RED RIVER AT WINNIPEG

HYDROMETEOROLOGIC PARAMETER
GENERATED FLOODS
FOR DESIGN PURPOSES

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September, 1999

TABLE OF CONTENTS

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Abstract

The 1997 Red River flood strained existing flood control works to near the limit and served as a reminder that the City of Winnipeg is not protected against larger floods such as that of 1826 or greater. Enhancement of the flood control system is being considered, but this cannot be properly done without knowledge of the magnitudes and return periods of major floods yet unseen. Flood records for the Red River at Winnipeg begin in 1875 with some anecdotal information for earlier events. Due to the relatively short record, standard frequency analysis may not give reliable estimates for major floods well beyond those recorded. This report describes the generation of 2000 spring flood peaks at Winnipeg based on an analysis of causal flood parameters, using a formula to determine peak flow. A correction factor is applied to the largest 34 flood peaks, based on a thorough analysis and flood routing of one of the major generated floods.

This study shows that natural flows on the Red River at James Avenue in Winnipeg could exceed 200,000 cfs once every 200 years, 245,000 cfs once every 500 years and 295,000 cfs once every 1000 years on average. Present flood control works are clearly inadequate to deal with floods of this magnitude.

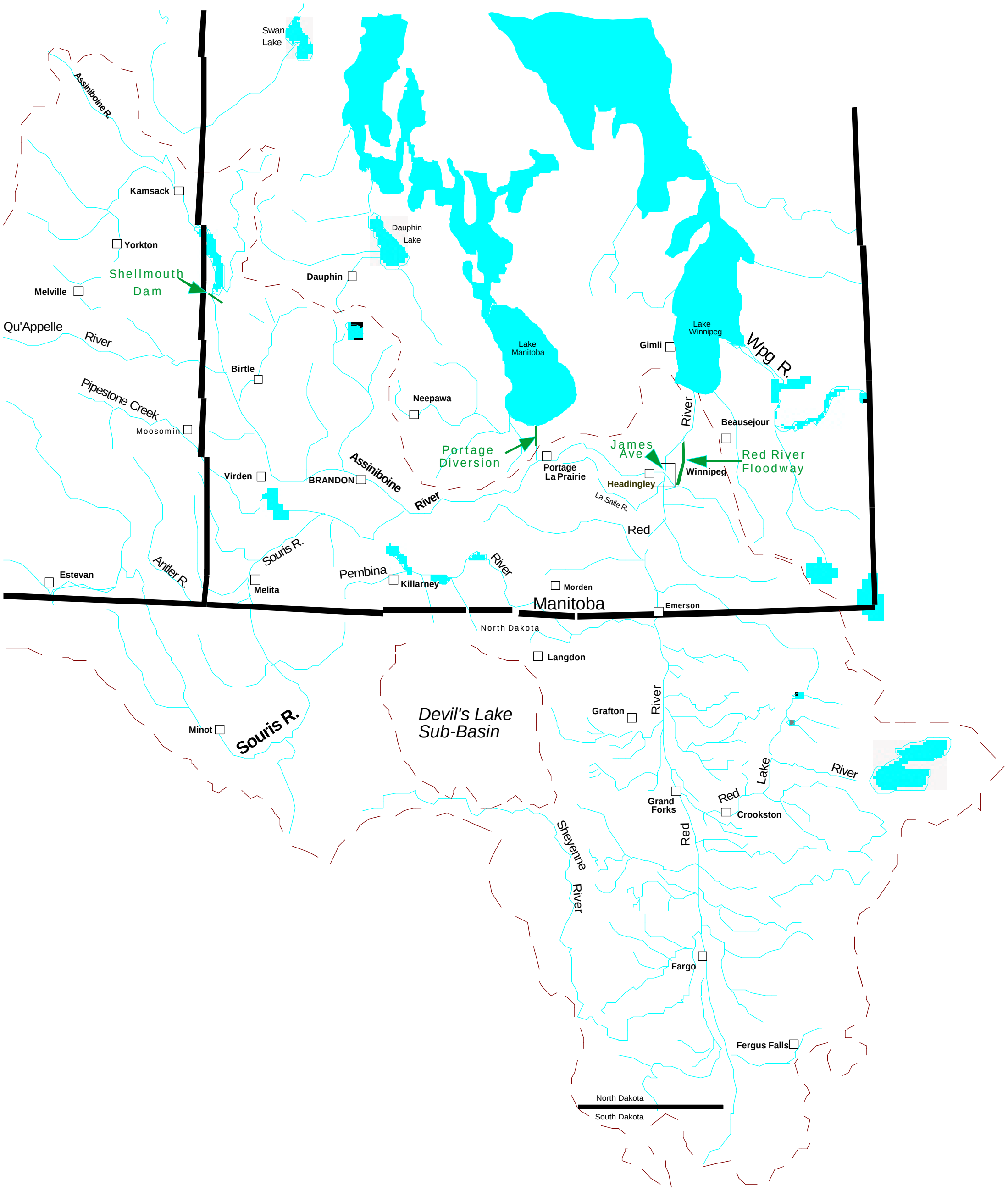
It is suggested that coincident major floods on the Red River and the Assiniboine River are very unlikely and that present control works on the Assiniboine River are adequate with respect to the City of Winnipeg. The more likely solution to the flood threat in Winnipeg would be to increase the capacity of the Red River Floodway. If peak flows in Winnipeg are to be no higher than 1997 crests, the Red River Floodway capacity required to control the 200 year, 500 year and 1000 year floods would need to be 95,000 cfs, 140,000 cfs and 190,000 cfs respectively. These figures do not include effects of possible strong south winds near the time of the crest, or backwater from the Floodway return flow, which would increase the required capacity somewhat further. The 1997 natural peak flow at James Avenue was 163,000 cfs and the peak Floodway flow was 66,000 cfs. At present, the Red River Floodway cannot convey more than 85,000 cfs without modifications.

1. Background

Following the 1950 Red River flood, the Royal Commission on Flood Cost Benefit (1958) recommended the construction of major flood control works to protect the City of Winnipeg from future devastation. The Red River Floodway, Portage Diversion and Shellmouth Reservoir were subsequently constructed and have protected the City from floods for the period 1969 – 1999. The location of these works is shown on Figure 1.

Figure 1

RED RIVER WATERSHED



The magnitude of the 1997 flood was a reminder; however, those larger floods beyond the capacity of the present control works have occurred (1776, 1826) and will again occur. There is a risk that Winnipeg will some day be severely flooded if the present control works are not enhanced.

This study was initiated by the Water Resources Branch to further investigate the nature and extent of the flood risk for the City of Winnipeg. The magnitude and frequency of major floods must be known in order to do a rigorous economic assessment of enhanced flood mitigation alternatives. While frequency analysis of past flood peaks has provided much information on the risk (Booy, 1998), it is limited by its lack of consideration of the forcing factors producing floods. This study employs an analysis of causal flood parameters to estimate the magnitude and occurrence interval of major floods on the Red River at Winnipeg.

A method frequently used to compute design flood estimates is the Probable Maximum Flood (PMF) sanctioned by the World Meteorological Organization (WMO, 1973). This employs storm maximization and transposition and is well suited for rain generated floods on watersheds smaller than most meso-scale storms. The PMF method is not ideally suited for large watersheds such as the Red River. The U.S. Corps of Engineers employs a Standard Project Flood (SPF) based on a scaling down of a PMF estimate (Corps, 1960). A difficulty is that there is no return period associated with these design floods; therefore it is difficult to do a rigorous benefit cost analysis. An alternative methodology to estimate the magnitude and return period of major floods at Winnipeg was developed, as described herein.

2. Methodology

The initial objective was to develop a design flood for the Red River at Winnipeg in order to provide an indication of the extent to which flood control work might need to be enhanced. It was however realized that the design flood must be derived from a benefit/cost analysis and other considerations. What is required is a long time series of floods to facilitate the benefit cost analysis. The magnitude and likelihood of floods greater than that of 1997 would be of particular interest in defining the damage-frequency curve and in determining the required level of protection.

The most desirable method to generate a long time series of floods would be a hydrologic model, as physically based as possible and continuous in time. Calibrating such a model and development of hydrometeorological time series for inputs would be a major task. Due to restraints on time and resources, a simpler method based on an analysis of causal flood parameters was chosen. Most of the parameters for the past 60 years (1940 – 1999) were already available from flood forecasting studies of Manitoba Water Resources.
An analysis of the causal parameters showed that they are quite independent due to the vagaries of weather conditions over time. The methodology therefore would allow random generation of annual causal parameter sets. This would result in many parameter combinations not yet observed in the relatively short hydrometric record. Allowance for greater climatic extremes due to climate change was considered by adding some greater parameter values to the observed set, based on hydrometeorological considerations.

Generation of peak discharges for the Red River at Winnipeg for some 2000 generated parameter sets was done using a formula developed for spring runoff forecasting. This formula accounts for the effects of the various parameter interactions but only accounts for channel storage effects on flood peaks implicitly. To evaluate such storage effects explicitly, data for one of the large generated floods was routed using both the Muskingum method and the Mike II dynamic routing model recently calibrated by a consultant (Klohn Crippen, 1999) hired by the International Joint Commission (IJC) Red River Basin Task Force. To ensure that inputs for the large routed flood were reasonable, a plausible meteorological scenario was used, with the preceding fall and winter patterned after the 1996-97 conditions.

