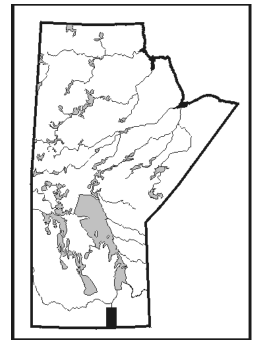
GS-30 RED RIVER FLOODING: EVOLUTIONARY GEOMORPHIC TRENDS AND EVIDENCE FOR MAJOR FLOODS IN RECENT CENTURIES (NTS 62H/W)



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SUMMARY

The Red River flood of 1997 was a major natural disaster that caused immense damage and disruption. But unlike many others disasters, there is much that can be done to reduce comparable damage in the future. Construction of additional dikes and diversions, as well as revised land use and water management practices, may spare residents of the valley a repeat of the damage and disruption they suffered in 1997, but the design of major works on both sides of the international boundary requires a better understanding of the risk. Research on the history, evolution, geomorphology, and stratigraphy of the Red River therefore is urgently required.

For example, was the great flood of 1826, which substantially exceeded the 1997 event, an extraordinarily rare event, or is such a flood likely to recur in coming decades? In as much detail as can be obtained, how did the 1826 event, and other documented floods, compare to 1997? Can the impact of additional great floods that may have occurred in recent centuries be seen in the geological features of the valley? Are climatic or tectonic processes changing the flood risk? Have changes to the landscape over the past century increased or decreased the likelihood of an 1826-magnitude event being repeated?

A research program designed to address these questions has received support from the International Joint Commission, and is now underway, under the co-ordination of the Geological Survey of Canada (GSC) and Manitoba Geological Services Branch (MGSB). Federal, provincial, university and private sector scientists on both sides of the border are co-operating in the effort.

INTRODUCTION

The geomorphology and stratigraphy of the Red River Valley, in addition to controlling the character of flooding, contain information about past flooding, as well as trends that may be changing flood frequency. Following the major flood of 1997, a research program was initiated to enhance understanding of Red River flood history, and the factors that control this flooding. Current efforts to mitigate flood hazard in the Red River Valley will benefit from research that addresses the following questions.

How large can the floods get and how often do large floods occur? The largest documented flood occurred in 1826, and archival sources include a report of an even larger event in 1776. To properly determine the flood magnitude to which the valley should be protected, the 1826 flood needs to be placed in the context of a flood record that extends beyond the period for which instrumental and descriptive written accounts are available. This topic is being addressed by better characterising the 1826 flood from archival sources, and by examining stratigraphic records that span a period that includes the 1826 event, to determine whether floods of this magnitude are rare or recurring.

How has the Red River Valley landscape changed in the past century and a half and have these changes affected the nature of flooding? The natural geomorphology and vegetation of the Red River Valley has been altered since the early 1870s by development of extensive agriculture, as well as construction of drainage channels, roads, and railways. Research is required into the impact this landscape modification has had on flood frequency, as well as changes in the way flooding occurs. To facilitate the comparison between the 1870s and present day landscape, the distribution of grassland, forest, scrub, and wetland in the Red River Valley of the 1870s is being mapped from archived surveyor's records.

Are there geologic processes that may be changing the flood risk? Since the end of the last glaciation, differential postglacial uplift has caused northern Manitoba to rise faster than southern Manitoba. For the northerly-flowing Red River, which follows a very gentle gradient, this uplift has resulted in the loss of valley gradient over time. The significance of this evolutionary trend both hydrologically, for high magnitude flows and geomorphically, for processes affecting the river needs to be established. Furthermore, there is a need to determine whether the river valley cross-section is stable, decreasing from net sedimentation or increasing from net erosion. Trends in climate also may be driving change in flood frequency. For example, the river may still be responding to the cooler, moister climate of the past three to four thousand years, following the several millennia of warmer, drier conditions that were typical of the early to middle portion of the postglacial period.

What are the geological controls that govern the character of the Red River flooding? The northerly-flowing Red River is incised into glacial Lake Agassiz deposits, and occupies a narrow river valley within the flat plain of the much larger Red River Valley. A broad zone of flooding occurs south of the City of Winnipeg where this river valley has an insufficient cross-sectional area to contain high magnitude flows. In contrast, flooding in the Selkirk area does not inundate the surrounding plain because the river valley is larger in cross-sectional area and therefore can contain the entire river flow. Furthermore, flooding is more extensive in northwesterly-flowing reaches immediately upstream from Winnipeg and Morris. A clarification of the geologic factors that control river base level and valley topography in this manner will provide a more fundamental understanding of Red River flooding.

The research program is beginning to address these questions by utilising available published and archival information, and by initiating mapping and stratigraphic investigations of the alluvial deposits and erosional features along the Red River. Following initiation of work a few days after peak flow in 1997, research will continue over a total of three field seasons, prior to completion in the year 2000.

