CLIMATOLOGICAL ANALYSIS OF RECENT DATA FROM THE ATHABASCA OIL SANDS AREA

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ABSTRACT

This report is a climatological analysis of recent data from the Athabasca Oil Sands area. Data sources included the MAPS network of automatic meteorological data acquisition, forestry lookout stations, minisondes, snow pack surveys, and the Atmospheric Environment Service observing station at Fort McMurray. The data were analysed using a computer package of statistical subroutines.

It was found that large variations existed in the mean values of meteorological data from the MAPS network. These variations were the results of statistical fluctuations due to the short period of record and terrain differences. To reduce the variations, MAPS temperature and precipitation were correlated with Fort McMurray values. Mean monthly values of temperature were well estimated by Fort McMurray values throughout the year and by forestry station measurements in summer. However, mean monthly precipitation was not reliably estimated by this technique. While the duration of summer rainfall correlated well with station elevation, rainfall amount varied considerably between MAPS and forestry station, due in part to the convective component of summer precipitation.

Surface winds were found to be strongly controlled by terrain. Speeds were generally higher at exposed locations and lower at low elevations. Terrain-induced flows were predominant during winter and autumn months, and during summer and spring evenings. Diurnal variation in direction due to surface heating was noted during summer and spring but was not dominant. A poorly defined veer of less than 20° was observed between the surface and 400-m wind directions in all seasons except winter. In winter, differences in direction between the two levels were apparently random due to flow decoupling in stable conditions.

Minisonde data exhibited expected trends to increased instability in afternoon hours and during spring and summer months, especially in the lowest layer. The most common stability categories at all levels in all seasons were neutral and slightly stable.

The report concludes with two important recommendations. The first is that thorough quality control checks be implemented before new data sets are used for analysis. The second and farther reaching is that meteorological data requirements in the Athabasca Oil Sands area be reassessed before meso-scale monitoring is reactivated.

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1. INTRODUCTION

A descriptive overview of the climate of the Athabasca Oil Sands area of northeastern Alberta was prepared by Longley and Janz (1978). They described the climate as definitely continental and generally cooler and drier than central parts of the province. Winters were characterized as having relatively little snow and summers as being short and cool. About two thirds of the annual precipitation fell in the summer months with several major rainstorms accounting for much of the total. Low level winds were considered light and governed by terrain effects. Although Longley and Janz examined all available historical climatological data, the primary source was the long-term Atmospheric Environment Service (AES) surface weather records from Fort McMurray.

In late 1976, an automated nine-station meteorological data acquisition (MAPS[1]) network came on-stream in the area. Hourly values of precipitation, wind speed and direction, temperature, and relative humidity were recorded.

The objective of this study was to climatologically analyse recently available data in the Athabasca Oil Sands area. While the primary data source was to be the MAPS network, other regional sources of data were to be utilized including minisondes, forestry lookout stations, and the AES Fort McMurray records. Statistics on mean, maximum, and minimum temperature and precipitation; precipitation durations; the relationship between evaporation and meteorological variables; vertical temperature profiles; and the variability of wind speed and direction were to be generated. Topographic influences on the diurnal variations of temperature, wind, and precipitation amounts were to be considered. Short-period records were to be adjusted for comparison with long-term records. An important outcome of the study was to determine how representative the short-term MAPS data are of the climate of the area.

In view of the large volume of data processed in this study, an efficient means of generating statistics was required. To this end,

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[1] MAPS is a trade name of Bristol Industries.

Statistical Analysis System (SAS), a package of statistical subroutines, was utilized. During the analysis, several thousand pages of tables were produced, primarily of MAPS network and forest station summaries. These tables are not included in this report, but are available for detailed study as computer printout in the offices of Research Management Division (RMD), Alberta Environment.

Section 2 of this report summarizes the data base used in this study and its limitations. Section 3 discusses the results of a correlation analysis of data from Fort McMurray and the MAPS network. Sections 4 and 5 examine temperature and precipitation trends in the area, based on MAPS and forestry station data. Section 6 presents an analysis of MAPS network winds and a comparison to 400-m pibal winds. Section 7 briefly analyses evaporation measurements from Mildred Lake and Section 8 summarizes results of a minisonde data stability analysis.

2. DATA BASE

2.1 MAPS NETWORK

The MAPS network of automated meteorological data collection stations came on-stream late in 1976. Hourly values of temperature, wind speed and direction, and precipitation were recorded on cassette tapes and later transferred to standard computer tapes. A brief description of each site including instrumentation is given in Milgate (1978). Station locations are given in Table 1 and in map form in Figure 1.

Measurements of hourly parameters from the MAPS network comprised the primary data source for this study. The data were supplied on computer tape by RMD. Although statistics on the number of missing data were generated by Alberta Environment, no attempt has been made, after recording, to control the quality of the recorded data.

In this study, simple data quality control checks were instituted. Because the emphasis was not on extensive quality control, only values beyond a specified range were flagged and excluded from further analysis. This range is shown in Table 2 for temperature, wind speed, and precipitation. MAPS, minisonde, forestry lookout, and Fort McMurray data were subjected to the same check. No attempt was made to interpolate between missing hours or days. Where hourly values of temperature or precipitation were summed to produce daily values, if more than two hours in the day were missing, then the day was designated as missing. When daily values were summed to produce monthly values, if more than seven days in the month were missing, then the month was designated as missing. Because daily values were formed from hourly, and then monthly values from the daily values, it is possible that 14 missing hours in a month could exclude that month from further analysis.

On the original data tapes, precipitation data were archived as the total amount fallen since some designated start date. In this study the amount in any given hour was found by subtracting the previous from the present hour's total. If the previous hour was missing, then the value two hours earlier was used. If that hour was

Table 1. MAPS network station locations.

		Latitude		Longitude				Elevation
Code	Station	Deg.	Min.	Deg.	Min.	Start	Stop	(m)
BCH	Birch Mountain	57	42	111	50	09/76	05/80	853
ELS	Ells	57	07	112	21	10/76	05/80	488
HLS	Fort Hills	57	22	111	32	09/76	05/80	351
RIC	Richardson	57	53	111	02	09/76	05/80	305
FBG	Firebag	57	38	111	10	09/76	04/80	274
MKG	Muskeg	57	08	110	54	09/76	05/80	652
SMT	Stony Mountain	56	23	111	16	09/77	07/82	762
TKW	Thickwood	56	53	111	39	11/76	12/81	518
LKM	Mildred Lake	57	05	111	35	09/76	12/81	310

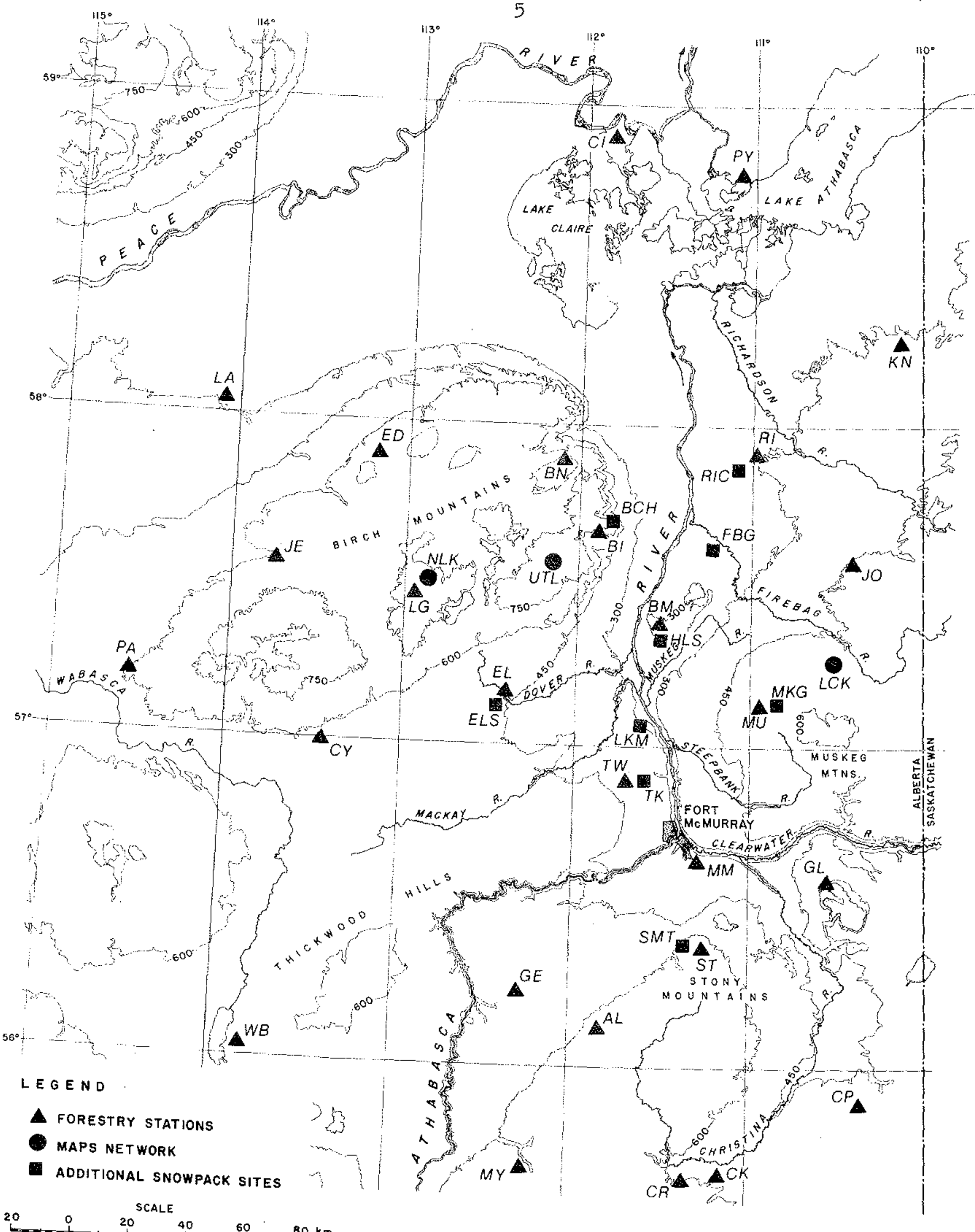

Figure 1. MAPS network, forestry station, and snowpack sampling sites in the Athabasca Oil Sands area.

Table 2. Allowable variable ranges for SAS analysis. Records with values outside these ranges were excluded from analysis.

Variable	Minimum	Maximum
Temperature	-60°C	40°C
Wind Speed	0 mph	100 mph
Precipitation (hour)	0 mm	50 mm
(day)	0 mm	150 mm

also missing, then precipitation for the hour in question was set to missing. Further details of data manipulation performed by SAS are found in Section 11.1.

During the course of the analysis, it became clear that the MAPS data were limited in terms of data quality, length of record at individual stations, and overlapping length of record among stations. Data quality summaries provided by RMD showed some stations were inoperative for several months at a time. The worst example was Stoney Mountain which had, of some four years of operational network time, only one July which passed all quality control checks. To achieve even this small quantity of data, originally planned quality control criteria had to be relaxed. This relaxation may well have caused problems with, for example, mean monthly temperatures. Seven days of missing values in one month (the maximum allowable) could encompass a period of unusually hot or cold weather. With only a few years of data available for averaging purposes, this might have resulted in unrepresentative mean monthly values.

In addition to data quality, the short length of record at MAPS stations also created problems. These were manifest as unstable mean values. Considerable variation was introduced when one value was replaced with another or when additional values were used. For many analyses this forced a decision of whether to use all available data, knowing that different record lengths at different stations would induce statistical fluctuations, or whether to utilize the longest common period of record at all stations, which in some cases was zero, or whether to reject individual stations with short periods of record and attain some compromise of record length (statistical stability) and area of coverage.

In summary, while the MAPS network provided the bulk of data for this study, it is suggested that results of the analysis are useful only in a limited context. Because of the very short period of overlapping records at stations, spatial variations in mean values of measurements are likely the result of statistical fluctuations. Further, the calculation of long-term normal values directly from the data is also suggested to be inappropriate because of the instability of mean values. This limits the usefulness of the MAPS data to the calculation of very short-term averages (perhaps a year or less) or to a case study type of analysis or to correlations with long-term stations (Section 3).

2.2 FORESTRY LOOKOUT STATIONS

A second source of data for this study was forestry lookout stations within the Athabasca Oil Sands area. These stations, manned during the summer months (usually May through September), reported daily total precipitation and daily maximum and minimum temperatures. Station location, elevation, dates of operation, and type of climate records are given in Environment Canada (1976). Data from 28 forestry lookout stations were analysed; typically, each station had data available for the last 15 years. One station (Fort Chipewyan) had erroneous date information recorded on the original data tape. Although other data could not be proven incorrect, this station was withdrawn from the analysis. Another station (Wabasca) was not found on the computer tape and was also not analysed. Forestry station locations are given in Figure 1 and Table 3.

Several quality control steps were performed on these data by AES (Department of Transport 1969). According to established practice, all data were checked and abnormal data, those inconsistent with other data from the same station, or those inconsistent with nearby stations, were flagged. The flagged data were then replaced by estimates or designated as missing.

In this study, quality control procedures beyond those outlined in Table 2 were not performed. Estimates were treated as valid data.

2.3 EVAPORATION

In addition to standard measurements, the climate station at Mildred Lake also records daily pan evaporation, an estimate of lake evaporation, wind mileage (wind run), and air temperature. These data were analysed to determine relationships among evaporation and measured values of temperature, wind run, and precipitation.

Table 3. Forestry station locations.

Code	Station	Latitude Deg.	Latitude Min.	Longitude Deg.	Longitude Min.	Elevation (m)
CI	Carlson	58	55	111	48	213
PY	Fort Chipewyan	58	46	111	07	219
KN	Keane	58	19	110	17	457
LA	Lambert Creek	58	03	114	09	305
ED	Edra	57	51	113	15	610
BN	Buckton	57	52	112	06	792
RI	Richardson	57	55	110	58	305
JE	Jean	57	31	113	45	762
LG	Legend	57	27	112	53	911
BI	Birch Mountain	57	40	111	50	610
BM	Bitumont	57	22	111	32	349
WB	Wabasca	56	02	113	50	524
MY	May	55	37	112	21	896
CR	Christina	55	35	111	21	822
JO	Johnson Lake	57	35	110	20	549
PA	Panny	57	11	114	37	692
CY	Chipewyan Lakes	57	00	113	25	564
EL	Ells	57	11	112	20	610
TW	Thickwood	56	53	111	39	603
MU	Muskeg	57	08	110	54	652
MM	Fort McMurray	56	39	111	31	371
GL	Gordon Lake	56	37	110	30	488
GE	Grande	56	18	112	13	533
AL	Algar	56	07	111	47	780
ST	Stony Mountain	56	23	111	14	762
CK	Conklin	55	37	111	11	541
CP	Cowpar	55	50	110	23	563

Quality control procedures were identical to those for the forestry lookout stations.

2.4 MINISONDES

Minisonde data collected in the Athabasca Oil Sands area from 1975 through 1979 were analysed to produce a stability climatology. The data were derived from several field programs conducted in the area, primarily by AES for Alberta Oil Sands Environmental Research Program (AOSERP) (Fanaki 1978, 1979; Fanaki et al. 1979) and by Syncrude Canada Ltd. (Slawson et al. 1980).

The AOSERP minisonde data were critiqued by Davison and Leavitt (1979) and found to have serious problems in some cases. Davison and Leavitt adopted the procedure of examining each ascent individually in the context of others which were near in space and time to remove inconsistent and erroneous records. This procedure was beyond the scope of this study and it is therefore probable that the present stability climatology contains some errors. One example of these errors is the presence of super-adiabatic lapse rates extending over a depth of several hundred metres. It is therefore imperative that the results of this analysis of minisonde data be used with caution.

Additional data quality checks were performed when the AOSERP and Syncrude data sets were combined and archived (Hansen and Leahey 1982). These checks were instituted primarily to detect errors of reproduction, and included assuring positive elevations and that winds, temperatures, and temperature gradients were within prespecified bounds. No effort was made to check data interconsistency.

2.5 SNOWPACK

Beginning in 1975, winter snowpack data were gathered in the area. Measurements were generally made once each month in January, February, and March but were occasionally also made in December and April. Measurement locations were not consistent in all months and years but generally included MAPS stations and several other sites. The locations of the snowpack survey sites used in this study are shown

Table 4. Snowpack survey locations with three or more years of record, 1975-1982.

Code	Station	Latitude		Longitude	
		Deg.	Min.	Deg.	Min.
BCH	Birch Mountain	57	42	111	50
ELS	Ells	57	07	112	21
HLS	Fort Hills	57	22	111	32
RIC	Richardson	57	53	111	02
FBG	Firebag	57	38	111	10
MKG	Muskeg	57	08	110	54
SMT	Stony Mountain	56	23	111	16
TKW	Thickwood	56	53	111	39
LKM	Mildred Lake	57	05	111	35
LCK	Lost Creek	57	17	110	29
UTL	Upper Tar Lake	57	20	112	08
NLK	Namur Lake	57	29	112	45

in Table 4. Note that the sites selected had at least three years of data.

In addition to location inconsistency, the archived snowpack data also exhibited some data type inconsistency, as shown in Table 5. Only snow depth measurements were undertaken in all years. Core depths (depth after compaction) and core weights from which snow density and water equivalency data may be generated were measured occasionally; that is, in some years and some months. Thus, a complete set of snowpack statistics could not be generated for all years.

The snowpack data had further problems. The documentation describing data collection or analysis procedures apparently does not exist. In some cases (for example, snow density) measurement units were not specified. In all cases measurement dates were inconsistent. For example, January snow depths were measured (over the years) in all weeks of the month, making it difficult to calculate an average snow depth at, say, 15 or 30 January without examining daily precipitation records as well.

Snowpack data, as summarized in Table 5, were provided on computer tape by RMD. In addition, water equivalency data for most stations were available from a previous study (Stanley Associates 1982). These data were also examined for evidence of spatial and temporal variations in this study.

Table 5. Archived snowpack data by year.

Year	Average Depth	Water Equivalence	Density	Core Depth	Core Weight
1975	X[a]		X		*[b]
1976	X		*	*	*
1977	X		X	*	*
1978	X	X	X		
1979	X	X	X	X	X
1980	X			*	*
1981					
1982	X			X	

[a] complete archive
[b] partial archive

3. MAPS-FORT MCMURRAY CORRELATION ANALYSIS

Two study objectives were contingent on results of a correlation between temperatures and precipitation from the Fort McMurray station and stations in the MAPS network. One objective was to quantify spatial variations throughout the oil sands area. The second objective was to create 30-year parameter normals based on appropriate normalization of the MAPS data and comparison with Fort McMurray data. The nature of the MAPS data, described previously, prevented the full accomplishment of these objectives.

Analysis of spatial variations requires either a long period of record at all stations within the area so that small differences in record length do not significantly alter the mean values, or identical periods of record. The MAPS data fulfill the second qualification only. The total network was operational for less than four years, a period that may be insufficient to produce stable averages. This is especially true of parameters (such as precipitation) which, in the case of summertime convective rainfall, have an inherently large spatial variation.

Thirty-year normals can be calculated for stations with less than 30 years of data provided two criteria are met (Environment Canada 1982). First, a standard station must exist nearby. A standard station is one with at least 28 years of good quality records. In this study, this criterion was met by the Fort McMurray airport synoptic observing station. Second, the short-period station must have at least five years of good quality data to make a valid comparison. None of the stations in the MAPS network met this second criterion. Some stations had as few as one year of data for certain months.

In spite of the fact that the correlation results cannot with confidence be used to determine spatial variation or long-term normals, the regressions themselves were performed. Although Environment Canada (1982) performs regressions on monthly data (e.g., total monthly precipitation or mean maximum monthly temperatures), the paucity of MAPS data for some months suggested first a regression based on daily values in order to increase the number of observations. The daily data were not stratified by season and thus represent an average over an entire year.

A linear regression equation was used of the form:

$$m = ax + b \qquad (1)$$

where: x = Fort McMurray observation
m = MAPS station observation
a = slope of regression equation
b = intercept

Linear correlation coefficients and Students t statistics were among the many parameters produced by the SAS analysis. The t statistic was used to determine if regression parameters were significantly different from zero.

Table 6 shows a summary of the Fort McMurray-MAPS correlation results. It contains values of R^2 (the square of the correlation coefficient showing the fraction of variance explained by the regression) for the following daily variables: maximum temperature, minimum temperature, mean temperature, and total precipitation. Apparently, temperature at MAPS stations is generally well correlated with temperature at Fort McMurray. The regression parameters (slope and intercept) are given in Table 7. In addition to near unity temperature correlation coefficients, t test statistics showed the slope and intercept to be different from zero, significant to better than the 99% level in all cases. This suggests that very accurate estimates of MAPS station temperatures can be made using Fort McMurray values.

Temperature regression statistics in Table 7 clearly show terrain effects. Maximum and mean temperatures at elevated stations (Birch Mountain, Muskeg, and Stony Mountain) are lower than at Fort McMurray. The effect of terrain on minimum temperatures is less well defined.

As expected, much less of the daily precipitation variances could be explained by the regression. Table 6 shows R^2 values of about 0.15 (R about 0.4), a small fraction of the temperature R^2

Table 6. Fort McMurray-MAPS correlation summary showing fraction of variance explained by regression (R^2).

Station	Daily Maximum Temperature	Daily Minimum Temperature	Daily Mean Temperature	Daily Total Precipitation	Monthly Total Precipitation
Birch Mountain	0.95	0.93	0.96	0.12	0.66
Ells	0.99	0.97	0.99	0.12	0.47
Muskeg	0.98	0.96	0.98	0.19	0.61
Thickwood	0.99	0.98	0.99	0.14	0.79
Mildred Lake	0.99	0.98	0.99	0.23	0.53
Fort Hills	0.99	0.98	0.99	0.17	0.53
Richardson	0.97	0.97	0.98	0.08	0.44
Stony Mountain	0.98	0.96	0.98	0.11	0.76
Firebag	0.98	0.98	0.99	0.11	0.51

Table 7. Daily temperature correlation summary.

Station	Maximum Temperature		Minimum Temperature		Mean Temperature	
	Slope[b]	Intercept[a]	Slope	Intercept	Slope	Intercept
Birch Mountain	0.95	-2.0	1.08	0.5	0.96	-1.0
Ells	0.98	-0.4	1.03	-1.4	1.00	-0.9
Muskeg	0.98	-1.9	0.98	0.5	0.98	-0.7
Thickwood	0.99	-0.9	0.98	0.5	0.98	-0.2
Mildred Lake	1.02	-0.2	1.01	0.5	1.01	0.2
Fort Hills	1.01	-1.0	0.99	0.6	1.00	-0.2
Richardson	1.02	-0.6	1.05	0.4	1.03	-0.2
Stony Mountain	0.96	-1.1	0.97	1.1	0.96	-0.0
Firebag	1.03	-0.7	1.03	0.2	1.03	-0.2

a °C
b dimensionless

value. This result suggested that further grouping of the data was necessary to improve the correlation. To this end, regressions were performed on monthly total precipitation. Values of R^2 for monthly total precipitation are also included in Table 6. The improvement over the daily total R^2 values is marked. Table 8 summarizes precipitation correlation statistics. Note that only two stations have correlation coefficients less than 0.7. Indeed, the correlations may be conservative for the following reason. Months were rejected from the SAS analysis if more than seven days were missing. However, if no records existed for certain days of a month, for example the first days of the first month of operations, and if the number of days missing was less than the cut-off value, then that month was included by SAS in the analysis. In addition, some months with missing days had unusually low precipitation totals, possibly indicative of missing precipitation events. These months were subjectively withdrawn from the regression analysis if their total precipitation was much less than at Fort McMurray or if it was much less than the same months of other years.

Monthly precipitation regression parameters (Table 8) were examined for evidence of spatial variability. Thickwood, the station nearest to Fort McMurray, had the highest correlation and averaged about 10% more precipitation annually. Stony Mountain and Birch Mountain, which represent the greatest differences in elevation from Fort McMurray, had the next highest correlation. Overall, no relation between regression parameters and elevation or distance from Fort McMurray could be discerned.

The seasonal variability of monthly total precipitation regression parameters was examined for the Thickwood station. The results are shown in Table 9. Spring precipitation at Thickwood was essentially independent of precipitation at Fort McMurray (R^2 near zero). Thickwood was observed to be somewhat atypical of MAPS stations in that its summer correlation coefficient was very high. It is expected that summer and spring correlation coefficients should be smaller than during autumn and winter because of the convective component of summer precipitation. The fact that spring coefficients

Table 8. Precipitation correlation summary.

	Daily Total			Monthly Total		
Station	Slope[a]	Intercept[b]	R[a]	Slope	Intercept	R
Birch Mountain	5.3	-0.2	0.35	1.06	1.1	0.81
Ells	4.3	-0.2	0.35	0.64	9.5	0.69
Muskeg	3.8	-0.1	0.44	0.70	8.1	0.78
Thickwood	5.3	-0.2	0.37	1.10	0.1	0.89
Mildred Lake	4.3	-0.1	0.48	0.88	7.1	0.73
Fort Hills	3.6	-0.1	0.41	0.73	7.2	0.73
Richardson	6.7	-0.3	0.28	0.44	15.9	0.66
Stony Mountain	5.3	-0.2	0.33	0.98	3.7	0.87
Firebag	4.8	-0.2	0.33	0.57	14.0	0.71

[a] dimensionless
[b] millimetres

Table 9. Seasonal variation of monthly total precipitation regression parameters at Thickwood, 1976-1981.

	Season[a]			
Parameter	Winter	Spring	Summer	Autumn
Correlation coeff. (R)	0.91	-0.13	0.97	0.93
R^2	0.82	0.02	0.94	0.87
Slope	1.15	-0.18	1.14	1.53
Intercept (mm)	2.4	32.8	-16.5	-13.0
Number of Months	9	7	5	8

[a] Winter = December + January + February
Spring = March + April + May
Summer = June + July + August
Autumn = September + October + November

were much different than summer coefficients is therefore likely due to the small sample size.

Thirty-year July normal temperatures and total precipitation values at MAPS stations were calculated using the regression parameters in Tables 7 and 8. The results are shown in Table 10 together with comparisons of 30-year normals at adjacent forestry stations. The MAPS 30-year normals of both temperature and precipitation show anticipated variations with terrain. Maximum temperatures are lower, minimum temperatures are higher, and precipitation is greater at stations with higher elevations. The tendency is for July MAPS temperature and precipitation, based on an annual regression equation, to be underpredicted compared to forestry station values. However, the difference between MAPS and forestry station normals has no apparent relation to terrain. Moreover, the MAPS values are within one standard deviation (see next sections) of the forestry values.

The question might arise of whether it is appropriate to compute July normals using regression parameters based on values measured throughout the year. This in itself might be expected to produce differences between the MAPS and forestry station values. The answer lies in the seasonal correlation coefficients in Table 9. As previously suggested, large differences among seasons are likely due to the small number of months comprising each season. A further reduction in numbers, required for the generation of monthly regression parameters, would be expected to create even larger differences. Thirty- year normals based on as few as one value (July at Stoney Mountain) have little merit regardless of the value of the correlation coefficient.

In summary, a linear regression of Fort McMurray against MAPS station temperature and precipitation was performed. Fort McMurray and all MAPS stations' minimum, maximum, and mean daily temperatures were found to be well correlated. Daily precipitation values were poorly correlated; however, correlations for total monthly precipitation were better. Most stations had monthly precipitation correlation coefficient values above 0.7. The correlation statistics were used to generate 30-year normal July values for the MAPS network. These values showed expected variations with terrain. However, the differences between MAPS and adjacent forestry values did not vary consistently with terrain, suggesting an insufficient length of record was used to generate the regression parameters.

Table 10. Thirty-year normal July MAPS temperature and precipitation from Fort McMurray correlation (temperature in degrees Celcius; precipitation in millimetres). Differences are forestry station values minus adjacent MAPS values.

Station	Maximum Temperature	Difference Maximum	Minimum Temperature	Difference Minimum	Mean Temperature	Difference Mean	Total Precipitation	Difference Total
Birch Mountain	20.0	-1.2	10.8	-1.3	14.8	-0.6	80.9	21.6
Ells	22.3	-0.6	8.4	0.8	15.5	0	57.8	15.1
Muskeg	20.8	0	9.8	-0.1	15.7	-0.4	60.9	26.4
Thickwood	22.0	-0.5	9.8	-0.6	15.9	-0.5	83.0	11.9
Mildred Lake	23.4		10.1		16.8		73.5	
Fort Hills	22.3	-0.7	10.0	-0.3	16.2	-0.5	62.2	15.5
Richardson	23.0	0.1	10.4	0.8	16.7	0.5	49.1	20.6
Stony Mountain	21.2	-1.2	10.3	-0.3	15.7	-0.7	77.6	29.2
Firebag	23.1		10.0		16.7		57.0	
Fort McMurray	23.1		9.5		16.4		75.4	

4. TEMPERATURE

Values of temperature from stations in the MAPS network and from forestry stations in the area were analysed to clarify local spatial and temporal trends. These are examined in the following sections. Section 4.1 presents hourly temperatures from a selected MAPS station. Sections 4.2 and 4.3 examine spatial and temporal variations of daily temperatures for both forestry and MAPS networks. Finally, Sections 4.4 and 4.5 present a brief analysis of frost-free periods in the area.

4.1 HOURLY TEMPERATURES

Ogives (cumulative frequency distributions) of hourly temperature were calculated for all stations within the MAPS network. The ogives were generated for the months January, April, July, and October, and one for all months during the year. All available hourly data from 1976 to 1981 were used. The ogives of hourly temperature were produced before the SAS check for the number of missing hours in each day of record. Thus, there may be some discrepancies among the hourly, daily, and monthly temperature statistics.

On the basis of the temperature correlation analysis presented in Section 3, Mildred Lake was chosen as a typical MAPS station. Its hourly ogives were plotted and are presented in Figure 2. Temperature values at selected percentiles are summarized in Table 11. Of the months examined, April had the greatest range in temperatures (60°C); July had the least (31°C). The annual temperature range was 77°C. Median temperatures at Mildred Lake ranged from -18°C in January to 16°C in July. The median annual temperature was 3°C.

4.2 DAILY TEMPERATURES FOR FORESTRY STATIONS

Daily minimum and maximum temperature values were generally available during the months of June, July, and August for the 13- or 14-year period ending in 1979 for the forestry stations listed in Table 3 and plotted in Figure 1. Two exceptions were the Carlson station, where only four years of data existed, and Fort McMurray, where only four years of data were analysed. From these data, SAS was

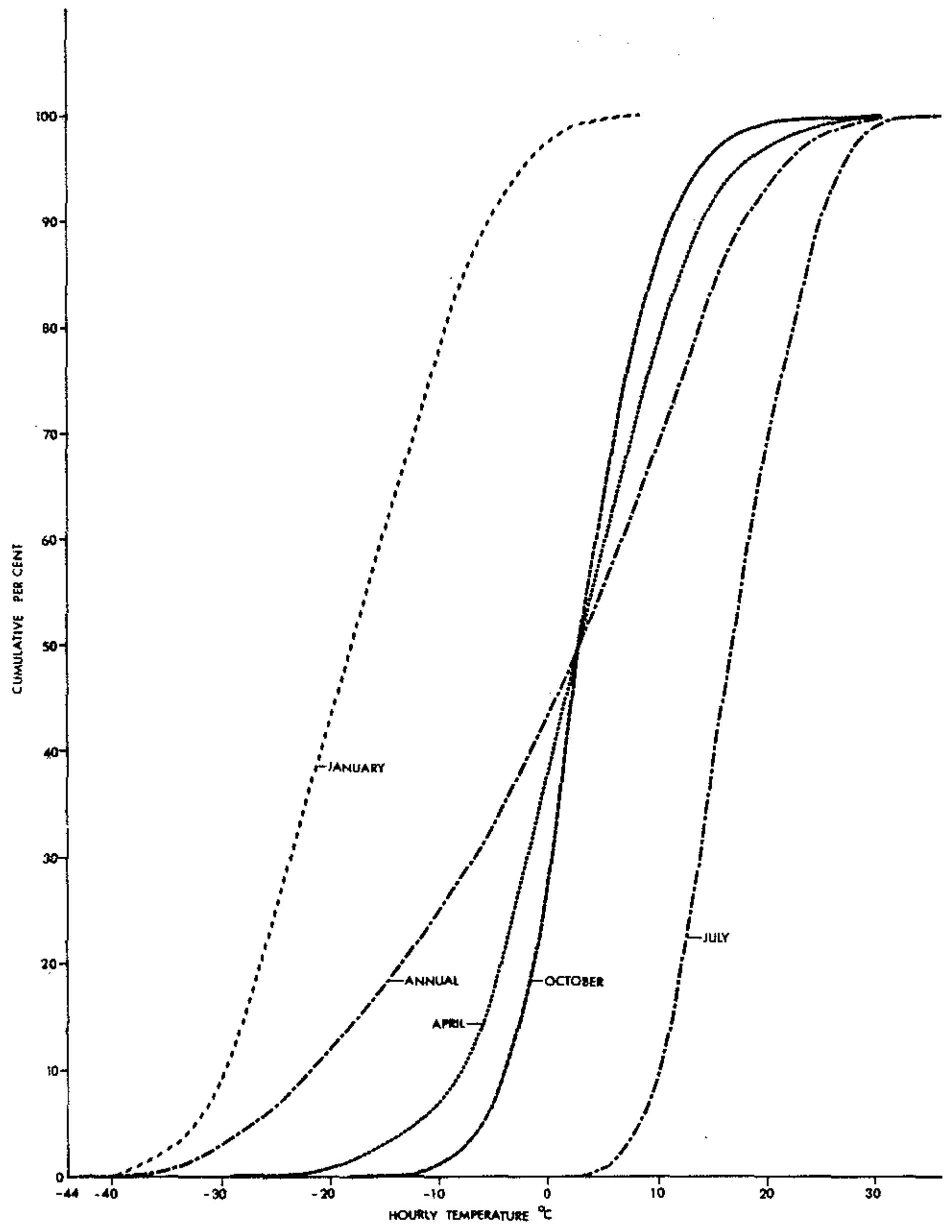

Figure 2. Ogives of hourly temperatures (°C) at Mildred Lake for selected months, 1976-1981.