The Hydrometeorological Parameter Generated Flood methodology for the Red River may be summarized as follows:

i Identify important causal parameters for floods
ii Compute parameters for a period long enough to define characteristics of the climate
iii Add some extreme parameter values to allow for climate change, considering atmospheric limitations
iv Generate 2000 causal parameter sets using a random number generator
v Convert the parameter combinations to peak flow at Winnipeg using a formula from past floods, with some modifications
vi Select one of the large floods and define a reasonable spatial and temporal meteorological scenario resulting in the associated causal parameters for the flood
vii Using the spatial and temporal inputs from step vi) develop flow hydrographs for the Red River at Halstad and all tributaries north to Winnipeg, using existing methodologies and some physical considerations with respect to incremental runoff, unit hydrograph shapes, etc.
viii Route the flows prepared in step vii) from Halstad to Winnipeg
ix Compare the routed flood peak to that generated with the formula and adjust the formula generated peaks for magnitudes above the 1997 flood
x Do a frequency analysis of the 2000 generated and adjusted spring flood peaks and estimate the return period of the larger events.

3. Selection of Causal Flood Parameters

The major causal parameters are quite well known based on experience and flood studies. The parameters used for this study are:

i Soil Moisture at Freeze-Up the Previous Autumn---Represented by Antecedent Precipitation Index (API)

ii Water Content of Snowpack---Represented by Total Winter Precipitation (WP)

iii Rate of Snowmelt---Represented by Melt Index, mean deg-days/day (MI)

iv Spring Rain Amount---Rainfall before the Spring Peak Date (SP)

- v Timing Factor---Percent of worst possible south-north progression of melt and rain (T)

The last factor has not been recognized in most historical flood reports. However, it is now well known that the timing of snowmelt and rainfall events has a major influence on flood peaks at Winnipeg. For operational forecasting, timing issues are dealt with by flood routing.

There are additional causal factors which influence the amount of runoff and flood peaks, such as soil frost depth, degree of clogging of ditches and tributaries with hard snow drifts or ice, the detailed spatial distribution of the soil moisture, snowcover and rainfall, detail on rainfall intensities, etc. Due to a lack of reliable historical data for these variables, they were not explicitly included in this study. However, the effect of some of these variables on major floods may be included implicitly through inter-correlation with the five major variables listed above. For example, an extreme snowpack would likely be associated with clogging of the drainage system. Furthermore, the effect of soil frost on runoff for predominately clay soils would be of relatively small significance for the extreme soil moisture levels which are very likely to precede major design floods. This is true because saturated clays have a near zero infiltrability whether frozen or not.

Historical reports have frequently mentioned the date of spring breakup as an important causal factor of Red River floods. A late breakup tends to be associated with a greater snowpack due to a longer winter, and with heavier spring rain and rapid melt conditions. However, these factors could also be quite low for a late breakup. The date of breakup is of no significance in itself as the possible associated effects are already included in the snowpack, spring rain and melt rate parameters.

4. Parameter Characteristics

This section presents the parameter values for the Red River Watershed for the 60-year period ending in 1999. A 61st value was added to account for increased variability under climate change.

a) Statistics for Past 60 Years

The values for each parameter for the period from 1940 – 1999 are shown on Table 1,

Table 1

RED RIVER WATERSHED----MAJOR CAUSAL FLOOD PARAMETERS

		1	2	3	4	5
Year	Natural Peak James Ave.	API	Melt Index	Winter Precipitation	Spring Precipitation	Timing Factor
1940	17600	1.87	6.3	1.85	0.98	55
1941	41800	2.17	8	3.50	1.89	50
1942	45600	3.52	6.6	3.23	0.24	60

Table 1 (continued)

RED RIVER WATERSHED----MAJOR CAUSAL FLOOD PARAMETERS

Year	Natural Peak James Ave.	1 API	2 Melt Index	3 Winter Precipitation	4 Spring Precipitation	5 Timing Factor
1943	42200	2.23	5.4	4.29	0.04	68
1944	17400	2.08	8.4	1.97	0.20	55
1945	52500	2.90	8.8	3.90	1.03	44
1946	38100	2.09	7.8	2.87	0.73	37
1947	36700	2.68	4.7	2.60	2.02	57
1948	75000	2.38	8.2	4.61	1.46	64
1949	48100	1.71	9.9	4.09	0.12	78
1950	108000	2.71	8.6	4.80	4.06	20
1951	37600	2.19	6.3	3.39	0.24	63
1952	35600	2.22	6.9	3.35	0.38	55
1953	12600	1.59	9.1	2.91	0.08	36
1954	17800	2.14	4.9	2.95	0.00	68
1955	52500	2.09	12.9	2.64	0.31	65
1956	69700	2.06	6.6	4.02	0.94	61
1957	21800	2.24	13.2	2.68	0.20	57
1958	15000	2.99	11.3	2.05	0.28	58
1959	33200	1.72	10.4	3.15	0.15	44
1960	69400	2.78	5.1	2.28	1.26	81
1961	9180	2.02	5.3	2.17	0.20	12
1962	57000	2.45	3.7	3.82	0.71	36
1963	23300	2.59	4.2	1.97	1.34	28
1964	35400	1.61	6.1	2.44	1.81	52
1965	64200	2.35	5.8	2.52	2.64	35
1966	88200	3.06	6	6.18	0.15	12
1967	59200	2.12	9.1	3.46	0.43	67
1968	15800	1.50	4.4	3.19	0.04	48
1969	78000	2.68	14.9	4.21	1.14	57
1970	80500	2.27	6.9	3.50	2.44	47
1971	53900	2.13	4.6	3.50	0.00	55
1972	56100	3.24	6.7	3.35	0.88	70
1973	18700	2.10	5.4	2.44	0.39	28
1974	96000	3.03	10.1	3.35	2.01	63
1975	59000	2.04	7.3	4.13	2.72	63
1976	63800	2.29	11.4	3.62	0.12	50
1977	6600	1.02	11.1	3.27	0.00	19
1978	62000	2.95	7	4.29	0.94	53
1979	107000	2.03	18	4.88	2.89	47
1980	31100	1.86	8	3.03	0.00	41
1981	5600	2.57	6	2.52	0.00	12
1982	51500	2.88	3.1	4.09	0.47	37
1983	49200	3.18	3	3.70	0.08	75
1984	37000	2.61	7.3	3.46	0.01	21

Table 1 (continued)

RED RIVER WATERSHED----MAJOR CAUSAL FLOOD PARAMETERS

Year	Natural Peak James Ave.	1 API	2 Melt Index	3 Winter Precipitation	4 Spring Precipitation	5 Timing Factor
1985	37000	2.64	8.3	2.48	0.00	50
1986	64000	2.70	5.4	3.15	0.55	60
1987	82600	2.29	8.6	4.17	0.00	48
1988	19900	2.02	7.5	2.99	0.00	30
1989	49000	1.81	3.5	4.96	0.70	43
1990	14200	1.77	3.6	3.19	0.16	30
1991	9800	1.75	3	2.36	0.06	30
1992	49400	2.82	5.4	3.11	0.07	44
1993	46000	2.06	9	3.66	0.16	51
1994	40000	2.50	7	3.94	0.15	55
1995	66200	3.20	11	4.49	0.00	35
1996	108000	2.89	10	4.88	0.12	75
1997	163000	2.49	11.6	8.60	0.10	62
1998	55000	2.82	2.7	3.70	0.00	28
1999	77000	2.96	9	4.69	1.38	44

Explanation of Parameters:

API; Index of soil moisture at freeze-up the previous autumn, based on weighted basin precipitation from May to October.
MELT INDEX; average degree-days per day at Grand Forks during the active melt period (deg. F).
WINTER PRECIPITATION; total basin precipitation from Nov. 1 of previous year to the start of active melt during the flood year (inches).
SPRING PRECIPITATION; total basin precipitation from the start of active spring melt to the date of the spring crest at Emerson (inches).
TIMING; an index of the south-north time phasing of the runoff based on the percentage of tributary peaks experienced on the date of the mainstem peak at specific points from Halstad to Winnipeg (percent of worst possible).

together with the natural peak discharge for the Red River at James Avenue in Winnipeg. “Natural” is defined as peak flows, which would have occurred in the absence of the Red River Floodway, Portage Diversion and Shellmouth Reservoir. These control works have been operated since 1969. The peak flows prior to 1969 are recorded flows downstream of the Assiniboine River in Winnipeg.