PREVIOUS RESEARCH

The stratigraphy of the deposits that the Red River traverses has been described by Teller (1976), Fenton et al. (1983), and Harris (1997). Nielsen et al. (1993) reported work on Red River alluvial stratigraphy in the City of Winnipeg. The geological history of the Assiniboine River, the understanding of which is required for an interpretation of long-term Red River history, has been interpreted by Teller and Last (1981), Rannie et al. (1989), and Rannie (1996a). Examples of syntheses of research into postglacial climatic history in the region are the works of Ritchie (1987) and Vance et al. (1995). Research on the regional paleoclimate of recent centuries includes the work of Allsopp (1977), Baker et al. (1993), Blair and Rannie (1994), Bryson (1980), Clark (1988; 1989; 1990), Frissell (1973), Gosnold et al. (1997), Heinselman (1973), Kemp (1982), Laird et al. (1996), Rannie (1983; 1990) Rannie and Blair (1995), Stockton and Meko (1983), Swain (1973), Will (1946). In addition, much work on this topic has focused on Devil's Lake, North Dakota, including work reported by Fritz et al. (1994; 1996), Vecchia and Wiche (1997), Wiche (1986), and Wiche et al. (1996; 1997). Published work on the relationship between climate and runoff in the region includes publications by Simons and King (1922), Zaltsberg (1990) and by Gosnold et al. (1998). Archaeological research conducted

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along the Red River that constrains interpretation of flood history includes work by Buchner (1989), Kroker (1989; 1997), Kroker and Goundry (1990; 1993; 1994), Kroker et al. (1991; 1992), and Quaternary Consultants Ltd., (1993). Literature related to interpretation of post-settlement landscape modification includes publications by Archibold and Wilson (1980), Department of the Interior, Canada (1883a; 1883b), Hildebrand and Scott (1987), Kerr (1960), Scott (1996), Warkentin and Ruggles (1970), and Watts (1960). Archival documents that provide information regarding Red River flooding include the writings of Belcourt (1849), Cochran (1832), James (1849), Jones (1836), Pope (1850), Provencher (1849a; 1849b; 1851a; 1851b), and Woods (1850). More recent books and popular publications that include information on Red River flood history include publications by Atwood (1970), Chafe (1973), Coues (1965), Patterson (1970), Pritchard (1947), Pritchett (1942), Robinson (1966), and Upham (1895). Reports describing flood protection works and analysing major Red River floods of this century, with an emphasis on the Canadian side of the border, include those by Booy and Morgan (1985), Calton (1979), Canada Department of Resources and Development (1953a; 1953b), Clark (1950), Heron (1950), Matheson (1947), McLaurin and Wedel (1981), and Rannie (1980; 1996b). Reports describing and analysing major floods, with an emphasis on the US side of the border, include those by Ball (1997), Bluemle (1997), Chandler (1911, 1918), Hammen (1980), Harrison (1968), Harrison and Bluemle (1980), Hartman (1997), Miller and Frink (1984), Nelson (1951), Osborne (1997), Ryan et al. (1993), United States Army Corps of Engineers (1972), United States Geological Survey (1952), Williams (1997), and Zien (1997). Examples of policy-oriented commentary that provides added perspective on the flood problem, as well as work on additional flood-related topics, include reports by Bevacqua (1997), Brigham (1997), International Joint Commission (1997), Krenz and Leitch (1993), Manitoba Water Commission (1998), Mayer (1997), Perkins (1997), and Sando (1997). Popular publications that describe the flood of 1997 include those by Bumsted (1993; 1997), Thomson et al. (1997), and Winnipeg Free Press (1997).

GEOMORPHOLOGY AND SEDIMENTOLOGY

Research on the fluvial geomorphology and stratigraphy of the upper terrace of the Red River between Emerson and St. Adolphe (Figure GS-30-1) is being conducted by G. Brooks of GSC. This work is designed to elucidate the age, origin and sedimentology of alluvial

