Some observations on peak stages during the 1826 Red River flood and the "Fleming Conundrum"

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Abstract: The 1826 flood in the Red River Settlement provides an important event for designing measures for reducing the flood risks in the city of Winnipeg. During recent hydraulic studies for an enlarged Floodway, the "Fleming Conundrum" was identified -- an anomaly between peak stages in the Winnipeg and Selkirk reaches and a zero-gradient zone on the water surface in the reach immediately downstream of the Forks. It is suggested here that strong winds immediately prior to the 1826 peak stage may have induced setup on the water surface; if so, this would exacerbate the "Conundrum" but may partially account for the zero-gradient zone. The latter may also reflect Sir Sanford Fleming's method of reporting peak stages surveyed from anecdotal accounts. The historical record provides some support for the suggestion that ice jamming early in the flood may have caused the reported peak water levels in the Selkirk area to have been anomalously high. The possibility of an unusually large input from the Assiniboine River is also noted.

Introduction

The 1826 flood was the largest known in the Red River Valley, with an estimated peak discharge about 40% greater than the natural flow in the 1997 "Flood of the Century" (Figure 1). The conditions which caused the 1826 flood have been described in detail by St. George and Rannie (2003). The event devastated the struggling Red River Settlement, led to the exodus of German and des Meurons settlers, precipitated the relocation of the Hudson's Bay Company headquarters from Upper Fort Garry (in present-day Winnipeg) to flood-free Lower Fort Garry (near Selkirk, 40 km downstream), and figured prominently in the debate in the 1870s about the location of the railway crossing of the Red River. Moreover, the flood

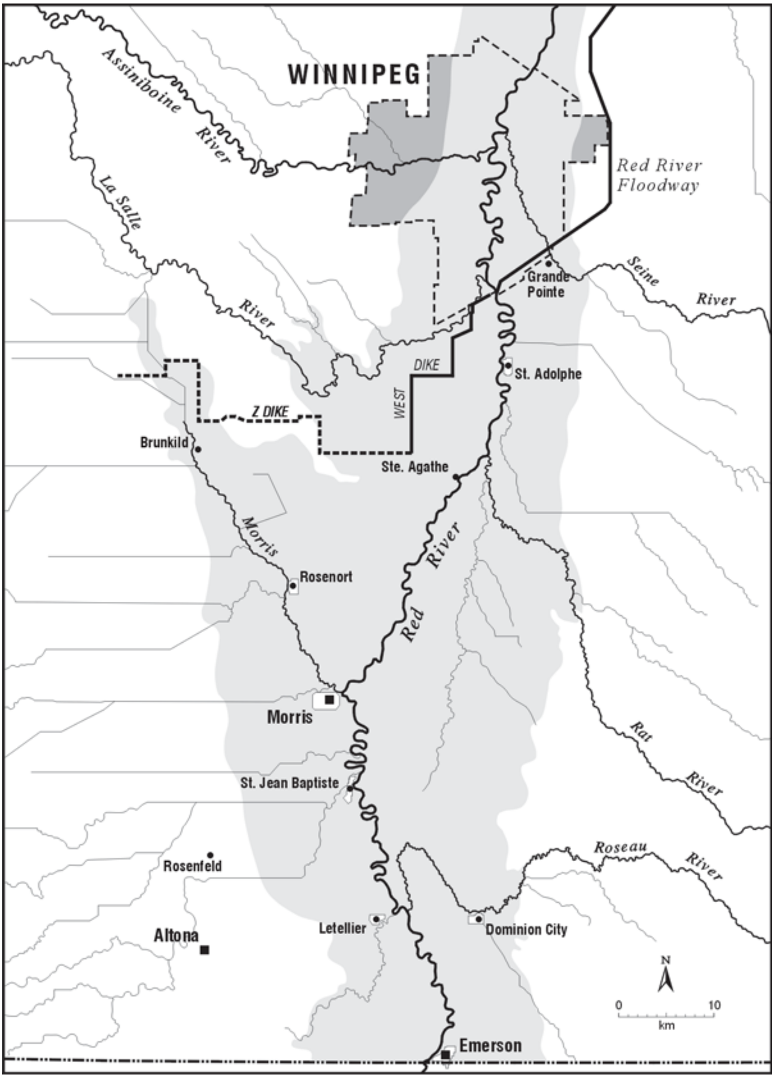

Figure 1: *Generalized extent of 1826 flood in Manitoba.*

had effects that reached beyond its importance in the early history of the Winnipeg region. Indeed, it can be speculated that without the example of the severe flood threat 1826 provided, a lower, more common, and less expensive standard might have been adopted for the flood protection system for Winnipeg after 1950; had that been the case, it is unlikely that Winnipeg would have escaped major damage from the 1997 flood.

