ENVIRONMENT CANADA

PRAIRIE & NORTHERN REGION

POINT PROBABLE MAXIMUM PRECIPITATION FOR THE PRAIRIE PROVINCES

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Executive Summary

This report complements a report by Hopkinson (1994) which focused on northern Saskatchewan. The latter was prepared primarily to provide guidance for the safe design of tailings ponds associated with the uranium mining industry in northern Saskatchewan. This report extends that guidance to the rest of the Prairie Provinces and is expected to have application in the design of similar structures with other types of mines, waste management facilities and industrial processing complexes. Such designs are intended to isolate a small catchment from the surrounding aquatic and terrestrial environment during extreme precipitation events, thus minimizing the risk of structural failure or dam over-topping.

Probable maximum precipitation (PMP) is used in the design of structures where failure would result in unacceptable environmental or physical damage or the loss of human life. This report derives the so-called "point" PMP for an area of the order of 1.0 square kilometre (km^2) and is concerned with rainfall durations of 1, 6 and 24 hours.

A contour map for determining the annual point PMP for the Prairie Provinces is provided and corresponds to the time of the PMP peak in mid to late July. Other figures illustrate how this PMP varies over the season from minimum values in the spring (April 30) to a representative peak July value and then decreases to minimum values again by November. This seasonal distribution of the PMP should be of value in reaching operational decisions about safe monthly water levels in ponds and reservoirs over the course of the year. Values of the July, 24-hour, point PMP for a number of representative locations on the prairies have been tabulated in the report.

For ponds, reservoirs, embankments, dikes, berms, dams, drainage channels and diversions with an associated runoff contributing area significantly greater than 1.0 km^2 (i.e. greater than 10 km^2), a so-called "areal" PMP over the drainage basin needs to be calculated. Areal PMPs have lower values than point PMPs but their derivation involves much more analysis and study than that needed for the point PMP information presented in this report. Design PMPs for certain important structures or large drainage basins could require consideration of snow-melt and rain plus snow-melt in deriving the probable maximum flood (PMF). Some offices of Environment Canada as well as private meteorological consultants may be prepared to derive areal PMPs for specific catchments.

This report does not address procedures for converting PMPs to PMFs, a service which is generally provided to industry by private consulting firms.

It is important to recognize that many water impoundments are designed initially for statistically-derived storm rainfall extremes with return periods of some

100 years. The PMP represents an upper bound and cannot be assigned a valid return period. PMPs are used to test and revise preliminary return-period designs to substantiate that the final design will function satisfactorily under the most extreme circumstances which are physically possible.

Structures and receiving waters can be protected in the following ways: by holding the PMP under normal reservoir operating conditions; by passing contaminated PMP overflows to secure holding areas which are not frequented by fish; or by otherwise preventing deleterious substances from entering waters frequented by fish. Overflows or embankment failures into waters frequented by fish must meet the provisions of the federal Fisheries Act and its associated Metal Mining Liquid Effluent Regulations and Guidelines (MMLERG).

Other water bodies may be governed by other water quality restrictions under provincial, federal or international agreements or guidelines. The use of the PMP in the design of important or environmentally-critical structures is meant to minimize, if not eliminate, the possibility of contamination of aquatic systems should these structures fail during an extreme rainfall event.

The basis of the point PMP calculation is an updated maximum 12-hour persisting dew point analysis. Although the present report had the benefit of 40 years of hourly dew point data compared to McKay (1963) who had at most ten years of data, the results were surprisingly consistent over the southern prairies. The updated persisting dew point analysis in this report had its greatest impact over north-eastern Alberta and north-western Saskatchewan where the maximum persisting dew point was analyzed to be one to four degrees Celsius higher than in McKay's report. In contrast, the present analysis was up to one degree Celsius colder over northern Manitoba, centred on Thompson.

This report also provides an assessment of the sensitivity of the PMP to climate change. Potentially a warmer atmosphere is capable of holding more water vapour which in turn would result in greater precipitable water. For the period 1953 to 1998, there is no evidence of a significant trend in maximum persisting dew point or in precipitable water derived from upper air soundings of the atmosphere. However a warming of even one degree Celsius in the maximum persisting dew point would result in a 9 % increase in the calculated precipitable water and, hence, the PMP.

Technical Summary

Convective rain storms of small areal extent are assumed to yield the greatest intensity of rainfall for the durations and area under consideration in this report.

Historically-significant prairie storms were reviewed and the most appropriate ones selected for maximization and transposition anywhere[1] in the prairie provinces. The PMP for mid to late July was derived for the uranium mining activity in the Rabbit Lake area of northern Saskatchewan and values at other locations were determined with respect to the variation in maximum inflow dew point temperature and changes in the elevation of the underlying terrain relative to Rabbit Lake. In addition, a seasonal distribution of PMP was calculated from April 15 to November 1. Some recommendations were made with respect to the temporal distribution of rainfall in the PMP storm and with respect to assumptions for antecedent conditions.

Annual point PMP estimates for 24 hours at a number of locations across the prairies were determined as follows:

Winnipeg	769 mm
Flin Flon	606 mm
Estevan	704 mm
Regina	624 mm
Saskatoon	569 mm
Lethbridge	513 mm
Calgary	419 mm
Edmonton	564 mm
Fort McMurray	503 mm

Certain designs may require the application of 1-hour and/or 6-hour PMPs as derived in this report.

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[1] The mountainous areas of western Alberta, the Cypress Hills in Alberta and Saskatchewan and other areas of marked topographic relief should be reviewed for the additional influence of orographic rainfall.

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Introduction

Late in 1991, a probable maximum precipitation (PMP) estimate for the Rabbit Lake uranium development was prepared for Hardy BBT Limited (Hopkinson - 1991a). Early in 1992, Dennis W. Lawson, Uranium Development Specialist, Environmental Protection Branch, Prairie and Northern Region, Environment Canada, requested a PMP estimate for Key Lake and suggested that a reference report be written which could be used by all mining projects in northern Saskatchewan where the PMP is needed for the design of tailings ponds and storage reservoirs, etc. Such a report was prepared (Hopkinson, 1994) to fulfil that need. This new report extends that analysis to the entire three prairie provinces and is intended to provide a design figure for small projects wherever the PMP is appropriate for the protection of the environment, property and human life.

The "probable maximum precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long term climatic trends" (WMO, 1986). In this report the area of concern is defined as 1.0 km^2. While this is considerably larger than most tailings ponds, it is not possible to resolve smaller scale rainfall. Data for even 1.0 km^2 are available for only a few storms. Most climatological observations of rainfall are generally considered to represent 25.0 km^2 so special techniques, such as so-called "bucket surveys", are needed to augment climatological network observations. Fortunately the Storm Rainfall in Canada (AES) series contains analyses of several prairie storms on such a scale.

Previous PMP estimates for specific drainage basins in the prairie provinces have used maximum 12-hour persisting dew point maps developed by McKay (1963). Very limited dew point data existed for the northern portions of the prairie provinces at the time of McKay's analysis. Thus, a thorough review of the maximum 12-hour persisting dew point was conducted for all meteorological stations with hourly dew point data in the prairie provinces in addition to stations just beyond the periphery of the prairies in neighbouring Ontario, NWT and British Columbia. The current review demonstrated that McKay's analysis was considerably in error over north-eastern Alberta and north-western Saskatchewan and to a lesser extent over northern Manitoba. Over the southern prairies, despite the advantage of 40 years of data, the current analysis was very similar to McKay's. For the purpose of this report, a revised maximum persisting dew point analysis was undertaken for the prairie provinces.

This report is based on the work done for the Rabbit Lake PMP estimate and extends that work to all areas of the prairie provinces. In addition, the seasonal variation of the PMP was derived as a planning tool for the operation of tailings ponds and similar structures.

Review of Historical Rainfall

In the previous report (Hopkinson, 1994), a thorough review of historical rainfall extremes was made with particular emphasis on northern Saskatchewan. Where possible, those results have been updated and are included in this section. Most of the sources used in the 1994 report have not been updated at the time of writing although the IDF (Intensity Duration Frequency) analyses are currently being updated. The only source of information which is current is the Canadian Climate Archive. There are a number of sources of extreme daily or short-duration rainfall which are applicable to this study. These include:

a) Canadian Climate Archive - includes all climatological day rainfall data for Canada in two data sets, dly04 which is quality controlled and dly02 which is raw rainfall data from automatic climate stations. The latter set involves an increasing fraction of the daily rainfall data generated in the 1990s because of the widespread introduction of autostations based on the Campbell Scientific dataloggers and also because of the automation of airport observing programs which was a consequence of the federal government downsizing program in 1995 and subsequent years.

- Using program RAINMAX all climatological rainfall data (dly04) from the 1800s to 1998 inclusive were scanned and the following were the most extreme one-day rainfalls in each climatological district (see Figure 1):

Table 1 Extreme one-day rainfalls for Saskatchewan

Climate District	Station	Date extreme one-day	Rainfall (mm)
Sask 401	Willmar	July 30, 1984	178.6
Sask 402	Cypress Hills	June 27, 1998	152.0
Sask 403	Cypress Hills Park	June 27, 1998	192.8
Sask 404	Denzil	July 6, 1975	106.7
Sask 405	Rosthern	July 1, 1962	154.7
Sask 406	Goodsoil	June 12, 1965	158.8
Sask 407	Paddockwood Exp St	August 21, 1954	90.2
Sask 408	Pelly 2	July 16, 1982	127.0

Since the previous report, new record one-day rainfalls were observed in both districts 402 and 403 - both for the same storm over the Cypress Hills on June

27, 1998. Also checked were the data in the dly02 archive. No new values approaching those in Table 1 were identified.

Figure 1 Climatological Districts

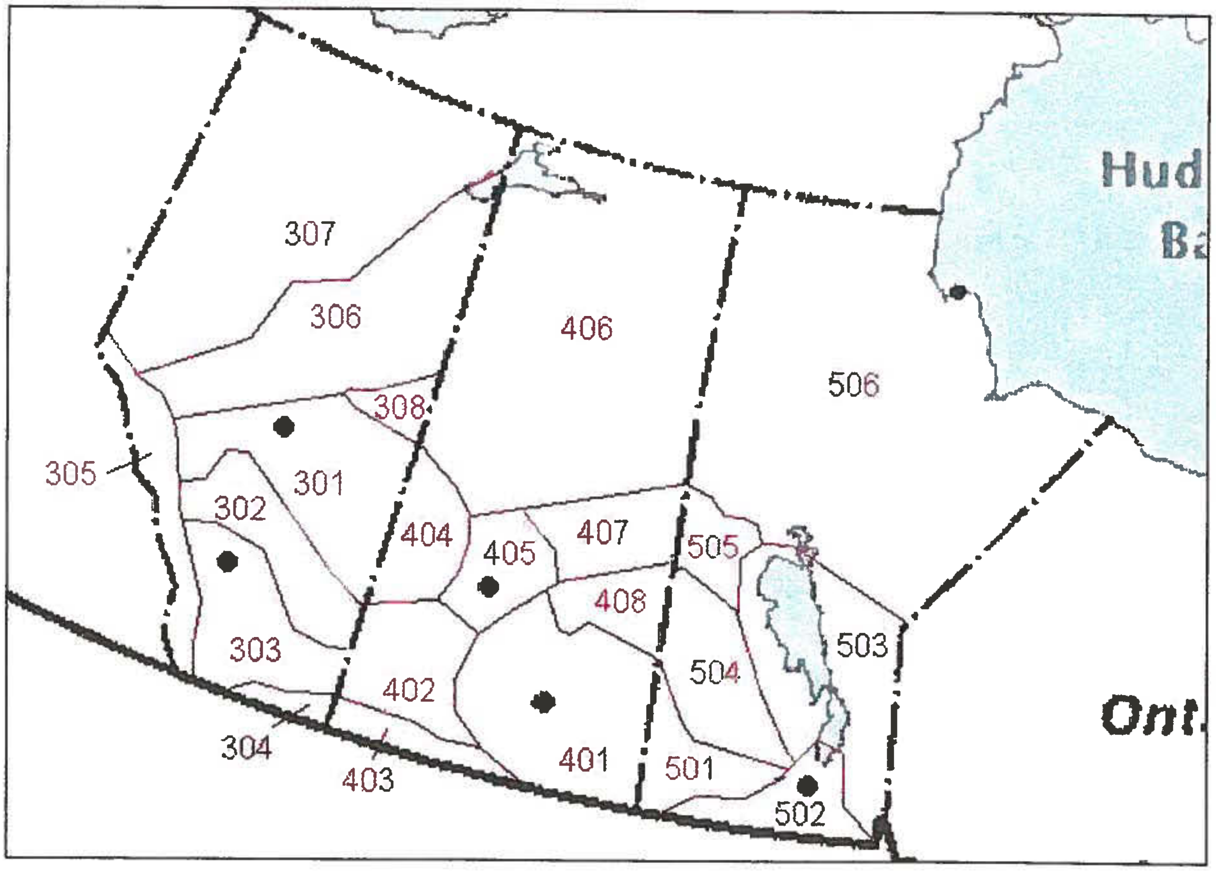


Table 2 Extreme one-day rainfalls for Manitoba

Climate District	Station	Date extreme one-day	Rainfall (mm)
Man 501	Waskada	June 29, 1935	167.1
Man 502	Sperling	June 24, 1997	165.0
Man 503	Beausejour	June 14 1973	193.5
Man 504	Lundar 45 W	August 7, 1975	186.7
Man 505	The Pas A	July 11, 1994	93.0
Man 506	Norway House	August 31, 1908	106.7

The only recent extreme one-day rainfalls in Manitoba were at Sperling - 165.0 mm - and The Pas - 93.0 mm. A few other values appeared in the top ten lists for climate districts 501 and 502. There were no other extreme rainfalls in the dly02 archive except for a spurious value of 700.4 mm on January 26, 1994 for Churchill which was obviously erroneous.

Table 3 Extreme one-day rainfalls for Alberta

Climate District	Station	Date extreme one-day	Rainfall (mm)
Alta 301	Stettler	June 30, 1970	165.1
Alta 302	Eckville South	June 30, 1970	213.1
Alta 303	Bassano Dam	May 31, 1923	170.9
Alta 304*	Bowness*	August 22, 1978	127.0
Alta 305	Lyndon	June 29, 1963	170.2
Alta 306	Pelican Mountain LO	June 28, 1970	136.9
Alta 307	Smoky LO	July 14, 1982	160.0
Alta 308	Cold Lake A	June 5, 1962	93.7

* excludes two values from Coutts - May 1903 - 255.0 and 203.2 - the published rainfall total for May, 1903 is 1.91 inches (48.5 mm) so an archive problem is assumed.

No new extreme rainfalls were noted for the climate districts in Alberta since the previous report (Hopkinson, 1994). The storm of June 6, 1995 represented seven of the top ten values in climate district 305 but not the most extreme value. The June 27, 1998 storm produced the fourth greatest one-day rainfall in climate district 303 (Medicine Lodge LO - 141.2 mm).

It was concluded that no new extreme rainfalls were observed in the last five years that would affect the list of envelope-producing storms previously identified.

b) Intensity-Duration-Frequency (IDF) analyses (AES, 1992) of extreme 5-minute to 24-hour rainfall as compiled from tipping bucket (recording) rain gauge data to the end of 1990.

- refer to d) for pertinent data

c) The "District and Station Climate Extremes on Microfiche", AES (1986).

- this was superseded by the data search in a) and d)

d) Extreme short duration rainfall data by province and Canada (Hogg, 1992).

Table 4 Extreme short duration rainfall on the prairies (recording rain gauge data) 1900 to 1987

	Alberta	Saskatchewan	Manitoba
1-hour	63.3 Lethbridge A 1982	81.5 Swift Current CDA 1964	96.3 Porcupine Mtn Bell L 1966
6-hour	85.1 Edmonton Mun A 1953	148.8 Regina A 1975	132.3 Porcupine Mtn Bell L 1966
12-hour	110.7 Edmonton Mun A 1953	151.6 Regina A 1975	154.0 Indian Bay 1982
24-hour	119.9 Edmonton Mun A 1953	153.4 Regina A 1975	154.0 Indian Bay 1982

Note that although the 24-hour values apply to any 24 consecutive hours, the density of stations is much less than the climatological network in a). Also note that this data set is eleven years out of date but the task of reviewing all the most recent short duration rainfall data in archive is a massive one. These data should be updated once the new IDF analyses are released.

e) Greatest Rainfall, Snowfall and Precipitation on any one Observation Day

- Alberta (AES, 1986b)
- Saskatchewan (AES, 1987a)
- Manitoba (AES, 1987b)

- superseded by a)

f) Storm Rainfall in Canada (AES, irregular publication series)

- refer to section - Rabbit Lake PMP Estimate

g) An Index to Storm Rainfall in Canada (Routledge et al, 1988)

- superseded by f) and a)

h) Bucket surveys or other storm reports not included in the Storm Rainfall in Canada series (e.g. Moser, 1975, Hopkinson, 1996)

All of these sources were searched in turn to identify extreme rainfall events of duration 24 hours (one day) or less. Virtually all of the greatest extreme rainfalls from one hour to 24 hours are part of the Storm Rainfall in Canada analyses. The one-hour extreme is dominated by the May 30, 1961 storm (258 mm) at Buffalo Gap in south-central Saskatchewan. The six-hour, twelve-hour and 24-hour extremes

(266.7, 362.0, and 381.0 mm) were all set by the Parkman storm in southeast Saskatchewan of August 3 to 4, 1985. An analysis of the Parkman storm appears in the Storm Rainfall in Canada series and includes the bucket survey data collected by Environment Canada in Regina. Neither of these majors storms occurred over or near one of the climatological stations and hence did not appear in Table 1.