Table 11. Hourly temperatures at selected percentile levels at Mildred Lake, 1976-1981 (temperatures to nearest Celsius degree).

Period	Percentile Level				
	0	10	50	90	100
January	-40	-30	-18	- 5	8
April	-29	- 8	2	14	31
July	3	10	16	25	34
October	-18	- 4	3	11	28
Annual	-43	-22	3	18	34

to calculate various average values for intercomparison. For the purposes of this section, "average" may be taken as the average over all years in the record of the mean of all daily values for a given month. Table 12 displays the codes for the various stations along with the number of years of record, the average mean July temperature, the average maximum July temperature, the average minimum July temperature, and the standard deviations about each average. The last column shows the average July diurnal temperature variations. The standard deviations of temperature are generally near 1.4°C, with the exception of the Fort McMurray (MM) and Keane (KN) stations where the values are near 1.9°C. These data have been used to generate Figures 3, 5, 7, and 9. For comparison, 30-year normals of the July mean, maximum, and minimum daily temperatures are listed in Table 13. These values were obtained from Environment Canada (1982) and are plotted in Figures 4, 6, and 8.

Figures 3 and 4 both show a strong negative correlation between mean July temperatures and elevation. The lowest values occur in the Birch Mountains, and the highest ones in the Lake Athabasca region. Secondary lows exist in the high ground east and south of Fort McMurray. Values are not consistently high in the Athabasca River valley, but rather achieve a saddlepoint in the Fort McMurray-Mildred Lake area. In Figure 4, a relatively strong temperature gradient exists between the Thickwood (TW) and Fort McMurray stations, leading to an anomaly in the above-mentioned pattern. The likely cause for this anomaly is its relatively high elevation.

Figures 5 and 6 display the spatial variation of the average maximum July temperatures. The range of values evident in these maps is somewhat greater than for the average mean temperatures, but the patterns are very similar. Once again, Fort McMurray shows an unusually high value as compared to the nearby Thickwood station.

The average minimum July temperatures in the Fort McMurray study area show a much smaller variation over the map area of Figures 7 and 8 than do the maximum temperatures. A negative correlation between these values and elevation does appear to exist, but it is much weaker than for Figures 5 and 6. For example, the hills south of

Table 12. Average July temperatures (°C) at forestry stations, 1966-1979.

Forestry Code	Years of Record	Mean Daily Average	Mean Daily St. Dev.	Maximum Daily Average	Maximum Daily St. Dev.	Minimum Daily Average	Minimum Daily St. Dev.	Diurnal Temperature Variation Average
LA	11	14.9	1.4	22.6	1.7	7.1	1.4	15.5
CI	4	16.8	1.3	22.9	1.3	10.7	1.5	12.1
KN	14	16.5	1.9	22.0	1.8	10.9	2.0	11.1
PA	14	15.1	1.4	20.5	1.6	9.6	1.4	10.9
JE	14	14.3	1.4	19.4	1.6	9.1	1.3	10.2
ED	13	13.8	1.5	18.8	1.7	8.8	1.4	10.0
LG	14	13.7	1.5	18.7	1.6	8.7	1.3	10.0
EL	13	15.2	1.2	21.1	1.2	9.3	1.3	11.9
BN	13	13.2	1.4	18.0	1.5	8.4	1.4	9.7
BI	14	14.0	1.5	18.4	1.5	9.5	1.5	8.8
BM	13	16.0	1.4	22.2	1.7	9.9	1.3	12.4
RI	14	16.9	1.5	22.6	1.6	11.2	1.4	11.4
MU	14	15.0	1.3	20.4	1.4	9.7	1.3	10.6
JO	14	15.3	1.4	20.5	1.6	10.1	1.3	10.4
CY	12	15.4	1.4	21.0	1.5	9.8	1.3	11.1
GE	14	15.3	1.2	21.6	1.4	8.9	1.1	12.6
AL	13	14.4	1.2	19.5	1.3	9.3	1.1	10.3
TW	14	15.2	1.2	21.1	1.3	9.3	1.3	11.7
MM	4	16.4	1.8	22.8	2.0	9.9	1.8	13.0
ST	13	14.6	1.0	19.3	1.0	9.9	1.1	9.4
GL	14	15.7	1.3	21.6	1.2	9.8	1.3	11.7
MY	14	14.7	1.3	19.5	1.4	9.9	1.3	9.6
CR	14	15.2	1.3	20.7	1.4	9.7	1.3	11.0
CK	14	15.4	1.3	20.8	1.3	10.0	1.3	10.7
CP	13	15.6	1.3	21.1	1.4	10.1	1.4	11.0

Table 13. Thirty-year normal July temperatures (°C) at forestry stations (from Environment Canada 1982).

Forestry Code	Mean Daily		Maximum Daily	Minimum Daily
	Average	St. Dev.	Average	Average
LA				
CI				
KN	16.8	1.9	22.5	11.0
PA	15.1	1.4	20.8	9.4
JE	14.4	1.4	19.7	9.1
ED	13.8	1.5	19.0	8.6
LG	13.9	1.5	19.1	8.6
EL	15.5	1.3	21.7	9.2
BN	13.6	1.4	18.6	8.6
BI	14.2	1.4	18.8	9.5
BM	16.3	1.4	22.7	9.8
RI	17.2	1.5	23.1	11.2
MU	15.3	1.3	20.8	9.7
JO	15.4	1.3	20.8	10.0
WB	16.4	1.2	22.0	10.9
CY	15.3	1.3	21.0	9.5
GE	15.4	1.2	22.0	8.8
AL	14.7	1.1	20.1	9.3
TW	15.4	1.2	21.5	9.2
MM	16.4	1.0	23.1	9.5
ST	15.0	1.1	20.0	10.0
GL	16.0	1.3	22.1	9.8
MY	15.1	1.4	19.9	10.1
CR	15.5	1.3	21.2	9.8
CK	15.7	1.3	21.2	10.2
CP	15.8	1.3	21.6	10.0
PY	16.0	1.4	22.4	9.7

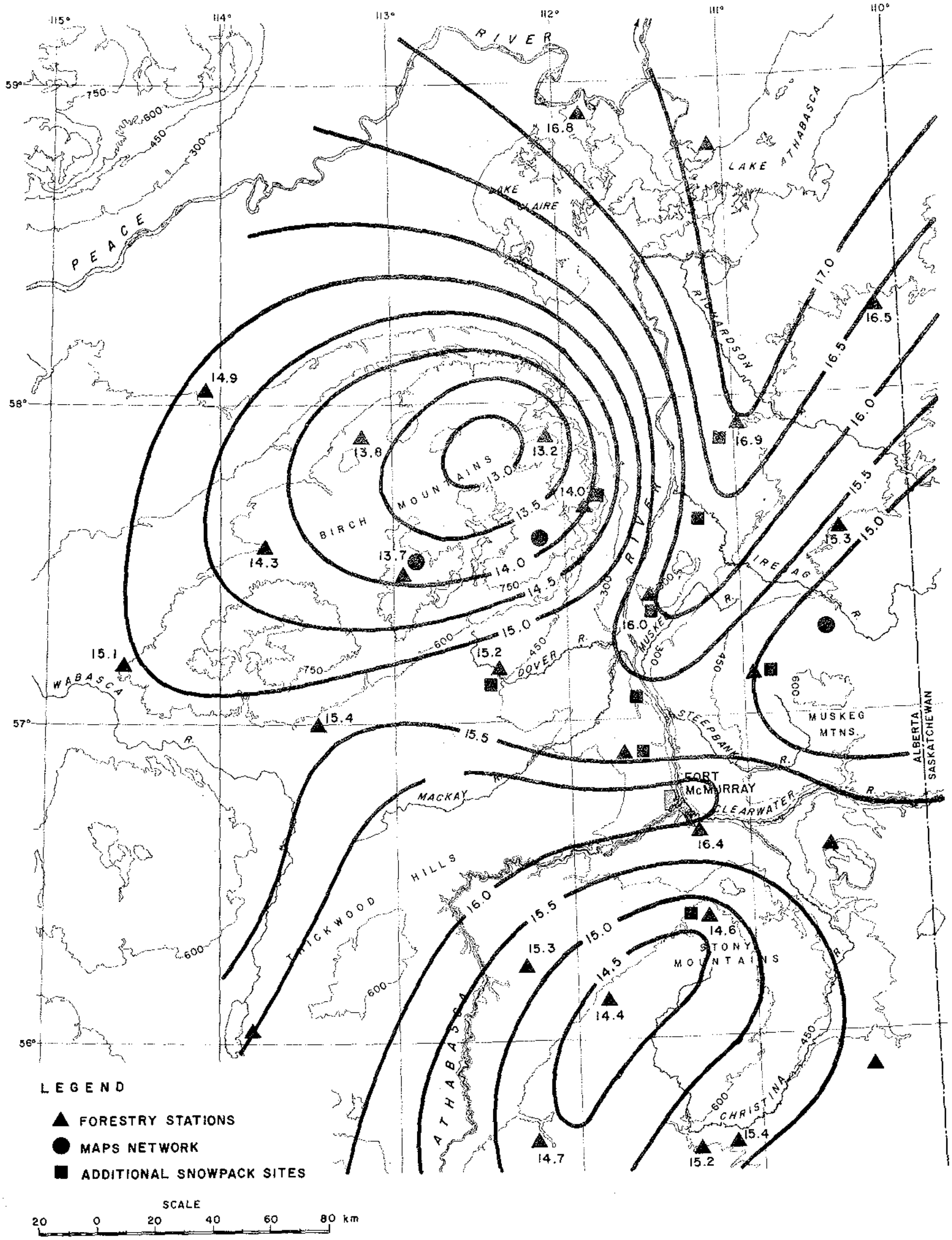

Figure 3. Average mean July temperatures (°C) at forestry stations, 1966-1979.

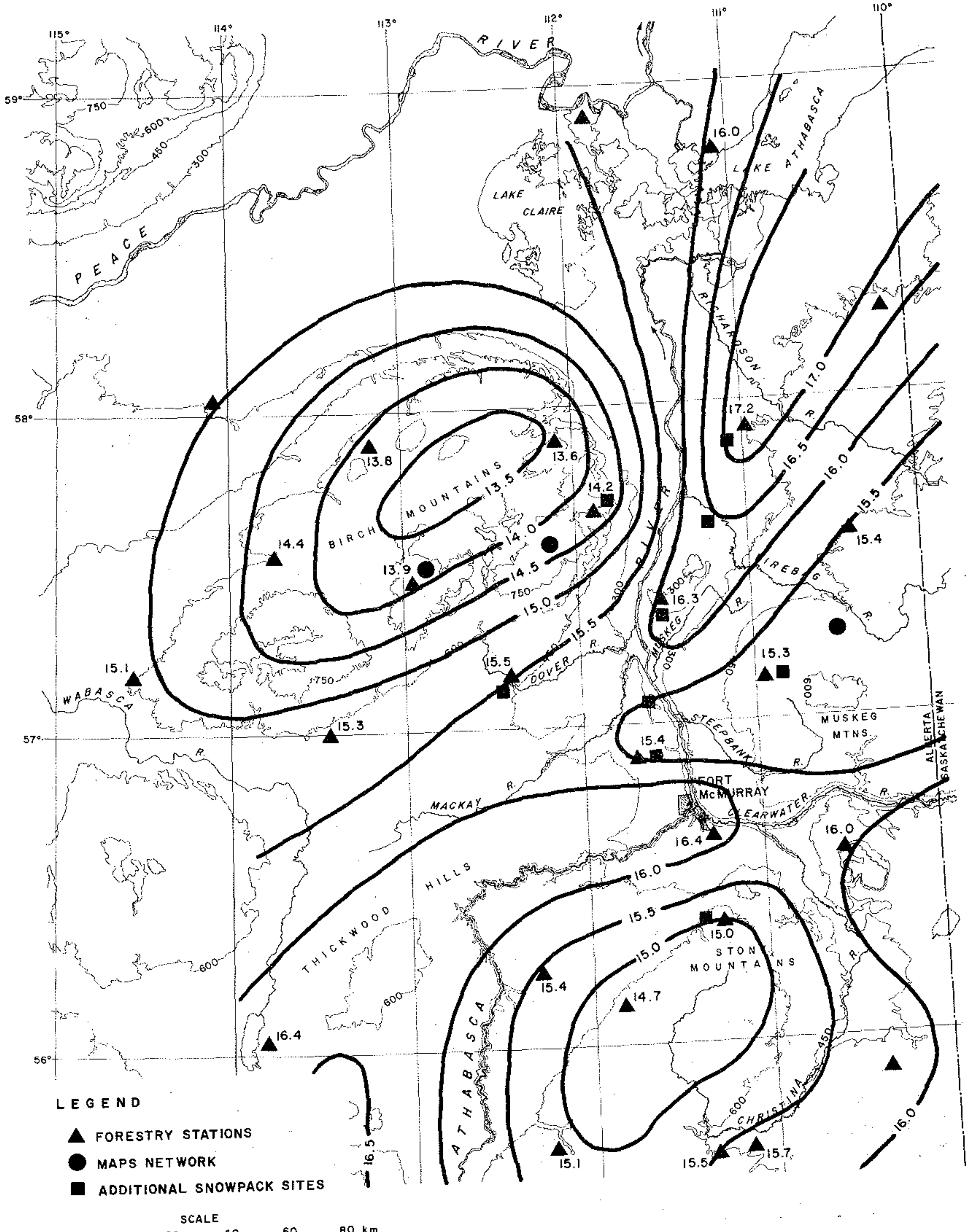

Figure 4. Thirty-year normal mean July temperatures (°C) at forestry stations.

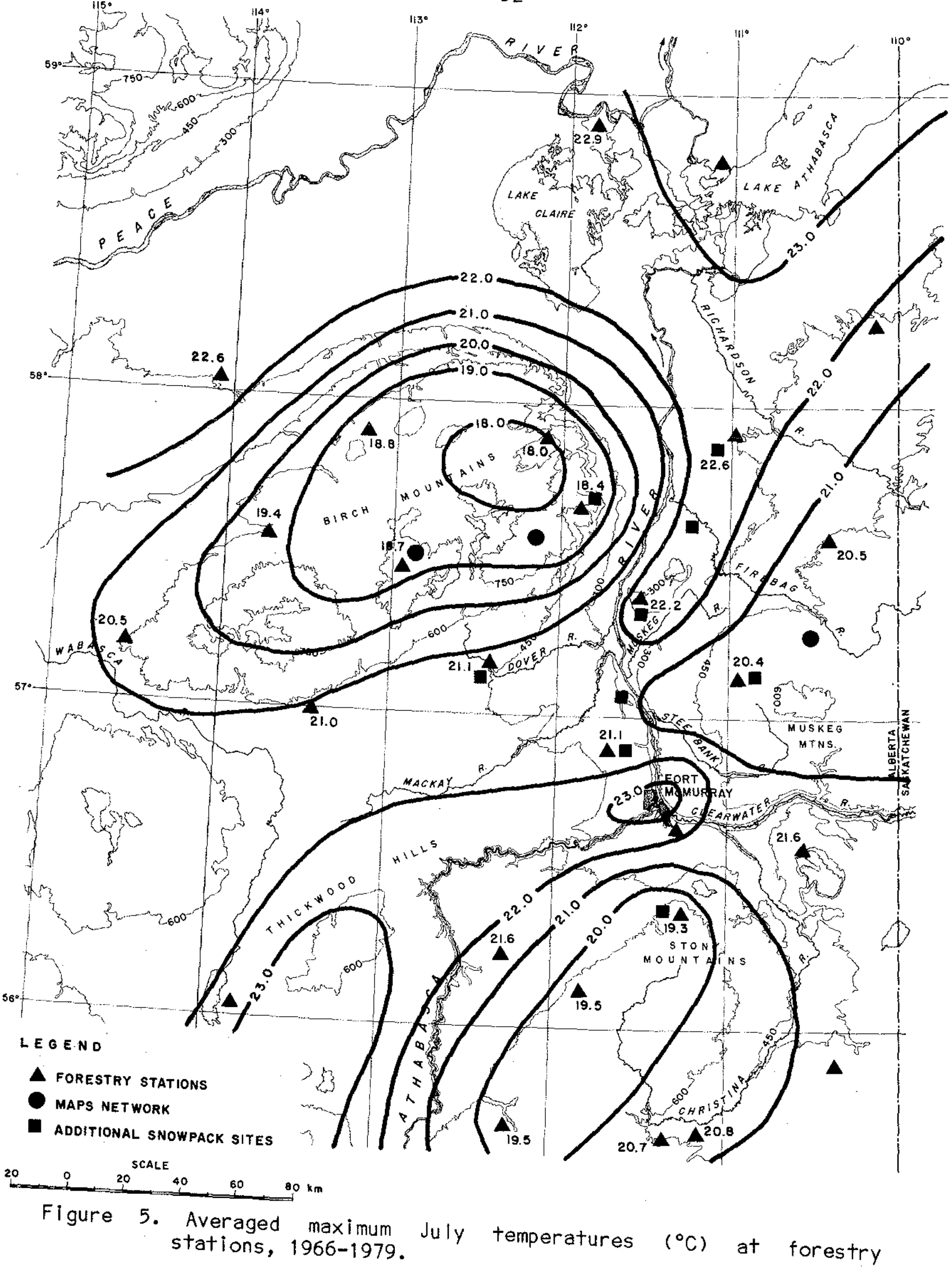

Figure 5. Averaged maximum July temperatures (°C) at forestry stations, 1966-1979.

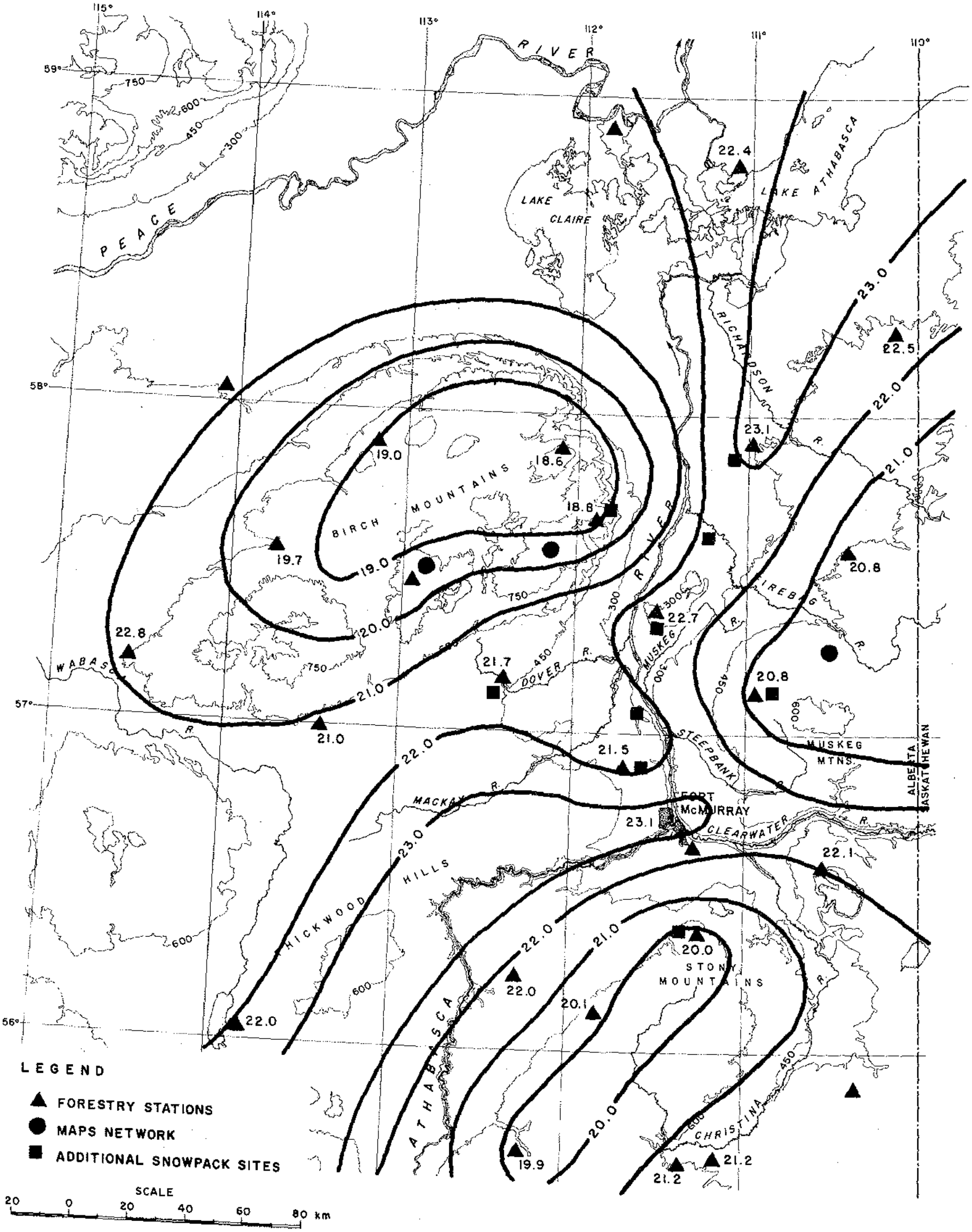

Figure 6. Thirty-year normal maximum July temperatures (°C) at forestry stations.

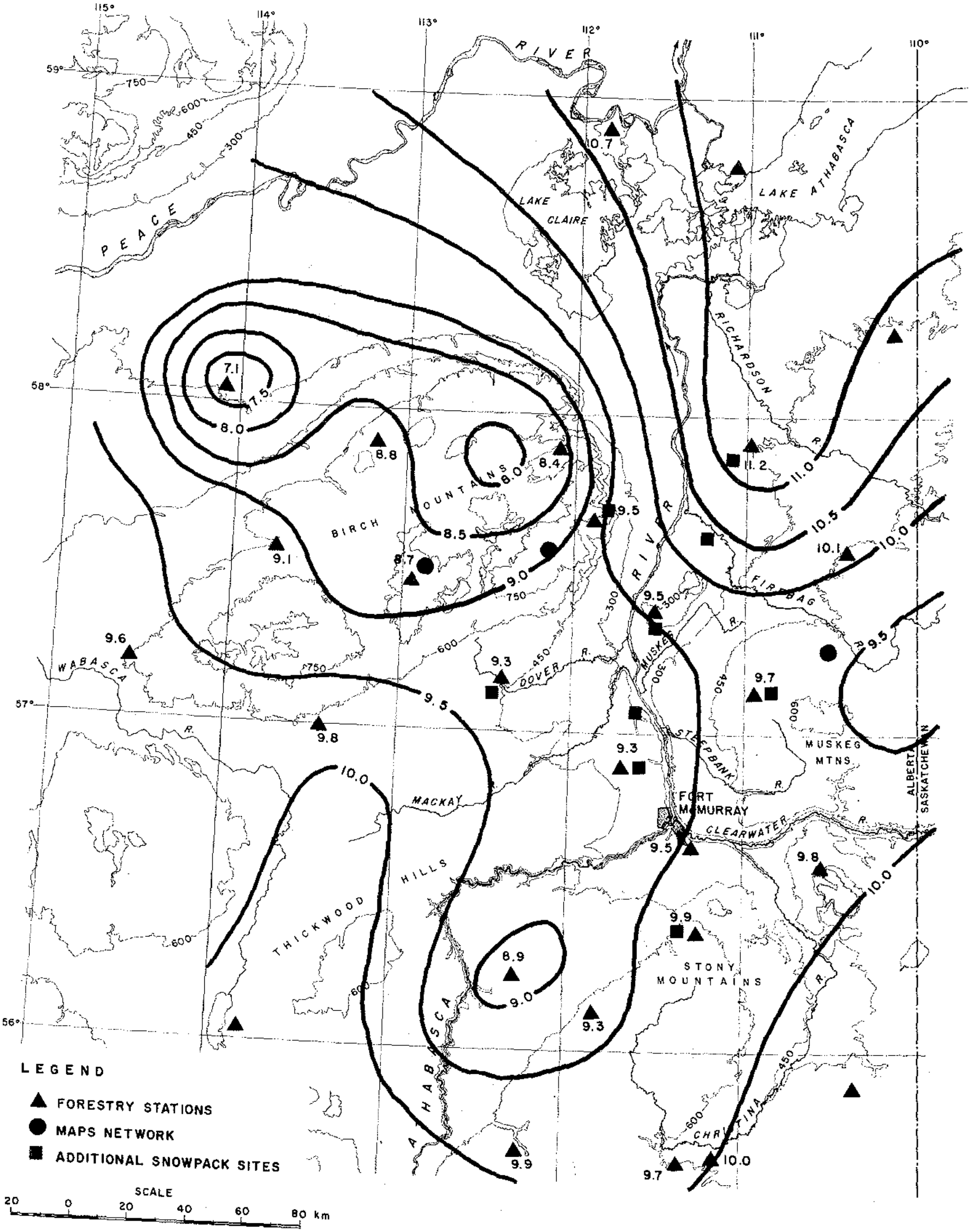

Figure 7. Average minimum July temperatures (°C) at forestry stations, 1966-1979.

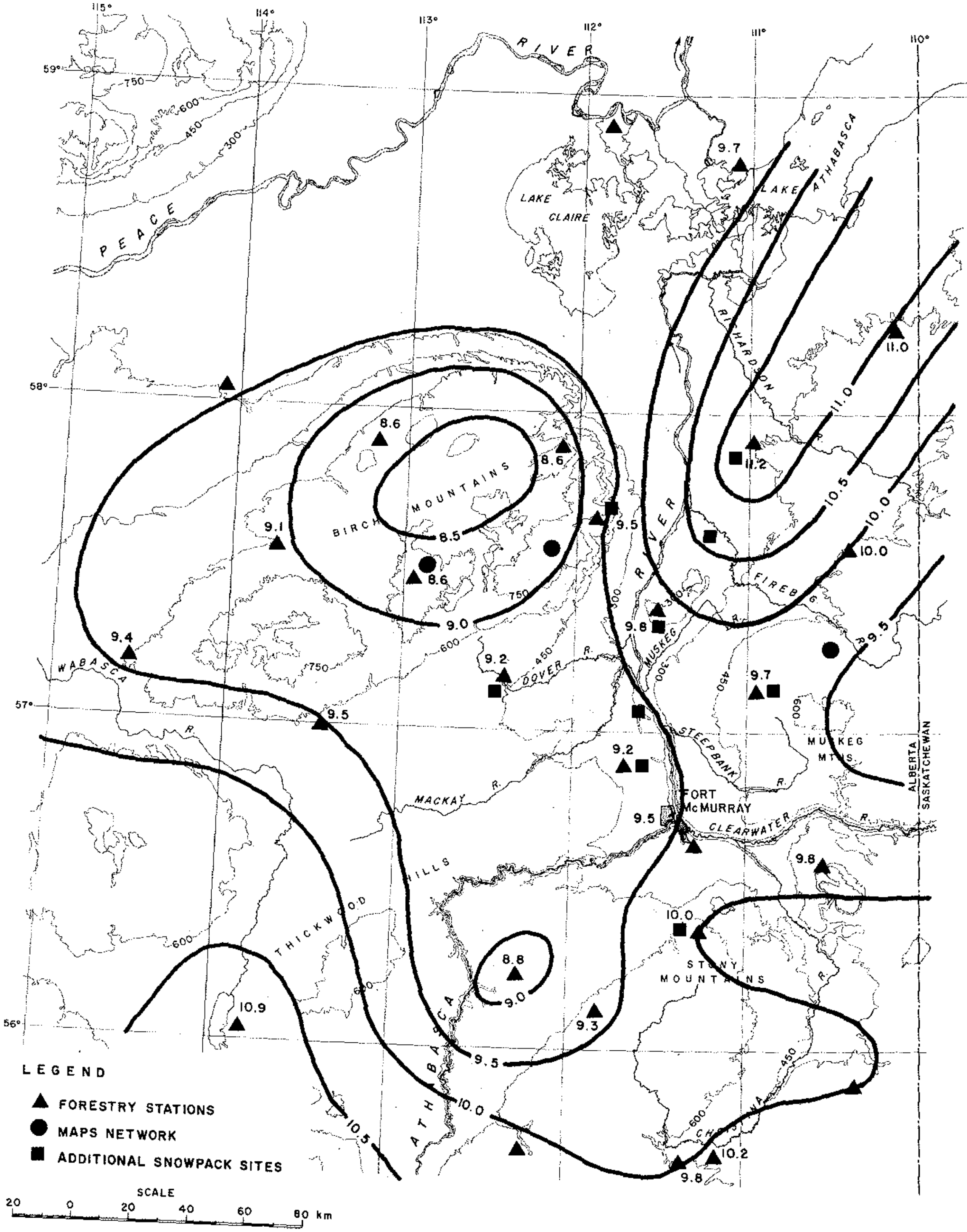

Figure 8. Thirty-year normal minimum July temperatures (°C) at forestry stations.

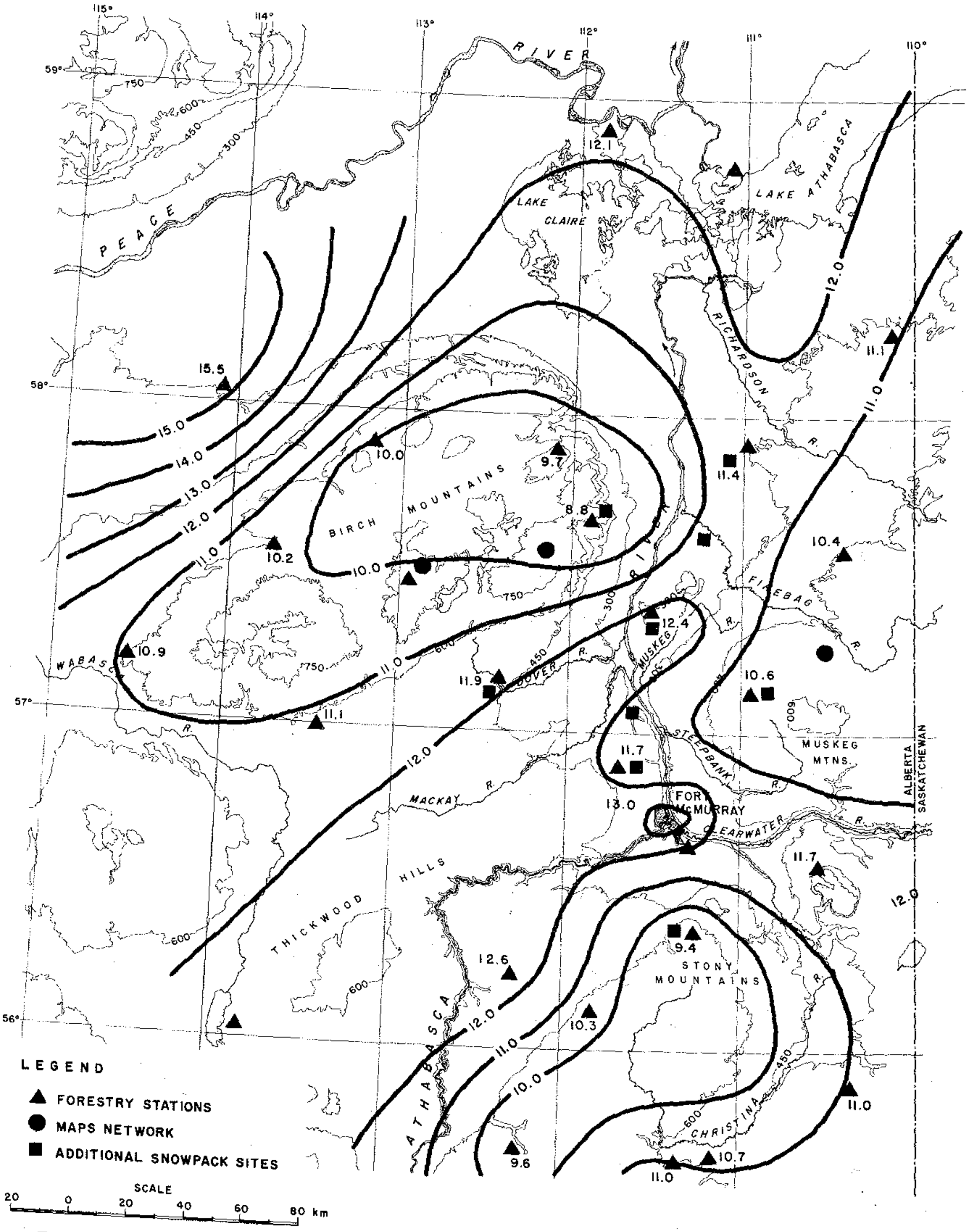

Figure 9. Average July diurnal temperature (°C) variation at forestry stations, 1966-1979.

Fort McMurray seem to have little effect upon the pattern. The lowest minima occur in the Birch Mountains, with a secondary minimum at the Grande (GE) station. A strong temperature depression at the Lambert Creek (LA) station does not appear to follow the general trend and may be an anomalous value. The agreement between the Thickwood and Fort McMurray stations is much better here than for mean or maximum temperatures.

The average July diurnal temperature variation (Figure 9) shows minima at higher elevations and maxima in the river valleys. Two unusually high values exist, one at Fort McMurray and one at Lambert Creek. The first is due to the high maximum temperature and the second to low minimum temperatures.

4.3 DAILY TEMPERATURES FOR THE MAPS STATIONS

Tables 14 through 17 display the average mean, maximum, minimum, and diurnal temperature variations for the MAPS stations during the months of January, April, July, and October, respectively. While the MAPS stations are more densely located than the forestry stations, and also provide hourly records rather than daily ones, their period of record is much shorter. At most, four years of data are available for the MAPS stations. As a result, when attempts are made to compare MAPS temperature records to those from the forestry stations, the differing record lengths could cause significant problems. In fact, even spatial variations within the limited area of the MAPS network are so great and apparently random that contouring of these values was not attempted. Evidence of these problems exists in Tables 14 through 17. In Table 14, for example, standard deviations about the average values vary by more than one order of magnitude. The average July mean temperatures in Table 16 do not agree well with the values obtained at the same locations by the forestry stations in Table 12. This again reflects the difference in record length of the two data sets. Differences of greater than 1°C may be noted in either a positive or negative sense. In addition, Table 14 illustrates the instability of mean values when short periods of record are used. Stations with four years of data have a much higher standard deviation

Table 14. Average January temperatures (°C) at MAPS stations, 1976-1981.