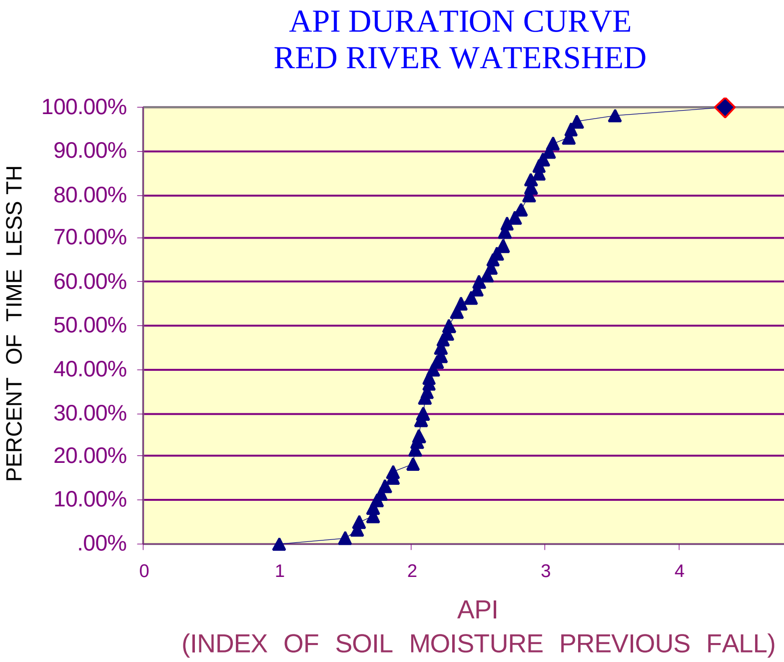
Causal parameters were not computed prior to 1940 due to insufficient data. Also the period from 1917 – 1939 produced no significant floods and may have been a climatological anomaly. The period 1940 – 1999 was considered long enough to define the recent climate of the Red River Watershed.

b) Adjustments for Climate Change

While many unknowns remain with respect to climate change, it is generally acknowledged that variability will increase and will result in greater extremes. To allow for some extremes not yet observed, one larger parameter value was added to the 60-year record. This is a conservative approach, which was deliberately chosen due to the uncertainties. The selected values were based on meteorological considerations and judgement and all are well below the maximum possible. For example, the API value was patterned after 1941 conditions with some modification. The values for climate change appear as the top value on the following duration curves for each parameter. While most are not significantly higher than the maximum for the 60-year period, it is significant that a second high value has been introduced into a 60-year time horizon. It was beyond the scope of this report to rigorously estimate effects of climate change based on global circulation models, which are not all in agreement.

Duration curves of the causal parameters are shown on Figures 2 through 6.

Figure 2



Duration curves of the causal parameters continued…

Figure 3

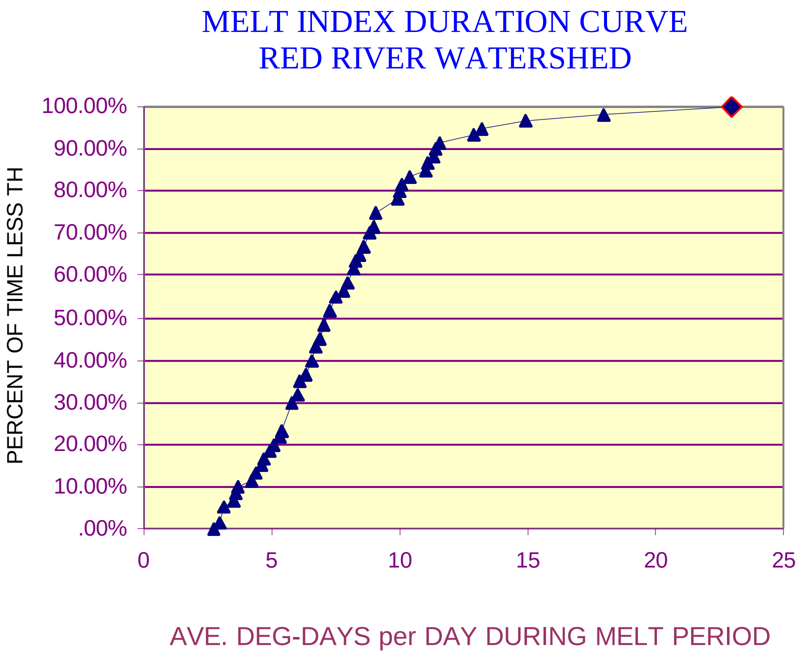
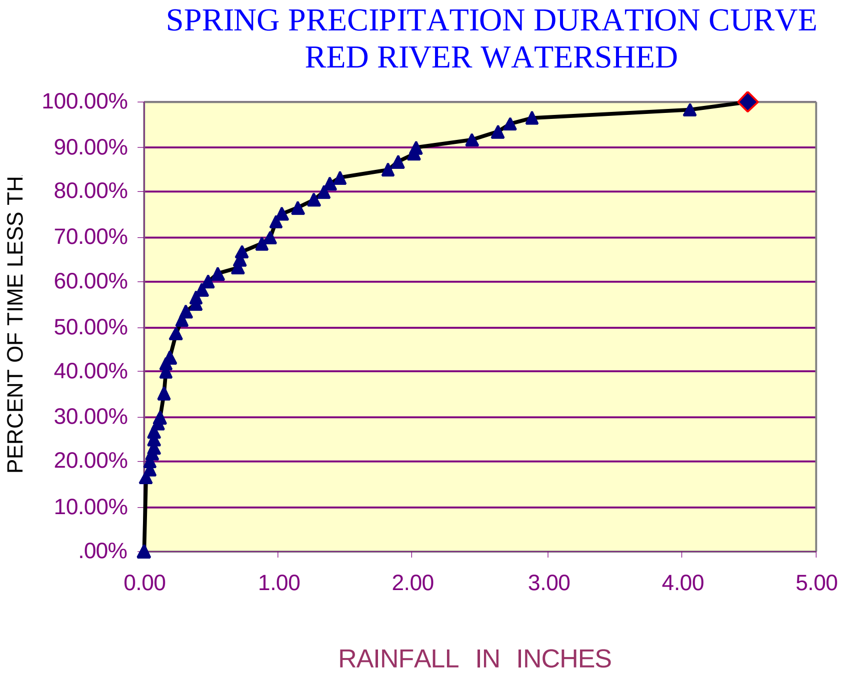


Figure 4



Duration curves of the causal parameters continued…

Figure 5

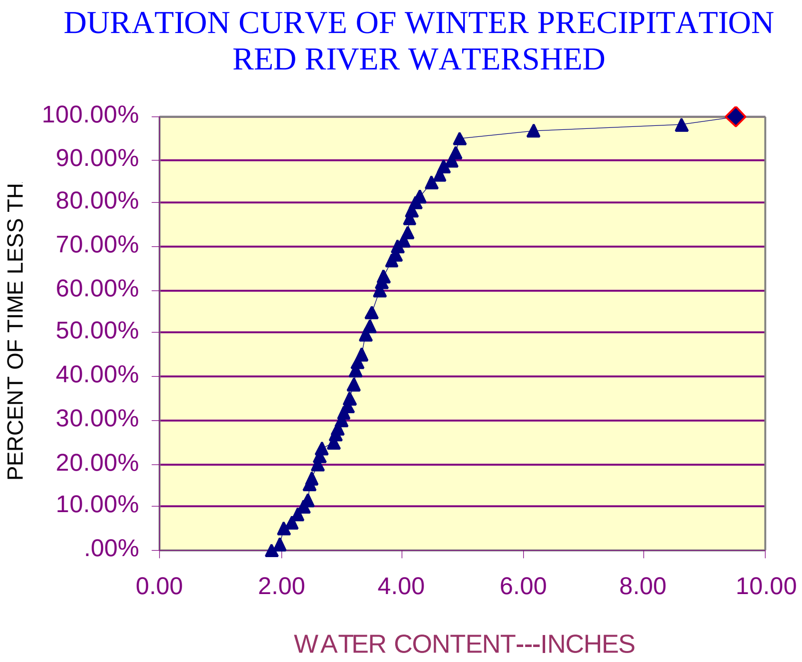
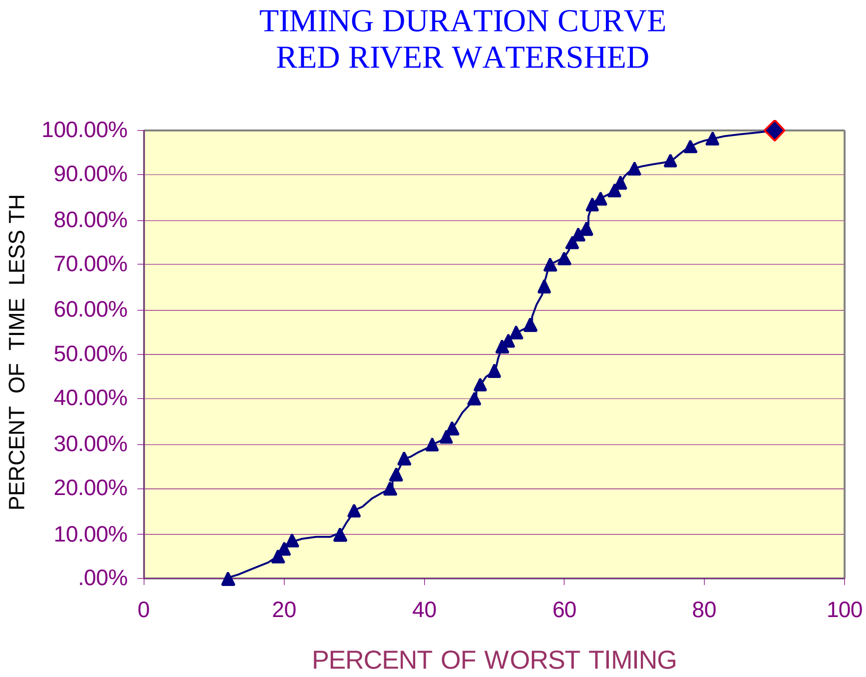


Figure 6



c) Relationship Between Parameters

A test was done to determine whether dependencies exist between the causal parameters. Simple regressions were run for two parameters at a time and the resultant correlation coefficient was tested for significance. The intercorrelation matrix is shown in Table 2.