Some of the older observed daily rainfall extremes are not included in the Storm Rainfall in Canada analyses but, in general, these pale in comparison to the figures just quoted (e.g. 167.6 mm in one climatological day at Indian Head CDA, June 15, 1897).

Because of the lack of rainfall data in northern Saskatchewan and northern Manitoba, no storm analysis from those areas appears in the Storm Rainfall in Canada series. The only documented major northern storm close to this area occurred on July 10 to 11, 1974 just east of Montreal Lake between 54°N and 55°N latitude. A bucket survey (Moser, 1975) revealed that this 12-hour storm produced 307 mm near its centre! Even though this storm lasted only 12-hours, it produced the third highest observed 24-hour rainfall in the prairie provinces.

A thorough review of all rainfall data sources listed in this section did not reveal any unknown rainfall extremes which exceeded or even approached the rainfall amounts or rates associated with the Buffalo Gap or Parkman storms. Some major rainfalls were identified that were not documented in one of the Storm Rainfall analyses but these values were of the order of 50% (or less) of those which comprise the envelope of extreme rainfall for durations of one to 24 hours. Two new summer storms have occurred since Hopkinson's (1994) report. The Alberta storm of June 6, 1995 had a very significant orographic component. This storm had a 24-hour rainfall extreme of 295 mm at Spionkop Creek. The second recent storm of note was that of June 27, 1998 which yielded up to 200 mm in 24 hours along the windward north slope of the Cypress Hills in southwest Saskatchewan and southeast Alberta. It too had a significant orographic component.

Review of Previous PMP and Related Studies

Rainfall Frequency Atlas

The Rainfall Frequency Atlas for Canada (Hogg and Carr, 1985) maps the mean and standard deviation of extreme 24-hour rainfall based on recording rain gauge data. Assuming a Gumbel distribution, it is possible to determine return period rainfall, R_t, for any location using the mean extreme, x, and standard deviation, s, of the annual rainfall extreme which appear on the maps:

$$R_t = x + K_t s$$

where K_t is the appropriate frequency factor for the double exponential distribution (Gumbel). For example, K_t for a 100 year return period is 3.137.

Hershfield (1977) developed a statistical method for estimating point PMP using hundreds of thousands of station-years of rainfall data from many countries. In Hershfield's method, the frequency factor is estimated for a 24-hour rainfall as follows:

$$K_{PMP} = (19)(10)^{-0.000965x}$$

where x is the mean extreme.

Applying Hershfield's K-factor to Hogg and Carr's map for selected sites on the prairies for a 24-hour duration yields point PMP estimates ranging from 180 mm to 200 mm along the northern edge of the prairie provinces to over 325 to 425 mm across the southern prairies. In general, the 24-hour statistical PMP based on the Hogg and Carr (1985) analysis of recording rain gauge data (mean and standard deviation of the annual 24-hour extremes) yields lower values in the north and higher values in the south. However, there are notable anomalies in this pattern

The method is very sensitive to the standard deviation because 85 to 90% of the statistical approach is attributable to the standard deviation times the K-factor. A review of the maps by Hogg and Carr (1985) shows patterns which probably have no physical basis. In general the recording rain gauge records are for a limited number of years and therefore, the statistics calculated from them may not be representative of the population statistics. For this reason, it is recommended that the mean extremes and standard deviations analyzed by Hogg and Carr (1985) not be used for estimating the point PMP on the prairies because the patterns are just too noisy based on short-term data. Rather, initial statistical estimates of the PMP should take advantage of the much longer records of climatological rainfall data for one or more climatological days. For shorter duration PMP (less than 24 hours), there is no similar offset.

Table 5 Sample calculation of 24-hour statistical PMP using the mean extreme and the standard deviation of the extreme from Hogg and Carr (1985)

Location	Mean Extreme (mm)	Standard Dev. (mm)	K(PMP)	PMP (mm)
Winnipeg	54.0	16.0	16.9	323.6
Flin Flon	42.5	14.5	17.3	293.2
Thompson	36.5	13.0	17.5	264.3
Churchill	29.0	9.5	17.8	198.2
Estevan	44.5	19.0	17.2	371.5
Regina	46.0	18.1	17.2	356.5
Saskatoon	39.5	14.5	17.4	291.9
La Ronge	45.5	16.5	17.2	328.9
Cree Lake	42.0	18.0	17.3	353.5
Lethbridge	45.5	18.0	17.2	354.6
Calgary**	40.0	16.0	17.4	318.1
Edmonton	45.5	22.0	17.2	423.3
Grande Prairie	40.0	19.9	17.4	385.9
Fort McMurray	41.0	20.1	17.3	389.6
Fort Smith (NWT)	28.0	8.5	17.9	179.8

** value estimated because station analysis was obscured by the map legend

McKay's (1965) Approach

G. A. McKay wrote several reports which could be used for estimating extreme rainfall in the prairie provinces during his secondment at the Prairie Farm Rehabilitation Administration (PFRA) in the early 1960s. The last in the series (McKay, 1965) provided maps similar to the Rainfall Frequency Atlas for Canada except that the coefficient of variation was plotted instead of the standard deviation. The coefficient of variation is the ratio of the standard deviation divided by the mean and it is believed to be more stable and conservative than the standard deviation alone. Also, the 24-hour rainfalls were based on climatological day records rather than on the recording rain gauge data used by Hogg and Carr (1985). Finally, McKay developed his own estimate of the frequency factor, K, which when applied to the prairies yielded values in the range of 18.9 to 23.6, generally higher than Hershfield's (1977) relationship which is always less than 19.

The form of the equation used by McKay is as follows:

$$PMP = P_x (1 + KC_v)$$

where P_x is the mean extreme for one climatological day and C_v is the coefficient of variation.

By computing the point PMP at various locations in the prairie provinces based on maps and the K factor provided by McKay (1965), one observes a range of values from 286 to 417 mm but the pattern is nonsensical (see Table 6). A minimum occurs at Winnipeg and the maximum at Calgary. The virtual absence of any station data over northern Saskatchewan may have led to an erroneous analysis of the mean extreme and coefficient of variation but that cannot be blamed for the problems in Table 6. Although the data used to derive McKay's (1965) maps were probably for a longer period of record than the short duration rainfall data available to Hogg and Carr (1985), they suffer from the same problem. The record length is still too short to adequately define the population statistics - particularly the coefficient of variation. Errors in the mean extreme will also influence the frequency factor, K.

Table 6 Determination of 24-hour PMP using McKay's (1965) statistical approach

Location	Mean (Inches)	Mean (mm)	Coefficient of Variation(%)	K Factor	PMP (inches)	PMP (mm)
Winnipeg	1.74	44.2	29	18.9	11.3	286.4
Flin Flon	1.53	38.9	41	20.7	14.5	368.7
Thompson	1.40	35.6	42	21.8	14.2	361.1
Churchill	1.36	34.5	47	22.4	15.7	398.2
Estevan	1.60	40.6	34	20.2	12.6	319.8
Regina	1.53	38.9	36	20.7	12.9	328.5
Saskatoon	1.35	34.3	38	22.3	12.8	324.9
La Ronge	1.54	39.1	36	20.6	13.0	329.2
Cree Lake	1.51	38.4	33	20.9	11.9	302.9
Lethbridge	1.41	35.8	41	21.8	14.0	355.9
Calgary	1.59	40.4	46	20.3	16.4	417.5
Edmonton	1.52	38.6	34	20.8	12.3	311.6
Grande Prairie	1.30	33.0	34	22.7	11.3	287.9
Fort McMurray	1.48	37.6	36	21.2	12.8	324.5
Fort Smith (NWT)	1.20	30.5	40	23.6	12.5	318.2

Thus, McKay's approach is not recommended as a means for determining small area PMPs for the Canadian prairie provinces.

RAIN30 or GRP208

A general report program, GRP208, on the AES Downsview main-frame computer, calculated the one-day to ten-day return period rainfall and PMP using observed annual maximum rainfalls for durations of one to ten climatological days. The PMP was calculated after Hershfield (1977) as described in the section, Rainfall Frequency Atlas.

With the removal of the AES Downsview main-frame computer late in 1994 and its replacement with the Atmospheric Information System (ATIS) based on mini-computer platforms (typically HP9000 workstations) and an Oracle database, this functionality was lost. The designers of the replacement system had originally planned to include a similar utility on the new system but this was one victim of the government's downsizing exercise, Program Review. Fortunately, the FORTRAN code for a similar program (RAIN30) had been downloaded from the Downsview main-frame computer prior to its removal and the program recompiled on a microcomputer. Small changes were made to the input-output code to adapt the program to the PC environment. Recently, a couple of small logic errors were corrected (Hopkinson, 1999). Except for the west coast of British Columbia and possibly some parts of Atlantic Canada, these changes had no impact on the computed PMP.

The program was applied to climatological stations at the same locations as were used in Tables 5 and 6. The results were recorded in Table 7 for all data up to and including 1998. The computed statistical PMP at individual sites was in the range of 288.1 mm at Fort Smith to 497.3 mm at Winnipeg St. John's College. However, it should be noted that the analysis based on Winnipeg Int'l A yielded a value of 328.7 mm. This provides some indication of the error than can arise from using even relatively long records. Regina's value of 475.6 mm is also anomalously high, attributable in part to a few events that were significantly greater than the 1:100 year return period rainfall as determined from the rest of the data set.

Of the three statistical approaches examined in this report, the use of RAIN30 provided the most consistent results but as the discussion in the previous paragraph suggested, there can be significant errors introduced by outliers or rare events in a sample of limited length. The output of RAIN30 provides guidance as to the general magnitude of the PMP event in an area but it is apparent that the results from just one analysis may be misleading. It is recommended that if RAIN30 is used for initial design, it be applied to the longest possible period of record for several stations which are proximate to the site of interest. One other by-product of RAIN30 is a list of historical rainfalls which may be of interest for modelling or may be used with other environmental data to better define basin response to extreme rainfall events.

Table 7 Statistical PMP for selected stations based on one climatological day

Climatological Station Name	Climate ID	Start year	End Year	# Years	Mean extreme	Std. Dev.	1:100y return period	PMP*
					(mm)	(mm)	(mm)	(mm)
Winnipeg Int'l A	5023222	1938	1998	60	54.0	16.2	104.7	328.7
Winnipeg St. John's College	5023243	1872	1943	64	51.2	26.1	133.1	497.3
Flin Flon	5050920	1927	1998	59	41.0	16.6	93.0	331.2
Flin Flon A	5050960	1968	1998	29	46.3	16.5	98.1	334.6
Thompson A	5062922	1967	1998	31	44.0	13.9	87.5	286.8
Churchill A	5060600	1943	1998	54	33.3	12.7	73.2	259.8
Estevan A	4012400	1944	1998	54	45.3	18.1	102.2	359.7
Regina A	4016560	1883	1998	103	45.4	24.9	123.6	475.6
Saskatoon A	4057120	1892	1998	98	41.0	17.2	94.9	340.4
La Ronge A	4064150	1959	1998	32	39.9	15.4	88.2	312.3
Cree Lake	4061861	1969	1993	23	41.6	17.4	96.4	350.5
Lethbridge A	3033880	1938	1998	60	43.6	18.3	100.9	361.6
Lethbridge CDA	3033890	1908	1998	81	42.9	19.7	104.9	384.8
Calgary Int'l A	3031093	1881	1998	114	43.0	19.9	105.4	388.1
Edmonton Municipal A	3012208	1937	1998	61	48.6	19.3	109.2	380.7
Edmonton	3032195	1880	1943	59	44.3	19.2	104.6	378.1
Grande Prairie A	3072920	1942	1998	56	40.3	19.1	100.1	374.3
Fort McMurray A	3062693	1944	1998	55	40.1	15.5	88.7	311.5
Fort Smith A	2202200	1943	1998	53	32.7	14.3	77.7	288.1

* Statistical PMP after Hershfield (1977). Daily rainfall data were analyzed using the computer program RAIN30. The mean annual extreme and standard deviation were determined for the climatological day and have been adjusted within the program by a factor of 1.13 to account for the average difference between any 24-hour period and a fixed climatological day.

Updated Maximum Persisting Dew Point Temperatures for the Prairie Provinces

McKay (1963) developed a set of maps of 12-hour maximum persisting dew point for the months of March to October based on limited data and in the case of the northern prairies, virtually no data. Therefore, a review of McKay's work was warranted and long overdue.

Maximum persisting dew point is defined as the highest dew point temperature which is equalled or exceeded during a specified period (e.g. 12 hours). For example, consider the following series of sample dew point temperatures covering a 12-hour period (13 values):

14 14 14 15 15 16 18 17 15 15 14 14 13

In this series the maximum 12-hour persisting dew point is 13. For the month of July, 744 twelve-hour windows would be considered and the maximum persisting 12-hour dew point for the month would be the greatest of the 744 possibilities.

Hourly dew point data are available in the Canadian Climate Archive, Dorval Quebec. The hourly portion of the archive commences in January 1953, so for some stations, a full 40 years (1953 to 1992) of hourly data were available for the return period analysis when this work was originally undertaken. At the time of writing, six more years of hourly dew point data are available but based on experience, it is not believed that the additional data would substantially alter the results of this analysis which was completed before the shut-down of the AES Downsview mainframe computer at the end of 1994.

A computer program on the AES Downsview computer, PERSDEW, was used to identify the annual 12-hour maximum persisting dew point for each month and the year as a whole. The method of moments is used to estimate the monthly and annual 100-year return period maximum 12-hour persisting dew point, assuming a Gumbel distribution.

Four classes of records were used for the persisting dew point analysis according to the completeness of the record (see Figure 2):

a) Primary - full 40 years of data -There were 33 such stations on or near the prairies and those are listed in Table 8 below.

b) Secondary - any stations with 21 to 39 years of data - There were 35 stations which fell in this category and they are listed in Table 9.

Table 8 Stations for dew point analysis with 40 complete years of data

NAME	Province	Climate ID	Lat(N)	Long(E)	No. Years	Elev(m)
Fort Smith A	NWT	2202200	60.02	-111.95	40	203
Hay River	NWT	2202400	60.87	-115.73	40	166
Churchill A	Man	5060600	58.75	-94.05	40	35
Dauphin A	Man	5040680	51.10	-100.05	40	305
Portage La Prairie A	Man	5012320	49.90	-98.27	40	270
The Pas A	Man	5052880	53.97	-101.10	40	271
Winnipeg A	Man	5022322	49.90	-97.23	40	239
Trout Lake	Ont	6010738	53.83	-89.87	40	219
Kenora A	Ont	6034075	49.80	-94.37	40	411
Sioux Lookout A	Ont	6037775	50.12	-91.90	40	390
Thunder Bay A	Ont	6048261	48.37	-89.32	40	199
Kamloops A	BC	1163780	50.70	-120.45	40	345
Fort Nelson A	BC	1192940	58.83	-122.58	40	382
Fort St. John A	BC	1183000	56.23	-120.73	40	694
Penticton A	BC	1126150	49.47	-119.60	40	344
Prince George A	BC	1096450	53.88	-122.67	40	676
Quesnel A	BC	1096630	53.03	-122.52	40	545
Broadview	Sask	4010879	50.38	-102.58	40	601
Estevan A	Sask	4012400	49.07	-103.00	40	572
North Battleford A	Sask	4045600	52.77	-108.25	40	548
Prince Albert A	Sask	4056240	53.22	-105.68	40	428
Regina A	Sask	4016560	50.43	-104.67	40	577
Saskatoon A	Sask	4057120	52.17	-106.68	40	500
Swift Current A	Sask	4028040	50.28	-107.68	40	818
Yorkton A	Sask	4019080	51.27	-102.47	40	498
Fort McMurray A	Alta	3062693	56.65	-111.22	40	369
Grande Prairie A	Alta	3072920	55.18	-118.88	40	669
Wagner/Slave Lake A	Alta	3066001	55.30	-114.78	40	581
Calgary A	Alta	3031093	51.10	-114.02	40	1084
Edmonton Mun A	Alta	3012208	53.57	-113.52	40	671
Lethbridge A	Alta	3033880	49.63	-112.80	40	929
Medicine Hat A	Alta	3034480	50.02	-110.72	40	717
Whitecourt A	Alta	3067372	54.15	-115.78	40	782

c) Tertiary - 10 to 20 years of data - There were only 10 stations that fell in this category and these are listed in Table 10.

d) Supplemental - observing program not 24 hours - Collins Bay, Cree Lake, Buffalo Narrows A, Meadow Lake A, Flin Flon A, and Brochet A. These sites were used in data-sparse areas to supplement other information. In the case of a discrepancy, preference was given to stations with complete 24-hour data.