MAPS Code	Years of Record	Mean Daily		Maximum Daily		Minimum Daily		Diurnal Temperature Variation
		Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average
ELS	3	-21.1	0.8	-14.8	1.0	-27.3	0.4	12.5
BCH	3	-18.2	0.3	-14.1	0.2	-22.4	0.3	8.0
LKM	4	-17.1	5.7	-13.0	5.2	-21.3	6.1	8.8
HLS	4	-16.1	5.8	-12.2	5.7	-19.9	6.2	7.7
FBG	3	-19.2	3.1	-14.9	3.4	-24.0	3.0	9.1
RIC	3	-20.4	0.7	-15.6	1.1	-25.6	0.5	10.3
MKG	3	-20.4	0.6	-16.9	0.6	-23.8	0.2	6.9
TKW	4	-16.6	6.0	-12.8	5.9	-20.6	6.1	7.9
SMT	4	-15.0	6.3	-15.5	6.2	-18.7	6.2	7.3

Table 15. Average April temperatures (°C) at MAPS stations, 1976-1981.

MAPS Code	Years of Record	Mean Daily		Maximum Daily		Minimum Daily		Diurnal Temperature Variation
		Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average
ELS	3	2.1	4.9	8.4	6.1	-5.1	3.8	13.3
BCH	3	0.3	5.9	4.8	6.5	-4.2	5.1	9.1
LKM	3	0.7	2.5	6.2	2.8	-4.9	2.1	13.1
HLS	4	1.2	3.6	6.6	4.5	-4.4	2.6	11.0
FBG	2	-0.4	3.3	5.1	4.2	1.8	8.6	11.5
RIC	4	3.0	4.6	9.3	5.5	-3.5	3.8	12.8
MKG	4	2.3	5.2	7.4	6.0	-3.1	4.2	10.5
TKW	4	1.5	4.7	7.1	5.7	-4.2	3.8	11.4
SMT	3	-1.2	2.0	3.1	2.3	-5.6	1.5	9.2

Table 16. Average July temperatures (°C) at MAPS stations, 1976-1981.

MAPS Code	Years of Record	Mean Daily		Maximum Daily		Minimum Daily		Diurnal Temperature Variation
		Average	St. Dev.	Average	St. Dev.	Average	St. Dev.	Average
ELS	3	15.0	1.9	21.6	2.3	7.3	1.5	14.4
BCH	1	12.7	-	16.7	-	8.1	-	8.6
LKM	4	17.3	1.7	24.0	2.0	10.5	1.6	13.4
HLS	4	16.3	1.7	21.8	2.0	10.4	1.4	10.4
FBG	3	16.7	2.2	23.0	2.6	9.6	1.5	13.4
RIC	2	15.7	0.1	21.2	0.1	9.4	0.1	12.1
MKG	2	15.8	2.9	20.3	3.1	10.9	2.4	9.4
TKW	3	16.0	1.6	21.8	1.7	10.1	1.7	11.7
SMT	3	15.7	1.7	20.4	1.5	10.9	2.1	9.5

Table 17. Average October temperatures (°C) at MAPS stations, 1976-1981.

MAPS Code	Years of Record	Mean Daily Average	Mean Daily St. Dev.	Maximum Daily Average	Maximum Daily St. Dev.	Minimum Daily Average	Minimum Daily St. Dev.	Diurnal Temperature Variation Average
ELS	2	3.4	0.4	9.2	0.9	-2.0	0.1	11.3
BCH	4	2.1	1.2	6.0	1.8	-1.3	1.0	6.5
LKM	5	3.5	2.1	8.2	2.5	-1.1	2.1	10.9
HLS	5	3.4	1.7	8.0	2.1	-0.7	1.6	8.8
FBG	4	3.9	0.4	8.4	0.7	-0.5	0.5	8.9
RIC	3	4.1	0.3	8.4	1.0	0.0	0.3	8.7
MKG	3	2.9	0.3	6.8	0.6	-0.8	0.3	7.8
TKW	5	3.4	2.0	8.1	2.5	-1.1	1.8	9.2
SMT	5	3.1	3.0	7.0	3.1	-0.6	3.2	7.6

than stations with three years of data. This is the result of a single warm month (January 1981).

Attempts to compare MAPS stations temperatures with temperatures from adjacent forestry stations using a common period of record were considered. However, since only summer temperatures were available at forestry stations, the comparison was not undertaken because the results could not be extended to other seasons.

4.4 ESTIMATION OF THE FROST-FREE PERIOD FROM FORESTRY STATION DATA

For this study, a frost event was defined as a temperature below 0°C for at least one hour. Table 18 shows the available data from the forestry stations during the period 1966 through 1979 from which to compute the frost-free period for each station. In this table, zeros indicate years where both a last spring and first fall frost were recorded; minus signs indicate only last spring frost was recorded; plus signs indicate only first fall frost was recorded; and blanks indicate all summer temperatures were above freezing. The large number of blanks in this table indicates that the period of above-freezing temperatures in this region must be longer than the operating period of most of the forestry stations, that is about 120 days. In some years (1967 to 1969), unusually late spring frosts were noted. In others (1974), unusually early fall frosts were recorded. The shortest mean frost-free periods were recorded by low-lying stations such as Fort McMurray and Lambert Creek (LA). Because most stations did not have a sufficient length of season to record both last spring and first fall frosts, no attempt was made to examine spatial variation in greater detail.

4.5 ESTIMATION OF THE FROST-FREE PERIOD FROM MAPS DATA

Despite the limited number of years of data available, the MAPS stations were expected to provide much more reliable estimates of the spatial variability of frost-free data than the forestry stations because data were collected year-round at the MAPS sites. Unfortunately, the relatively short record period of even the longest running

Table 18. The last spring frost, first fall frost, and frost-free period data recorded at the forestry stations, 1966-1979 ("0" indicates both a last spring and a first fall frost recorded; "-" indicates only last spring frost recorded; "+" indicates only first fall frost recorded; "M" indicates no data).

Forestry Code	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
LA	M	M	M	0	0	0	0		0	+	0	0	0	0
CI	M		-	-										
PY														
KN		-	-	-			-							
PA		-	0	-								+		
JE	0	-	-	-				+				0		-
ED	-	-	0	-				+	0	+		-	0	0
LG	0	-	0	-				+	+		-	0	0	-
EL		-	0	-					+					
BN	0	-	0	-	-	+		+	+			-	-	-
BI	M	-	-	-					+			0		0
BM		-	+	-		+			+					+
RI				-										
MU		-	-	-					+			+		
JO		-	-	-	+				+					+
WB														
CY		-		-								+		
GE		-	0	-		+			+			+	+	
AL	-	-	-	-					+			+		
TW	M	-	0	0	+	+			0				+	-
MM	M	M	M	M	M	M	M	M	M	M	0	0	0	0
ST		-	-	-					+			-	-	
GL									+				+	
MY	-	-	-	-				+				-		
CR	M	-	-	-										
CK	-	-	-	-										
CP		-	-	-										

MAPS stations has been even further degraded for some stations by either their relatively late deployment (Stony Mountain), or their early shut-downs (Ells, Birch Mountain, Firebag, and Richardson). Table 19 indicates the MAPS stations from which the frost-free periods could be calculated. In this analysis only data from 1977, 1978 and 1979 were used. The data for these three years have been combined in Table 20 to produce an average frost-free period for each station. Large variations in last spring and first fall frosts preclude inclusion of limited data from other years for only a selected number of stations. The large differences in the periods cannot be explained by topographic variations. The variation in the frost-free periods estimated by the MAPS stations is so great that a map of these values was not plotted. Clearly, more years of data are required to stabilize the mean values.

Table 19. Years with available frost-free period data at MAPS stations, 1976-1981.

MAPS Code	1977	1978	1979	1980	1981
ELS	X	X	X		
BCH	X	X	X		
LKM	X	X	X	X	X
HLS	X	X	X	X	
FBG	X	X	X		
RIC	X	X	X		
MKG	X	X	X		
TKW	X	X	X	X	X
SMT		X	X	X	X

Table 20. Frost-free period at the MAPS stations for selected years (period in days).

MAPS Code	1977	1978	1979	Mean
ELS	60	42	67	56
BCH	182	131	120	144
LKM	177	170	143	163
HLS	158	135	127	140
FBG	94	99	64	86
RIC	139	134	114	129
MKG	160	131	120	137
TKW	184	135	126	148
SMT	-	145	105	125

5. PRECIPITATION

Precipitation values from stations in the MAPS network and from forestry stations in the area were analysed to determine local spatial and temporal trends. These are examined in the following sections. Section 5.1 presents ogives of hourly precipitation at a selected station and examines short duration precipitation events. Sections 5.2 and 5.3 present an analysis of daily precipitation totals for both the MAPS and forestry network, including consecutive days with precipitation. Finally, Section 5.4 examines snowpack data collected in the area.

5.1 HOURLY PRECIPITATION

Ogives of hourly precipitation were calculated for all stations within the MAPS network for the months January, April, July, and October. An ogive representing the entire year was also calculated. All available hourly data from 1976 to 1981 inclusive were used in the analysis. Thus, ogives were produced prior to the check for number of missing hours each day performed by SAS. Snowfall and rainfall were distinguished on the basis of hourly temperature; snowfall was assumed when the temperature was below 0°C. Discrepancies in the data may exist because different quality control checks are made for hourly, daily, and monthly records.

To give an example of the results of the SAS analysis, a typical MAPS station was chosen. Ogives of hourly precipitation at Mildred Lake (LKM) were plotted in Figure 10. Of the months examined, July had the largest average number of hours with measurable precipitation (about 4.8%, or some 36 hours) and January had the fewest number (about 1.5%, or 11 hours). The total for the year was about 200 hours (2.3%). July had the highest frequency of precipitation hours above 2 mm, followed by April and then October and January. Of the months examined, maximum hourly precipitation occurred in January and July (44 mm).

Short duration precipitation statistics (number of consecutive precipitation hours) were produced for each station in the MAPS network. Precipitation amount as a function of duration, for the

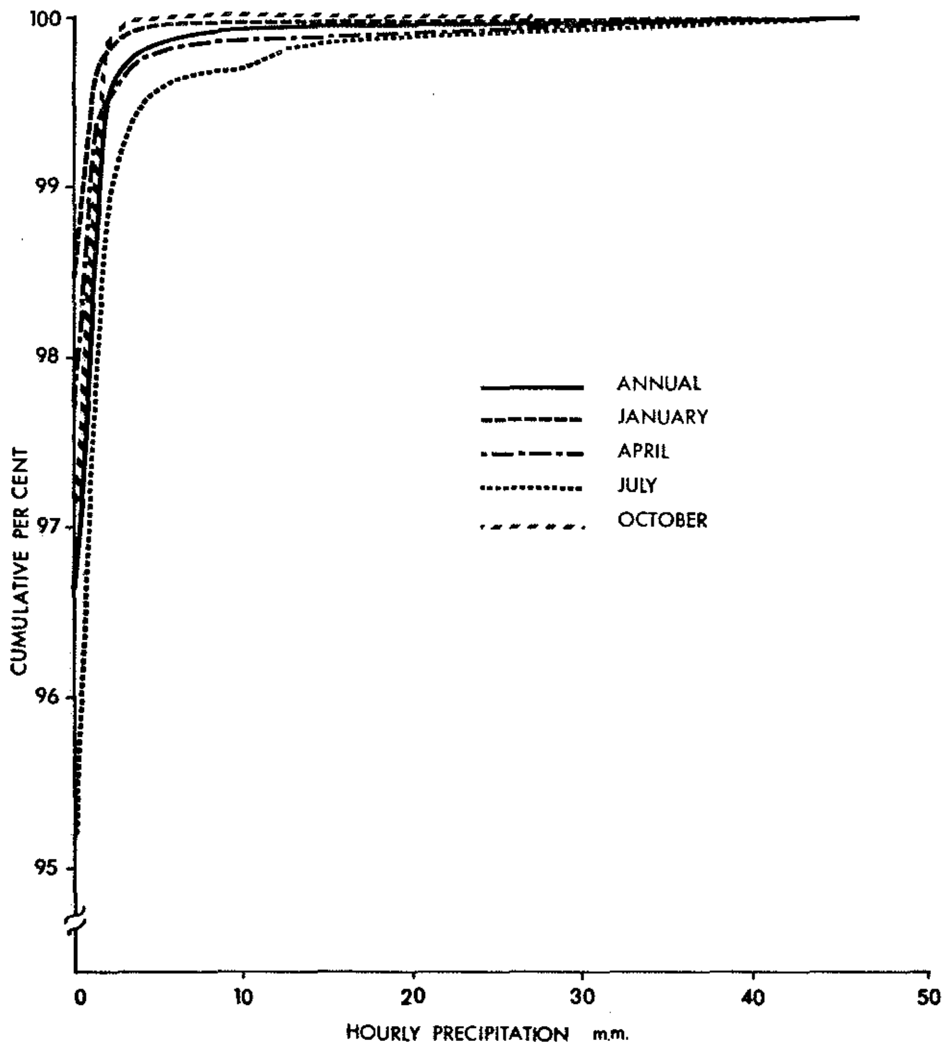

Figure 10. Ogives of hourly precipitation (mm) at Mildred Lake for selected months, 1976-1981.

entire period of station record, is presented in Section 11.2. Summaries of these statistics are shown in Tables 21 and 22. Table 21 shows the maximum number of consecutive precipitation hours and the maximum amount of precipitation occurring in consecutive hours of MAPS stations for the duration of the network. Terrain influences are apparent. Stony Mountain has both the longest duration and the largest amount recorded in consecutive hours. Birch Mountain and Thickwood have the next longest durations, while Thickwood has the next largest amount. Table 22 shows maximum one- and two-hour precipitation events during the period 1976-1981. No apparent relation exists between station location and short duration maxima.

Comparison of Table 22 with short duration rainfall density statistics at Fort McMurray based on data from 1966 to 1973 shows major differences. Table 23, abstracted from Longley and Janz (1978), presents these data. Maximum one-hour precipitation at all MAPS stations is apparently much greater than the amount based on a 25-year return period. This immediately raises questions about the validity of the MAPS hourly precipitation data. Recall that MAPS precipitation was found by subtracting the total at the preceding hour. If the preceding hour was missing, the one before it was used. This suggests one possible cause for the high hourly rates. They might actually be accumulations over two hours. Examination of the individual hourly precipitation values generated by SAS does not disprove this. Hours with values above about 30 mm invariably end or begin a series of either missing or zero precipitation days, or more often, are single precipitation events in a series of missing or zero precipitation days. However, even if high one-hour durations are actually two-hour accumulations, according to Table 23 they are still larger than 25-year return period amounts. Note also that the one-hour values are very near the 50-mm cut-off value assumed by SAS, suggesting the likely existence of even larger one-hour values.

Comparison of Table 23 with forestry station precipitation amounts and durations in Section 11.3 suggests that large one-hour precipitation totals at MAPS stations are errors. Forestry stations, during the summers of 1966 to 1979, typically have zero to two, or

Table 21. Maximum number of consecutive precipitation hours and maximum precipitation amount occurring in consecutive hours at MAPS stations, 1976-1981.

Station	Maximum Duration		Maximum Amount	
	Duration (h)	Amount (mm)	Duration (h)	Amount (mm)
Muskeg	9	26	2	48
Firebag	9	34	9	34
Stony Mountain	25	117	25	117
Birch Mountain	19	65	19	65
Richardson	11	33	2	54
Fort Hills	10	44	1	46
Thickwood	19	80	19	80
Mildred Lake	12	52	12	52
Ells	13	40	13	40

Table 22. Maximum one-hour and two-hour precipitation (mm) at MAPS stations, 1976-1981.

Station	Duration one hour	Duration two hours
Muskeg	47	48
Firebag	49	18
Stony Mountain	48	47
Birch Mountain	49	30
Richardson	45	54
Fort Hills	46	23
Thickwood	48	25
Mildred Lake	46	30
Ellis	49	11

Table 23. Short duration precipitation amounts at Fort McMurray, 1966-1973 (from Longley and Janz 1978).

Return Period	Rainfall Amounts (mm)								
Years	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	5.3	7.8	9.3	11.5	13.5	17.6	27.6	33.6	43.2
5	6.9	10.3	13.8	16.4	19.0	27.0	40.8	50.4	61.0
10	7.9	12.1	16.8	19.7	22.6	33.4	49.2	62.4	73.7
25	9.2	14.3	19.8	23.9	27.2	41.1	60.0	76.8	91.4

occasionally three, periods of one day's duration with precipitation totals greater than 40 mm. MAPS stations, during the period 1976 to 1981, typically had two or three hours with totals greater than 40 mm. Precipitation amounts from similar periods at sites where forestry and MAPS stations are adjacent were compared. The comparison suggested that days with relatively high daily totals at forestry stations were days with several hours of precipitation at MAPS stations. Conversely, hours with very high precipitation at MAPS stations were not associated with high daily totals at forestry stations. In addition, high hourly MAPS values occurred throughout the year, whereas such precipitation would be expected to occur with seasonal rainfall.

The two-hour duration maximum totals in Table 22 can also be compared to those in Table 23. All but three of the MAPS values were less than the 10-year return period values and four were less than the five-year return period values. These comparisons suggest that even two-hour MAPS duration data are suspect. Only a detailed examination of the archived data can determine the cause of the questionable hourly values.

5.2 DAILY PRECIPITATION DISTRIBUTIONS FOR FORESTRY STATIONS

Daily precipitation amounts (separated into rain and snow categories) are available for the forestry stations during the months of June, July, and August for up to 14 years. Table 24 shows the period of record for each station, the average overall years of the record of the total July precipitation, the standard deviation about this average, and the 30-year normal July precipitation amounts as obtained from Environment Canada (1982). The agreement between the 14-year values and the 30-year normals is quite good except for the Christina (CR), Ston Mountain (ST), Thickwood (TW), and Grande (GE) stations, where differences of about 10 mm exist. Note also that the four years of Fort McMurray record reproduced, coincidentally and almost exactly, both the 30-year mean and standard deviations. The data from Table 24 have been plotted in Figures 11 and 12. In these maps, there is a strong correlation between elevation and July total precipitation. The highest rainfall amounts occur in the

Table 24. Average and 30-year normal precipitation (mm) for the forestry stations.

Forestry Code	Years of Record	July Total Precipitation		July Total Precipitation	
		Average	St. Dev.	30-year Normal	St. Dev.
LA	11	70.3	42.3		
CI	4	66.4	37.9		
KN	14	64.7	28.1	61.5	25.6
PA	14	82.2	49.3	84.1	47.6
JE	14	111.7	64.0	114.0	56.8
ED	14	97.9	57.7	104.9	57.7
LG	14	92.5	48.4	94.1	42.8
EL	14	73.3	26.9	72.9	29.6
BN	14	105.2	71.0	101.7	62.1
BI	14	103.8	50.8	102.5	46.6
BM	14	79.5	31.3	77.7	30.3
RI	14	69.3	23.0	69.7	32.3
MU	14	91.8	30.7	87.3	33.8
JO	14	91.7	38.3	85.3	36.9
CY	12	62.7	30.3	67.2	29.1
GE	14	87.4	39.0	77.3	37.6
AL	14	108.7	42.1	106.3	43.2
TW	14	106.1	50.9	94.9	45.7
MM	4	75.0	31.3	75.4	33.2
ST	14	115.1	45.0	106.8	44.5
GL	14	89.4	34.8	83.1	34.7
MY	14	116.8	42.7	115.9	46.3
CR	14	104.7	41.5	88.4	33.7
CK	14	100.3	34.0	99.6	35.7
CP	14	89.9	34.8	89.0	39.8

Birch Mountains and the hills south of Fort McMurray. The lowest values exist near Lake Athabasca, with another low in the upper Athabasca River valley. A col exists between the two, that is, in the Fort McMurray area. The high gradient that was noted in the temperature data of Section 4.2 between the Fort McMurray and Thickwood stations also appears in the precipitation data.

The relatively high values of standard deviation reflect the large variation in total monthly rainfall during the summer months. The large variation in summer precipitation is even more evident in the maximum daily precipitation as given for the months of June, July, and August, and over the summer in Table 25. This variation is due partly to the convective nature of the precipitation.

5.3 DAILY PRECIPITATION DISTRIBUTIONS FOR MAPS STATIONS

Table 26 outlines the average total precipitation over all years of record for the months of January, April, July, and October, and the standard deviations about these values for each of the MAPS stations. All of the stations have at least three years of such data, with one station (LKM) having six years. As for the forestry stations, the MAPS values show large variations in the standard deviations. While large values of the coefficient of variation (standard deviation divided by mean) might be expected during July, because of the convective component of the precipitation, similar values for the January data are somewhat surprising. The high variability of the precipitation makes it difficult to map the precipitation field over the study area. If the number of years of record was increased substantially, much of the variation due to the quasi-random nature of the precipitation would likely be removed, and long-term trends could be established.

The maximum daily precipitation values noted for each month of the year over all years of record for each of the MAPS stations are given in Table 27. As was observed in the comparable forestry statistics, large spatial variations exist. Large month-to-month variations in the data of Table 28 reflect an insufficient length of record. These data are not representative of annual precipitation variations.

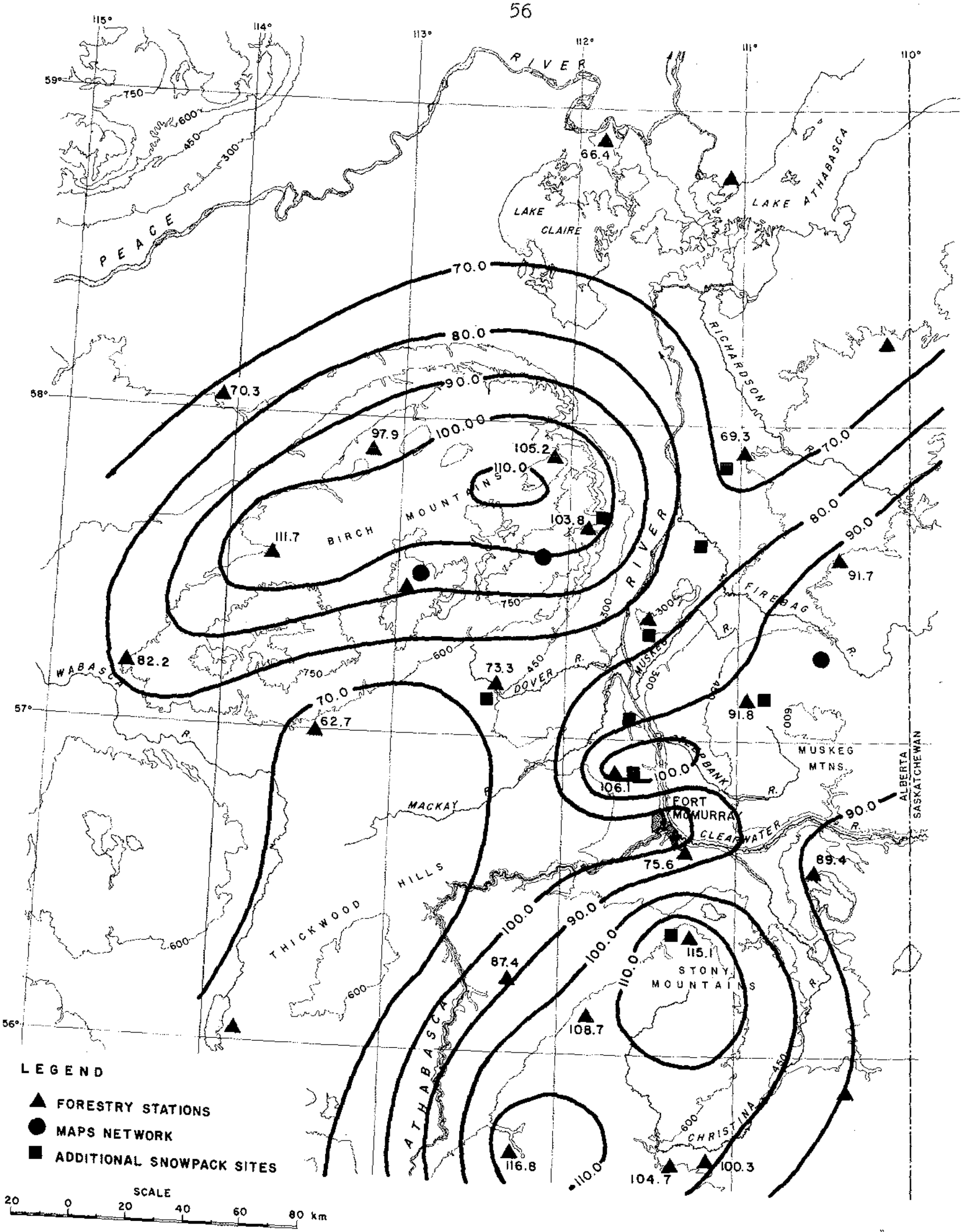

Figure 11. Mean July precipitation (mm) at forestry stations, 1966-1979.

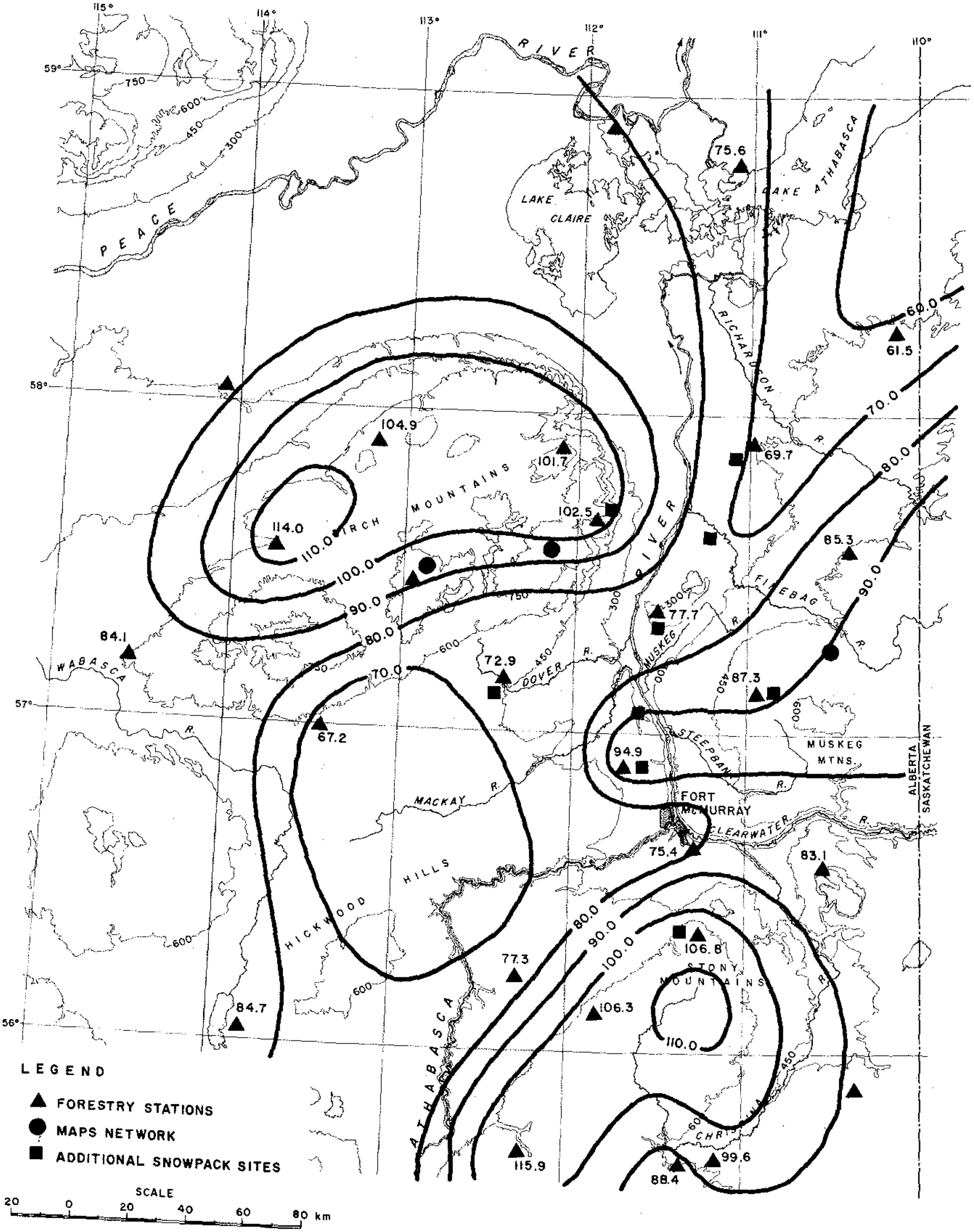

Figure 12. Thirty-year normal mean July precipitation (mm) at forestry stations.

Table 25. Maximum daily precipitation (mm) for the summer months at forestry stations, 1966-1979.

Forestry Code	Summer Daily Maximum	June Daily Maximum	July Daily Maximum	August Daily Maximum
LA	54	50.8	54.4	46.2
CI	21	12.7	20.3	21.1
KN	41	31.7	40.6	38.6
PA	80	58.9	62.0	80.3
JE	80	59.4	80.3	52.6
ED	76	45.7	75.9	51.1
LG	50	46.5	49.8	48.9
EL	52	41.4	42.4	51.9
BN	73	72.9	54.1	47.2
BI	85	62.7	84.6	56.1
BM	66	28.7	57.9	66.0
RI	39	34.3	37.6	38.6
MU	87	57.9	53.8	86.6
JO	58	50.3	48.5	57.9
CY	61	60.7	30.5	61.0
GE	84	68.8	40.1	83.8
AL	68	43.9	67.8	58.4
TW	90	51.8	60.2	90.1
MM	95	17.3	36.1	94.5
ST	115	79.0	42.9	115.3
GL	101	47.0	50.0	101.1
MY	102	101.6	73.2	58.2
CR	81	80.8	50.5	65.0
CK	71	70.9	40.9	48.0
CP	117	68.8	44.5	117.1

Table 26. Average precipitation (mm) for selected months at the MAPS Stations, 1976-1981.

	January Total Precipitation				April Total Precipitation				July Total Precipitation				October Total Precipitation			
MAPS Code	Years of Record	Average	SD[a]	CV[b]	Years of Record	Average	SD	CV	Years of Record	Average	SD	CV	Years of Record	Average	SD	CV
ELS	4	19.5	9.6	49	4	26.8	29.0	108	3	52.7	16.0	30	4	27.5	26.0	95
BCH	4	13.5	8.9	66	4	25.8	30.2	117	3	41.7	39.6	95	4	27.8	9.3	33
LKM	5	19.8	16.5	83	5	21.8	26.3	121	5	56.8	34.5	61	6	22.8	25.7	113
HLS	4	7.5	3.9	52	5	26.6	20.2	76	4	58.0	43.7	75	5	24.4	17.5	72
FBG	4	21.5	16.3	76	3	31.7	30.0	95	3	49.0	9.8	20	4	40.3	20.1	50
RIC	4	14.8	13.8	93	4	21.5	14.2	66	3	59.0	12.8	22	4	35.0	12.1	35
MKG	4	17.0	15.5	91	4	28.8	25.3	88	3	64.0	26.0	41	4	29.0	7.4	26
TKW	5	9.6	5.3	55	5	25.4	22.9	90	4	61.3	37.1	61	5	28.6	32.1	112
SMT	4	13.3	4.6	35	4	28.0	27.1	97	4	64.5	26.5	41	5	27.4	26.3	96

[a] Standard deviation (mm)
[b] Coefficient of variation in percent

Section 11.4 documents the number of days each month with measurable precipitation at both MAPS stations and forestry stations. The MAPS results show an annual trend of more precipitation days in summer than winter. This is due to the difference in time scales of the precipitation producing mechanisms. Winter events are caused by frontal passages or upper disturbances which occur perhaps weekly and last for one or two days. Convective precipitation is induced largely by summer surface heating which has a time scale of one day.

5.4 SNOWPACK

Snowpack statistics were generated for 12 sites in the oil sands area for the period 1976 to 1982. The sites were chosen on the basis of record length which ranged from three to six years.

A summary of the statistics is presented in Table 28. The mean and standard deviation of snow depth and water equivalency are shown for the months January, February, and March. As mentioned in Section 2.5, snow measurements were taken, over the years, during various weeks of the month. Thus, the values in Table 28 represent an average within each month as well as year to year, and might therefore be considered as mid-month snowpack values.

The month-to-month variation of snow depth was examined. Mean January depth was significantly different from the mean February and March depths at the 95% confidence level. However, at none of the stations were the mean February and mean March depths significantly different at the same level of confidence. Water equivalency data were more variable; at some stations, month-to-month variations were significant at the 95% level but at others they were not. Longer periods of record are required to reduce these uncertainties.

In spite of potential sampling problems described previously, spatial variations in the snowpack were examined. Figures 13 through 16 show mean mid-month snow depth and water equivalency for January and March. Figure 13 shows an unexpectedly weak trend for deeper snowcover at higher elevations. The highest station, Birch Mountain, has the least snowcover; however, it is also on an east-facing slope. Stoney Mountain, at a lower elevation but on a western slope, has the deepest

Table 27. The maximum daily precipitation (mm) at the MAPS stations, 1976-1981. Snow has been converted to equivalent water.

MAPS Code	Annual Maximum	January	February	March	April	May	June	July	August	September	October	November	December
ELS	43	28	8	6	34	10	19	30	29	43	22	10	6
BCH	70	22	13	9	34	18	13	45	38	70	17	5	5
LKM	70	45	14	8	36	13	13	44	40	70	25	10	13
HLS	50	5	14	8	30	12	18	34	50	50	27	8	10
FBG	46	43	12	5	35	7	16	19	17	46	41	8	10
RIC	40	20	20	7	16	14	11	25	17	40	21	7	8
MKG	35	35	6	10	30	12	13	23	33	21	12	6	5
TKW	85	4	9	13	23	13	13	47	85	61	23	9	13
SMT	117	8	4	7	30	13	24	33	117	20	20	6	7

Table 28. Snow depth and water equivalency statistics for late winter snowpack, 1976-1982.