This paper explores several factors which may have affected the peak stage (water level) in the Winnipeg area, particularly as they relate to the "Fleming Conundrum" which emerged during post-1997 hydraulic studies for an expanded Red River Floodway.

Peak Stages in 1826 and the Nature of the "Fleming Conundrum"

In the late 1870s, Sir Sandford Fleming commissioned surveys of the high water marks for the 1826 and 1852 floods as part of a study to determine the best location for the Canadian Pacific Railway crossing of the Red River (Fleming, 1880). The surveys, conducted by James Rowan, were based on interviews with long-time residents and the results from several independent testimonies were found to "agree closely" (Fleming, 1880, p. 276). Fleming's original data for eleven locations along the Red are given in Table 1. These elevations were subsequently adjusted (shown in Table 1) to reflect a change in the reference section from the Main St. bridge to the James Avenue Pumping Station and to the City Datum of 727.57 feet above sea level (Red River Basin Investigation, 1953b).

These adjusted high water marks became the standard reference points for all subsequent studies of the 1826 and 1852 floods. After the 1950 flood, the Red River Basin Investigation (RRBI) used these high water marks and a slope-area (Manning-type) methodology to estimate the 1826 discharge for two reaches, one just upstream of Lower Fort Garry (199,800 cfs or 5658 m^3/sec) and the other between Lower Fort Garry and Selkirk (256,000 cfs or 7250 m^3/sec). The conventionally-accepted 1826 peak discharge of 225,000 cfs (6372 m^3/sec) was taken as the approximate average of these two estimates. In similar fashion, Fleming's 1852 high water marks for four reaches yielded an average of 165,000 cfs (4673 m^3/sec) and the 1826 and 1852 values were then used to define the upper region of the stage-discharge relation for the Red River at the Redwood Bridge.

The "Fleming Conundrum" (so-named by Carson *et al.*, 2002) arose when Fleming's high water marks were used by KGS Group during hydraulic studies for expanded flood protection for Winnipeg (KGS Group, 2001). KGS Group found that when the water surface was projected upstream from the Selkirk area or downstream from Winnipeg, the resulting profiles didn't agree with Fleming's data: *either* downstream water levels (from Lockport to Selkirk) were considerably higher than would be

Table 1: Fleming's High Water Mark Elevations and Subsequent Adjusted Values (Fleming, 1880; RRBI, 1953b)			
	Miles from Mouth of Assiniboine	Height of 1826 Flood (feet asl)	Adjusted Heights Used by the RRBI
Mouth of Assiniboine	0	769	764.5
Point Douglas	2	769	764.5
North of St. John's Church	4	769	764.5
North of Kildonan Church	7	768	763.5
South of Tait's Creek	12	766	761.5
Near St. Andrew's Church	18	759	754.5
About 2 miles above S. Fort	20	755	750.5
Stone Fort (Lower Fort Garry)	22	752	747.5
About 2 miles below S. Fort	24	748	743.5
Selkirk	27	738	733.5
St. Peter's Church	31	730	725.5

expected for peak flows associated with the levels reported in Winnipeg, *or* the peak stages in Winnipeg were considerably lower than could be explained by flows that would be required to generate the downstream maximum stages (Figure 2).

A secondary puzzling aspect of Fleming's data was also noted by KGS: three identical water elevations over a 4-mile (6 km) reach immediately below the Forks (Table 1), suggesting zero slope in the water surface. Since some gradient would have been required to sustain flow, KGS Group raised questions about the accuracy of Fleming's surveyed data.