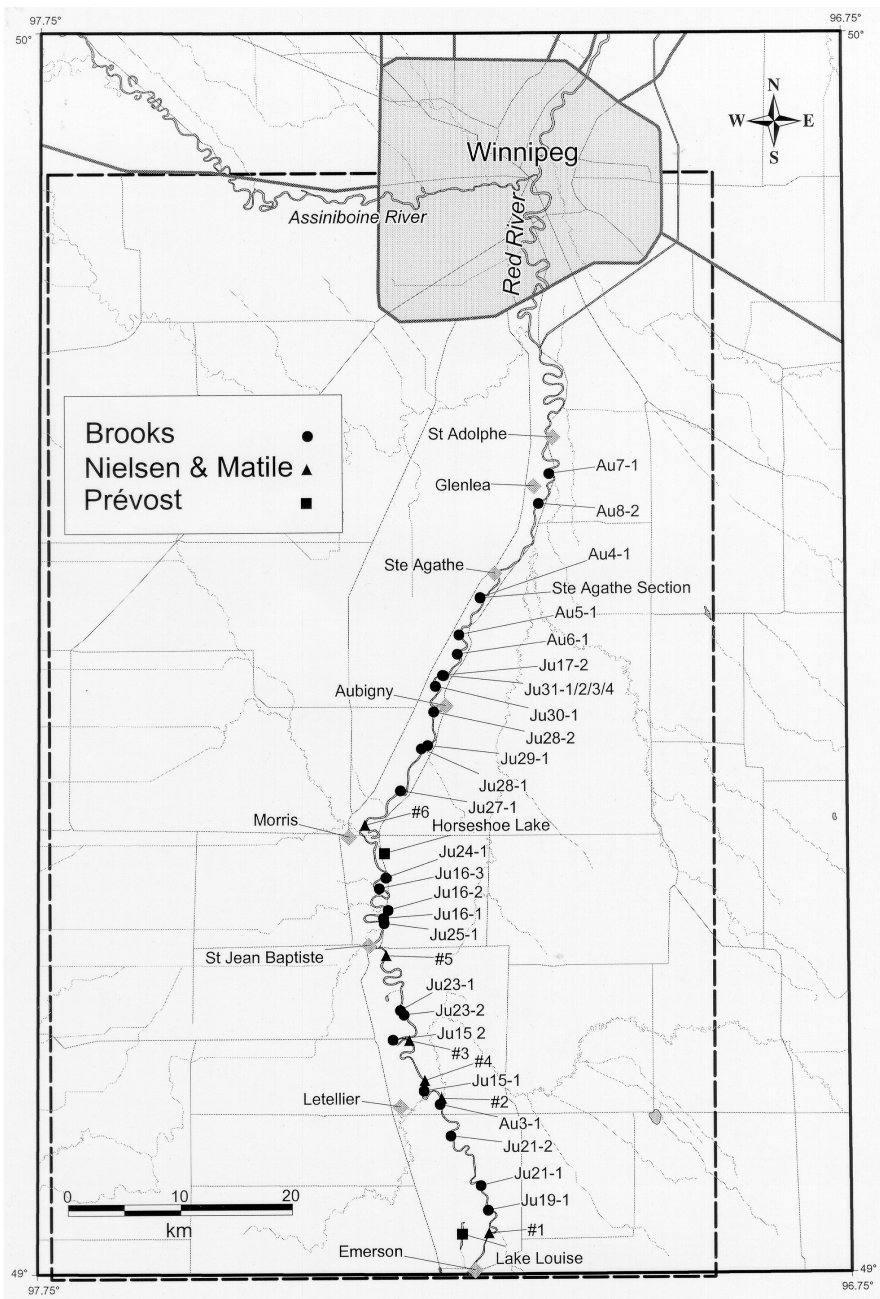

Figure GS-30-1: Location of 1998 study sites.

deposits for the purpose of identifying overbank sediments attributable to extreme floods such as the 1826 event. The work will, furthermore, increase understanding of channel dynamics and sedimentation and their relationship to fundamental controls on the evolution of the fluvial system such as uplift, sediment supply, and climate change. Following several weeks of reconnaissance in 1997, fieldwork in 1998 was conducted along the Red River by boat during a five-week period in July and August. Stratigraphic sections at 26 sites in the upper terrace (Figure GS-30-1) were logged and numerous organic samples, in most cases charcoal or bone, were collected for radiocarbon dating.

In general, observed Red River alluvial stratigraphy of the upper terrace is relatively uncomplicated, broadly consisting of epsilon cross-bedded channel deposits or vertical accretion deposits capped with overbank sediments. The deposits primarily consist of silt and clay that reflect the fine grained suspended load typical of the river, although some sand beds were encountered. In many sections, the bedding in alluvial deposits is obscured by soil development, either contemporary processes or paleosols. Notably, however, one section between Morris and Aubigny contained three silty beds that stand out as possible discrete flood deposits.

Although analysis is ongoing, several preliminary observations may now be made. Despite its very low gradient, the Red River is very active geomorphically. Significant sedimentation occurs along the river banks in the form of a drape of silt and clay, locally up to 10-15 cm in thickness. The banks along both straight and curved channel reaches experience mass movements in the form of very slow slides or slumps. Fluvial erosion is actively occurring along the toe of such banks. Net sedimentation along many river meanders is occurring along the down-stream extension of the concave bank well beyond the meander apex rather than at a point bar deposit situated at the apex itself. Overall, the Red River represents a style of low-energy, silt-clay alluvial system that is poorly documented in the fluvial geomorphology and sedimentology literature.

STRATIGRAPHIC AND TREE-RING EVIDENCE FOR RECENT FLOODING

Stratigraphic and geochronological analyses of flood deposits exposed on the lower Red River alluvial bench being carried out by E. Nielsen and G. Matile of MGSB will clarify flood history during recent centuries. Selected alluvial sediment exposures examined during a reconnaissance survey in 1997 were logged in detail in August and September of 1998 (Figure GS-30-1). These sediments are made up of couplets that consist of coarse silt or clayey silt overlain by finer textured clay or silty clay (Figure GS-30-2). The couplets were measured to test the hypothesis that these are individual flood deposits, each with a thickness proportional to the magnitude and/or duration of the associated flood. Detailed sedimentological observations, including measurements of rising flood and slackwater bed thickness, texture, nature of contacts, as well as evidence of slumping and channelling, were recorded at five sites on the lower floodplain, in an area of what seems to be high recent overbank sedimentation rates between Emerson and St. Jean Baptiste. The measured sections, located near the bottom of the channel and well below the upper terrace, vary between 2.7 and 5.8 metres in height and contain from 46 to over 155 flood couplets. Casual observations also were made at numerous other sites between Emerson and Morris (Figure GS-30-1).