	JANUARY					FEBRUARY					MARCH				
		Depth		Water Equiv.			Depth		Water Equiv.			Depth		Water Equiv.	
	No.	Mean (cm)	St. Dev. (cm)	Mean (mm)	St. Dev. (mm)	No.	Mean	St. Dev.	Mean	St. Dev.	No.	Mean	St. Dev.	Mean	St. Dev.
Birch Mountain	5	29	2.7	57	8.1	4	39	5.8	71	1.2	6	40	8.6	78	2.0
Bitumount	4	33	8.1	58	1.9	4	48	1.4	68	2.2	6	43	1.1	83	2.7
Ells	5	36	3.7	63	1.4	3	49	6.7	75	1.0	5	48	8.6	80	1.8
Firebag	3	31	3.7	58	1.2	3	51	1.1	63	1.4	4	40	5.4	72	1.5
Mildred Lake	4	30	7.2	48	1.2	4	42	1.2	65	1.7	5	41	9.2	75	2.3
Muskeg	5	36	3.1	70	1.4	4	52	3.0	98	8.8	6	48	6.9	96	3.1
Richardson	5	31	5.0	58	1.0	4	43	1.0	77	1.5	4	41	7.7	79	1.5
Thickwood	4	41	7.8	77	1.0	4	47	1.3	83	1.8	5	54	5.3	93	2.1
Lost Creek	3	38	4.5	75	1.4	3	48	7.4	77	1.7	4	44	1.2	87	3.7
Namur Lake	3	34	2.5	59	9.2	3	43	4.2	75	5.4	4	40	6.3	72	1.9
Upper Tar Lk.	4	38	2.6	69	2.2	3	43	1.1	71	1.8	4	45	4.5	90	2.5
Stony Mountain	4	43	6.0	-	-	4	53	1.5	-	-	5	55	8.6	-	-

mean January snow cover. Stations near the Athabasca River valley generally have the lowest mean snow depth.

The March mean snow depth shows no trend for increasing depth with elevation. Rather, the trend is clearly latitudinal, with the least snow cover in northern-most areas. This is consistent with data for Fort McMurray and Embarras (situated about 50 km north of Richardson in the Athabasca River valley) presented by Longley and Janz (1978).

Figures 14 and 16 compare mean water equivalency at mid-month during January and March. January equivalencies are about 20% less than those of March but follow a similar spatial pattern. Although water equivalencies were unavailable for Stony Mountain, no association with elevation or latitude is apparent.

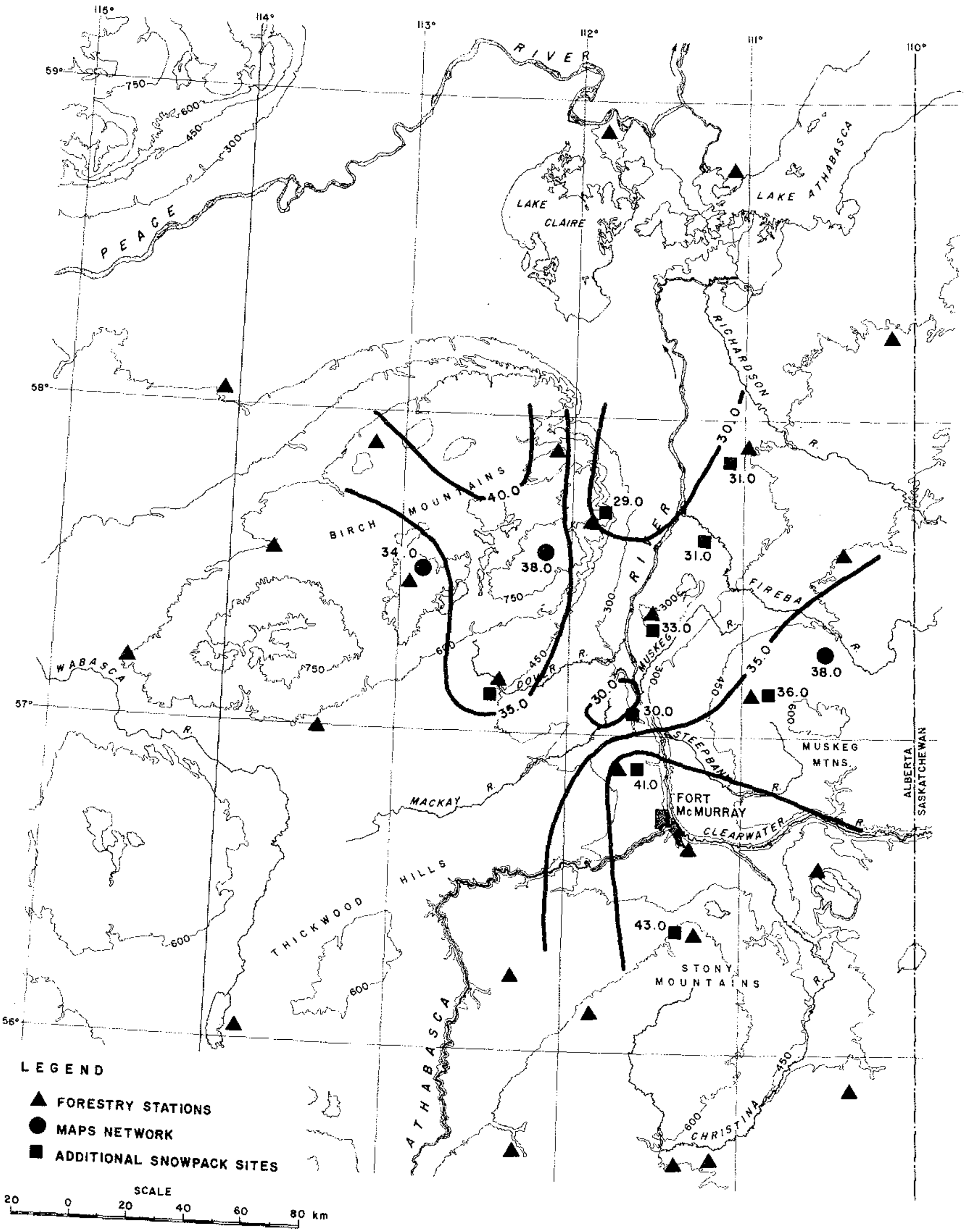

Figure 13. Mean January mid-month snow depth (cm), 1976-1982.

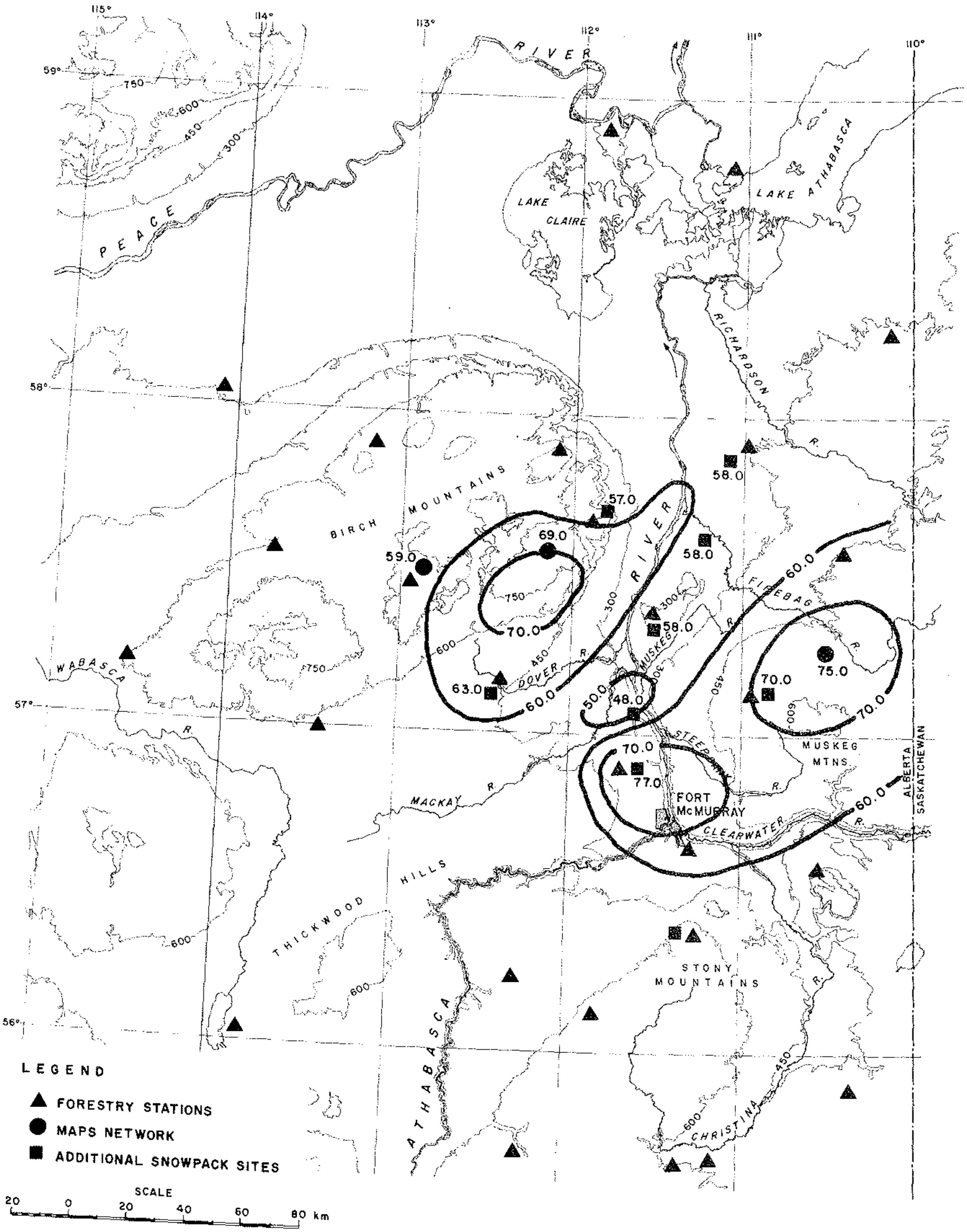

Figure 14. Mean January mid-month water equivalency (mm), 1976-1982.

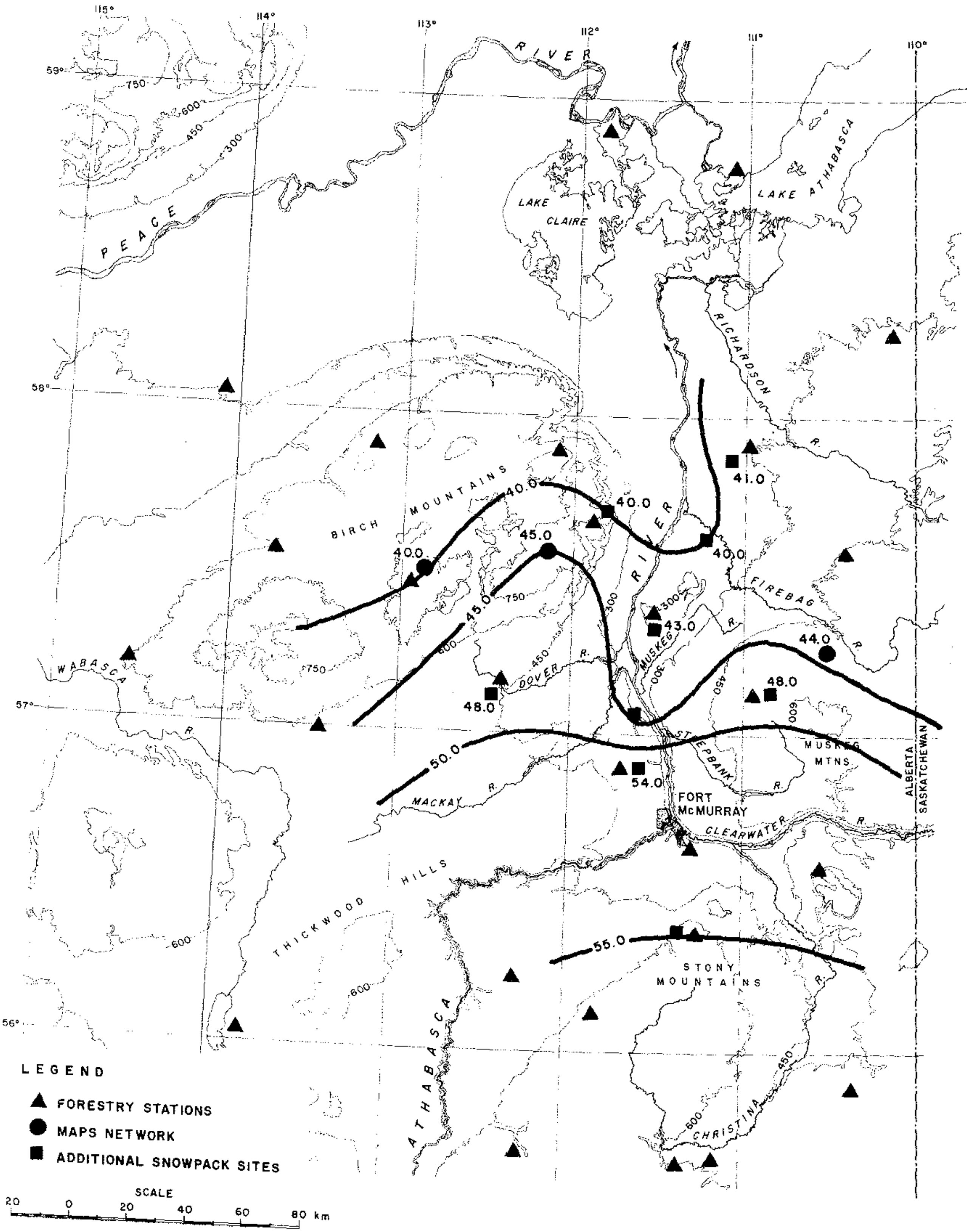

Figure 15. Mean March mid-month snow depth (cm), 1976-1982.

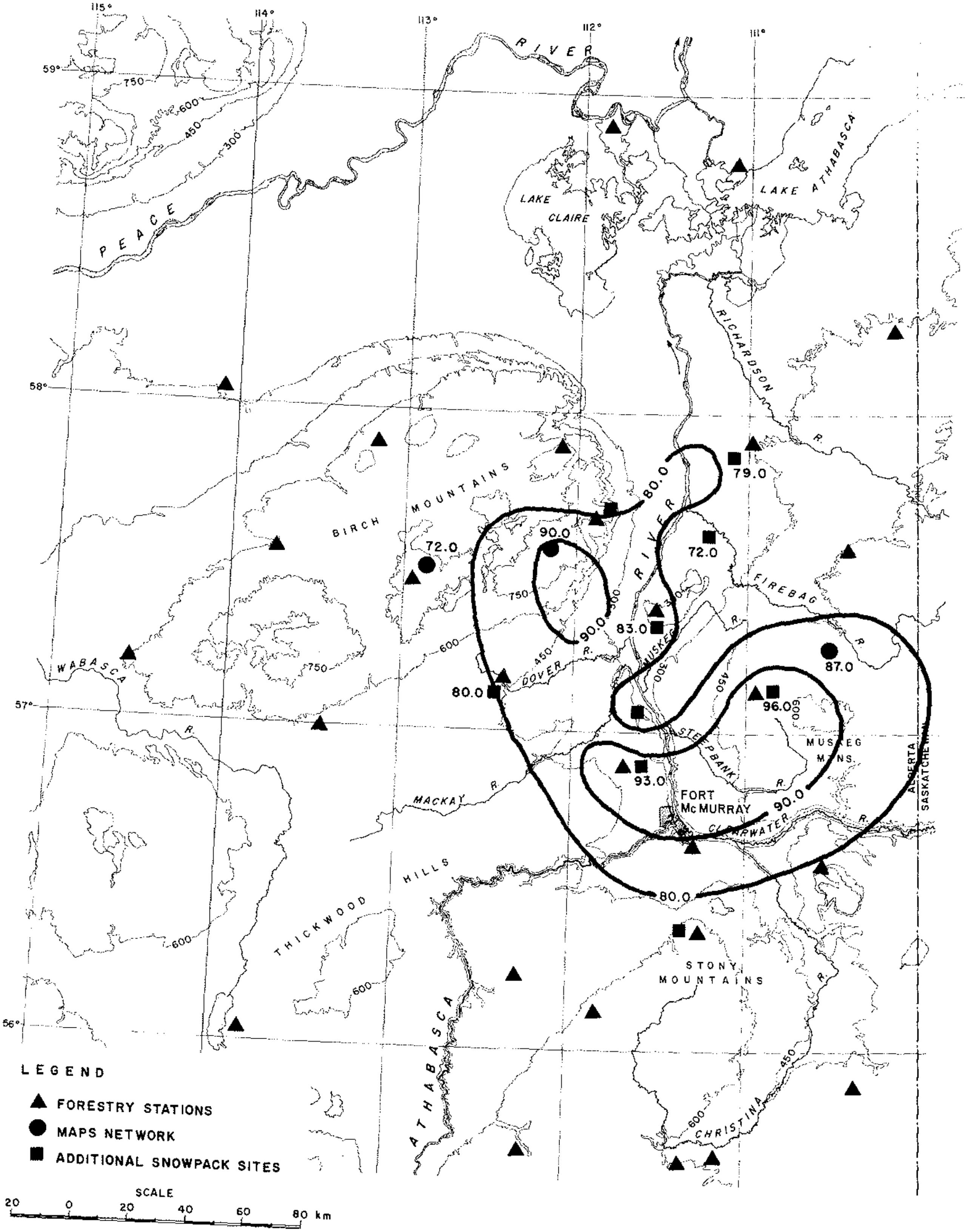

Figure 16. Mean March mid-month water equivalency (mm), 1976-1982.

6. WIND

6.1 DIURNAL VARIATION

Wind speed and direction measured at MAPS stations were examined by hour of day for evidence of diurnal variation. The months January, April, July, and October were chosen to show seasonal trends. All months of data from 1976 to 1981 were used in the analysis.

The diurnal variation of wind speed at four selected MAPS sites is shown in Table 29. Wind speeds in January appeared to be relatively constant throughout the day, although some evidence existed (Mildred Lake and Birch Mountain) for a slight reduction during mid-afternoon. Conversely, in April, a maximum in speed occurred during mid- to late afternoon. Stony Mountain also showed evidence of a secondary maximum near midnight. In July the afternoon wind speed maximum was slightly more prominent (larger amplitude) and slightly broadened to include all afternoon hours with a local maximum between 1500 and 1700 h. In October the time of maximum speeds depended on station location. Stony Mountain showed no trend with time of day. Birch Mountain had a maximum at 0800 h with late night and morning speed generally high. Mildred Lake and Muskeg retained maxima in late and mid-afternoon, respectively. In general, terrain appeared not to influence diurnal variations of wind speed to any significant degree.

The diurnal variation of wind direction was also examined. Time frequency plots are found in Section 11.5. In January at Stony Mountain, the directions north, south, and west predominated throughout the day. North and south occurred most frequently during nighttime hours; west winds dominated with a northwest component becoming important for several hours in later afternoon. Winds from the south are likely indicative of downslope flow at this site. At Birch Mountain, northwest winds dominated with secondary maxima at southwest and north. Northwest winds occurred less frequently during daytime hours when west and south components were somewhat enhanced. At Muskeg, winds were most frequently from north or south. Winds from the south dominated from about midnight to sunup, north winds from sunup to mid-afternoon, and northwest winds in late afternoon. At Mildred Lake,

Table 29. Hourly variation of mean wind speed (km/hr) at selected MAPS stations, 1976-1981. Times are local.

Month	Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	Mildred Lake	6.5	6.8	6.7	6.5	6.6	6.4	6.3	6.2	6.0	6.4	6.1	6.0	6.4	6.3	5.9	5.9	6.3	6.6	6.9	6.8	6.7	6.7	6.8	6.8
	Muskeg	9.8	9.4	8.9	9.4	8.7	9.1	9.2	9.2	9.2	9.1	9.0	9.1	9.4	8.8	9.0	9.2	9.4	9.3	9.8	10.0	10.0	10.0	10.0	10.0
	Birch Mtn.	17	18	17	18	17	17	17	17	17	17	18	18	16	16	16	16	17	17	18	18	17	18	17	18
	Stony Mtn.	8.8	9.3	9.0	8.9	9.4	8.6	8.8	8.9	9.0	9.4	9.1	11	9.0	8.9	8.9	8.7	8.6	8.8	8.9	8.9	8.6	8.7	8.3	9.4
April	Mildred Lake	8.9	8.9	8.8	8.7	8.6	8.5	8.7	8.7	8.5	9.1	9.9	9.7	10	11	11	11	12	11	10	9.7	9.3	9.2	9.7	9.5
	Muskeg	14	13	14	14	14	14	13	13	13	14	14	14	14	15	14	14	15	14	13	12	12	13	14	14
	Birch Mtn.	16	17	16	17	17	17	17	17	17	17	16	16	17	17	18	18	18	17	16	14	15	16	16	16
	Stony Mtn.	15	15	15	15	15	15	14	14	14	15	14	15	16	16	15	15	16	15	15	13	13	14	15	16
July	Mildred Lake	6.9	6.9	6.8	7.0	7.2	6.9	7.1	8.0	7.7	8.3	9.3	9.7	10	11	11	10	10	9.9	9.4	8.2	7.4	7.5	7.5	7.1
	Muskeg	10	10	10	10	10	10	9.0	10	10	10	11	12	12	12	13	12	13	12	11	9.9	8.7	9.4	9.7	9.7
	Birch Mtn.	12	11	12	12	13	13	13	13	13	14	15	16	15	15	16	15	17	16	15	13	12	11	11	12
	Stony Mtn.	7.6	7.6	7.9	7.9	8.2	8.6	8.0	8.2	8.3	8.4	9.0	9.6	9.8	10	11	11	9.9	10	9.1	8.5	7.7	7.2	7.2	7.6
October	Mildred Lake	8.0	8.3	8.1	8.0	8.3	8.4	8.4	8.6	8.2	8.4	9.2	9.5	10	11	11	11	11	9.6	9.5	9.2	9.4	9.1	8.9	8.5
	Muskeg	14	13	13	14	14	14	15	15	14	15	16	16	17	17	17	16	15	15	14	16	15	14	15	15
	Birch Mtn.	19	19	19	19	19	19	19	20	19	19	18	18	18	17	17	16	15	15	17	18	19	19	19	18
	Stony Mtn.	13	12	12	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	12	12	12	12	13	12

south-southeast winds were most frequently observed with a secondary maximum at north. This pattern persisted throughout the day except for 1700 h (approximate sundown) when north winds occurred most frequently. January wind frequencies at both Mildred Lake and Muskeg were strongly influenced by the channeling effect of the Athabasca River Valley. Diurnal variations were not clearly shown at any of the stations.

April direction frequencies began to show diurnal variations more clearly. At Stony Mountain, the prevalent directions were south, north and west. Downslope (south) winds occurred most frequently between 2200 and 1100 h. North winds were most important between 1100 and 2200 h. West and northwest winds were also important during daylight hours. At Birch Mountain, northerly and westerly winds were prevalent throughout the day. Superimposed on this pattern was a general wind shift from southwest just after midnight, through west and northwest at about 0700 and to north in mid-afternoon, remaining northerly until midnight (winds from west and north are downslope). Winds from the southeast quadrant occurred very rarely during late night and early morning hours but more frequently during afternoon and early evening. Winds at Muskeg tended to be from south (downvalley) and southeast (downslope) from about 2100 to 0900 h with north, northwest, and west winds more important during the remainder of the day. At Mildred Lake, north and southeast winds were predominant and occurred with approximately equal frequency before 1200 h and after 2000 h. Westerly (including southwest and northwest) and northerly winds were important during the remainder of the day.

Diurnal variations in direction were most evident in July. Although winds throughout the day at Stony Mountain were primarily from the northwest quadrant, winds from the south (downslope) quadrant were enhanced beginning as early as 1800 until approximately 1000 h. North (upslope) winds occurred relatively frequently from 0700 to 2200 h. At Birch Mountain (with an eastern exposure), the pattern was somewhat different. Winds from the west (downslope) were most prevalent but especially so from 2100 to 1000 h. Winds from the southeast (upslope) quadrant occurred rarely at night but relatively frequently between 1000 and 1700 h. July winds at Muskeg were distributed almost equally among all compass points. The general trend was enhanced west and northwest (upslope) winds during the hours 0900 and 1900 (along with decreased east and south winds), with a shift to increased east and south winds beginning late evening and maintaining until mid-morning. Mildred Lake winds were predominantly from the north and southwest, with northwest quadrant winds secondarily important. North winds occurred equally frequently at all hours and southwest winds more frequently between 1200 and 0700 h. Mildred Lake winds showed less diurnal variation than the other stations. Channeling of winds by the Athabasca River valley at this site appeared to dominate other effects. All sites except Muskeg exhibited more frequent surface westerly flow in July (and October) compared to other months. The reason for this may have been more frequent westerly flow at upper levels.

October wind frequencies showed less evidence of diurnal effects than April. At Stony Mountain, winds were predominantly west with secondary peaks at south and north. West winds occurred slightly less frequently in early evening hours with concurrent slight increases in both north and south directions. At Birch Mountain, virtually all winds were from southwest through west to north with west winds the most frequent. South winds were somewhat enhanced during the hours 1400 to 2100 h. Muskeg winds were most often west and south. East winds were rare at all hours; northwest winds were enhanced between 1200 and 1600 h. Mildred Lake winds were more uniformly distributed but with maxima at southeast, southwest, and north. No change was evident with time of day. October wind frequencies at all stations showed neither the strongly terrain-dominated flows of January nor the diurnal heating patterns evident in July flows.

6.2 SEASONAL VARIATION

Mean monthly wind speeds and prevailing directions were examined for evidence of annual fluctuations. Mean speeds (Table 30) at MAPS stations generally followed the trend discussed by Longley and Janz (1978); that is, the windiest months were the transition months, usually May and October. At exposed sites, such as Stony and Birch

Table 30. Mean monthly wind speeds (km/h) at MAPS stations, 1976-1981.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Stony Mountain	9.0	9.4	9.4	9.9	9.0	8.6	8.6	9.6	11	12	10	9.6	9.7
Richardson	5.4	5.4	5.9	6.9	11	10	7.8	9.4	8.0	8.0	7.4	6.4	7.6
Mildred Lake	6.4	6.2	8.0	9.4	9.1	8.3	8.3	7.7	7.7	9.1	9.3	8.3	7.5
Fort Hills	7.8	7.7	8.2	10	9.9	8.5	9.3	7.2	8.6	9.6	7.8	6.4	7.8
Thickwood	11	12	11	10	10	8.5	10	9.1	8.2	11	11	9.3	10
Ells	7.5	8.2	9.4	9.3	8.5	7.5	6.9	6.4	6.4	8.3	7.5	5.9	7.7
Birch Mountain	17	17	16	16	16	15	14	14	15	18	16	17	16
Muskeg	9.3	14	14	14	13	12	11	11	13	15	11	9.8	12

mountains, the lowest wind speeds occurred in summer. At sites located near the Athabasca River valley, the lowest wind speeds were found in winter and secondarily in late summer. Highest speeds throughout the year were found at Birch Mountain. Wind speeds were generally lower in the Athabasca River valley than at exposed sites, with the exception of Thickwood (near the valley but at a higher elevation) which had the second highest wind speed.

Table 31 shows the frequency of calms (speeds less than about 4 km/h) at MAPS stations. An obvious annual trend exists in that the summer months had fewer hours of calm than other months, with calms occurring most frequently in winter. Terrain effects appeared to be conflicting. As expected, Birch Mountain had the lowest frequency of calms. Conversely, Stony Mountain, also at a high elevation, had the highest frequency. This was especially evident during winter months. Although the site was designed to be properly exposed, its location on a north facing slope combined with frequent south winds suggested a sheltering effect to be the cause. In general, no apparent relation existed between terrain and the seasonal variation in frequency of calms.

Monthly prevailing wind directions were also examined and are presented in Table 32. Winds at sites in or near the Athabasca River valley appeared entirely under the influence of the valley (winds primarily oriented north or south). In many other cases, for example Ells, winds from the prevailing direction (west) occurred only several percent more frequently than from other directions (east-northeast). Winds at Ells, together with Birch Mountain, also showed effects of the presence of the Birch Mountains. Stony Mountain winds were also influenced by terrain. In no cases were there obvious annual trends in prevailing wind directions, although as shown in the previous section, westerly winds occurred relatively more frequently in summer and autumn months than in the other two seasons.

The seasonal trend in diurnal wind variation was also documented in the previous section. In spring and summer months during daylight hours an upslope flow component was frequently observed and at night a downslope or downvalley component was noted. In autumn months

Table 31. Percent calms at MAPS stations, 1976-1981.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stony Mountain	26	29	26	3	1	2	4	3	6	20	22	23
Richardson	21	20	18	15	8	2	3	2	4	13	4	10
Mildred Lake	15	12	9	5	1	2	2	2	6	4	3	5
Fort Hills	15	9	10	13	6	1	1	1	1	1	2	6
Thickwood	13	13	11	6	1	1	1	1	1	2	4	10
Ells	8	6	4	5	4	3	4	5	4	4	7	7
Birch Mountain	5	2	1	1	0	0	1	1	1	8	5	2
Muskeg	5	3	2	1	2	3	3	1	1	1	2	4

Table 32. Prevailing wind direction at MAPS stations by month, 1976-1981.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stony Mountain	W	S	N	N	W	N	W	N	S	W	W	W
Richardson	S	SSE	S	NW	S	S	S	NNW	S	S	S	S
Mildred Lake	SSE	N	N	N	N	N	N	N	N	SE	SE	N
Fort Hills	S	S	NNE	NNE	NNE	N	N	N	N	N	N	W
Thickwood	N	N	N	N	N	N	N	N	N	N	N	N
Ells	WNW	ENE	WNW	WNW	NE	W	W	WNW	W	W	W	WNW
Birch Mountain	WNW	WNW	NNW	N	N	N	W	WNW	WNW	WNW	WNW	WNW
Muskeg	S	SSE	S	S	E	N	W	NNW	SE	WSW	WSW	WSW

when wind speeds were relatively high neither terrain-induced nor diurnal heating effects were dominant although channeling effects were evident. In winter with relatively low wind speeds, terrain effects were dominant and were especially evident at valley stations such as Mildred Lake.

6.3 COMPARISON OF MAPS AND 400-M PIBAL WINDS

Winds from selected MAPS stations (Mildred Lake, Muskeg, Birch Mountain, and Stony Mountain) were compared to pibal winds near the 400-m level that were obtained during field programs conducted from 1976 to 1978. Stony Mountain and Birch Mountain were chosen because of their high elevations and differences in exposure; Muskeg because it was thought to be relatively free of terrain influence; and Mildred Lake as a comparison site where winds were strongly influenced by terrain.

Some differences in characteristics of the MAPS and pibal data sets were relevant. As discussed by Davison, Davies et al. (1981) and Davison, Hansen et al. (1981) pibal measurements were essentially instantaneous. MAPS wind speeds were 10-minute averages and directions were instantaneous. Somewhat more scatter might therefore be expected in the pibal measurements.

MAPS winds were compared on an hour-by-hour basis with pibal winds. For each individual MAPS station, only those hours with MAPS speed and direction and a pibal measurement between 300 and 500 m were considered for analysis. Joint frequencies of pibal measurements with each MAPS site were calculated. Because all four MAPS stations chosen were operational during most of the pibal measurement period, pibal directional frequencies were very similar (typically 1% standard deviation) regardless of which of the four MAPS station data periods was used. The pibal directional frequencies were therefore averaged into a single distribution as shown in Table 33. Only pairings with more than 100 hours each season were used to produce these average values. In addition to the frequency comparisons of Table 33, joint frequencies by season of each MAPS wind direction measurement and concurrent pibal measurements were produced. These joint distributions

Table 33. Comparison of selected MAPS and pibal 400-m wind direction frequencies (%).

Season	Station	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Number[a]
Winter	Mildred Lake	10	7	1	1	2	4	12	2	17	10	4	4	4	2	2	0	174
	Muskeg	2	3	3	1	1	5	13	8	8	21	17	3	2	4	7	3	179
	Birch Mtn.	6	1	1	1	0	2	0	2	5	7	15	7	21	22	7	5	178
	Stony Mtn.	0	0	0	0	0	11	29	16	8	13	11	5	8	0	0	0	38
	PIBAL	3	3	3	2	13	10	10	8	7	5	8	8	11	5	1	2	531
Spring	Mildred Lake	11	5	4	4	22	8	9	7	7	8	6	5	9	8	3	4	225
	Muskeg	11	4	3	3	12	4	7	7	5	14	3	3	5	5	7	6	225
	Birch Mtn.	16	4	6	4	7	5	8	1	7	6	7	2	9	8	9	3	215
	Stony Mtn.	11	17	11	4	2	2	6	6	0	2	9	4	9	9	0	9	47
	PIBAL	10	13	4	3	4	5	5	5	7	6	5	9	7	6	2	7	665
Summer	Mildred Lake	4	2	3	1	0	4	11	17	10	10	11	9	6	5	5	5	198
	Muskeg	5	3	3	1	1	2	10	8	9	11	8	13	11	5	7	5	215
	Birch Mtn.																	0
	Stony Mtn.																	0
	PIBAL	5	5	3	1	1	0	5	9	13	5	9	13	13	8	6	4	413
Autumn	Mildred Lake	13	2	1	0	1	1	7	11	10	10	13	13	8	4	2	4	257
	Muskeg	5	2	2	1	2	0	6	9	7	16	14	13	12	5	4	3	278
	Birch Mtn.	6	2	4	2	2	0	1	0	2	7	10	8	3	15	8	4	249
	Stony Mtn.	4	0	0	1	1	1	0	2	14	8	14	19	23	7	5	3	155
	PIBAL	5	4	3	1	1	0	2	4	8	9	11	14	23	11	4	3	939

[a] Pibal frequencies were similar regardless of which MAPS station period of record was used and therefore an average value was calculated.

were too numerous to be included in this report but are available in table form at the offices of RMD and are summarized in the following paragraphs. Statistics on the difference between 400-m pibal and 10-m MAPS wind directions were not produced. For these analyses the seasons were defined as winter (December, January, February), spring (March, April, May) summer (June, July, August), and autumn (September, October, November).

