ENVIRONMENT CANADA

ATMOSPHERIC ENVIRONMENT SERVICE

POINT PROBABLE MAXIMUM PRECIPITATION
IN
NORTHERN SASKATCHEWAN

Prepared by

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Executive Summary

Probable Maximum Precipitation (PMP) is used in the design of structures, the failure of which 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. The main application would be in the use of the 24-hour point PMP for confirming the design of tailings ponds and storage reservoirs for contaminated water which would cause significant environmental degradation to downstream receiving waters in the event of rupture or overtopping.

A contour map for determining the annual point PMP for northern Saskatchewan is given in Figure 3 at the PMP peak in mid to late July. Figure 5 illustrates how this PMP varies over the year from minimum values in the winter months December to March to a representative peak July value for northern Saskatchewan of about 450 mm and then decreases to minimum values again by December. This seasonal distribution of the PMP should be of value in reaching operational decisions as to safe monthly water levels in ponds and reservoirs over the course of the year. Values of the July, 24-hour, point PMP for Saskatchewan uranium developments have been tabulated in the report and can be derived for other locations in northern Saskatchewan using Figure 3.

For ponds, reservoirs, embankments, dykes, 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 PMP's have lower values than point PMP's. A comparison of areal and point PMP's is contained in the report for the area near Cluff Lake. The Atmospheric Environment Service is prepared to consider deriving areal PMP's for northern Saskatchewan on a cost recovery basis.

Design PMP's for certain important structures or large drainage basins could require consideration of snowmelt and rain plus snowmelt in deriving the Probable Maximum Flood (PMF). The Atmospheric Environment Service is available for consultation as to any such needs.

This report does not address procedures for converting PMP's to PMF's, a service which is generally provided to industry by private consulting firms.

It is important to recognize that water impondments are normally 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. PMP's are used to test and revise preliminary return-period designs so as 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 to waters frequented by fish must meet the provisions of the federal Fisheries Act and its associated Metal Mining Liquid Effluent Regulations and Guidelines (MMLERG). Environment Canada, Conservation and Protection, Environmental Protection administers the MMLERG. These regulations apply to base metal mines, including uranium mines (but excluding gold mines which use cyanide) and compliance is mandatory. Environment Canada, Environmental Protection, also administers the general pollution prevention provisions of the federal Fisheries Act.

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Technical questions concerning PMP's and PMF's should be directed to the former while those regarding their applications under the Fisheries Act and its MMLERG should be directed to the latter.

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* On April 1, 1994, under restructuring within the new Prairie and Northern Region of Environment Canada, the stated responsibilities of the Atmospheric Environment Service will fall under the new Environmental Services Branch and those of Conservation and Protection, under the Environmental Protection Branch.

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 to northern Saskatchewan. The PMP for mid to late July was derived for the Rabbit Lake area 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 1 to November 1. Also, some recommendations were made with respect to the time distribution of rainfall in the PMP storm and with respect to assumptions for antecedent conditions.

Annual point PMP estimates over 24 hours for former, existing and currently proposed uranium mining developments in northern Saskatchewan were determined as follows:

Uranium City	456 mm
Cluff Lake	497 mm
Key Lake	493 mm
McArthur River	469 mm
McClean Lake	466 mm
Cigar Lake	471 mm
McMahon Lake	463 mm
Rabbit Lake	466 mm

An assessment of the areal PMP over a 155 km^2 basin at Cluff Lake yielded a 24-hour PMP of 393 mm. This 25% greater than an estimate provided to Hardy BBT Limited based on the available persisting dew point analysis (Hopkinson, 1991c). The updated persisting dew point analysis in this report had its greatest impact on the PMP along the western edge of the study area.

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 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, Western 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. This report is intended to fulfil that need.

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 12-hour persisting dew point maps developed by McKay (1963). Very little dew point data existed from northern Saskatchewan at the time of McKay's analysis so a thorough review of the 12-hour persisting dew point was conducted for all appropriate meteorological stations within or near the study area. The review demonstrated that McKay's analysis was considerably in error over the western edge of the study area. For the purpose of this report, a revised persisting dew point analysis was developed for northern Saskatchewan.

This report documents the work done for the Rabbit Lake PMP estimate and extends that work to all areas of northern Saskatchewan from 55° N to 60° N (study area). In addition, the seasonal variation of the PMP was derived as a planning tool for the operation of tailings pond and small storage reservoirs.

2.0 Review of Historical Rainfall

There are a number of sources of extreme daily or short-duration rainfall which are applicable to this study. These include:

a) Digital Archive of Canadian Climatological Data - includes all climatological day rainfall data for Canada

- Using program RAINMAX all climatological rainfall data from the 1800's to 1990 inclusive were scanned and the following were the most extreme one-day rainfalls:

Climate District	Station	Date extreme one-day	Rainfall (mm)
Sask 401	Willmar	July 30, 1984	178.6
Sask 402	Woodrow	June 14, 1970	97.0
Sask 403	Robsart	June 8, 1972	112.5
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
* includes all of northern Saskatchewan			
Alta 302	Eckville South	June 30, 1970	213.1
Man 503	Beausejour	June 14, 1973	193.5

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

- 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).

- The following rainfall extremes (mm) were based solely on recording rain gauge data from 1900 to 1987:

	ALTA	SASK	MAN
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).

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

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

- superseded by a)

f) Storm Rainfall in Canada (AES)

- refer to Table 1

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)

All of these sources were searched in turn to identify extreme rainfall events of duration one day (24 hours) 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 Buffalo Gap storm of May 30, 1961 (258 mm). The six-hour, twelve-hour and 24-hour extremes (266.7, 381.0, and 381.0 mm) were all set by the Parkman storm 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 AES in Regina.

Some of the older observed daily rainfall extremes are not included in the Storm Rainfall 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, June 15, 1897). For northern Saskatchewan, the most extreme climatological day rainfall was 158.8 mm at Goodsoil on June 12, 1965. Some other climatological day extremes for climatological stations in northern Saskatchewan are:

Cluff Lake	62.2 mm	July 7, 1981
Cree Lake	72.7 mm	July 24, 1978
Collins Bay*	54.1 mm	August 26, 1976
Island Falls	68.8 mm	July 7, 1957
Key Lake	68.7 mm	June 27, 1990
Stanley	63.5 mm	June 29, 1970
Stony Rapids	69.9 mm	August 12, 1969
Uranium City A	46.7 mm	June 27, 1962
Waskesiu Lake	88.4 mm	June 26, 1974
Whitesand Dam	61.2 mm	August 17, 1978
Lac La Ronge	91.9 mm	June 28, 1970
La Ronge A	77.7 mm	June 28, 1970
Kinoosao	61.5 mm	August 17, 1978
Ile a la Crosse	69.3 mm	July 10, 1967
Foster Lake	65.3 mm	July 12, 1979
Fond du Lac	49.8 mm	July 20, 1917
Cigar Lake	57.0 mm	August 28, 1991

* The IDF, 24-hour extreme for Collins Bay is 63.7 mm in 1985 and an unofficial value of 81 mm was reported in 1991.

These values from a relatively sparse network of mainly short-term stations are hardly an adequate representation of northern Saskatchewan. Observed one-day extreme rainfalls generally range from around 45 mm along the northern edge of the province to about 60 to 70 mm in the main uranium mine latitude belt to around 90 mm along the southern edge of the study area (55°N).