Table 2

Correlation Coefficients (R) between Parameters

	API	WP	MI	SP	T
API	---	0.34	0.21	0.29	0.26
WP	0.34	---	0.38	0.33	0.24
MI	0.21	0.38	---	0.37	0.31
SP	0.29	0.33	0.37	---	0.16
T	0.26	0.24	0.31	0.16	---

The value of the correlation coefficient R at the one- percent level of significance for 60 degrees of freedom is 0.325 (Statistical Methods, 1967). This means that if the R-value is less than 0.325 the chance that there is any meaningful relationship between the variables is less than one percent. While some of the parameters have correlations somewhat greater than the 1% significance level, the correlations are very weak. Even for the strongest relationship (between winter precipitation and melt index) only 14 percent of the variance is explained by regression, leaving 86 percent to randomness. This means that the causal parameters are essentially independent. This is reasonable from a meteorological standpoint. The driving forces determining weather conditions in the Red River watershed are determined by complex energy interactions over the lands and oceans around the globe. While a certain amount of persistence may occur due to phenomena such as El Nino and Le Nina, there are other driving forces involved, which frequently disrupt atmospheric patterns, thus resulting in randomness. There is little persistence within a season or from one season to the next. Even when persistence exists in the upper atmospheric circulation, temporary deviations from the pattern can result in storms, which upset a trend in precipitation, and/or temperature, which may have developed.

5. Generation of 2000 Spring Flood Peaks at Winnipeg

Since the causal parameters have been shown to be quite independent, it is possible to randomly generate additional sets of annual flood parameters. This is desirable since many possible parameter combinations, which have not occurred during the relatively short period of record, are of interest. With five parameters, each of which may take on 61 different values, the number of possible combinations is staggering. It is similar to the Canadian Lotto 649 where one picks six numbers out of 49 to win the jackpot. For the flood parameters it is more like a “561”, where the biggest flood would occur if all five parameters came in near their maximum value. If only three of the parameters come in high and the other two are low (there might be low soil moisture and little spring rain) one would get a smaller flood perhaps like that of 1966, which would be analogous to the consolation prize in the lottery. The analogy is not exact, however, since the lottery requires exact numbers whereas “close” is good enough for the flood parameters. Nevertheless, the odds of having all five parameters near their maximum in one flood season is quite low and has not occurred in the observed period of record, except perhaps in 1826. Generation of a long series of parameters would shed light on how often adverse combinations might occur.

a) Generating Sets of Causal Parameters

The objective was to generate 2000 sets of the five causal parameters. This was done according to the following steps:

i A random number generator was used to generate a number from 1 to 100.
ii The number from step i) was entered into the duration curve of 61 values for the first causal parameter and the corresponding parameter value recorded.
iii The above steps were repeated in succession for the other four parameters, thus generating the first set of causal parameters.
ivThe above steps were repeated until 2000 parameter sets had been generated.

b) Conversion to Natural Peak Discharges

The 2000 sets of generated causal flood parameters were converted to 2000 values of natural peak discharge for the Red River at James Avenue in Winnipeg. This involved use of a formula based on a non-linear regression analysis of data for past flood years. The regression formula was modified slightly so as to produce very good accuracy for large recorded floods such as 1997, since formula accuracy is most important for major floods. Since parameter values for even larger floods do not significantly exceed recorded values, the formula should give a reasonable estimate of the peak for the more unfavorable parameter combinations generated. The formula used is as follows:

$$\text{PEAK (cfs)} = 149(\text{API})^{1.5}(\text{WP} + \text{SP})^{1.5}(\text{MI})^{0.3}(\text{T})^{0.4}$$

c) Review of Parameter Generated Floods

The ten largest floods generated, together with their causal parameters, are listed in Table 3.

Table 3

First Approximation of Largest of 2000 Floods -- Based on Formula

YEAR	PEAK (CFS)	API	WP	MI	SP	T
1349	381,000	3.99	9.4	3.6	2.8	60
398	355,000	3.05	8.8	7.0	4.3	64
982	355,000	3.42	4.9	18.7	4.4	72
1002	302,000	2.70	9.3	9.0	2.7	76
1698	295,000	3.40	8.7	9.0	1.2	63
1330	273,000	3.04	9.3	6.0	2.5	55
1394	256,000	3.62	8.2	9.0	0.1	66
1451	237,000	4.33	6.9	5.0	1.3	63
850	233,000	3.20	8.9	8.0	0.2	65
219	211,000	2.70	9.5	7.3	0.1	88

Most of the large floods resulted from high soil moisture in the autumn and heavy winter precipitation. Spring rain varied from little for some floods to more than 4 inches for others. All had relatively unfavorable timing scenarios.

The 2000 generated spring flood peaks may be considered as occurring consecutively over time, if formulation of the causal parameters is truly random in the real world. This reveals some interesting temporal aspects of the flood peaks which could result from randomness alone. For example three major floods of 1826 magnitude or greater generated in the “fourteenth century” but none in twelve other “centuries”. There were no floods of 1826 magnitude or greater during the periods from 399 to 849 and from 1699 to 2000.

The generated flood peaks given in this section are preliminary. All peaks greater than the 1997 peak (163,000 cfs) are later adjusted based on results of the detailed flood simulation described in the following section.

6. Detailed Simulation of a Major Flood (HPRF)

The generation of 2000 flood peaks relied on a formula to convert causal parameters into flood peaks at Winnipeg, based mainly on data for past floods. The formula relates meteorological based parameters to peak flows and gives a reasonable first approximation of possible flood peaks in Winnipeg. However, the formula cannot fully incorporate the non-linear effects of physiographic features such as flood plain storage. The actual evolution of a major flood is extremely complex particularly with respect to timing factors, runoff generation, channel storage, etc. It is therefore desirable to investigate whether a typical generated major flood peak would be reasonably accurate based on a more thorough analysis of the inputs, which must conform to a plausible meteorological scenario, and other factors. This section describes the more rigorous generation of a major flood peak based on timing scenarios for the inputs, runoff generation, sub-basin hydrograph preparation, and flood routing. To facilitate discussion this will be called the Hydrometeorologic Parameter Routed Flood (HPRF).