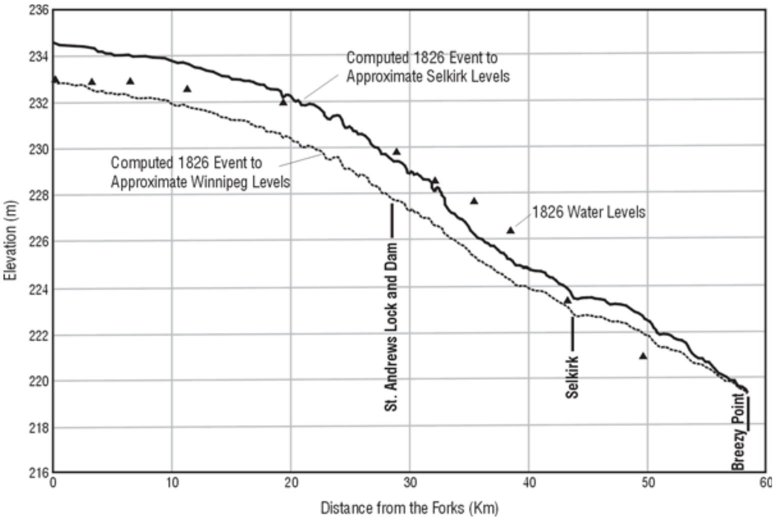

Figure 2: *The "Fleming Conundrum" (modified from Carson et al., 2002)*

KGS Group considered numerous possible explanations for the anomaly and concluded that it probably arose from a combination of possible errors in high water marks reported by Fleming and/or possible temporary elevation of water levels by ice jams early in the rising limb.

Wind Setup

Wind setup is defined as "the vertical rise in the still-water level on the leeward side of a body of water caused by wind stresses on the surface of the water" (American Geological Institute, 1966, p. 322) (Figure 3). Although setup can be ignored in most floods elsewhere because of their limited spatial extent, it can seriously aggravate flood conditions in the

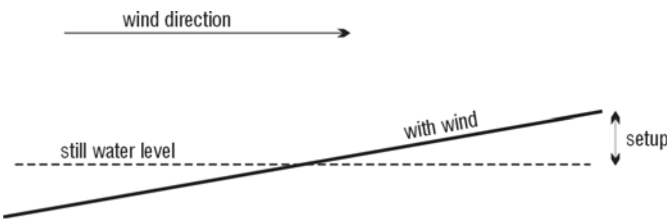

Figure 3: *Schematic definition of wind setup.*

northern Red River valley where the inundated area during major floods is exceptionally large; in 1997 this area became popularly known as the Red Sea and for convenience this name will be applied to the 1826 flood zone in this paper. In 1997, the Manitoba portion of the Red Sea covered about 2000 km^2 and the 1826 area would have been somewhat larger. With a flooded area this large, wind setup on the northern margin of the Red Sea may add significantly to the water stage which would otherwise be achieved by hydrologic conditions alone (i.e. under calm conditions where stages are governed only by discharge).

The 1826 flood occurred long before systematic monitoring of the weather began but fortunately, a great deal of knowledge about the event is preserved in archival materials. Much of this information is summarized in the RRBI reports, in Rannie (1999, 2001), and in St. George and Rannie (2003). Particularly important are the journals kept by Francis Heron and Reverend David Jones which provide considerable detail about weather conditions during the flood, as well as its progress, and human consequences. These sources indicate that peak stage occurred about May 20-21 (Table 2).

Table 2: Indications of Peak Water Stage Date

May 20	**We were considerably encouraged this morning by hearing that the river had fallen considerably at Pembina; we were confirmed in this hopeful information from the water being almost stationary in both our rivers since last night. (Jones, 1826)**
May 22	**We were much comforted this morning in finding that the Main River has lowered two inches during the night. (Jones, 1826)** **The inundation seems to have reached at length, its extreme height, it being imperceptible whether the water rose or fell during the last thirty-six hours. (Red River Journal, 1826)**

Wind directions and strength reported by Heron and Jones during May 1826 are given in Table 3. The most striking feature is the period of strong winds from southern quadrants for at least four days (May 15-18) just prior to the peak (and possibly longer since wind directions were not reported from May 10-14 or on May 19). On May 20, when Jones first reported the river to be “almost stationary”, wind direction had switched to Northwest.