Because of the lack of rainfall data in northern Saskatchewan, no storm analysis from that area appears in the Storm Rainfall in Canada series. The only documented major storm close to the study 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, Table 1 shows that it produced the third highest observed 24-hour rainfall in Saskatchewan.

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.

3.0 Review of Previous PMP and Related Studies

3.1 Rainfall Frequency Atlas

The Rainfall Frequency Atlas for Canada (Hogg and Carr, 1985) maps the mean and standard deviation of extreme 24-hour rainfalls. 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 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 northern Saskatchewan for a 24-hour duration yields point PMP estimates ranging from 170 mm to 180 mm along the northern edge of the province to over 300 mm along the 55 N latitude. A secondary minimum of less that 250 mm is noted near Buffalo Narrows in the southwest corner of the study area. In contrast, a maximum of over 350 mm extends along an axis from Fort McMurray toward Cree Lake. These latter features may be spurious because recording rain gauge records in and near the study are on which the frequency atlas is based are generally shorter than 25 years.

3.2 McKay's (1965) Approach

G. A. McKay developed several reports for estimating extreme rainfall in the prairie provinces during his secondment at the Prairie Farm Rehabilitation Administration (PFRA) in the early 1960's. 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. Also the 24-hour rainfalls were based on climatological day records rather than recording rain gauge data. In addition, McKay developed his own estimate of the frequency factor, K, which when applied to northern Saskatchewan yielded values in the range of 20.6 to 22.7, considerably higher than Hershfield's (1977) relationship which is always less than 19.

By computing the point PMP at various locations in northern Saskatchewan based on McKay's (1965) maps and K factor, one observes a range of values from 345 to 405 mm but the pattern is nonsensical. A minimum occurs north of Buffalo Narrows but then values increase northward reaching over 390 mm north of Lake Athabasca. 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. However, McKay's (1965) frequency factor, K, relationship resulted in estimates which are closer in magnitude to the point PMP estimates derived in this report using the rational method.

3.3 GRP208

A general report program, GRP208, on the AES Downsview main-frame computer, calculates 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 is calculated after Hershfield (1977) as described in section 3.1. The program was applied to several long-term climate records in northern Saskatchewan. The computed statistical PMP at individual sites was in the range of 230 to 360 mm. More details are provided in section 5.0 but most records were too short to provide consistent results and all values are substantially less than the rational PMP derived in this report.

4.0 Updated Maximum Persisting Dew Point Temperatures for Northern Saskatchewan

McKay (1963) developed a set of maps of 12-hour maximum persisting dew point for the month's March to October based on limited data and in the case of northern Saskatchewan, 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 points 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 persisting value 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 Digital Archive of Canadian Climatological Data at AES headquarters, Downsview, Ontario. 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. A computer program on the AES Downsview computer, PERSDEW, was used to identify to 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 year return period 12-hour maximum 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:

a) Primary - full 40 years of data - Fort Smith A, Fort McMurray A, Cold Lake A, The Pas A, Churchill A

b) Secondary - approximately 25 years of data - Thompson A, Lynn Lake A, Uranium City A

c) Tertiary - 10 to 20 years of data - Ennadai Lake, Fort Resolution, Fort Chipewyan, La Ronge A

d) Supplemental - observing program not 24 hours - Collins Bay, Cree Lake, Buffalo Narrows A, Meadow Lake A, Flin Flon A, Brochet A

For each station, all monthly maximum persisting dew point temperatures were plotted against the Julian day of occurrence. Figure 1 shows a sample for Fort Chipewyan. An envelope of the observed maximum persisting values was added manually to the graph. Also the 1:100 year persisting dew point estimates for each month were plotted on the day of the month closest to July 15 and a trace of the 1:100 line was added manually. The shape of the envelope of observed maxima was used as a guide for plotting the July 1:100 year return period estimate. Because the record at Fort Chipewyan is only 17 years, the 1:100 year curve fell well above the envelope of actual values but assumed a similar shape.

The peak annual value at each station was adjusted to the 100 kPa level and plotted on a map (Figure 2) of the region. Compared to McKay's mid-July map, large differences were noted along the western edge of the study area where the maximum 12-hour persisting dew point values in Figure 2 exceed those developed by McKay from one to over three degrees Celsius. The largest difference (over 3 C) occurred near Lake Athabasca along the Alberta/Saskatchewan boundary. Differences of the opposite sign and of a much smaller magnitude (-0.5 C) were typical of the eastern edge of the study area. On the southern prairies (not shown), a preliminary analysis indicated relatively small differences between McKay's report and the extension to Figure 2.

The resulting pattern indicates essentially east-west oriented lines of equal maximum persisting dew point with values decreasing by about 1.0 C for every two degrees latitude northward. The exception occurs near Lake Athabasca where these lines tip toward the northwest.

The seasonal distribution of 12-hour maximum persisting dew point was abstracted from the curves for individual stations like Figure 1. Monthly maps of maximum persisting dew point will be the part of a separate report which updates the persisting dew point analyses for the prairie provinces.

Hogg (personal communication, 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 near the study area (The Pas, Fort Smith and Edmonton Stony Plain) and none within the study area. 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 precipitable water to 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 the day.

c) Many historic storms occurred prior to the introduction of radiosonde equipment in the mid to late 1940's. 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 inversion layer. 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 possible using surface dew point data. Also, all historical storms in the Storm Rainfall in Canada series could be maximized by this technique. For cold winter months with continuous snow cover, surface dew point data are not appropriate.

5.0 Rabbit Lake PMP Estimate

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 northern Saskatchewan. There are no physical barriers or meteorological reasons why any of the storms considered could not have occurred over northern Saskatchewan. The results are recorded in Table 1.

The lack of storm data for northern Saskatchewan 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 in northern Saskatchewan, although the network is too sparse to record many such events. This storm is identified in Table 1 as SJUL1074 where "S" signifies Saskatchewan; "JUL" the month of occurrence; "10" the starting date and "74" the year. In Table 2, 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 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.

For each selected storm, the twelve-hour persisting 100 kPa inflow dew point temperature was determined from weather maps as specified by the WMO (1986). Also abstracted was the average 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. This can be done manually from tables such as those that appear in Annex A of the WMO Manual (1986). It is assumed in this procedure 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. A summary of the significant storms, and their pertinent details appears in Table 2.

Each storm could be maximized in place by first finding the maximum persisting 100 kPa dew point temperature possible and then multiply the storm rainfall by the ratio of corresponding maximum precipitable water to the actual storm precipitable water

$$R_{max} = (W_{max}/W_{act})\ R_{act} \qquad (1)$$

where "max" and "act" subscripts refer to maximum and actual values respectively. R denotes rainfall (mm) and W, precipitable water (mm). To transpose the storm to another location, the maximum persisting 100 kPa dew point and precipitable water must be determined at the site of interest and adjusted by the relationship as shown in equation 2.

$$R_{maxt} = (W_{maxt}/W_{max})\ (W_{max}/W_{act})\ R_{act} \qquad (2)$$

In this expression, the maximized in-place rainfall must be multiplied by the ratio of the maximum precipitable water at the site of interest W_{maxt} to that where the storm occurred W_{max}. In fact, equation 2 can be simplified to

$$R_{maxt} = (W_{maxt}/W_{act})\ R_{act} \qquad (3)$$

where the "maxt" subscript signifies the maximum value at the transposed site.

The revised maximum persisting dew point map (Figure 2) described in Section 4.0 was used as input the program RWATR. The resulting precipitable water was considered applicable to from July 15 to 31 as all curves of the maximum persisting dew point at individual stations have a relatively flat distribution during this period (see Figure 1).