Age determinations are being undertaken by a combination of dendrochronology, Pb-210 and Cs-137 isotope analysis, C-14 dating, macrofossil biostratigraphy, as well as analysis of 19th and 20th century artefacts found in many of the deposits. Dendrochronological analyses will be carried out on 16 *in situ* tree stumps rooted in the flood deposits at depths between 0.9 and 5.9 metres. An additional 13 allochthonous logs recovered from depths between 0.2 and 5.0 metres will also be analysed. Cross-sectional discs were collected from 26 oak, 4 ash and 7 elm logs found lying on the riverbank or in questionable stratigraphic context. These will be used to build a tree-ring database that may be used for cross-dating buried trees and paleoenvironmental reconstructions, including flood history. In addition, cores were taken from 10 living oak trees at Fort Dufferin, near Emerson, and 10 living oaks at St. Jean Baptiste. Ten living ash trees were also cored; four at Site # 1, five at Site #4 and one in St Jean Baptiste (Fig. GS-30-1). Sediments at one site were sampled for Pb-210 and Cs-137 dating, and two sites were sampled for macrofossil analysis. Wood, bone, and charcoal samples were collected for radiocarbon dating from numerous sites. Buried bottles, that may be associated with a specific time period, were recovered at five sites.

These studies show that the alluvial bench of the Red River is a highly dynamic environment, with abundant evidence of flood impacts. Dead trees are widespread due either to high sedimentation rates around their trunks, ice damage to their bark, prolonged submergence, or a combination of these factors. Between Emerson and Morris, recently-deposited sediments of variable thickness unconformably over-lie older, slumped upper terrace deposits in most sections. The older slumped terrace deposits, which are common and widespread, consist largely of homogeneous yellow silt and black topsoil, whereas the over-lying flood deposits comprise organic-rich brown to grey laminated silt and clay. In these deposits the widespread presence of both living and dead trees in growth position, and with numerous adventitious roots (Figure GS-30-3), indicates active and steady overbank sedimentation in recent decades. Only a few sites show evidence of significant sporadic sedi-mentation, as indicated by the position of adventitious roots on buried tree trunks. Furthermore, the presence of bottles and other refuse dat-ing to the 1950s, buried as much as 1-2 metres below the

Figure GS-30-2: Flood laminations exposed in an approximately 4 m high section in the alluvial bench at a site 1 km north of St. Jean Baptiste.

surface, suggest that deposits of the alluvial bench date to the late 19th and 20th centuries. At several sites, bison bones occur at the unconformity between the yellow silt and the overlying floodplain deposits, but nowhere have they been found above the contact. This further suggests that even the oldest alluvial bench deposits may not predate 1825 to 1850, the approximate date when bison became extinct in southern Manitoba.

In addition to stratigraphic investigations along the river, efforts also are underway to obtain a stratigraphic record of past flooding from Lake Winnipeg, using cores previously collected by GSC and MGSB, as well as cores recently collected by members of the Freshwater Institute of Fisheries and Oceans Canada.

DIATOM STRATIGRAPHY

In an attempt to obtain a flood record of at least several centuries, cores from oxbow lakes on the upper Red River terrace are being analysed for diatom stratigraphy, by C. Prévost of the GSC, with the assistance of A. Grenier. Recent studies have demonstrated the usefulness of these siliceous microfossils in recognising inundation events and other paleohydrologic phenomena. These lake sediments potentially offer a unique opportunity to reconstruct Red River flood history. Flood-deposited sediments are likely to contain a diatom flora markedly different from that of a small lake, or may even be barren of diatoms. Such distinctive diatom assemblages could serve as a stratigraphic marker for flood events.

Field work conducted in June 1997 verified a distinct diatom flora for 1997 flood sediments. Sediments were sampled at twenty-three sites on uncultivated fields, and from the banks and terraces of the Red River. Preliminary results indicate that these sediments contain mixed assemblages of diatoms, depicting no dominant taxon, and unusually high abundances of diatom fragments and broken valves. Short gravity cores, 30 cm long, also were also collected in 1997 from two oxbow lakes; Lake Louise near Emerson (49°02'00" N, 97°13'55" W; NTS Emerson, 62 H/3), and Horseshoe Lake, near Morris (49°20'20" N, 97°19'30" W; NTS Morris, 62 H/6). The 1997 Red River flood deposits were clearly visible at the top of both sediment sequences, as a 1.5 cm thick unit at Lake Louise and a 3 cm thick unit at Horseshoe Lake. In the underlying lake sediments, below the 1997 flood layer, no similarly-well-defined strata were apparent.

Longer cores were obtained from both sites in May 1998. A Livingston corer was used to recover a core 0.65 m long from Lake Louise and a core 1.10m long from Horseshoe Lake. Hard clay prevented coring to greater depths. Both cored sequences showed gradational changes from soft, clayey gyttja, down to hard, black/grey, shell-rich clay. The hard sediments that prevented additional penetration are richly fossiliferous, implying that these are alluvial, rather than glaciolacustrine, sediments.