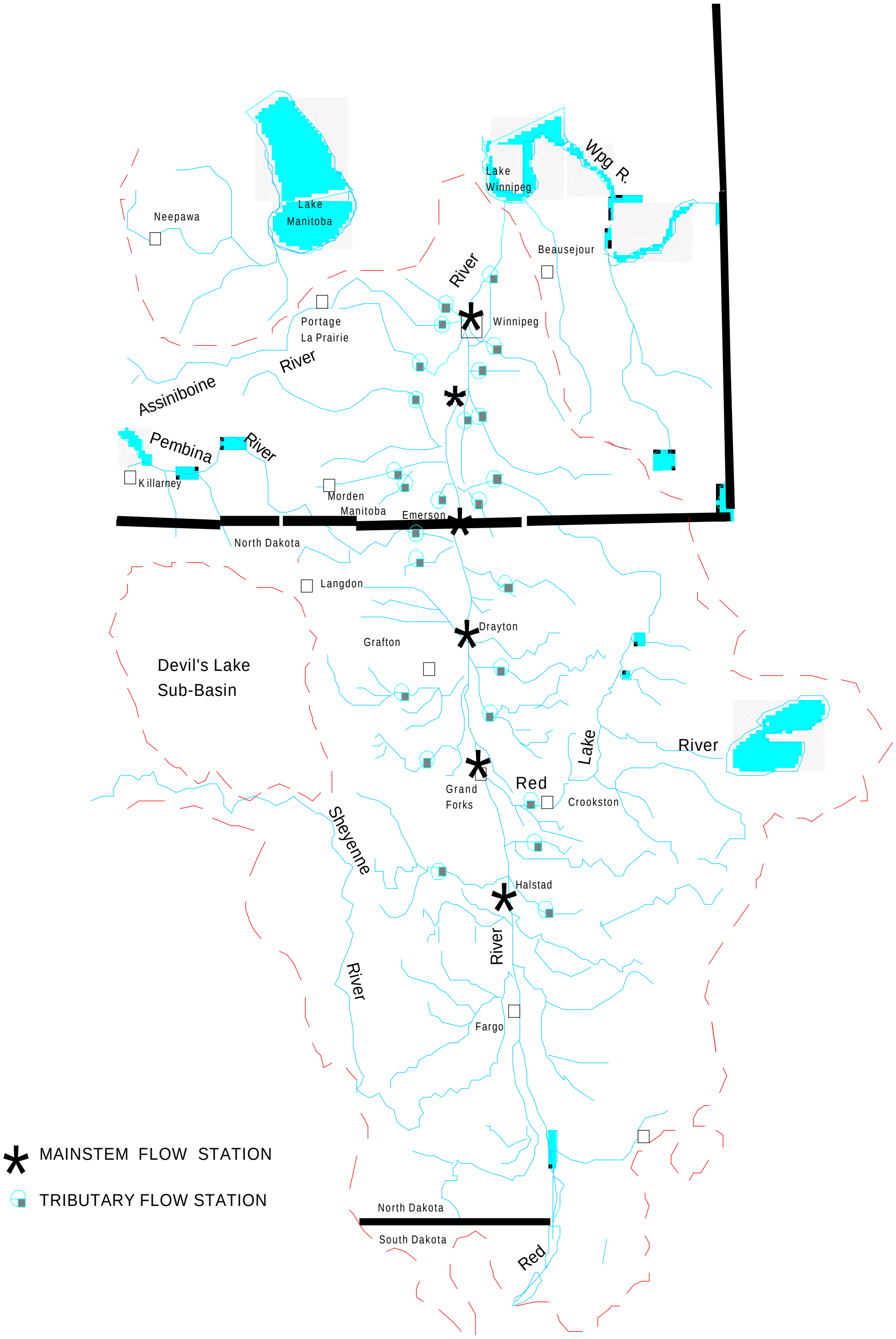
a) Basin Configuration

In order to develop a more reliable peak flow at Winnipeg for a given set of input parameters, it is necessary to distribute those parameter inputs both spatially and temporally in a fashion based on a plausible meteorological scenario. The spatial configuration for the HPRF consists of the Red River upstream of Halstad, which for this purpose is treated as a sub-basin, and all the gauged tributaries of the Red River from Halstad to Winnipeg. This involves 27 gauged sub-basins and 14 ungauged areas, the latter of which are indexed to the nearest representative gauged stream. Inputs such as soil moisture, snowcover, rain, etc were assigned to each of the 27 gauged sub-basins except the Assiniboine River, which was treated differently, as will be discussed later. Runoff and daily streamflow hydrographs were generated for all 41 sub-basins based on the selected spatial and temporal inputs. The process is described in greater detail in the following sub-sections. Streamflow data were obtained from Water Survey of Canada and the United States Geological Survey. Meteorological data were obtained from Environment Canada and the U.S. National Weather Service.

The gauging station locations for the 27 gauged sub-basins, along with mainstem gauging stations are shown on Figure 7. James Avenue is just downstream of the confluence with the Assiniboine River in Winnipeg.

Figure 7

RED RIVER WATERSHED STATIONS FOR FLOOD ROUTING



b) Causal Parameter Values

Basin conditions and inputs for the HPRF flood could be chosen arbitrarily by choosing high values from the duration curves of 61 input parameter values presented earlier. However, this would lead to questions as to the appropriateness of the selected inputs. In order to make the parameter selections more realistic and plausible, conditions for the largest observed flood (1997) were used as a guide. The causal parameters were then adjusted somewhat so that they would produce one of the large floods (over 300,000 cfs) according to the formula earlier used to generate 2000 floods, while at the same time remaining well within a plausible meteorological scenario for the flood. The parameter values which met these required conditions and which were chosen are shown in Table 4, together with values for some observed floods. They resulted in a natural peak flow of 355,000 cfs at Winnipeg according to the formula.

Table 4

CAUSAL PARAMETERS FOR LARGE RED RIVER FLOODS

	HPRF	60 YEAR MAXIMUM	60 YEAR MEDIAN	1997	1979	1950	1966
Soil Moisture	2.7	3.5	2.3	2.5	2.0	2.7	3.0
Snowpack	8.0	8.6	3.4	8.6	4.9	4.8	6.2
Melt Rate	16	18	7	12	18	9	6
Spring Rain	4.0	4.1	0.3	0.1	2.9	4.1	0.2
Timing	75	81	50	62	47	20	12

The soil moisture and snowpack and the melt rate for HPRF are not very different from those of the 1997 flood. The 1997 snowpack conditions (early April storm included) are considered quite extreme, so a somewhat lesser value was chosen for the HPRF. The HPRF melt rate for most of the U.S. portion is also similar to that of 1997, but the melt from Grand Forks northward is faster. The advantage of having many parameters similar to those of 1997 was that it enabled use of observed 1997 snowmelt runoff and tributary flows as a guide for HPRF snowmelt runoff for most sub-basins. In essence then the HPRF consisted largely of superimposing several major rainstorms upon the observed 1997 runoff conditions, together with very unfavorable timing factors and a fast northerly melt which would favor growth of the crest as it moved northward. Use of 1997 as a foundation for the HPRF significantly reduces uncertainties with respect to runoff and tributary hydrograph generation.

c) Selection of a Plausible Meteorological Scenario

It is important that the spatial and temporal distribution of the causal factors are reasonable from a meteorological standpoint. The assumptions with respect to the spring weather are very critical since the spatial distribution of melt and rainfall, amounts of rain etc. are highly important in determining runoff volumes, hydrograph shape and flood peak. Following are the main assumptions for the HPRF.

i Melt would start in the Fargo area in mid April, i.e. two weeks later than in 1997. This is not unreasonable considering the conditions in 1826 and in late April to May of 1979.

ii The pattern of snowmelt would be very similar to that of 1997 in its earlier stages, with significant melt occurring in the portion above Halstad before serious snowmelt developed further north. The snowpack losses which occurred from Grand Forks northward in March 1997 would not occur for the HPRF due to a dominant weather front allowing melt in the Fargo area while maintaining below freezing temperatures from Grand Forks to Winnipeg.

iii A major storm, similar that of early April, 1997 would occur in late April bringing 2.5 inches of rain to the U.S. portion and 2.0 inches water content of snow to the Manitoba portion.

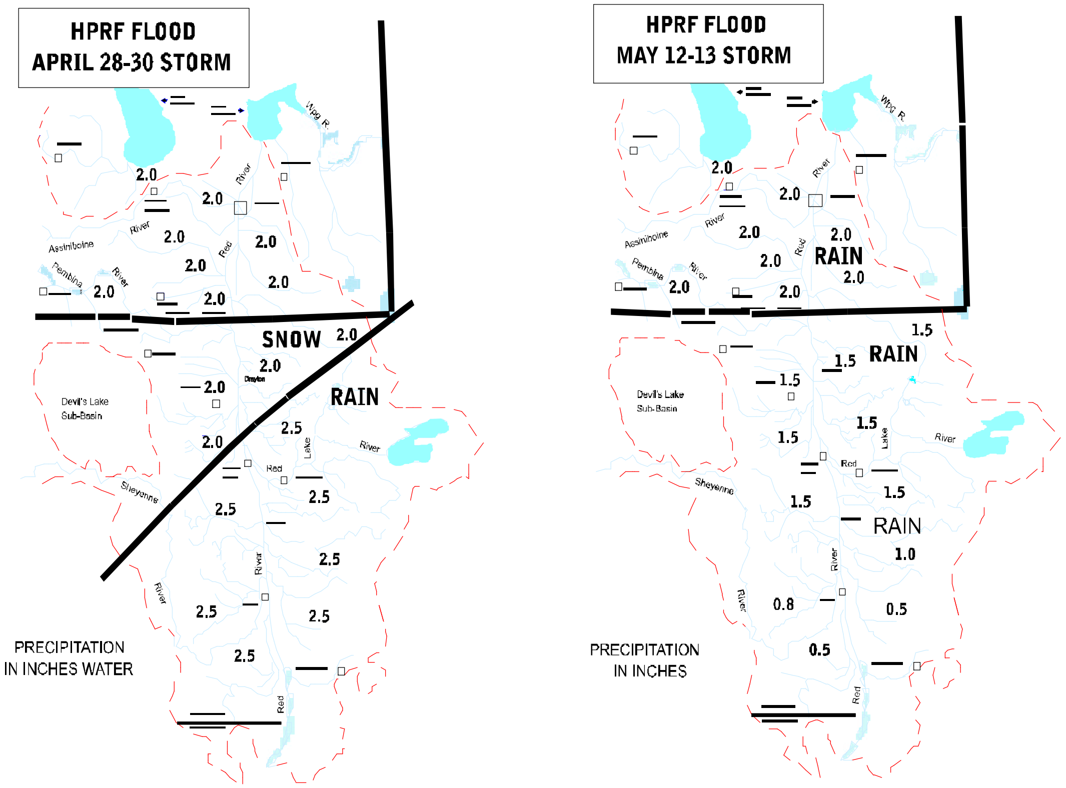
iv Melt from Grand Forks to Emerson would be delayed a little longer relative to areas further south than it was in 1997. From Emerson to Winnipeg it would not begin until May 7. This scenario would be expedited by the high albedo’s in northern areas due to the late April storm.

v Around May 7 a melt pattern similar to that of April 1979 would develop. This would quickly melt remaining snow from Halstad to Emerson and would melt the entire snowpack from Emerson to Winnipeg in 3-4 days.

vi A major rainstorm would occur May 12-13 just after the rapid melt in northern regions. There would be 2.0 inches of rain in the Manitoba portion and 1.5 inches in the U.S. portion. These rain amounts are considerably less than what fell during the first week of May 1950. However, it was assumed that this rain would fall in a 24 hour period.

The spatial distribution of precipitation for the late April and May storms used for the HPRF is shown on Figure 8.