The dew point temperature reaches its peak during the latter half of July so all summer storms were maximized to that period. All storms considered in this report were judged to be meteorologically possible at any time throughout the main summer months (late May to early September). This departs somewhat from the WMO (1986) practice of limiting the maximization window to plus or minus 15 days of the storm occurrence. However, so long as care is taken to screen out storms not meteorologically possible, the practice of maximizing all relevant storms to the July peak is acceptable (Hogg, 1985). This logic is also used to estimate the seasonal variation of the PMP in Section 7.0.

The maximum persisting dew point from Figure 2 and the calculated precipitable water at Rabbit Lake are included in Table 2. All storms have been maximized using this value as shown in Table 3. The actual and maximized rainfall are listed for durations of 1, 6 and 24 hours for all the critical storms. The greatest 6-hour value for all storms is only slightly more than the greatest 1-hour value and is based on the same storm (SASK-5-61) which suggests there is not a suitable six-hour storm upon which to base a PMP estimate. The envelope of maximized rainfall would indicate that the 6-hour point PMP is somewhat underestimated by this procedure in comparison to the 1-hour and 24-hour values. This reflects the relative lack of documented storms for small areas.

Based on the available storms, the envelope (or PMP) of maximized values for 1.0 km^2 at Rabbit Lake is as follows:

Duration	**1-hour**	**6-hour**	**24-hour**
PMP (mm)	329.8	331.0	465.9
IDF (R_{100}) (mm) *	28.0	46.8	73.3
Greatest Observed (mm) #	23.5	40.8	63.7
Statistical PMP (mm) #	93.3	141.0	230.6

* Based on Collins Bay (AES, 1992)
\# Collins Bay - 16 years of record, 1973-1989

The last three lines were taken or derived from the latest Intensity Duration Frequency (IDF) analysis published by AES (1992). The statistical estimates (see Section 3.3) of the PMP for the given durations are much less than the PMP derived in this report. However, the storm SASK-7-74, with 307 mm of rainfall in a mere 12 hours, would indicate that the statistical approach underestimates the PMP in northern Saskatchewan. Also, the statistical approach of Hershfield (1977) has never been validated for northern Canada and in particular, northern Saskatchewan. The rational approach used in this report is consistent with observational data such as SASK-7-74. The record length for Collins Bay (16 years) is barely adequate to attempt the statistical calculation and may suffer from sampling error. Statistical PMP estimates based on Cree Lake or Island Falls are substantially greater than those based on Collins Bay data (e.g. the Cree Lake 24-hour statistical PMP is 360 mm). However, the rational PMP estimates derived in this report provide the best estimates of PMP and the greatest assurance that structures like tailings ponds will not fail.

6.0 Regional Point PMP for Northern Saskatchewan

The PMP for any site in northern Saskatchewan can be determined by knowing the PMP at Rabbit Lake and the ratio of the maximum precipitable water at the site in question to that at Rabbit Lake as follows:

$$PMP_x = (W_x/W_r)\ PMP_r \qquad (4)$$

where "x" refers to the required site and "r" refers to Rabbit Lake. By superimposing the July lines of equal maximum dew point on a topographic map of northern Saskatchewan, it was possible to calculate the precipitable water at many locations across the north. These values were then expressed as a percentage of the precipitable water at Rabbit Lake and manually analyzed using 5% contours. The result appears in Figure 3.

6.1 Sample Calculation - Cluff Lake - July 15 to 31

To estimate the 24-hour, point (1.0 km^2) PMP for Cluff Lake, abstract the percentage P from Figure 3 for 58°22'N 109°31'W. In this case, the value of P is 104.5%; therefore the estimated 24-hour PMP at Cluff Lake is

$$PMP_{24} = (1.045)\ 466\ mm$$

$$= 487\ mm$$

This compares favourably with a detailed calculation of 497 mm derived for Environmental Protection using site specific data. A previous PMP calculation for Cluff Lake of 395 mm (Hopkinson, 1991c) was developed using McKay's persisting dew point map for July. The difference in the PMP of 100 mm is attributable to the significant change in persisting dew point analysis in northwest Saskatchewan.

An error in reading Figure 3 of plus or minus 1% would cause an error of ± 5 mm in the estimated PMP. The difference between the detailed calculation an using Figure 3 is 10 mm representing a 2% error due to a difference between the elevation at the site and the general surrounding topography. This is still well within the uncertainty associated with other aspects of the PMP estimation procedure at a specific location.

7.0 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 for the year when heavy rainfall events are possible (i.e. not winter), Figure 4 was derived from the maximum persisting dew point curve for Rabbit Lake (as represented by Collins Bay available from 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 4.

In principle, this distribution is strictly applicable to Rabbit Lake because the maximum persisting dew point does not change in the same way all points in northern Saskatchewan. Also included in Table 4 are the calculations done at Cree Lake, Uranium City, La Ronge and Fort Chipewyan, Alberta. These seasonal distributions were plotted in Figure 5 except for Cree Lake which has a distribution virtual identical to Collins Bay (Rabbit Lake). As can be seen, the seasonal distribution at the other locations departs from that at Rabbit Lake by up to 11%.

The seasonal distribution of PMP based on the revised dew point analysis is similar at all sites. However, both Uranium City and Fort Chipewyan have a somewhat flatter distribution than the three other sites which demonstrate a more peaked distribution. The Fort Chipewyan distribution is recommended for Cluff Lake. The Collins Bay distribution with its similarity to Cree Lake's, is recommended for Key Lake, McArthur River, Cigar Lake and the other uranium mines in the vicinity of Collins Bay. The La Ronge distribution is applicable to the southern portion of the study area between 55°N and 56°N latitude.

The July value of the point PMP can be determined at any location by abstracting the ratio from Figure 3 and applying it to the Rabbit Lake point PMP as described in Section 6.1. If an estimate for mid May is required near La Ronge, one should use the ratio given in Table 4 (i.e. 42%) to adjust the peak (July) estimate to mid May. For other dates (e.g. June 07), one could interpolate from Table 4 or Figure 5. By using the seasonal distribution for the closest location given in Table 4, it is possible to reduce the error in the seasonal distribution for locations other than Rabbit Lake to about 5% or less.

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 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 using a Gumbel distribution. These 100-year return period values were compared to the seasonal distribution of maximum precipitable water derived 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 Fort Smith is illustrated in Figure 6.

The two curves are similar but there are notable differences partially attributable to factors mentioned in Section 4.0. 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 early spring and late fall,

b) the maximized precipitable water from both approaches is comparable in June and September, and

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

The most critical difference is that noted in July and August when there is up to a 20% difference in the calculated precipitable water. However, as noted in Section 4.0, the temporal resolution of the upper air data is much less than the surface dew point data. Because of this and other limitations previously mentioned, these findings are presented for information but precipitable water from the few regional upper air stations was not used in this report.

Occasionally, lacking other data, the seasonal distribution of extreme rainfall (climatological day) is used to help define the seasonal distribution of the PMP. A sample of six long-term climatological stations in northern Saskatchewan was used to derive a composite of extreme rainfall for each month. The composite values (mm) were converted to a percentage of the summer maximum and plotted in a similar fashion as the 100-year return period dew point values in Figure 1. Similarly the precipitable water computed from dew point and upper air data were expressed as a percentage of their respective summer maximum values. The results were plotted in Figure 7. In general, the dew point-based distribution agrees well with the observed distribution of extreme rainfall except for August. Similar distributions of observed extreme rainfall over southern Saskatchewan tend to peak in June whereas the potential for a large rain storm is greater in mid July. The distribution based on upper air data is somewhat flatter and exhibits a positive bias with respect to the other two approaches in the spring and fall.

