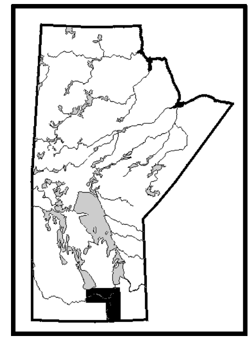
GS-33 CONTRIBUTIONS OF DENDROCHRONOLOGY TO FLOOD HAZARD ANALYSIS IN THE RED RIVER BASIN, MANITOBA

by S. St. George[1] and E. Nielsen



St. George, S. and Nielsen, E. 2002: Contributions of dendrochronology to flood hazard analysis in the Red River basin, Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 283–286.

SUMMARY

Research conducted by the joint Manitoba Geological Survey–Geological Survey of Canada (MGS–GSC) dendrochronological laboratory in Winnipeg has provided baseline geoscientific data critical to the understanding of past hydroclimatic change in Manitoba and its impact on flood hazards in the Red River valley and local groundwater supplies. The current tree-ring record for the Red River basin extends back to AD 1286 and has been used to construct a flood history for the Red River at Winnipeg that spans the last 350 years. Since AD 1648, anatomical signatures in riparian trees document extreme floods in 1997, 1979, 1950, 1852, 1826, 1762 and 1747. This record implies that the risk of flooding changes over time and therefore, the risks of future flooding for Winnipeg and other communities in the Red River valley might be better estimated using techniques that account for non-stationairity and non-randomness introduced by climatic and landscape changes. Tree-ring estimates also suggest that while southern Manitoba's hydroclimate has been relatively stable over the last 200 years, conditions prior to permanent Euro-Canadian settlement were much more variable and persistent. Finally, statistical modelling suggests that, during the 20th century, hydraulic groundwater heads near Winnipeg had a greater range prior to the 1960s, most prominently during an interval of lowered groundwater levels between 1930 and 1942.

INTRODUCTION

In 1999, the Manitoba Geological Survey (MGS) and Geological Survey of Canada (GSC) established a joint dendrochronology laboratory at the MGS office in Winnipeg. This facility has supported ongoing research into past climatic change and its influence on natural hazards in Manitoba. Although researchers at the laboratory have been involved with a number of ancillary projects, particularly those related to archeological dating, work has focused mainly on providing baseline scientific data to better understand flood hazards for communities in the Red River valley. This report summarizes recent projects related to Red River flooding as well as long-term climatic variability and change in Manitoba and its impact on local groundwater resources.

DENDROCHRONOLOGY IN THE RED RIVER BASIN

Trees growing in temperate regions can provide a wide range of information related to past environmental change and extreme events, since the annual rhythm of tree growth represents an absolutely dated annual record that can span several hundred or even thousands of years. The current tree-ring network in southern Manitoba includes specimens collected from three main sources. Samples from living trees were collected at 16 sites inside a 100 km long riparian corridor following the Red River. Timbers were recovered from nearly a dozen historical buildings and Euro-Canadian archeological sites, the majority of which were located inside present-day Winnipeg. Lastly, subfossil logs were recovered from alluvial sections (between Emerson and Morris on the Red River and between Portage la Prairie and Winnipeg on the Assiniboine River) that were exposed during low water stages. The combined record for the Red River basin includes 398 crossdated trees and extends from AD 1286 to 1999 (St. George and Nielsen, 2002).

Flood Hazards in the Red River Valley

More than any other large city in Canada, Winnipeg has suffered repeated physical, social and economic injury due to severe flooding. Although Winnipeg largely escaped the "flood of the century" in 1997 without enduring serious damage, the Red River still forced the evacuation of over 28,000 people in Manitoba and had a direct economic impact of roughly $500 million. Similar large floods threatened Winnipeg in 1979 and 1950 and caused extensive damage to the fledgling Red River Settlement in 1861, 1852 and 1826.

Conventionally, the future risk of extreme floods is estimated from the occurrence of such floods in the past. The likelihood of future floods greater than those observed in the historical record is estimated by extrapolation. However, since instrumental flood records are often less than 100 years in length, extrapolated return intervals for large floods

[1] Geological Survey of Canada, 360-1395 Ellice Avenue, Winnipeg, Manitoba, R3G 3P2

are highly uncertain. For example, the flood-frequency curve for the Red River in Winnipeg, originally derived in the 1960s, changed substantially when updated with additional years of data (Burn and Goel, 2001). Furthermore, the flood-frequency approach assumes that flood-generating processes do not change over time and that floods are random in time and space (Baker et al., 2002). These assumptions have been criticized as arbitrary and unrealistic (Klemeš, 1989), especially since flooding is a dynamic process that is often affected by geomorphological, geological and climatic change (Baker et al., 2002). Although these changes can occur very slowly, they may be very significant when considered over the time horizons used in the design of flood protection structures (typically between 100 to 1,000 years).

