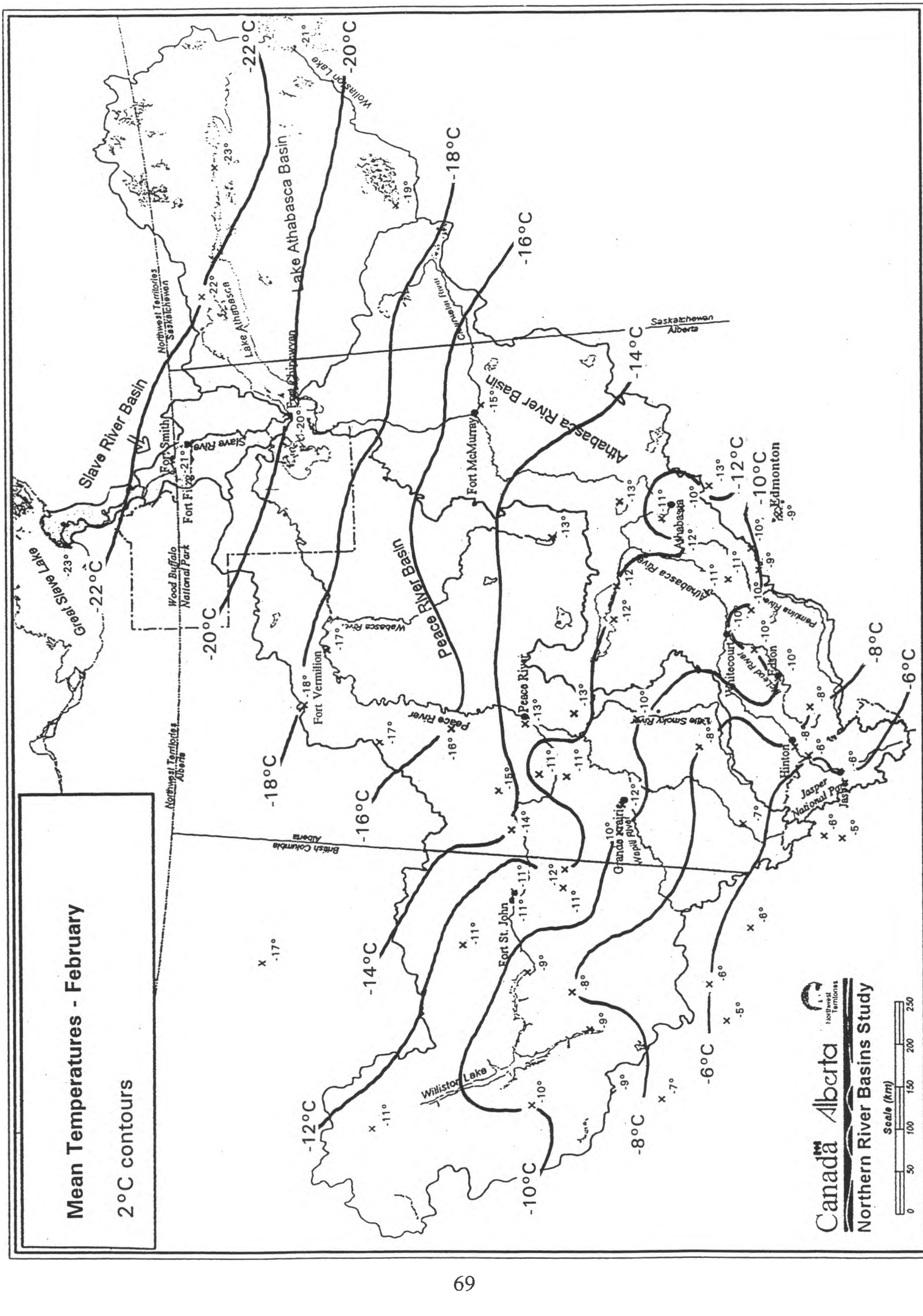


Meteorological Stations
and their Station Numbers
Great Slave Lake
2202000 x Fort Resolution
Slave River Basin
Fort Smith
Fort Fi 2202200
Slave River
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Uranium City
x 4068340
Stony Rapids
x 4067795
Lake Athabasca
Lake Athabasca Basin
Collins Bay
4061630 x
Wollaston Lake
Cree Lake
x 4061861
Fort Nelson
1192940 x
High Level
3073146
Fort Vermilion
3072720
Fort Chipewyan
3072658
Keg River
x 3073640
Wabasca River
Peace River Basin
Ware
1188696 x
Williston Lake
Wonowon
1188973 x
Notikewin East
3074902 x
Peace River
Fort McMurray
3062693
Athabasca River Basin
Cleardale
307JF5R
Eureka River
x 3072475
Fort St John
1183000
Baldonnel
1180585
3075040
x Peace River
Germansen Landing
1183090 x
Hudson 1183FLO x
Hope BCHPA Dam
3072520 x Fairview
Wabasca
x 3076908
Pine Pass 1186A71 x
Arras 1180490 x
x
1182285
Dawson Creek
Wanham x
3076940
Beaverlodge
3070560
Fahler
x 3072600
Mackenzie 1184790 x
Slave Lake
3066001
Calling Lake
3061117
Kalder Lake 1093777 x
Kinuso 3063646 x
x 3072920
Grande Prairie
x 3076675
Valleyview
Athabasca 2
x 3060321
Fort St James 1092970 x
Cross Lake
3061920
Little Smoky
Meanook
3064400
Simonette
3075937 x
Fort Assiniboine
306KFE3 x
x 3014800 Newbrook
Aleza Lake 1090300 x
Prince George A 1096450 x
Whitecourt
3067370
x 3061200 Campsie
Grande Cache
3072880 x
Ronan
Dome Creek 1092520 x
Shining Bank 3065885 x
3065541
x 3015960 Sion
Edson
3062244
3012817
Glenevis
Edmonton (Municipal)
3012208
Entrance
3062440 x
Jasper East Gate 3063523 x
x 3065505
Robb
Mount Robson Ranch 1095289 x
Valemount 1178339 x
Jasper x
3053520
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

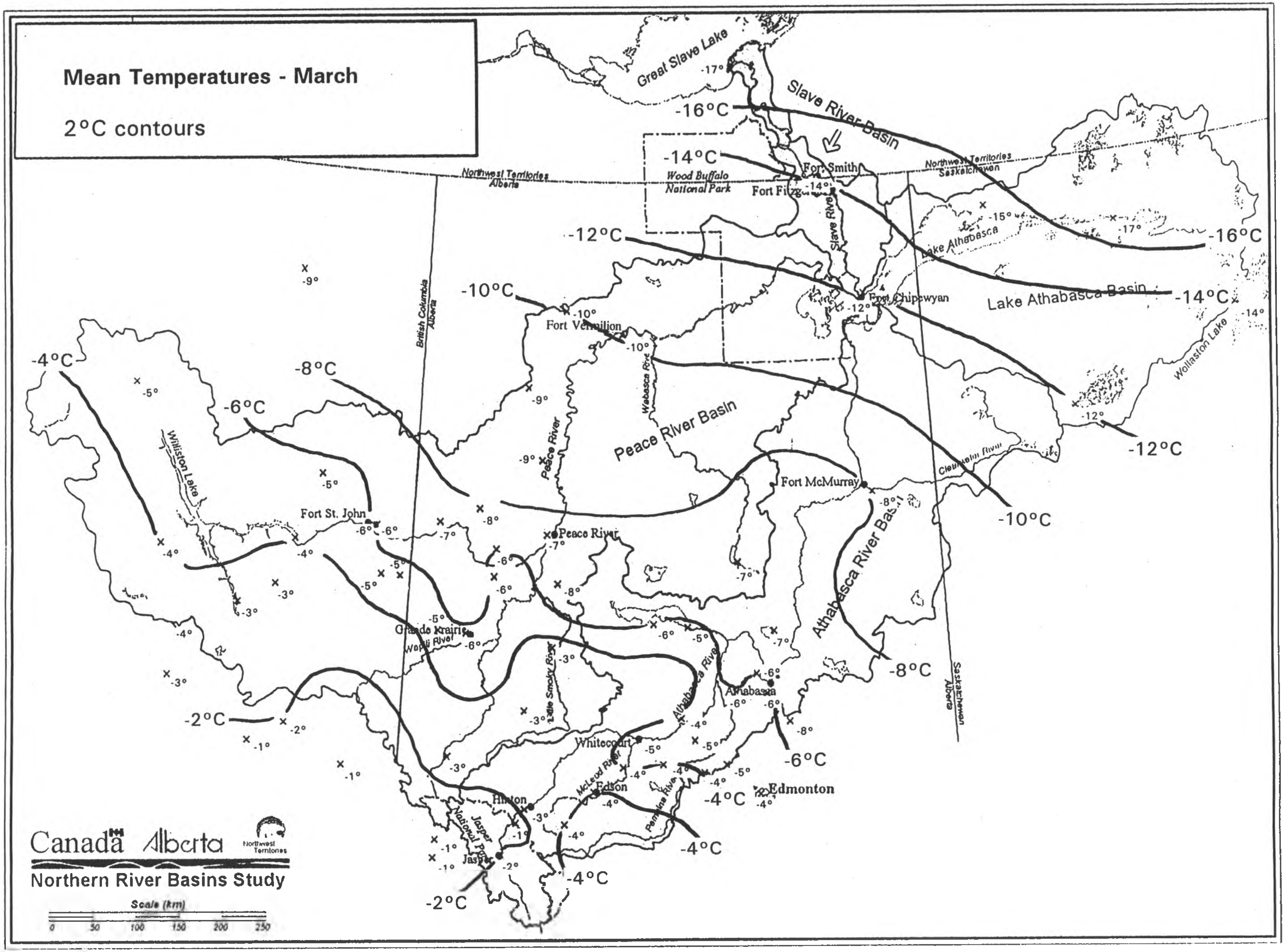
APPENDIX B:

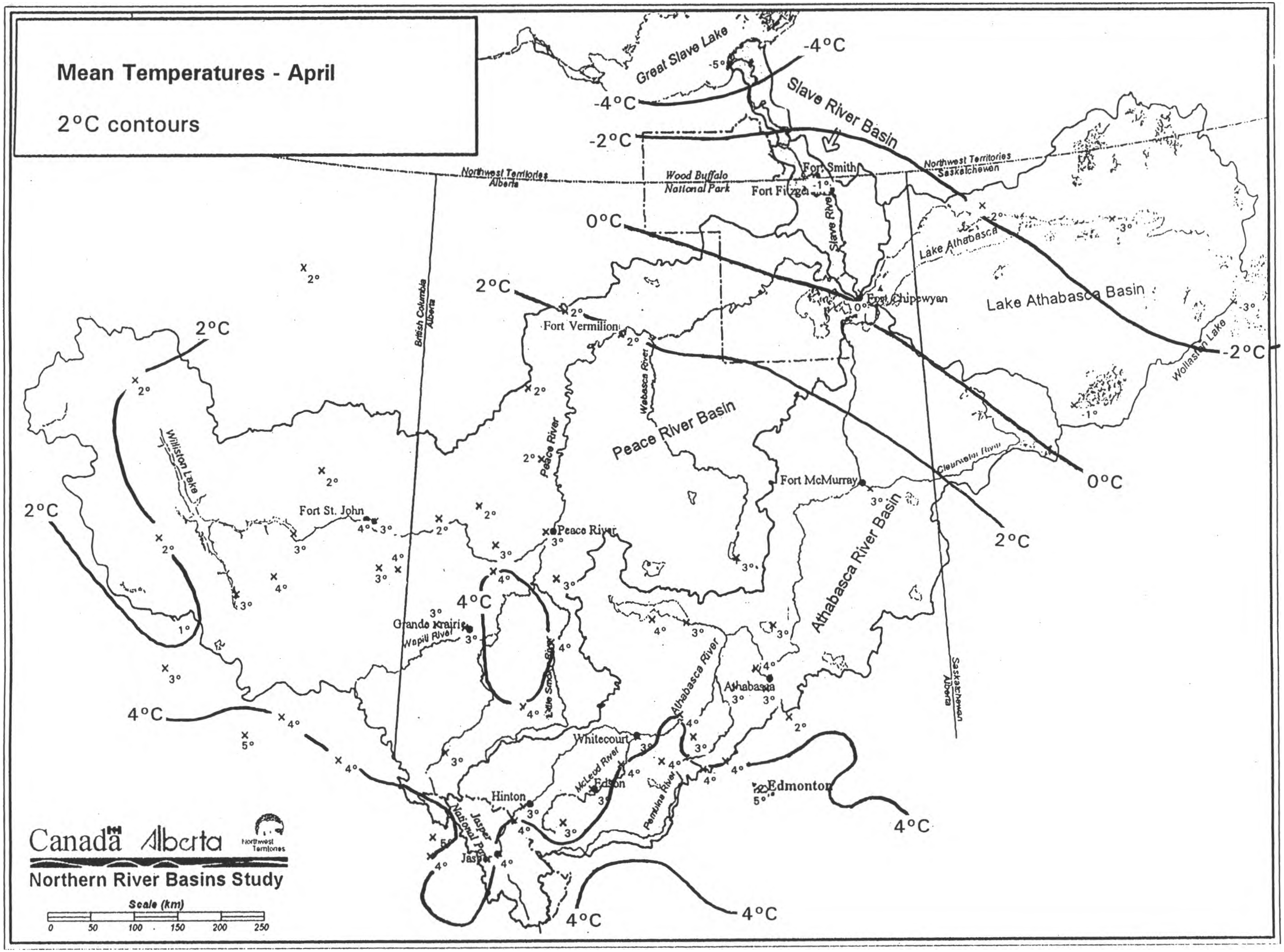
MONTHLY MAPS OF TEMPERATURES, NORTHERN RIVER BASINS

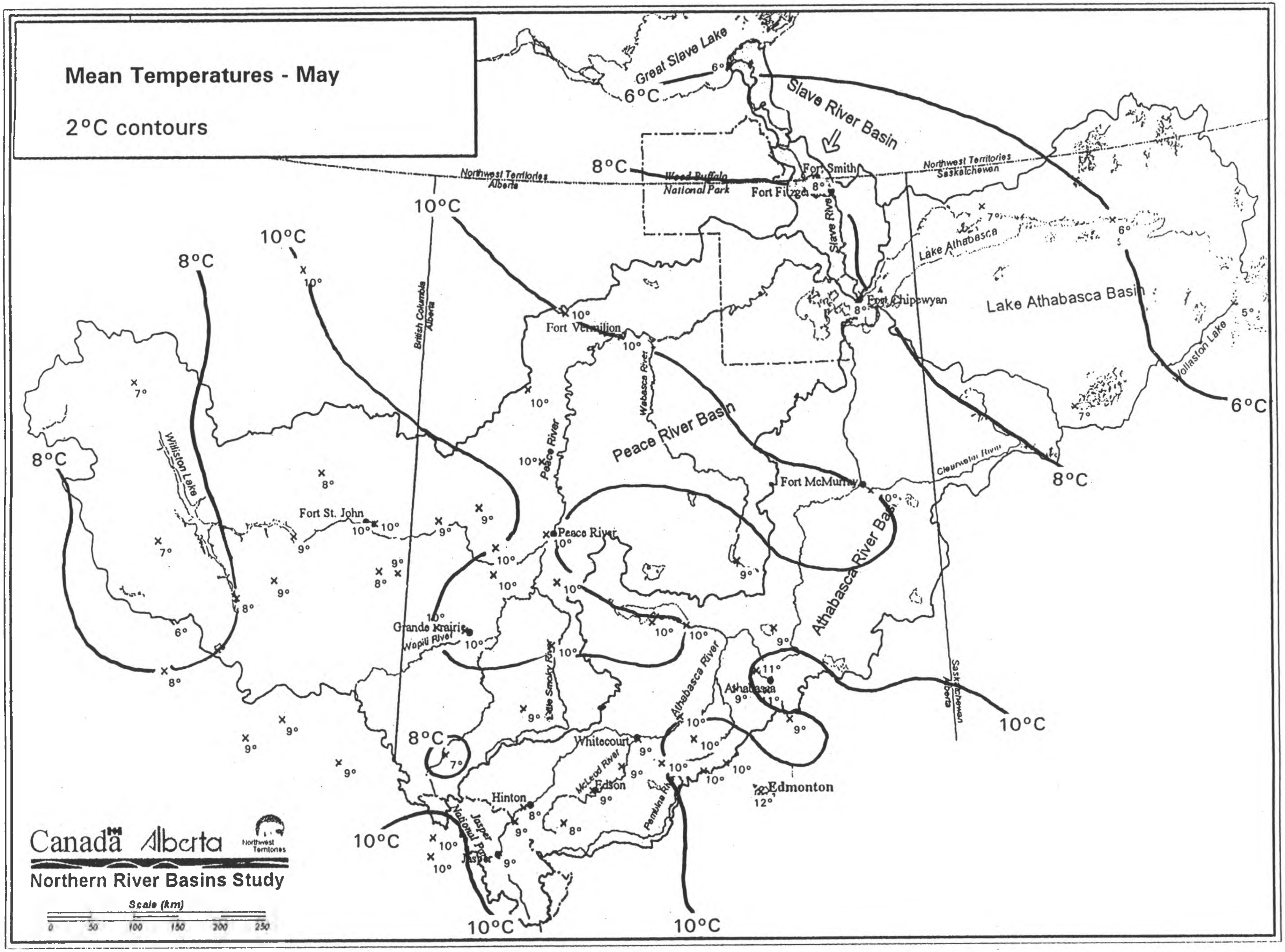

Mean Temperatures - January
2°C contours
Slave River Basin
Lake Athabasca Basin
Peace River Basin
Athabasca River Basin
Great Slave Lake
Wood Buffalo National Park
Fort Smith
Fort Chipewyan
Lake Athabasca
Wollaston Lake
Fort McMurray
Fort Vermilion
Peace River
Smoky River
Grande Prairie
Fort St. John
Williston Lake
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper National Park
Jasper
Northwest Territories
Alberta
Saskatchewan
British Columbia
Canada
Alberta
Northern River Basins Study
Scale (km)

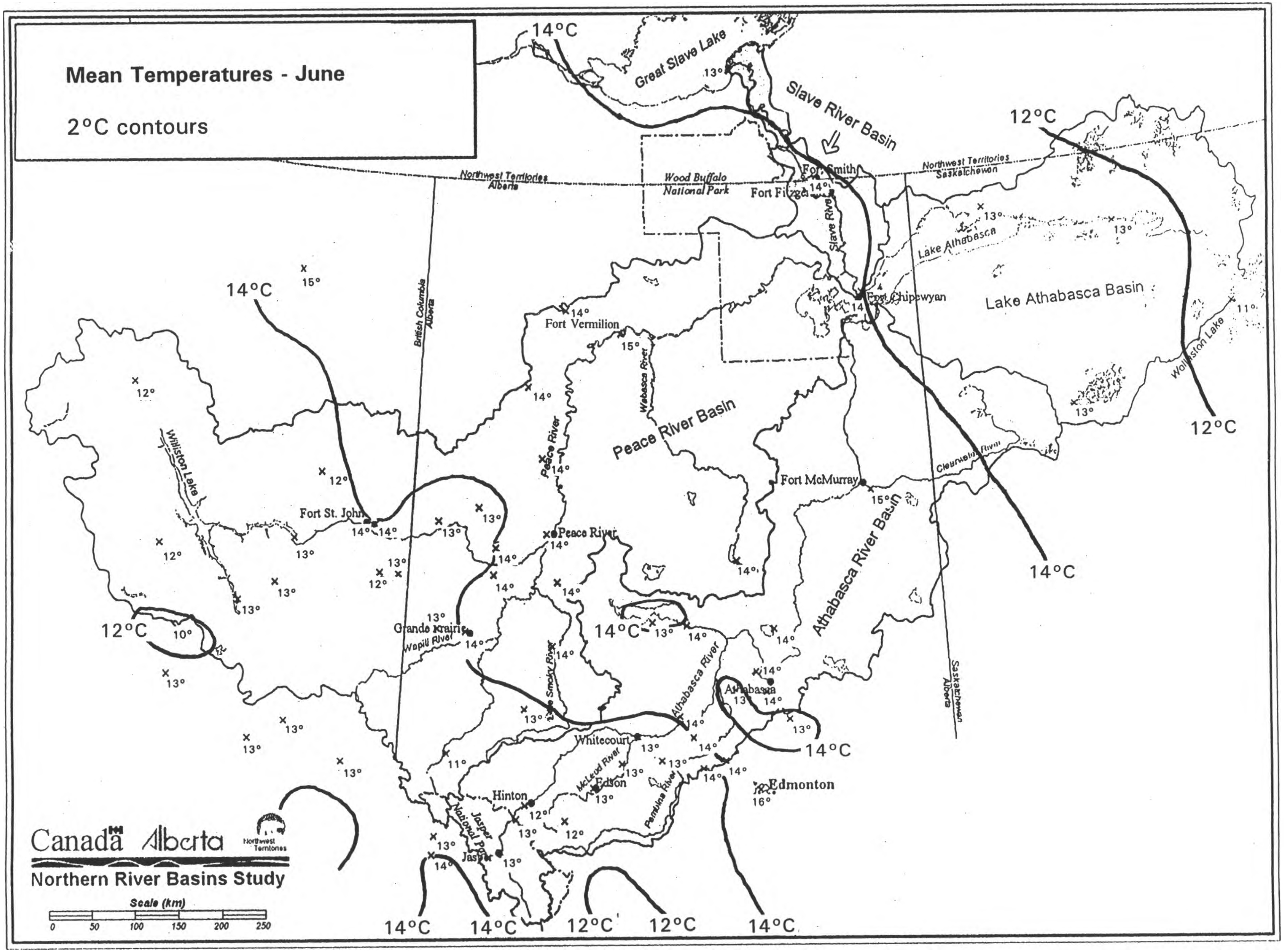


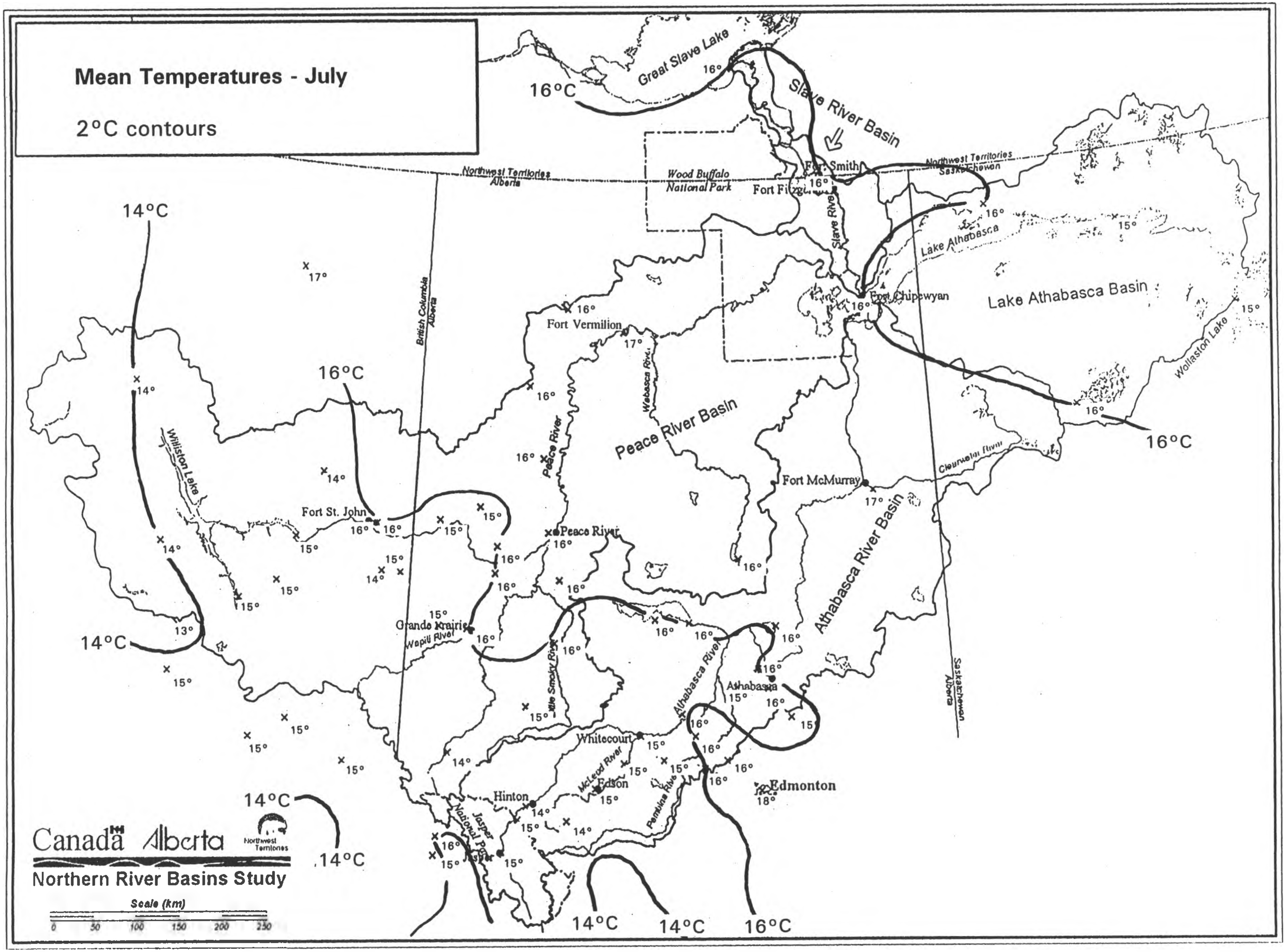
Mean Temperatures - February
2°C contours
Slave River Basin
Lake Athabasca Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Fort Smith
Fort Fitzgerald
Slave River
Wood Buffalo National Park
Lake Athabasca
Fort Chipewyan
Wollaston Lake
Northwest Territories
Saskatchewan
Alberta
British Columbia
Fort Vermilion
Wabasca River
Peace River
Fort McMurray
Athabasca
Edmonton
Whitecourt
Edson
McLeod River
Pembina River
Little Smoky River
Grande Prairie
Wapiti River
Hinton
Jasper
Jasper National Park
Fort St. John
Williston Lake
-22°C
-20°C
-18°C
-16°C
-14°C
-12°C
-10°C
-8°C
-6°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250