The seasonal distribution based on precipitable water calculated from surface dew point data appears realistic relative to observed rainfall extremes in northern Saskatchewan. It is also internally consistent with the methodology used in this report to maximize and transpose storms.

7.1 Sample Calculations

The following examples should provide sufficient guidance to determine the point PMP at any time for any site in the study area.

a) La Ronge - mid May

The July ratio for La Ronge found in Figure 3 is 125% and the mid May adjustment for La Ronge from Table 4 is 42% of the peak July value. Thus, the 24-hour point PMP for La Ronge on May 15 is

$$PMP_{May\ 15} = (466)\ (1.25)\ (0.42)$$

$$= 245\ \text{mm}$$

b) Buffalo Narrows - November 1

The July ratio for Buffalo Narrows in Figure 3 is 117%. La Ronge is the closest station so its distribution should be applied. Table 4 or Figure 5 indicate that the November 1 PMP is 25.4% of the summer peak so

$$PMP_{Nov\ 01} = (466)(1.17)(0.254)$$

$$= 138\ \text{mm}$$

c) Cluff Lake - December 31

The methodology outlined above is not applicable in winter months but a survey of winter rainfall extremes indicates that 25 mm would be adequate over the northern portion of the study area increasing to 50 mm along the southern edge. Thus in the case of Cluff Lake or any of the other uranium mining developments, 25 mm is applicable from mid November to mid March.

8.0 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 indicted 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 over northern Saskatchewan.

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 period 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 nature are limited in spatial and temporal extent. Even mesoscale convective complexes such as the Parkman storm are sustained for 12-hours or less whereas isolated intense thunderstorm cells such as the Buffalo Gap storm go through their life cycle in little over one hour.

9.0 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 reservoir. It is recommended that "normal" 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 northern Saskatchewan from 55°N to 60°N with the use of Figure 3. For the PMP at other times of the summer season, Table 4 and Figures 4 or 5 should be referenced and the location recommended in Section 7.0 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) in Section 8.0.

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 in the future. However, the estimates provided in this report are the best possible given the limitation 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 snowmelt, snowpack maximization, and rain plus snowmelt may be required. The Atmospheric Environment Service is available for consultation regarding any such requirements and may be prepared to derive site-specific areal PMP's for unique situations on a cost recovery basis.

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TABLE 1: Results of storm search for Rabbit Lake, Saskatchewan

Basin ID	Gross Area (km^2)
RABBIT LAKE	1.0

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,,,

Table 2: Basic data for storms significant to Rabbit Lake 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	
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

Identity No.	Max persisting Dew Point (C)	Precipitable Water (mm)
RABBIT LAKE	20.5	47.81

Table 3: Maximization and transposition of storms to Rabbit Lake, Sask.

Storm	Precipitable Water (mm)	Ratio for RABBIT LAKE
Sask-7-74	49.77	0.96
Sask-6-21	50.19	0.95
Sask-7-46	37.53	1.27
Sask-6-62	31.63	1.51
Man-6-35	35.15	1.36
USA-6-06	31.92	1.50
SASK-5-61	37.40	1.28
SASK-8-85	39.10	1.22
SASK-6-63	31.31	1.53

Storm maximization and transposition to RABBIT LAKE

Storm		1 hr rain (mm)	6 hr rain (mm)	24 hr rain (mm)
Sask-7-74	Actual	25.6 *Ratio =	153.7	307.3
	Maximized	24.6 ↙	147.6	295.2
Sask-6-21	Actual	35.6	213.4	330.2
	Maximized	33.9	203.3	314.5
Sask-7-46	Actual	42.3	254.0	254.8
	Maximized	53.9	323.6	324.6
Sask-6-62	Actual	66.0	207.8	213.9
	Maximized	99.8	314.1	323.3
Man-6-35	Actual	32.0	191.8	201.4
	Maximized	43.5	260.9	273.9
USA-6-06	Actual	M	189.8	259.1
	Maximized	M	284.3	388.1
SASK-5-61	Actual	258.0	258.9	258.9
	Maximized	329.8	331.0	331.0
SASK-8-85	Actual	44.5	266.7	381.0
	Maximized	54.4	326.1	465.9
SASK-6-63	Actual	133.3	190.5	M
	Maximized	203.5	290.9	M
	MAX	329.8	331.0	465.9

$R_{maxt} = (W_{maxt}/W_{act})\, R_{act}$

(W_{act}: actual storm precipitable water)

Table 4: Seasonal Distribution of PMP for selected sites in northern Saskatchewan

Collins Bay Seasonal PMP distribution

Date	D.P.(C) @ 490 m	D.P.(C) @ 100 kPa	Precip. Water(mm)	% of Max
Apr01	2.0	4.9	11.04	23.1
Apr15	3.7	6.5	12.86	26.9
May01	5.8	8.6	15.72	32.9
May15	8.8	11.3	20.31	42.5
Jun01	12.5	15.0	28.77	60.2
Jun15	15.4	17.7	36.98	77.3
Jul01	17.4	19.4	43.24	90.4
Jul15	18.5	20.5	47.81	100.0
Aug01	18.4	20.4	47.37	99.1
Aug15	17.2	19.2	42.46	88.8
Sep01	15.2	17.5	36.30	75.9
Sep15	12.6	14.9	28.50	59.6
Oct01	9.4	12.0	21.70	45.4
Oct15	6.8	9.5	17.12	35.8
Nov01	4.3	7.0	13.49	28.2

Uranium City Seasonal PMP distribution

Date	D.P.(C) @ 318 m	D.P.(C) @ 100 kPa	Precip. Water(mm)	% of Max
Apr01	2.1	4.1	11.17	24.1
Apr15	4.5	6.2	13.61	29.3
May01	7.9	9.7	18.87	40.7
May15	11.1	12.6	24.69	53.2
Jun01	14.3	15.8	33.15	71.5
Jun15	15.9	17.3	38.17	82.3
Jul01	17.3	18.6	42.77	92.2
Jul15	18.0	19.5	46.39	100.0
Aug01	18.0	19.4	45.97	99.1
Aug15	16.7	18.0	40.51	87.3
Sep01	15.1	16.4	35.02	75.5
Sep15	12.9	14.3	28.89	62.3
Oct01	10.8	12.2	23.80	51.3
Oct15	8.2	9.9	19.22	41.4
Nov01	5.2	6.8	14.39	31.0

Cree Lake Seasonal PMP distribution

Date	D.P.(C) @ 497 m	D.P.(C) @ 100 kPa	Precip. Water(mm)	% of Max
Apr01	2.5	5.3	11.43	22.7
Apr15	3.8	6.6	12.94	25.7
May01	5.3	8.2	15.08	29.9
May15	9.5	12.1	21.84	43.4
Jun01	13.4	15.7	30.63	60.8
Jun15	15.9	18.2	38.63	76.7
Jul01	17.8	19.9	45.15	89.7
Jul15	18.9	21.1	50.36	100.0
Aug01	18.7	20.9	49.46	98.2
Aug15	17.4	19.6	43.93	87.2
Sep01	15.8	18.1	38.27	76.0
Sep15	12.8	15.1	28.96	57.5
Oct01	9.8	12.3	22.25	44.2
Oct15	7.0	9.8	17.56	34.9
Nov01	4.4	7.2	13.71	27.2

