The 1997 Red River flood in Manitoba, Canada

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Abstract: Record flooding of the Red River valley in the spring of 1997 caused extensive damage. In Manitoba, Canada, the emergency measures operation was one of the largest in Canadian peacetime history. Although the cost of the flood in Manitoba was very large ($500 million), flood control and damage reduction programmes successfully averted losses which would otherwise have been catastrophic. The causes and evolution of the flood, the emergency measures, the operation of the flood control system, and some issues raised by the event are described from a Manitoba perspective.

Introduction

In the spring of 1997, the Red River valley of Manitoba, North Dakota, and Minnesota experienced record flooding. Beginning with the dyke failure and inundation of Grand Forks, ND, on April 19, coupled with the fires that simultaneously devastated a large area of the downtown, national and even international attention was focussed on the region as the flood crest moved down valley into southern Manitoba. Dubbed the "Flood of the Century" by the media, it was in fact the largest discharge in almost 2 centuries (since 1826). This paper will review the flood from a Manitoba perspective, with particular attention to the emergency measures and the functioning of Manitoba's flood control and damage reduction system. Some broad issues raised by the event will be noted.

General Background to Flooding, Flood Control and Damage Reduction Measures in the Red River Valley

Beginning with the earliest historical accounts in the 1790's, the Red River valley has had a long record of flooding. At least 10 major floods occurred in the 19th Century, with those of 1826, 1852, and 1861 (in descending order) being the largest and, until 1997, larger than any since. Throughout most of the 19th Century, however, the population of the valley was small. Agricultural settlement and the development of urban centres (particularly Winnipeg) from the 1880's onward coincided with a long period of comparitively few floods and none of significant areal extent. Consequently, the majority of the population had little experience with floods and were unprepared for the disastrous 1950 event (the largest in the Manitoba reach of the river since 1861) which inundated 1650 km^2 and forced the evacuation of around100,000 people within the valley. Approximately $30 million (in 1950 dollars) were paid in damages and the true cost may have exceeded $100 million (United States Geological Survey 1950).

Following the 1950 flood, numerous federal and provincial agencies examined alternative ways to avert similar disasters in the future. The most immediate response was the construction of primary dykes (with sewer pumping stations) within the city which could contain flows up to a stage of 26.5 ft[1,2]; with emergency dyking on top of the primary system, this protection could be extended to the 1950 stage (30.4 ft above local datum). By 1997, this dyking system had reached a length of 110 km, much of which was incorporated into the street and boulevard system. In 1956, a Provincial Royal Commission was appointed to determine the relative economic benefits of the alternative schemes proposed by the studies and to recommend a course of action.

The Commission's report, issued in 1958, recommended a combination of structural measures to protect Winnipeg (Figure 1). The most important, and largest, of these was the Red River Floodway[3], a 47-km excavated earth channel designed to divert flow in excess of about 78,000 cfs around the eastern perimeter of Winnipeg. Flow into the channel is regulated by gates on the Red River at the southern city limit which elevate water levels upstream