Laboratory work consisting of core extrusion, subsampling at a 1-cm interval for diatom analyses and acid-processing for digestion of organics is complete. Mounting of microscope slides for systematic identification and enumeration of diatoms is underway. In addition both long cores were subsampled to isolate and identify macrofossils that may be dated by radiocarbon analysis, in order to address the timing of oxbow abandonment and sediment accumulation.

ARCHAEOLOGICAL EVIDENCE

Efforts to obtain additional information about past flooding from archaeological data obtained from fluvial sediments and cultural strata in Winnipeg is being carried out by S. Kroker of Quaternary Consultants Ltd., 130 Fort Street, Winnipeg.

While archaeologists routinely record stratigraphic profiles above a cultural stratum under investigation, this data is seldom interpreted in terms of geological or climatic events that postdate the cultural occupation. In areas that experience repeated sedimentation episodes, the cultural horizons may serve as temporal markers between succeeding depositional events, especially when there has been insufficient time elapsed for the formation of a soil horizon. In addition, the cultural identification of the occupants provides a broad temporal range for the occupation, whereas radiocarbon dates obtained from organic materials within the archaeological horizon can provide more exact dating of the previous flood episode.

Several archaeological investigations at The Forks, the junction of the Red and Assiniboine Rivers, have produced much stratigraphic data that may be used to determine sedimentation and soil accretion regimes. The foci of these projects has been varied. Some studies investigated only cultural horizons as recent as the early 1800s, whereas others yielded evidence of occupations as far back as 6000 years ago. The current effort is focussed on utilising available, minimally-published data, in attempt to delineate alluvial sedimentation and hence flood frequency.

The excavations at Fort Gibraltar I, which was occupied from 1810 to 1816 just north of the junction of the rivers, yielded profiles that contain evidence of discrete strata laid down by flooding after the destruction of the fort. These include strata that can be linked to recorded historic floods. A 3-m stratigraphic profile obtained in 1997, 0.8 km northwest of The Forks, includes at least ten discrete pre-Fur Trade cultural horizons. All horizons contain culturally identifiable ceramics, indicating that the lowest horizon, at a depth of 3.05 m, postdates AD 800. The uppermost 1.45 m is tentatively linked with a nearby archaeological horizon that has an associated radiocarbon date of 580±70 yr. BP (BGS-1460) (ca AD 1400). This indicates that at least ten flood episodes occurred within those 600 years. Additional radiocarbon dates are forthcoming and will enable refinement of the dating of some of these episodes. Evidence obtained during the excavations of a campsite

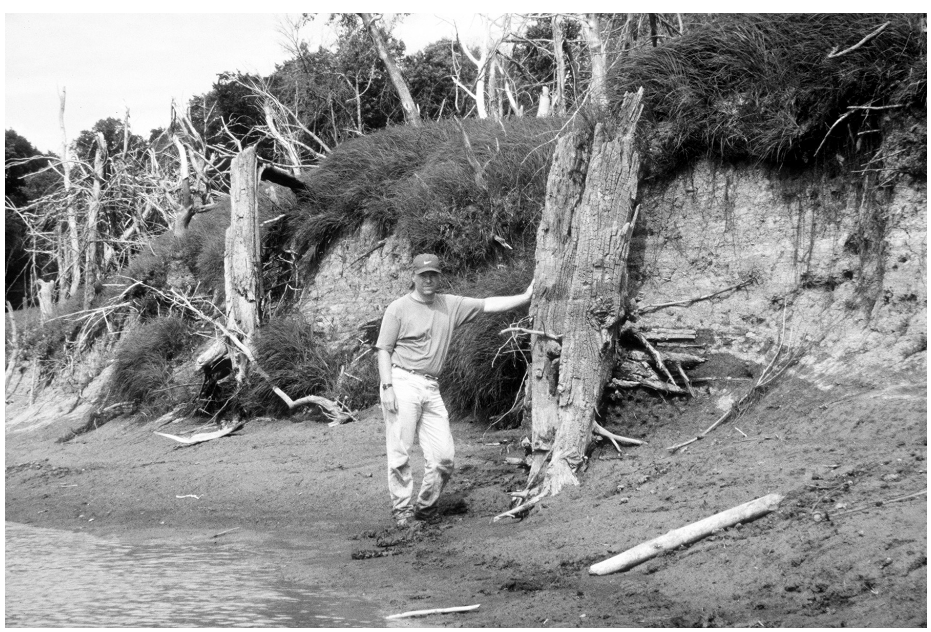

Figure GS-30-3: Cottonwood tree stumps with adventitious roots, indicating recent rapid burial by overbank sedimentation followed by later erosion. Person for scale is 1.83 m tall; site is located 4 km north of Letellier.

immediately adjacent to the north bank of the Assiniboine River indicates considerable sand deposition both prior to and after occupation that has been radiocarbon dated at 2870±80 yr. BP (BGS-1316). These sand deposits suggest that the Assiniboine River was flowing in its present channel, at least intermittently, nearly three millennia ago.