Fort Chipewyan Seasonal PMP distribution

Date	D.P.(C) @ 232 m	D.P.(C) @ 100 kPa	Precip. Water(mm)	% of Max
Apr01	3.5	4.8	12.46	22.6
Apr15	6.0	7.2	15.56	28.2
May01	9.4	10.6	21.30	38.7
May15	12.0	13.1	26.80	48.6
Jun01	14.9	16.0	34.90	63.3
Jun15	17.2	18.2	42.56	77.2
Jul01	18.7	19.7	48.67	88.3
Jul15	20.2	21.1	55.10	100.0
Aug01	20.2	21.1	55.10	100.0
Aug15	19.2	20.2	50.88	92.3
Sep01	17.0	17.9	41.43	75.2
Sep15	14.0	15.0	31.87	57.8
Oct01	10.9	12.0	24.23	44.0
Oct15	7.5	8.6	17.71	32.1
Nov01	5.1	6.3	14.32	26.0

La Ronge A Seasonal PMP distribution

Date	D.P.(C) @ 375 m	D.P.(C) @ 100 kPa	Precip. Water(mm)	% of Max
Apr01	4.5	6.7	13.87	23.5
Apr15	5.7	7.6	15.10	25.6
May01	7.5	9.5	18.05	30.6
May15	10.9	12.8	24.56	41.7
Jun01	15.2	16.9	35.88	60.9
Jun15	17.7	19.4	45.05	76.4
Jul01	19.6	21.1	52.50	89.1
Jul15	20.8	22.4	58.95	100.0
Aug01	20.8	22.4	58.95	100.0
Aug15	19.2	20.8	51.11	86.7
Sep01	17.1	18.7	42.28	71.7
Sep15	14.0	15.8	32.43	55.0
Oct01	10.0	11.9	22.59	38.3
Oct15	8.0	10.0	18.91	32.1
Nov01	5.5	7.5	14.96	25.4