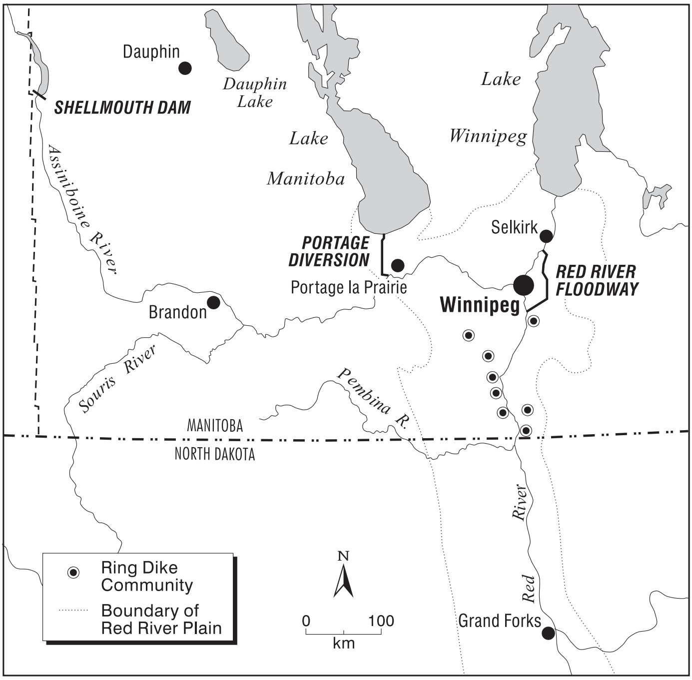

Figure 1: *General location map.*

and cause excess flow to be diverted around the city, rejoining the Red 16 km north of Winnipeg where channel capacity is sufficient to convey the entire flow. Forty-three kilometers of dykes extend east and west of the river to prevent water from bypassing the control structure and entering the city. The *normal* operating rules for the Floodway limit the upstream elevation to that which would occur naturally (i.e. with no flood control measures) to avoid increasing the risk for upstream properties. This procedure would restrict stages within the city to a maximum of 25.5 ft or 1 ft below the level of the primary dykes. Under more severe conditions, however, when stage in Winnipeg could not be maintained at this level, these rules could be superceded to divert more water through the Floodway (as much as 100,000 cfs under the most extreme conditions). This would, however, require elevating the upstream water level beyond the "natural" uncontrolled level.

The second largest structure is the Assiniboine Diversion, an excavated 29 km-long earth channel 3 km west of Portage la Prairie (Figure 1) which is capable of diverting up to 25,000 cfs northward into Lake Manitoba, thereby preventing the water from entering the Red River in Winnipeg. Finally, the Shellmouth Dam on the upper Assiniboine provides additional control of Assiniboine water heading for the Red River.

With emergency dyking of low areas between the city's primary dykes and the river, the system was designed to protect Winnipeg from floods up to 169,000 cfs with a Return Period estimated by the Royal Commission at 165 years under normal operating conditions. The routing of water through this system during such a design flood is shown on Figure 2.

After major flooding in 1966, attention turned to the Red River valley south of Winnipeg. The eight largest communities (Figure 1) were surrounded by ring dykes which provided protection against flows up to the 1950 level. Under a federal/provincial Flood Damage Reduction Agreement (signed in 1976 and extended in 1981) the community ring dykes were raised to the 100-year level (and in some cases extended to enclose a larger area), flood forecasting capability was improved, and detailed maps of the flood hazard zones were prepared. A particularly important new element in these agreements provided for non-structural, institutional measures intended to discourage or regulate development in the flood hazard zone. Through these measures, senior governments agreed to withdraw mortgage guarantees and development incentives for new construction in the flood hazard zone which was not flood-proofed to the 100-year level.

Construction of the structural elements began in 1962; the Floodway was completed in 1968 and within 4 years all other components were in place. Their effectiveness was demonstrated almost immediately. From 1969 to 1979, the average flow of the Red River was the highest on record and the system was used to manage flows exceeding minimum flood stage in 9 of the 11 years. Two of these events, 1974 and 1979, were particularly large. In 1979, the estimated *uncontrolled* stage in Winnipeg was within a few centimeters of the 1950 level, flooding was extreme throughout the valley, and more than 7,000 people were evacuated; in Winnipeg