Table 9 Stations for dew point analysis with 21 to 39 years of data

NAME	Province	Climate ID	Lat(N)	Long(E)	No. Years	Elev(m)
Ennadai Lake	NWT	2301100	61.13	-100.92	25	324
Brandon A	Man	5010480	49.92	-99.95	34	409
Flin Flin A	Man	5050960	54.68	-101.68	24	304
Gillam A	Man	5061001	56.35	-94.70	22	145
Gimli	Man	5030140	50.63	-97.05	38	221
Lynn Lake A	Man	5061646	56.70	-101.07	24	371
Thompson A	Man	5062922	55.80	-97.87	26	215
Armstrong A	Ont	6040325	50.28	-88.90	30	323
Atikokan A	Ont	6020379	48.75	-91.62	22	393
Red Lake A	Ont	6016975	51.07	-93.82	29	375
Kelowna A	BC	1123970	49.97	-119.38	27	430
Cranbrook A	BC	1152100	49.53	-115.77	23	939
Dawson Creek A	BC	1182285	55.73	-120.18	24	654
Williams Lake A	BC	1098940	52.18	-122.07	32	940
Hudson Bay A	Sask	4083321	52.82	-102.32	33	357
Moose Jaw A	Sask	4015320	50.33	-105.55	39	577
Wynyard	Sask	4019035	51.77	-104.20	25	561
Cree Lake	Sask	4061861	57.35	-107.13	23	499
La Ronge A	Sask	4064150	55.10	-105.30	26	369
Uranium City	Sask	4068340	59.57	-108.48	24	318
Cold Lake A	Alta	3081680	54.42	-110.28	38	541
Edson A	Alta	3062241	53.58	-116.42	33	924
Fort Chipewyan A	Alta	3082658	58.77	-111.12	25	232
Footner Lake A	Alta	3073146	58.62	-117.17	22	338
Lac La Biche A	Alta	3063685	54.77	-112.02	23	568
Banff	Alta	3050520	51.18	-115.57	28	1397
Coronation	Alta	3011880	52.10	-111.45	35	798
Jasper	Alta	3053520	52.58	-118.07	29	1061
Peace River A	Alta	3075040	56.23	-117.43	34	571
Red Deer Penhold A	Alta	3025480	52.18	-113.90	39	905
Rocky Mountain House	Alta	3015522	52.43	-114.92	30	988
Vermilion A	Alta	3016800	53.35	-110.83	29	619

Figure 2 Record Length of Stations Used in Persisting Dew Point Analysis

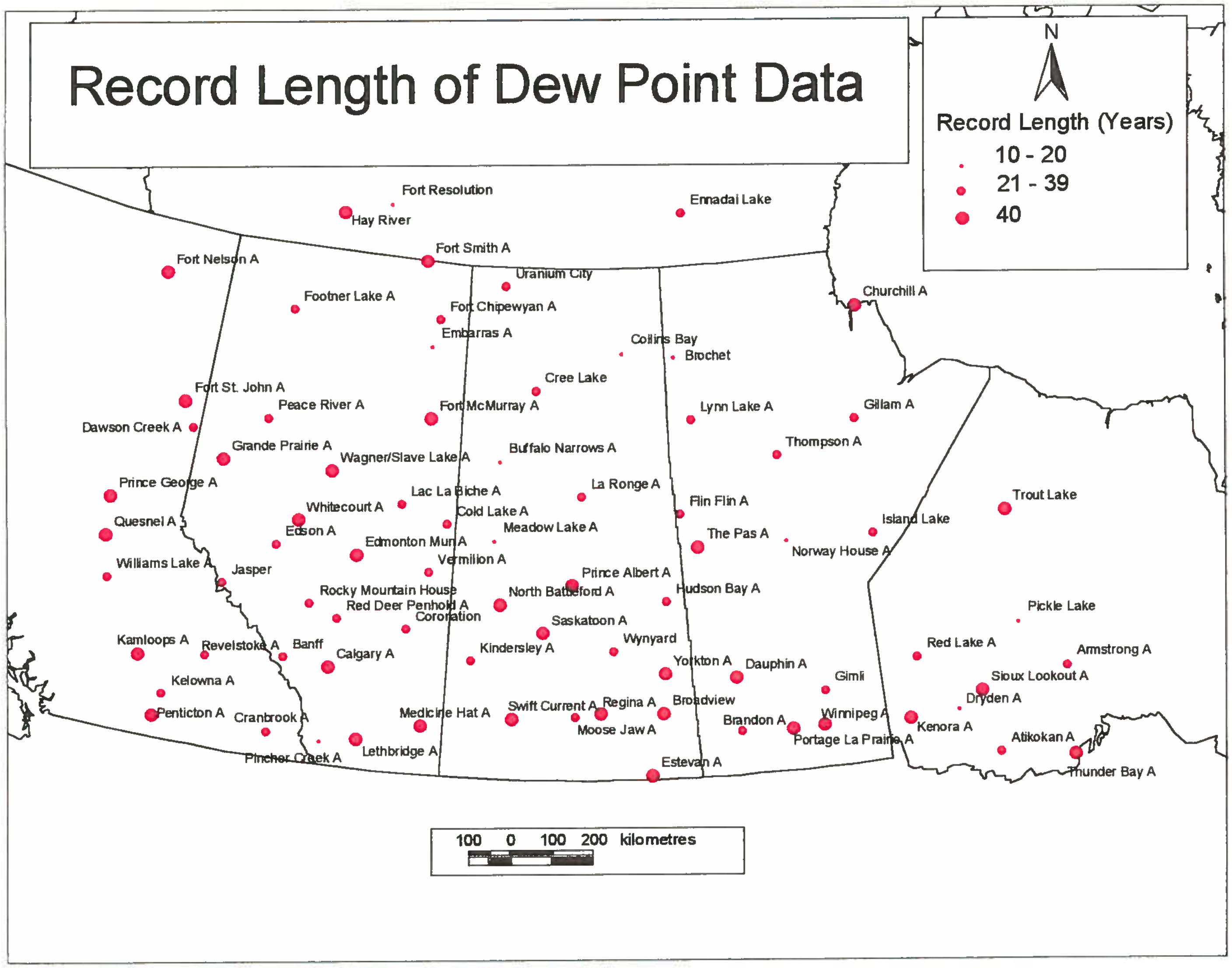


Table 10 Stations for dew point analysis with 10 to 20 years of data

NAME	Province	Climate ID	Lat(N)	Long(E)	No. Years	Elev (m)
Fort Resolution	NWT	2202000	61.18	-113.68	18	164
Brochet	Man	5060518	58.05	-101.62	17	343
Norway House A	Man	506B047	53.97	-97.83	20	223
Dryden A	Ont	6032119	49.83	-92.75	20	412
Pickle Lake	Ont	6016525	51.45	-90.20	15	369
Meadow Lake A	Sask	4065058	54.13	-108.52	15	480
Buffalo Narrows A	Sask	4060982	55.83	-108.43	17	434
Collins Bay	Sask	4061630	58.18	-103.70	14	492
Embarras A	Alta	3062360	58.20	-111.38	10	236
Pincher Creek A	Alta	3035202	49.52	-114.00	17	1190

For each station, all monthly maximum persisting dew point temperatures were plotted against the Julian day of occurrence. Figure 3 shows a sample plot for Regina A. The 1:100 year 12-hour persisting dew point estimates for each month were plotted on the day of the month closest to July 15 and a line connecting the 1:100 year values was plotted in the figure. For months prior to July, the value was plotted on the last day of the month whereas for months after July, it was plotted on the first day of each month. An envelope (not shown) of the actual values was often used in refining the shape of the 1:100 curve. Some obvious outliers were ignored.

A similar analysis was performed for all 78 stations for which sufficient dew point data were available. It should be noted that the results were not considered reliable in the winter months. At that time, snow cover could affect the actual persisting dew point values which would not necessarily be representative of the moisture in the column of air above the station. Similar influences were noted in areas on the east and west coasts of Canada. These ocean regions are often dominated by a marine stratum which usually is not indicative of the moisture content of the troposphere.

The peak annual value at each station was adjusted to the 100 kPa pressure level and plotted on a map (Figure 4) of the region. Compared to McKay's mid-July map, large differences were noted over northern Alberta and north-western Saskatchewan where the maximum 12-hour persisting dew point values in Figure 4 exceeded those developed by McKay from one to over four degrees Celsius. The largest difference (over 4.0 C) occurred near Fort Smith along the Alberta/NWT boundary. Differences of the opposite sign, but of a much smaller magnitude (-0.5 to -1.0 C), were typical of northern Manitoba. The greatest negative difference was centred between Norway House and Thompson. On the southern prairies, a comparative analysis indicated relatively small differences between McKay's report and Figure 4.

Figure 3 Monthly Maximum 12-Hour Persisting Dew Point and 1:100 Year Curve

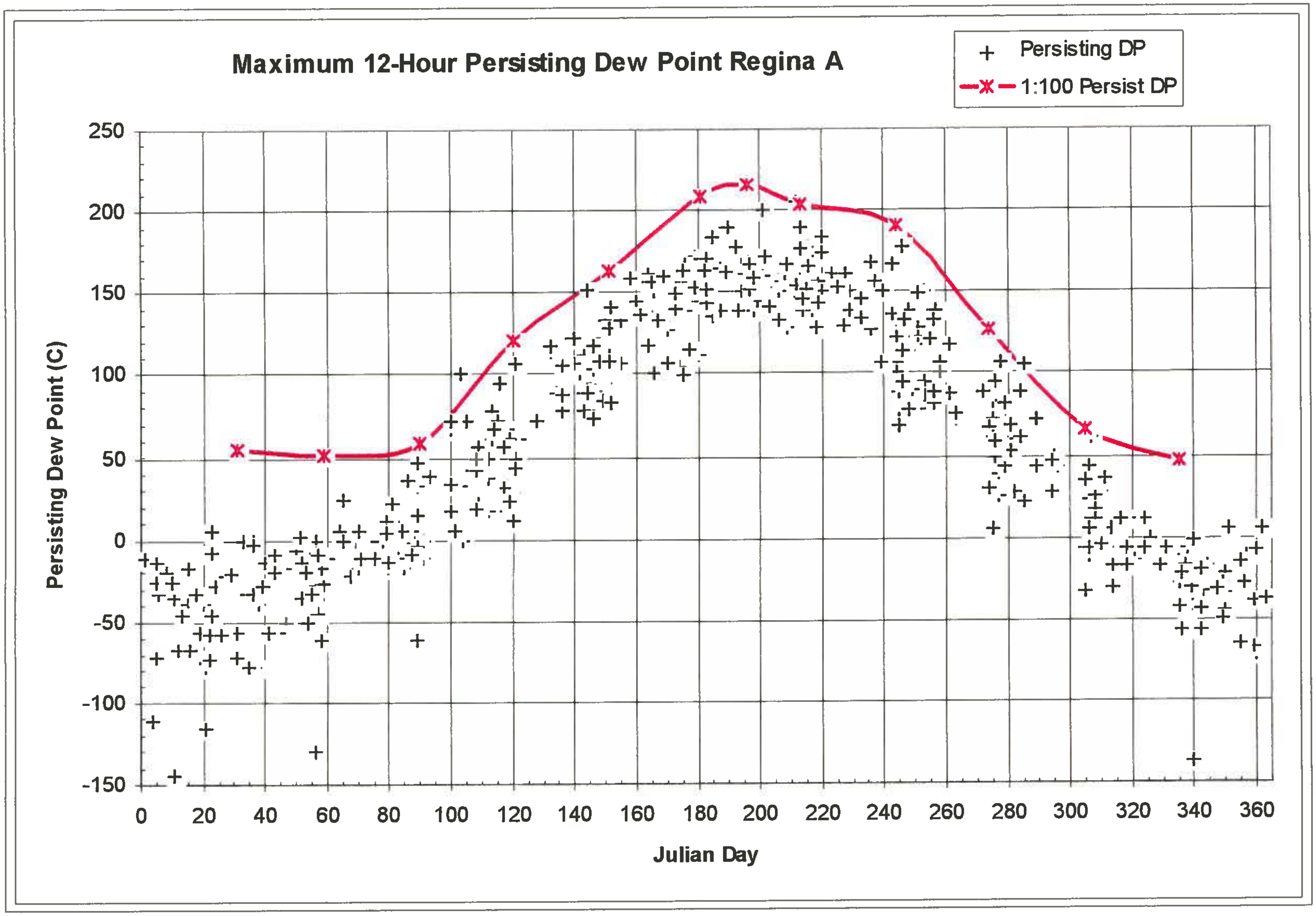
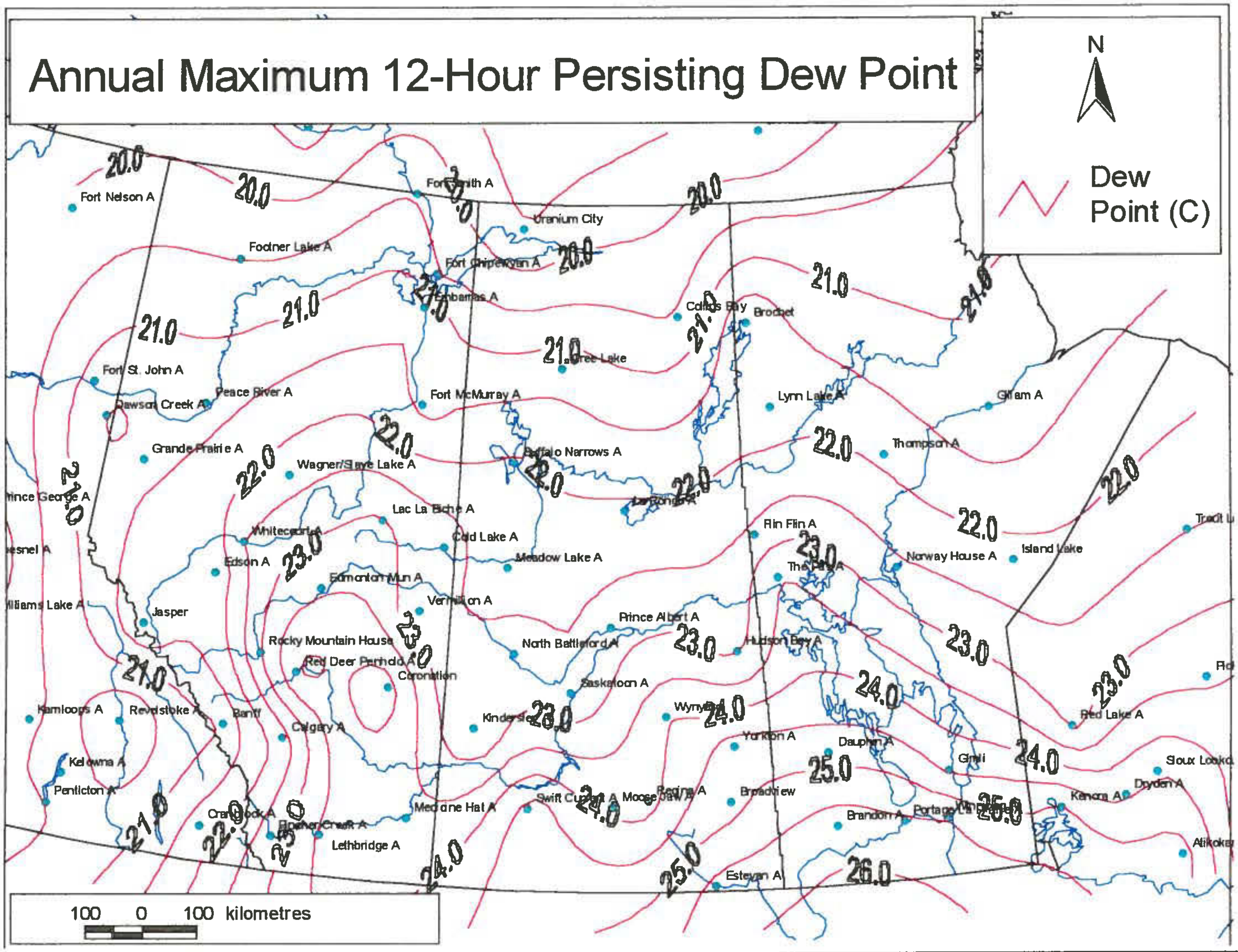


Figure 4 Maximum 12-Hour Persisting Dew Point (C) at 100 kPa



An estimate of the PMP at Cluff Lake uranium development (Hopkinson, 1991c) based on the persisting dew point analysis of McKay (1963), considerably underestimated the PMP relative to the information in this report which is based on the updated persisting dew point analysis in Figure 4. This underscores the need for a good persisting dew point analysis and the care that must be taken in data-sparse areas.

The resulting pattern indicates essentially east-west oriented lines of equal maximum 12-hour persisting dew point with values decreasing by about 1.0 C for every two degrees latitude northward. This pattern is notably altered along the foothills and mountains of south-west Alberta. The highest values of 26.0 C are over extreme southern Manitoba and the lowest 19.5 C, north of Lake Athabaska

The seasonal distribution of maximum 12-hour persisting dew point was abstracted from the curves for selected stations like that illustrated for Regina in Figure 3. This will be discussed in further detail in the section, Seasonal Distribution of the PMP.

Hogg (1993) suggested that precipitable water computed directly from radiosonde soundings may be better than precipitable water inferred from 12-hour persisting dew points. There was technical merit in considering radiosonde data (upper air) in a study such as this, but, in the end, this report is based solely on 12-hour persisting dew points for the following reasons:

a) Very few radiosonde stations are located within or near the prairies. This sparse spatial network was not sufficient to define the spatial pattern of maximized precipitable water over the study area or to provide definitive inflow of precipitable water for historic storms.

b) Unlike the surface data which have a one-hour temporal resolution, upper air data have a 12-hour resolution. Neither observation time (0000 UTC or 1200 UTC) will necessarily represent the maximum (12-hour persisting) precipitable water for a given day.

c) Many historic storms occurred prior to the introduction of radiosonde equipment in the mid to late 1940s. Thus, those older storms would have to be deleted from this study if upper air data were used instead of surface dew point data.

d) Precipitable water derived from upper air data is particularly important when surface dew point data do not represent the precipitable water in the upper air sounding. For example, extensive snow cover or a marine stratum will result in a surface dew point which may be quite unrelated to the precipitable water of the air above the surface-based inversion. During the prime summer months of

May to September, surface dew points under saturated pseudo-adiabatic conditions are good indicators of the precipitable water through a deep layer of the troposphere. The assumptions are less valid in April and October when continuous snow cover is possible. As demonstrated later in this report, maximized precipitable water in these shoulder months was not greatly in error. However, the use of surface dew point data is not applicable to the winter months November to March.