Figure 1: 12–hr Persisting Dew Point

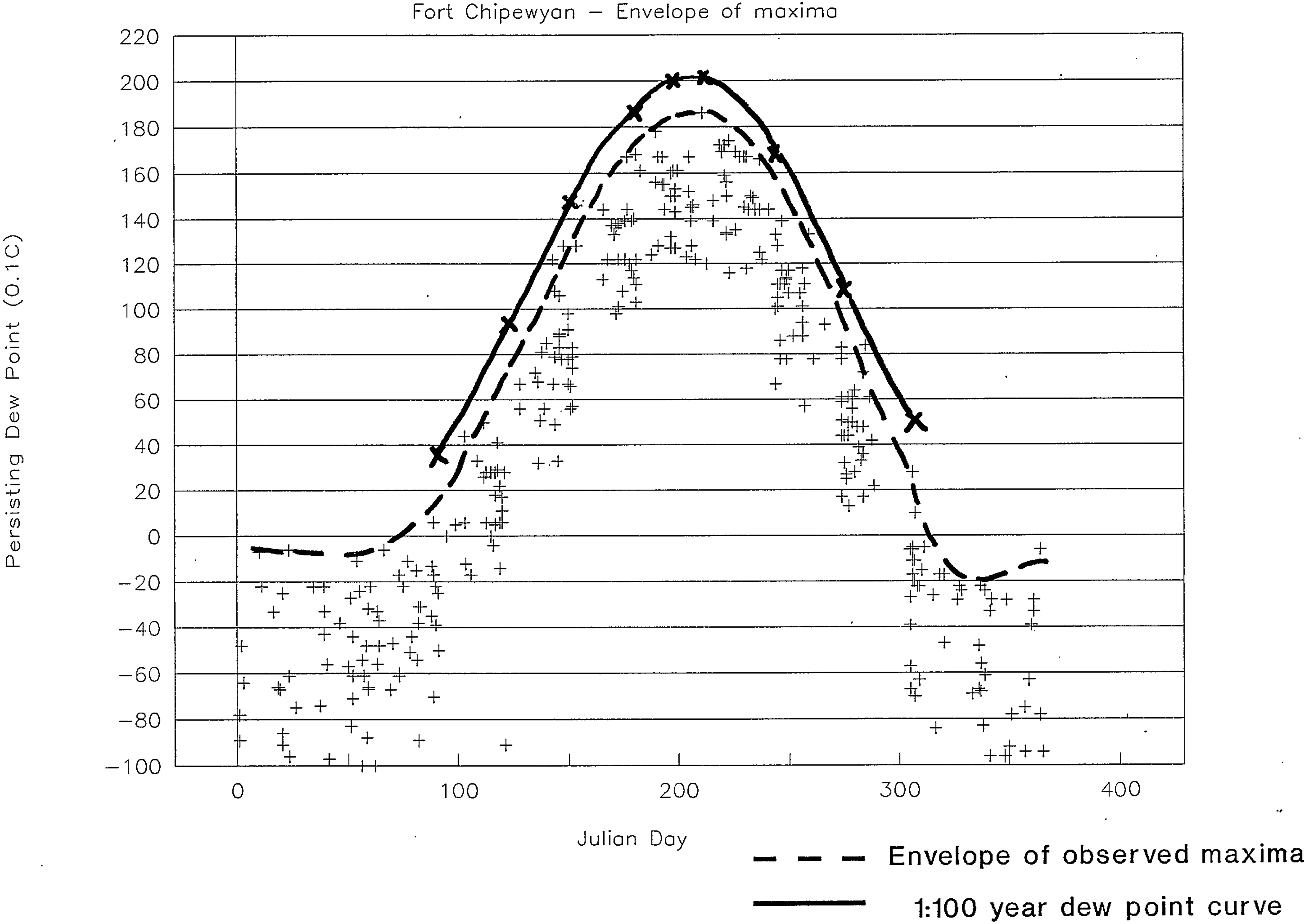
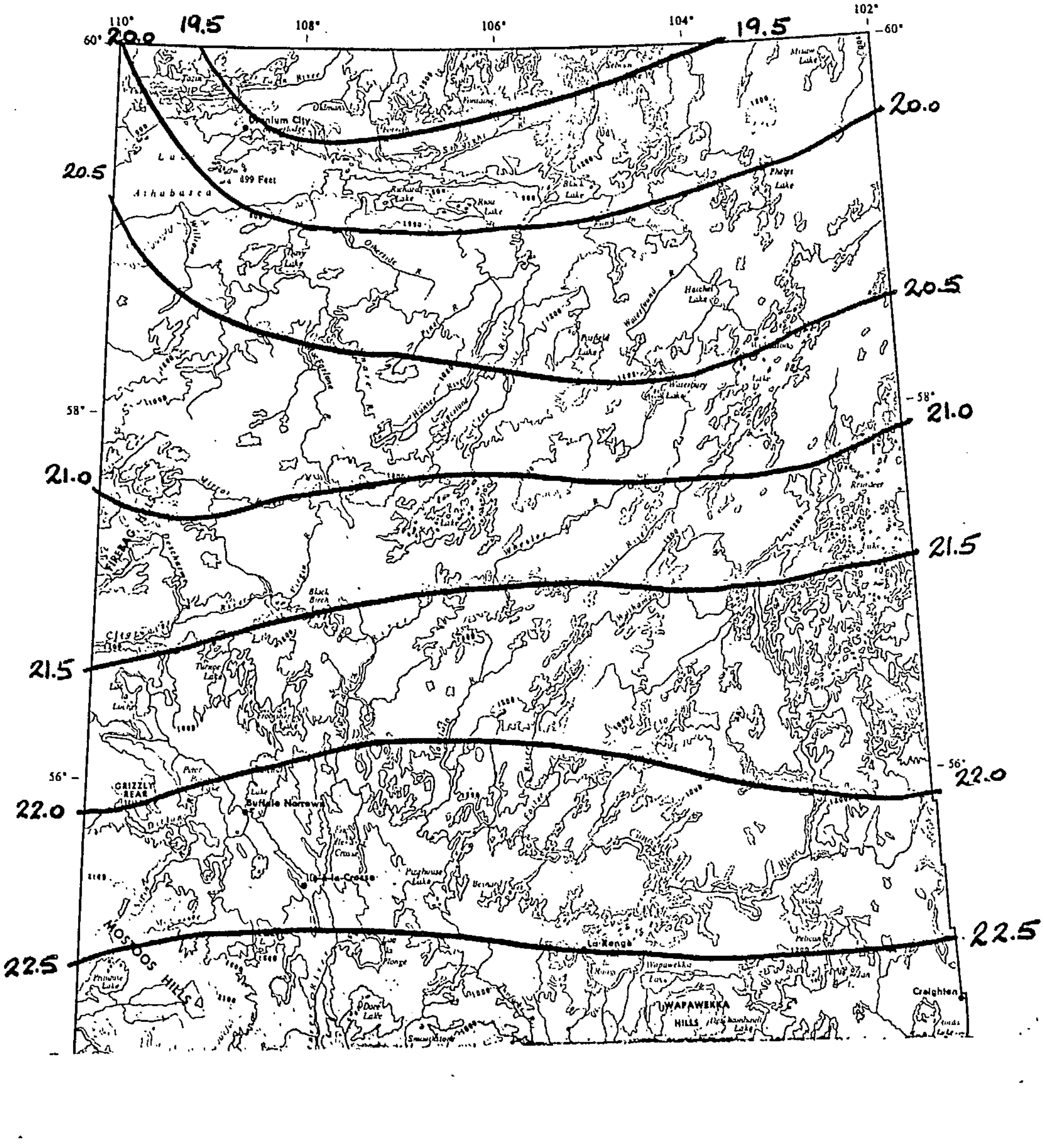
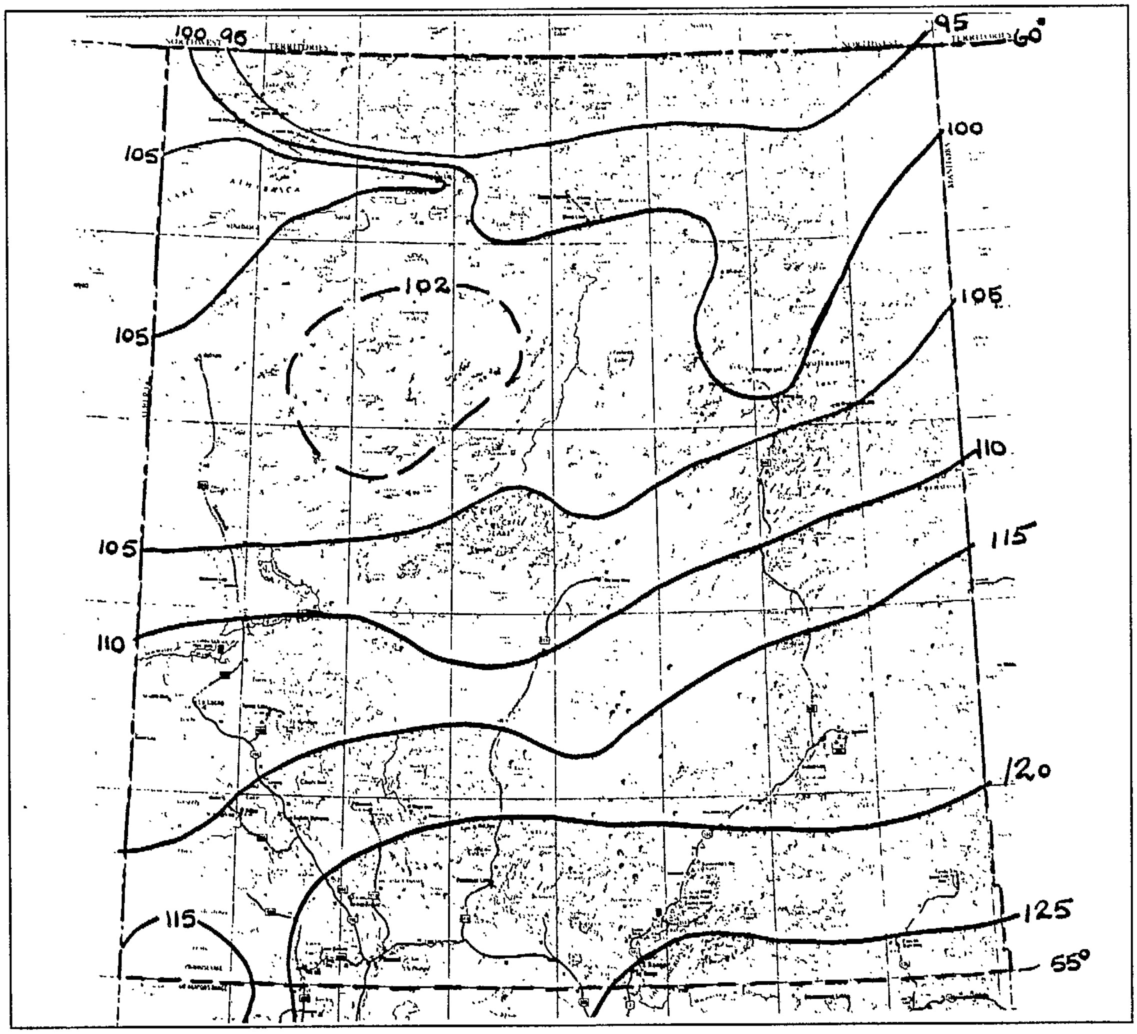