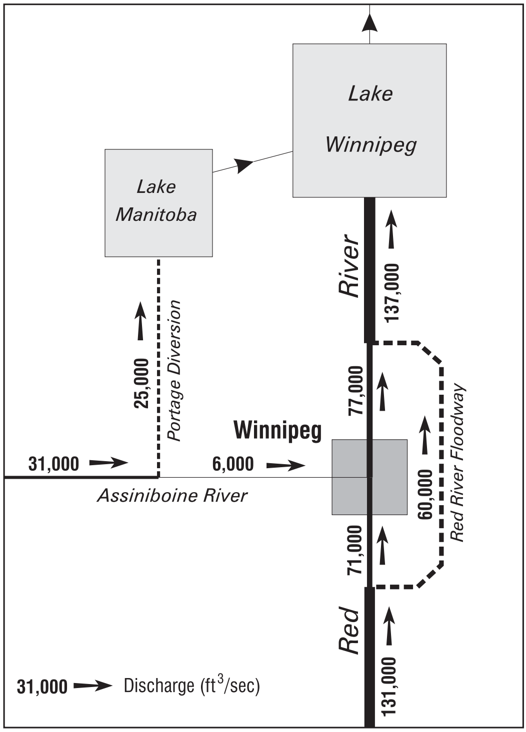

***Figure 2:** Routing of flow during a design flood (modified from Mudry et al. 1981).*

and within the community ring dykes, however, property damage was neglible and normal city activity in Winnipeg was scarcely affected. Mudry et al. (1981) estimated that by 1979, the gross value of damage reduction exceeded $1 billion (in 1979 dollars) and that the entire cost of the system had been more than recovered from *net* damage reduction. After this flood institutional measures were strengthened and individuals in the rural areas outside the ring dykes were assisted in elevating or dyking existing residential and some other types of buildings.

The system's value was again demonstrated during near-record flooding in 1996. South of Winnipeg, this event was the third largest *recorded* flood (only 1-1.5 ft lower than 1950/79) and in Winnipeg, the estimated *uncontrolled* flow equalled 1950/79 (because of a large contribution from the Assiniboine). Floodwater inundated a large area, isolating numerous communities and individual residences, but because of the control structures and damage reduction measures, the requirement for emergency measures was minor. Only about 100 homes required evacuation, and the total flood cost in Manitoba was only $12 million (Manitoba Government Information Services, 1996).

Flood Forming Conditions in 1997

The weather during the winter of 1996-97 exhibited all of the classic preconditions for large floods in the Red River valley. After a wet fall and early onset to winter, winter snowfall was much above average. More importantly, the absence of significant thaw from November to March caused the accumulated water content of the snowpack to be much above normal throughout the Red River watershed.

At the beginning of the flood forecasting process in February, then, the combination of these factors was indicating major flooding, possibly to the 1979 level . Since this was well within the capacity of the flood protection system, flood preparations were locallized and no extraordinary emergency measures were being contemplated. Furthermore, a gradual melt beginning in early March suggested that the snowpack runoff might be released in a manageable fashion. By late March, forecast peak levels (assuming normal weather) were being revised downward and there was some prospect that widespread damage might be avoided.

This optimism was changed dramatically by a record snowfall on April 5-6 over most of the Red River basin. At Winnipeg, 58 cm were recorded and as much as 90 cm fell in the southern part of the basin. Although all major floods on the Red River have been the result of snowmelt, unusually heavy precipitation just before or during the snowmelt period is required to produce floods of 1950/79 or larger size. In 1997, the April blizzard provided this crucial event, transforming what would have been a large but manageable flood into one far exceeding any since gauge records began (in 1875 for stages in Winnipeg).

The importance of this snowfall can be gauged from the fact that in the1950 and 1979 floods, runoff from the watershed above

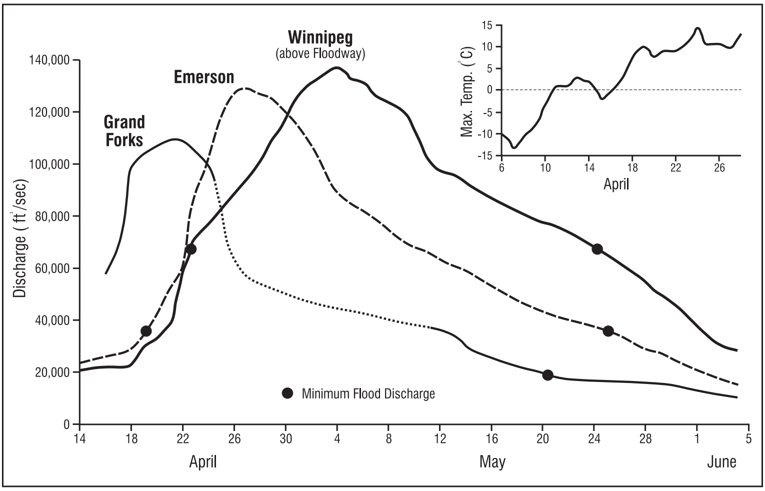

Figure 3: *Hydrographs at Grand Forks, Emerson and Winnipeg (above Floodway) with minimum flood discharge. Inset: Daily maximum temperatures at Winnipeg, April 6-28.*