Figure 8



d) Estimating Runoff

Since the soil moisture and winter snowcover were similar in magnitude to those of 1997, the flow hydrographs for all sub-basins as recorded in 1997 were used as the foundation for the HPRF. The remaining task was to estimate runoff coefficients from the two storm events (items iii and vi in the previous sub-section). For the Manitoba tributaries all the runoff would essentially occur in unison due to the rain falling just after completion of snowmelt. Estimation of incremental runoff from the two major spring storms was done by examining incremental runoff coefficients at the top of existing forecasting relationships. Care was taken so as not to exceed reasonable limits. For U.S. tributaries, incremental runoff was estimated from examination of rainfall runoff for 1950 and 1979. Incremental runoff was increased beyond what had been observed in these events, to account for the greater inputs of the HPRF and for possible frozen ground effects which were not included in the peak generation formula. Total runoff for the HPRF was in the 7 to 8 inch range compared to the 4 to 5 inch range for 1997.

e) Time Distribution of Runoff

Unit hydrographs based on runoff for fast melt events such as 1969 and 1979 were used as a starting point to convert the incremental storm runoff to daily flows for each sub-basin. The hydrographs were steepened somewhat to account for the faster response of heavy rain falling on a relatively flooded landscape and for the higher velocities of the tributaries.

f) Assiniboine River Natural Contribution

While the Assiniboine River is only one of many tributaries of the Red River, it deserves particular attention due to its size and due to the fact that it joins the Red River right in the City of Winnipeg. It's flows cannot be controlled by the Red River Floodway but are controlled by the Portage Diversion and, to some extent, the Shellmouth Reservoir. During the 1997 flood peak in Winnipeg, flows on the Assiniboine River were reduced to 800 cfs at Winnipeg.

Selection of the Assiniboine River contribution for a major flood at Winnipeg must be done with caution so that the assumptions with respect to the causal flood parameters follow a plausible meteorological scenario. Floods on specific watersheds such as the Red River usually develop due to a concentration of precipitation over one geographic area, with repeated storms traversing the same region. It is therefore unlikely that causal flood parameters would be extreme over both the Red River and Assiniboine River watersheds for any given spring event. Weather systems simply are not large enough to produce very heavy precipitation over the entire area. If extreme inputs are used for the Red River Watershed south of Winnipeg, then it is very unlikely that they will also be extreme for the Assiniboine River Watershed, except perhaps for the downstream area from Brandon to Winnipeg.

There is no reliable record of coincident major floods on the Red River and the Assiniboine River. A "major" Assiniboine River flood is herein considered as one producing a natural flow contribution to the Red River in excess of 30,000 cfs. A historical researcher of floods has suggested that the 1826 and 1852 Red River floods may have had a 40,000 cfs to 50,000 cfs contribution from the Assiniboine River (Rannie, 1998). This is based on reports of overbank flows between Portage la Prairie and Whitehorse Plains (near St. Francois Xavier). These high flow estimates may not be accurate since the natural bankfull capacity of the Assiniboine River is only 15,000 cfs in this area. Significant flooding and overflows would have been observed even if the peak flow at Portage la Prairie during these events had been little more than 23,000 cfs, as it was in 1923 and 1969. A Manitoba Water Resources Branch report (Morris, 1955) describes overflows of the Assiniboine River in 1923, when the recorded peak at Headingley was less than 21,000 cfs. Such overflows are cited for even smaller events due to ice jams downstream of Portage la Prairie. Despite diking, significant overflows occurred in this area in 1969, the year before the Portage Diversion went into operation. The Headingley peak in 1969 was 21,000 cfs. It is furthermore unknown whether the peaks on the Red and Assiniboine rivers were coincident in 1826 and 1852. If not, the contribution to the Red River crest at Winnipeg could have been even less. It is also noted that the large flat floodplain of the Assiniboine River between Portage la Prairie and Winnipeg attenuates Portage la Prairie crests under natural conditions.

The Assiniboine River has produced only two floods with natural peak flows in excess of 22,000 cfs at Headingley this century, in 1974 and in 1976. Large floods are uncommon due to the topography and soils in the watershed, which are conducive to relatively low runoff coefficients. The total natural Assiniboine River contributions to the Red River, considering floodplain storage from Portage la Prairie to Winnipeg and La Salle River overflows as outlined in an Assiniboine River report (PFRA, 1952), were 26,000 cfs in 1974 and 40,000 cfs in 1976. The 1976 Assiniboine River flood was generated in upstream portions of the watershed and occurred well after the Red River crest, contributing less than 20,000 cfs to the crest at James Avenue in Winnipeg. The odds of coincident major floods on the Red and Assiniboine rivers are therefore very low based on observations as well as on the meteorological considerations discussed earlier.

The portion of the Assiniboine River downstream of Brandon, including the Souris River downstream of Souris, frequently produces an early peak at Portage la Prairie. The highest such peak this century occurred in 1974, resulting in a 26,000 cfs contribution to the Red River. Causal parameters for this downstream portion of the Assiniboine River could be high for a major Red River flood due to its proximity to the Red River. With the delayed melt pattern for northerly portions of the Red River, as postulated in the HPRF, it is quite conceivable that an early peak of this magnitude could contribute heavily to the natural flood peak at Winnipeg. In 1974, this early peak on the Assiniboine coincided perfectly with the crest on the Red River in the Winnipeg area.

Based on the above considerations, the Assiniboine River natural contribution to the HPRF therefore was set at 26,000 cfs at Headingley including the local inflow from Portage la Prairie to Winnipeg. Associated overflow to the La Salle River, based on the previously noted PFRA report, was 1500 cfs.

g) Channel Routing

The hydrographs of total daily flows for each sub-basin, based on the HPRF input scenario, were routed down the main channel of the Red River using two methods.

The first was the Muskingum routing method, which was calibrated from Halstad to Winnipeg using 1997 flood data. This method has been used operationally from Emerson to Winnipeg for several decades. Some adjustments to the routing parameters were made, based on the experience of the 1979, 1996 and 1997 floods.

The second routing method was the Danish Mike ll model calibrated on the Red River from Grand Forks to Lake Winnipeg by the consultant Klohn Crippen, hired by the IJC Red River Basin Task Force. This model was calibrated on 1997 flood data and verified on 1979 and 1996 floods. The Model was run with HPRF inputs from Grand Forks to the Floodway Inlet. It was not run up to James Avenue due to incomplete calibration through the City of Winnipeg for major natural flows and the lack of time to do further calibration work.

h) Results

Peak discharges at the Floodway Inlet and at James Avenue obtained from the HPRF flood routings are shown in Table 5.

Table 5

HPRF Flood Peaks For Two Routing Procedures

	HPRF Peak Discharges (cfs)	
	Floodway Inlet	**James Avenue**
Mike 11 Routing	289,000	*325,000
Muskingum		
- 1997 Routing Parameters	249,000	289,000
- Scaled-up Parameters	229,000	265,000

*Estimated by adding Inlet peak to incremental flow from scaled-up Muskingum ie. 289,000 + (265,000 – 229,000)

The scaled-up Muskingum routing parameters were obtained by incrementing the storage parameter K by an amount similar to the difference between the values obtained from the 1979 and 1997 calibrations. It would appear logical that the greater floodplain of the HPRF would be associated with a greater attenuation of the mainstem crests.

The difference of 60,000 cfs between the MIKE 11 routed flood and the Muskingum (scaled-up) is quite significant. Either the Muskingum is over-estimating attenuation due to the floodplain or MIKE 11 is overly efficient in moving the flows. While Muskingum is a relatively simple method it has worked well for flow routing of past floods. The storage factor K needed to be raised somewhat going from the 1979 to the 1997 flood calibrations. It is difficult to believe that it would not be somewhat greater again for the HPRF. Using 1826 modeled river levels as a guide, it appears that the flooded area for the HPRF would be at least 40 percent greater than for 1997.

The MIKE 11 model has significant advantages including the use of physical data (cross-sections) to estimate flood storage. Extrapolation of a one-dimensional dynamic model to much higher flows is nevertheless subject to considerable uncertainty according to some experienced hydraulic modelers in Canada and the United States. Calibration of these models is quite complex and involves many decisions and representations of hydraulic processes. The model can be made to reproduce specific floods quite well but may require significant changes for much bigger or smaller events.

It is impossible to say which of the modeled HPRF peak discharges in the Winnipeg area represents the best estimates based on the generated inputs. Due to the very limited experience with MIKE 11 on the Red River, use of this estimate without any regard to the established trends of the Muskingum seemed a little extreme. The Muskingum results using the 1997 routing parameters were therefore used as a compromise.

7. Adjustment of Formula Generated Floods Based on HPRF

The formula used to generate peaks, given in section 5(b), works quite well for flood magnitudes up to the 1997 level. However, it appears to overestimate natural peaks at Winnipeg for greater floods. The parameters used for the HPRF resulted in a formula peak of 355,000 cfs. The detailed HPRF approach with flood routing for the same inputs produced a peak of 289,000 cfs at James Avenue. The difference stems from the relative simplicity of the formula, which does not fully account for the increased floodplain storage of major floods.

Adjustment of formula generated peaks above the 1997 natural peak of 163,000 cfs was done using a sliding scale which duplicated the adjustment required at the HPRF level. The equation is as follows:

$$\text{Formula Peak Reduction (cfs)} = 0.344\,(FP - 163{,}000)$$

Where FP is a formula generated peak

This equation causes the greatest reduction for the largest peaks. The reductions become increasingly less for smaller peaks with no reduction for peaks of 163,000 cfs or less. Of the 2000 generated peaks, 34 were adjusted based on this method.

8. Review of 2000 Generated Natural Peaks

A list of the 34 generated natural floods which were greater than the 1997 flood is shown on Table 6. These included the adjustments discussed in Section 7.