A commonly used method for estimating wind setup is given in Equation 1 (Saville et al., 1962; Bruce and Clark, 1966):

Table 3: Wind Conditions, May, 1826
(Red River Journal; *Jones Journal*)

	Direction	Strength		Direction	Strength
May 1	NE		May 15	SE	blowing hard; storm all night
May 2	as yesterday		May 16	SW	Strong
May 3	E	*stormy in extreme*	May 17	SW	Windy
May 4	SE		May 18	SW	
May 5	SW	strong	May 19		high; quite a hurricane
May 6			May 20	NW	**Strong**
May 7	variable		May 21	**W**	**strong gale**
May 8	NE		May 22	variable	*very furiously*
May 9	NW		May 23	variable	*still raging furiously*
May 10		tempest	May 24	SW	strong gale
May 11		tempestuous	May 25		
May 12	same as yesterday		May 26	SE	
May 13		tempest	May 27	W	Windy
May 14		*unusually stormy*	May 28	variable	
			May 29	SW	
			May 30	wind and weather the same	
			May 31		

$$S = \frac{V^2 f}{KD} n \cos \theta \qquad (1)$$

where S = setup (ft.); V = wind velocity (mph); f = fetch (mi.); D = average water depth (ft.); n = coefficient depending on lake shape; θ = angle between wind direction and fetch; K = coefficient (1400-1600)

Table 4 shows estimated setup calculated from Equation 1 for various combinations of average wind velocity, water depth, and effective fetch,

Table 4: Estimated Setup in 1826 Calculated from Equation 1

Wind Velocity (kmph)	Setup (m) for Fetch of 75 km			Setup (m) for Fetch of 30 km		
	D = 2.0 m	D = 2.5 m	D = 3.0 m	D = 2.0 m	D = 2.5 m	D = 3.0 m
30	0.50	0.40	0.33	0.20	0.16	0.13
40	0.89	0.71	0.60	0.36	0.29	0.24
50	1.39	1.11	0.93	0.56	0.45	0.37
60	2.01	1.60	1.34	0.80	0.64	0.53
70	2.73	2.18	1.82	1.09	0.87	0.73

assuming winds from due south (cos θ = 1.0), no correction for lake shape (n), and K = 1500.

The actual wind speeds in 1826 are not known but the descriptions suggest they were strong and, given their duration, probably persistent. On the Beaufort Scale a velocity of 40 kmph is characterized as a "strong breeze" and this seems a minimum which might have engendered the historical comments. Water depth would have varied along the line of fetch but based on peak stages reported in Fleming (1880) and 1997 conditions, an average depth of 2.5 m is reasonable. The appropriate fetch to assume for 1826 conditions is also uncertain. Although no topographic barrier exists between Lockport and Morris (or even beyond), a greater wooded area on the floodplain and particularly along the La Salle River (Hanuta, 1998; 2001) may have reduced effective fetch or impeded the full development of setup. Thus, Table 4 gives estimates for two fetches: 75 km (approximately from Lockport to Morris) and 30 km (approximately from Lockport to the La Salle River). For wind speeds of 40-50 kmph, water depth of 2.5 m, and a fetch of 75 km, Table 4 indicates that a setup 0.71-1.11 m (2.3-3.6 ft.) might have occurred; for the shorter

30 km fetch, the calculated setup was 0.29-0.45 m (1.0-1.5 ft) for the same conditions.

Equation 1 was developed to predict setup on a horizontal water surface whereas the surface of the 1826 “Red Sea” would have sloped northward (i.e. in the same direction as the wind) and river flow in that direction would have relieved some of the wind stress on the water surface. Faure *et al.* (2000) of the Canadian Hydraulics Centre (CHC) used a two-dimensional hydrodynamic model to estimate setup which could be expected from 10- and 50-year winds (45 and 62 kmph respectively) acting on an 1826-magnitude flood *occurring over a modern landscape*. Their results are shown on Figure 4 for several locations on the dykes and in the vicinity of the Red River Floodway inlet (the locations B, C, E, and F are probably the most relevant to the 1826 peak stages in the Winnipeg area because they lie on a line orthogonal to south winds).

