A SURVEY OF
HYDROCLIMATE, FLOODING, AND RUNOFF
IN THE RED RIVER BASIN
PRIOR TO 1870

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Prepared for the Geological Survey of Canada

September, 1998

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The writer is grateful to Betty Harder and Maggie Fredrickson for their assistance in the preparation of the manuscript, to Weldon Hiebert for drafting the figures, and to the staff of the Manitoba and Hudson's Bay Company Archives.

19th CENTURY HYDROCLIMATE OF RED RIVER BASIN

INTRODUCTION

The 19th Century was the culmination of a 400-500 year period of generally deteriorated climate known as the Neoboreal, or Little Ice Age during which widespread areas of the northern Hemisphere, and the mid-latitudes in particular, experienced cooler and wetter conditions (Lamb, 1982). Although various writers have placed different temporal boundaries on the Little Ice Age, most consider it to have extended until the late 19th Century. Thus the period of most of the fur trade era, the establishment and growth of the Red River Settlement and early Winnipeg, and the beginning of instrumental records of climate and streamflow in the Red River basin, belonged to a different climatic regimen, involving changes in the predominant circulation patterns, different climatic normals, and presumably, different responses in the natural and human phenomena dependent upon them.

For several reasons, the Red River might be expected to be particularly sensitive to changes in climate since these are most clearly expressed at the peripheries of bioclimatic regions where relatively small changes may produce major shifts in boundaries. The drainage basin of the Red River is in such a region. The basin lies astride the transition from humid forested regions in the east to subhumid and semiarid conditions to the west, receiving runoff from both. This difference between these regions might have been even more pronounced under the natural vegetation of the pre-settlement period. The basin approximates the modern average winter position of the "Arctic Front" and is in the normal path of storm tracks crossing the northern Great Plains from their origins in the lee of the Rocky Mountains, particularly those from Alberta. The runoff ratio (runoff÷precipitation) for the basin is very low, generally only 3-7% of precipitation. Thus, averaged over a long period, evapotranspiration accounts for more than 90% of precipitation. The basin is, then, particularly sensitive to even small changes in runoff ratio caused by changes in precipitation, evapotranspiration, and/or land surface condition.

From an analysis of floodplain sediments in small valleys tributary to the upper Mississippi River, Knox (1993) concluded that "modest climatic changes" (1-2EC in mean annual temperature and 10-20% in mean annual precipitation) caused "large and sometimes abrupt adjustments in both magnitudes and frequencies of floods in the Upper Mississippi Valley." (p. 432). Ashmore and Church (in press) suggested that future climate change would produce an 'amplification effect' whereby future precipitation changes would cause disproportionately larger changes in discharge, that the changes in higher magnitude flood flows would be disproportionately greater than changes in mean flow, and that streamflow in regions with very low runoff ratios would be most sensitive to climate change. The effect of this 'amplification' would be to shift the flood frequency curves upward and to cause them to diverge, i.e. the effect would be greater at the upper regions of the curves. Comparing a wet period (1941-1960) and a dry period (1921-1940), they concluded

> The eastern prairies...seem to be an area of highly sensitive flood flow regimes. In this region (whereas) mean annual flow increases between 1920-1940 and 1940-1960 were of the order of 30% in the prairie source streams, mean annual flood increases are typically 50-100%. The upward shift in flood frequencies during wetter periods is proportionally greater in the eastern prairies than in the mountain-source rivers of the prairies... Historic records in the eastern prairies show a marked sensitivity to climatic fluctuations, with large reductions in streamflow and maximum flows during warmer and drier years. Warmer winters will reduce snow accumulation leading to reductions in magnitude of the annual snowmelt flood. During historical warmer periods the size of the 20 year flood has decreased by a factor of 2-4 in large prairie streams, indicating considerable climatic sensitivity. (Ashmore and Church, in press)

Ashmore and Church were discussing the effects of future climate warming on streamflow but the argument could be applied equally in reverse, i.e. for changes projected backwards in time, and from warmer to cooler conditions.

Runoff in the basin is strongly concentrated in the freshet period; about 60% of average runoff occurs in April-May, rising to about 70% if June is included, and all modern floods of consequence have occurred within the snowmelt period. Although each flood has its own distinct features, the following are considered to be typical factors in the formation of large spring floods:

- An abnormally wet late summer and autumn which saturates the ground prior to freezeup.