Estimates of flood risks in the Red River valley can be enhanced by using markers preserved in natural archives, such as trees and lake sediments, that were left by past extreme floods. Paleofloods are floods that occurred in the past that were not recorded by direct or indirect human observation (Baker et al., 2002). Paleoflood hydrology can greatly improve our understanding of local flood hazards by reducing the uncertainty in estimates of long return-period floods and by adding a historical component to flood hazard assessment (Baker et al., 2002). Extreme Red River floods (on the order of the 1950 flood or larger) cause bur oak (*Quercus macrocarpa* Michx.) growing along the river to develop distinctive anatomical markers (Fig. GS-33-1; St. George and Nielsen, 2000; St. George and Nielsen, in press) that can be used to identify older and previously unknown Red River floods.

Tree-ring evidence provides a record of flooding for the lower Red River basin (LRB), between Winnipeg and Morris, that extends from AD 1648 to 1999 (St. George and Nielsen, in press). During that period, anatomical signatures provide evidence for seven high-magnitude floods: 1997, 1979, 1950, 1852, 1826, 1762 and 1747. Although the five most recent flood rings are coincident with known high-magnitude floods, signatures in 1747 and 1762 predate local instrumental and historical flood records and represent previously unknown floods. Despite comments by an early fur trapper that suggests flooding was unusually extensive in 1776 (Ross, 1856), we find no tree-ring evidence for such an event. The flood signature record for the LRB contains three periods during which the Red River generated multiple high-magnitude floods: the mid 1700s, the mid 1800s and the latter half of the 20th century. Conversely, the record also indicates that the LRB experienced prolonged intervals with little to no extreme flooding, particularly between 1648 and 1746, 1763 and 1810, and 1862 and 1949. Tree-ring evidence also suggests that the Red River flood of 1826 was clearly exceptional and was the most severe flood that occurred in at least the last 352 years. Subfossil logs collected from river alluvium likely originated from upstream reaches in North Dakota and Minnesota and therefore document flood history in the upstream portion of the basin. Tree-ring records from alluvial oaks span the interval AD 1448 to 1997, and contain anatomical signatures for nine floods: 1762, 1747, 1741, 1727, 1726, 1682, 1658, 1538

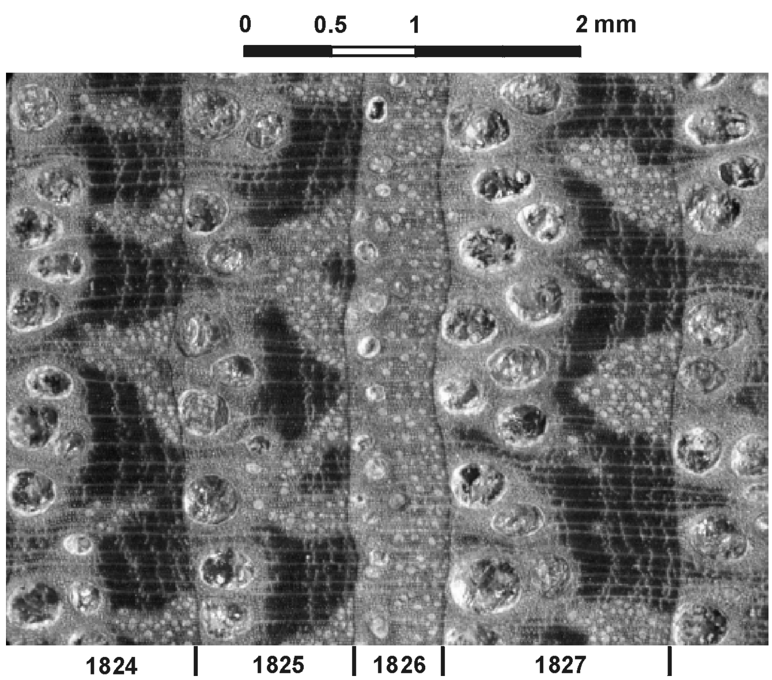


Figure GS-33-1: Flood signatures associated with Red River flooding are characterised by shrunken earlywood vessels. Several flood signatures for 1826 contain anatomical abnormalities, including disrupted latewood and flame parenchyma, that are not present in flood signatures for other years. From St. George and Nielsen (in press).

and 1510. However, since sample depth for the upper basin is relatively low (only five alluvial logs contain flood signatures), this dataset cannot estimate the relative magnitude for upper basin floods.