In conclusion, this report utilized surface dew point data instead of upper air data to determine the maximum precipitable water because of the much better spatial (horizontal) and temporal resolution. Also, all historical storms in the Storm Rainfall in Canada series could be maximized by using this technique. For cold winter months with continuous snow cover, surface dew point data are not appropriate indicators of total precipitable water.

It is possible to refine the persisting dew point curve by using 15-day or even shorter analysis periods but the sample size is insufficient at this time to yield stable estimates of the 1:100 year return period persisting dew point for periods of less than one month. At least 50 years of dew point data are recommended before attempting such a refinement to the analysis. That criterion should be met for at least 33 stations by 2003.

Rabbit Lake PMP Estimate

This section is a duplicate of that included in the northern Saskatchewan PMP report (Hopkinson, 1994) because the discussion is central to the methodology and will permit the use of this report without reference to the previous report.

All of the depth-area-duration data for Manitoba and Saskatchewan storms and a few Alberta storms (pure prairie storms only) from the Storm Rainfall in Canada series have been entered into a set of files for access by the computer program STORMDAT (Hopkinson, 1991b). The program will select the ten highest ranking storms for a given area and duration and provide the actual or interpolated rainfall for each of the selected storms. All storms which occurred in the prairie area of the three prairie provinces can be transposed to any other area on the prairie provinces with the exception of the mountainous region of southwest Alberta. Care must also be taken in other upland regions such as the Cypress Hills. There are no physical barriers or meteorological reasons why any of the storms considered could not have occurred elsewhere in the prairie provinces. The results are recorded in Table 11.

Table 11 Results of storm search for Rabbit Lake mine

Maximum observed rainfall amount (mm) for 1 km^2

1 HOUR DURATION		6 HOUR DURATION		24 HOUR DURATION	
Storm ID	amount	Storm ID	amount	Storm ID	amount
SJUN2575	26.5	SJUL1074	153.7	MSEP1775	200.7
SJUN2483	27.8	SJUN2575	158.8	MJUN2935	201.4
MJUN2935	32.0	SJUN2483	167.0	SJUN1262	213.9
SJUN1721	35.6	SJUN0863	190.5	MAUG1057	236.2
SJUL0846	42.3	MJUN2935	191.8	SJUL0846	254.8
SAUG0385	44.5	SJUN1262	207.8	SMAY3061	258.9
SJUN2560	53.6	SJUN1721	213.4	UJUN0606	259.1
SJUN1262	66.0	SJUL0846	254.0	SJUL1074	307.3
SJUN0863	133.3	SMAY3061	258.9	SJUN1721	330.2
SMAY3061	258.0	SAUG0385	266.7	SAUG0385	381.0

Key

S....... Saskatchewan,Month,Day,Year
M....... Manitoba,,,
A....... Alberta,,,
U....... USA,,,

Some storms that have been particularly significant for PMP for moderate-sized catchments have been the Springbank (Montana) storm commencing June 17, 1921, the Rhodes Ranch (Montana) storm of July 9-10, 1946, the Warwick (Montana) storm of June 6, 1906 and the storm of July 10, 1974 over the Cub and Wapawekka Hills of central Saskatchewan. In more recent times, the Parkman (southeast Saskatchewan) storm of August 3, 1985 (Hopkinson, 1986a and 1986b) is particularly significant for small to moderate-sized catchments for durations from 6 to 24 hours. The Buffalo Gap (southern Saskatchewan) storm of May 30, 1961 was the most significant storm for short durations up to six hours.

The lack of storm data for northern Saskatchewan and Manitoba reflects the very sparse climatological network north of 55° N. The best documented northern storm occurred between 54° and 55° N in the area of the Cub and Wapawekka Hills on July 10, 1974 (Moser, 1975). This twelve-hour storm produced 307 mm and was the subject of a bucket survey by Saskatchewan Environment. It does not appear in Atmospheric Environment Service (AES) Storm Rainfall in Canada series but the depth-area-duration information has been added to the STORMDAT data base. This storm is evidence that extreme rainfalls are possible at more northern latitudes, although the network is too sparse in Manitoba or Saskatchewan to record many such events. This storm is identified in Table 11 as SJUL1074 where "S" signifies Saskatchewan; "JUL" the month of occurrence; "10" the starting date and "74" the year. In Table 12, this same storm is designated SASK-7-74 which conforms to the AES storm analysis naming convention. A similar coding has been used to identify all the Storm Rainfall in Canada storms but differs from the coding used for STORMDAT (e.g. SMAY3061 is designated SASK-5-61 in the Storm Rainfall in Canada series). The storm naming convention used in STORMDAT makes provision for more than one storm in a particular month, and is more amenable to file naming used in DOS on a micro-computer.

The Alberta Forestry data of the past 35 years has greatly enhanced the climate network in northern Alberta compared to its easterly neighbours. As a result, several storms covering northern Alberta appear in the Storm Rainfall in Canada series.

For each selected storm, the twelve-hour persisting inflow dew point temperature was determined from weather maps and adjusted to 100 kPa as specified by the WMO (1986). Also abstracted was the topographic height for the location where the maximum 1.0 km^2 rainfall occurred. Using these two values it is possible to determine the precipitable water (mm) for a saturated column of air from the land surface to the 30 kPa pressure level (approximately 10000 m elevation). This can be done manually from tables such as those that appear in Annex A of the WMO Manual (1986). In this procedure, it is assumed that the vertical distribution of the dew point temperature is defined by the pseudo-adiabatic lapse rate. It is possible to calculate the coordinates of the pseudo-adiabat and to calculate the precipitable water using a numerical procedure. For this report, the program RWATR (Hopkinson, 1982), which uses the numerical approach, was employed. The numerical approach is preferred because it is more accurate then manual two-way interpolation from a table. A summary of the significant storms, and their pertinent details appears in Table 12.

Table 12 Basic data for storms significant to Rabbit Lake mine point PMP

Identity No. Name	Gross Area (km^2)	Mean Elevation(m)
Rabbit Lake	1.0	490
Sask-7-74		
12 hour persisting dew point @ 1000 mb		20.6 C
Storm basin elevation (m)		400.0 m
Precipitable water		49.77 mm
Sask-6-21 ref USA Hydromet Rep. #55 (1984)		
12 hour persisting dew point @ 1000 mb		22.2 C
Storm basin elevation (m)		800.0 m
Precipitable water		50.19 mm
Sask-7-46		
12 hour persisting dew point @ 1000 mb		18.7 C
Storm basin elevation (m)		700.0 m
Precipitable water		37.53 mm
Sask-6-62		
12 hour persisting dew point @ 1000 mb		17.3 C
Storm basin elevation (m)		800.0 m
Precipitable water		31.63 mm
Man-6-35		
12 hour persisting dew point @ 1000 mb		17.6 C
Storm basin elevation (m)		600.0 m
Precipitable water		35.15 mm
USA-6-06 ref USA Hydromet Rep. #55		
12 hour persisting dew point @ 1000 mb		17.8 C
Storm basin elevation (m)		900.0 m
Precipitable water		31.92 mm
SASK-5-61		
1 hour persisting dewpoint at 1000 mb		18.9 C
Storm basin elevation (m)		760.0 m
Precipitable Water		37.40 mm
SASK-8-85		
12 hour persisting dewpoint at 1000 mb		18.9 C
Storm basin elevation (m)		640.0 m
Precipitable Water		39.10 mm
SASK-6-63		
12 hour persisting dewpoint at 1000 mb		15.8 C
Storm basin elevation (m)		465.0 m
Precipitable Water		31.31 mm
	Max persisting Dew Point (C)	Precipitable Water (mm)
RABBIT LAKE	20.5	47.81

Figure 5 Location of Grid Points Used for Precipitable Water Analysis

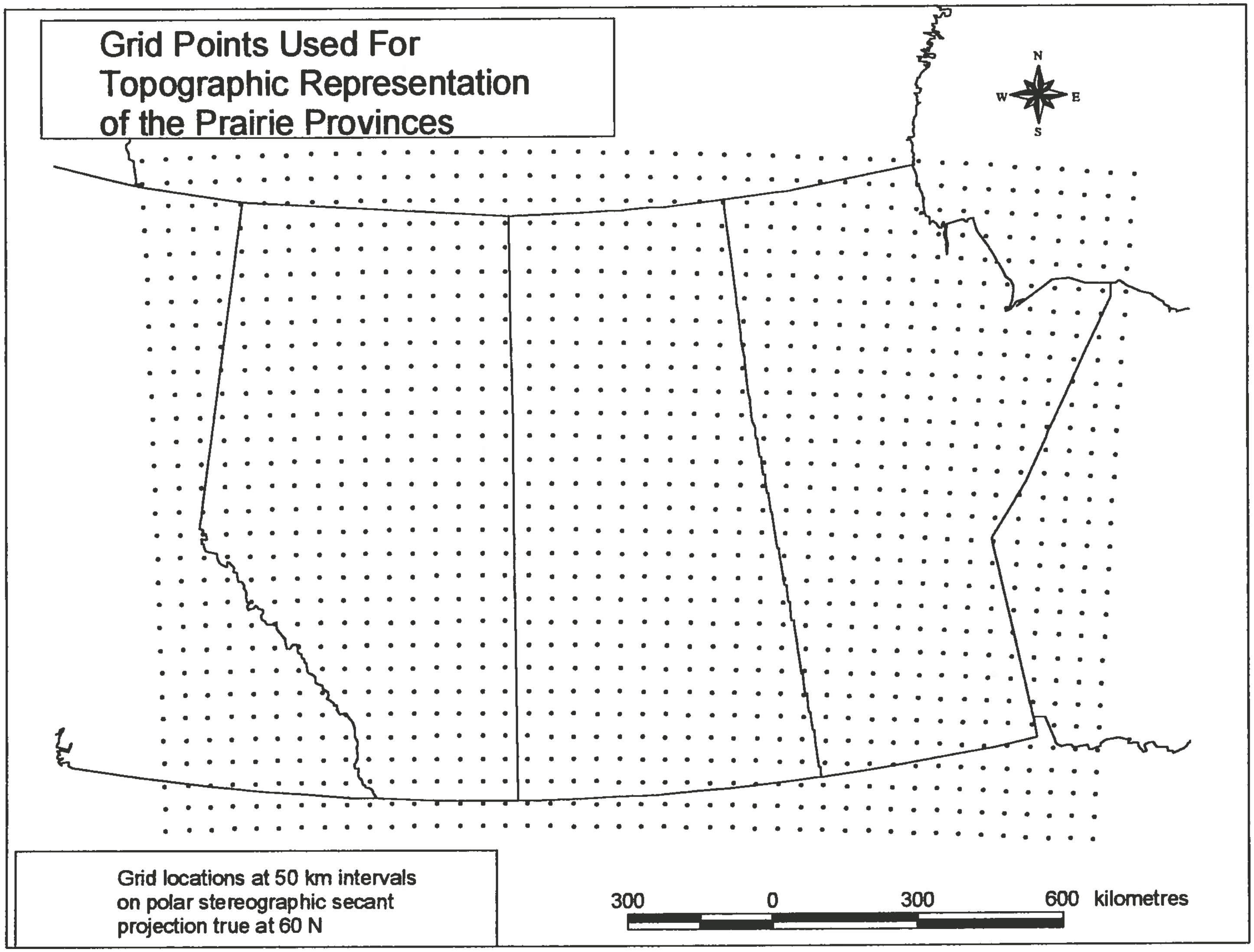


Figure 6 Elevation(m) at Grid Points Used to Calculate Precipitable Water

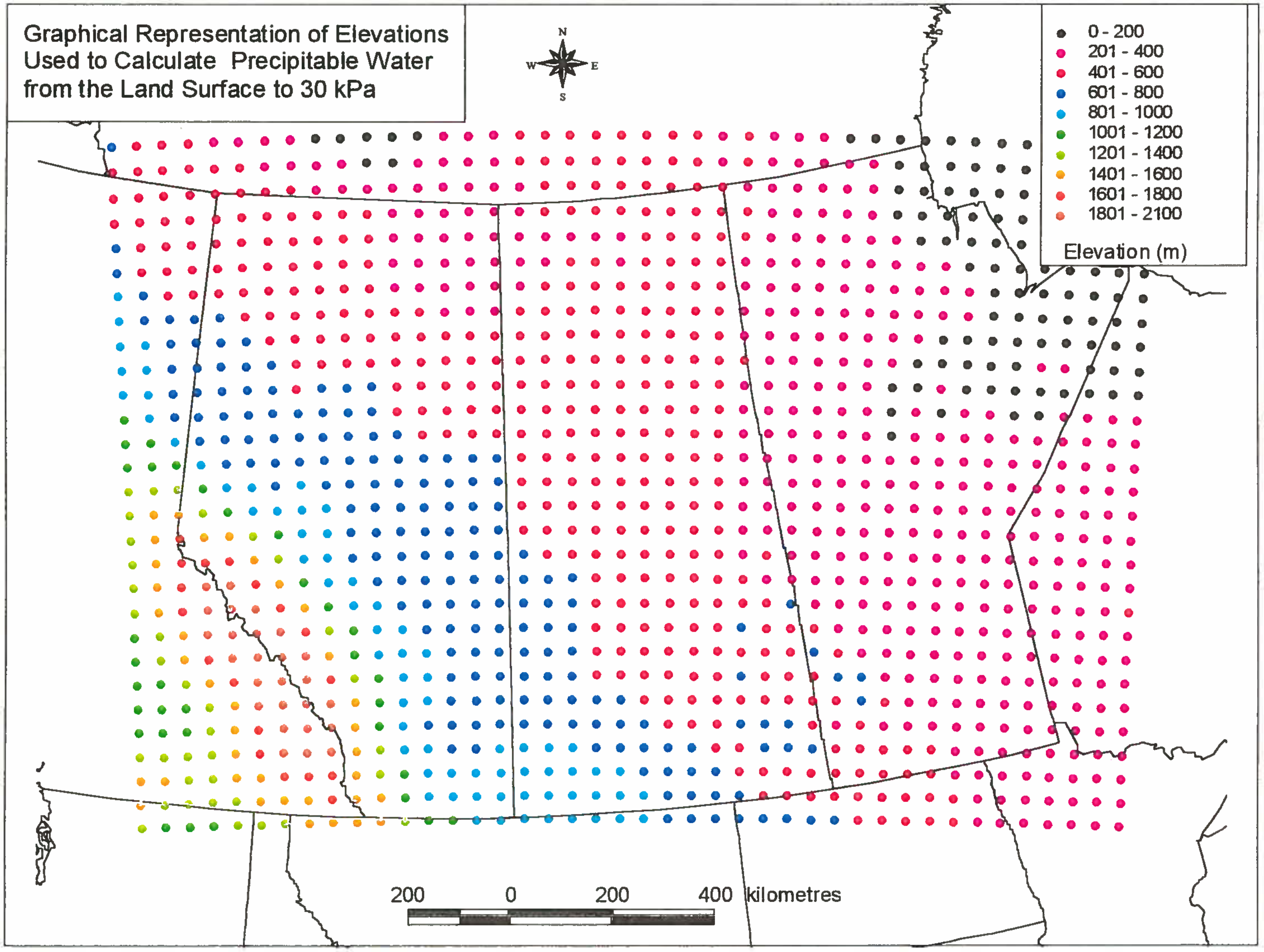
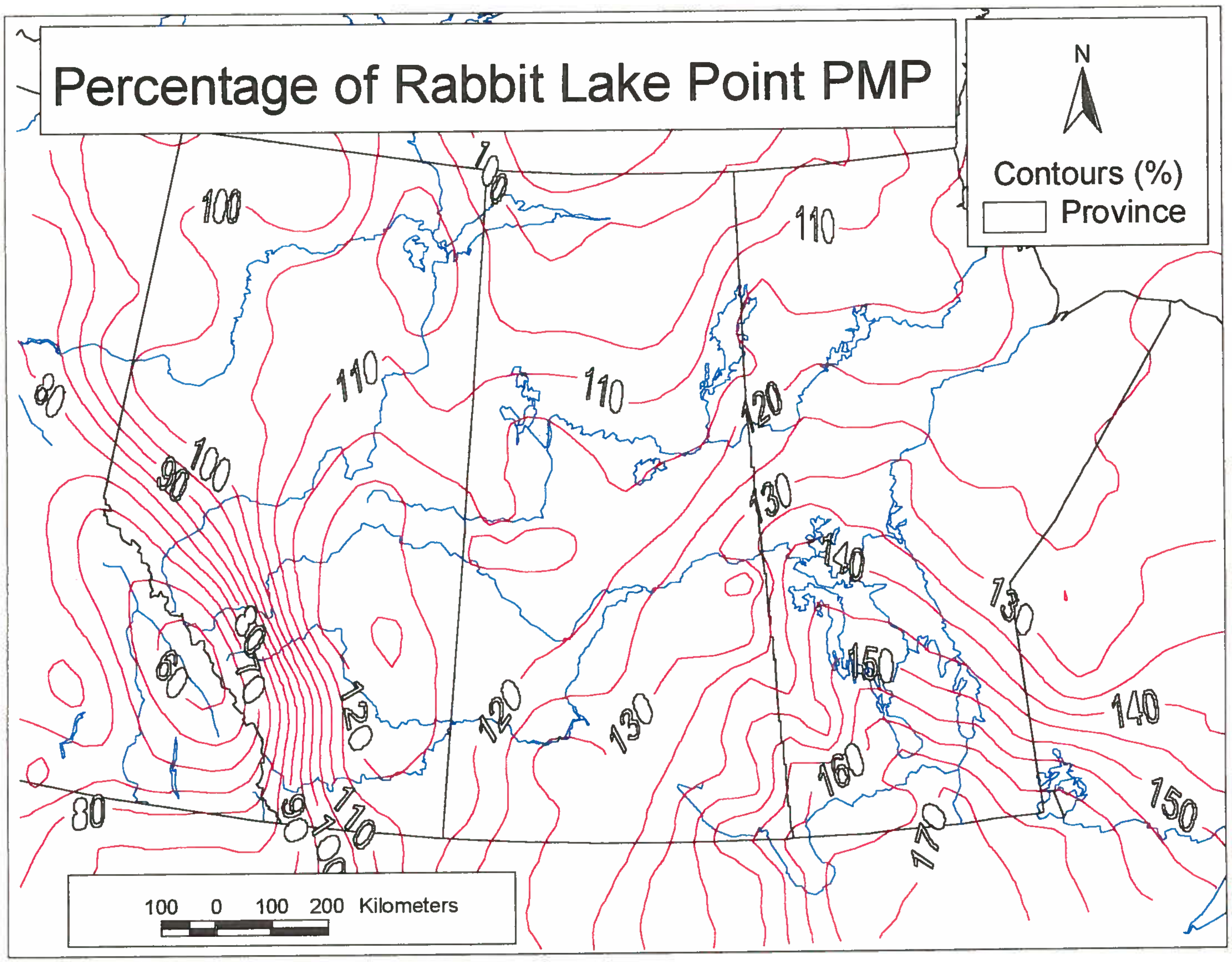