- Severe cold and freezeup prior to the first significant snowfall to permit frost to penetrate deeply.

- A cold winter with heavy snow over the entire watershed and minimal thawing, producing a heavy standing snowpack at the end of winter.

- A late spring which slows the release of snowpack water, followed by a rapid transition from sub-freezing to melting temperatures.

- Above normal late-winter precipitation near the breakup period or during the melt period. This may occur as a heavy late winter snowfall (as in 1966 or particularly 1997) or significant rainfall during the period of flood formation (as in 1950 or 1979).

In flood frequency analysis, it is important that the data be drawn from as homogeneous a time series as possible, yet all of these causative factors are subject to climate change and might be expected to have shifted significantly between the 19th and 20th Centuries. Since the 1950 flood intensified interest in the hydrologic history of the

Red River, much has been learned about the nature of the 19th Century late Little Ice Age climate of the Great Plains region of the United States and Canada but this growing body of literature has not been incorporated into the understanding of the nature and causes of 19th Century floods and the general hydrologic environment in which they occurred. In Part A of this report, the literature relating to the 19th Century climate of the Red River basin region will be surveyed to provide such a context.

Instrumental records in Winnipeg, although the longest in western Canada, began only in 1872. Fortunately, historical materials available in the Manitoba and Hudson's Bay Company Archives and other documents of the period provide abundant first-hand observations of climatological and hydrologic phenomena from 1793 onward. These sources have been used in studies of the largest 19th Century floods (eg. Canada Department of Resources and Development, 1953a) and selectively for other purposes (eg. Allsopp, 1977; Blair and Rannie, 1994; Rannie, 1983,1990) but no comprehensive survey of 19th Century weather has been compiled. Also, existing lists of 19th Century floods have generally been based on incomplete surveys of the archival records (eg. Miller and Frink, 1984, Table 4 in Part B) and, in consequence, a number of events have been overlooked. As Kemp (1982) concluded:

> [These sources] provide the only available documentary material of any kind in much of central North America for the period preceding the European agricultural colonization of the plains and, if allowance is made for the imprecision and subjectivity associated with such records, they can provide an insight into the weather and climate of the area, as well as an indication of their impact on the activities of those who lived and worked there. (Kemp, 1982, p. 40)

The problem of incorporating historical data into flood frequency analysis has been considered by Gerard and Karpuk (1979), among others.

> In many instances...hydrometric records cover only a relatively short period of time. The probability estimates of rarer events is then poor. Such estimates could be significantly improved by the consideration of historical data...other than the standard hydrometric data. The effort to collect such historical data is usually limited. This is because only historical information on the most extreme floods is usually used quantitatively. Any other historical data that can be collected are generally qualitative and of varying reliability and therefore are difficult to incorporate into quantitative analysis. (Gerard and Karpuk, 1979, p. 1153).

For the Red River, only the three largest events of the pre-instrumental record (1826, 1852, 1861) are normally used in frequency analysis because their peak stages and discharges have been estimated with tolerable accuracy. Other significant events have not been included, probably because, as Gerard and Karpuk observed,

> ...it is difficult to allocate a rank and record length to each reported peak...Because of this only the one or two highest stages in the historical record are commonly utilized in estimating high water probability distribution, the major emphasis being placed on hydrometric records for which both a rank and record length can usually be simply allocated. Much potentially useful information in the historic record is therefore rejected. (Gerard and Karpuk, 1979, p. 1164).

The importance of including the largest historical events in flood frequency analysis has been demonstrated by Booy and Morgan (1985). Their analysis showed, among other things, a dramatic decrease in the Return Period for design floods on the Red River when the two largest historic floods were added to the recorded flow series. Their conclusions, however, also assume that the historic floods were drawn from the same frequency distribution as the recorded series.

The writer has compiled a database of archival materials consisting of approximately 19,000 entries from 1793 to 1870. Although a large number of these are not in themselves informative (eg. references to “cold” in January), taken collectively they do provide a portrait of the nature of the seasons in the Red River Valley for the majority of years in the 19th Century prior to 1870. More important for the purposes of this report are the abundant direct references to river conditions, particularly those which are unusually high or low, and the weather conditions which produced them. In Part B of the report, these materials will be used to reconstruct the flood history of the Red and Assiniboine Rivers in more detail than has been done in previous studies. Part C will extend the analysis to non-flood years by inferring the general runoff conditions in the basins for as many years as the data allow.