Winnipeg during the *entire* months of April and May was 50-70 mm. Thus, the 1997 storm added an amount of water to the basin approximately equal to the entire runoff during the two largest *recorded* floods. This was, of course, in addition to the heavy existing snowpack. Furthermore, although the southernmost portion of the basin received rain, the fact that most of this precipitation over the majority of the basin fell as snow had a critical effect on the timing of the runoff. Had the precipitation fallen entirely as rain, runoff would have been more rapid and as the main flood crest moved downvalley, much of the local runoff would have been dissipated and contributions by tributaries would have been smaller. This is, in fact, the normal pattern during major snowmelt floods— in Manitoba, tributaries have normally peaked before the main Red River crest arrives. In 1997, however, the blizzard was followed by 10 days of cold, mostly subfreezing, temperatures and very little melt, further delaying the runoff process. At Winnipeg, for example, only 10 maximum degree-days above 0°C accumulated between April 7 and April 17 (Figure 3 inset). In the southern part of the basin, however, more of the precipitation occurred as rain and very warm temperatures set in more quickly. Thus exceptional runoff was generated quickly in the southern basin but delayed further north. When strongly positive temperatures returned in Manitoba on April 18, snowmelt was being generated simultaneously over the entire Red River valley and the tributaries were close to their peaks as the main flood crest from the United States arrived. A crucial point which will be discussed below was the fact that the Assiniboine basin escaped this snowfall almost entirely.

Emergency Measures

In March, some preparations had begun to protect the most vulnerable areas from possible flooding to the 1950/79 levels. After the blizzard, forecast stages were revised upward to 2-3 ft above the 1950/79 level and emergency measures were begun in earnest. The assistance of the Canadian Armed Forces was formally requested by the Province on April 10. Flood formation along the southernmost reach of the Red began in the following week, reaching its peak in Fargo on April 18 and in Grand Forks on April 21-22. The unprecedented discharge being recorded at Grand Forks caused further upward revisions of forecast peak stages throughout the Manitoba portion of the valley. These revisions and the catastrophic dyke failure in Grand Forks, elevated the flood preparations in Manitoba to those of a full-scale emergency and the images of flood and fire to the south galvanized the Manitoba populace.

In the valley south of Winnipeg, community ring dykes were raised to accommodate the forecast peaks with about 2 ft of freeboard and highway gaps through the dykes were closed. Outside the ring dykes, individual dykes were raised or constructed around several thousand residences and other buildings. Most farm animals and poultry were evacuated and equipment was moved to higher ground.

A State of Emergency was declared on April 20 and 21 for areas in the immediate path and on April 22, the Provincial government declared a general State of Emergency for the entire Red River valley. Although voluntary evacuation of some areas had begun earlier, a schedule of mandatory evacuations was recommended on April 23 and by April 30, 17,000 people had been evacuated from the valley, with a further 7,000 within Winnipeg (Manitoba Natural Resources 1997a). The total number of evacuees eventually reached 27,400 (*Globe and Mail* 1997). The magnitude of the task led to further requests for military personnel and equipment. Ultimately, 8,500 army, navy, air force, and coast guard personnel were deployed in the largest Canadian military operation since the Korean War. These personnel supplemented a civilian "army" of several thousand provincial employees, countless engineers, surveyors, equipment operators and others with technical skills seconded from the private sector, and tens of thousands of volunteers who built and patrolled dykes, maintained pumps, managed evacuation centres and supported others with cooking, transportation, etc.. In all its aspects, the month-long emergency management operation was the largest in Canadian peacetime history.

The most dramatic of the emergency measures was the construction of the "Brunkild" or "Z" dyke. As the flood crest approached Winnipeg, concern was expressed that the very high stages expected upstream of the Floodway might permit water from the Red and upper Morris Rivers to bypass the western portion of the Floodway wing dyke and enter the city via the La Salle River (which joins the Red just downstream of the Floodway control structure). To prevent this, an extraordinary engineering operation extended the wing dyke westward by 26 km (the Brunkild or "Z" Dyke) and augmented 15 km of the existing dyke (Figure 4). Construction of the dyke began on April 24 and continued on a 24-hour basis until its completion on April 28 (improvements were made over the next several days). In the main construction period, up to 400 pieces of earth-moving equipment were used to emplace approximately 750,000 m^3 of earth, 142,000 tonnes of limestone, 2,000 1-tonne "super sandbags", and 4,000 bales of straw. Forty kilometers of snow fence, 8 kilometers of oil boom and 2.4 kilometers of derelict vehicles were installed to absorb wave energy (Manitoba Natural Resources, 1997b). More than 450 people were involved in the effort, supported by airdropped flares to permit work at night.