Figure 2: 12-Hour Persisting Dew Point (C) at 100 kPa



June 11, 1993

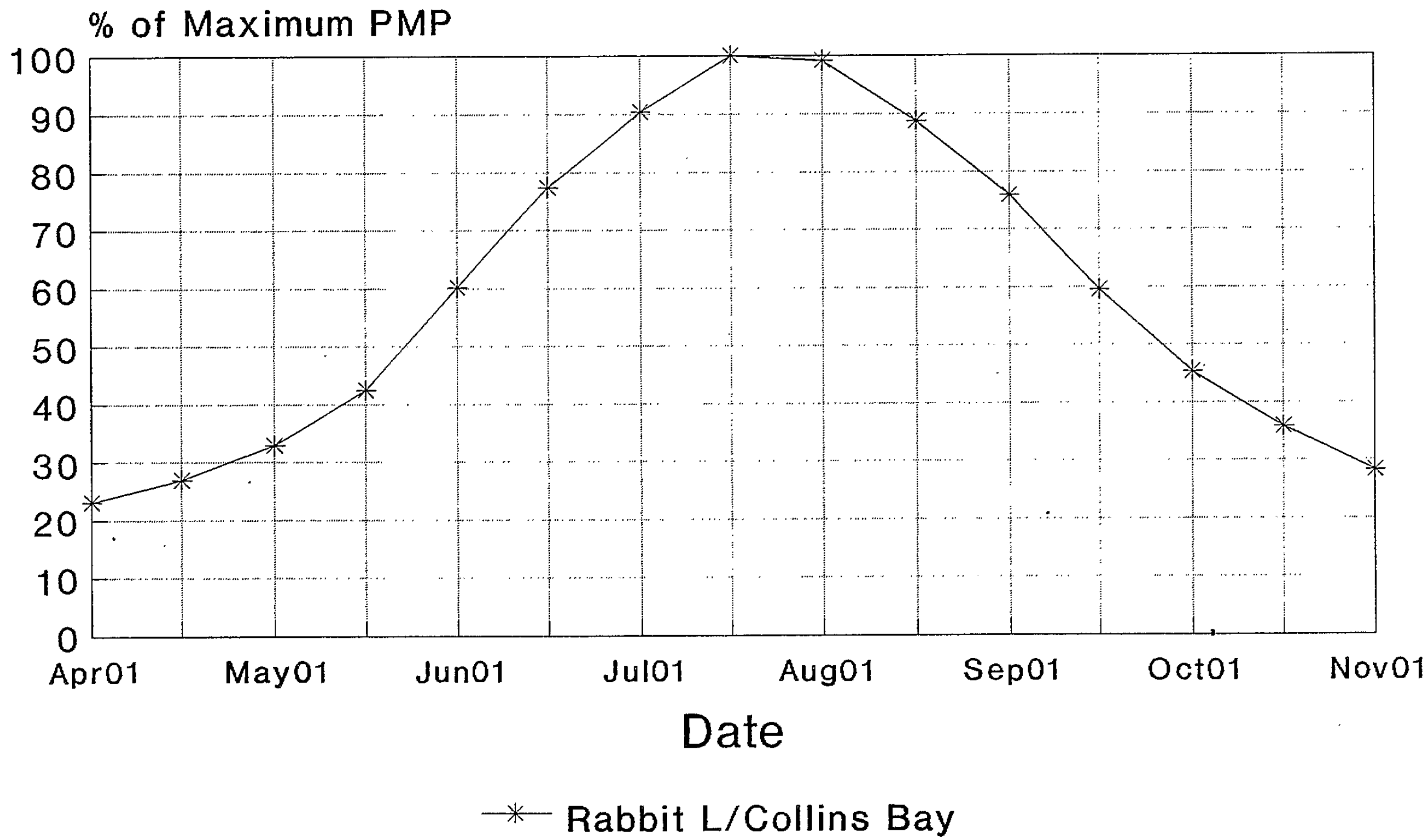
Figure 3
Percentage of Rabbit Lake PMP



Apply percentage to 466 mm to calculate the point PMP at locations on the map.