In winter, pibal winds had a broad maximum in frequency extending from east through south to west, with local maximum at east and west. At Mildred Lake, the 10-m winds were primarily from south-southeast and secondarily from north, indicative of valley channeling. No organized rotation with height was observed; wind shifts of more than 90° were common. At Muskeg surface winds were predominantly southeast through southwest. Large, almost random differences in direction between the two levels were observed; for example, on thirteen occasions when surface winds were southwest, 400-m winds were from the east. Birch Mountain winds had a broad maximum centred on west-northwest. Little organized rotation with height was observed, except for a slight backing (much less than one 16-point compass point) with height when surface winds were in the southwest quadrant. A similarly slight backing was observed in the southwest quadrant at Stony Mountain. Note that MAPS wind directions were based on a 16-point compass, whereas pibal winds were recorded to the nearest degree. Therefore, for individual hours, differences in wind direction were restricted to multiples of 22.5° (approximated by 20°).

In spring, pibal winds were primarily north with a broad secondary maximum centered on southwest. At Mildred Lake surface winds were primarily north and southeast with a west component. A weak trend for a 20° veer with height was apparent but on many occassions upper winds from all directions were channeled to south or south-southeast at the surface. At Muskeg, surface wind direction maxima occurred at north, east and south - southwest. Again a tendency existed for winds to veer by about 20° with height. At Birch Mountain surface winds were primarly from north with secondary maxima at east-southeast, south, and west-northwest. The joint frequency distribution gave no evidence of rotation with height but the data were broadly distributed about the no-rotation axis. At Stony Mountain, few spring data points existed and those with no apparent rotation with height.

Summer pibal data had maxima at south and west with a minor peak in the distribution at north-northeast. Surface winds at Mildred Lake exhibited a very broad maxima centred on south. A loosely-defined veer of about 20° with height was evident. At Muskeg surface winds showed a broad maximum centered on south. A tendency existed slightly for more than a 20° veer with height but with exceptions: west-southwest pibal winds were generally associated with west-southwest surface winds. No summer data existed for the Stony Mountain and Birch Mountain sites.

Autumn pibal winds had a broad maximum from south through west to west-northwest. At Mildred Lake, a major maximum existed centred on southwest with a secondary maximum at north. Joint frequency data showed evidence of a 20° veer with height. Evidence also existed of northerly channeling at the surface, particularly when 400-m winds were north-northeast and west. Muskeg surface winds showed a broad maximum centred on south-southwest with a minor frequency maximum for winds from north. As at Mildred Lake, a tendency existed both for a 20° veer with height and for northerly channeling at the surface. Stony Mountain surface winds had a broad frequency maximum centred at southwest but with the highest frequency occurring at west. A very slight veer with height (less than 20°) was evident. At Birch Mountain frequency peaks occurred at southwest and west. Good agreement was found (few outliers) with a slight backing (much less than 20°) with height.

In addition to directional shear with height, speed shear was also investigated by fitting a power law to individual hourly values. The power law formulation took the form

$$U_{400} = U_{10} \, (Z_{400}/Z_{10})^{p} \qquad (2)$$

where U_{400} and U_{10} are wind speeds at a level near 400 m and the surface, Z_{400} and Z_{10} are the height above ground of the pibal level and MAPS wind measurement, and p is the power law exponent. In this analysis data were stratified by season only. No attempt was made to remove low wind speed or flow-decoupled cases, or to further stratify by wind direction as in Leahey and Hansen (1982).

A summary of the exponent statistics is presented in Table 34. Of note are large variations in the mean value of the exponent and the relativley large standard deviations. Large standard deviations might be expected for several reasons: flow de-coupling during stable conditions; errors in measurement in low wind speed conditions; and instantaneous wind measurements made at some time during the same hour at different locations that are quite different from statistical considerations and because of terrain influences (see Davison, Hansen et al. 1981).

Mean values of p were typically about 0.2 but with large variations. With exponent values of 0.2, and assuming pibal winds measured near the 400-m level, 400-m wind speeds are found to be about twice the value at the surface. From Table 34, Muskeg is observed to have exponent values relatively near zero, as does the single Birch Mountain value. This is consistent with high mean wind speeds at these two stations (Table 30). Mildred Lake had relatively large p values, especially during winter and autumn months. During these seasons flow decoupling occurred frequently as evidenced by lack of systematic wind turning the height. In addition, stable conditions result in generally large values of the exponent. Irwin (1979) reported p values in rural locations ranging from 0.07 in very unstable conditions to 0.15 in near neutral conditions to 0.55 in very stable conditions. The Mildred Lake values had a seasonal trend in p consistent with Irwin's results, but the relatively high p values in summer, combined with relatively low wind speeds, suggest a sheltering effect on the surface winds there. Relatively large p values at Stoney Mountain in winter and autumn are consistent with the large frequency of calms (Table 31) during these seasons. Hanna et al. (1982) recommended that power law extrapolations from the surface should not extend above 200 m because of increasing inaccuracies so that the values in Table 34 should be compared with caution to the "typical" results of Irwin.

Table 34. Power law exponent statistics for MAPS and pibal 400-m wind speed profiles, by season.

Station	Winter			Spring			Summer			Autumn		
	Mean	SD[a]	N[b]	Mean	SD	N	Mean	SD	N	Mean	SD	N
Mildred Lake	0.48	0.30	113	0.33	0.23	163	0.27	0.17	193	0.35	0.19	231
Muskeg	0.08	0.20	147	0.06	0.20	168	0.17	0.16	206	0.17	0.17	248
Birch Mtn.										0.09	0.14	97
Stony Mtn.	0.30	0.18	26	0.90	0.16	45				0.21	0.15	155

[a] Standard deviation
[b] Number of observations

6.4 SUMMARY OF TERRAIN EFFECTS

Winds from all MAPS stations examined in depth (Mildred Lake, Muskeg, Stony Mountain, Birch Mountain, and Ells) showed strong evidence of very significant terrain influence. Effects were found in diurnal and seasonal variations, in mean annual wind speeds, and in comparison to plume level winds.

Mildred Lake winds in general exhibited obvious channeling effects of the Athabasca River valley. In all seasons except spring, winds were predominantly from the north or south along the valley axis. In spring winds were most frequently from the east.

Stony Mountain winds had an obvious and consistent north or south orientation. This was likely due to its location at the southeast edge of a slope angling southwest to northeast, even though this feature should apparently channel winds southwest to northeast. This orientation was present at all times of the year.

Winds at Ells were also subject to terrain influence. Throughout the year, a significant fraction of winds were from the northeast. This was likely due to the presence of Birch Mountain, located about 50 km north and northwest of Ells. In addition, winds from east-southeast through south to southwest were very rarely occurring throughout the year despite the absence of large-scale terrain features for many kilometres in those directions.

Birch Mountain winds also showed directional persistence, although perhaps not to the degree of Stony Mountain and Ells. A small secondary peak of winds from the north could be explained by the station siting at the eastern edge of the Birch Mountains where the terrain angles north to south. Similarly to Ells, winds from directions east-southeast to south occurred rarely in all seasons, perhaps because of the downstream blocking effect of the Birch Mountains.

Winds at Muskeg also appeared to exhibit channeling effects of the Athabasca River valley. Winds in winter and spring were predominantly from the north and south. Easterly winds that might be due to drainage from the higher terrain in that direction occurred infrequently.

Mean wind speeds also illustrated terrain influences. In general stations with the highest elevation had the highest speeds and those with lowest elevation had the lowest speed, as expected. Despite its location near the Athabasca River valley, Thickwood had high wind speeds because of its relatively exposed siting and high elevation. Stony Mountain was an exception to this general trend as evidenced by a high frequency of calms and low mean winds speeds.

Terrain also influenced the diurnal variations of wind direction. At valley stations such as Mildred Lake in summer, nighttime winds were aligned along valley, whereas daytime winds had a higher frequency of east and west winds. At stations where slope flows were generated (for example, Muskeg), flow tended to have upslope components during the day and downslope components at night. In no cases did the diurnal variation dominate the flow regime.

Terrain effects were also apparent in the comparison of surface winds to 400-m winds. Power law exponents were generally nearer zero (indicating high surface wind speeds) at exposed sites such as Muskeg and Birch Mountain, and larger at sheltered sites such as Mildred Lake.

7. EVAPORATION

Pan evaporation was measured daily at Mildred Lake in the oil sands area. Data from 1973 to 1981 were used in a multiple linear regression analysis with simple available weather observations. These weather variables included daily precipitation, mean temperatures, and windrun.

Tables 35 and 36 present a summary of evaporation regression statistics from the SAS analysis. Table 35 represents values valid for the days when all the variables, that is, pan evaporation, precipitation, windrun, and mean temperature, were recorded. Table 36 is similar except that precipitation was not required.

With precipitation included in the regression (Table 35), about 45% of the variance throughout the year can be explained by the regression, with a higher fraction explained in spring months. Summer months have the lowest correlation coefficients. Estimates of wind and temperature regression coefficients were generally reliable with standard error of about 20 to 30% of the estimates. Precipitation coefficients were significantly different from zero only for the months April through June. Estimates of the intercept were usually not significantly different from zero. The occurrence of negative values for precipitation coefficients appears to reflect the reduction of direct radiation due to cloud formation. The annual trend in the R^2 value is interesting and suggests a seasonal variation in predictor variables not used in the regression.

Exclusion of precipitation from the regression (Table 36) results in several changes. First, the number of available records more than doubles. This should tend to increase the significance of the coefficient estimates. For temperature and windrun, the standard error was generally 10 to 20% of the estimate. Again, estimates of the intercept were not significantly different from zero. The second change is the overall reduction from 0.45 to 0.35 of the fraction of variance explained by the regression. This is an expected result in that a reduction in the number of predictor variables should decrease the fraction of variance explained. The third change is a slight modification of the annual trend in R^2. The minimum value of R^2

Table 35. Daily evaporation correlation statistics at Mildred Lake, 1973-1981, by month.

Month	Number of Days	Intercept	Coefficients: Precipitation (mm)	Wind (km)	Temperature (°C)	R^2
April	18	-0.33	-4.3	0.029	0.22	0.88
May	61	0.48	-0.16	0.025	0.21	0.57
June	75	0.95	-0.10	0.000	0.23	0.42
July	75	0.83	-0.02	0.003	0.18	0.23
August	61	-0.42	-0.00	0.027	0.16	0.31
September	87	0.00	-0.01	0.017	0.11	0.60
October	25	0.34	-0.29	-0.001	0.08	0.41
Total	402	0.35	-0.26	0.013	0.17	0.45

Table 36. Daily evaporation correlation statistics at Mildred Lake, 1973-1981, by month.

Month	Number of days	Intercept	Coefficients		R^2
			Wind (km)	Temperature (°C)	
April	45	-0.14	0.013	0.30	0.68
May	142	0.17	0.013	0.26	0.47
June	140	-0.87	0.013	0.29	0.41
July	187	-1.77	0.016	0.30	0.36
August	185	-0.29	0.008	0.22	0.22
September	179	-0.48	0.017	0.15	0.32
October	55	0.20	0.006	0.09	0.27
Total	933	-0.60	0.013	0.24	0.35

now occurs in August rather than July, with September and October having somewhat higher values.

It is worthwhile at this point to examine the set of predictor variables that has not been included. Instead of mean daily temperature, the maximum daily temperature and diurnal variation may have been more appropriate. Maximum temperature is likely indicative of the temperature at the evaporating surface while diurnal temperature variation is closely related to incoming solar radiation (Baier and Robertson 1965). Solar energy at the top of the atmosphere may also be appropriate. Baier and Robertson found that with only maximum temperatures, diurnal variation, and solar energy at the top of the atmosphere included in the regression, the fraction of variance explained was 0.46, similar to the average result in Table 36. When solar energy at the surface, windrun, and vapor pressure deficit were included, they found R^2 to be about 0.70. These values represented averages at several locations across Canada.

Estimates of latent evaporation at Mildred Lake were made from measurements of monthly mean pan evaporation according to Holmes and Robertson (1958). They found latent evaporation and open pan evaporation to be highly correlated and found the following relation (upon conversion to SI units):

$$LE = 9.4 + 12.3\ PE \qquad (3)$$

where LE is daily latent evaporation in millilitres and PE is daily pan evaporation in millimetres. The equation was determined as an average over several Canadian locations. Table 37 contains results for Mildred Lake using this relation. The mean values of pan evaporation in this table were taken from days when pan evaporation, windrun, and mean temperature were recorded. Values of latent evaporation at Mildred Lake are within the range of Canada-wide monthly values given by Holmes and Robertson. Their summer values ranged from about 0.4 L to 2.4 L. Because of the use of an average relation, the monthly latent evaporation values should be considered first estimates.

Table 37. Mean daily pan evaporation and estimated monthly latent evaporation[a] by months at Mildred Lake, 1973-1981.

Month	Pan Evaporation (mm)	Latent Evaporation (L)
April	4.1	1.8
May	4.3	1.9
June	4.7	2.0
July	5.0	2.2
August	3.7	1.7
September	4.4	1.9
October	0.8	0.6

[a] Latent evaporation (LE) calculated from pan evaporation (PE) by
$LE = n(9.4 + 12.3\ PE)$
where n is the number of days in each month.

8. MINISONDE STABILITY ANALYSIS

Minisonde data collected in the Athabasca Oil Sands area from 1975 to 1979 were analysed in an attempt to define a stability climatology. The data set was discussed in a previous section. The SAS analysis technique for the minisonde data is presented in Section 11.1.

Several parameters were considered appropriate to indicate atmospheric stability or dispersive ability. Among these were the temperature gradient, the bulk Richardson number, and the dimensionless height Z/L, where L is the Monin-Obukov length and Z is the height above ground. The minisonde data alone are insufficient to produce values of L since estimates of the surface heat flux are required. The surface temperature and wind speed are required for the calculation of the bulk Richardson number since the usual procedure is to define the bottom of each layer at the surface and so include the region of buoyancy production. Unfortunately, the lowest level of minisonde data is typically 50 to 60 m.

The temperature gradient appeared to be the only reasonable alternative. It was not recommended as the optimum measure of stability (Hanna et al. 1977) because it does not contain explicit allowance for mechanically-produced turbulence; however, in the absence of more appropriate parameters it can give an indication of stability.

The procedure for the stability analysis was as follows. The atmosphere below 500 m was divided into three layers (as in Table 38). The temperature gradient in each level was the calculated and assigned to a stability category as defined in Table 39. It is recognized that this United States Atomic Energy Commission (USAEC) classification scheme was thought to be inappropriate for general use in the Athabasca Oil Sands area (Davison and Leavitt 1979) because it was designed to use measurements at 10 and 60 m. However, it has the advantage of classes that coincide with Pasquill stability categories and a fine resolution of the temperature gradients. The temperature gradient values were further stratified by season and time of day but not by release location. The temperature gradient was defined as the temperature difference between the layer top and bottom divided by the

Table 38. Layer definition for minisonde analysis.

Layer	Elevation (m)
1	$60^{a} \leq Z < 150$
2	$150 \leq Z < 300$
3	$300 \leq Z < 500$

[a] Typical height above ground of lowest level.

Table 39. Stability classifications according to USAEC Guide 1.23 (from Davison and Leavitt 1979).

Stability Classification	Pasquill Categories	Temperature change with height (°C/100 m)
Extremely unstable	A	< -1.9
Moderately unstable	B	-1.9 to -1.7
Slightly unstable	C	-1.7 to -1.5
Neutral	D	-1.5 to -1.5
Slightly stable	E	-0.5 to 1.5
Moderately stable	F	1.5 to 4.0
Extremely stable	G	> 4.0

elevation difference. The statistical program that analysed the data produced a relatively large volume of detailed results; a summary of those results is provided here in Tables 40 and 41.

The summary in Tables 40 and 41 illustrates a potential problem with some of the minisonde data. Note the relatively large frequency of category A stability in winter (in catgory A, temperature decreases with height at about twice the adiabatic rate). This is unusual and suggests the trapping of a shallow layer of warm air very near the surface. Note also that category A occurred occasionally in spring in the evening and night between 1800 and 0600 h. This suggests that some of the minisonde profiles should be used with caution.

Seasonal variations of stability class are presented in Table 42. In this table, time of release and layer have been ignored. Spring and summer had approximately equal frequencies in all categories except the most stable wherein spring had slightly higher frequencies than summer. Compared to other seasons, winter had a much higher fraction of stable conditions at all levels, over half of which were category E. During the rest of the year, conditions were mostly neutral. Throughout the year, approximately 80% of minisonde releases were in neutral or slightly stable conditions (between about 60 m and 500 m). This is also clearly illustrated in Table 41 where given any season or time of day, and given a stability category in the lowest layer, the most common stability categories in upper layers were overwhelmingly neutral and slightly unstable.

Time-of-day variations in stability category are presented in Table 43. Seasonal and layer differences have been ignored. The data showed a trend from slightly stable conditions in late night and early morning to predominantly neutral in afternoon and evening. Unstable conditions occurred most frequently in the afternoon; moderately stable conditions occurred most often in the early morning.

Variation of stability with height is shown in Table 44, where time-of-day and seasonal differences have been ignored. At all levels, the most common stability category was neutral to slightly stable. The lowest layer exhibited the widest variation of stability with the most stable and unstable categories ocurring there much more

Table 40. Number frequency of minisonde releases, by season, time of day, stability category and layer.

Season	Time[a]	A			B			C			D			E			F			G		
		1[b]	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Winter	1																					
	2	1	2	1	4	1		1	2		30	15	15	59	91	116	47	28	23	28	10	2
	3	13	3	1	1	1	2	6	1		64	56	44	63	79	82	21	13	20	7	3	1
	4																					
Spring	1	1									14	13	7	8	10	19	5	4			1	
	2	25	3	1	15	3	1	13	6	3	93	118	107	66	88	138	18	37	10	11	1	
	3	45	6	2	12	1	3	15	6	1	88	145	161	30	30	27	2		1			
	4	2						1			5	9	10	1	1		1					
Summer	1						1	1			18	2	3	30	53	14	14	19		3		
	2	39	4		11	4		17	5	4	77	107	102	20	62	79		12	3		2	
	3	32	3	2	12	3	2	19	6	2	81	141	120	15	10	16		1		1		
	4					1			1		16	14	18	4	3	1						
Autumn	1							2				1	1	4	1	1	2	1	1			
	2	7		1	4			11	1		72	54	48	59	50	66	23	22	23	5	1	
	3	20	1		3			8	2	1	100	81	78	28	21	30	6	3	3	2		
	4										1	1	1									

[a] 1 = 0001 - 0600 h; 2 = 0601 - 1200 h; 3 = 1201 - 1800 h; 4 = 1801 - 2400 h.
[b] layer

Table 41. Most common (mode) minisonde stability category in levels 2 and 3, by season and time of day, given a stability category in level 1.

Season	Time[a]	A		B		C		D		E		F		G	
		2[b]	3	2	3	2	3	2	3	2	3	2	3	2	3
Winter	1														
	2	A	E	D	D	C		E	E	E	E	E	E	E	E
	3	D	D		E	D	D	E	E	E	E	E	E	E	E
	4														
Spring	1	F	E					D	E	E	E	F	E		
	2	D	D	D	D	D	E	D	D	E	E	E	E	F	E
	3	D	D	D	D	D	D	D	D	D	D	E	D		
	4	D	D			D	D	D	D	D	D	E	D		
Summer	1					E	E	E	E	E	E	E	E	E	G
	2	D	D	D	D	D	D	D	D	E	E				
	3	D	D	D	D	D	D	D	D	D	D			D	D
	4							D	D	D	D				
Autumn	1					D	D					E	E		
	2	D	D	D	D	E	E	D	D	E	E	E	E	E	E
	3	D	D	D	D	D	D	D	D	D	D	E	D	E	D
	4							D	D						

a 1 = 0001 - 0600 h; 2 = 0601 - 1200 h; 3 = 1201 - 1800 h; 4 = 1801 - 2400 h.
b layer

Table 42. Frequency of occurrence of minisonde stability category by season.

	A	B	C	D	E	F	G
Winter	0.10[a]	0.11	0.07	0.11	0.33	0.44	0.65
	0.02[b]	0.01	0.01	0.23	0.51	0.16	0.05
Spring	0.40	0.41	0.33	0.33	0.28	0.18	0.17
	0.06	0.03	0.03	0.50	0.31	0.05	0.01
Summer	0.37	0.40	0.41	0.35	0.21	0.14	0.08
	0.06	0.03	0.04	0.57	0.25	0.04	0.00
Autumn	0.13	0.08	0.19	0.22	0.18	0.24	0.10
	0.04	0.01	0.03	0.57	0.34	0.11	0.01

[a] Fraction of stability category by season (i.e., 10% of all occurrences of category A occurred in winter.)

[b] Fraction of season by stability category (i.e., 2% of winter stabilities were category A.)

Table 43. Frequency of occurrence of minisonde stability category by time of day.

Time (h)	A	B	C	D	E	F	G
0001 - 0600	0.00	0.00	0.01	0.23	0.55	0.18	0.02
0601 - 1200	0.04	0.02	0.03	0.38	0.40	0.11	0.03
1201 - 1800	0.07	0.02	0.03	0.61	0.22	0.04	0.01
1801 - 2400	0.02	0.01	0.02	0.82	0.11	0.01	-

Table 44. Frequency of occurrence of minisonde stability category by layer.

Height (m)	A	B	C	D	E	F	G
60 - 150	0.12	0.04	0.06	0.42	0.25	0.08	0.04
150 - 300	0.01	0.01	0.02	0.51	0.34	0.09	0.01
300 - 500	0.01	0.01	0.01	0.47	0.45	0.06	0.00

frequently than in the upper layers. About one half of the releases showed evidence of a temperature inversion (categories E and F) in the layer between 300 and 500 m. Davison, Hansen et al. (1981) suggested 400 m to be a typical height for oil sands plant plumes in the area. The exact location of the inversion with respect to the plume will therefore be important for accurately predicting plume dispersion.

In summary, a brief climatological analysis of minisonde-derived stability has been presented. The analysis was meant to illustrate some general properties of the data, including variation with season, time of day, and height above ground. The data showed expected variations of stability with these parameters. The temperature gradient was chosen as a measure of stability, despite its shortcomings. An improved stability climatology, perhaps based on a Richardson Number, would need to use surface measurements as well as those at higher elevations.

9. SUMMARY AND RECOMMENDATIONS

9.1 SUMMARY

The object of this study was to climatologically analyse recently available data in the Athabasca Oil Sands area. The study was to stress spatial variations within the area, especially as they might be caused by terrain, and the normalization of short-term records to provide long-term estimates. The primary source of short-term data was the recently disbanded MAPS network. Longer-term data were available from forestry stations and the Fort McMurray observing station. The nature of the data bases determined the degree of accomplishment of the study objectives.

The MAPS network data covered an insufficient period of record to determine with confidence, and without correlation to longer-term stations in the area, the long-term mean values of meteorological parameters and their spatial variations. With typically three or four years of data available at these stations, spatial and seasonal variations in temperature and especially precipitation could explained by random fluctuations generated by the short record length. Wind data, on the other hand, appeared to be better behaved in that spatial and temporal variations could be linked to terrain features or explained from meteorologcal principles. Because the surface wind data had such a great spatial variation, it was difficult to ascertain whether or not the short-term behaviour was representative of long-term data.

Other types of data measured in the area were generally not suited to deriving climatologies. Snowpack data for January and March exhibited conflicting spatial organizations indicative of insufficient record length. Estimates of atmospheric stability from minisonde data were adequate but could be improved by inclusion of surface data. Meteorological data from forestry stations were of sufficient length but covered only the summer months. Evaporation data were also of sufficient record length but were difficult to transform into estimates of spatial variation.

9.2 CONCLUSIONS

9.2.1 Temperature

Correlation results using daily temperature showed that temperatures at MAPS stations could be reasonably well estimated from the Fort McMurray observations. Further, the derived 30-year normal MAPS temperatures had a similar spatial variation to local 30-year normal patterns of forestry station July temperatures. However, the magnitude of the difference between the forestry station and MAPS temperatures was not constant, nor did it clearly vary with elevation. While the use of annual regression parameters likely contributed to this difference, the lack of spatial organization of the difference suggests that random fluctuations due to the short record length could largely be the cause. Despite this difference, temperatures at MAPS stations can be estimated either by Fort McMurray temperature throughout the year or by forestry stations in summer months with acceptably small errors.

Analysis of hourly temperatures at Mildred Lake during the period 1976 to 1981 showed a median annual temperature of 3°C and an annual temperature range of 77°C. Transition months such as April and October had the widest range of temperatures. July had the narrowest range.

Spatial variations of mean July maximum and minimum temperatures were strongly functions of terrain. Areas of high elevation had temperatures about 1 to 2°C cooler than low lying areas. Spatial organization was weaker for minimum temperatures. Diurnal variation of temperature was generally 3°C more in low lying areas than at high elevations. A large gradient in maximum and minimum temperatures existed between Fort McMurray and nearby Thickwood, likely due to the higher elevation at Thickwood.

According to Longley and Janz (1978), the mean frost-free period in the area is about 50 days. The average frost-free period at MAPS stations based on data from 1977 to 1979 inclusive was about 100 days, which agrees with data provided by forestry stations from 1966 to 1979. A difference in definition of the frost-free period appears to exist.

9.2.2 Precipitation

Precipitation at MAPS stations was correlated with precipitation at Fort McMurray. Correlations using daily precipitation totals were poor; however, those using monthly totals were better in that all but two stations had correlation coefficients above 0.7. Thirty-year July normals fit the spatial patterns of the forestry station normals. Again, the spatial variation of the difference between MAPS and forestry stations was not clearly linked to terrain. The inherently large spatial variability of precipitation requires that a large number of years are needed to produce reasonable regression coefficients from which to predict long-term values.

Analysis of hourly precipitation at Mildred Lake during the period 1976 to 1981 showed a median value of 200 hours of precipitation annually. Of this total, most hours occurred in July (about 36) and the least in January (about 11). Large values of precipitation of one or two hours duration at MAPS stations were found to be erroneous based on comparisons with daily precipitation totals at adjacent forestry stations. A clear relation existed between terrain and the largest consecutive number of hours of precipitation at each MAPS station. Highest elevations were coincident with longest durations.

Spatial variation of mean July precipitation was found to be related to terrain. The largest amounts were recorded at the highest elevations. The range of July precipitation in the area was from 60 to 115 mm.

Snowpack data measured in the period 1976 to 1982 were found generally to have no clearly organized spatial pattern due partly to an insufficient length of record and partly to inconsistent measurement techniques.

9.2.3 Wind

The diurnal variation of wind was examined for the months January, April, July, and October. No variation with time of day was observed in January or October. Diurnal variation was observed in April but was most prominent in July when wind speeds were about 20% higher during afternoon hours than late night hours. Wind directions in July had apparent upslope components during daylight hours and downslope or downvalley components at night. In January, winds were controlled strongly by terrain at all hours. At no stations did diurnal effects dominate the flow regime.

As found by Longley and Janz (1978), the windiest times of the year were the transition seasons: spring and autumn. Winters had the lowest annual speeds. Although, in general, highest elevations experienced the least number of calms, the most frequent calms were experienced during autumn and winter at Stoney Mountain. Similarly, mean monthly wind speeds were highest at high elevations. No trend in prevailing monthly wind directions that might indicate an annual variation in terrain influence was observed.

A comparison of pibal winds measured at 400 m with MAPS station winds at coincident times showed that the MAPS winds were not generally representative of the pibal winds throughout the year. Differences in direction between the 400-m and MAPS winds in winter were sometimes large and apparently random due to flow decoupling near the surface in stable conditions. In other seasons, differences were more organized with a poorly defined trend to less than a 20° veer between the surface and 400 m (based on a 16-point compass). A wind veering with height is expected from considerations of surface friction. In many cases, likely those with stable conditions near the surface, MAPS winds were indicative of terrain influence (especially valley channeling), regardless of the 400-m flow.

The large differences between winds measured at different locations were caused largely by terrain effects. It is concluded that surface winds at one location cannot be used with confidence to estimate winds at other locations in the Athabasca Oil Sands area.

9.2.4 Evaporation

A linear regression analysis showed that almost half of the variance of daily evaporation measurements could be explained by variations in daily windrun, mean temperature, and precipitation. Increases in temperature and wind speed increased rate; the occurrence of precipitation decreased evaporation, likely through its inhibition of incoming radiation. Summertime estimates of latent evaporation using pan evaporation measurements were within the range of Canada-wide values found by Holmes and Robertson (1958).

9.2.5 Minisonde

A statistical analysis of minisonde data was undertaken with the aim of developing a stability climatology for the Athabasca Oil Sands area. Despite its shortcomings, temperature gradient was used to estimate stability. The results of the analyses showed that stability, defined at three levels between about 60 m and 500 m above ground, was predominantly (approximatey 80%) neutral or slightly stable, based on the USAEC seven-category stability scale. Seasonal trends of higher frequencies of stable conditions in winter and unstable conditions in spring and summer were noted. Hourly trends of more frequent stable conditions in late night and early morning than in the afternoon and evening were evident. Variations with height showed that a much wider range of stability classes existed in the lowest layer, while the upper layers remained largely neutral to slightly stable regardless of stability in the lower layer. It was concluded that surface measurements, in addition to those at higher elevations, are required to provide an improved stability climatology.

9.3 RECOMMENDATIONS

1. It is recommended that future studies involving new data sets begin with a thorough examination and assessment of data quality. The assessment should be undertaken by someone with a knowledge of both meteorology and the instrumentation, who has access to records of installation and maintenance. Only after this step should analyses with the data be undertaken.
2. It is recommended that the requirements for meteorological data acquisition in the Athabasca Oil Sands area be reassessed. It is suggested that the only justification for a network such as MAPS is as surface-based input to air quality models. It is recommended that the data

requirements of models suitable for use in the area be ascertained before meteorological monitoring is re-established.

3. In view of the influences of terrain on surface and plume level winds in the area, it is recommended that a three-dimensional complex terrain flow model be developed and that existing MAPS and minisonde data be used as appropriate for testing of the model.
4. It is recommended that MAPS precipitation data be re-examined in greater detail. The purpose would be twofold. First, to investigate causes of occasional high hourly values and to flag the suspect hours. Second, to perform further regression analysis of the MAPS data with the Fort McMurray data to improve the correlation statistics.
5. It is recommended that subsequent snowpack measurements be undertaken on a common date each month (for example, the last day) and that all measurement procedures be fully documented. It is also recommended that the same sites be used each year in order to build a sufficient record length for climatological analysis.
6. If spatial variations of frost-free period within the area are considered important, it is recommended that frost-free periods at MAPS stations be correlated with those at Fort McMurray in a manner similar to temperature and in this way produce long-term estimates.

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11. APPENDICES

11.1 DESCRIPTION OF THE SAS ANALYSIS PROCEDURES

11.1.1 Introduction

The Statistical Analysis System (SAS) software package produced the tables that formed the basis for this report. SAS procedures were applied to data sets that were created from the original data records; these data sets are then operated upon by statistical tools that were contained within SAS.

The logical steps that are required for each task are as follows: (1) input of the raw data; (2) derived variable definition and quality control; and (3) output of statistical data. In this section, a description of these steps for the tables associated with this report is given.

11.1.2 MAPS Data

For each MAPS station, hourly values of precipitation, wind, and temperature variables were recorded. Tables of these hourly values are required as well as tables of daily and monthly averages. These analyses are now described in turn.

11.1.2.1 Hourly Analysis.

1. Input. Since each year of data is on a separate file, it was necessary to read all six files for each station. The raw data were read as given and stored on files labeled FILE1, FILE2, ... FILE6. In each record, the year, month, day, hour, precipitation amount, wind direction, wind speed, and temperature are given.
2. Secondary Variable Definition and Quality Control. The six input files were merged to a data set ALL. The station name was defined and the date was derived from the year, month, and day variables. The temperature value was decoded so that its value was available in degrees Celsius and it was then rounded to the nearest

integer. The data set was then sorted by station, year, month, day, and hour values.

The quality control steps were carried out in data set ALL2. Temperature values less than -60 and greater than 40 were deemed to be errors and were set to missing. Negative wind speeds or wind speeds greater than 100 were also set to missing. The precipitation value in the raw data set was its cumulative value. To obtain the amount of precipitation that fell in the hour in question, PHOUR, the cumulative value for that hour, PPTN, was decreased by the value of PPTN in the preceding hour. If the value for the preceding hour was missing, then the value two hours earlier was used. If this value was also missing, then the precipitation for the hour in question was set to missing. If the cumulative value for the hour in question was negative or missing, then the precipitation for this hour was set to missing. If PHOUR was greater than 50 mm, then an error was deemed to have occurred and PHOUR was again set to missing.

If the temperature for a given hour was less than 0°C, then all precipitation that fell in that hour was deemed to be snow. If the temperature was greater than or equal to 0°C, then all precipitation for that hour was deemed to be rain. If the temperature was missing, then both rain and snow values were set to missing. If this occurred when the value of PHOUR was non-zero, then the sum of rain and snow amounts would not be equal to the total precipitation as one would normally expect.

Wind speed and the time of day were placed in intervals which were defined by the variables XSPD and TIME. The boundaries of these intervals are given in Table 45.

3. Output. From the data set ALL2 given, hourly temperatures were produced for the four months, January, April, July, and October, and for the year as a whole. Cross-tabulations of wind speed and direction were given.

Table 45. Range of WSPD and HOUR for each value of XSPD and TIME.