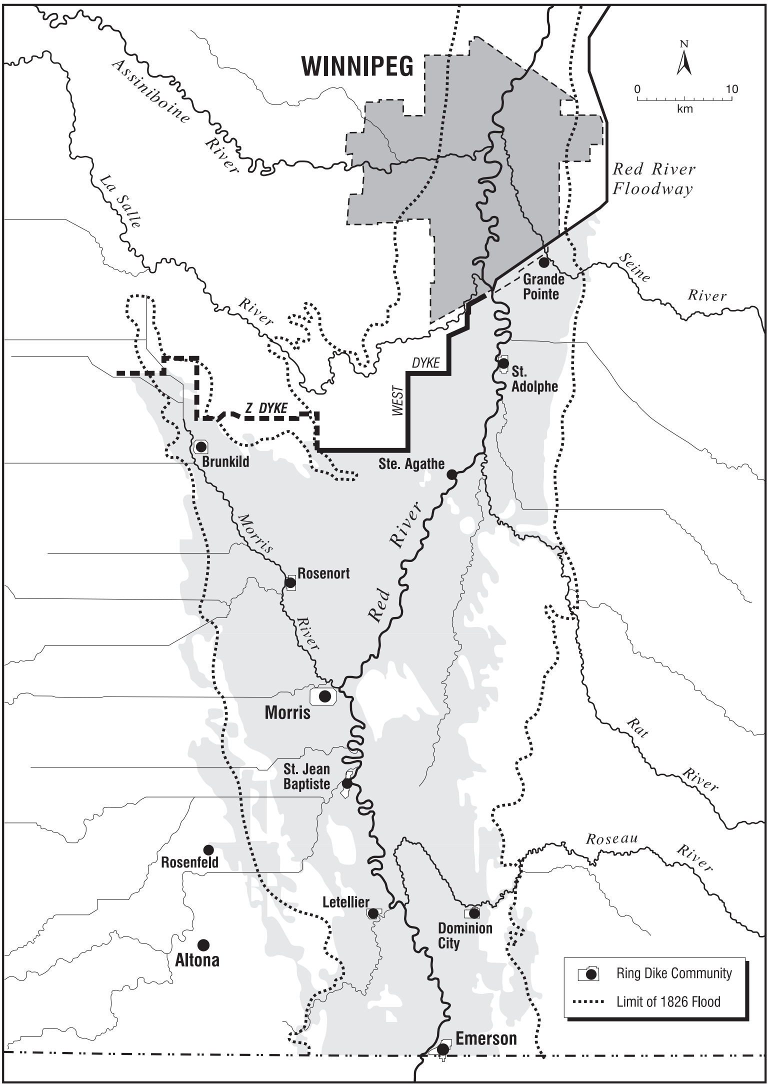

Figure 4: *Flooded area in Manitoba, Z Dyke and limits of 1826 flood.*

In Winnipeg, the control system was expected to maintain peak stages at about 2 ft below the level of the primary dyke system. Consequently, the emergency dyking (involving 6.5 million sandbags and extensive earth dykes) was limited to about 570 (mostly residential) properties in areas between the primary dyke and the river. In addition, a 4 km-long earth dyke was constructed in the southern area of the city to redirect the flow of the La Salle River in the event that the Brunkild Dyke was breached. Residents of 3456 homes in several of these areas were evacuated, most as a precautionary measure, and others were put on evacuation notice should conditions worsen. Because of this dyking, only about 30 properties within the city were flooded, although a further 74 were damaged by basement flooding after about 30 mm of rain on May 7 exceeded the sewer pumping capacity (City of Winnipeg 1997).

North of Winnipeg, downstream from the Floodway outlet, the greater channel capacity was sufficient to carry the entire flow without flooding. Nevertheless, sandbag dykes were required to protect numerous homes on very low ground, particularly where locallized flooding occurred at the junctions of tributaries with the Red.