LANDSCAPE RECONSTRUCTION

A reconstruction of the Red River Valley landscape in the 1870s is being compiled by I. Hanuta of the University of Toronto. Human-induced modification of the landscape since this time may have had a significant impact on both the frequency and magnitude of flooding, as well as the character of floods of a given magnitude. In order to obtain a baseline for assessment of landscape modification, the state of the flooded area in the 1870s was mapped from archival sources.

In the 1870s, the Department of the Interior conducted the Dominion Land Survey (DLS) under the provisions of the Dominion Lands Acts. These surveys, conducted in preparation for agricultural development of western Canada, produced technical and descriptive records and maps that are now stored at the Provincial Archives of Manitoba. The DLS township maps have prescribed symbols and shading that describe the landscape, as well as written descriptions of terrain. For this investigation, the earliest available DLS township maps were used to produce a landscape classification for the 1870s, based on both map shading and text descriptions. Content analysis, a method for the derivation of quantitative information from textual material, was used to review and assess written descriptions of the landscape obtained from the township plans.

The pre-settlement landscape was classified as prairie, woodland, scrub or wetland. On the original township plans, much uniformity existed among the words used to describe landscapes and other phenomena, whether across the study area or from surveyor to surveyor. A content analysis of root words and phrases therefore could be used to classify several hundred landscape polygons. The most commonly usedroot word is 'prairie' (n = 223) and along with 'grass' (n = 4) and 'field' (n = 2) were classified as prairie. 'Poplar' (n = 171), 'oak' (n = 77), and 'elm' (n = 12) were classified as woodland. 'Willow' (n = 170), 'scattering/scattered poplar' (n = 9), and 'brush' (n = 5) were classified as scrub. 'Marsh' (n = 73), 'hay' combined with 'land', marsh', 'ground', or 'swamp' (n = 67), as well as 'weeds' (n = 39) were classified as wetland.

Compilation of a detailed digital map that will display this four-category classification is currently underway. A generalized map showing prevalent cover (Figure GS-30-4) shows, however, that prairie was the most extensive landscape in the study area, especially in Ranges 1 and 2 West. Progressing northward and eastward, there was more diversity, including extensive wetlands in the northwest, as well as woodland and scrub in the northeast and east.