WSPD Value	XSPD Value	HOUR Value	TIME Value
0	0	1, ≤ 6	1
1, ≤ 3	1	7, ≤ 12	2
4, ≤ 7	2	13, ≤ 18	3
8, ≤ 12	3	19, ≤ 24	4
13, ≤ 18	4	missing	missing
19, ≤ 24	5		
25, ≤ 31	6		
32, ≤ 38	7		
39, ≤ 46	8		
47, ≤ 54	9		
55, ≤ 63	10		
64, ≤ 75	11		
≥ 76	12		
missing	missing		

In these tables, the wind speed categories were defined by the values of XSPD as given by Table 45. The wind direction categories were specified by a 16-point compass combined with the calm category. These cross tabulations were given for each month and for the entire year. For each of the four months given above, similar cross-tabulations of wind speed and direction were stratified according to the time of day using the variable TIME (see Table 45). Average wind speeds for each direction; each direction and each month; and each direction, each month and each time of day were also calculated. This output was found at the end of the program output. Ogives of hourly rainfall, snowfall, and precipitation amount were also given for each of these four months and for the year as a whole.

11.1.2.2 Daily Analysis.

1. Input. Variables involved in daily analyses included the mean, maximum, and minimum daily values of temperature, hourly rainfall, snowfall, and total precipitation. In addition, the cumulative daily rainfall, snowfall, and total precipitation were also used. In the program, the variable names are as given in Table 46. The data set containing these variables is called DAY1.
2. Secondary Variable Definition and Quality Control. The variable TVAR was defined to be the difference between the daily maximum and daily minimum and was called the daily temperature variation.
   If three or more hours in a day had missing values for any hourly variable, then the daily variables derived from these hourly values were set to missing. This test was carried out for precipitation, rain, snow, and temperature variables independently. After this quality control step, the surviving daily data were stored in data set DAY2.

Table 46. Variable names for daily analysis.

Variable	Daily Mean	Daily Maximum	Daily Minimum	Daily Accumulation
TEMP	TMEAN	TMAX	TMIN	-
PHOUR	PMEAN	PMAX	PMIN	PSUM
RAIN	RMEAN	RMAX	RMIN	RSUM
SNOW	SMEAN	SMAX	SMIN	SSUM

3. Output. Ogives of TMEAN, TMAX, TMIN, and TVAR were given for each month and for the year as a whole. The mean, standard deviation, minimum, and maximum values were also given for each month and for all months taken together. Ogives were also provided for the precipitation variables PMEAN, PMAX, PMIN, PSUM, RMEAN, RMAX, RMIN, RSUM, SMEAN, SMAX, SMIN, and SSUM and the secondary statistical parameters were calculated for PSUM, RSUM, and SSUM. The number of frost-free days in each year was calculated in data sets DAY3 and DAY4. Frost was deemed to have occurred when the minimum temperature fell below 0°C.

11.1.2.3 Monthly Analysis.

1. Input. Variables involved in the monthly analysis included the mean, minimum, maximum, and accumulation of the daily temperature mean, minimum, and maximum values, and the daily mean maximum and accumulation of precipitation, rain, and snow values. The variable names are given in Table 47. The data set containing the variables is MONTH2.
2. Secondary Variable Definition and Quality Control. In order for the monthly variables in Table 44 to be valid, it was necessary that no more than seven missing values occurred in the antecedent daily variable for the month in question. The quality control step was carried out in the data set MONTH3.
3. Output. For each month in the data set, the total accumulated rain, snow, and precipitation was provided. Monthly mean, minimum, and maximum values of the daily mean, minimum, and maximum temperatures were also given.

11.1.2.4 Comparison of MAPS and 400-m pibal winds.

1. Input. Data sets INT1 contained 31031 values of MAPS wind speed and direction (SPD, DIR). Data set A2

Table 47. Variable names for monthly analysis.

Variable	Monthly Mean	Monthly Minimum	Monthly Maximum	Monthly Accumulation
TMEAN	MEANTM	MINTM	MAXTM	SUMTM
TMIN	MEANTN	MINTN	MAXTN	SUMTN
TMAX	MEANTX	MINTX	MAXTX	SUMTX
PMEAN	MEANPM	MINPM	MAXPM	SUMPM
PMAX	MEANPX	MINPX	MAXPX	SUMPX
PSUM	MEANPS	MINPS	MAXPS	SUMPS
RMEAN	MEANRM	MINRM	MAXRM	SUMRM
RMAX	MEANRX	MINRX	MAXRX	SUMRX
RSUM	MEANRS	MINRS	MAXRS	SUMRS
SMEAN	MEANSM	MINSM	MAXSM	SUMSM
SMAX	MEANSX	MINSX	MAXSX	SUMSX
SSUM	MEANSS	MINSS	MAXSS	SUMSS

contained 20836 values of minisonde and pibal wind speed and direction (WSPD, WDIR).

2. Secondary variable definition and quality control. Both data sets were sorted by month and time and ALL (the merged set of WSPD and WDIR) was also sorted by layer. Directions for the pibal winds were converted to a 16-point compass. Variable SEP stored the elevation nearest 400 m. The two data sets were then merged to form MGR with 898 concurrent observations of MAPS and minisonde data (at Muskeg; other stations had slightly different numbers). Power law wind exponent was then defined as:

   ALPHA = LOG (WSPD/SPD)/LOG(ELEV/10)

   where ELEV is the elevation of SEP.

3. Output Average monthly windspeed was listed for each hour of the day. Two-way frequencies of hour-of-day against wind direction were output for each month. For each season, two-way frequencies of MAPS direction against 400-m direction were printed. Finally PROC MEANS was used to list variable ALPHA statistics.

11.1.3 Forestry Data

For each forestry station, daily values of maximum, minimum, and average temperature and accumulated rainfall, snowfall, and precipitation were given. Since hourly values and wind information were not available, only tables of daily and monthly precipitation and temperature statistics can be provided.

11.1.3.1 Daily Analysis.

1. Input. The data on the original tape archive were recorded such that one record contained all the measurements of a weather element (for example, mean temperature) for all days in a month. The data sets FORSET, D1, D2, D3, D4, D5, and D6 rearranged this data format so that one record

contained all six weather elements for a given day. These records formed the data set ALL2.

2. Secondary Variable Definition and Quality Control. The quality control process for the forestry data was identical with the process for the MAPS stations which was described previously with the following exceptions.

   The values of rainfall and snowfall were not secondary variables inferred from precipitation and temperature information but were given directly. One may therefore expect the precipitation value to be the sum of the rainfall and snowfall values.

   The precipitation values were not the accumulated values from record to record but were the actual values for the day in question. Therefore, the complications that arose in the MAPS data were not a problem here. In the MAPS hourly data precipitation, amounts greater than 50 mm were deemed to be errors and were set to missing. In the forestry daily data this cutoff figure was set to 150 mm. Otherwise, all out-of-range tests for this data set were identical to those described previously for MAPS data. Only data after 1965 and during the summer months were considered in the analysis.

3. Output. Tables of daily values were taken from the data set ALL3, which was an earlier version of ALL2.

   Ogives of the three temperature parameters and TVAR = TMAX - TMIN were given for the three months separately and for the entire data set. Similar tables were also produced for daily rainfall, snowfall, and precipitation. In addition, mean value, standard deviation, maximum, and minimum values of the three precipitation variables were given for each month.

   The frost-free period was calculated from the values of TMIN in the same way as was done for the MAPS data.

11.1.3.2 Monthly Analysis.

1. Input. The derivation of monthly variables from daily values was identical to the process described for MAPS stations. The data set containing monthly data is MONTH3.
2. Secondary Variable Definition and Quality Control. This step was identical to that described for MAPS stations. The data set MONTH4 contains the monthly data after quality control.
3. Output. Output tables of monthly variables were as described for MAPS stations.

11.1.4 Minisonde Data Analysis

11.1.4.1 Input. Every record on this file contains the year, month, day, hour, minute, elevation, variable type, and value. On the original file 20 836 wind speed and 20 656 temperature values were found. All such values coincided with elevations less than 500 m.

11.1.4.2 Secondary Variable Definition and Quality Control. The wind speed file A2 and the temperature file C2 were merged by year, month, day, hour, minute, and elevation. This increased the resulting data at ALL to include 30 755 records. The secondary variable LAYER, SEASON and TIME were defined as shown in Table 48. The temperature for the first reading in each layer was given the value TMINE and the last reading a value TMAXE.

Average, minimum, and maximum values of temperature, windspeed, elevation, TMINE, and TMAXE were obtained for each value of RELEASE (time) and LAYER. The variable names are given in Table 49. There were 8591 different combinations of RELEASE and LAYER which implies that approximately four readings per layer were made. These data make up the data set LEVEL1.

Data set LEVEL1 was then broken into three parts according to the value of LAYER. The set LEVEL1A (LAYER = 1) has 2514 observations, the set LEVEL2A (LAYER = 2) has 2619 observations, and the set LEVEL3A

Table 48. The range of ELVE, MTH, and HOUR for each value of LAYER, SEASON, and TIME.

ELEV value	LAYER value	MTH value	SEASON value	HOUR value	TIME value
0, < 150	1	1, 2, 12	1	0^{a}, $\leq 6^{b}$	1
150, < 300	2	3, 4, 5	2	6^{a}, $\leq 12^{b}$	2
300, < 500	3	6, 7, 8	3	12^{a}, $\leq 18^{b}$	3
		9, 10, 11	4	18^{a}, $\leq 24^{b}$	4

[a] value included only if MIN = 0
[b] value included only if MIN = 0

Table 49. Variable names for minisonde analysis.

Variable	Layer Mean	Layer Maximum	Layer Minimum
TEMP	TMEAN	TMAX	TMIN
WSPD	WMEAN	WSPDMX	WSPDMN
ELEV	EMEAN	ELMAX	ELMIN
TMINE	TMNMEAN	TMNMAX	TMNMIN
TMAXE	TMXMEAN	TMXMAX	TMXMIN

(LAYER = 3) has 2649 observations. There were 809 observations in the set LEVEL1 in which the value of LAYER was not 1, 2, or 3. The temperature gradient was then defined for all observations in LEVEL1A, LEVEL2A, and LEVEL3A and these values were then grouped into seven intervals defined by the variables R1, R2, and R3, as given in Table 50. Finally, these three data sets were merged according to the release time to form the data set RTOT, a data set with 2741 observations.

For many of these observations the values of at least one of R1, R2, and R3 are undefined. This is due to a missing value of temperature in the first or last observation in the layer or to the value of wind speed being absent for all observations in the layer. In the first layer, temperature is absent for 932 observations and wind speed is absent in a further 343 observations. In the second layer, 1139 and 330 observations have missing temperature or wind speed values, respectively; in the third, 1194 and 322 observations are so affected. When the data sets are merged, only 967 observations have non-missing values for all of R1, R2, and R3.

The number of minisonde releases on file (2289) is larger than the number analysed by SAS (967). There are several reasons for this difference. In some cases, one or both of wind speed and temperature observations are missing for a particular level. A random examination of the data indicates that wind speed was the datum most often missing. The most common cause of missing R1, R2, or R3 values, as indicated above, was the fact that wind speed and temperature were not always defined on the same level. SAS computes a temperature gradient only if temperature is the topmost and bottommost observation in a layer. For example, suppose a layer contains alternating observations of wind speed, wind direction, and temperature. Even though there may be an adequate number of observations of temperature to define a gradient, SAS defines the gradient as missing because, with alternating observations, temperature cannot be both the topmost and bottommost observation, given equal numbers of each observation type in the layer.

Table 50. The range of R temperature gradient for each value of R1, R2, and R3.

R Value (°C/100 m)	Value of R1, R2, or R3
$R < -1.9$	1
$-1.9 \leq R \leq -1.7$	2
$-1.7 \leq R < -1.5$	3
$-1.5 \leq R < -0.5$	4
$-0.5 \leq R < 1.5$	5
$1.5 \leq R < 4.0$	6
$R \geq 4.0$	7

11.1.4.3 Output. Joint frequency tables for R1, R2, and R3 are presented (1) without stratification; (2) stratified according to the variable TIME (see Table 49); (3) stratified according to the variable SEASON (see Table 49); and (4) stratified according to TIME and SEASON.

11.1.5 Evaporation

11.1.5.1 Input. The input format for the data base was similar to the data base for the forestry stations. Each record had all the daily data for a particular variable for a given month. Before these data could be analysed, it was necessary to rearrange them so that all variables for a given day were on the same record. Also, the total precipitation data were only available in another data base (SAVE.DAY2) which was also read by this program. The evaporation data were in the data set D1, the wind data in D2, and the temperature data in D3. The four separate files were merged by YR, MTH, and DAY to yield the final data set ALL.

11.1.5.2 Secondary Variable Definition and Quality Control. All negative values of precipitation, wind run, and temperature were set to missing. Temperatures less than -50 and greater than 40 were assumed to be errors and were set to missing. Of the 2480 records in the data set ALL, 1333 had missing temperature values and 1520 had missing evaporation values.

11.1.5.3 Output. The mean, standard deviation, minimum value, maximum value, and standard error of the mean were calculated for each month and each year of the data set. Then a multiple linear regression of the form

$$EVAP = A + B * PSUM + C * TEMP + D * WIND$$

was performed for each month. A second regression of the form

EVAP = A + B * TEMP + C * WIND

was also performed. All four variables were never present together for the months of November to March inclusive and the analysis, as a result, could not be performed for these months.

The output for the regression analysis is well labeled and reasonably straightforward to those familiar with the technique.

11.2 CONSECUTIVE HOURS WITH PRECIPITATION

This appendix provides a summary of the number of consecutive hours of precipitation at stations within the MAPS network as function of the amount of precipitation that fell during the interval. These numbers are accumulations over all available precipitation hours. Station down-time (if it occurred) will prevent these results from representing fully annual statistics.

STATION: Stony Mountain
PERIOD: October 1977 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	490	125	19	7	4	3	4	3	9	0	5	3	3	6	2				683	81.5
2		46	25	9	10	2	2	2	1			1			1				99	11.8
3			6	6	5	1	1	1	1	1									22	2.6
4					5		2	3	2										12	1.4
5					1		1	1	3	1	1								8	1.0
6								2											2	0.2
7								1		3			1						4	0.5
8-9									1	1									2	0.2
10-12											1	1							2	0.2
≥ 13												1						1	2	0.2
COLUMN TOTAL	490	171	50	22	25	6	10	13	17	6	7	6	4	6	3	-	-	1	837	
	58.5	20.6	6.0	2.6	3.0	0.7	1.2	1.6	2.0	0.7	0.8	0.7	0.5	0.7	0.4	0	0	0.1		

STATION: Muskeg
PERIOD: October 1976 to April 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	366	64	33	12	9	2	2	3	2	4	1	3	7	4	1				513	80.3
2		25	17	21	7	3	3								1				77	12.1
3			6	4	7	2	1	1	1	1									23	3.6
4				2	4	2	4		2										14	2.2
5					3		1	1											5	0.8
6							1	1	2		1								5	0.8
7											1								1	0.2
8-9													1						1	0.2
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	366	89	56	39	30	9	12	6	7	5	3	3	8	4	2	0	0	0	639	
	57.3	13.9	8.8	6.1	4.7	1.4	1.9	0.9	1.1	0.8	0.5	0.5	1.3	0.6	0.3	0.0	0.0	0.0	100	

STATION: Ells
PERIOD: October 1976 to May 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	412	59	11	4	2	3	5	1	1	1	1	3	3	3	2				511	82.6
2		36	20	6	5	1	1	1	1					1					72	11.6
3			8	2	2	2		1	1										16	2.6
4				2	4		4		1										11	1.8
5							1			1									2	0.3
6							1	1	1	1			1						5	0.8
7																			0	0
8-9									1										1	0.2
10-12																			0	0
≥ 13														1					1	0.2
COLUMN TOTAL	412	95	39	14	13	6	12	4	6	3	1	3	4	5	2	0	0	0	619	
	66.6	15.3	6.3	2.3	2.1	1.0	1.9	0.6	1.0	0.5	0.2		0.6	0.8	0.3	0	0	0		

STATION: Mildred Lake
PERIOD: September 1976 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	523	94	23	7	3	3	4	3	3	1	6	4	1	6	4				685	78.7
2		43	25	8	7	5				2	2		1						93	10.7
3			6	12	13		5	2		1	1		1						41	4.7
4				3	5	4	7	2	1	1				1					24	2.8
5					1	2	3	3			1								10	1.1
6							1	2	2	2		1							8	0.9
7									2	1									3	0.3
8-9								1				2							3	0.3
10-12										1			1			1			3	0.3
≥ 13																			0	0
COLUMN TOTAL	523	137	54	30	29	14	20	13	8	9	10	7	4	7	4	1	0	0	870	
	60.1	15.7	6.2	3.4	3.3	1.6	2.3	1.5	0.9	1.0	1.1	0.8	0.5	0.8	0.5	0.1	0	0		

STATION: Thickwood
PERIOD: January 1977 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS

	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	716	42	13	7	1	3	4	5		4	8	5	5	3	3				821	84.7
2		43	16	6	2	2		2	1			1							73	7.5
3			8	7	4	3	4	3		3									32	3.3
4				3	1	4	5	1	1	1		1							17	1.8
5					2	3	2	1	1		2								11	1.1
6						1	1	2		2									6	0.6
7																			0	0
8-9									4	1			1						6	0.6
10-12														1					1	0.1
≥ 13												1				1	1		3	0.3
COLUMN TOTAL	716	85	37	23	10	16	16	14	7	11	10	8	6	4	3	1	1	0	968	
	74.0	8.8	3.8	2.4	1.0	1.7	1.7	1.4	0.7	1.1	1.0	0.8	0.6	0.4	0.3	0.1	0.1	0		

STATION: Fort Hills

PERIOD: September 1976 to September 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	77	367	4	29	1	7	5	3	2	5	3	3	3		4				513	82.4
2		5	8	35		12	7	1	1			1							70	11.5
3			2	3	1	7	5	2		1	1								22	3.5
4						1	2	2		2			1						8	0.3
5										1			1						2	0.2
6													1	1					1	0.3
7								1											2	0.3
8-9								1		1					1				3	0.5
10-12																				
≥ 13																				
COLUMN TOTAL	77	372	14	67	2	27	19	10	3	10	4	4	6	1	5				621	
	12.1	60.3	2.3	10.8	0.3	4.4	3.1	1.6	0.5	1.6	0.6	0.6	1.0	0.2	0.8					

STATION: Richardson
PERIOD: September 1976 to May 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	331	73	27	17	13	4	3	13	4	8	10	8	3	2	2				518	81.4
2		20	18	10	8	3	2	1			2	1		1		1			67	10.5
3			2	10	5	3	2	2	1										25	3.9
4				2	7	1	1	1	1	1									14	2.2
5							1		1		2								4	0.6
6								4			1								5	0.8
7																				
8-9								1			1								2	0.3
10-12														1					1	0.2
≥ 13																				
COLUMN TOTAL	331	93	47	39	33	11	9	22	7	9	16	9	3	4	2	1	0	0	636	
	52.0	14.6	7.4	6.1	5.2	1.7	1.4	3.5	1.1	1.4	2.5	1.4	0.5	0.6	0.3	0.2	0	0		

STATION: Birch Mountain
PERIOD: September 1976 to May 1980

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	440	17	11	3	1	1		3	1	1	4	4		4	2				492	79.1
2		38	16	6		4	1	3	3	2	1		1						75	12.1
3			9	5	3	2			2		1								22	3.5
4					2	2	3	1	1										9	1.4
5					3	1	1	4			1								10	1.6
6							1	1	1	1									4	0.6
7								3											3	0.5
8-9								1			1								2	0.3
10-12										2			1	1					4	0.6
≥ 13																1			1	0.2
COLUMN TOTAL	440	55	36	14	9	10	6	16	8	6	8	4	2	5	2	1	0	0	622	
	70.7	8.8	5.8	2.3	1.4	1.6	1.0	2.6	1.3	1.0	1.3	0.6	0.3	0.8	0.3	0.2	0	0		

STATION: Firebag
PERIOD: October 1976 to April 1980

PRECIPITATION (mm)

CONSECUTIVE NO. OF PRECIPITATION HOURS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	363	69	18	8	4	5		2	4	1	1	1	2	6	3				487	80.9
2		36	16	8	4	2					1								68	11.3
3			7	7	7	3	1	1											26	4.3
4				2	2	2	3	2	1	1									13	2.2
5							1	1		2									4	0.7
6								2		1									3	0.5
7																			0	0.0
8-9														1					1	0.2
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	363	105	41	25	17	12	5	8	5	5	2	1	2	7	4	0	0	0	602	
	60.3	17.4	6.8	4.2	2.8	2.0	0.8	1.3	0.8	0.8	0.3	0.2	0.3	1.2	0.7	0.0	0.0	0.0	100	

11.3 CONSECUTIVE DAYS WITH PRECIPITATION

11.3.1 MAPS Network

This appendix provides data on the number of consecutive days with precipitation as a function of the amount of precipitation falling within a given interval. These numbers are accumulations over all available days of data in the period 1976 to 1981. Note that station down-time (if it occurred) will bias the results from representing fully annual statistics.

STATION: Stony Mountain

PERIOD: October 1977 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	66	31	16	6	7	3	3	6	3	1	5	1			2				150	54.7
2		8	9	12	4	6	6	7	6	2	1	5	3	2	1	1			73	26.6
3			3	1	5	2		4	1		3	1	2		2				24	8.8
4				1					1	2	2	1		2			1	1	11	4.0
5								2	2		1		1	1	1	1			9	3.3
6									1				1		1				3	1.1
7														1		1			2	0.7
8-9											1								1	0.4
10-12																		1	1	0.4
≥ 13																			0	0
COLUMN TOTAL	66	39	26	20	16	11	9	19	14	5	13	8	7	6	7	3	1	2	274	
	24.1	14.2	10.2	7.3	5.8	4.0	3.3	6.9	5.1	1.8	4.7	2.9	2.6	2.2	2.6	1.1	0.4	0.7		

STATION: Muskeg
PERIOD: October 1976 to April 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	65	18	15	11	14	3	4	3	2	1	2	2	2	2		2			146	61.9
2		8	6	5	8	3	7	5	3	5	1	2	2	2					57	24.2
3				2	2		3	4	2		2	1	1		1				18	7.7
4					1			2				1	1	2	1	1		1	10	4.2
5										2									2	0.8
6															1	1			2	0.8
7																			0	0.0
8-9																			0	0.0
10-12																1			1	0.4
≥ 13																			0	0.0
COLUMN TOTAL	65	26	21	18	25	6	14	14	7	8	5	6	6	6	3	5	0	1	236	
	27.5	11.0	8.9	7.7	10.6	2.5	5.9	5.9	3.0	3.4	2.1	2.5	2.5	2.5	1.3	2.1	0.0	0.4	100	

STATION: Ells
PERIOD: October 1976 to May 1980

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	62	27	8	7	4	5	3	1	2	2	1	3	2	1	1				129	61.1
2		5	8	8	6	3	7	3	4	1	1	3							49	23.2
3				4		3	1		5		1	1	3	2		1	1		22	10.4
4							1	2			1	1							5	2.4
5								1			1								2	0.9
6															1	1			2	0.9
7																			0	0
8-9																	1		1	0.5
10-12																1			1	0.5
≥ 13																			0	0
COLUMN TOTAL	62	32	16	19	10	11	12	7	11	3	5	8	5	3	2	3	2	0	211	
	29.4	15.2	7.6	9.0	4.7	5.2	5.7	3.3	1.4	1.4	2.4	3.8	2.4	1.4	0.9	1.4	0.9	0		

STATION: Mildred Lake

PERIOD: September 1976 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	80	28	14	13	7	5	4	1	6	2	3	3	2	2					170	55.2
2		9	7	12	6	7	7	9	8	10	5	6		5	2				93	30.2
3			2	2	2	1	2	2	1	4	3		1	2	2	1	1		26	8.4
4						3	1		2	1			1	2					10	3.2
5						1	1			1	1					1			5	1.6
6												1						1	2	0.6
7														1					1	0.3
8-9																			0	0
10-12																	1		1	0.3
≥ 13																			0	0
COLUMN TOTAL	80	37	23	27	15	17	15	12	17	18	12	10	4	12	4	2	2	1	308	
	26.0	12.0	7.5	8.8	4.9	5.5	4.9	3.9	5.5	5.8	3.9	3.2	1.3	3.9	1.3	0.6	0.6	0.3		

STATION: Thickwood
PERIOD: January 1977 to December 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	91	29	10	8	4	5	4	2	2	5	1	1	3	4	1				170	56.9
2		14	7	9	5	3	8	5	6	6	2	1		3	1	1			71	23.7
3			2	2	1	1	6	2	2	3	1	3		3					26	8.7
4					1	1		3	1		2	1	2	4	1			1	17	5.7
5								3	2									1	6	2.0
6													1	1			1		3	1.0
7									1		1				1	1			4	1.3
8-9												1			1				2	0.7
10-12																			0	0
≥ 13																			0	0
COLUMN TOTAL	91	43	19	19	11	10	18	15	14	14	7	7	6	15	5	2	1	2	299	
	30.4	14.4	6.4	6.4	3.7	3.3	6.0	5.0	4.7	4.7	2.3	2.3	2.0	5.0	1.7	0.7	0.3	0.7	100	

STATION: Fort Hills
PERIOD: September 1976 to September 1981 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	15	93	4	29	2	13	12	9	1	5	8	2	1	1					195	69.9
2		1	3	14		8	5	1	5	5	2	5	2	1	2	1			55	19.7
3			1			1		3	3	6	1	1	1	1		2			20	7.2
4								1		1	1			1	1				5	1.8
5										1	1								2	0.7
6															1				1	0.4
7																	1		1	0.4
8-9																				
10-12																				
≥ 13																				
COLUMN TOTAL	15	94	8	43	2	22	17	14	9	18	13	8	4	4	4	3	1	0	279	
	5.4	33.7	2.9	15.4	0.7	7.9	6.1	5.0	3.2	6.5	4.7	2.9	1.4	1.4	1.4	1.1	0.4	0		

STATION: Richardson

PERIOD: September 1976 to May 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	42	15	15	13	11	7	5	6	1	4	3	5	2	1	1				131	57.0
2		9	8	6	4		6	8	3	2	3	4	5	2	1	1			62	27.0
3				1		1	1	3	1	3	6	3		1	1	3			23	10.0
4								2	1		1	1	2			1	1		10	4.3
5											1			1					2	0.9
6												1				1			2	0.9
7																				
8-9																				
10-12																				
≥ 13																				
COLUMN TOTAL	42	24	23	20	15	8	12	19	6	9	14	14	9	5	3	6	1	0	230	
	18.3	10.4	10.0	8.7	6.5	3.5	5.2	8.3	2.6	3.9	6.1	6.1	3.9	2.2	1.3	2.6	0.4	0		

STATION: Birch Mountain

PERIOD: September 1976 to May 1980 PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	75	22	11	6	5	2	2	2	2	1	3	2		3		1			137	59.6
2		11	10	8	3	3		3	3	3	2	1	4	2	2	1			56	24.3
3			1	1		3	1		2	1	2	4	1						16	7.0
4				2	1	1	2	1	1	2	1								11	4.8
5								2				1						1	4	1.7
6								1			1			1					3	1.3
7											1		1						2	0.9
8-9																1			1	0.4
10-12																			0	0
≥ 13																			0	0
COLUMN TOTAL	75	33	23	17	9	9	5	9	8	7	10	8	6	6	2	2	0	1	230	
	32.6	14.3	10.0	7.4	3.9	3.9	2.2	3.9	3.5	3.0	4.3	3.5	2.6	2.6	0.9	0.9	0	0.4	10.0	

STATION: Firebag
PERIOD: October 1976 to April 1980

PRECIPITATION (mm)

CONSECUTIVE NO. OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	43	26	9	8	4	5	4	2	2	1	1	2	1	4	1				113	54.9
2		4	11	7	4	7	6	2	8	2	4	2	1		2				60	29.1
3				3	2	1	2	3	2	3	2	1		2		1			22	10.0
4								1	2		2	1				1	1		8	3.9
5							1		1										2	1.0
6									1										1	0.5
7																			0	0.0
8-9																			0	0.0
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	43	30	20	18	10	13	13	8	16	6	9	6	2	6	3	2	1	0	206	
	20.9	14.6	9.7	8.7	4.9	6.3	6.3	3.9	7.8	2.9	4.4	2.9	1.0	2.9	1.5	1.0	0.5	0.0	100	

11.3.2 Forestry Stations

This appendix provides data on the number of consecutive days with precipitation as a function of the amount of precipitation that fell during a given interval. These numbers are accumulations over all months of operation (generally June, July, and August) for all years of operation from 1966 to 1979.

STATION: Birch Mountain
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	31	17	16	11	7	3	5	6	5	4	4	1				1			125	46.6
2	2	1	7	9	3	3	4	8	6	7	3	3	2	6	1	4	1		70	26.1
3			2	1	2	2	3	2	2	5	3	6	1	3	3				35	13.1
4				1	1			2	1	6	2	1	2	1	3	1	1		22	8.2
5									1				1	1	1				4	1.5
6											1	1			1	2		2	7	2.6
7																				
8-9													2				1	1	4	1.5
10-12																		1	1	0.4
≥ 13																				
COLUMN TOTAL	33	18	25	22	13	8	12	18	15	22	13	12	8	11	9	8	3	4	268	
	12.3	6.7	9.3	8.2	4.9	3.0	4.5	6.7	5.6	8.2	4.9	4.5	3.0	4.1	3.4	3.0	1.1	1.5		

STATION: Stony Mountain
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	28	17	8	9	3	6	7	3	6	4	1	2	2	1			1		105	40.2
2	4	4	6	4	5	2	8	6	5	5	3	3		5	1	1			62	23.8
3		2		3		2	4	4	4	4	2	4	3	4	1	2		1	40	15.3
4							2	1	4		3	1	3	3	1	3		3	24	9.2
5							2			1	2	2	3	2	2		2		16	6.1
6									2						3		1		6	2.3
7													2			1		2	5	1.9
8-9										1						1	1		3	1.1
10-12																				
≥ 13																				
COLUMN TOTAL	32	23	14	16	8	10	23	14	21	15	11	12	13	15	8	8	5	6	261	
	12.3	8.8	5.4	6.1	3.1	3.8	8.8	5.4	8.0	5.7	4.2	4.6	5.0	5.7	3.1	3.1	1.9	2.3		

STATION: Bitumont
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	26	18	13	8	9	7	7	8	5	2	2		1		1	1			122	47.5
2	2	4	6	4	7	5	13	2	8	1	3	1	4	1					61	23.7
3	1		1	2	1	1	1	3	5	3	1	4	4	3		1			31	12.1
4				1			3		3	2	2		5	2	1	2			21	8.2
5								1	2	2	4	1		2	1	1			14	5.4
6											1			2		1			4	1.6
7																1			1	0.4
8-9																3			3	1.2
10-12																				
≥ 13																				
COLUMN TOTAL	29	22	20	15	17	13	24	14	23	10	13	6	14	10	3	10			257	
	11.3	8.6	7.8	5.8	6.6	5.1	9.3	5.4	8.9	3.9	5.1	2.3	5.4	3.9	1.2	3.9				

STATION: Ells

PERIOD: 1966 to 1979

PRECIPITATION (mm)

	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	27	20	10	17	5	6	10	6	8	3	1	2	2	1	1				125	48.6
2	4	5	7	4	6	3	4	9	7	6	9	3	3	1		1			72	28.0
3				7	2		4	3	4		1	5	4	2	1	1			34	13.2
4										2	1	2		3	1				9	3.5
5				1					2				1	2					6	2.3
6															2		1		3	1.2
7										1	1				2	1	1		6	2.3
8-9										1									1	0.4
10-12																	1		1	0.4
≥ 13																				
COLUMN TOTAL	31	25	17	29	13	9	18	18	21	13	13	12	10	9	7	3	3		257	
	12.1	9.7	6.6	11.3	5.1	3.5	7.0	7.0	8.2	5.1	5.1	4.7	3.9	3.5	2.7	1.2	1.2			

STATION: Cowpar
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	29	17	18	7	7	3	3	7	5		3	2	2						112	42.4
2	3	7	10	6	7	5	3	5	9	8	3	3	1	3	3	1	1		78	29.5
3			1	1	2	1	7	5	4	2	2	9	2	2					38	14.4
4				1			2	2	3	1	1	2	3	2	1			1	19	7.2
5						1					2	2				1		1	7	2.7
6											1	1	1	1	1				5	1.9
7														2		1	1		4	1.5
8-9																				
10-12																1			1	0.4
≥ 13																				
COLUMN TOTAL	32	24	29	15	16	10	15	19	21	11	12	19	9	10	5	4	2	2	264	
	12.1	9.1	11.0	5.7	6.1	3.8	5.7	7.2	8.0	4.2	4.5	7.2	3.4	3.8	1.9	1.5	0.8	0.8		

STATION: Keene
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	30	19	13	8	7	1	10	4	4	3	2	2							117	47.4
2	8	8	3	3	7	7	11	6	6	6		3	1	2		1			72	29.1
3		1	1	1		3	2	4	8	2	5	4	1	2	2	1			37	15.0
4								1	1	2	2	1	2						9	3.6
5												3			1	2			6	2.4
6						1						1	1						3	1.2
7															1				1	0.4
8-9												1				1			2	0.8
10-12																				
≥ 13																				
COLUMN TOTAL	38	28	17	12	14	12	23	15	19	13	9	15	5	4	4	5			247	
	15.4	11.3	6.9	4.9	5.7	4.9	9.3	6.1	7.7	5.3	3.6	6.1	2.0	1.6	1.6	2.0				

STATION: May
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	28	16	9	11	3	8	4	5	5	2	4	2		1					109	41.4
2	2	4	7	7	3	3	5	1	5	7	5	6	3	3	1	1	2		65	24.7
3				1	2	1	3	4	2	4		6	6	6	2		1	2	40	15.2
4								3	2	2	2	4	2	4	3	1	1	1	25	9.5
5									1		1	2	2		2	1	1	2	12	4.6
6							1							3		1	2		7	2.7
7												2	1	1					4	1.5
8-9																				
10-12																				
≥ 13																	1		1	0.4
COLUMN TOTAL	30	20	16	19	8	12	13	13	15	15	12	22	14	18	8	4	8	5	263	
	11.4	7.6	6.1	7.2	3.0	4.6	4.9	4.9	5.7	5.7	4.6	8.4	5.3	6.8	3.0	1.5	3.0	1.9		