Progress and Magnitude of Flood

The progress of the flood, from Grand Forks to Winnipeg is shown on Figure 3. The crest at Grand Forks occurred on April 21-22 and reached Emerson on the Manitoba-United States border on April 27. Even before the arrival of the main crest, however, widespread flooding was occurring along most of the Manitoba portion of the valley due to the melting of the heavy snowpack. Minimum flood stage was reached at Emerson and Morris on April 19 and in Winnipeg on April 22. The 1979 stage was reached in Emerson on April 23 and by April 25, 1979 levels had been equalled or exceeded along the entire river.

Most of the Red River tributaries in Manitoba were reaching their peaks in the April 20-25 period, close to the arrival of the main flow from the United States portion of the basin. The extensive nearly flat land bordering the river permitted floodwaters from both the Red and its tributaries to merge and spread over a broad area.

Eventually, the Manitoba portion of the flooded area created a 2000 km^2 water body with a maximum width of about 40 km, quickly named the "Red Sea" by the media (Figure 4).

Although the storage provided by this "lake" would normally flatten the hydrograph somewhat as the flood wave moved toward Winnipeg, much of the potential storage was already occupied by overland runoff and tributary overflow. This may partially account for the fact that peak stages exceeded 1979 levels by progressively larger amounts downstream- by 1.23 ft (0.38 m) at Emerson on April 27, 2.08 ft at Morris (April 30), 3.4 ft at Ste. Agathe (May 2), 4.19 ft at St. Adolphe (May 3), and 6.31 ft upstream of the Floodway at Winnipeg (May 4). These stages were generally 10-15 ft above minimum flood stage.

At Winnipeg, the Floodway began operation to control flow through the city on the evening of April 21, 13 days before the arrival of the main flood crest, to manage the high flows being generated by snowmelt over just the Manitoba portion of the valley. At the Floodway entrance, peak discharge of 138,000 cfs did not occur until May 4. Discharges on that day at various points in the vicinity of Winnipeg and on the Assiniboine (Figure 5) demonstrate the gravity of the situation and the magnitude of the disaster the flood control system averted. Without the control system, it is estimated that Winnipeg peak stage would have reached 34.3 ft (Warkentin, 1997), about 4 ft above the 1950 level and 8 ft above the primary dyking system. Such an uncontrolled flow would have flooded much of the city and forced the evacuation of a large percentage of the population of 650,000. With the flood control system operating, however, peak stage in the city was limited to 24.5 ft, 2 ft below the primary and secondary dykes.

As Figure 5 shows, most of this protection was due to the Floodway which at the flood peak carried 47% of the upstream flow (65,100 cfs) around the city. Once the crest was reached on May 4, the operation of the Floodway became a compromise among competing (and partially contradictory) objectives within Winnipeg and upstream of the Floodway. In both locations, the longer water levels against the dykes remained high, the greater was the potential for failure, leakage, or overtopping by waves and wind setup. In Winnipeg, where most secondary dykes were on the riverbank, the