The CHC study was not intended to simulate actual 1826 conditions but rather was designed to investigate water levels in the vicinity of the Floodway inlet should an 1826 magnitude discharge occur in the future. Thus the circumstances assumed in the CHC study differed from those which would have existed in 1826. The modern dyke on the downwind boundary would maximize setup in comparison with the 1826 flood when no such retaining wall existed and water would have been able to spread across gentle gradients downstream. In addition, as was noted above, a greater wooded area on the floodplain in 1826 might have impeded the full development of setup in comparison with the modern condition. In these respects, then, the setup which might have occurred in 1826 would probably have been somewhat smaller than the values calculated by CHC. However, the fetch used by the CHC study was much shorter (10-15 km) than might have been the case under natural 1826 conditions, limited in the north by the dyke wall and to the south by road elevations on the modern landscape. The duration of the south winds assumed by CHC (sustained peak velocity from the south for 11 hours) was also considerably shorter than the three or more days which might be inferred from the historical data.

Despite the difference in methodology, the results from Equation 1 and the CHC study appear to be comparable. For example, CHC data for their “cross-section” are representative of conditions at Points E and F on Figure 4. If their fetch and average depth from that “cross-section” are used in Equation 1, predicted setups for 45 and 62 kmph winds are 0.29 m and 0.54 m respectively. It is concluded, then, that the difference between the CHC and Equation 1 setup estimates is principally attributable to differences in fetch.

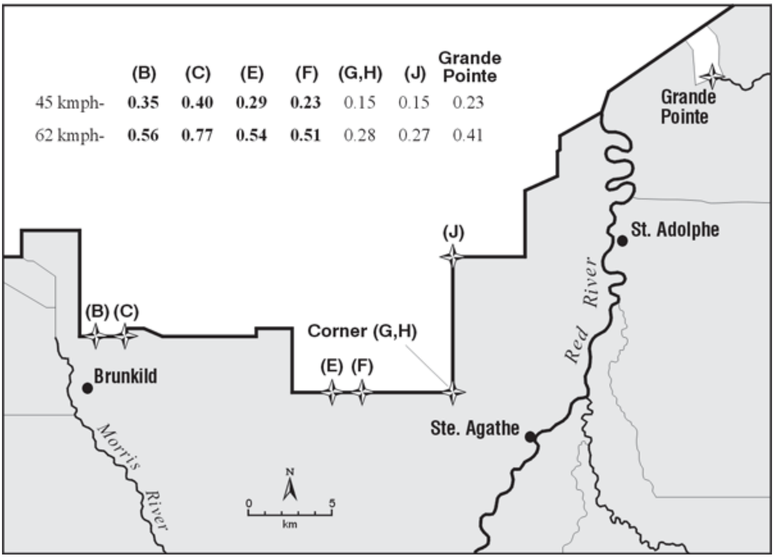

Figure 4: Estimated setup on the dykes adjacent to the Red River Floodway for an 1826-magnitude flood (modified from Faure et al., 2000)

Setup of 0.3-1.1 m in 1826 would have offset some of the downstream slope of the water surface and thus may partially explain the flat slope indicated by Fleming's survey data for the vicinity of the Forks. However *setup would also compound the main element of the Conundrum because its effect would have been to increase stages in the Winnipeg area*. If a setup component were subtracted from Fleming's high water marks, the stages in Winnipeg would have been even lower than Fleming reported and the Conundrum would be even more pronounced.

The coincidence in the timing of the peak stage on May 20-21 and the reversal of wind direction from strong south to strong north on May 20 (or possibly May 19) is also notable. Could the relaxation of the wind stress have contributed to stabilization of water levels?

Fleming's Survey Methodology

Although wind setup might address some of the concern over the "zero slope reach", this element of the "Conundrum" might have another solution. As was noted above, Fleming's original data were modified to reflect changes in reference section and a precisely defined City Datum.