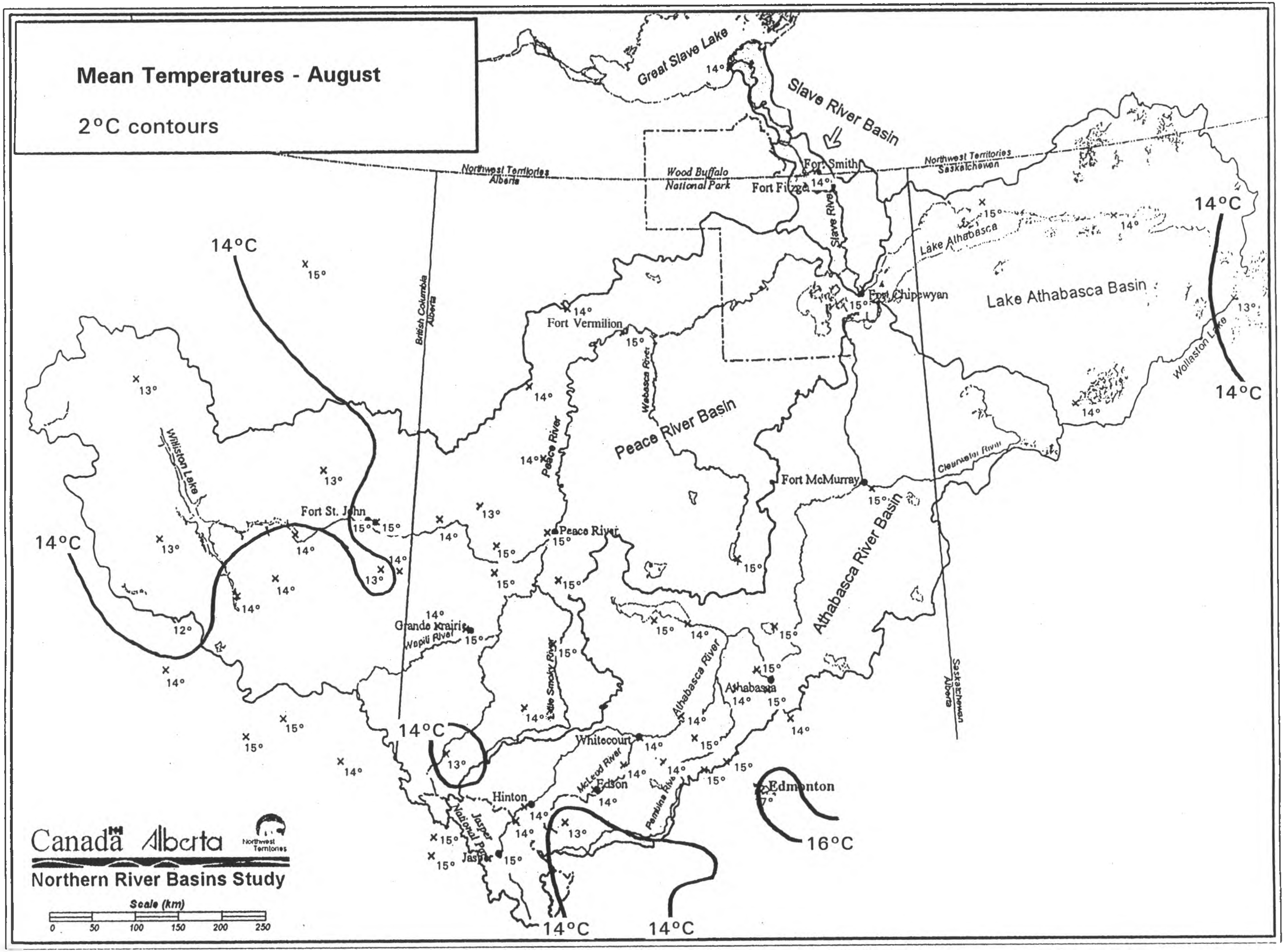

Mean Temperatures - March
2°C contours
Great Slave Lake
Slave River Basin
Fort Smith
Fort Fitzgerald
Wood Buffalo National Park
Northwest Territories
Alberta
Saskatchewan
British Columbia
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Fort Vermilion
Peace River Basin
Wabasca River
Peace River
Williston Lake
Fort St. John
Fort McMurray
Athabasca River Basin
Clearwater River
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper
Jasper National Park
-16°C
-14°C
-12°C
-10°C
-8°C
-6°C
-4°C
-2°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250

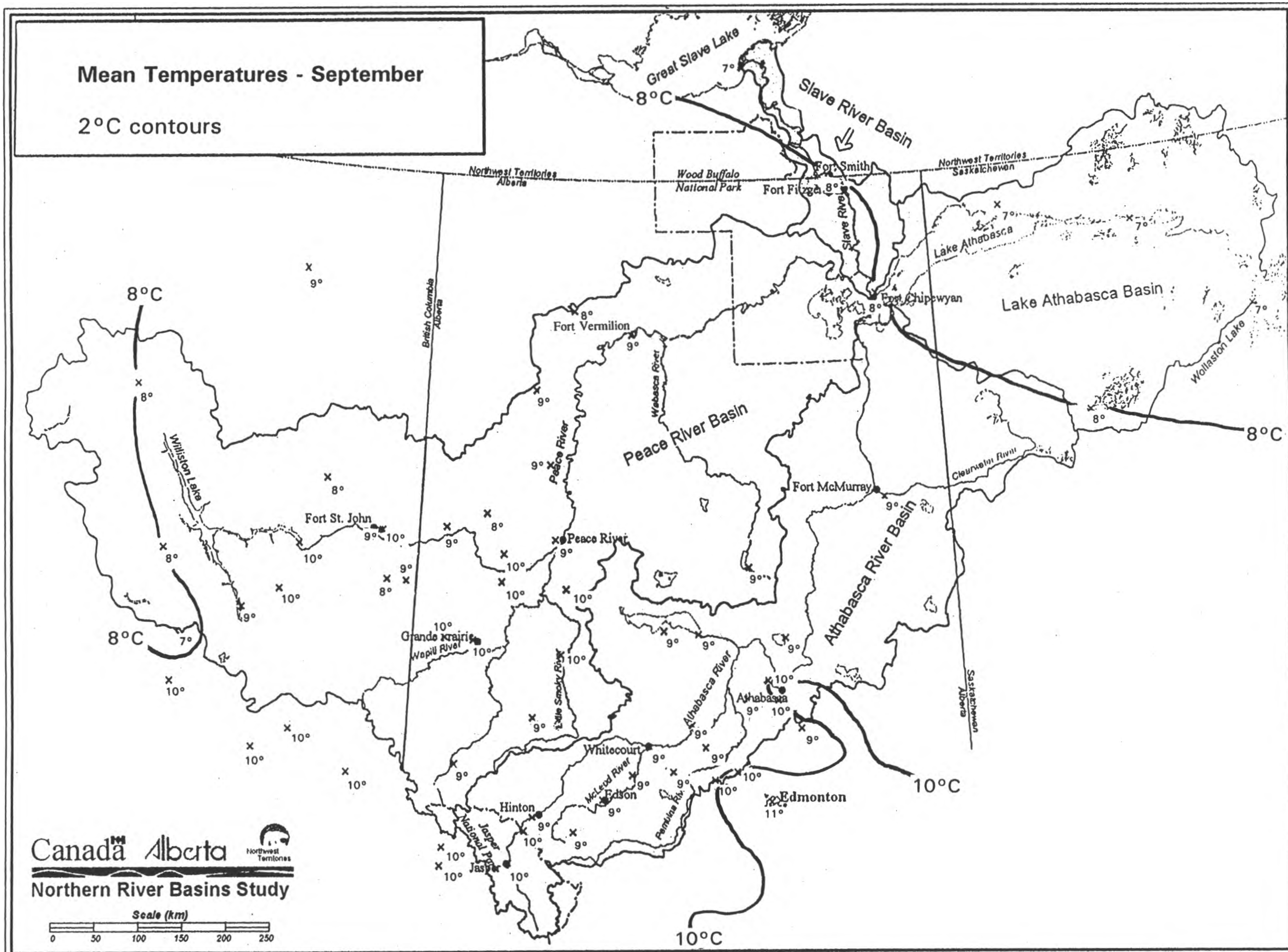

Mean Temperatures - April
2°C contours
Great Slave Lake
Slave River Basin
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Lake Athabasca
Lake Athabasca Basin
Wollaston Lake
Fort Chipewyan
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
British Columbia
Alberta
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Fort McMurray
Clearwater River
Athabasca River Basin
Athabasca River
Athabasca
Saskatchewan
Alberta
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
-4°C
-2°C
0°C
2°C
4°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250


Mean Temperatures - May
2°C contours
Great Slave Lake
Slave River Basin
Fort Smith
Fort Fitzgerald
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Lake Athabasca
Lake Athabasca Basin
Wollaston Lake
Fort Chipewyan
Slave River
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
Fort St. John
Williston Lake
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Edmonton
Pembina River
Hinton
Jasper National Park
Jasper
6°C
8°C
10°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250

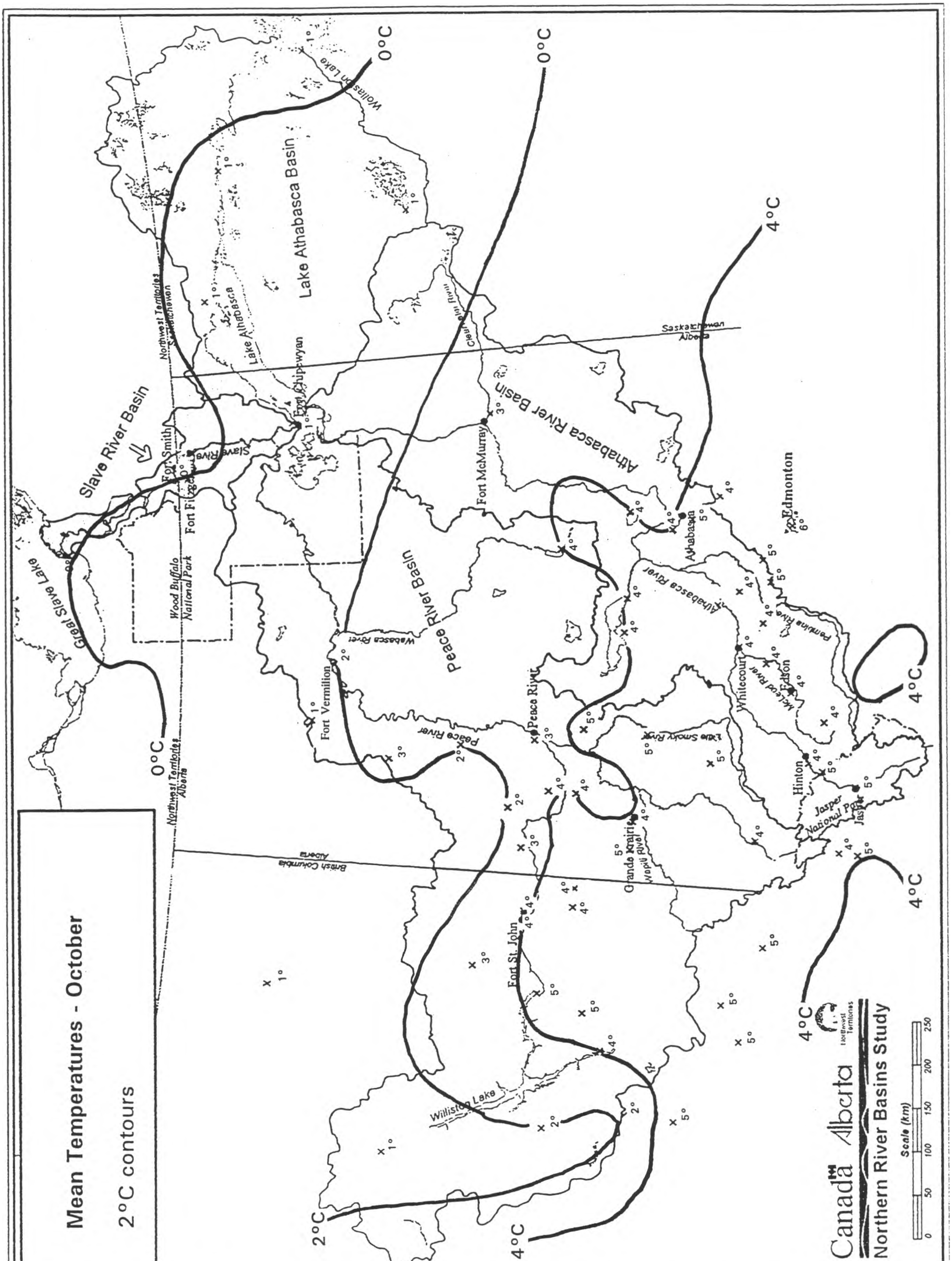

Mean Temperatures - June
2°C contours
Great Slave Lake
Slave River Basin
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Fort Smith
Fort Fitzgerald
Slave River
Fort Chipewyan
Lake Athabasca
Lake Athabasca Basin
Wollaston Lake
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
14°C
12°C
14°C
12°C
14°C
14°C
12°C
14°C
14°C
14°C
14°C
12°C
12°C
14°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250