Flood frequency analysis is based on the assumption that the flood flows are independent and identically distributed random variables (National Research Council, 1999). However, these 'high' and 'low' flood modes in the Red River record, which have extended from several decades to nearly a century, imply that the risk of flooding changes over time. Statistical analysis of the instrumental and historical flood series for the Red River indicate that high flows over the last 200 years have been clustered (Booy and Morgan, 1985) and non-stationary (Burn and Goel, 2001). Therefore, the risks of future flooding for Winnipeg and other communities in the Red River valley might be better estimated using techniques that account for non-stationairity and non-randomness introduced by climatic and landscape changes.

Tree-ring data can also provide additional information about the mechanisms that have contributed to extreme floods in the past. For example, flood signatures present in oaks collected from the Assiniboine River suggest that the two basins, which have dramatically different hydroclimates, flooded simultaneously in 1510, 1538 and 1826. This evidence demonstrates that while synchronous floods are rare, they are certainly possible. The Assiniboine River and Red River floods in 1826 were also coincident with severe frost damage recorded at tree-ring sites across the south-central United States (Stahle, 1990), which implies that unusual spring weather extended throughout central North America.

Long-term Hydroclimatic Change in the Red River Basin

Although intuition suggests that extreme floods would be more common under a wetter climate, specific climatic thresholds leading to shifts in regional flood hazards are difficult to determine. Estimated annual (prior August to current July) precipitation derived from regional bur oak ringwidth indicates that southern Manitoba's hydroclimate has been relatively stable over the last 200 years (Fig. GS-33-2; St. George and Nielsen, 2002). Although this stability was interrupted briefly by pronounced wet intervals in the late 1820s and 1850s, hydroclimatic conditions since permanent Euro-Canadian settlement were much less variable and persistent than those prior to AD 1790. The reconstruction indicates that the Red River basin experienced extremely dry conditions between AD 1670 and 1775, with below normal precipitation occurring approximately two years out of three.

In the past, hydroclimatic change in southern Manitoba has occurred at two distinct temporal and spatial scales. Over the last 300 years, most individual dry years were associated with widespread drought across much of the North American interior. However, longer-term multi-decadal shifts in hydroclimate, such as the AD 1700 dry interval, appear

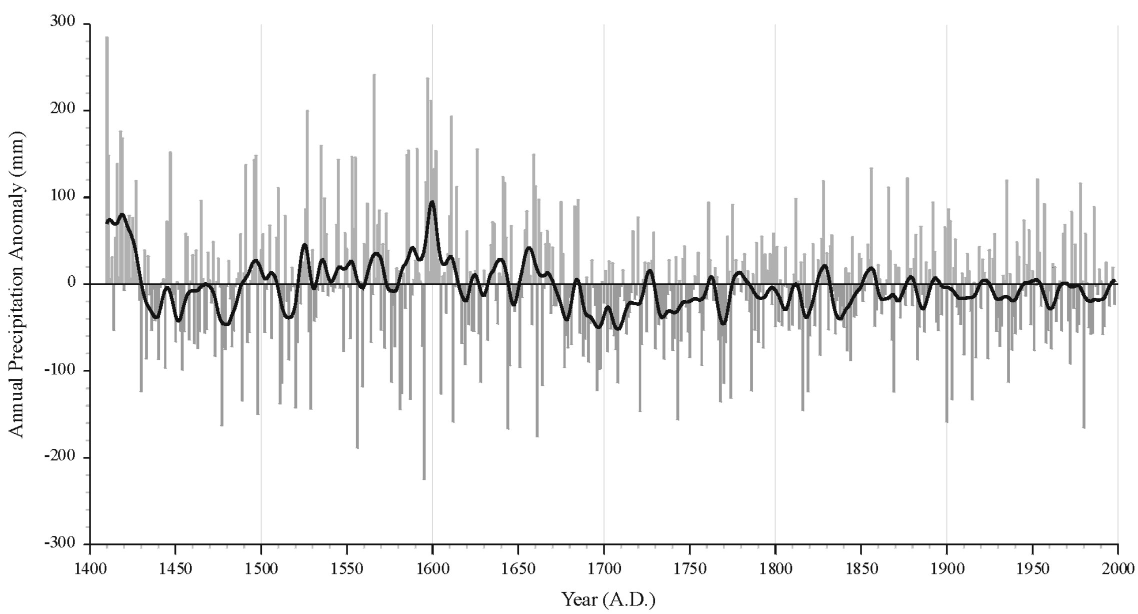


Figure GS-33-2: Reconstructed annual (August–July) precipitation at Winnipeg from AD 1409 to 1998. Units are mean annual precipitation deviations from 1961 to 1990. Black line represents 15-year weighted running mean. From St. George and Nielsen (2002).