A notable effect of these adjustments was the addition of one decimal place to Fleming's original elevations (Table 1), giving the appearance of greater survey accuracy than was implied in Fleming's report. Whereas Fleming only reported the high water marks to the nearest foot, the adjusted values provided for one decimal place, implying survey accuracy approximately to the nearest 0.5 ft. Fleming's high water marks clearly were rounded to the nearest foot, a sensible treatment given the methodology and the long time-span since the flood. It is possible that if the upstream elevation was rounded downward and the downstream elevation was rounded upward, then a gradient of as much as 1 foot (0.3 m) *could* have existed over the 6 km between the upper and lower stations without this being apparent from subsequent versions of Fleming's data. This is approximately the gradient which KGS Group estimated should have occurred in this reach in both 1997 and 1826. Thus the "missing gradient" may be a product of Fleming's data treatment and some flattening by wind setup. This scenario, if true, would reduce slightly but not resolve the main element of the Conundrum because rounding could account for only 0.15 m (0.5 ft) of the 0.5-0.75 m "shortfall" in Fleming's elevations at the mouth of the Assiniboine and as was noted above, consideration of wind setup would exacerbate the shortfall.

Ice Conditions

KGS Group (2001) suggested that the anomalously high water levels in the Selkirk area may have been caused by temporary ice jamming early in the flood and thus were not a reflection of open water peak flows. In their Scenario #2, they hypothesized that "the water levels in Winnipeg occurred as reported, and the high water levels near Selkirk were caused during the early stages of the flood, and resulted from a temporary ice jam that was subsequently washed downstream and dissipated." (KGS Group, 2001, p. 15).

Historical references to ice conditions and changes in stage from breakup to the flood peak are given in Table 5. The descriptions during the first days of May indicate that the ice was very thick (4-4.5 feet) and remained strong and intact as the water began to rise. Breakup occurred over a 3-4 day period from May 4 to May 8. On May 4, Jones (1826) reported that the ice "started" but a general breakup and evacuation of the ice did not begin until May 5. The following day (May 6), the rising water carried the ice away "in immense masses" and Jones reported that by the end of the day most of the ice was gone. The Assiniboine broke up early on the morning of May 7 and by May 8, both rivers had "become almost

Table 5: References to Ice Conditions in Jones and Red River Journals

May 1	Every creek pours in its tributary flood and the water has already overflowed its banks in many places, though there is scarcely any diminution of the snow in the plains around…The ice has not yet moved though elevated nearly up to the level of the banks and it is unusually weighty being in general Four feet thick; in consequence the houses, which are set upon the edge of the river are in the greatest danger of being swept away. (Jones, 1826) The ice in the Rivers begins to rise in consequence of the flush of waters pouring into them from the plains… (Red River Journal, 1826)
May 3	The river rose six feet last night perpendicularly… The ice has just started towards the lake; the water keeps rising alarmingly… (Jones, 1826) The ice in the Rivers has attained the height that floods reached at the highest pitch last summer, and the water in several places has overflowed the banks… (Red River Journal, 1826)
May 4	No apparent sign of deliverance yet, last evening when the ice started, the river slackened considerably; but rose again in the morning. The ice continued stationary all this day…The water is now within 4 feet of the Church… (Jones, 1826) The water in the Rivers rose about 5 feet perpendicular during the last twenty-four hours, and the ice is now on a level with the highest banks, but is still so thick and strong that even the present flush of waters have not sufficient force to break it up… (Red River Journal, 1826)
May 5	On a point of the river above us four houses and a barn were swept off by the force of the ice and the ruins floated past us to-day on the surface thereof… The ice is uncommonly weighty being generally four feet & a half thick. The force of it is inconceivable; the loftiest elm trees are carried away like the most inconsiderable things… (Jones, 1826) About 2 P.M. the ice in the Red River at length broke up in an awful rush; carrying away cattle, houses, trees and every thing else that came in its way-The river overflowed its banks every where, and carried the ice with great velocity to a greater distance from its course, than had ever been seen before by the oldest inhabitants… (Red River Journal, 1826)
May 6	Most part of the heavy ice is now gone which must be so far in our favour…The water rose considerably during this day… (Jones, 1826) The waters continued to increase during the last night and this day-The ice during the same time ran past without intermission in immense masses, mingled with the wrecks of houses, fences, trees etc. (Red River Journal, 1826)
May 7	About 4 A.M. the ice in the Assiniboine River broke up and the waters therein rose as high as those of the Red River. The immense discharge of ice poured in from the former, into the latter mentioned, made this scene as destructive as terrific… (Red River Journal, 1826)
May 8	The rivers have become almost clear of ice, but the waters increase apace… (Red River Journal, 1826)
May 9	The waters still rose, and the whole country has assumed the appearance of a large Lake… (Red River Journal, 1826)
May 11	The floods continued to rise, considerably throughout the last twenty four hours… (Red River Journal, 1826)
May 13	The water during the whole week has been gradually rising… (Jones, 1826)
May 14	The waters rise so rapidly… (Red River Journal, 1826)
May 15	During the night the water rose six inches which is a great deal considering the extent of the surface which it now occupies… (Jones, 1826)
May 17	The waters rise at the rate of two feet in twenty four hours… (Red River Journal, 1826)
May 18	The waters continue to rise at the rate of 10 inches in the space of twenty four hours… (Red River Journal, 1826) … we were glad to find that it had only risen one inch above a mark I made on the casement of the window yesterday. (Jones, 1826)
May 19	The waters rising at the rate of four inches in twenty four hours… (Red River Journal, 1826)
May 20	…the water being almost stationary in both our rivers since last night. (Jones, 1826)
May 22	We were much comforted this morning in finding that the Main River has lowered two inches during the night… (Jones,1826) The inundation seems to have reached at length, its extreme height, it being imperceptible whether the water rose or fell during the last thirty-six hours… (Red River Journal, 1826)