Figure 7 Percentage of Precipitable Water at Rabbit Lake Uranium Mine



Seasonal Distribution of the PMP

The seasonal distribution of the PMP is significant to some operations at times other than mid to late July. For planning purposes, at other times of the year when heavy rainfall events are possible for anywhere on the Canadian prairies (i.e. not winter), Figure 8 was derived from the maximum persisting dew point curve for Rabbit Lake (as represented by Collins Bay data available from the persisting dew point analysis). The abstracted dew point values were adjusted to 100 kPa and then used to calculate the associated precipitable water. Tabular results are presented in Table 15.

To derive Table 15, intermediate dew point values (15-day) were interpolated along the curve joining the monthly values as determined using the persisting dew point program, PERSDEW. The only exception to this was the period from June 30 to August 1 when the three plotted points were explicitly defined by PERSDEW.

Figure 8 Seasonal Distribution of PMP at Rabbit Lake Uranium Mine, Sask.

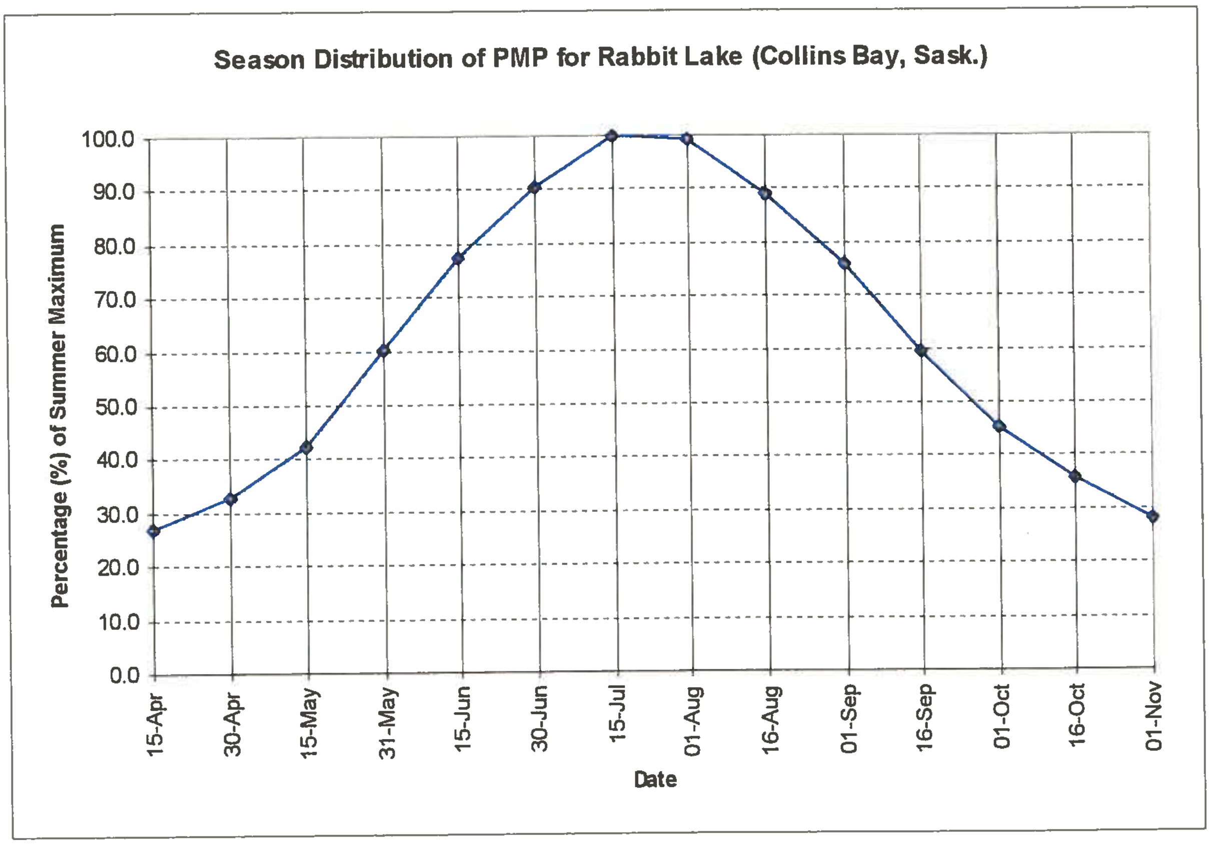


Table 15 Seasonal Distribution of PMP

Precipitable Water (mm)

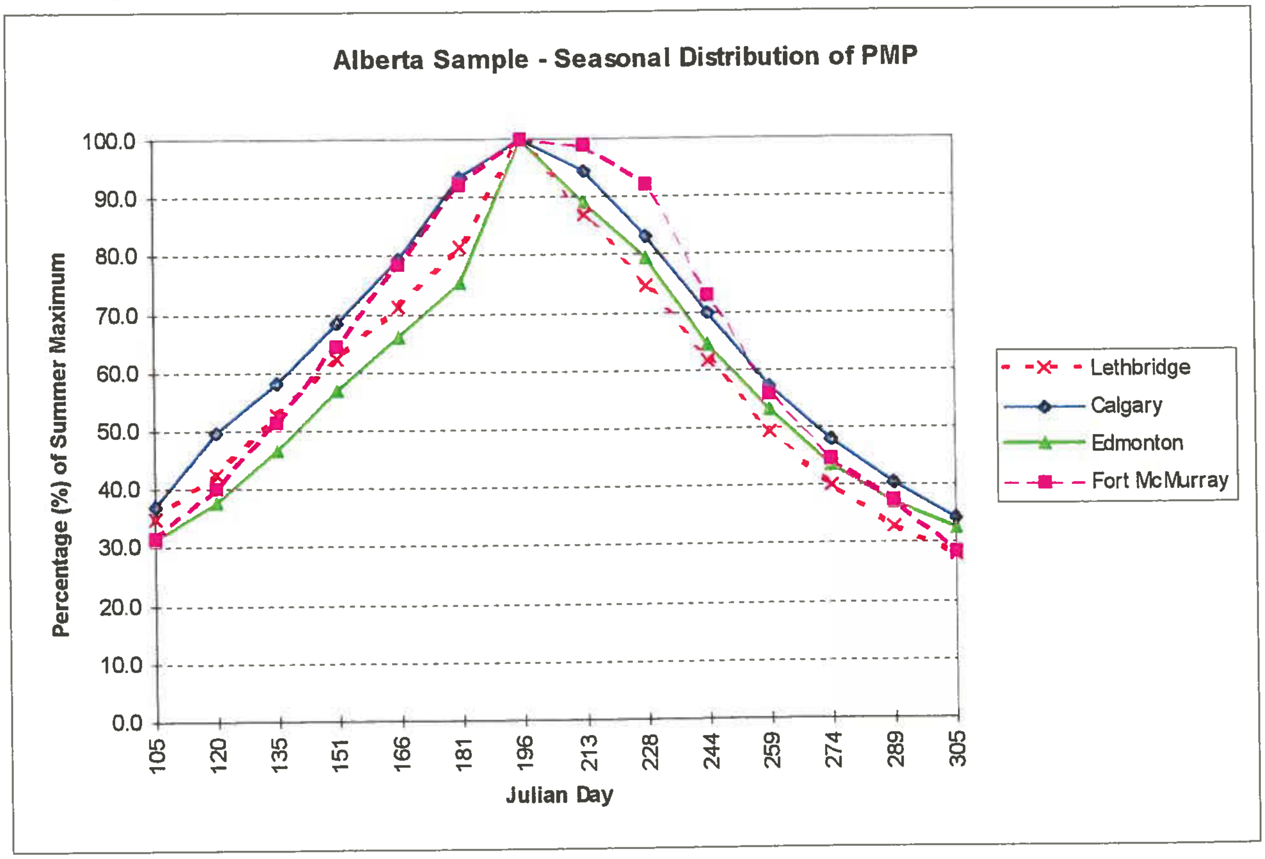
Date	Julian Day	Regina	Winnipeg	Calgary	Fort McMurray	Edmonton	Flin Flon	Estevan	Saskatoon	Lethbridge	Rabbit Lake
15-Apr	105	20.5	24.6	16.1	16.2	18.2	14.8	22.4	17.9	19.1	12.9
30-Apr	120	27.5	35.4	21.6	20.4	22.1	19.0	31.7	22.4	23.3	15.7
15-May	135	32.9	44.4	25.3	26.3	27.2	30.1	37.6	30.0	28.9	20.3
31-May	151	38.9	57.5	29.7	32.9	33.3	43.0	44.0	41.1	34.1	28.8
15-Jun	166	49.0	65.5	34.4	40.1	38.7	48.3	54.2	50.3	39.0	37.0
30-Jun	181	59.0	73.9	40.6	47.2	44.0	55.7	65.5	54.5	44.5	43.2
15-Jul	196	63.1	81.2	43.4	51.2	58.5	57.2	70.9	56.0	54.7	47.8
01-Aug	213	56.6	69.6	40.9	50.8	52.0	56.7	66.0	52.6	47.6	47.4
16-Aug	228	54.6	66.7	36.1	47.2	46.5	51.4	58.8	48.9	40.9	42.5
01-Sep	244	49.9	66.7	30.3	37.3	37.6	45.0	53.7	42.7	33.8	36.3
16-Sep	259	38.6	59.5	24.8	28.6	31.1	36.5	43.6	34.8	27.0	28.5
01-Oct	274	27.8	45.2	20.8	22.9	25.5	28.8	34.2	25.8	22.0	21.7
16-Oct	289	21.3	36.4	17.5	19.1	21.6	20.6	26.8	20.0	17.9	17.1
01-Nov	305	16.9	24.6	14.9	14.6	19.1	16.7	20.7	15.9	15.4	13.5

Seasonal Distribution as a % of Summer Maximum

Date	Julian Day	Regina	Winnipeg	Calgary	Fort McMurray	Edmonton	Flin Flon	Estevan	Saskatoon	Lethbridge	Rabbit Lake
15-Apr	105	32.5	30.3	37.1	31.6	31.1	25.9	31.6	32.0	34.9	27.0
30-Apr	120	43.6	43.6	49.8	39.9	37.8	33.2	44.7	40.0	42.6	32.8
15-May	135	52.2	54.7	58.3	51.3	46.5	52.6	53.0	53.6	52.8	42.5
31-May	151	61.7	70.7	68.5	64.2	56.9	75.2	62.1	73.4	62.3	60.3
15-Jun	166	77.7	80.6	79.3	78.3	66.2	84.4	76.4	89.8	71.3	77.4
30-Jun	181	93.6	91.0	93.5	92.2	75.2	97.4	92.4	97.3	81.4	90.4
15-Jul	196	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
01-Aug	213	89.8	85.7	94.4	99.1	88.9	99.1	93.1	93.9	87.0	99.2
16-Aug	228	86.6	82.1	83.3	92.2	79.5	89.9	82.9	87.3	74.8	88.9
01-Sep	244	79.1	82.1	69.8	72.8	64.3	78.7	75.7	76.3	61.8	75.9
16-Sep	259	61.2	73.3	57.2	55.8	53.2	63.8	61.5	62.1	49.4	59.6
01-Oct	274	44.0	55.7	47.9	44.6	43.6	50.3	48.2	46.1	40.2	45.4
16-Oct	289	33.8	44.8	40.4	37.3	36.9	36.0	37.8	35.7	32.7	35.8
01-Nov	305	26.8	30.3	34.3	28.5	32.6	29.2	29.2	28.4	28.2	28.2

In principle, this distribution is strictly applicable to Rabbit Lake because the maximum persisting dew point does not change in the same way at all locations in the prairie provinces. Also included in Table 15 are the calculations done at other representative sites across the prairies. These seasonal distributions were plotted in Figures 9, 10 and 11. As can be seen, the seasonal distribution shows some variability from station to station. The distribution at Edmonton is more peaked than at Fort McMurray. The distribution at Winnipeg illustrates a curious secondary peak on September 1. This probably indicates some limitations of the analysis because of the limited sample size. The other possible conclusion is that the unusual distributions such as for Winnipeg are a reflection of the true climatology, but the physical basis for this secondary maximum is not immediately apparent.

Figure 9 Seasonal Distribution of PMP at Selected Alberta Stations



If the point PMP is required for some other location than those given in Table 15 or Figures 8 to 11, then it is recommended that the closest station for which the seasonal distribution is available be used as a guide.

The July value of the point PMP can be determined at any location by abstracting the ratio from Figure 7 and applying it to the Rabbit Lake point PMP as described in the previous section. If an estimate for mid May is required near Calgary, one should use the ratio given in Table 15 (i.e. 58%) to adjust the peak (July) point PMP to mid-May.

Figure 10 Seasonal Distribution of PMP at Selected Stations in Saskatchewan

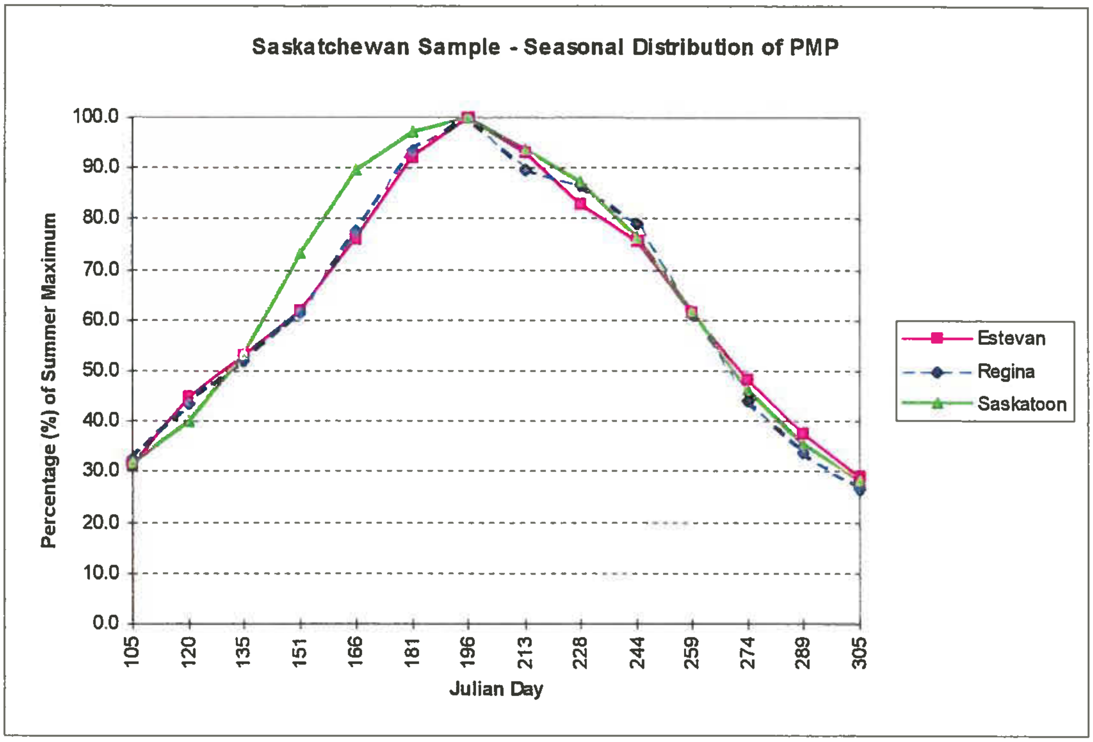
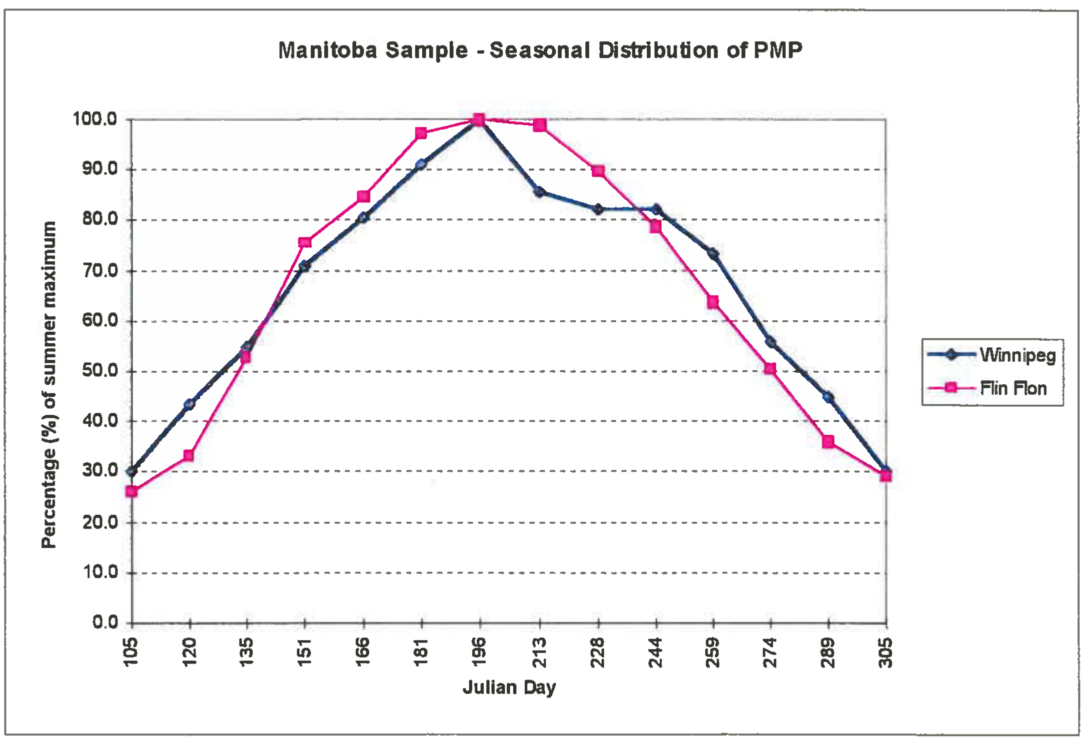