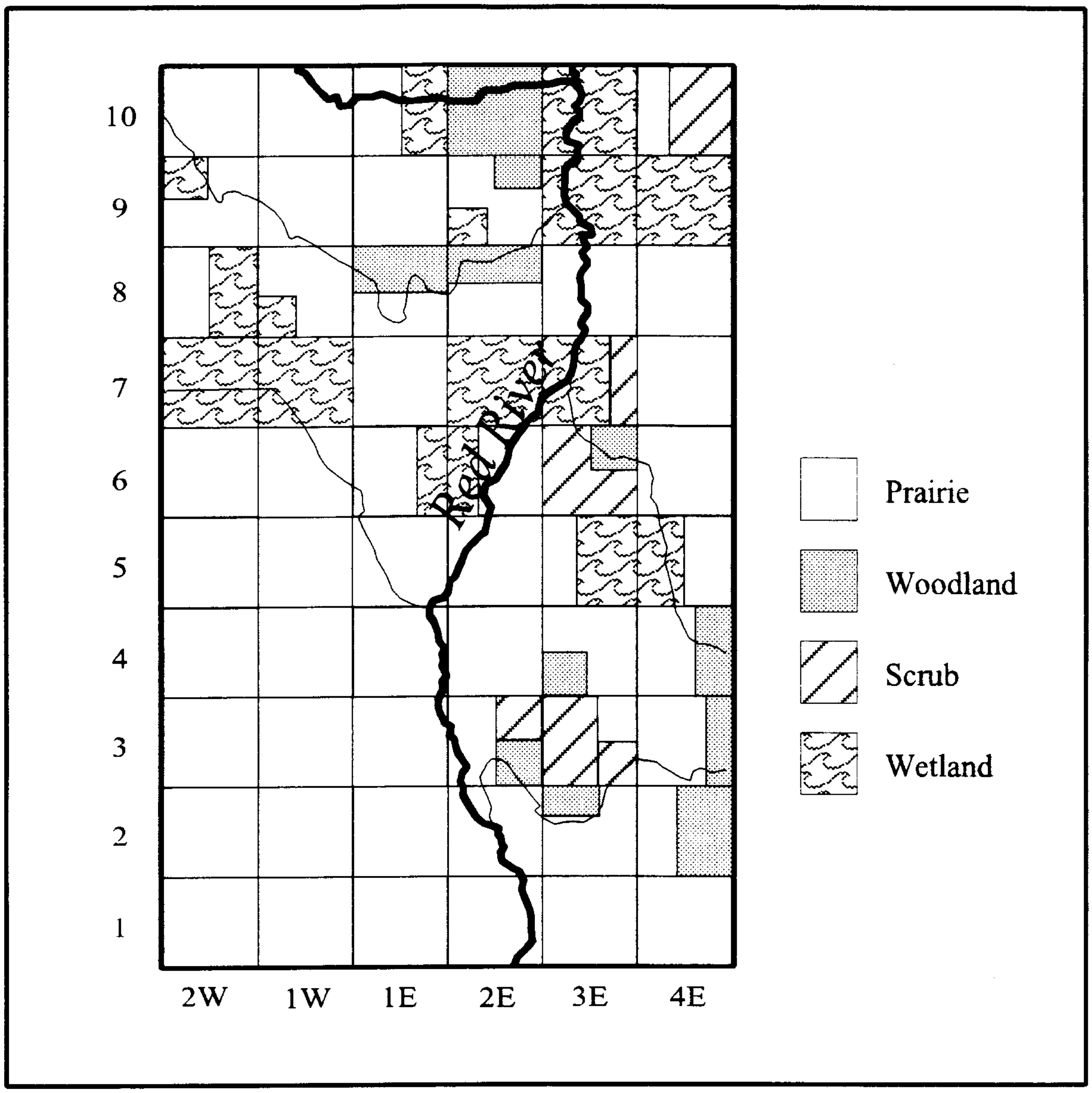

Figure GS-30-4: Generalized map showing most prevalent 1870s vegetation cover by township. The map area is outlined by a dashed line in figure GS-30-1.

These archival data are of great value in establishing baselines and in defining changes to the environment, primarily due to the short time span over which the surveys were carried out, their systematic nature over the entire region, and the very high, albeit imperfect, consistency with which the work was done.

PRE-1870 HYDROCLIMATE, FLOODS AND RUNOFF IN THE RED RIVER VALLEY

A synthesis of archival information on documented floods, as well as climatic conditions associated with this flood history, is being carried out by Dr. W. F. Rannie of the University of Winnipeg. Literature on the 19th century climate of the northern Great Plains indicates that the Red River basin experienced many of the characteristics considered typical of the waning stage of the Little Ice Age. The climate of the basin in the last century differed significantly from that of the 20th century with respect to most climate and streamflow measurements related to hydrological processes. For example, river breakup was normally later, not uncommonly in early May, and freezeup occurred earlier. In mid-century at least, average temperature in all seasons was lower and fall-winter-spring precipitation was greater. Although several droughts occurred early in the century, few occurred after about 1820. The frequency of extreme summer rainfall appears to have been somewhat greater, possibly associated with differences in atmospheric pressure patterns over the Great Plains. Evapotranspiration may have been smaller and average runoff was probably higher. The levels of Devil's Lake appear to have been higher during most of the period. Finally, land cover and drainage were significantly different from 20th century conditions.

The flood history of the Red River prior to 1870 is being reconstructed from a database of over 19,000 entries that describe the climate, hydrology, and related environmental conditions, compiled from documents in the Province of Manitoba and Hudson's Bay Company Archives, as well as other historical sources. Descriptive accounts of extensive flooding and high water events were compared with the 1948, 1950, 1966 and 1979 events in an attempt to rank order the floods and estimate discharge ranges (Figure GS-30-5). Flooding appears to have occurred more frequently and with greater severity prior to 1870 than since. Fourteen events approximating or exceeding 1948 magnitude were identified between 1798 and 1870, compared with eight such events after 1870. Nine of the pre-1870 events were probably of 1966 magnitude or greater, compared with six after 1870.

During the record 1826 and 1852 floods, conditions in the Assiniboine basin appear to have been as severe as those in the Red River basin. By comparison to modern discharge records, it may be estimated that the Assiniboine contributed as much as 40,000-50,000 cfs to the flow of the Red downstream of the Forks during these events. How much of this water actually reached the Red, rather than being, in part, naturally diverted to Lake Manitoba, is uncertain, but if 40,000 cfs is assumed, the implied peak discharges for the Red River upstream of the Forks are 185,000 cfs in 1826 and 125,000 cfs in 1852. In 1997, a peak flow of 138,000 cfs was recorded above the Floodway and when local inputs between the Floodway and the Forks from, for example, the La Salle River, are added, peak natural discharge exceeded 140,000 cfs. The 1997 flood has generally been considered to have been comparable to the 1852 event, but given the probable role of the Assiniboine in 1852, it may be that on the Red River above the Forks the 1997 flood was actually larger than 1852, and may have had a peak discharge approaching 80% of the 1826 event.

The database was also used to categorize annual runoff, on a water-year basis, from 1793 to 1870 as very low, low, normal, high, or very high (Figure GS-30-6). Above normal years outnumbered those below normal, a pattern opposite to that of the modern record. It is concluded that runoff was generally greater prior to 1870 than since. Only three relatively short periods of successive low/very low runoff years were identified - 1803/04-1804/05, 1815/16-1817/18, and 1861/62-1863/64. In contrast, there were two periods of five successive high or very high runoff years - 1823/24 to 1827/28 and 1847/48 to 1851/52, and other periods in which a concentration of high runoff years occurred - 1798-1806, 1811-1815, and 1857-61. The pre-1870 runoff record was divided into three broad time periods: 1) 1793/94 to 1827/28, a period of high variability; numerous floods and several drought episodes; 2) 1828/29 to 1846/47, a period of stability and no floods when runoff seems to have fluctuated within the "normal" range; and 3) 1847/48 to 1869/70, a period of frequently high runoff and several major floods, with one extreme drought in 1862-64.

The apparent differences in hydrologic regime between the pre-1870 period and the period of record suggests that historic floods such as those of 1826, 1852 and 1861 might not be part of the same population as the modern data used to construct frequency curves and that incorporating them into frequency analysis should be done with caution.