Mean Temperatures - July
2°C contours
Great Slave Lake
Slave River Basin
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Northwest Territories
Alberta
Saskatchewan
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
British Columbia
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
14°C
16°C
13°
14°
15°
16°
17°
18°
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

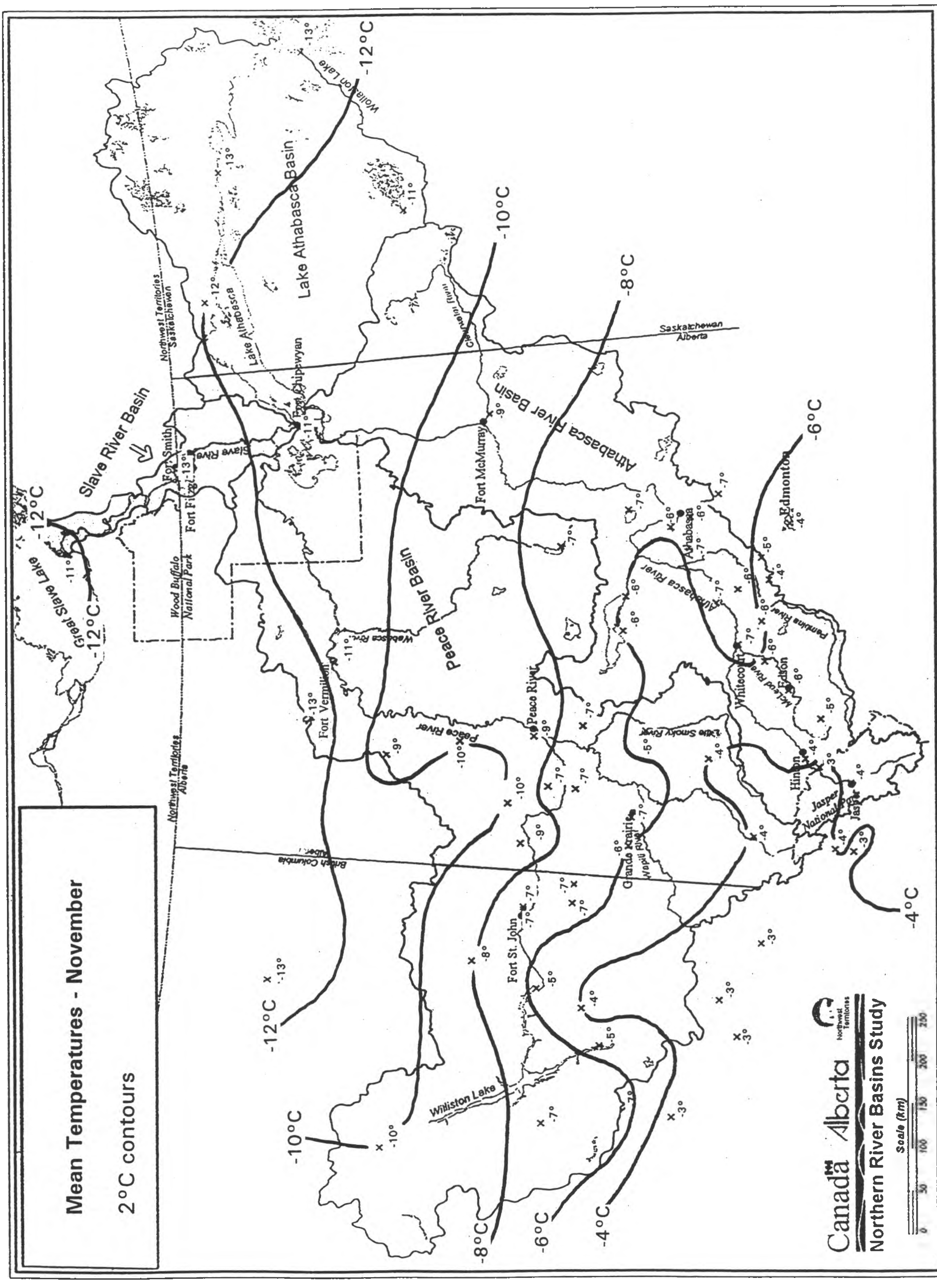

Mean Temperatures - August
2°C contours
Great Slave Lake
Slave River Basin
Fort Smith
Fort Fitzgerald
Slave River
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Clearwater River
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Athabasca River Basin
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
14°C
16°C
12°
13°
14°
15°
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250



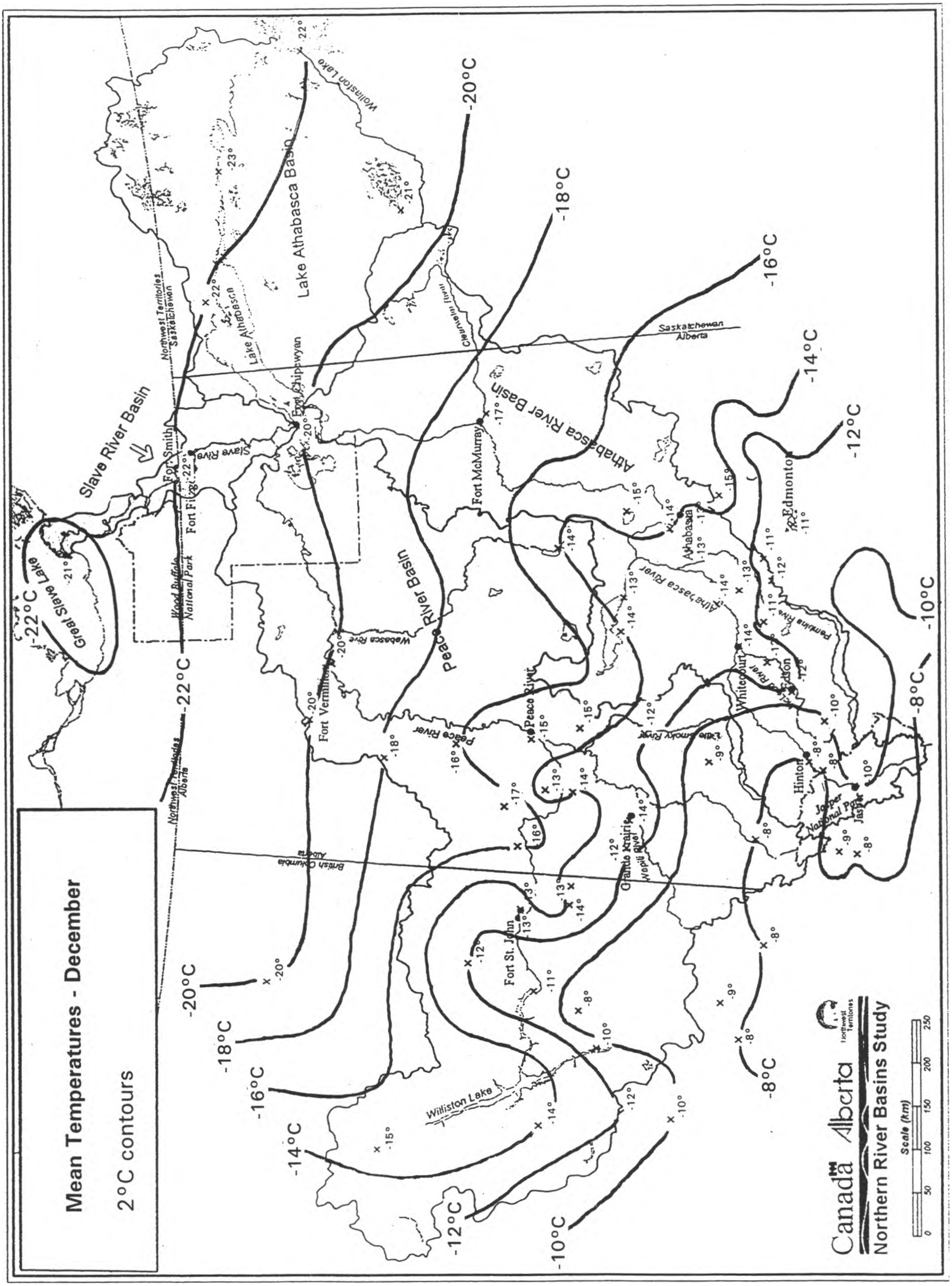
Mean Temperatures - September
2°C contours
Slave River Basin
Lake Athabasca Basin
Peace River Basin
Athabasca River Basin
Great Slave Lake
Lake Athabasca
Wollaston Lake
Williston Lake
Wood Buffalo National Park
Jasper National Park
Fort Smith
Fort Chipewyan
Fort Vermilion
Fort McMurray
Fort St. John
Peace River
Grande Prairie
Athabasca
Whitecourt
Edson
Hinton
Jasper
Edmonton
Slave River
Peace River
Wabasca River
Clearwater River
Athabasca River
Little Smoky River
McLeod River
Pembina Riv.
Wapiti River
Northwest Territories
Alberta
Saskatchewan
British Columbia
8°C
10°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250



Mean Temperatures - October
2°C contours
Lake Athabasca Basin
Slave River Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Wollaston Lake
Lake Athabasca
Wood Buffalo National Park
Fort Smith
Fort Chipewyan
Fort McMurray
Fort Vermilion
Peace River
Grande Prairie
Fort St. John
Williston Lake
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper
Jasper National Park
Wabasca River
Athabasca River
Pembina River
Little Smoky River
McLeod River
Wapiti River
Slave River
Clearwater River
Northwest Territories
Saskatchewan
Alberta
British Columbia
0°C
2°C
4°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