to have been restricted to the northeastern Plains. As long-term hydroclimatic change seems to have operated independently of larger-scale droughts, it is possible that the mechanisms driving changes in regional aridity depend on the temporal and spatial scales under investigation. These paleoenvironmental records indicate that natural variation in this region can generate shifts in precipitation regimes that last for several decades and extend over several thousand square kilometres (St. George and Nielsen, 2002). As a consequence, it seems likely that climatic case studies in regional drought and flood planning based exclusively on experience during the 20^{th} century may dramatically underestimate true worst-case scenarios. Past changes in regional precipitation on the order of roughly ten percent that occurred under 'natural climatic' conditions also appear to have exerted a significant influence on regional flood risks, at multi-decadal and centennial time scales.

Estimated Changes in Groundwater during the 20^{th} Century

In Winnipeg, instrumental groundwater records begin in the early 1960s. These records are too short to identify decadal or multi-decadal trends within an aquifer and make it difficult to determine the long-term impact of climatic variation on groundwater usage. G. Ferguson and S. St. George (work in progress, 2002) used a suite of climatic and tree-ring data to estimate historic groundwater levels through most of the 20^{th} century, prior to instrumental observation. This analysis indicates that while hydraulic heads in a shallow semiconfined aquifer are strongly linked to changes in hydroclimatic conditions during the preceding hydrological year, hydraulic heads in deeper hydrostratigraphic units are largely insensitive to climatic forcings at decadal time scales. Hydraulic heads near Winnipeg had a greater range prior to the 1960s, most prominently during an interval of lowered groundwater levels between 1930 and 1942. When compared to the effects of groundwater withdrawals, it appears that natural variations due to climatic variability in hydraulic heads in the Winnipeg area are relatively insignificant, which suggests that usage remains the most important issue related to groundwater management. This project has also demonstrated that the inclusion of non-traditional parameters related to regional hydroclimate, such as tree-ring records, can improve the performance of empirical groundwater models.

ACKNOWLEDGMENTS

C. Bater and E. Carlson served as extremely capable laboratory and field assistants during 2002.

REFERENCES

Baker, V.R., Webb, R.H. and House, P.K. 2002: The scientific and societal value of paleoflood hydrology; *in* Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology, P.K. House, R.H. Webb, V.R. Baker and D.R. Levish (ed.), American Geophysical Union, Washington, p. 1–20.

Booy, C. and Morgan, D.R. 1985: The effect of clustering of flood peaks on a flood risk analysis for the Red River; Canadian Journal of Civil Engineering, v. 12, p. 150–165.

Burn, D.H. and Goel, N.K. 2001: Flood frequency analysis for the Red River at Winnipeg; Canadian Journal of Civil Engineering, v. 28, p. 355–362.

Klemeš, V. 1989: The improbable probabilities of extreme floods and droughts; *in* Hydrology of Disasters, O. Starosolszky and O.M. Melder (ed.), James and James (Science Publishers) Ltd., p. 43–51.

National Research Council 1999: Improving American River Flood Frequency Analysis; National Academy Press, Washington, 132 p.

Ross, A. 1856: The Red River Settlement: Its Rise, Progress, and Present State; Smith, Elder and Co., London.

St. George, S. and Nielsen, E. 2000: Signatures of high-magnitude 19th century floods in *Quercus macrocarpa* tree rings along the Red River, Manitoba, Canada; Geology, v. 28, p. 899–902.

St. George, S. and Nielsen, E. 2002: Hydroclimatic change in southern Manitoba since AD 1409 inferred from tree rings; Quaternary Research, v. 58, p. 103–111.

St. George S. and Nielsen, E. in press: Paleoflood records for the Red River valley, Manitoba, Canada derived from anatomical tree-ring signatures; The Holocene.

Stahle, D. W. 1990: The tree-ring record of false spring in the southcentral USA; PhD thesis, Arizona State University, Phoenix, Arizona, 272 p.