STATION: Johnson Lake
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	36	12	19	9	7	8	9	6		3	1	3		1	1				129	47.3
2	1	2	5	6	6	6	10	4	6		2	3	3	3		1			58	21.2
3	1			3	1		2	3	8	5	4	7	3	1		1			39	14.3
4			1	1			3	1	5	3	2	2	7	1			3		29	10.6
5									1	1	1	2		4	2	1	2		14	5.1
6															1				1	0.4
7																				
8-9														1			1	1	3	1.1
10-12																				
≥ 13																				
COLUMN TOTAL	38	14	25	19	14	14	24	14	20	12	10	17	13	11	4	3	6	1	273	
	13.9	5.1	9.2	7.0	5.1	5.1	8.8	5.1	7.3	4.4	3.7	6.2	4.8	4.0	1.5	1.1	2.2	0.4		

STATION: Buckton
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	34	9	13	13	9	4	3	5	3	5	3	1	1	1					114	
2	4	3	2		6	3	12	14	2	3	3	3	3	1		2		1	52	20.7
3		1	3	1	1		6	2	4	5	4	1	1	1	3				33	13.1
4	1			1				1	3	2	2	6	1	5	2		3	1	28	11.2
5									1			4	2		1	1			9	3.6
6											1				1	2	2		6	2.4
7																1		1	2	0.8
8-9												1	1					2	4	1.6
10-12																1		1	2	0.8
≥ 13																1			1	0.4
COLUMN TOTAL	40	13	18	15	16	7	21	12	13	15	13	16	9	8	7	8	5	6	251	
	15.9	5.2	7.2	6.0	6.4	2.8	8.4	4.8	5.2	6.0	5.2	6.4	3.6	3.2	2.8	3.2	2.0	2.4		

STATION: Conklin

PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	27	20	8	13	4	7	2	5	5	2			2	2					116	43.0
2	6	3	9	6	5	4	5	2	5	5	3	3	6	5	3	2			72	26.7
3			4	3		1	5		4	5	3	4	3	1		1			34	12.6
4							2	1	1	4	2	1	4	3	3	1		2	24	8.9
5			1					1	2				3	1	1	2	1		12	4.4
6						1					1	1			4	1			8	3.0
7												1							1	0.4
8-9											1								1	0.7
10-12													1			1			2	0.0
≥ 13																			0	0.4
COLUMN TOTAL	33	23	22	22	9	13	14	9	17	16	10	10	19	12	11	8	1	2	270	
	12.2	8.5	8.1	8.1	3.3	4.8	5.2	3.3	6.3	5.9	3.7	3.7	7.0	4.4	4.1	3.0	0.4	0.7		

STATION: Richardson
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	34	27	15	13	9	9	10	8	4	1	1	4	1						140	55.3
2	1	5	9	3	3	5	7	6	10	2	2	1	3			1			58	22.9
3				1		1	3	5		2	3	5	2	4	1				27	10.7
4									2	2	2	4	1	2	1				14	5.5
5									1	1		2	2	1	1		1		9	3.6
6												1							1	0.4
7																			0	0.0
8-9											1	1				1			3	1.2
10-12															1				1	0.4
≥ 13																			0	0.0
COLUMN TOTAL	35	32	24	17	12	15	20	19	17	8	9	18	9	7	4	2	1	0	253	
	13.8	12.6	9.5	6.7	4.7	5.9	7.9	7.5	6.7	3.2	3.6	7.1	3.6	2.8	1.6	0.8	0.4	0.0		

STATION: Fort McMurray
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	40	20	7	5	5	4	3	2					1	1					123	45.6
2	18	13	6	9	6	1	12	2	4		3	2	1	1					78	28.9
3	4	3	2		3	3	3	2	4	4	1	1	1	1					32	11.9
4				1	2	1	1	2	5	1	5	1	2		1			1	23	8.5
5								1		3	2		1	2		1			10	3.7
6									1										1	0.4
7								1	1							1			3	1.1
8-9																			0	0.0
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	62	36	15	15	16	9	19	10	15	8	11	4	6	5	1	2	0	1	270	
	23.0	13.3	5.6	5.6	5.9	3.3	7.0	3.7	5.6	3.0	4.1	1.5	2.2	1.9	0.7	0.7	0.0	1.4		

STATION: Jean
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	28	18	14	7	2	7	8	4	5	4	1	1	1		1	1			114	44.0
2	2	9	4	2	3	3	11	5	4	7	1	4	2	2	3	1		1	64	24.7
3			2		1	1	1	7	5	4	5	4	1	3	2		2	2	40	15.4
4							1	2	1	1	2	2	1	3	1	1			15	5.8
5									1	1	1			3	2	4	1		13	5.0
6									2		1	1		3					7	2.7
7														1			1		2	0.8
8-9																3			3	1.2
10-12																			0	0.0
≥ 13																		1	1	0.4
COLUMN TOTAL	30	27	20	9	6	11	21	18	18	17	11	12	5	15	9	10	4	4	259	
	11.6	10.4	7.7	3.5	2.3	4.2	8.1	6.9	6.9	6.6	4.2	4.6	1.9	5.8	3.5	3.9	1.5	1.5		

STATION: Muskeg
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	24	14	8	5	11	9	7	7	4	2	2		1						107	41.8
2	8	3	9	8	5	3	11	5	4	5	2	1	2	2	3	2		1	73	28.5
3			1	3	2		2	4	3	4	3	7	1	1	1	1		2	33	12.9
4				1			2		2	1	4	3	1	1	1	1			17	6.6
5							1					2	1	3	3			1	11	4.3
6										1		3	1			1			6	2.3
7															1	1			2	0.8
8-9										1	1		1	1			1	1	6	2.3
10-12																	1		1	0.4
≥ 13																			0	0.0
COLUMN TOTAL	32	17	18	17	18	12	23	16	13	14	12	16	8	8	9	6	2	2	256	
	12.5	6.6	7.0	6.6	7.0	4.7	9.0	6.3	4.7	5.5	4.7	6.3	3.1	3.1	3.5	2.3	0.8	0.8	100	

STATION: Thickwood
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	26	11	13	5	7	3	11	8	5	3	2	3	2		2		1		109	42.2
2	3	5	6	6	4	6	9	7	5	8	1	2	2	4		1	1		70	27.1
3		2	2	2	1	1	4		3	3	3	2	3	4	2	3			35	13.6
4						1	3	1	1	2	3	1	2	1	1	4			20	7.8
5								4			3			1	1	1			10	3.9
6											1	1	1	1					4	1.6
7										1			1		1	2	3		8	3.1
8-9																	1	1	2	0.8
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	29	18	21	13	12	11	27	20	14	17	13	9	11	11	7	11	6	1	258	
	11.2	7.0	8.2	5.0	4.7	4.3	10.5	7.8	5.4	6.6	5.0	3.5	4.3	4.3	2.7	4.3	2.3	0.4	100	

STATION: Gordon Lake
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	37	13	9	8	7	5	3	5	8	6	3	2	3	1	1				120	46.5
2	2	2	8	5	2	4	7	7	6	5	8	5	1	1		2			65	25.2
3		1		2	1	1	6	3	2	4	5	2	4	2		1	1	1	36	14.0
4					1	1	2	1	7	2		3	4	1	2			1	25	9.7
5													1	3					4	1.6
6									1		1	1			2	1		1	7	2.7
7																			0	0.0
8-9																			0	0.0
10-12																			1	0.4
≥ 13																			0	0.0
COLUMN TOTAL	39	16	17	15	11	11	18	16	24	17	17	13	13	8	5	4	1	3	258	
	15.1	6.2	6.6	5.8	4.3	4.3	7.0	6.2	9.3	6.6	6.6	5.0	5.0	3.1	1.9	1.6	0.4	1.2	100	

STATION: Carlson
PERIOD: 1968 to 1974 (June)

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	17	4	5	3	3	2	1		2	2									42	55.2
2	1	2	2	1	2	3	2	1		1	2	1							18	23.7
3			1				2	1		1		1		2					8	10.5
4			1		1				1	1									4	5.3
5									1										1	1.3
6										1	1								2	2.6
7																1			1	1.3
8-9																			0	0.0
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	18	6	9	4	6	5	5	2	4	6	3	2	0	2	0	1	0	0	76	
	23.7	7.9	11.8	5.3	7.9	6.6	6.6	2.6	5.3	7.9	3.9	2.6	0.0	2.6	0.0	1.3	0.0	0.0	100	

STATION: Algar
PERIOD: 1968 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	29	29	11	8	5	5	9	5	6	2	5		4	1	2				125	47.0
2	2	3	5	6	1	2	5	3	8	4	9	5	4	4	2				63	23.7
3				1	2	3	6	3	2	2	3	5		3	2	1	1		34	12.8
4				3	1		1		1	3	2	4	1	3	1	2			22	8.3
5									1		1	2	1	1	3	3		1	13	4.9
6															2	2			4	1.5
7										2						1			3	1.1
8-9											1					1			2	0.8
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	31	32	16	18	9	10	21	11	18	13	21	16	10	12	12	10	1	1	266	
	11.7	12.0	6.0	6.8	3.4	3.6	7.9	4.1	6.8	4.9	7.9	6.0	3.6	4.5	4.5	3.6	0.4	0.4	100	

STATION: Grande

PERIOD: 1968 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	35	16	13	10	7	10	5	3	4	4	3	2	1	1					121	45.7
2	3	6	3	4	9	8	7	4		4	11	5	2	3		2			71	26.8
3		1	2		2	3	3	1	5	2	3	4		1	4	1	1	1	34	12.8
4							1	1		4	1	2	2	3	3				17	6.4
5							1	2		1		1		3	3	2	1		14	5.3
6										1		1	2						4	1.5
7								1	1										2	0.8
8-9														1					1	0.4
10-12																			0	0.0
≥ 13																	1		1	0.4
COLUMN TOTAL	38	23	18	14	18	21	17	12	10	16	18	15	7	12	10	5	3	1	265	
	14.3	8.7	6.8	5.3	6.8	7.9	6.4	4.5	3.8	6.0	6.8	5.7	2.6	4.5	3.8	1.9	1.1	0.4	100	

STATION: Chipewyan Lakes
PERIOD: 1967 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	25	14	12	7	2	7	4	3	8		1		1						94	44.8
2	5	6	5	5	1	7	3	2	10	3	5	3	1	3					59	28.1
3	2	1				2	4	1	1	2	3	2	5		1		1		25	11.9
4			1				3		2	1		1	2	2		1			13	6.2
5									1		2	1		3		1			8	3.8
6								1		1		1	1	2					6	2.9
7												1							1	0.4
8-9												2							2	0.8
10-12														1					1	0.4
≥ 13																	1		1	0.4
COLUMN TOTAL	32	21	18	12	3	16	14	7	22	7	11	11	10	11	1	2	2	0	210	
	15.2	10.0	8.6	5.7	1.4	7.6	6.7	3.3	10.5	3.3	5.2	5.2	4.8	5.2	0.4	0.8	0.8	0.0	100	

STATION: Christina
PERIOD: 1967 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	20	20	3	9	4	4	3	4	3	2	2	4	3	1	1				97	38.8
2	4	4	6	7	4	4	7	7	3	5	6	6	1	3		2	2		72	29.0
3		2	1	4	1	2	3	2	3	2	6	3	1	3		2	1		36	14.5
4				1		1	1		1	3	4	5	2	3	2		1		24	9.7
5								1		3	1	1			1		1	1	9	3.6
6								1	1			1	2		1	1			7	2.8
7												1							1	0.4
8-9																1			1	0.4
10-12														1		2			3	1.2
≥ 13																			0	0.0
COLUMN TOTAL	24	26	10	21	9	11	14	15	11	15	19	21	9	11	5	8	5	1	250	
	9.7	10.5	4.0	8.5	3.6	4.4	5.6	6.0	4.4	6.0	7.7	8.5	3.6	4.4	2.0	2.8	2.0	0.4	100	

STATION: Panny
PERIOD: 1966 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	24	16	11	13	6	7	9	6	6	1	2		1	2					110	44.4
2	2	6	9	3	5	5	7	4	7	5	5	4			1	2	1		66	26.6
3		2	1	1	4	1	4	3	2	1	1	2	1	2					25	10.1
4					1		1	1	3	3	2	1	2	3	1	1	1		20	8.1
5							1	1		1	2	4	1	2		3	1		16	6.5
6											1		1	3				1	6	2.4
7												1		2					3	1.2
8-9															2				2	0.8
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	26	24	21	17	16	13	22	15	18	11	13	12	6	14	4	6	3	1	248	
	10.5	9.7	8.5	6.9	6.5	5.2	8.9	6.0	7.3	4.4	5.2	4.8	2.4	5.6	1.6	2.4	1.2	0.4	100	

STATION: Lambert Creek
PERIOD: 1969 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	15	14	8	12	6	5	4	4	2	2	2	1	1						86	46.0
2	7	7	7	4			5	9	2	2	4	5	2	2	1				57	30.5
3			1	1	1	1		5	2	2		2	3	2					20	10.6
4				1				1	2		1		1	1	3				10	5.3
5					1					1	1		1		3	1		1	9	4.8
6														2					2	1.1
7								1			1		1						3	1.6
8-9															2				0	0.0
10-12																			0	0.0
≥ 13																			0	0.0
COLUMN TOTAL	22	21	16	18	8	6	9	20	8	7	9	8	9	7	7	1	0	1	187	
	11.6	11.1	8.5	9.5	4.2	3.2	4.8	10.6	4.2	3.9	4.8	4.2	4.8	3.7	3.7	0.5	0.0	0.5	100	

STATION: Legend
PERIOD: 1969 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	32	16	9	12	11	6	9	7	3	3	2	1	1	2					127	47.6
2	3	3	5	2	4	6	5	8	6	3	5	5	1	4		2			62	23.2
3			1	3	1	2	4	1	2	2	5	6	3	4		2			36	13.5
4					2				5	1	2	2	2	3		1			18	6.8
5								1		1	2	2	1	2	2	3	1	1	16	6.0
6										1		1							2	0.8
7														1		1			2	0.8
8-9											1				1				2	0.8
10-12														2					2	0.8
≥ 13																			0	0.0
COLUMN TOTAL	35	19	15	17	18	14	18	17	16	11	17	17	8	18	3	9	1	1	267	
	13.1	7.2	5.6	6.3	6.8	5.3	6.8	6.3	6.1	4.2	6.3	6.3	3.0	6.8	1.1	3.4	0.4	0.4	100	

STATION: Edra
PERIOD: 1969 to 1979

PRECIPITATION (mm)

CONSECUTIVE NUMBER OF PRECIPITATION DAYS	1	2	3	4	5	6	7-8	9-10	11-13	14-16	17-20	21-25	26-30	31-40	41-50	51-70	71-90	>91	ROW TOTAL	
1	23	16	10	17	8	4	6	5	3	2	2	1		1					104	40.6
2	2	6	6	3	6	12	6	9	11	2	5	3	1	4	2				78	30.5
3			2	1			4		4	3	5	1	3	2	1	1			27	10.5
4							1	1	2	2	3	3	1	3		2		2	20	7.8
5									2	1	2	2	1	2	3	1		2	16	6.3
6										1	1	2		1		1			6	2.3
7													1	1					2	0.8
8-9													1						1	0.4
10-12																	2		2	0.8
≥ 13																			0	0.0
COLUMN TOTAL	25	22	18	21	14	16	17	15	22	11	18	12	8	14	6	5	2	4	256	
	9.8	8.6	7.0	8.2	5.5	6.3	6.6	5.8	8.6	4.3	7.0	4.7	3.1	5.5	2.3	2.0	0.8	1.6	100	

11.4 NUMBER OF DAYS EACH MONTH WITH MEASURABLE PRECIPITATION

11.4.1 MAPS Network

This appendix contains tables for each station in the MAPS network of the number of days in each month from 1976 to 1981 with measurable precipitation. Also included in the tables are the mean, maximum, and minimum days per month along with the standard deviation. Months marked with "*" were not included in these statistical calculations because of suspected missing precipitation data at either the beginning or end of the month. Note that the flagged months occur in pairs or at the start or end of a series of missing months.

Station: Stony Mountain

YEAR	MONTH											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976												
1977										8	9	13
1978	8	6	8	8	18	13	12	21	18	13	12	10
1979	8	11	6	15	7	13	11	11	2	4	9	11
1980	10	5	13	1	9	11	17	18	18	2	16	14
1981	7	7	10	10	7	14	8	2*	*1	15	10	14
Mean	8.3	7.3	19.3	11.0	10.7	12.8	12.0	16.7	12.7	8.4	9.2	12.4
St. Dev.	1.3	2.6	3.0	3.6	6.4	1.3	3.7	5.1	9.2	5.6	2.2	1.8
Max.	10	11	13	15	18	14	17	21	18	15	12	14
Min.	7	5	6	8	7	11	8	11	2	2	6	11

Station: Muskeg

YEAR	MONTH											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976										7*	-	-
1977	7	5	10	4	12	11	14	13	8	8	10	9
1978	7	2	6	8	10	15	14	14	16	10	12	10
1979	7	10	10	17	11	19	14	12	10	6	8	5
1980	6	7	11	3*								
1981												
Mean	6.8	6.0	9.3	9.7	11.0	11.7	14.0	13.0	11.3	8.0	10.0	8.0
St. Dev.	0.5	3.4	2.2	6.7	1.0	3.1	0.0	1.0	4.2	2.0	2.0	2.6
Max.	7	10	11	17	12	15	14	14	16	10	12	10
Min.	6	2	6	4	10	9	14	12	8	6	8	5

Station: Ells

YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976										6*	-	-
1977	5	4*	-	6	2	13	17	15	15	2	7	9
1978	6	2	8	8	13	11	13	20	15	1*	*5	7
1979	5	10	10	15	6	13	11	9	13	11	3	8
1980	6	2	15	2	7							
1981												
Mean	5.5	4.7	11.0	7.8	7.0	12.3	13.7	14.7	14.3	6.5	5.0	8.0
St. Dev.	0.6	4.6	3.6	5.4	4.5	1.2	3.1	5.5	1.2	6.4	2.8	1.0
Max.	6	10	15	15	13	13	17	20	15	11	7	9
Min.	5	2	8	2	2	11	11	9	13	2	3	7

Station: Mildred Lake

YEAR	MONTH											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976										9	-	-
1977	9	11	6	2*	-	11	13	-	-	*3	12	10
1978	7	3	7	6	14	15	16	16	14	9	12	13
1979	7	13	11	12	9	8	11	12	10	9	7	7
1980	7	4	11	1	12	6	14	15	13	2	9	15
1981	9	7	7	6	7	12	12	4	3	13	3	10
Mean	7.8	7.6	8.4	6.3	10.5	10.6	13.2	11.8	10.0	8.4	8.6	11.0
St. Dev.	1.1	4.3	2.4	4.5	3.1	3.4	1.9	5.4	5.0	4.0	3.8	3.1
Max.	9	13	11	12	14	15	16	16	14	13	12	15
Min.	7	3	6	1	7	6	11	4	3	2	3	7

Station: Thickwood

YEAR	MONTH Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976												
1977	7	9	10	-	-	-	-	-	*8	11	12	13
1978	6	5	9	10	10	7	11	16	17	10	12	11
1979	8	13	14	14	13	12	16	12	-	*3	7	11
1980	7	4	15	2	10	8	20	21	17	2	10	13
1981	7	6	7	12	4	13	7	5	8	16	10	9
Mean	7.0	7.4	11.0	9.5	9.5	10.0	13.5	13.5	14.0	9.8	10.2	11.4
St. Dev.	0.7	3.6	3.4	5.3	3.8	2.9	5.7	6.8	5.2	5.8	2.0	1.7
Max.	8	13	15	14	13	13	20	21	17	16	12	13
Min.	7	4	7	2	3	7	7	5	8	2	7	9

Station: Fort Hills

YEAR	MONTH Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976									4	6*	-	-
1977	9	12	6	5	10	-	-	10	11	6	2	7
1978	6	3	6	6	13	11	13	14	14	5	10	7
1979	3	7	8	9	5	9	9	11	9	6	4*	-
1980	-	4	6	1	8	5	13	14	12	2	4	9
1981	6	4	6	9	6	10	10	2*	*2	-	-	-
Mean	6.0	5.8	5.8	6.0	8.4	8.8	11.3	12.3	10.0	4.8	5.3	7.7
St. Dev.	2.4	3.9	1.8	3.3	3.2	2.6	2.1	2.1	3.8	1.9	4.2	1.2
Max.	9	12	8	9	13	11	13	14	14	6	10	9
Min.	3	2	6	1	5	5	9	10	9	2	2	7

Station: Richardson

YEAR	MONTH Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976									7	9*	-	-
1977	-	7	4	6	10	15	13	10	11	5	2*	-
1978	8	2	8	8	2*	-	14	12	13	11	12	11
1979	7	10	11	19	7	10	13	16	18	10	9	8
1980	15	8	10	7	8							
1981												
Mean	10.0	6.8	8.3	10.0	8.3	12.5	13.3	12.7	12.3	8.7	10.5	9.5
St. Dev.	4.4	3.4	3.1	6.1	1.5	3.5	0.6	3.1	4.6	3.2	2.1	2.1
Max.	15	10	11	19	10	15	14	16	18	11	12	11
Min.	7	2	4	6	7	10	13	12	7	5	9	8

Station: Birch Mountain

YEAR	MONTH											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976									7	5	-	-
1977	7	7	14	2	-	-	1	12	15	13	12	13
1978	9	5	8	11	16	18	12	15	18	12	8	9
1979	5	12	11	17	13	8	10	17	9	7	7	4
1980	9	6	11	6	7							
1981												
Mean	7.5	7.5	11.0	11.3	14.5	13.0	11.0	14.7	12.3	10.0	9.0	8.7
St. Dev.	1.9	3.1	2.4	5.5	2.1	7.1	1.4	2.5	5.1	5.0	2.6	4.5
Max.	9	12	14	17	16	18	12	17	18	13	12	13
Min.	5	5	8	6	13	8	10	12	7	5	7	4

Station: Firebag

YEAR	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976										8*	-	-
1977	6	6*	-	-	*3	9	7	8	3	8	9	10
1978	8	3	7	8	5	8	13	14	17	12	11	12
1979	6	13	11	12	5	9	12	15	13	8	7	6
1980	11	11	13	3*								
1981												
Mean	7.8	9.0	10.3	10.0	5.0	8.7	10.7	12.3	11.0	9.3	9.0	9.3
St. Dev.	2.4	5.3	3.1	2.8	0.0	0.6	3.2	3.8	7.2	2.3	2.0	3.1
Max.	11	13	11	12	5	9	13	14	17	12	11	12
Min.	6	3	7	8	5	8	7	8	3	8	7	6

11.4.2 Foresty Stations

This appendix contains ogives in table form of the number of days in each summer month from 1966 to 1979 with measurable precipitation. Also included are the mean, maximum, and minimum values, along with the standard deviation and the number of years of record. Ogive values are in percent.

Month: June

	CI	KN	LA	ED	BN	RI	JE	LG	BI	BM	MY	CR	JO	PA	CY	EL	TW	MU	MM	GL	GE	AL	ST	CK	CP
5						7								8											
6																									
7		7								14							7			7					
8	40	14				14			7		7						14			14		7	7	7	7
9		36			7		7	7	21				7	23	17					29		14			29
10			9	7	14	29		21		21	14	8	21	31	33	23		21			7		14	29	
11		43	36	14				29		29	29		29		42	59	29				21	29			
12		64		21	21	50	29	43	29		43	23		38	50	62	36	36	50	57	36	43	29		36
13	80	86		43	29	79	50	57	36	50		31	64				43	57	75	71	50	50	36	43	50
14	100	100	64	50	36	86	57		43	57	57		71	46	58	77	50	64			57	64	50		57
15			82	64	50	93	79	71	64	71	71	77	79	54	67		64	79	100	86	64	79	57	57	79
16				93	57		93	79	86			85	92	62	75		71	93			71	86	71	79	86
17			91	100	64			86		93	93			85							93	93	79	86	
18			100		79	100			93	100		92	100	100	92	85	79			93		100	93	100	93
19					86			93			100	100			100	92	93								100
20					93											100		100			100		100		
21							100		100								100			100					
22					100			100																	
Min.	8	7	10	10	9	5	9	9	8	7	8	10	9	5	9	10	7	10	12	7	10	8	8	8	8
Mean	11	11	14	14	16	12	14	14	14	13	14	15	13	13	13	13	14	13	13	12	13	13	14	14	13
Max.	14	14	18	17	22	18	21	22	21	18	19	19	18	18	19	20	21	20	15	21	20	18	20	18	19
St. Dev.	2.6	2.2	2.5	2.1	3.6	3.0	2.7	3.6	3.5	3.4	3.1	2.3	2.5	4.3	3.6	3.5	4.0	4.0	1.2	4.1	3.7	3.5	3.8	3.1	3.9
No.	5	14	11	14	14	14	14	14	14	14	14	13	14	13	12	13	14	14	4	14	14	14	14	14	14

Month: July

	CI	KN	LA	ED	BN	RI	JE	LG	BI	BM	MY	CR	JO	PA	CY	EL	TW	MU	MM	GL	GE	AL	ST	CK	CP
5																									
6															8	7									
7	25									7					17							7			
8		7	9						14					14	25										
9		21	27	7	14	7		14	21	14					33	14	7				29				
10		36	36	21	21	29	14	29		21			7								36	21	7		7
11	50		45	29		36	21					7		21		21		7		29					14
12		43	63		29		29	43	36	29	14			36		29	21	14	25	36				7	29
13		57		36	36	50	36		43	43		21	14	43	50	50	29	21		43		36	29	14	36
14		79	73	50	43	79	43	50	57	50	43			50	75	64	43	29	50	50			36	43	64
15	75		82		57		50				57	29	57				64	50		71	50	43		64	
16	100	93	91	57	64	86	57	57	71	71		50	64	57	83	79		57	75	79	64	50	43	71	
17			100				79	64	79		71	57	71	79		93	71	71			79		50	86	
18		100		64	71	100	86	79	86	86	86	86	93	86	92		86	79		93	93	71	57		79
19				79	79		93	100	93		93	93	100	93		100	93		100	100		93	64	100	86
20				93	93						100				100			86			100	100	79		100
21					100		100		100			100						100					100		
22										100				100			100								
23				100																					
Min.	7	8	8	9	9	9	10	9	8	7	12	11	10	8	6	6	9	11	12	11	9	7	10	12	10
Mean	12	13	12	15	15	13	15	14	14	15	16	16	16	15	13	12	15	16	15	14	14	15	15	15	15
Max.	16	18	17	23	21	18	21	19	21	22	20	21	19	22	20	19	22	21	19	19	20	20	21	19	20
St. Dev.	3.6	2.9	2.9	4.3	4.0	2.8	3.3	3.8	3.9	4.3	2.4	2.5	2.3	4.0	4.2	4.0	4.2	3.0	2.6	2.7	3.9	4.0	4.0	2.0	3.3
No.	4	14	11	14	14	14	14	14	14	14	14	14	14	14	12	14	14	14	4	14	14	14	14	14	14

Month: August

	CI	KN	LA	ED	BN	RI	JE	LG	BI	BM	MY	CR	JO	PA	CY	EL	TW	MU	MM	GL	GE	AL	ST	CK	CP
4			9									7													
5			18			7	7													7	7			7	
6			27			14	14		7		7			7			7				14				7
7	25	29	36		14	29		7	14	14		29	7	14	8	7		7		21	29	7			21
8			45	7		36				29	14	36	14	29	17	21	14			36		21	7	14	
9	50	36	55	21	29	50		14	21	36				36		29	21	21					21		36
10	75	50	63	36		57		21	29		21		36		25	50	29	43		43		29	29	21	
11	100	57		43	50		36	36	50	50		43	43	43	42	57	36	50		50			36		
12		71		57			57	57	57	71		57	50		50	64	50	57		57	36	50		36	50
13		86	82	64	64	64			79		29		71	57		79	64	79	25	64	50	64	43	50	57
14		93	91	71	71	71		79	86	86	57		79	79	58		86	86	75	71	86	79	57	57	71
15				86	100	86	86			93	79	71	86		75	100		100		79		86	71		86
16			100			93	93	86		100	86	86		86	83		93			86	93	100	86	64	93
17		100		100		100		93	93			93			92				100		100		93	86	
18												100	93		100		100							93	
19											93		100	93									100	100	100
20							100	100			100			100						100					
21									100																
Min.	7	7	4	8	7	5	5	7	6	7	6	4	7	6	7	7	6	7	13	5	5	7	8	5	6
Mean	9	9	10	11	10	11	13	13	11	11	14	12	12	12	13	11	11	10	15	12	12	12	13	13	12
Max.	11	17	16	17	15	17	20	20	21	16	20	18	19	20	18	15	17	15	17	20	17	16	19	19	19
St. Dev.	1.5	4.0	3.8	3.3	3.8	4.1	3.8	3.3	4.3	2.9	3.6	4.4	3.3	4.2	3.4	2.6	4.0	3.7	1.5	4.2	3.8	2.8	3.3	4.8	3.7
No.	4	14	11	14	14	14	14	14	14	14	14	14	14	14	12	14	14	14	4	14	14	14	14	14	14

11.5 HOURLY VARIATION OF WIND DIRECTION AT MAPS STATIONS

This section presents plots of wind directions (based on a 16-point compass) against time of day at selected MAPS stations (Mildred Lake, Muskeg, Birch Mountain and Stony Mountain) for four selected months (January, April, July, and October). Frequencies are in percent. Contour interval is 5% beginning at 5%.

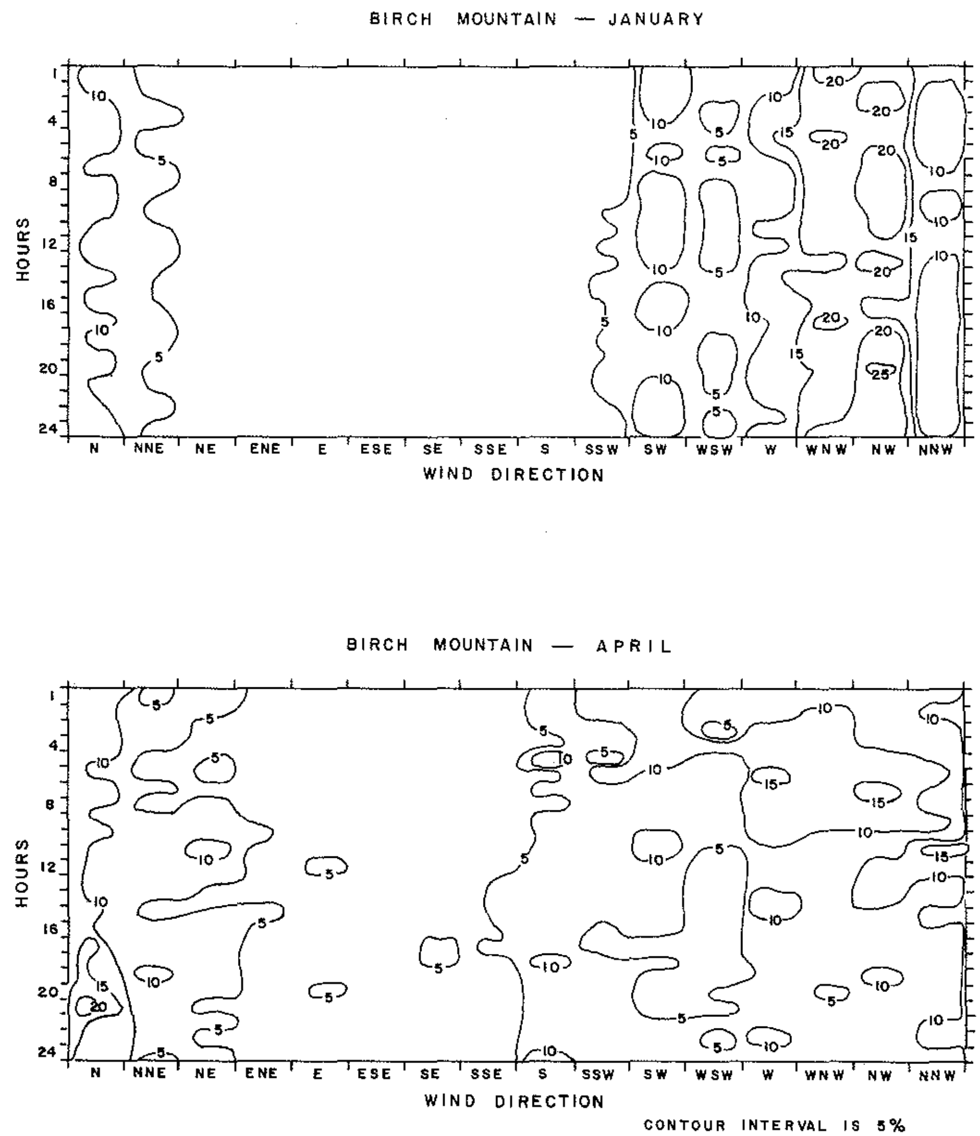
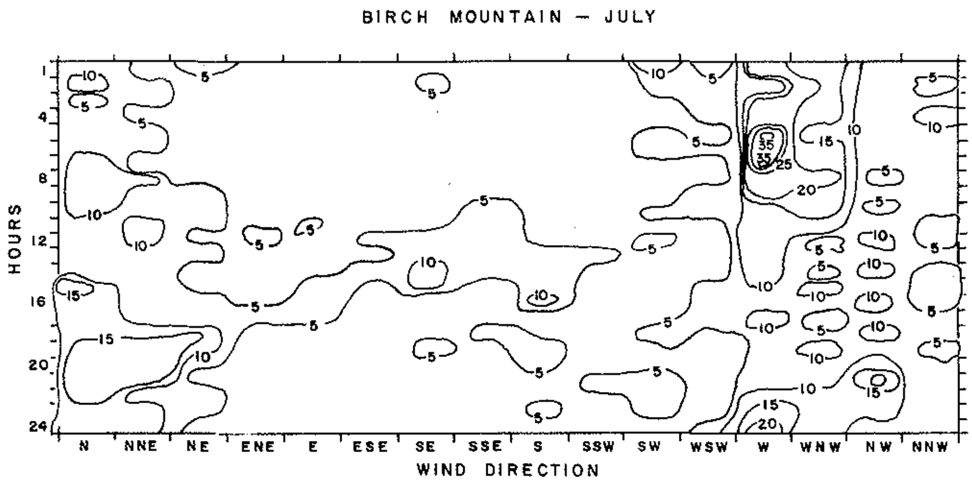


Figure 17. Wind direction frequency plots for Birch Mountain, January and April.