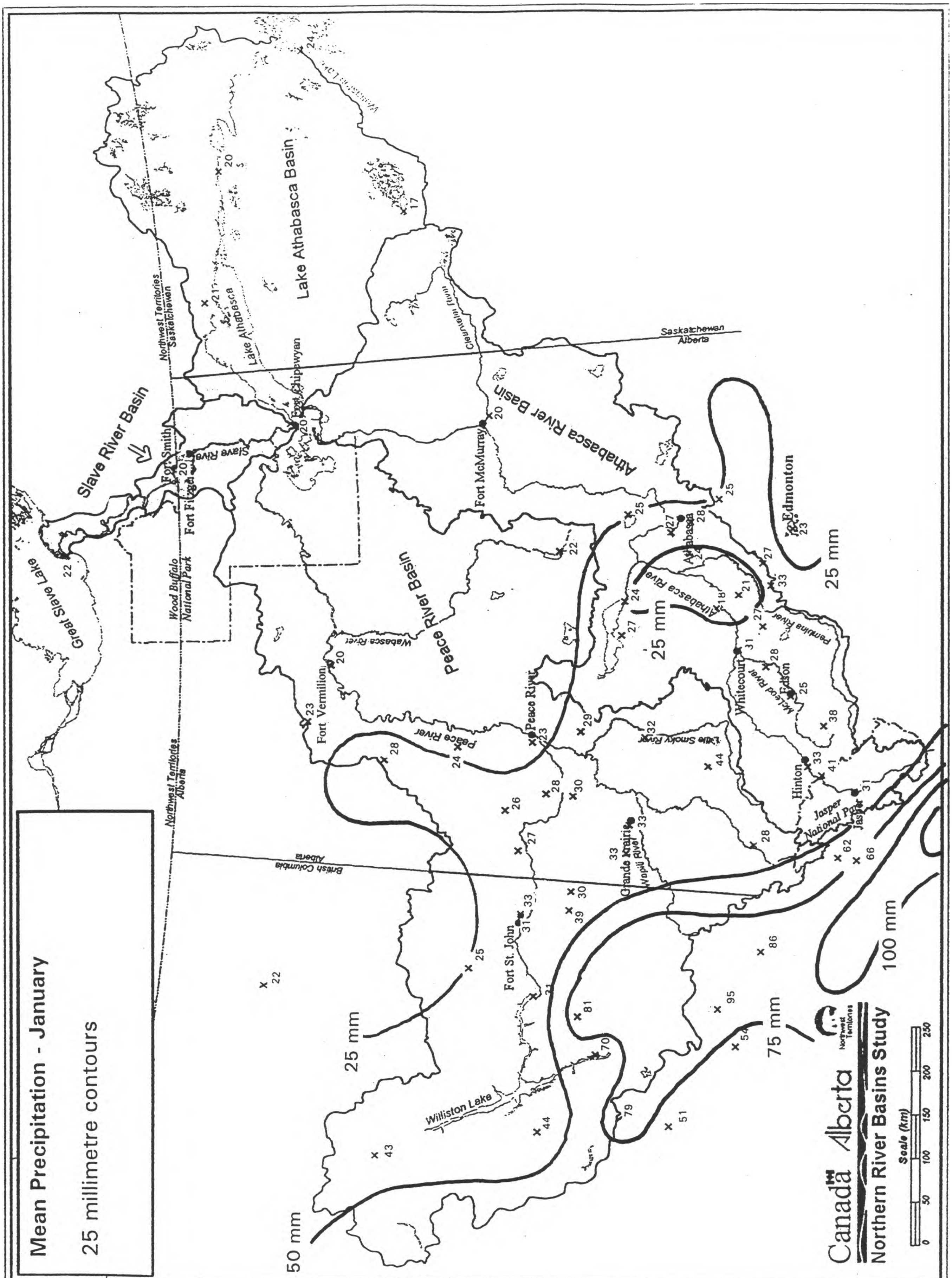


Mean Temperatures - November
2°C contours
Slave River Basin
Great Slave Lake
Fort Smith
Fort Fitzgerald
Slave River
Wood Buffalo National Park
Fort Chipewyan
Lake Athabasca
Lake Athabasca Basin
Wollaston Lake
Fort McMurray
Athabasca River Basin
Athabasca River
Athabasca
Edmonton
Pembina River
Whitecourt
McLeod River
Edson
Hinton
Jasper
Jasper National Park
Little Smoky River
Grande Prairie
Wapiti River
Peace River Basin
Peace River
Wabasca River
Fort Vermilion
Fort St. John
Williston Lake
Northwest Territories
Saskatchewan
Alberta
British Columbia
-12°C
-10°C
-8°C
-6°C
-4°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

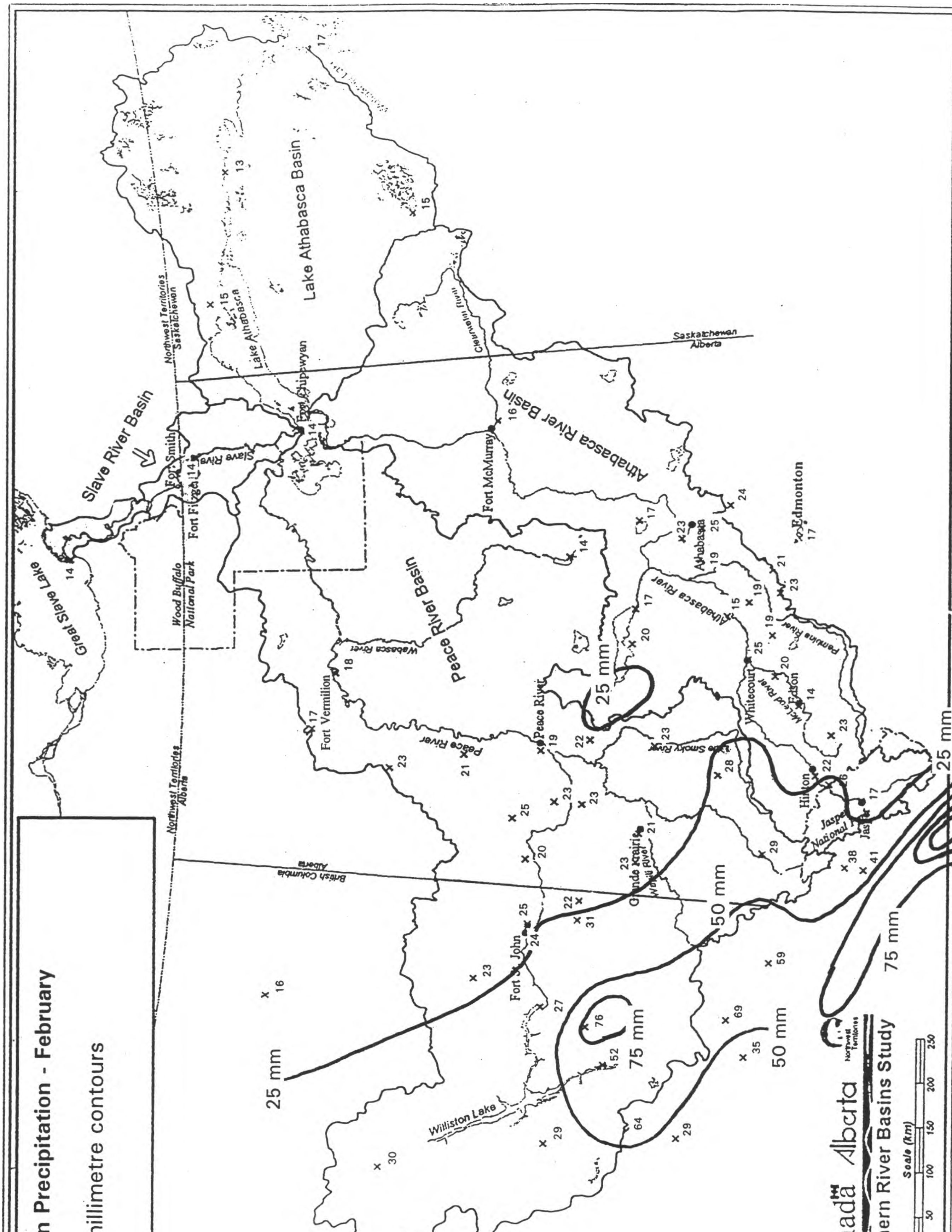

Mean Temperatures - December
2°C contours
Slave River Basin
Lake Athabasca Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Lake Athabasca
Wollaston Lake
Williston Lake
Wood Buffalo National Park
Jasper National Park
Northwest Territories
Alberta
Saskatchewan
British Columbia
Fort Smith
Fort Fitzgerald
Fort Chipewyan
Fort McMurray
Fort Vermilion
Peace River
Grande Prairie
Fort St. John
Athabasca
Edmonton
Whitecourt
Hinton
Jasper
Slave River
Wabasca River
Athabasca River
Little Smoky River
Pembina River
-22°C
-20°C
-18°C
-16°C
-14°C
-12°C
-10°C
-8°C
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

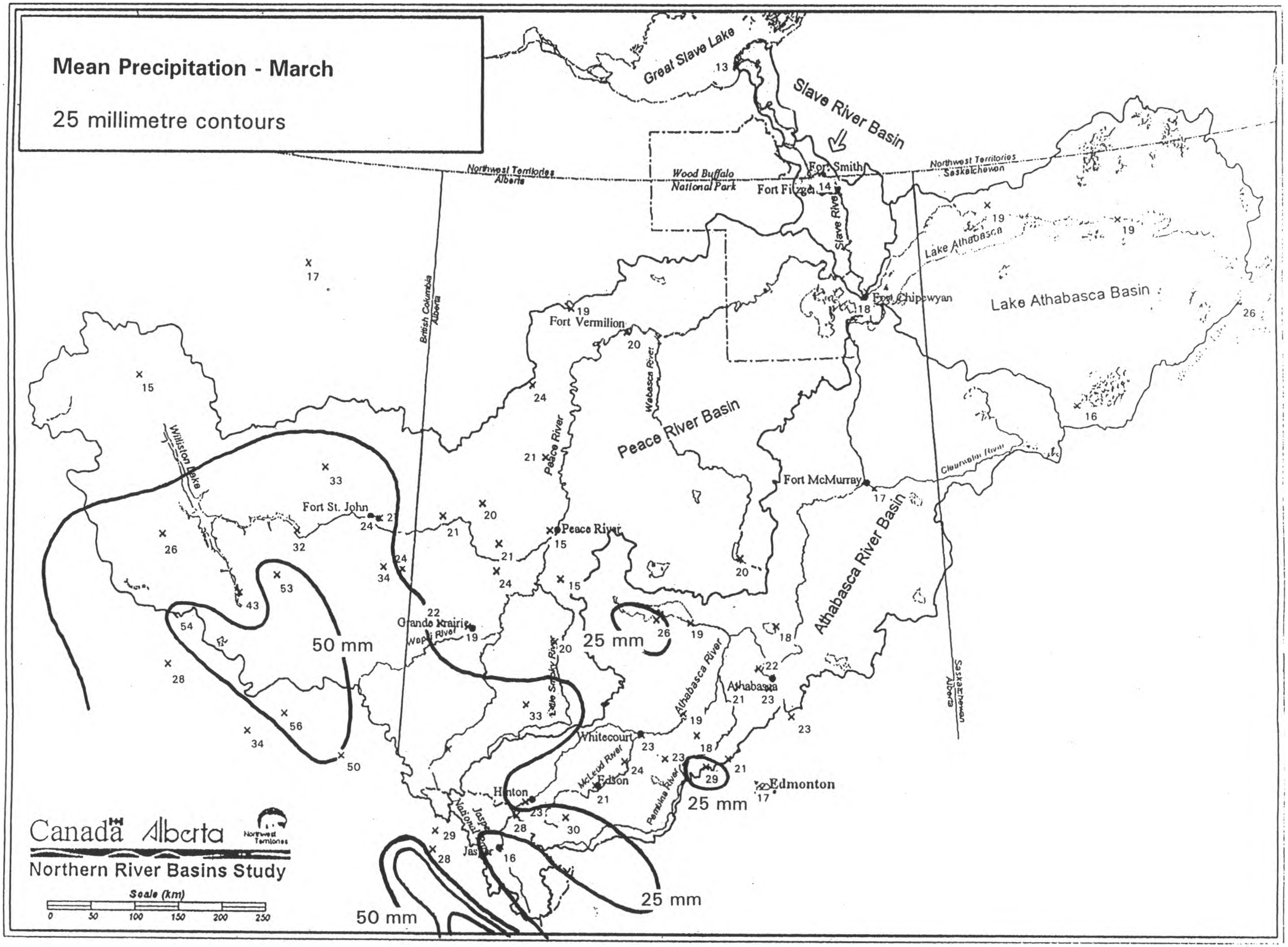
APPENDIX C:

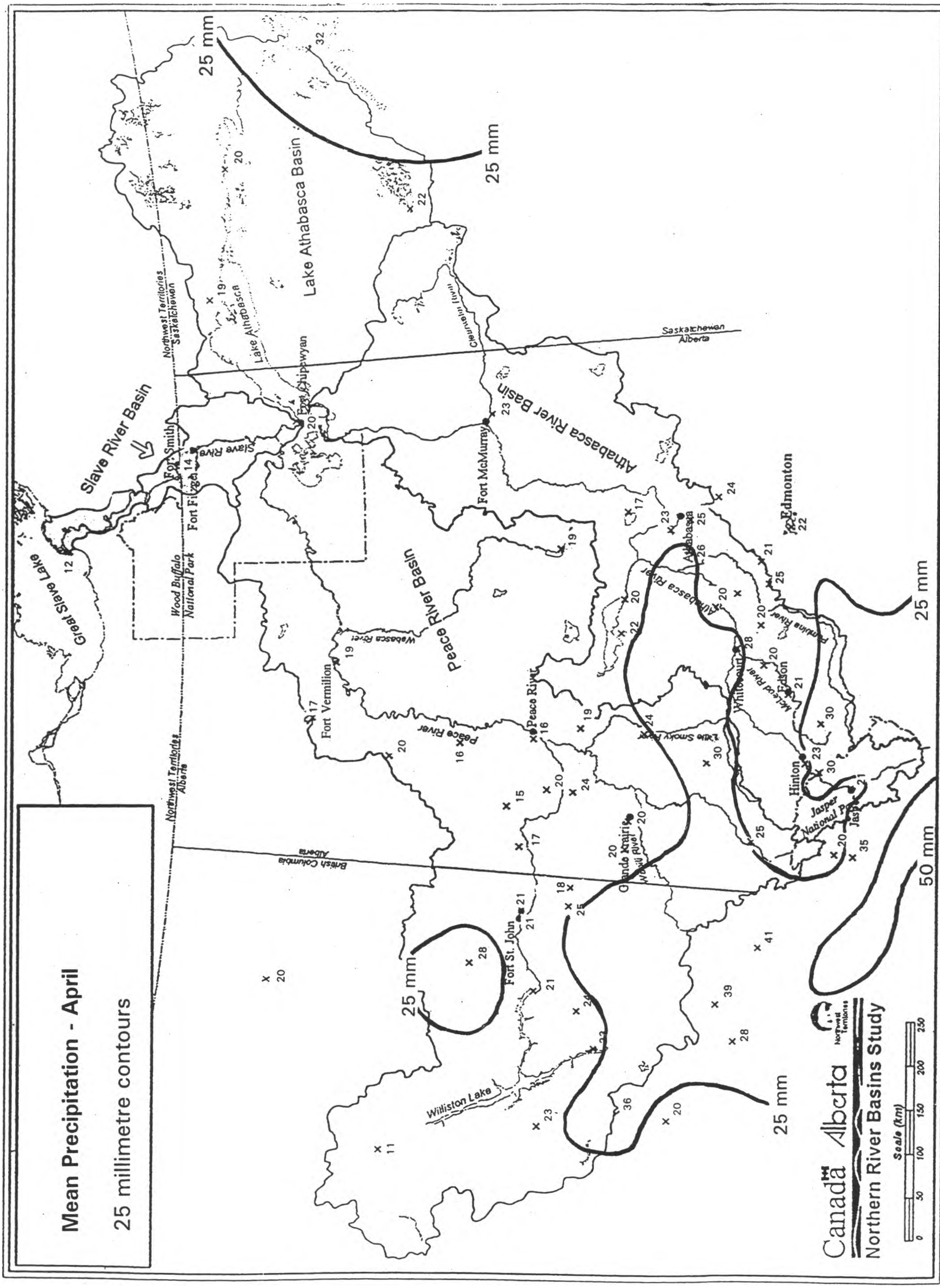
MONTHLY MAPS OF PRECIPITATION, NORTHERN RIVER BASINS

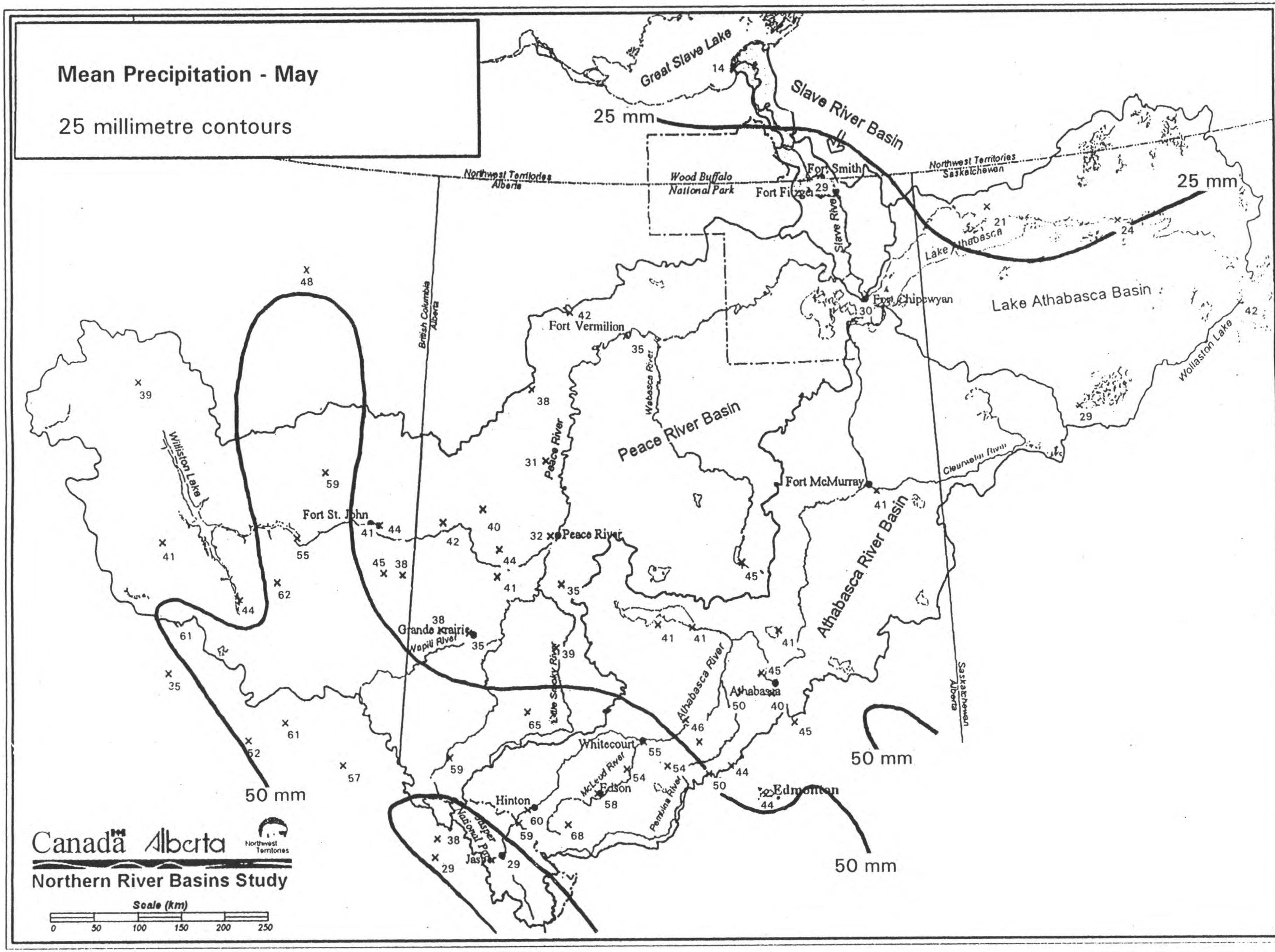


Mean Precipitation - January
25 millimetre contours
Lake Athabasca Basin
Slave River Basin
Peace River Basin
Athabasca River Basin
Great Slave Lake
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Fort Chipewyan
Lake Athabasca
Fort McMurray
Fort Vermilion
Peace River
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper
Jasper National Park
Grande Prairie
Fort St. John
Williston Lake
Northwest Territories
Saskatchewan
Alberta
British Columbia
25 mm
50 mm
75 mm
100 mm
Canada
Alberta
Northern River Basins Study
Scale (km)

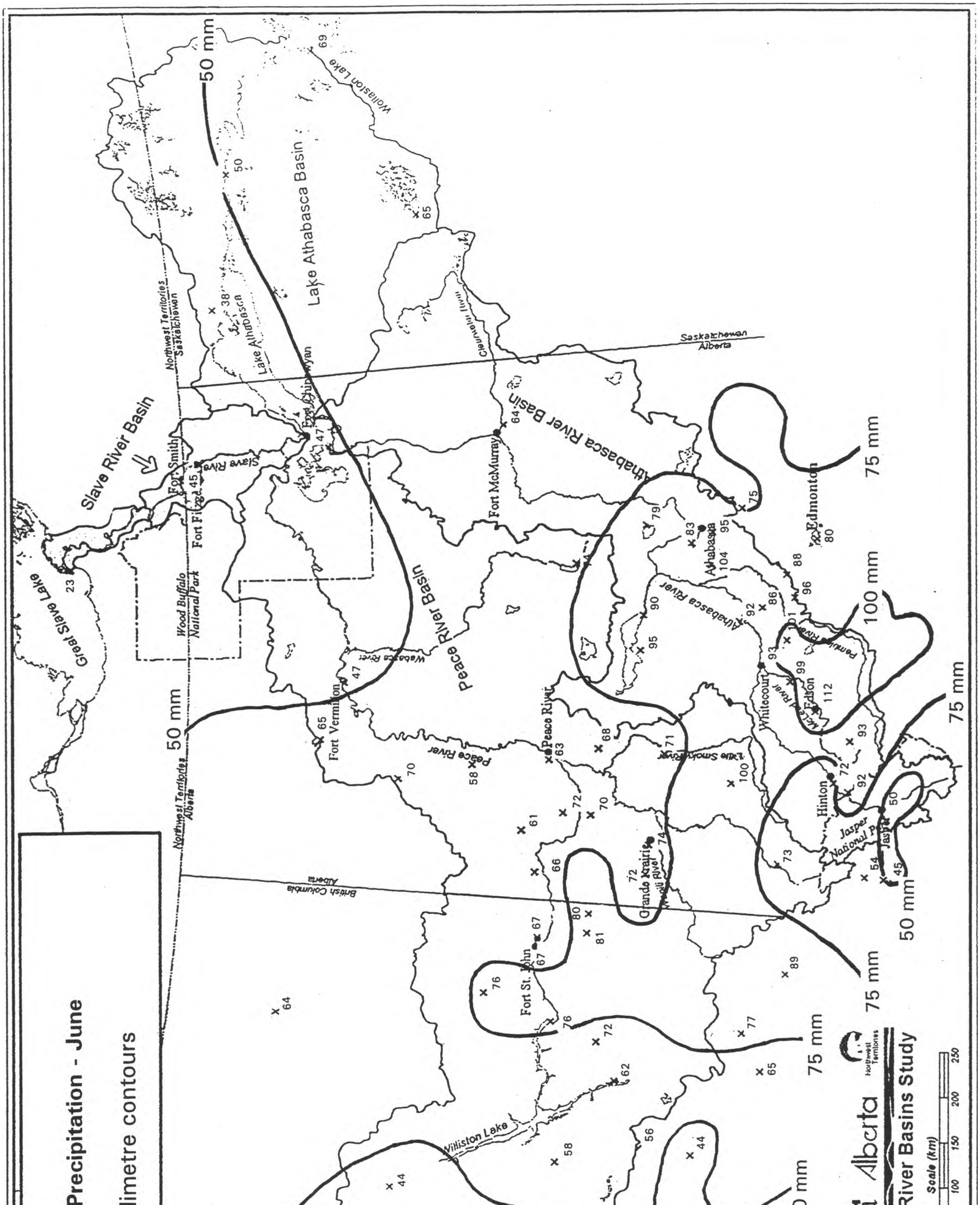

Mean Precipitation - February
25 millimetre contours
Lake Athabasca Basin
Slave River Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Lake Athabasca
Wood Buffalo National Park
Jasper National Park
Williston Lake
Fort Smith
Fort Fitzgerald
Fort Chipewyan
Fort McMurray
Fort Vermilion
Peace River
Fort St. John
Grande Prairie
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper
Slave River
Wabasca River
Athabasca River
Pembina River
McLeod River
Little Smoky River
Wapiti River
Clearwater River
Northwest Territories
Saskatchewan
Alberta
British Columbia
25 mm
50 mm
75 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250


Mean Precipitation - March
25 millimetre contours
Great Slave Lake
Slave River Basin
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper
Jasper National Park
50 mm
25 mm
25 mm
25 mm
50 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250

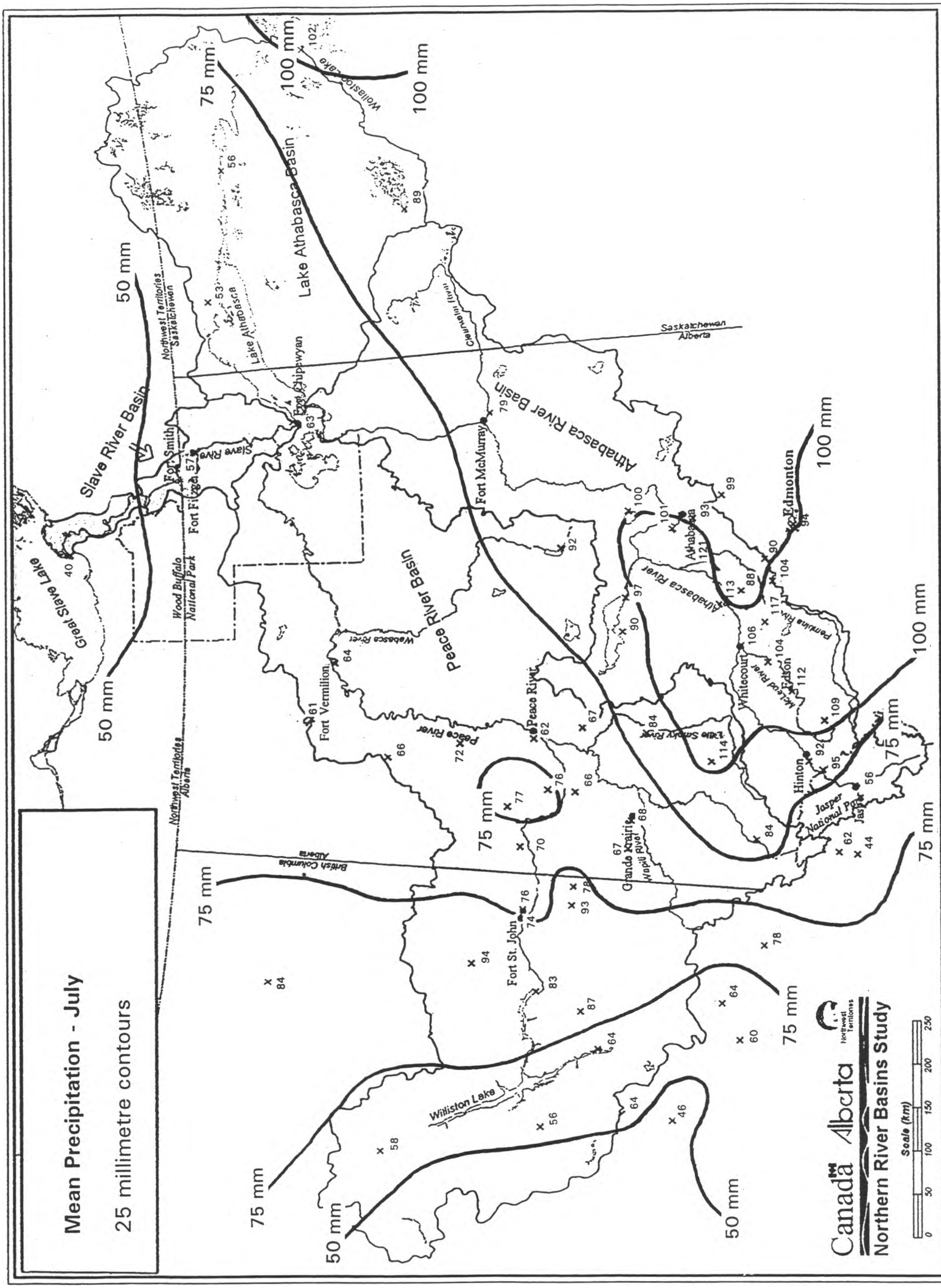

Mean Precipitation - April
25 millimetre contours
Slave River Basin
Peace River Basin
Athabasca River Basin
Lake Athabasca Basin
Great Slave Lake
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Fort Chipewyan
Lake Athabasca
Fort McMurray
Fort Vermilion
Wabasca River
Peace River
Fort St. John
Williston Lake
Grande Prairie
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Hinton
Jasper National Park
Jasper
Edmonton
Northwest Territories
Saskatchewan
Alberta
British Columbia
25 mm
50 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250