clear of ice" (Red River Journal, 1826). Stages increased dramatically during this entire period.

The historical accounts make no direct mention of ice jamming but Jones' statement on May 4 that "when the ice started… the river slackened considerably" suggests that some of the rapid early rise in stage was attributable to an ice jam downstream. Both of the historical observers were located in the Winnipeg area and thus their comments do not necessarily reflect conditions as far downstream as Selkirk. Nevertheless, the indication that ice jamming did occur, however briefly, in the Winnipeg area and the descriptions of the quantity, integrity, thickness, and strength of the ice discharged from May 5-8 support KGS Group's suggestion that ice jamming may have occurred at Selkirk as well, producing a temporary peak water level in excess of the stage which would have been achieved under open-water conditions. After May 8, the water level in the Winnipeg area rose continually but more gradually, such that the peak stages reported in the vicinity of the Forks were clearly unrelated to ice jamming.

The historical record, then, is not incompatible with the KGS Group Scenario #2 explanation of the Fleming Conundrum quoted above.

The Contribution of the Assiniboine River

A further complication arises from uncertainty about the contribution of the Assiniboine River. In an earlier paper Rannie (2002) argued that the Assiniboine also experienced extreme discharge in 1826, that the Assiniboine contribution may have been as much as 20% of the upstream flow, and that the peaks on the two rivers may have been unusually synchronous. The Assiniboine joins the Red at the Forks where Fleming's surveys began and thus the effects of its contribution would appear to have been reflected in the downstream peak stages reported by Fleming. However, the high stage of the Red would have moved the actual confluence considerably to the west of its normal location (perhaps to the vicinity of Sturgeon Creek). Under these conditions, the water arriving from the Assiniboine would probably not have been a "point" addition but may have been distributed along a reach of the Red extending from the La Salle River in the south to some distance north of the present confluence.

Conclusions

The peak stage of the 1826 flood is a complex matter. The secondary puzzle identified by KGS Group in Fleming's high water data – that of the zero gradient reach – might be accounted for by a combination of wind setup on the northern margin of the Red Sea and Fleming's data treatment. Setup, however, would exacerbate the main element of the "Conundrum" – the anomaly in water levels between Winnipeg and Selkirk. There is some support for, and no data to contradict, the suggestion that the anomalously high peak stages in the Selkirk area were caused by ice jamming early in the flood. These factors and the role of abnormally large influx from the Assiniboine should be considered in future discussions of 1826 flow conditions.

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