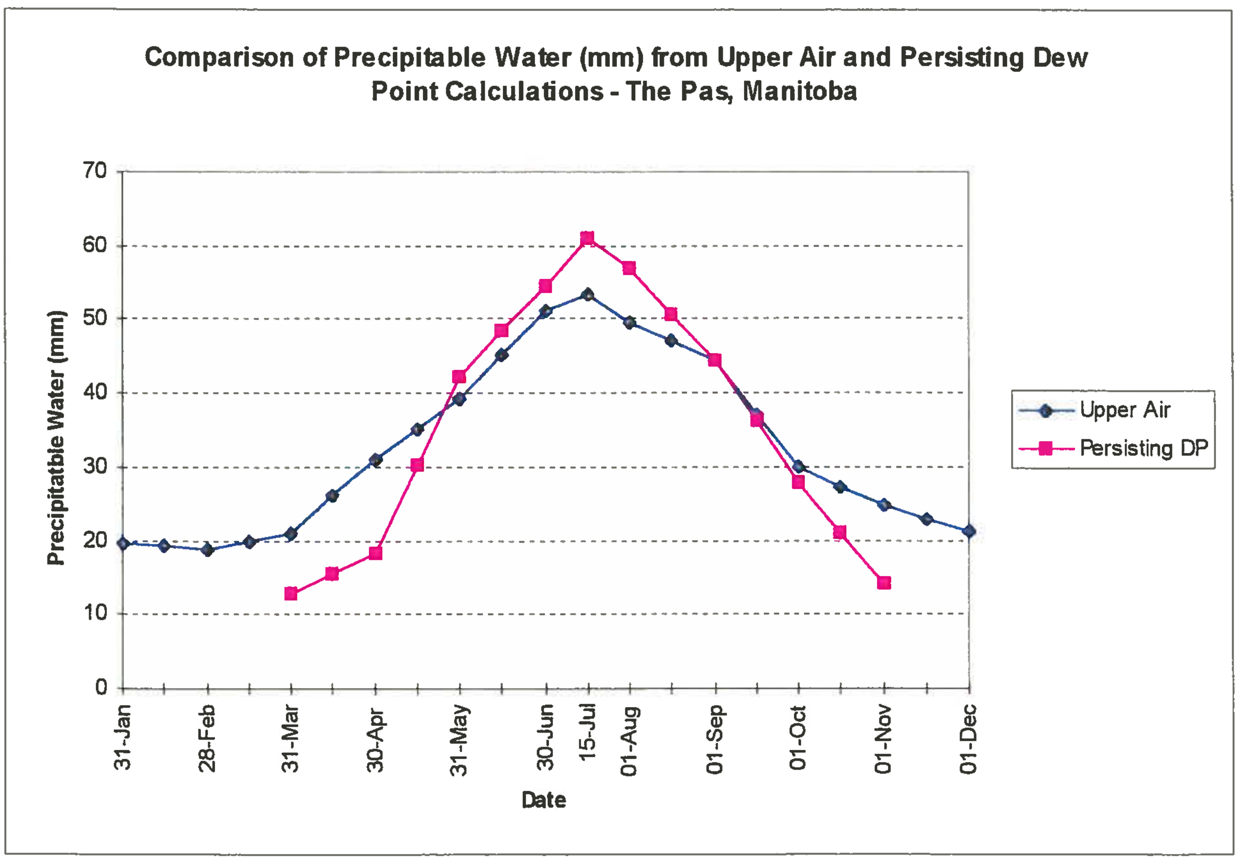
Figure 11 Seasonal Distribution of PMP at Selected Stations in Manitoba



For other dates (e.g. June 07), one could interpolate from Table 15 or Figures 8 to 11 as appropriate.

The seasonal distribution of maximized precipitable water based on upper air data was determined using the program, GUMWATER, supplied by W. D. Hogg. The program was run on the Downsview main-frame computer prior to 1995. The program was adapted to a micro-computer by Hopkinson in 1998 for use in the PMP study for the proposed Phase II development of the Churchill River, Labrador hydroelectric project. The program computes the precipitable water for each upper air sounding at a radiosonde station, determines the maximum monthly values for each year and calculates the return period precipitable water for return periods up to 100 years (assuming a Gumbel distribution). These 100-year return period values were compared to the seasonal distribution of maximum precipitable water derived from the 100-year dew point curve for the same station. This process was repeated for The Pas, Fort Smith, Edmonton Stony Plain and Fort Nelson. A sample comparison for The Pas is illustrated in Figure 12.

Figure 12 Comparison of Seasonal Distribution of Precipitable Water Using Upper Air and Persisting Dew Point Data for The Pas, Manitoba



The two curves are similar but there are notable differences partially attributable to factors mentioned previously. Features common to all of the upper air comparisons are as follows:

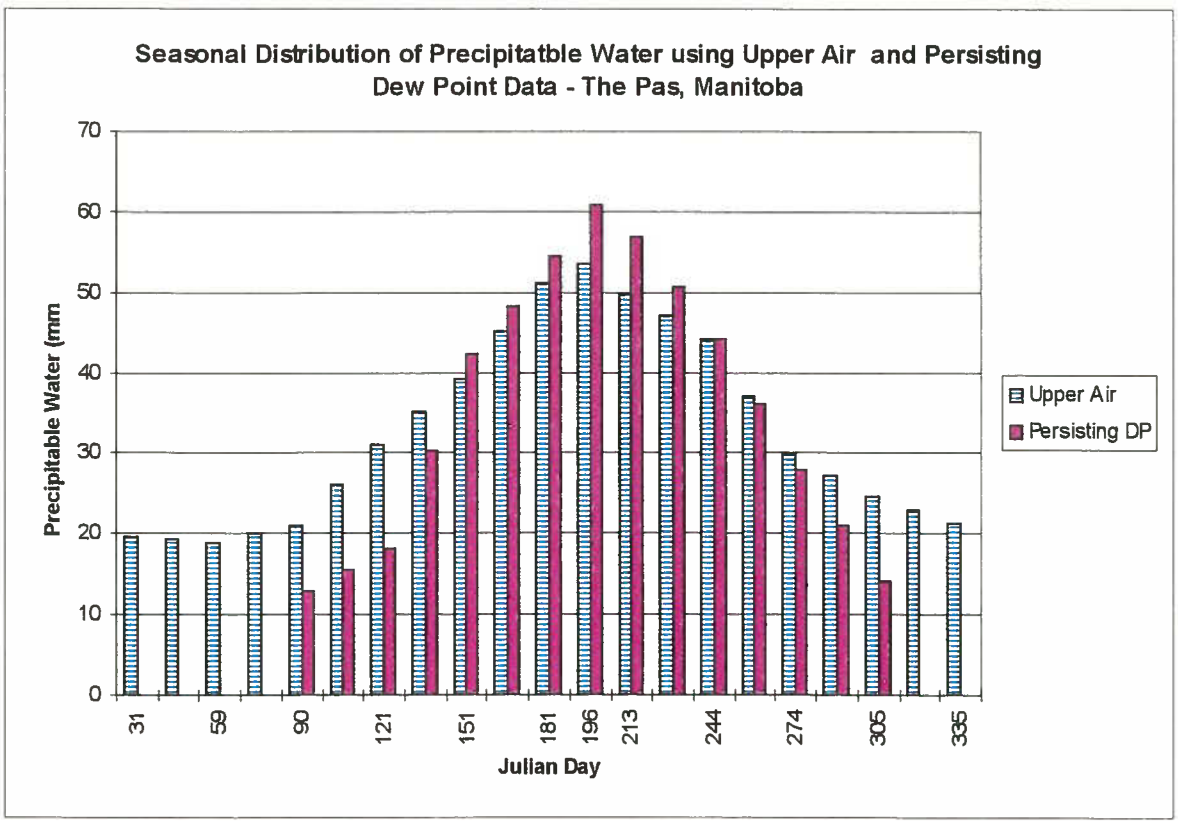
a) the dew point-based curve generally falls below the upper air curve in the spring and late fall;

b) the maximized precipitable water from both approaches is comparable on May 31 (Julian day 151) and September 1 (Julian day 244); and

c) the maximized precipitable water in June, July and August from the dew point-based curve always exceeds the upper air-based curve.

Figure 13 provides an alternate visualization to Figure 12. It should be noted that intermediate values (15-day) were interpolated for Figures 12 and 13 to provide a linear scale along the abscissa. No persisting dew point-based values are shown for the winter months because the assumption that the surface dew point is representative of the tropospheric sounding is not valid when there is a snow cover.

Figure 13 Alternate Representation of Seasonal Distribution of Precipitable Water from Upper Air and Persisting Dew Point Analyses for The Pas, Manitoba



The most critical difference is that noted in July when there is up to a 15% difference in the calculated precipitable water. However, as noted previously, the temporal and spatial resolution of the upper air data is much less than the surface dew point data. Because of this limitation, these findings are presented mostly for information. Precipitable water from the few regional upper air stations was not used in this report but may be of significance to special site-specific projects (see Table 16).

Table 16 Maximum (1:100 Year) Precipitable Water from Upper Air Stations on the Canadian Prairies

Date	Julian Day	The Pas Upper Air	Churchill Upper Air	Edmonton Stony Plain	Fort Smith Upper Air	Fort Nelson Upper Air
31-Jan	**31**	19.7	16.7	22.5	20.7	21.0
28-Feb	**59**	18.9	17.9	19.7	19.6	19.9
31-Mar	**90**	21.0	20.8	19.5	17.5	17.4
30-Apr	**121**	31.1	29.6	25.3	25.2	21.2
31-May	**151**	39.2	40.7	33.0	36.5	34.1
30-Jun	**181**	51.2	50.2	39.4	43.9	39.6
15-Jul	**196**	53.4	49.2	38.2	43.0	41.5
01-Aug	**213**	49.7	49.7	40.7	49.7	40.1
01-Sep	**244**	44.3	46.2	34.3	34.6	35.2
01-Oct	**274**	29.9	31.8	28.5	32.8	30.5
01-Nov	**305**	24.7	27.1	23.1	23.7	24.0
01-Dec	**335**	21.2	17.0	20.8	20.2	20.7

The seasonal distribution based on precipitable water calculated from surface dew point data appears realistic relative to observed rainfall extremes on the Canadian prairies. It is also internally consistent with the methodology used in this report to maximize and transpose storms. Hence, for most applications it is recommended that the maximum precipitable water be determined from the maximum persisting dew point for all summer PMP calculations on the prairies. For PMP estimates in the spring when operations must cope with snow-melt and saturated or frozen soils, maximum precipitable water from upper air data should be considered.

Sample Calculations

The following examples should provide sufficient guidance to determine the point PMP at times other than mid-July for any site in the prairie provinces:

a) The Pas - mid-May

The July ratio for The Pas found in Figure 7 is 136% and the mid-May adjustment for Flin Flon from Table 15 is 52.6% of the peak July value. Thus, the 24-hour point PMP for The Pas on May 15 is

$$PMP_{May\ 15} = (466)\ (1.36)\ (0.526)$$

$$= 333 \text{ mm.}$$

b) Saskatoon - November 1

The July ratio for Saskatoon in Figure 7 is 122%. Table 15 and Figure 10 indicate that the November 1 PMP is 28.4% of the summer peak so

$$PMP_{Nov\ 01} = (466)(1.22)(0.284)$$

$$= 161 \text{ mm.}$$

Mass Curve for the PMP Storm

Both the 1-hour and 6-hour PMP estimates have resulted from the maximization of the Buffalo Gap storm of May 30, 1961. The time distribution of that storm is as follows:

first 20 minutes	10%
next 40 minutes	90%

The 24-hour PMP at Rabbit Lake is derived by the maximization and transposition of the Parkman storm of August 3 to 4, 1985. The temporal distribution in this storm is not well known, but information from farmers near the observed maximum rainfall indicated that the bulk of the rain fell in 8 hours and the remaining 25.4 mm, in the last 16 hours

	Amount	% of total
first 8 hours	355.6	93.3
last 16 hours	25.4	6.7

These ratios should be applied to the 24-hour PMP estimate to define the mass curve of the 24-hour PMP storm elsewhere in the prairie provinces.

Both of the above storms (SASK-5-61 and SASK-8-85) occurred during very dry periods, but it is recommended that "normal" antecedent precipitation be used to establish the state of the receiving basin (e.g. tailings pond, etc.) prior to the PMP storm.

The 24-hour point PMP represents an adequate design criterion for structures such as tailings ponds because there is no evidence of longer duration storms (e.g. 72 hours) yielding significantly greater maximized rainfall than the 24-hour PMP for areas of 1.0 km^2 or smaller. The reason is that such intense rainfalls are the result of convective clouds (thunderstorms) which, by their nature, are limited in spatial and temporal extent. Even mesoscale convective complexes such as the Parkman storm are sustained for 12 or fewer hours whereas isolated intense thunderstorm cells such as the Buffalo Gap storm go through their life cycle in little over one hour.

Comparison of Statistical and Rational PMP Estimates

The statistical approaches of Hogg and Carr (1985), McKay (1965) and the computer program RAIN30 based on Hershfield (1977) are all based on a sample of annual one-day or 24-hour extreme rainfall events observed at a fixed location. In principle, the longer the record of observations, the greater the probability that the sample statistics of the mean extreme and the standard deviation of the annual extremes represent the population statistics. A comparison of the statistical PMP estimates to the rational estimates is shown in Table 17.

The statistical PMP calculations are very sensitive to the analysis of the standard deviation. The K-factor of the order 17 for Hogg and Carr (1985) and RAIN30 and anywhere from 19 to 23 for McKay (1965) amplify any errors in the standard deviation in the calculation of the PMP. The standard deviation analysis in Hogg and Carr (1985) for the 24-hour period shows a very noisy pattern with strange singularities which make no physical sense. There is a general decrease in the mean extreme and the standard deviation toward the north and that is understandable but thereafter the details of the pattern appear to reflect a sampling error, namely that the record length is just too short to determine statistics which reflect the population statistics. This is particularly noticeable in the values determined from Hogg and Carr (1985) because the record length for most of the recording rain gauge stations is less than 30 years. Hence, the use of the Hogg and Carr (1985) analysis to calculate the statistical PMP on the prairies is not recommended.

McKay's (1965) report also suffers from inadequate record length although when he undertook his analysis in the 1960s, the climatological rainfall records at many locations were much longer than those used in the short duration rainfall analyses used by Hogg and Carr. There is a general decrease in the mean extreme from south to north but McKay's annual analysis has some unexplained singularities. Also the lack of data over northern portions of the three prairie provinces is evident in the analysis. McKay used a higher frequency factor, K, than that advocated by Hershfield. McKay's determination of the K-factor was based on a relatively small sample of prairie and Montana storms whereas Hershfield processed thousands of station-years of data to determine the frequency factor. It is suggested that the frequency factor derived by McKay, while prairie-specific, is based on insufficient data.