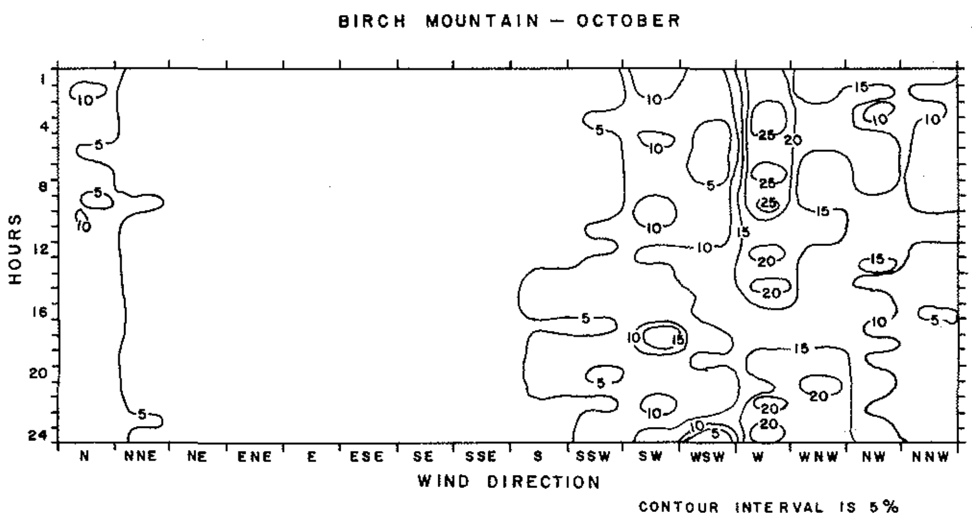


Figure 18. Wind direction frequency plots for Birch Mountain, July and October.

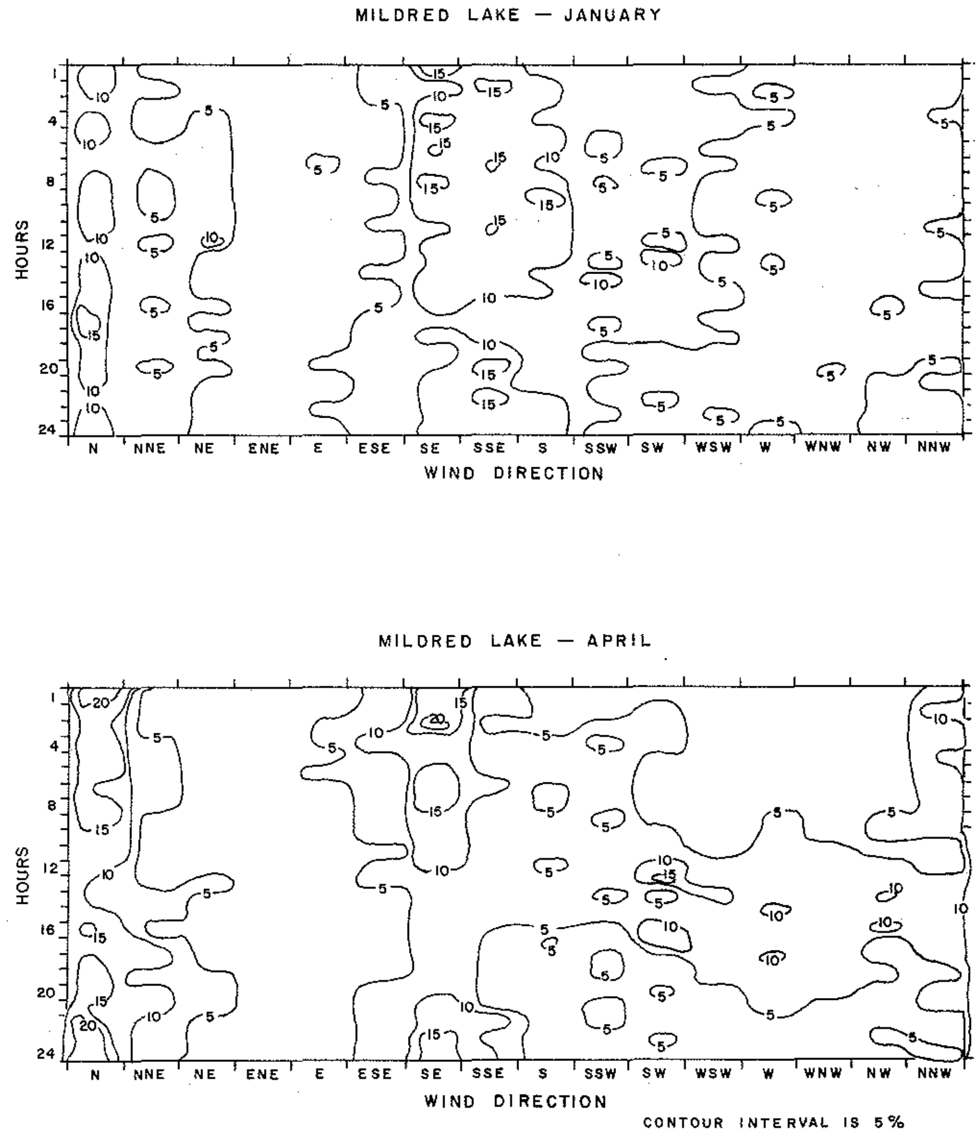


Figure 19. Wind direction frequency plots for Mildred Lake, January and April.

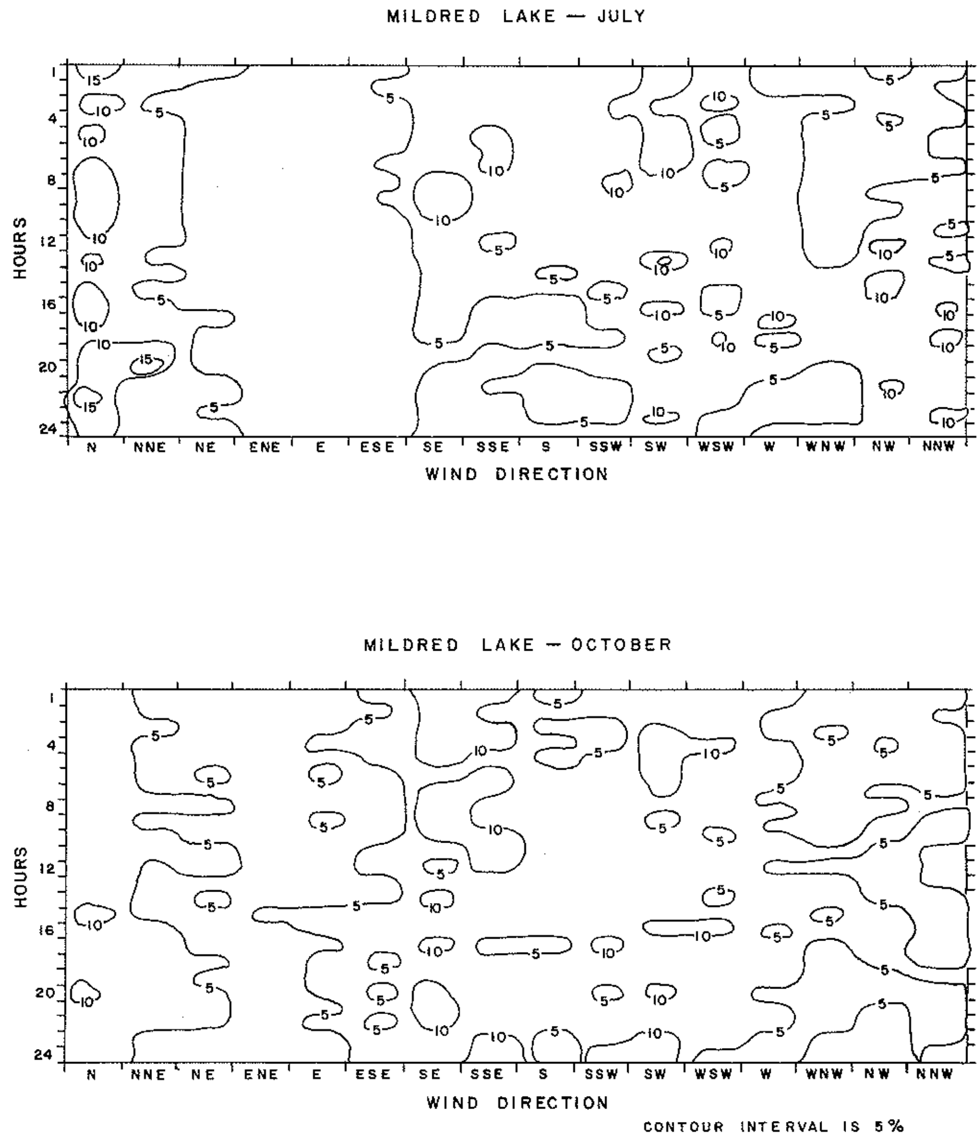
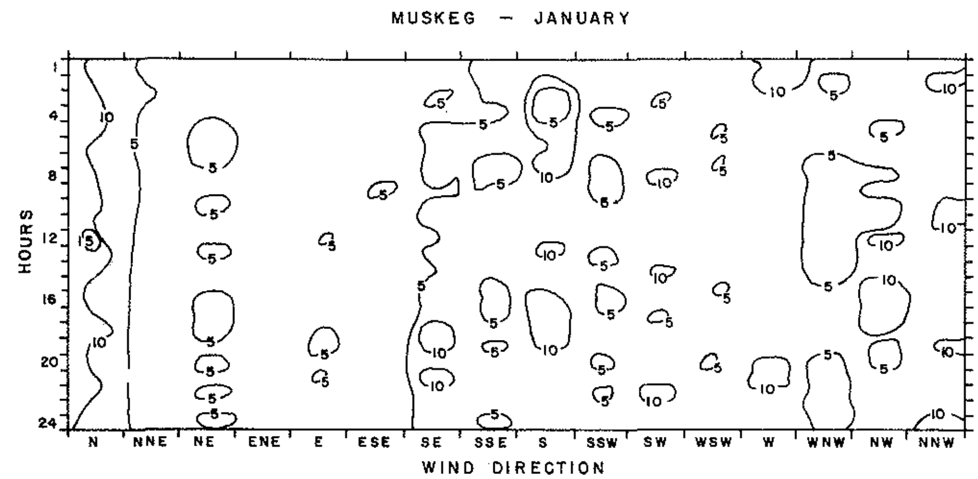


Figure 20. Wind direction frequency plots for Mildred Lake, July and October.



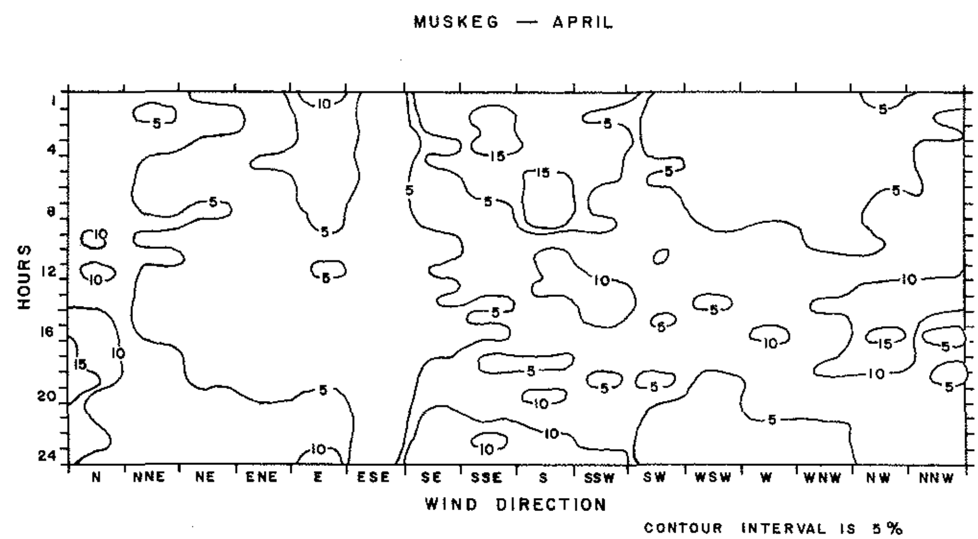


Figure 21. Wind direction frequency plots for Muskeg, January and April.

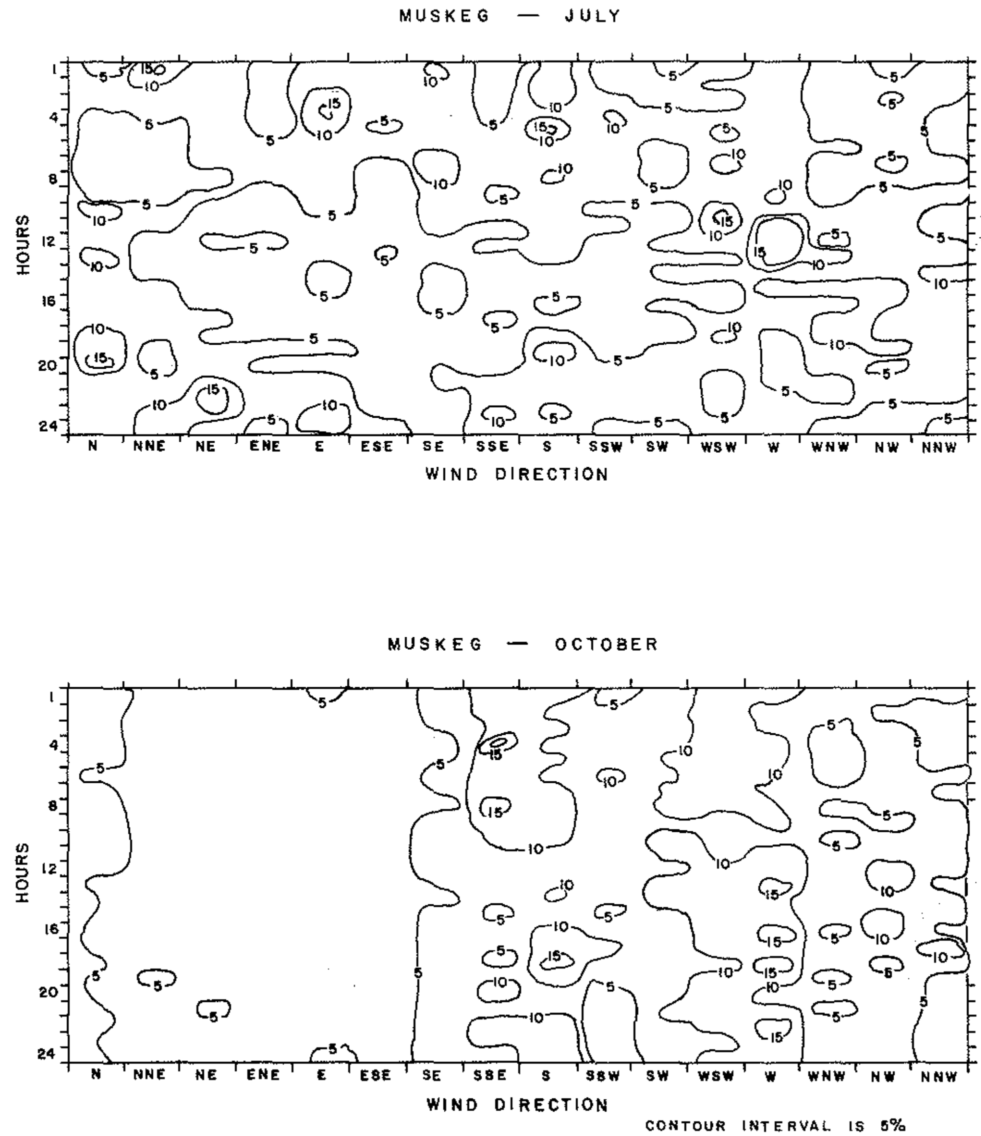


Figure 22. Wind direction frequency plots for Muskeg, July and October.

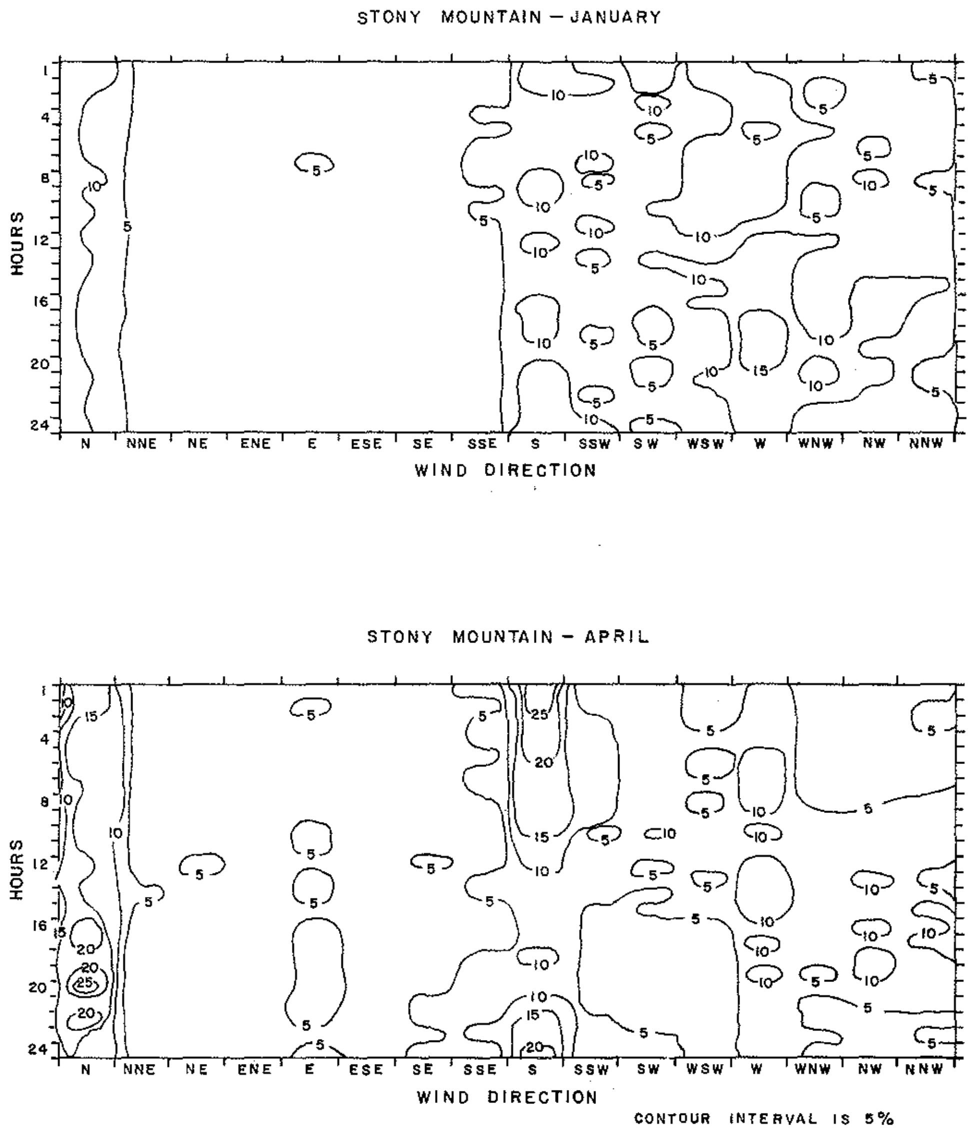
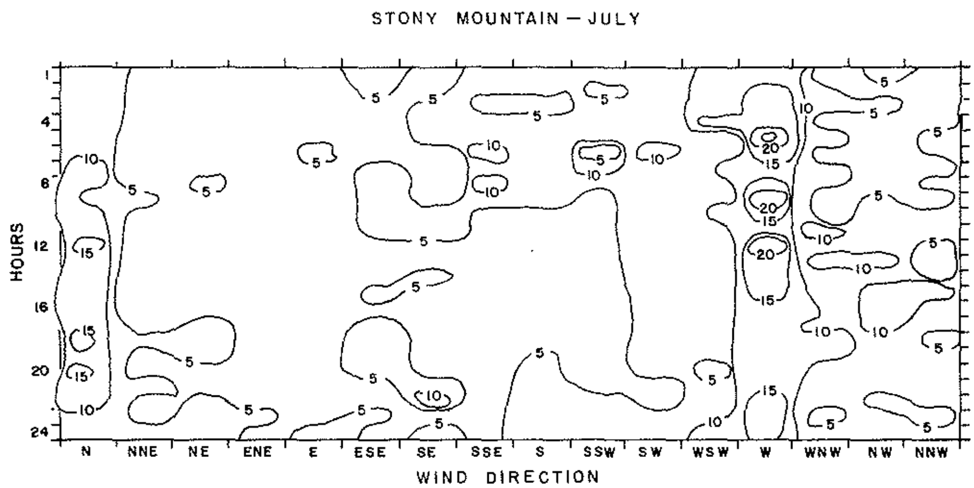


Figure 23. Wind direction frequency plots for Stony Mountain, January and April.



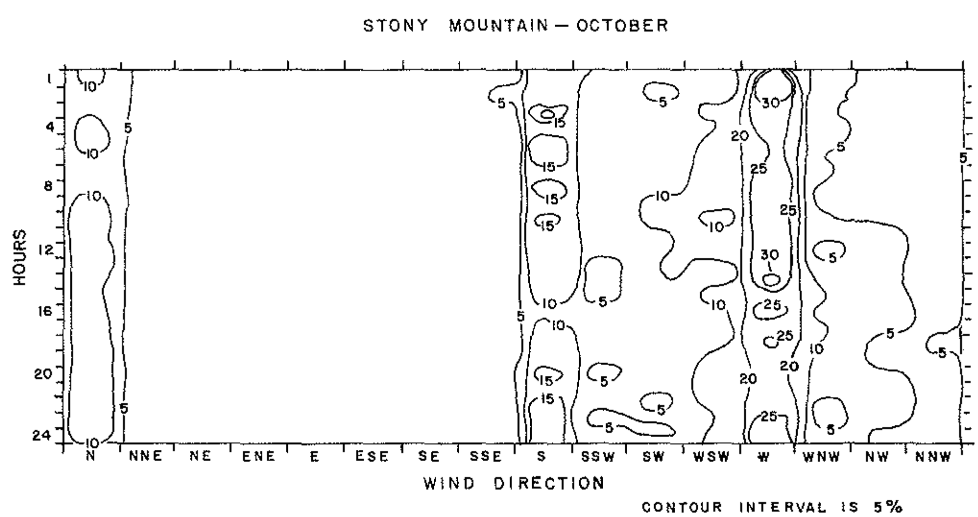


Figure 24. Wind direction frequency plots for Stony Mountain, July and October.

LIST OF AOSERP RESEARCH REPORTS

1. AOSERP first annual report, 1975.

2. Walleye and goldeye fisheries investigations in the Peace-Athabasca Delta --1975.

3. Structure of a traditional baseline data system. 1976.

4. A preliminary vegetation survey of the AOSERP study area. 1976.

5. The evaluation of wastewaters from an oil sand extraction plant. 1976.

6. Housing for the north--the stackwall system; construction report--Mildred Lake tank and pump house. 1976.

7. A synopsis of the physical and biological limnology and fishery programs within the Alberta oil sands area. 1977.

8. The impact of saline waters upon freshwater biota (a literature review and bibliography). 1977.

9. A preliminary investigation into the magnitude of fog occurrence and associated problems oil sands area. 1977.

10. Development of a research design related to archaeological studies in the Athabasca oil sands area. 1977.

11. Life cycles of some common aquatic insects of the Athabasca River, Alberta. 1977.

12. Very high resolution meteorological satellite study of oil sands weather: "a feasibility study". 1977.

13. Plume dispersion measurements from an oil sands extraction plant, March 1976.

14.

15. A climatology of low-level air trajectories in the Alberta oil sands area. 1977.

16. The feasibility of a weather radar near Fort McMurray, Alberta. 1977.

17. A survey of baseline levels of contaminants in aquatic biota of the AOSERP study area. 1977.

18. Interim compilation of stream gauging data to December 1976 for AOSERP. 1977.

19. Calculations of annual averaged sulphur dioxide concentrations at ground level in the AOSERP study area. 1977.

20. Characterization of organic constituents in waters and wastewaters of the Athabasca oil sands mining area. 1978.

21. AOSERP second annual report, 1976-77.

22. AOSERP interim report covering the period April 1975 to November 1978.

23. Acute lethality of mine depressurization water to trout-perch and rainbow trout: Volume I: 1979.

24. Air system winter field study in the AOSERP study area, February 1977.

25. Review of pollutant transformation processes relevant to the Alberta oil sands area. 1977.

26. Interim report on an intensive study of the fish fauna of the Muskeg River watershed of northeastern Alberta. 1977.

27. Meteorology and air quality winter field study in the AOSERP study area, March 1976.

28. Interim report on a soils inventory in the Athabasca oil sands area. 1978.

29. An inventory system for atmospheric emissions in the AOSERP study area. 1978.

30. Ambient air quality in the AOSERP study area, 1977.

31. Ecological habitat mapping of the AOSERP study area: Phase I. 1978.

32. AOSERP third annual report, 1977-78.

33. Relationships between habitats, forages, and carrying capacity of moose range in northern Alberta. Part I: moose preferences for habitat strata and forages. 1978.

34. Heavy metals in bottom sediments of the mainstem Athabasca River upstream of Fort McMurray: Volume I. 1978.

35. The effects of sedimentation on the aquatic biota. 1978.

36. Fall fisheries investigations in the Athabasca and Clearwater rivers upstream of Fort McMurray: Volume I. 1978.

37. Community studies: Fort McMurray, Anzac, Fort MacKay. 1978.

38. Techniques for the control of small mammal damage to plants: a review. 1979.

39. The climatology of the AOSERP study area. 1979.

40. Mixing characteristics of the Athabasca River below Fort McMurray-- winter conditions. 1979.

41. Acute and chronic toxicity of vanadium to fish. 1978.

42. Analysis of fur production records for registered traplines in the AOSERP study area, 1970-75.

43. A socio-economic evaluation of the recreational use of fish and wildlife resources in Alberta, with particular reference to the AOSERP study area. Vol. I: summary and conclusions. 1979.

44. Interim report on symptomology and threshold levels of air pollutant injury to vegetation, 1975 to 1978.

45. Interim report physiology and mechanisms of air-borne pollutant injury to vegetation, 1975 to 1978.

46. Interim report on ecological benchmarking and biomonitoring for detection of air-borne pollutant effects on vegetation and soils, 1975 to 1978.

47. A visibility bias model for aerial surveys of moose in the AOSERP study area. 1979.

48. Interim report on a hydrogeological investigation of the Muskeg River basin, Alberta. 1979.

49. The ecology of macrobenthic invertebrate communities in Harley Creek, northeastern Alberta.

50. Literature review on pollution deposition processes. 1979.

51. Interim compilation of 1976 suspended sediment data for the AOSERP study area. 1979.

52. Plume dispersion measurements from an oil sands extraction plant, June 1977.

53. Baseline states of organic constituents in the Athabasca River system upstream of Fort McMurray. 1979.

54. A preliminary study of chemical and microbial characteristics of the Athabasca River in the Athabasca oil sands area of northeastern Alberta. 1979.

55. Microbial populations in the Athabasca River. 1979.

56. The acute toxicity of saline groundwater and of vanadium to fish and aquatic invertebrates. 1979.

57. Ecological habitat mapping of the AOSERP study area (supplement): Phase I. 1979.

58. Interim report on ecological studies on the lower trophic levels of Muskeg rivers within the AOSERP study area. 1979.

59. Semi-aquatic mammals: annotated bibliography. 1979.

60. Synthesis of surface water hydrology. 1979.

61. An intensive study of the fish fauna of the Steepbank River watershed of northeastern Alberta. 1979.

62. Amphibians and reptiles in the AOSERP study area. 1979.

63. Analysis of AOSERP plume sigma data. 1979.

64. A review and assessment of the baseline data relevant to the impacts of oil sands developments on large mammals in the AOSERP study area. 1979.

65. A review and assessment of the baseline data relevant to the impacts of oil sands development on black bear in the AOSERP study area. 1979.

66. An assessment of the models LIRAQ and ADPIC for application to the Alberta oil sands area. 1979.

67. Aquatic biological investigations of the Muskeg River watershed. 1979.

68. Air system summer field study in the AOSERP study area, June 1977.

69. Native employment patterns in Alberta's Athabasca oil sands region. 1979.

70. An interim report on the insectivorous animals in the AOSERP study area.

71. Lake acidification potential in the AOSERP study area. 1979.

72. The ecology of five major species of small mammals in the AOSERP study area: a review. 1979.

73. Distribution, abundance, and habitat associations of beavers, muskrats, mink, and river otters in the AOSERP study area, northeastern Alberta. 1979.

74. Air quality modelling and user needs. 1979.

75. Interim report on a comparative study of benthic algal primary productivity in the AOSERP study area. 1979.

76. An intensive study of the fish fauna of the Muskeg River watershed of northeastern Alberta. 1979.

77. Overview of local economic development in the Athabasca oil sands region since 1976. 1979.

78. Habitat relationships and management of terrestrial birds in northeastern Alberta. 1979.

79. The multiple toxicity of vanadium, nickel, and phenol to fish. 1979.

80. History of the Athabasca oil sands region, 1890 to 1960's. Volume I: socio-economic developments. Volume II: oral history. 1980.

81. Species distribution and habitat relationships of waterfowl in in northeastern Alberta. 1979.

82. Breeding distribution and behaviour of the White Pelican in the Athabasca oil sands area. 1979.

83. The distribution, foraging behaviour and allied activities of the White Pelican in the Athabasca oil sands area. 1979.

84. Investigations of the spring spawning fish populations in the Athabasca and Clearwater rivers upstream from Fort McMurray: Volume I. 1979.

85. An intensive surface water quality study of the Muskeg River watershed. Volume I: water chemistry. 1979.

86. An observational study of fog in the AOSERP study area. 1979.

87. Hydrogeological investigation of Muskeg River basin, Alberta. 1980.

88. Ecological studies of the aquatic invertebrates of the AOSERP study area of northeastern Alberta. 1980.

89. Fishery resources of the Athabasca River downstream of Fort McMurray, Alberta: Volume I. 1980.

90. A wintertime investigation of the deposition of pollutants around an isolated power plant in northern Alberta. 1980.

91. Characterization of stored peat in the Alberta oil sands area. 1980.

92. Fisheries and habitat investigations of tributary streams in the southern portion of the AOSERP study area. Volume I: summary and conclusions. 1980.

93. Fisheries and aquatic habitat investigations in the MacKay River watershed of northeastern Alberta. 1980.

94. A fisheries and water quality survey of ten lakes in the Richardson Tower area, northeastern Alberta. Volume I: methodology, summary, and discussion. 1980.

95. Evaluation of the effects of convection on plume behaviour in AOSERP study area. 1980.

96. Service delivery in the Athabasca oil sands region since 1961. 1980.

97. Differences in the composition of soils under open and canopy conditions at two sites close-in to the Great Canadian Oil Sands operation, Fort McMurray, Alberta. 1980.

98. Baseline condition of jack pine biomonitoring plots in the Athabasca oil sands area: 1976-1977.

99. Synecology and autecology of boreal forest vegetation in the AOSERP study area. 1980.

100. Baseline inventory of aquatic macrophyte species distributions in the AOSERP study area. 1980.

101. Woodland caribou population dynamics in northeastern Alberta. 1980.

102. Wolf population dynamics and prey relationships in northeastern Alberta.

103. Analysis of the leisure delivery system 1972-1979, with projections for future servicing requirements.

104. Review of requirements for air quality simulation models. 1980.

105. Approaches to the design of a biomonitoring program using arthropods as bioindicators for the AOSERP study area. 1980.

106. Meteorological factors affecting ambient SO_2 concentrations near an oil sands extraction plant. 1980.

107. Small mammal populations of northeastern Alberta. Volume I: populations in natural habitats. 1980.

108. Small mammal populations of northeastern Alberta. Volume II: populations in reclamation areas. 1980.

109. Symptomology and threshold levels of air pollutant injury to vegetation, 1979-1980.

110. Physiology and mechanisms of airborne pollutant injury to vegetation, 1979-1980.

111. Ecological benchmarking and biomonitoring for detection of airborne pollutant effects on vegetation and soils. 1980.

112. A study of human adjustment in Fort McMurray. Volume I: field study and results. 1980.

113. A laboratory study of long-term effects of mine depressurization groundwater on fish and invertebrates. 1980.

114. Aquatic biophysical inventory of major tributaries in the AOSERP study area. Volume I: summary report. 1980.

115. Report on an ecological survey of terrestrial insect communities in the AOSERP study area. 1980.

116. An assessment of benthic secondary production in the Muskeg River of northeastern Alberta. 1980.

117. Development of a chemically reactive plume model for application in the AOSERP study area. 1981.

118. Alberta Oil Sands Environmental Research Program, 1975-1980. A summary report. 1981.

119. Airshed management system for the Alberta oil sands. Volume I: A Gaussian frequency distribution model. 1981.

120. Airshed management system for the Alberta oil sands. Volume II: meteorological data.

121. The metabolism of selected organic compounds by microorganisms in the Athabasca River.

122. Soil inventory of the AOSERP study area. in prep.

123. Circulation of water and sediment in the Athabasca delta area. 1981.

124. Airshed management system for the Alberta oil sands. Volume III: validation and sensitivity studies.

125. The 1981 snowpack survey in the AOSERP study area. 1981.

126. Modelling the topographic effects on winds in the Alberta oil sands area. 1982.

127. Alberta Oil Sands Environmental Research Program annual report 1981/82. in prep.

128. A comparative study of benthic algal primary productivity in the AOSERP study area. 1982.

129. Athabasca Oil Sands precipitation chemistry studies: 1976-79 and 1981. 1982.