Table 6

Red River at James Avenue, Winnipeg
Generated Flood Peaks Greater than 1997 Natural Peak

Year	Peak (cfs)	Year	Peak (cfs)
1349	306,000	1362	182,000
398	289,000	1033	182,000

Table 6 continued

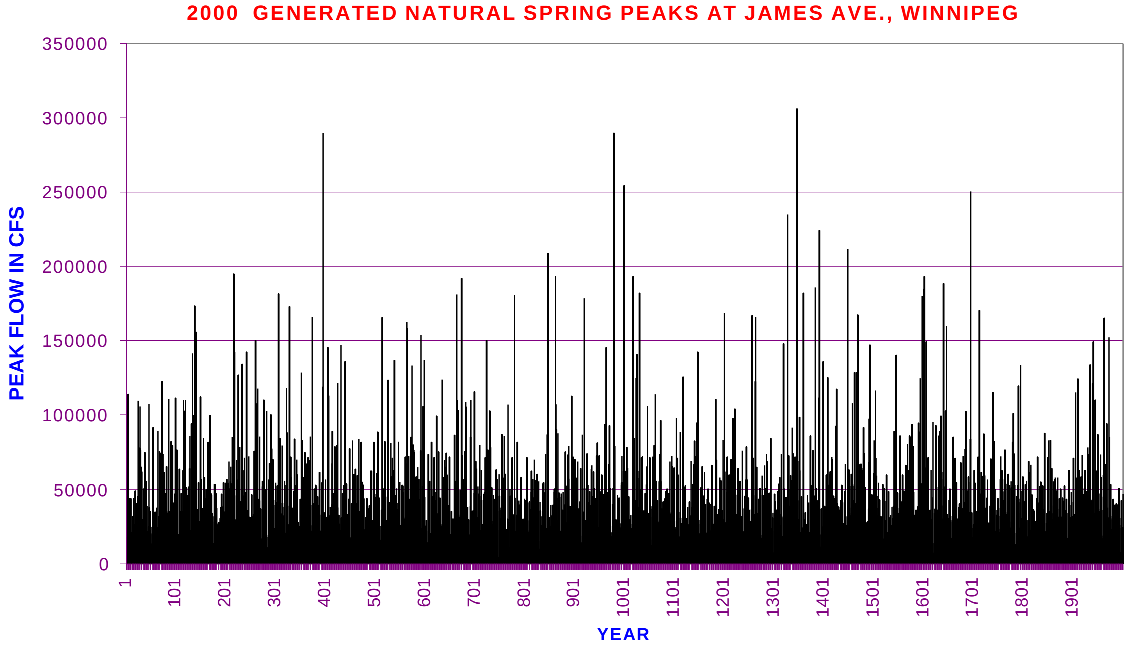
Red River at James Avenue, Winnipeg
Generated Flood Peaks Greater than 1997 Natural Peak

Year	Peak (cfs)	Year	Peak (cfs)
982	289,000	309	182,000
1002	254,000	1033	182,000
1698	250,000	309	182,000
1330	235,000	666	181,000
1394	224,000	782	181,000
1451	212,000	1600	180,000
850	209,000	922	179,000
219	195,000	331	173,000
864	194,000	141	173,000
1605	193,000	1715	170,000
1020	193,000	1203	169,000
676	192,000	1471	167,000
1642	189,000	1266	166,000
1386	186,000	517	166,000
1602	185,000	1965	165,000

The year of the flood is of little significance and is shown only to give a sense of the temporal aspect of the randomly generated floods.

The 2000 generated natural peak discharges including adjustments are shown on Figure 9.

Figure 9



A review of the 2000 generated spring flood peaks following adjustments based on the HPRF reveals the following for the Red River at James Avenue in Winnipeg:

i A total of 34 natural floods greater than that of 1997 were generated, i.e. once every 59 years on average. This compares well with data and anecdotal information from 1776 to 1999, where floods of this magnitude have occurred four times or once every 56 years on average.

ii Six floods exceeded the 1826 estimated peak of 225,000 cfs.

iii Three floods had a peak of 289,000 cfs or greater, the largest being 306,000 cfs.

A frequency analysis of the 2000 generated peaks was performed using the Log Pearson Type 3 method used by many agencies. The peaks for selected return periods are shown in Table 7.

Table 7

Natural Peaks – Red River at James Avenue

Return Period (Years)	**Peak (cfs) Log Pearson 3**
1000	295,000
500	245,000
200	200,000
100	170,000
50	150,000
33	135,000
20	110,000

9. Flow Components in the Winnipeg Area

Natural flood peaks at James Avenue in Winnipeg are of general interest and may be required to determine natural stages for operation of flood control works. However, the source of flows producing the natural peaks is of vital interest for design purposes such as determining the location and required capacity of control works and their effectiveness in reducing the peak flows in the City of Winnipeg.

The following natural flow components are of particular interest due to their proximity to major flood control works and/or the City of Winnipeg.

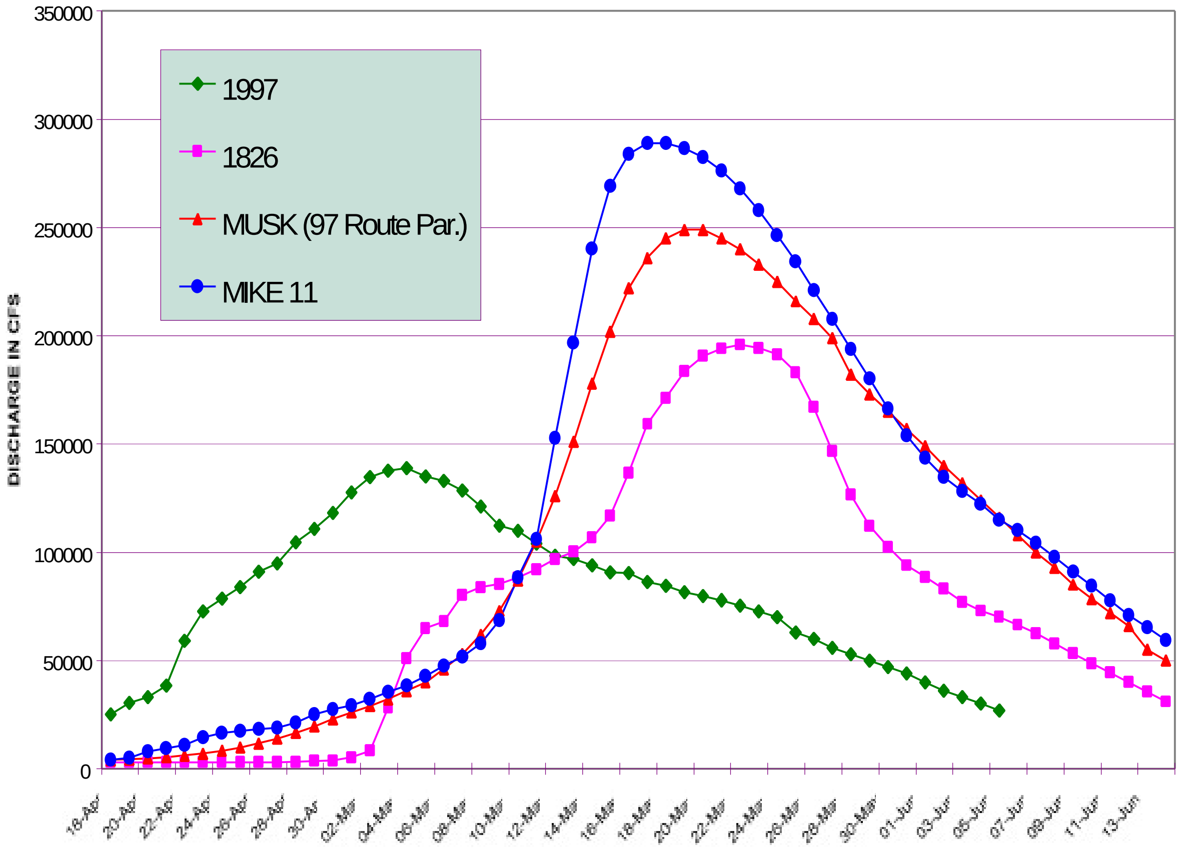
Red River upstream of Red River Floodway
Assiniboine River at Portage la Prairie
Assiniboine River at Headingley
La Salle River at St. Norbert

Sturgeon Creek at St. James
Seine River at Grande Pointe
Winnipeg Area Local (Omand's, Truro, etc.)

Flows of the Red River upstream of the Floodway Inlet are of particular interest because they are by far the largest component and present the main threat to the City of Winnipeg. Factors such as the rate of rise of the flow hydrograph, the duration of flows above critical threshold values etc may be of considerable interest for design in addition to the peak flow. Discharge hydrographs above the Floodway Inlet for the HPRF are shown in Figure 10, together with observed flows for 1997 and estimated flows for 1826.

Figure 10

1997, 1826 and HPRF FLOWS – RED RIVER ABOVE FLOODWAY INLET



The 1826 flows at the Inlet were estimated from river observations taken at the Forks in Winnipeg by Francis Heron of the Hudson Bay Company (R. H. Clark, 1950), with allowance for Assiniboine River and local flow components. The HPRF flood hydrographs are shown for the two methods of flood routing described in Section 6(g), the Muskingum and MIKE 11 methods. The Muskingum flows are those based on the routing parameters, which produced good results for the 1997 flood.