Table 17 Comparison of PMP Estimates

Station	PMP (Hogg & Carr)	Ratio to Rational	PMP (McKay)	Ratio to Rational	PMP (RAIN30)	Ratio to Rational	PMP Rational
Winnipeg	323.6	0.42	286.4	0.37	328.7	0.43	769
Flin Flon	298.6	0.49	368.7	0.61	331.2	0.55	606
Thompson	264.3	0.46	361.1	0.62	286.8	0.50	578
Churchill	198.2	0.36	398.2	0.72	259.8	0.47	550
Estevan	371.5	0.53	319.8	0.45	359.7	0.51	704
Regina	356.5	0.57	328.5	0.53	475.6	0.76	624
Saskatoon	291.9	0.51	324.9	0.57	340.4	0.60	569
La Ronge	328.9	0.62	329.2	0.62	312.3	0.59	531
Cree Lake	353.5	0.72	302.9	0.62	350.5	0.72	489
Lethbridge	354.6	0.69	355.9	0.69	361.6	0.70	513
Calgary	318.1	0.76	417.5	1.00	388.1	0.93	419
Edmonton	423.3	0.75	311.6	0.55	380.7	0.68	564
Grande Prairie	385.9	0.83	324.5	0.70	311.5	0.67	466
Fort McMurray	389.6	0.77	287.9	0.57	374.3	0.74	503
Fort Smith (NWT)	179.8	0.36	318.2	0.63	288.1	0.57	503
Mean	**322.6**	**0.59**	**335.7**	**0.62**	**343.3**	**0.63**	**559**

The Environment Canada computer program RAIN30 uses Hershfield's recommended frequency factor. The resulting PMP estimates also suffer from limited sample size although potentially there is much more data for the northern prairies today than there was in 1965 and records in the south are much longer than those available to McKay.

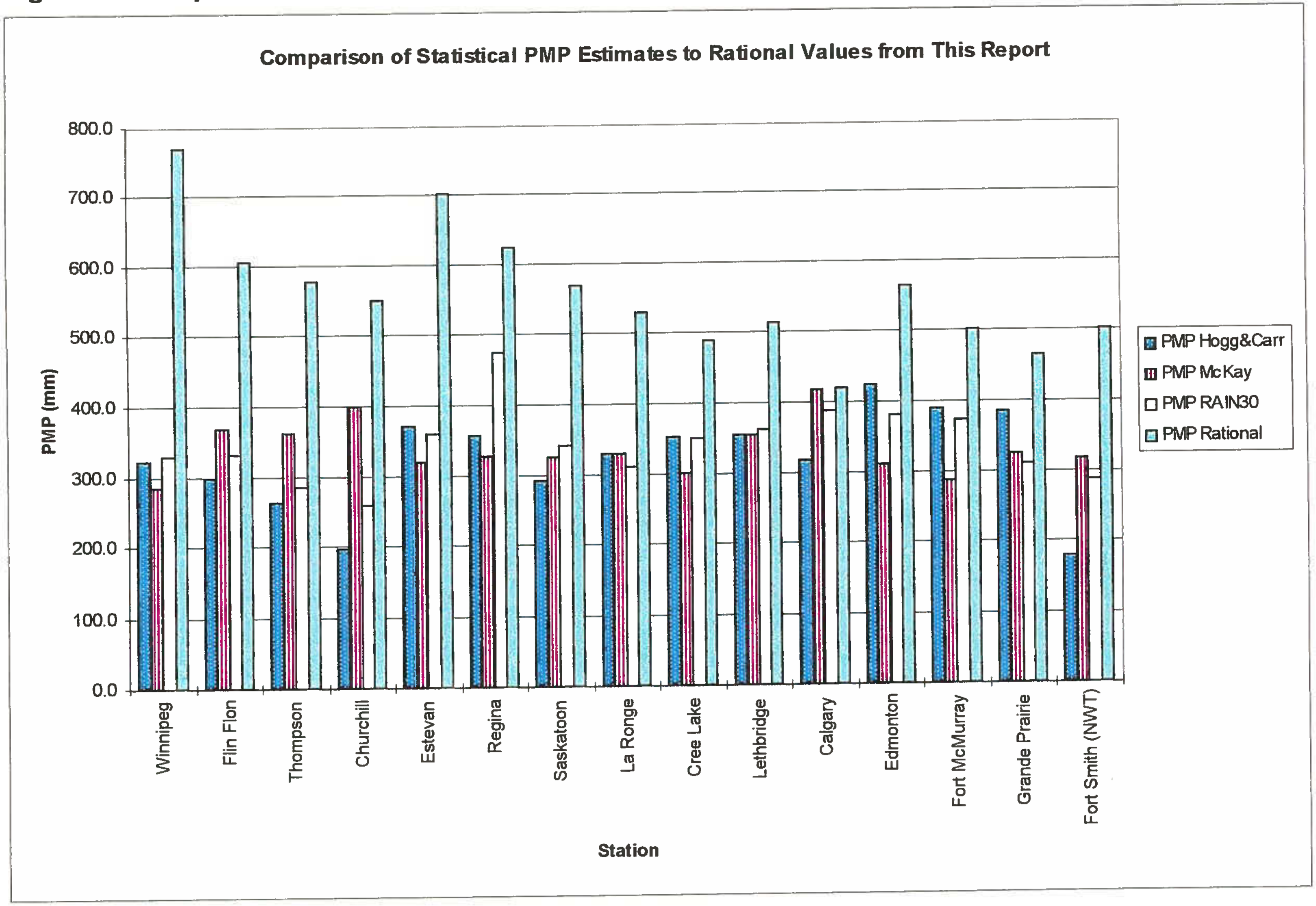
When RAIN30 was run on the older Winnipeg record, a PMP value for one day of 497 mm was calculated, compared to 329 mm based on the last 60 years of data at the Winnipeg airport. This was the largest difference for an individual site noted for any of the RAIN30 calculations for places with multiple stations or stations from different time periods. It is perhaps an extreme case but it suggests that errors of up to 50 % are possible using RAIN30 based on a single station analysis. RAIN30 is the most scientifically-sound of the statistical approaches reviewed in this study, but for the reason just explained, it is recommended that the program be run for several nearby locations even for a preliminary estimate of the PMP.

The rational method of storm maximization and transposition used in this report yields values much higher than the statistical approaches for most sites across the prairies. The difference is particularly striking over Saskatchewan and Manitoba and less so over Alberta. It is notable that at Calgary, the estimates of the 24-hour PMP from both RAIN30 and McKay's methodology are very close to the estimate from the rational method. The 114 year record of climatological rainfall measurements at Calgary might be providing a better estimate of population statistics or may contain a few outliers that strongly influence the statistics. Conversely, the rational method may be breaking down because of the higher terrain of the foothills and because the rational method does not account for orographic enhancement.

For a graphical comparison, Figure 14 provides a visual representation of the data in Table 17. The difference at Winnipeg is particularly notable but could have been reduced if the 497 mm estimate from RAIN30 using data from Winnipeg St. John's College had been used in the comparison.

Elsewhere the rational method appears to be more physically consistent than the statistical approaches but yields values about 40% higher than the statistical estimates. The rational method has the advantage of using rainfall data from the entire prairie provinces and even the adjacent American states of Montana and North Dakota. By using the principles of maximization and transposition, it is possible to overcome the limitations of sampling rainfall at fixed locations for limited time periods. The precipitable water calculations have used the updated maximum persisting dew point analyses based on far more extensive data than were available to McKay in the early 1960s and took advantage of today's computer processing capabilities. The updated dew point analyses permitted much better definition of this field in the northern half of all three prairie provinces. Therefore, the rational PMP estimates as determined using the methodology outlined in this report are recommended for use with small projects in the prairie provinces of up to 1.0 km^2 in area.

Figure 14 Comparison of PMP Estimates at Selected Locations on the Prairies



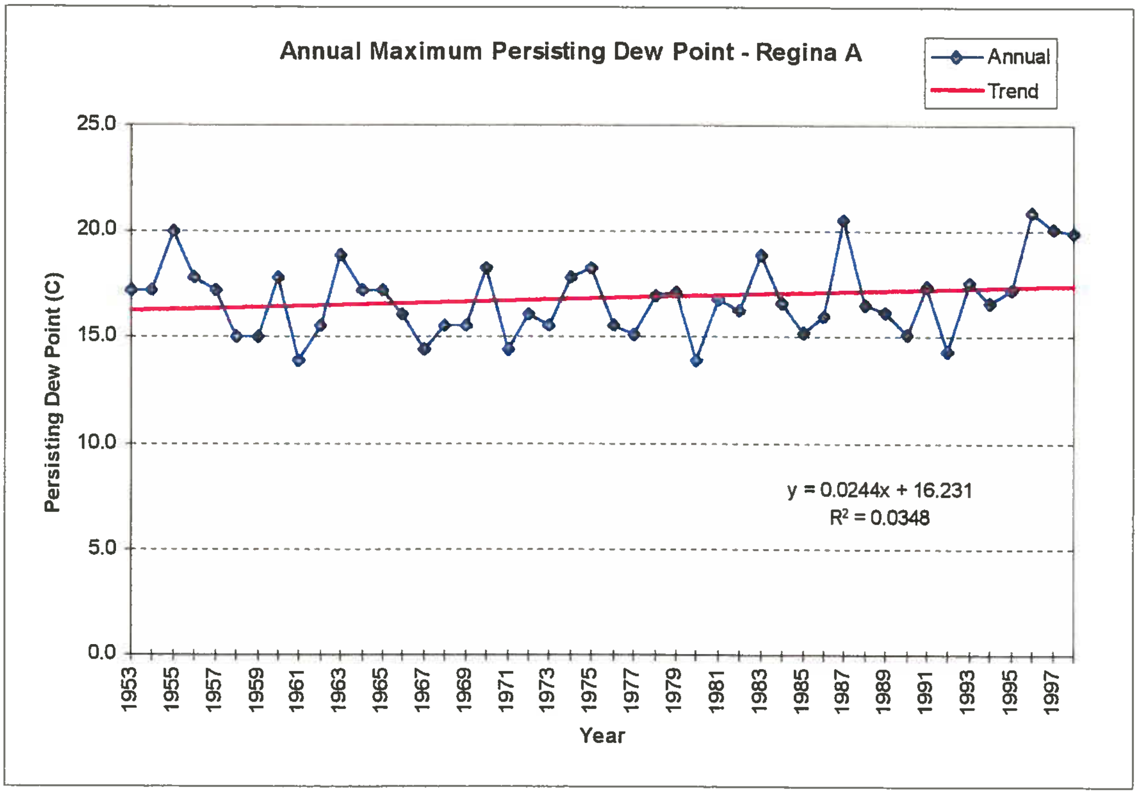
Trends in Dew Point Data and Implications for PMP Calculations

In recent years there has been considerable interest in climate change and its possible impact on hydrologic design. In this particular application, a trend in the maximum persisting dew point could result in an altered estimate of the PMP based on the principles of storm maximization and transposition.

For a representative site like Regina A, an increase in the maximum 12-hour persisting dew point of 1.0 C would result in an increase of 9% in the calculated precipitable water. By inference, this should result in an increase in the rational PMP at Regina of an equivalent amount. Similarly a 2.0 C increase in the maximum persisting dew point at Regina would yield an increase of 19% in the available precipitable water and, hence, the PMP.

As seen in Figure 15, no significant trend is evident in the persisting dew point data for Regina A. A review of data from other sites on the prairies confirmed that there was no significant trend in the persisting dew point data which form the basis of this report. However, a review of the upper air data for The Pas does suggest an upward trend in the maximum precipitable water as determined from upper air soundings from 1963 to 1992.

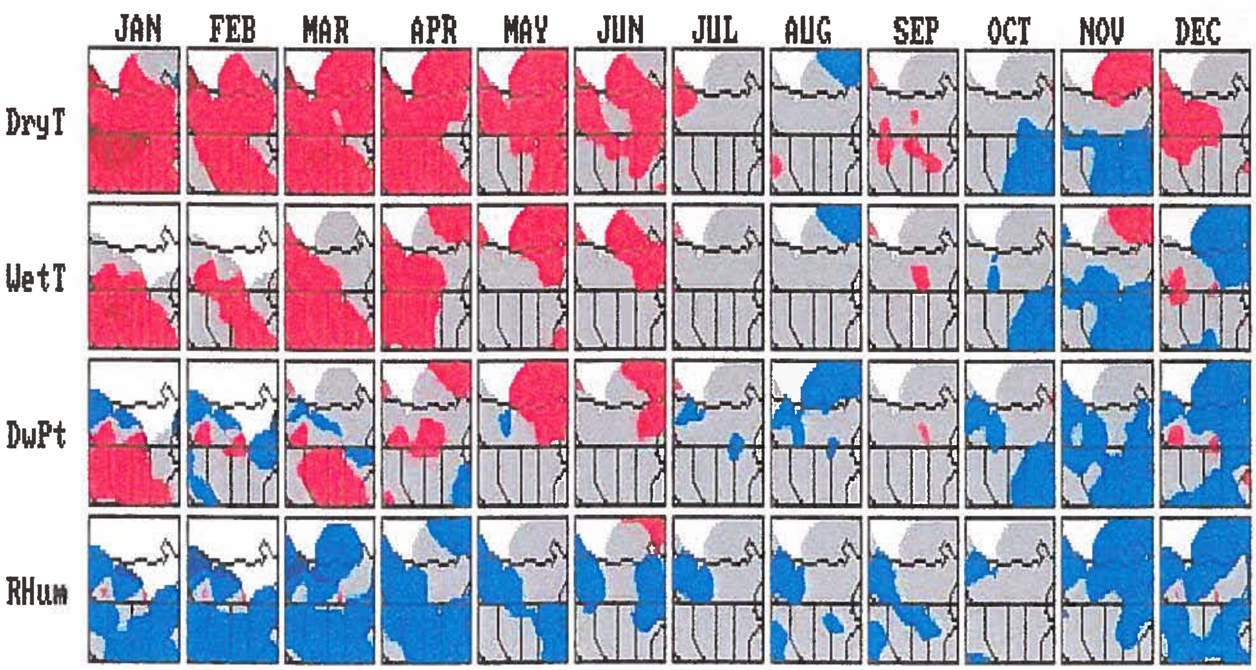
Figure 15 Trend in maximum 12-hour persisting dew point at Regina A



The trend in Figure 15, while slightly positive, is not statistically significant even at the five percent level of confidence (i.e. the calculated F statistic from the regression analysis is just 1.58 which is less than $F_{1,44,.05}$=4.0). Note that the values depicted in Figure 15 have not been adjusted to 100 kPa but are those measured at the station elevation.

The hypothesis that dew points have not changed significantly on the prairies in the last 45 years is supported by Treloar et al (1998). The summer months in Figure 16 for dew point (DwPt) show no trend in the hourly dew point temperature over the prairie provinces. The red colour signifies significant warming or positive trend and blues, a significant cooling or negative trend. The grey colour, which dominates the prairie provinces during the summer months, is indicative of no significant trend. Thus, neither the maximum persisting dew point nor the hourly dew point provide any evidence of a statistically significant trend over the past 45 years.

Figure 16 Trends in Temperature and Humidity in Western Canada 1953 to 1997 (after Treloar et al, 1998)



Summary

This report is intended to assist in the design of high risk structures such as tailings ponds, contaminated water reservoirs and ore storage pads for uranium mines. A 24-hour point PMP should be adequate for the determination of freeboard in operating a tailings pond or small reservoir. It is recommended that normal (1961 to 1990) precipitation be assumed over the preceding twelve months for determining antecedent conditions. The annual (mid- to late July) PMP can be determined for any point in the prairie provinces with the use of Figure 7. For the PMP at other times of the summer season, Table 15 and/or Figures 8 to 11 should be referenced and the location closest to the project be used to adjust the peak (mid- to late July) PMP to the date of interest. For special applications where rate of rainfall is of concern, one, six and 24-hour PMP estimates can be derived. Information has been provided to help define a mass curve for the PMP storm(s).

As sampling of small-area storms improves with radar technology and better storm detection (e.g. Weather Watchers Network), it may be possible to improve PMP estimates for small areas in the future. However, the estimates provided in this report are the best possible given the limitations of the current and past climatological network in the prairie provinces.

It should be noted that the PMP estimates in this report apply only to areas of 1.0 km^2 or smaller. It is not possible to readily infer the PMP for larger areas from the point values. If PMP estimates are required for larger areas for important structures, a specific study may be required to select the appropriate storms for maximization and transposition. For large basins, consideration of snow-melt, snow pack maximization, and rain plus snow-melt may be required. The Atmospheric Environment Service may be consulted regarding any such requirements and some offices may be prepared to derive site-specific areal PMPs for unique situations on a cost-recovery basis.