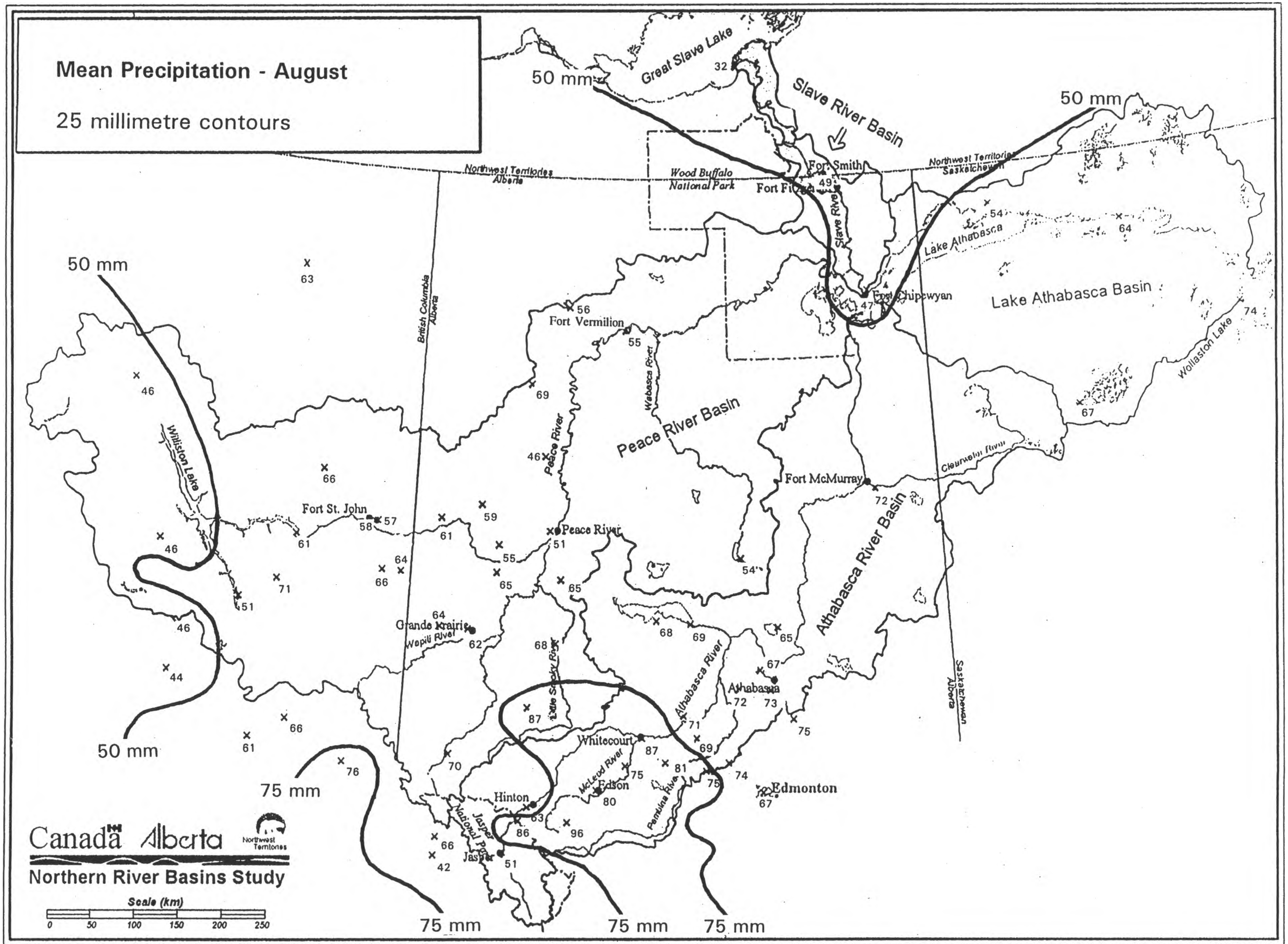
Mean Precipitation - May
25 millimetre contours
Great Slave Lake
Slave River Basin
25 mm
25 mm
50 mm
50 mm
50 mm
50 mm
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
Saskatchewan
Alberta
British Columbia
Alberta
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250

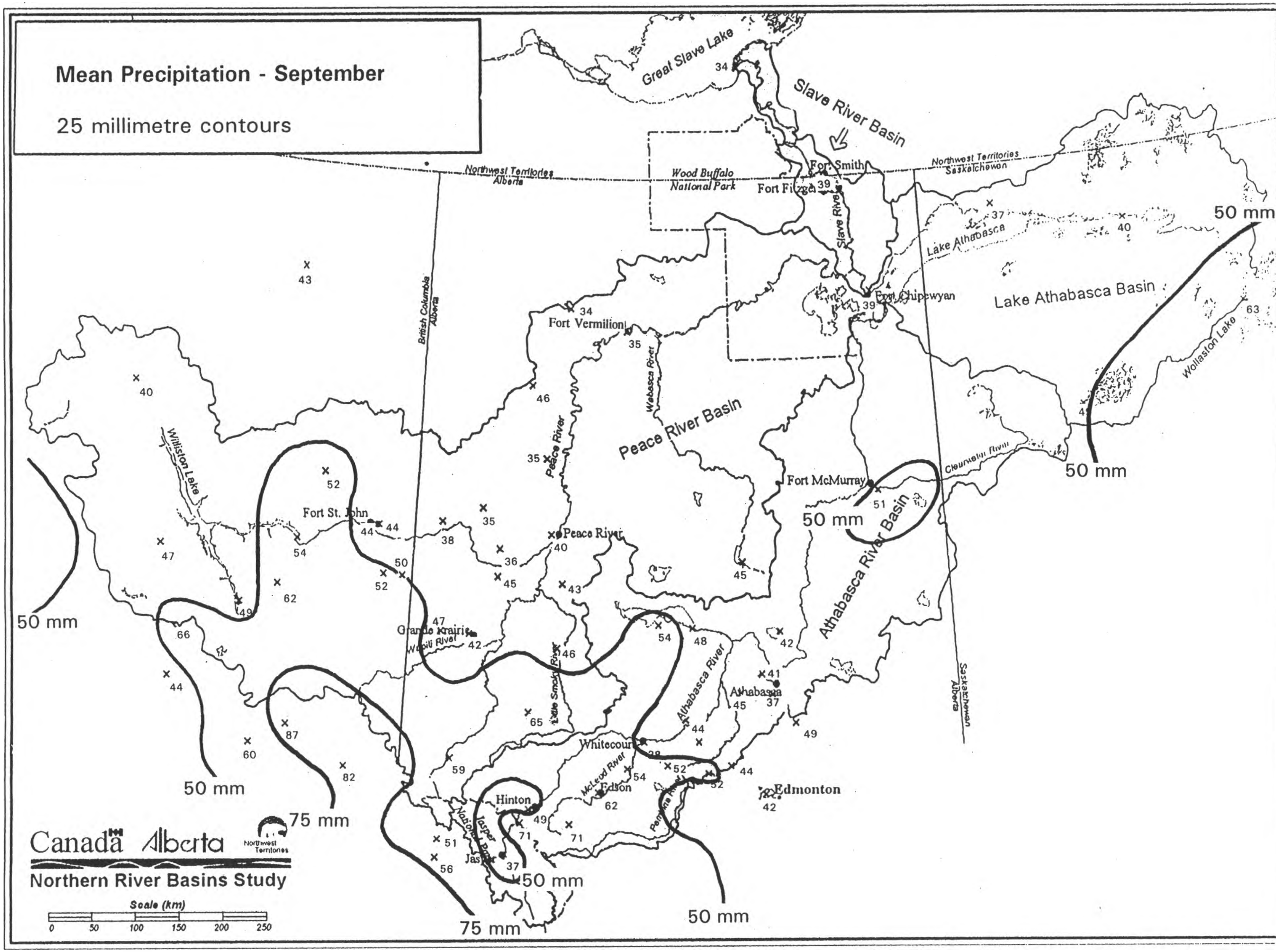


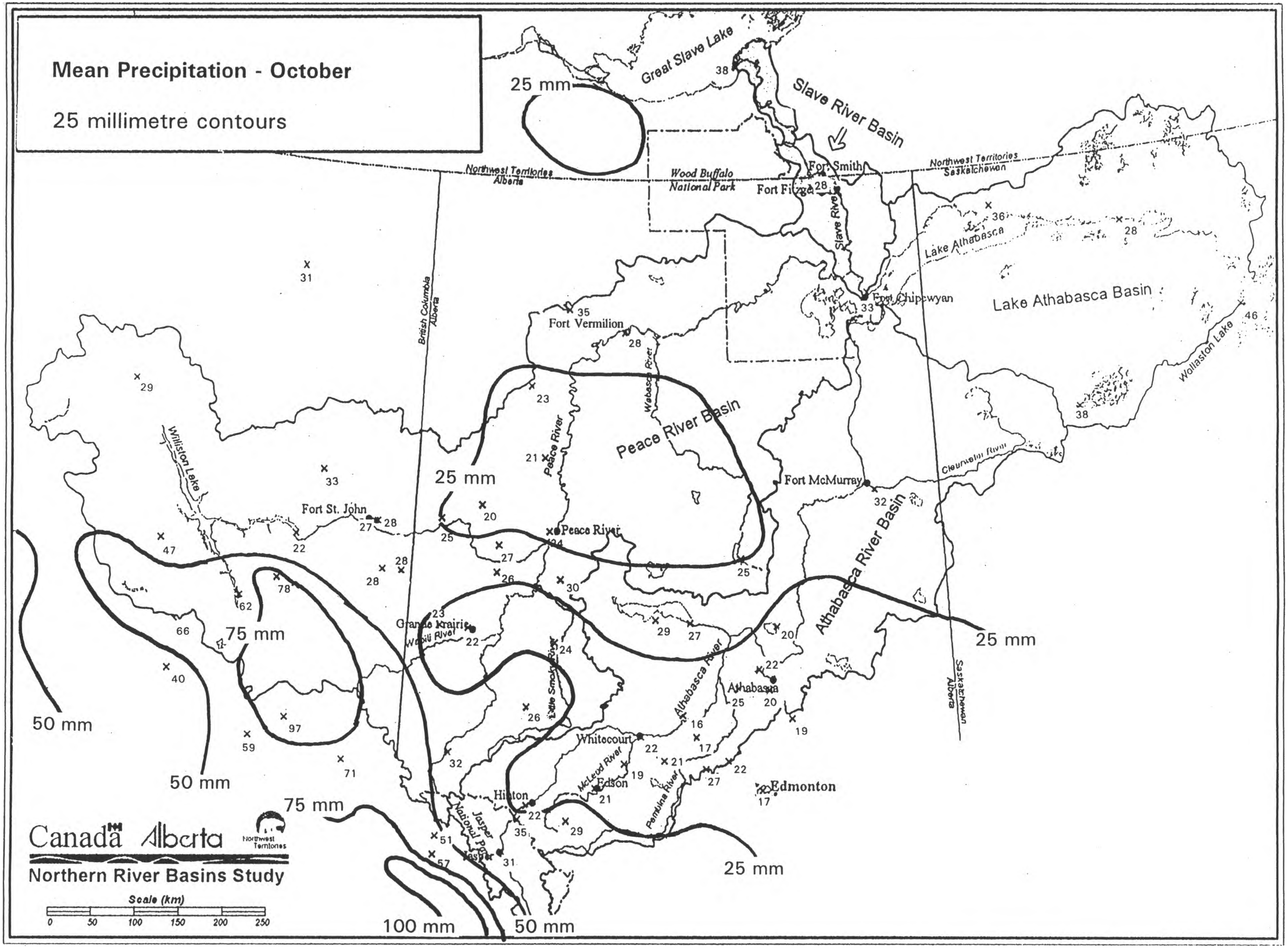
Mean Precipitation - June
25 millimetre contours
Slave River Basin
Lake Athabasca Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Wood Buffalo National Park
Lake Athabasca
Wollaston Lake
Fort Smith
Fort Fitzgerald
Fort Chipewyan
Fort McMurray
Fort Vermilion
Peace River
Fort St. John
Grande Prairie
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper
Jasper National Park
Williston Lake
Slave River
Wabasca River
Athabasca River
Little Smoky River
Pembina River
McLeod River
Clearwater River
Northwest Territories
Saskatchewan
Alberta
British Columbia
50 mm
75 mm
100 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