Computation of natural flows at Headingley requires an accounting of floodplain attenuation as well as overflow to the La Salle River. Curves developed by W.A. Cook in 1962 based on a previously cited PFRA report were used. Local flows from Portage la Prairie to Headingley were added. La Salle River flows are a combination of watershed flows and overflows from the Assiniboine River.

The magnitude of flows on the lower Assiniboine River and other local flow components contributing to the peak at James Avenue may be poorly related to the magnitude of flows on the Red River at the Floodway Inlet. Timing factors are critical and there may be significant differences in runoff magnitudes due to spatial variability of causal parameters. For design purposes, however, it may be assumed that the local flow components will increase with the magnitude of the natural flood peak at James Avenue. As discussed earlier, the Assiniboine River downstream of Brandon, the Souris River downstream of Souris and particularly the local streams in the Winnipeg area would in most cases be subjected to the same storm systems giving rise to the major flows on the Red River at the Floodway Inlet.

The natural flow components in the Winnipeg area were estimated for various flood magnitudes at James Avenue, based on recorded data, estimates from 1826 and HPRF floods, and the considerations discussed above. The flow components for the Assiniboine River and smaller streams given in Table 8 are not necessarily spring crests but rather the estimated contribution at the time of the crest at James Avenue.

Table 8

Natural Flow Components (cfs) in the Winnipeg Area
For Red River Design Floods

Red River James Ave. Peak	Assiniboine R. Portage la Prairie	Assiniboine R. Headingley	La Salle R. St. Norbert Total Flow	Sturgeon Creek St. James	Seine River Grande Pointe	Winnipeg Local	Red River Above Floodway
295,000	29,000	26,000	10,000	3,000	2,500	1,100	252,400
245,000	27,000	25,000	8,000	2,500	2,000	900	206,600
200,000	25,000	24,000	5,000	2,000	1,500	700	166,800
170,000	23,000	22,000	4,500	1,800	1,200	600	139,900
150,000	20,000	20,000	4,000	1,600	1,000	600	122,800
135,000	18,500	19,000	3,500	1,400	800	500	109,800

10. Effects of Wind on Peak Discharges

Strong south winds over the vast flooded area of the Red River Valley during major floods could cause a northward surge of water due to the frictional drag, causing a temporary increase in discharge. This could cause an increase in the peak discharge for major floods if such winds were to occur within a period of about five days before to five days after the wind eliminated crest. Computation on the possible effect of wind on water levels at the Floodway Inlet have been computed in a previous study (Kuiper, 1998). These wind set-ups were converted to flows using discharge relationships for the Red River Control Structure and the Red River Floodway.

The increase in inflow is variable, depending on the flood magnitude. For this exercise, computations have been done for one flood magnitude only; that relating to a river stage of 778 feet at the Floodway Inlet. This is the maximum level that existing control works can withstand.

Estimates of the increase in peak discharge at the Floodway Inlet due to wind are shown in Table 9. Wind information was obtained from Environment Canada (Hopkinson, 1988). It has been estimated that the strong south winds would blow for a period of 12 hours, as is often the case. The wind data for a 12-hour duration is the maximum for any day during the month of May. This was reduced by a factor of 0.6 to account for the reduced likelihood of such winds occurring during a given 10 day high water period.

Table 9

Increase in Peak Discharge Due to South Winds
Red River at Floodway Inlet – Stage of 778 feet

Return Period (years)	Month of May 12-Hour Duration Wind Speed (mph)	Wind Reduced To 10 Days (mph)	Red River At Floodway Inlet	
			Level Increase	Flow Increase
2	15	9	0.3	3,200
5	30	18	1.2	12,600
10	40	24	2.2	23,100
20	48	29	3.3	34,600

The increases in flow are quite significant, especially for return periods of 10 and 20 years. These additional flows have not been included in natural flow estimates shown on Tables 5-8. Caution should be exercised in the use of these wind induced incremental flows. They are likely over-estimated, as the relatively shallow floodplain would not allow for a free return flow of water at lower depths, as assumed in the Zuider Zee formula used by Professor Kuiper. Also, inclusion of incremental wind related flows greater than the 2-year return period value would increase the return period of the resultant peaks. It would nevertheless seem prudent to use some incremental wind flows as a margin of safety for design purposes. The five year return period value is recommended for floods greater than that of 1997.

11. Controlled Flow Considerations

The Red River Floodway, Portage Diversion and Shellmouth Reservoir have been operated since 1969 to reduce flood peaks on the Red River and the Assiniboine River. During this time it has been found that Shellmouth Dam has little effect on many flood peaks in the City of Winnipeg due to inopportune timing. Because of the northerly location of the upper Assiniboine River, runoff tends to start late and then takes nearly two weeks to reach Winnipeg, by which time the crest has often passed the City. The Red River Floodway and the Portage Diversion have been highly effective in reducing crests in Winnipeg. However, the 1997 flood stressed the flood control system and served as a reminder that the City of Winnipeg is not protected for floods significantly larger than that of 1997. The adequacy of the flood control system is being reviewed under auspices of the International Joint Commission.

Table 10 shows the Red River Floodway capacities which would be required to protect the City of Winnipeg from the floods magnitude generated in this report. It is based on the following assumptions:

i The diking system in the City of Winnipeg would continue to have a capacity of 80,000 cfs (24.5 feet) at James Avenue.
ii The flow on the Assiniboine River would be controlled to the maximum possible with the existing Portage Diversion capacity of 25,000 cfs. Headingley flows would consist only of local flows downstream of Portage la Prairie at the time of the crest in Winnipeg.

iii The West Dike extending from the Red River Floodway Control Structure to the Brunkild area would be raised sufficiently to prevent by-pass flows into Winnipeg via the La Salle River

iv There would be no backwater from the Floodway return flow near Lockport to the City of Winnipeg. Such backwater is, however, likely to develop for the largest floods, reducing the flow capacity through the City. This, together with possible backwater from bridges, would result in levels considerably higher than the 1997 peak of 24.5 feet at James Avenue for 80,000 cfs. Dikes in the City would need to be raised or additional Floodway capacity would be needed. Quantification of these factors was beyond the scope of this report.

v Wind effects would not significantly affect the peak flow, as was the case in 1997. If desired, incremental flows due to wind may be added to the required Floodway discharge capacity as deemed appropriate.

Table 10

Design Floods Under Controlled Conditions

James Avenue Natural		Portage Diversion (cfs)	Headingley Controlled (cfs)	James Avenue Controlled (cfs)	*Floodway Discharge (cfs)
Return Period (years)	Flow (cfs)				
1000	295,000	25,000	3,500	80,000	190,000
500	245,000	25,000	3,000	80,000	140,000
200	200,000	25,000	3,000	80,000	95,000
100	170,000	23,000	3,000	80,000	67,000
50	150,000	20,000	3,000	80,000	50,000

*At the present time, the Red River Floodway cannot convey more than 85,000 cfs without modifications (Gonzalez, 1999).

12. Recommendations

The results of this study demonstrate the vulnerability of the City of Winnipeg to major floods. Unless other measures are undertaken the capacity of the Red River Floodway needs to be increased by at least 55,000 cfs to handle the 500 year flood, and by at least 105,000 cfs to cope with the 1000 year flood. These values could be even larger depending on the amount of backwater from Lockport and possible backwater from bridges. They could be somewhat larger yet if wind effects on peak flows at the Floodway Inlet are included. Increased dike elevations within the City would decrease the required enhancement of the Floodway.

This study was done relatively quickly based primarily on collated data already available from flood forecasting studies. Given time and resources, a more thorough approach to computation of design floods could be taken, by applying a suitable hydrologic model to long time series of hydrometeorlogic data. There is some doubt, however, whether such an approach would result in a significant improvement in accuracy and whether the large amount of additional work would be warranted.

Effects of winds on peak flows and water levels for floods of 1997 magnitude or greater should be more thoroughly investigated, preferably using a two dimensional hydrodynamic model. Backwater from the Floodway return flow to Winnipeg and possible backwater from bridges in the Winnipeg area should be further investigated. These factors must be included in design scenarios for enhanced flood control works.

It is recommended that the possibility of a major rainfall generated flood, not necessarily a spring event, be investigated. The record summer floods of 1993 in the upper Mississippi and Missouri River Watersheds demonstrates the danger posed by a series of extreme rainfall events. Climate change could allow such conditions to be repeated somewhat further north in the Red River Watershed.

The frequency program should be modified to handle up to 2000 years, so that a Log-Pearson Type 3 analysis of the peaks generated in this study can be plotted.

The results of this study are available as input to the broader “Risk Analysis Study – City of Winnipeg Flood Protection” now underway by KGS Group consultants of Winnipeg, under auspices of the International Joint Commission. Additional information ensuing from this study, such as design discharges for other return periods, are available upon request.

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Acknowledgements:

The author wishes to acknowledge the assistance of Anderson Premdas, Forecast Systems Technologist of Manitoba Water Resources, who performed the random number generation and helped assemble an electronic version of this report. Rick Bowering, Head of Surface Water Management of Manitoba Water Resources reviewed the report and provided helpful comments. Computer Graphics of Manitoba Natural Resources drafted some of the figures. Word processing was done by Joyce Maynard, Manitoba Water Resources.