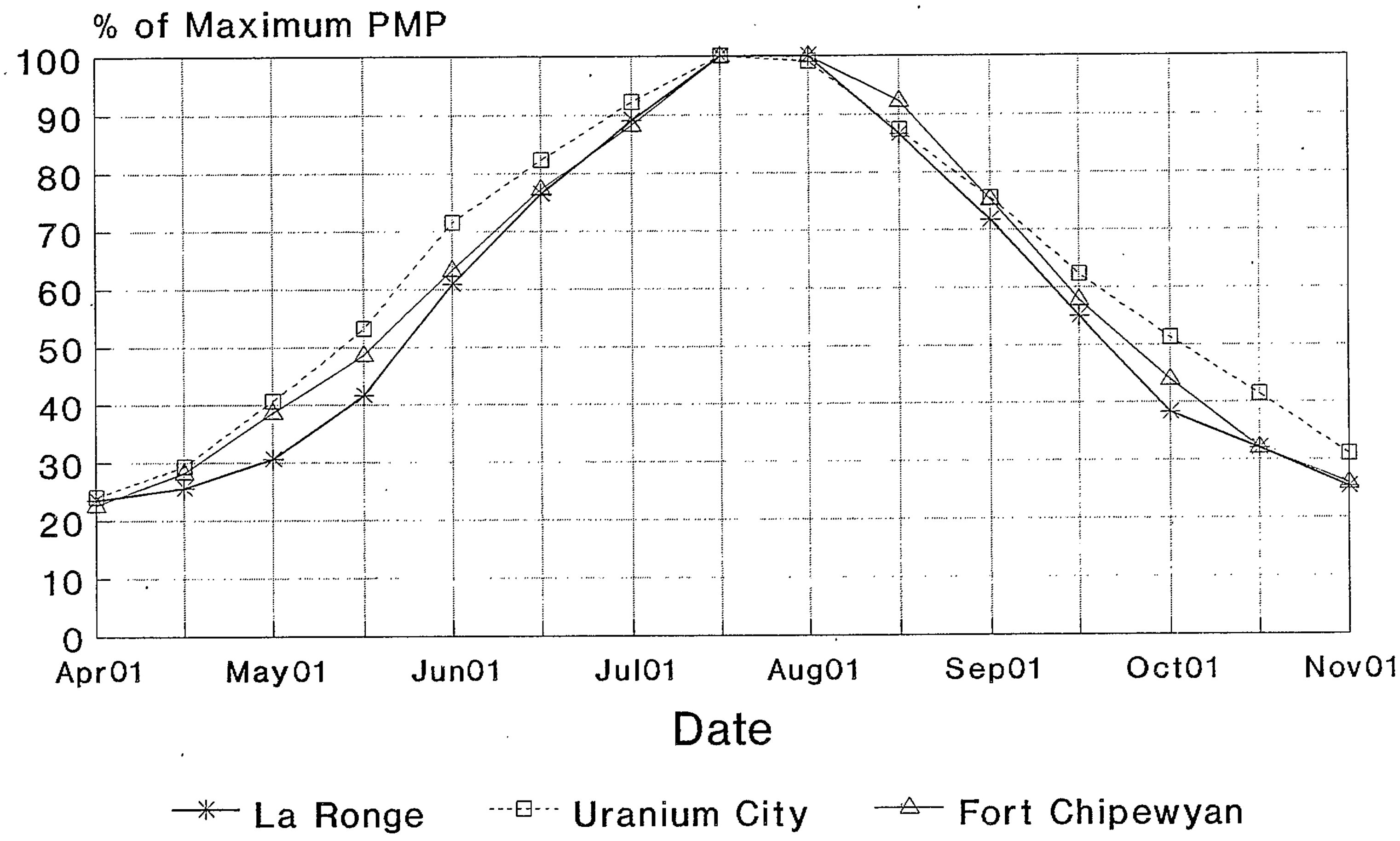
Valid for mid to late July

Figure 4: Seasonal Distribution of PMP at Rabbit Lake



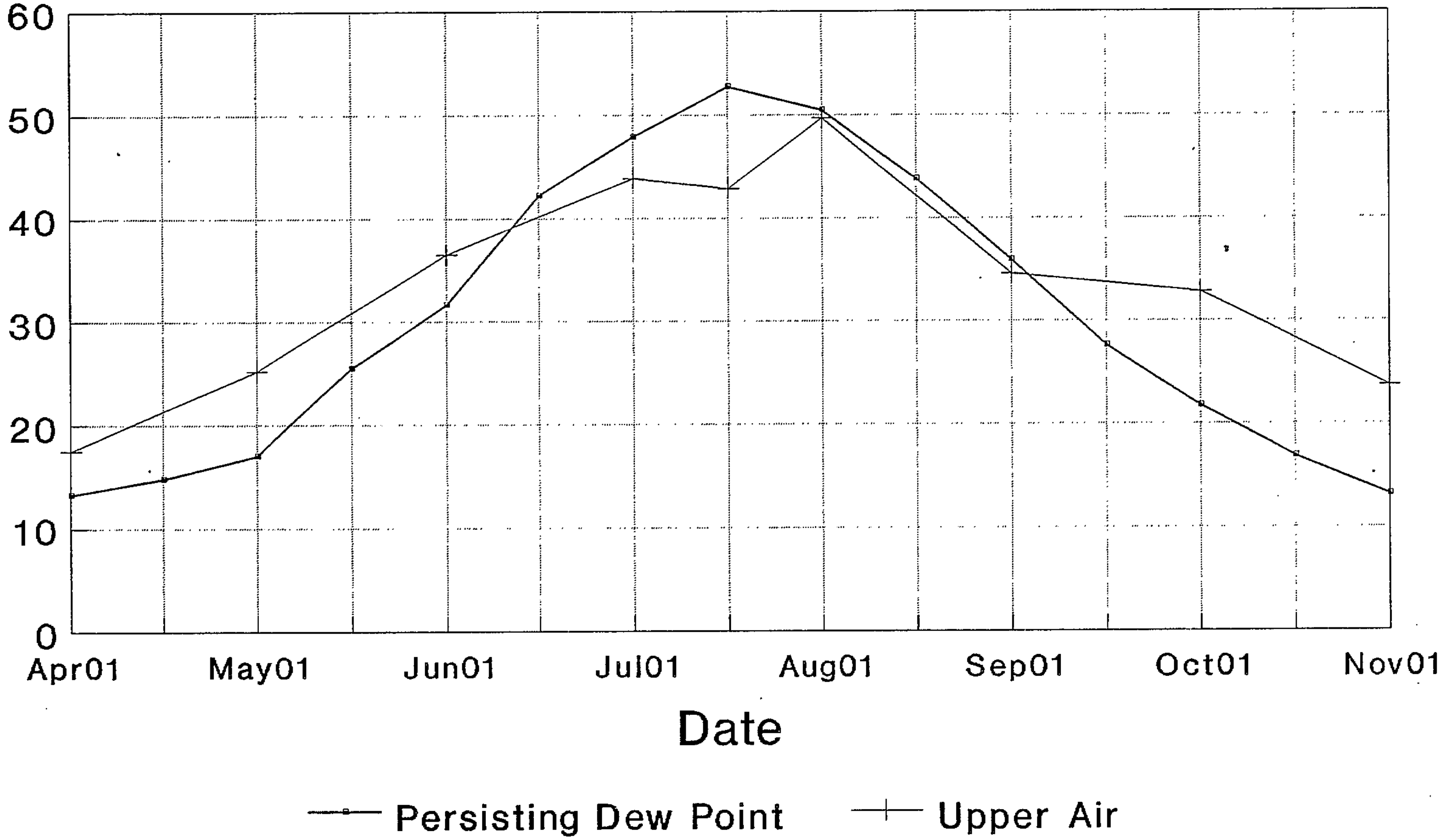
Values from November to March not applicable (snow cover affects analysis)

Figure 5: Seasonal Distribution of PMP
for all durations and areas



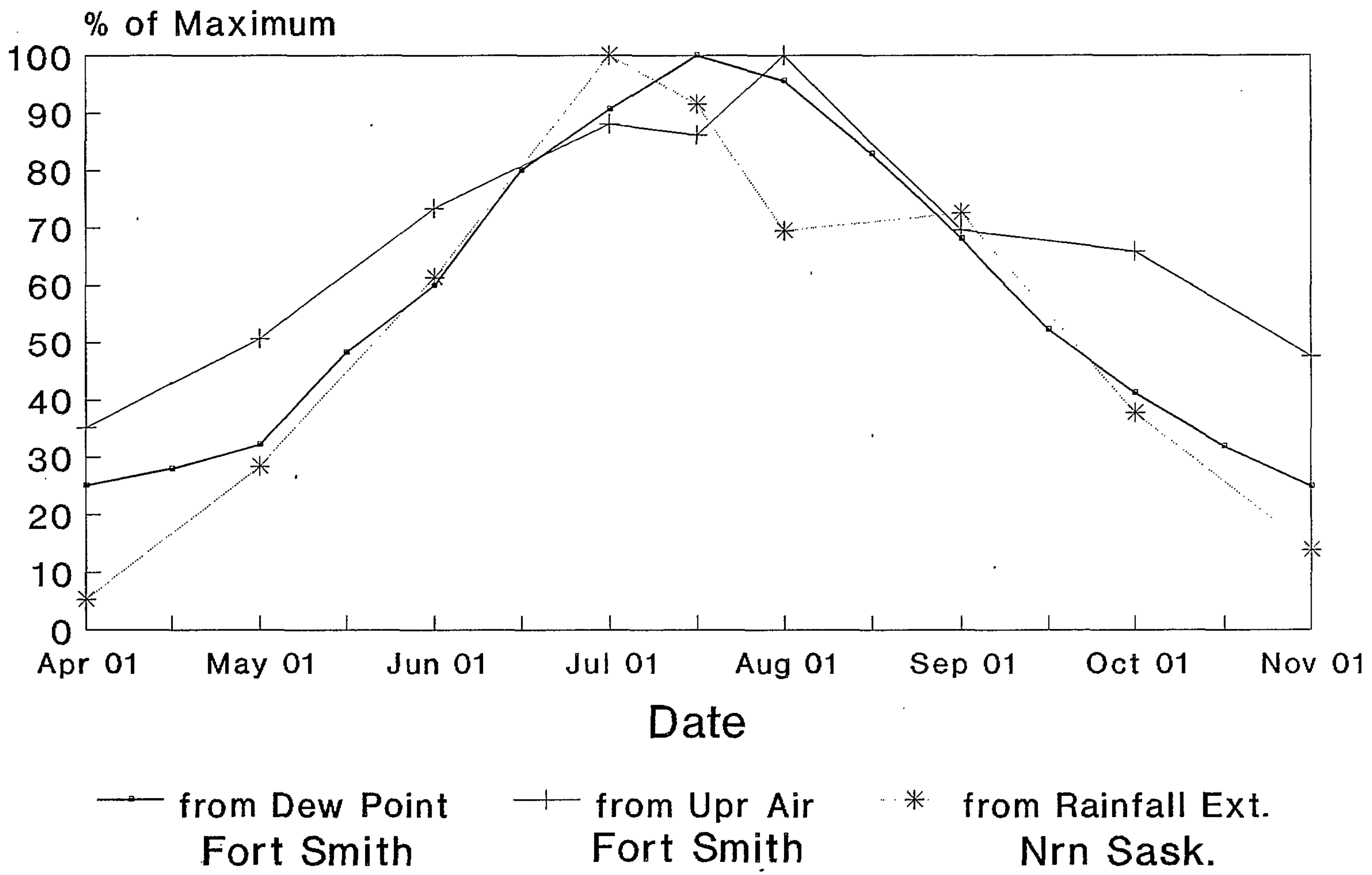
Values from November to March not applicable (snow cover affects analysis)

Figure 6: Seasonal Distribution of Precipitable Water - Fort Smith



March 1994

Figure 7: Seasonal Distribution of PMP
Comparison of Methods



March 1994