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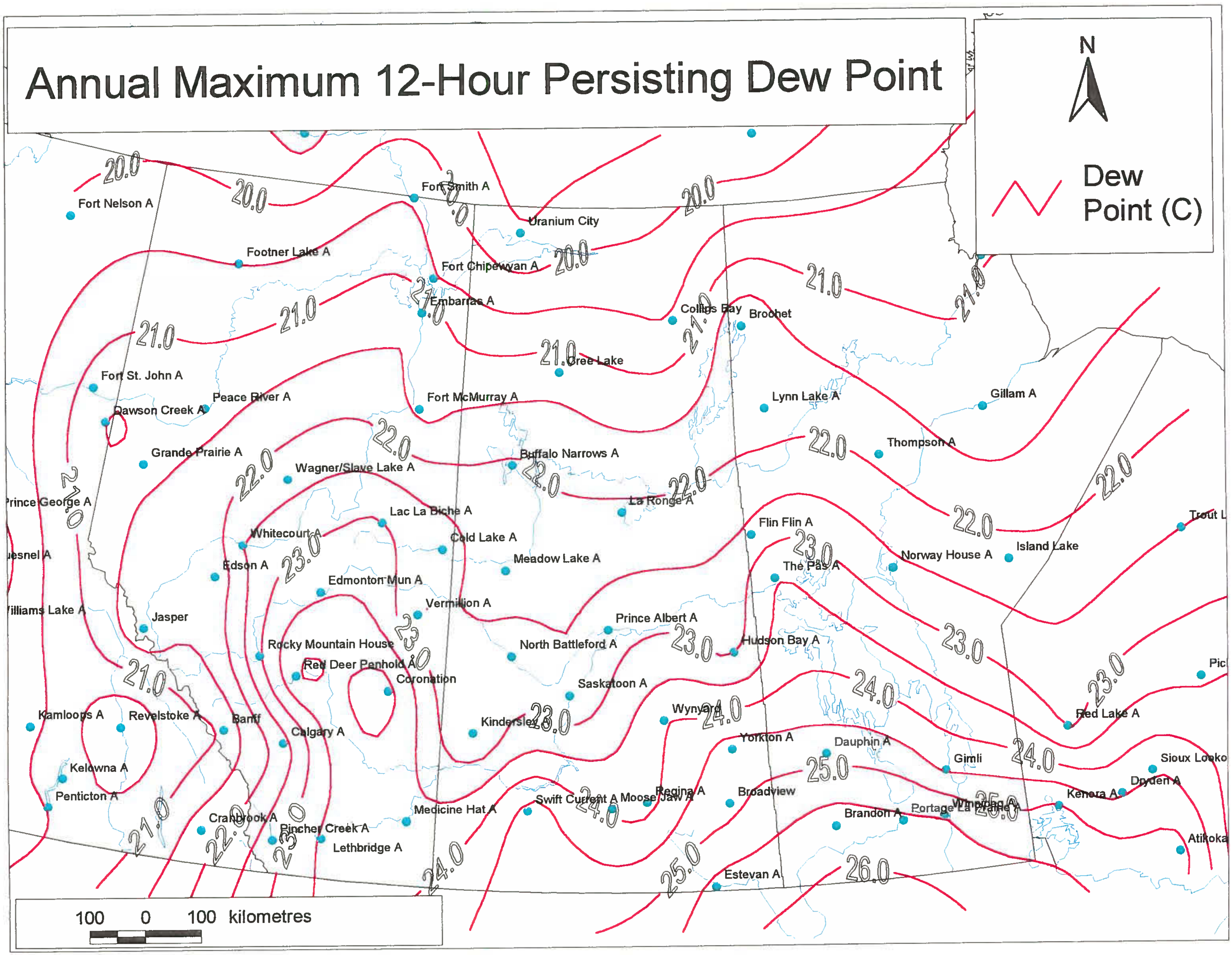
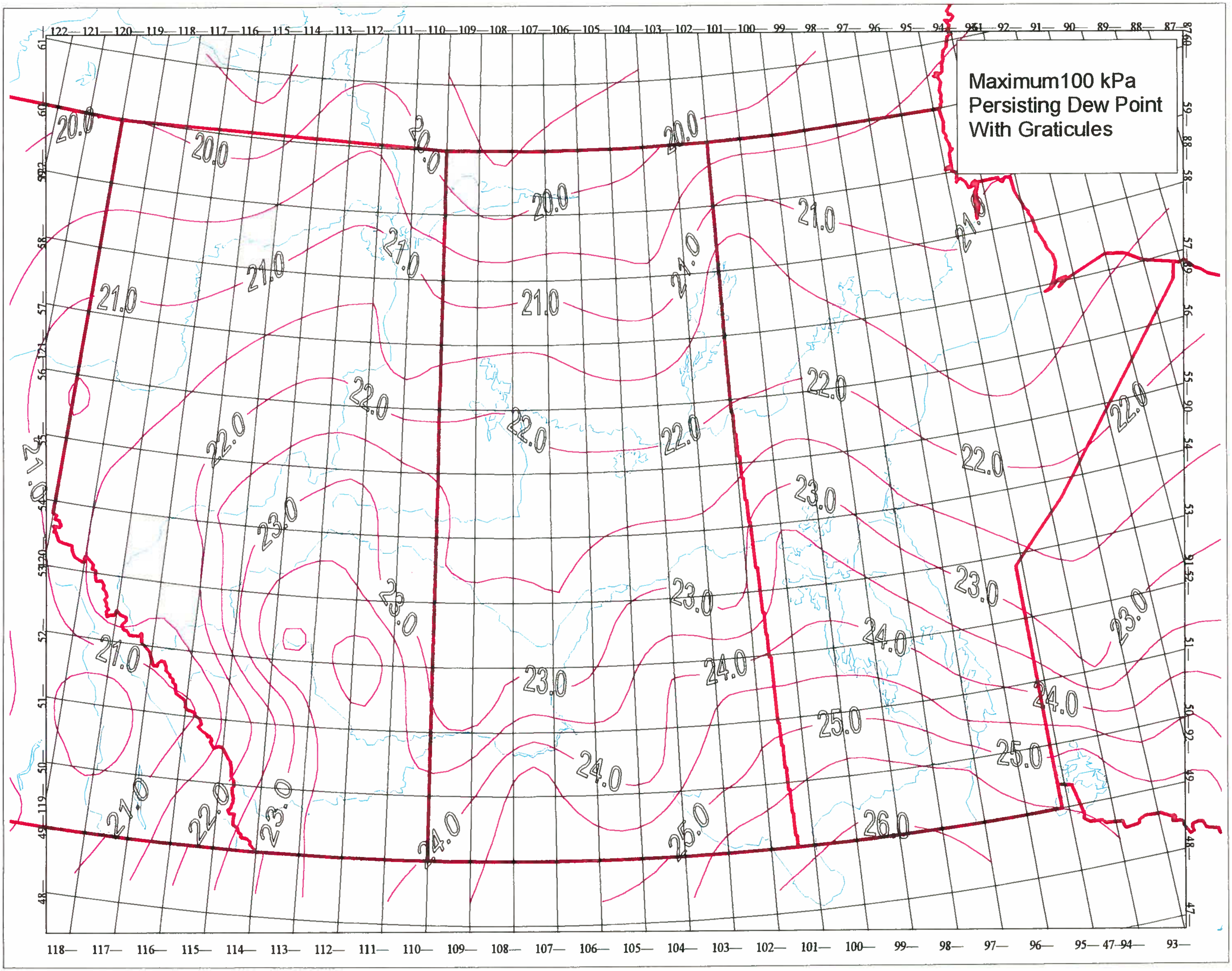
Appendix - Working Figures

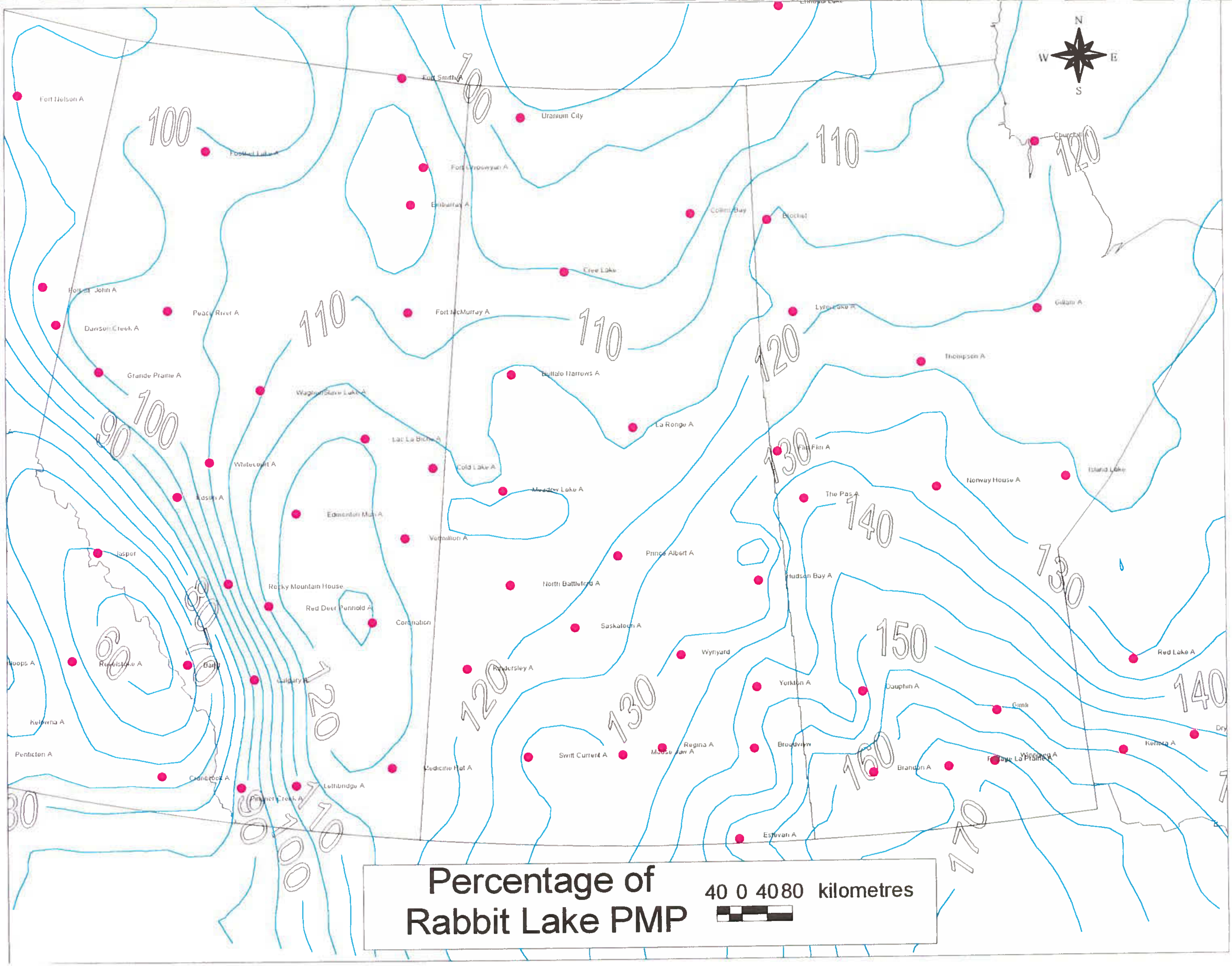
Maximum Persisting 100 kPa Dew Point with Reference Locations
Maximum Persisting 100 kPa Dew Point with Graticules
Percentage of Rabbit Lake PMP with Reference Locations
Percentage of Rabbit Lake PMP with Graticules

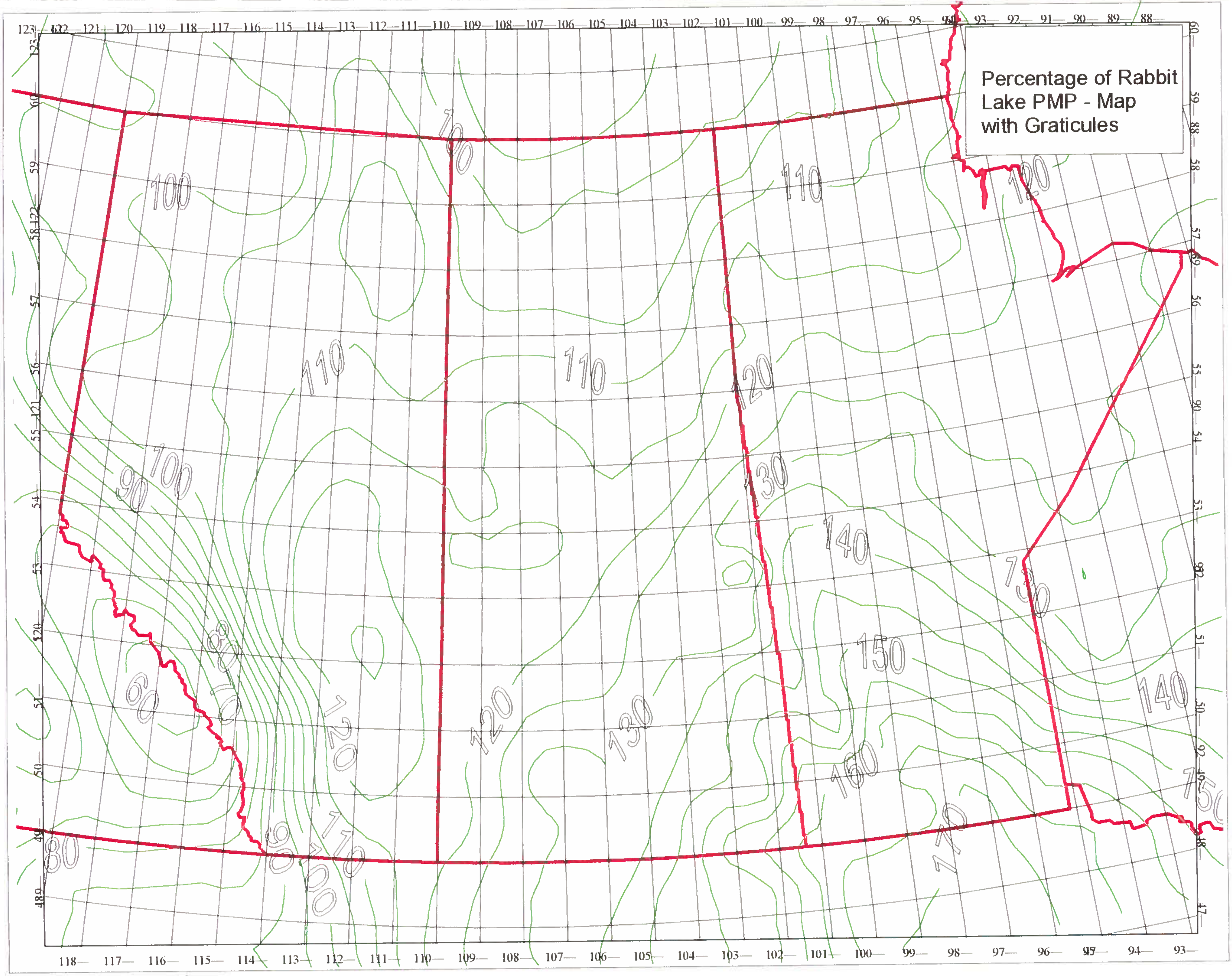


Annual Maximum 12-Hour Persisting Dew Point
N
Dew Point (C)
100 0 100 kilometres
20.0
21.0
22.0
23.0
24.0
25.0
26.0
Fort Nelson A
Fort Smith A
Uranium City
Footner Lake A
Fort Chipewyan A
Embarras A
Collins Bay
Brochet
Fort St. John A
Dawson Creek A
Peace River A
Cree Lake
Fort McMurray A
Lynn Lake A
Gillam A
Grande Prairie A
Wagner/Slave Lake A
Buffalo Narrows A
Thompson A
Prince George A
La Ronge A
Lac La Biche A
Whitecourt A
Cold Lake A
Flin Flon A
Trout L
Edson A
Meadow Lake A
Norway House A
Island Lake
The Pas A
Edmonton Mun A
Vermilion A
Williams Lake A
Jasper
Prince Albert A
Rocky Mountain House
North Battleford A
Hudson Bay A
Red Deer Penhold A
Coronation
Saskatoon A
Pic
Kamloops A
Revelstoke A
Banff
Kindersley
Wynyard
Red Lake A
Calgary A
Yorkton A
Dauphin A
Kelowna A
Gimli
Sioux Lookout
Penticton A
Swift Current A
Moose Jaw A
Regina A
Broadview
Dryden A
Kenora A
Cranbrook A
Medicine Hat A
Brandon A
Portage La Prairie A
Winnipeg A
Pincher Creek A
Atikokan
Lethbridge A
Estevan A



Maximum100 kPa
Persisting Dew Point
With Graticules
20.0
21.0
22.0
23.0
24.0
25.0
26.0


Percentage of
Rabbit Lake PMP
40 0 40 80 kilometres
N
W
E
S
Fort Nelson A
Fort Smith A
Uranium City
Fort Chipewyan A
Embarras A
Cree Lake
Collins Bay
Brochet
Churchill
Gillam A
Lynn Lake A
Thompson A
Fort McMurray A
Buffalo Narrows A
La Ronge A
Flin Flon A
The Pas A
Norway House A
Island Lake
Fort St. John A
Dawson Creek A
Peace River A
Grande Prairie A
Whitecourt A
Edson A
Jasper
Revelstoke A
Kamloops A
Kelowna A
Penticton A
Cranbrook A
Pincher Creek A
Lethbridge A
Medicine Hat A
Calgary A
Banff
Rocky Mountain House
Red Deer Penhold A
Coronation
Edmonton Mun A
Vermillion A
Lac La Biche A
Cold Lake A
Meadow Lake A
Prince Albert A
North Battleford A
Saskatoon A
Kindersley A
Swift Current A
Moose Jaw A
Regina A
Wynyard
Hudson Bay A
Yorkton A
Broadview
Estevan A
Dauphin A
Brandon A
Gimli
Portage La Prairie A
Winnipeg A
Red Lake A
Kenora A
60
70
80
90
100
110
120
130
140
150
160
170


Percentage of Rabbit Lake PMP - Map with Graticules
100
100
110
110
110
120
120
120
120
130
130
130
140
140
150
160
170
100
90
80
70
60
80
90
100
110