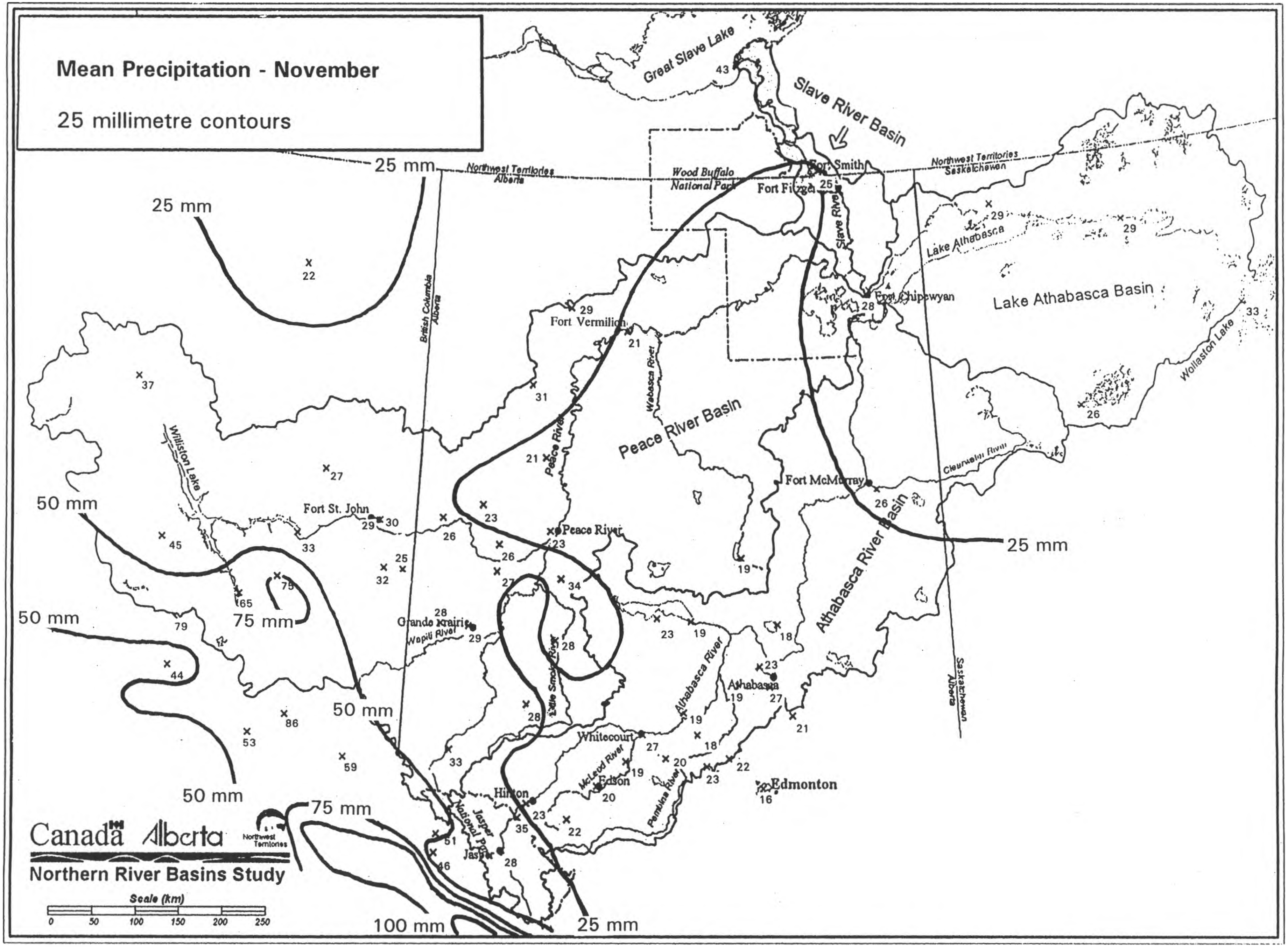


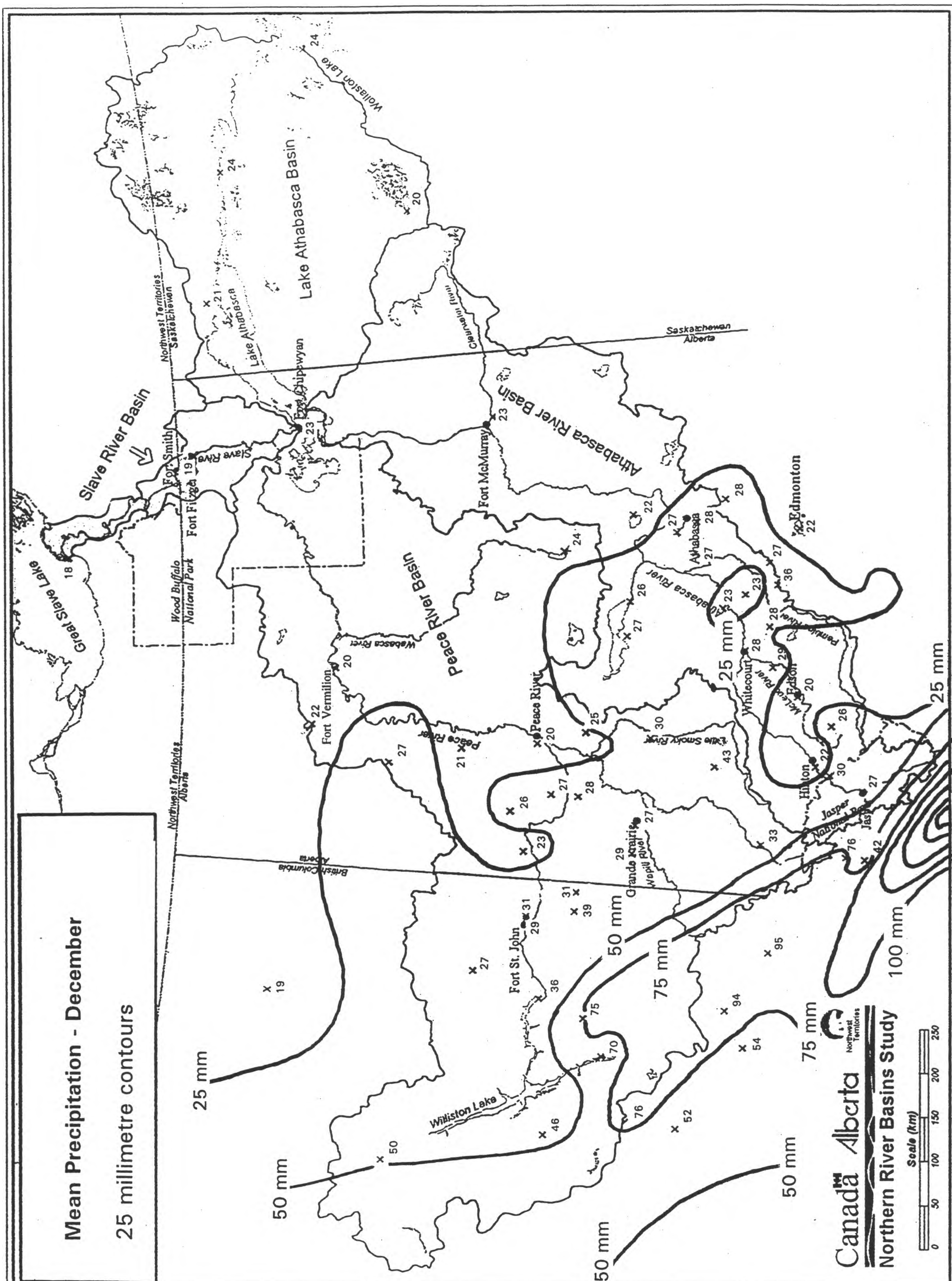
Mean Precipitation - July
25 millimetre contours
Great Slave Lake
Slave River Basin
Lake Athabasca Basin
Peace River Basin
Athabasca River Basin
Lake Athabasca
Wollaston Lake
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Fort Chipewyan
Fort McMurray
Fort Vermilion
Peace River
Fort St. John
Grande Prairie
Athabasca
Edmonton
Whitecourt
Edson
Hinton
Jasper
Jasper National Park
Williston Lake
Northwest Territories
Saskatchewan
Alberta
British Columbia
50 mm
75 mm
100 mm
Canada
Alberta
Northern River Basins Study
Scale (km)


Mean Precipitation - August
25 millimetre contours
Great Slave Lake
Slave River Basin
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Northwest Territories / Alberta
Northwest Territories / Saskatchewan
Lake Athabasca
Fort Chipewyan
Lake Athabasca Basin
Wollaston Lake
Clearwater River
Fort McMurray
Athabasca River Basin
Saskatchewan / Alberta
British Columbia / Alberta
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Williston Lake
Fort St. John
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
50 mm
75 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250


Mean Precipitation - September
25 millimetre contours
Great Slave Lake
Slave River Basin
Fort Smith
Fort Fitzgerald
Slave River
Wood Buffalo National Park
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
British Columbia
Alberta
Saskatchewan
Alberta
Lake Athabasca
Lake Athabasca Basin
Wollaston Lake
Fort Chipewyan
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Clearwater River
Athabasca River Basin
Athabasca River
Athabasca
Edmonton
Whitecourt
McLeod River
Edson
Pembina River
Hinton
Jasper National Park
Jasper
Little Smoky River
Grande Prairie
Wapiti River
Fort St. John
Williston Lake
50 mm
75 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250


Mean Precipitation - October
25 millimetre contours
Great Slave Lake
Slave River Basin
Northwest Territories
Alberta
Northwest Territories
Saskatchewan
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
British Columbia
Alberta
Williston Lake
Fort St. John
Fort McMurray
Clearwater River
Athabasca River Basin
Saskatchewan
Alberta
Grande Prairie
Wapiti River
Little Smoky River
Athabasca River
Athabasca
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
25 mm
50 mm
75 mm
100 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250


Mean Precipitation - November
25 millimetre contours
Great Slave Lake
Slave River Basin
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Northwest Territories
Alberta
Saskatchewan
British Columbia
Lake Athabasca
Lake Athabasca Basin
Fort Chipewyan
Wollaston Lake
Clearwater River
Fort Vermilion
Wabasca River
Peace River Basin
Peace River
Fort McMurray
Athabasca River Basin
Athabasca River
Athabasca
Fort St. John
Williston Lake
Grande Prairie
Wapiti River
Little Smoky River
Whitecourt
McLeod River
Edson
Pembina River
Edmonton
Hinton
Jasper National Park
Jasper
25 mm
50 mm
75 mm
100 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0 50 100 150 200 250


Mean Precipitation - December
25 millimetre contours
Slave River Basin
Lake Athabasca Basin
Athabasca River Basin
Peace River Basin
Great Slave Lake
Wood Buffalo National Park
Fort Smith
Fort Fitzgerald
Slave River
Fort Chipewyan
Lake Athabasca
Wollaston Lake
Fort McMurray
Fort Vermilion
Wabasca River
Peace River
Little Smoky River
Athabasca River
Athabasca
Edmonton
Whitecourt
Pembina River
McLeod River
Edson
Hinton
Jasper
Jasper National Park
Grande Prairie
Wapiti River
Fort St. John
Williston Lake
Northwest Territories
Saskatchewan
Alberta
British Columbia
25 mm
50 mm
75 mm
100 mm
200 mm
Canada
Alberta
Northwest Territories
Northern River Basins Study
Scale (km)
0
50
100
150
200
250

APPENDIX D: TERMS OF REFERENCE

No contractual Terms of Reference were prepared for the work documented in this report. The work was undertaken by the author as a contribution in kind from his employing agency and represents a part of his responsibilities to the working committee of the Synthesis and Modelling Component of the Northern River Basins Study.