ACKNOWLEDGEMENTS

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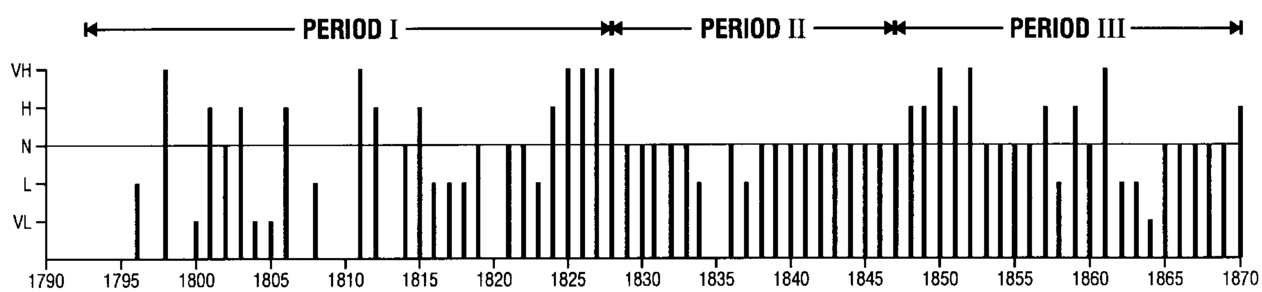

Figure GS-30-5: Comparison of suggested range for pre-1870 historical flood magnitudes with measured discharge for post-1870 floods.

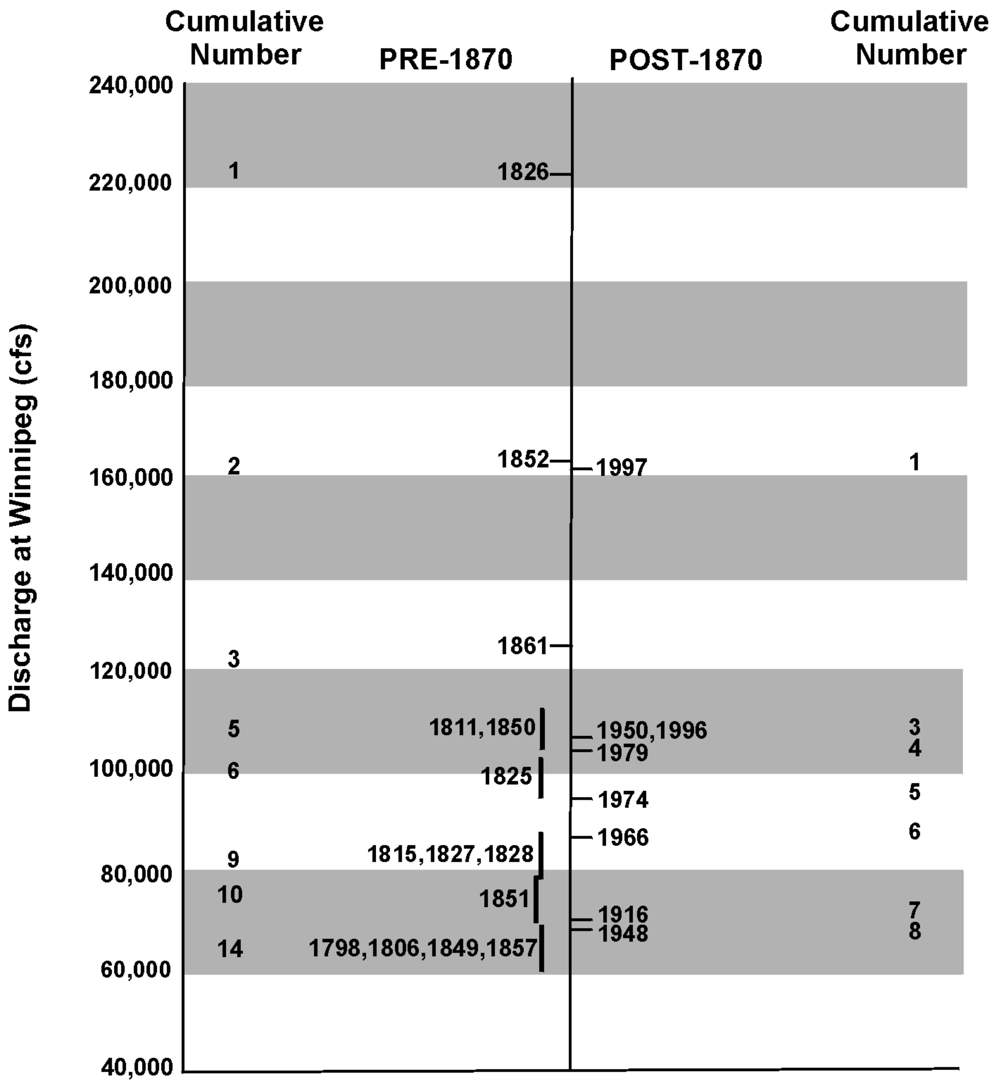

Figure GS-30-6: Runoff category, 1793-1794 water-year to 1869-1870 water-year.

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