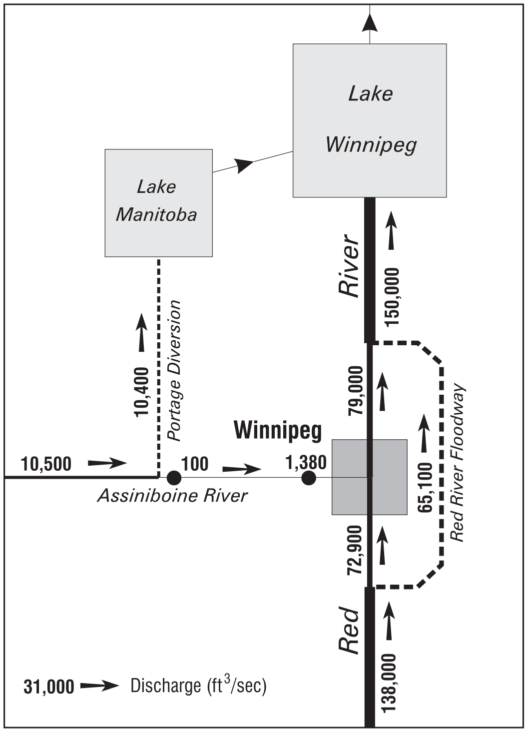

Figure 5: *Routing of flow on May 4, 1997.*

threat of bank collapse from the weight of the dykes became an urgent concern. Thus, even after the crest had passed, water continued to be diverted at a high rate to reduce stages within the city as rapidly as possible and permit secondary dykes to be lowered or dismantled earlier. In addition, lowered city stages reduced the potential for damages from sewer backup if significant rainfall occurred. The permissable rate of stage reduction in the city was limited, however, by concern that too rapid a drop might itself have caused dyke or bank failure. Upstream of the Floodway, lower levels were desirable to reduce the pressure against dykes and eliminate the threat from wave action, wind setup, and leakage. When stages within the city fell below minimum flood level, flow through the Floodway was reduced more quickly, reaching zero on June 3.

Less well-appreciated by the media and public was the role played by the Assiniboine Diversion in reducing flows within Winnipeg. Although maximum runoff in the Assiniboine basin was only 0.17 m^3/sec/km compared with 1.18 m^3/sec/km^2 in the Red, flows were nevertheless above average and in the days leading up to the Red River crest at Winnipeg, approximately 11,700 cfs were being diverted out of the Red River system, virtually eliminating downstream flow toward Winnipeg (on May 2, flow downstream of the Diversion actually reached zero). Without this ability to reduce flow in Winnipeg, discharge within the city would have been about 15% greater and stages possibly 2.5 ft higher, exceeding the level of the primary dykes. To handle this additional water by routing more through the Floodway (which was already carrying about 9% more than its normal design capacity) would have further compromised the already critical state of the surviving dyked buildings within the backwater zone, and reduced the capacity to accommodate higher flows which might have developed with adverse weather.

The estimated *uncontrolled* peak stage and discharge in Winnipeg were 34.3 ft and 163,000 cfs respectively (Warkentin, 1997), approximately equal to the values estimated for the second largest known flood, in 1852. Thus, in 204 years of documented flood history in Manitoba, the 1997 flood was exceeded only by the 1826 event (which reached a stage about 2 ft higher in Winnipeg). The most recent frequency curves indicate that from Emerson to Winnipeg, the 1997 flood had a Return Period of 110-120 years.

The relative discharges of the Assiniboine and Red Rivers in 1852 are not known. Interestingly, however, diary entries by Reverend Abraham Cowley indicate that the Assiniboine exceeded bankfull stage from Portage la Prairie to modern-day Headingley:

> May 22, 1852: Reached Portage la Prairie; Here the people have been flooded out of their houses...
>
> May 24, 1852: Left Portage la Prairie & descended the river till nearly sun set... It has become difficult to land when one wishes the banks being generally overflowed.

May 25, 1852: Reached White Horse Plain much of it is overflowed...

Prior to 20th Century dyking, natural bankfull discharge along this reach was 12-15,000 cfs (Mudry et al. 1983) and the quotations above indicate that discharges significantly in excess of this value were occurring close to the Red River peak date (c. May 19). If the uncontrolled 1997 peak stage in central Winnipeg was about the same as in 1852, it is possible that the 1997 flow on the Red upstream of the city may have been somewhat larger than in 1852.

As severe as the 1997 event was, but for two factors, it could have been significantly worse. The first was the favourable flow pattern of the Assiniboine River. As was noted above, most of the Assiniboine basin escaped the major blizzard that produced the exceptional runoff in the Red River basin. Upstream of the Assiniboine Diversion, discharge peaked at 29,500 cfs on April 20, two weeks earlier than the crest of the Red (at Winnipeg), and fell rapidly thereafter; by April 22, it was only 14,980 cfs, well within the capacity of the Diversion to re-route the entire flow as discharge of the Red approached critical levels. By the crest date of the Red (May 4), it had fallen to 10,500 cfs. In contrast, in 1996 maximum discharge was 32,700 cfs and the maximum ever recorded was 51,700 cfs in 1976. Clearly, the Assiniboine is capable of generating much more runoff than occurred in 1997 and had significant areas of the basin been affected by the blizzard, it is likely that peak discharge would have been larger and would have occurred somewhat later. Even the 1996 discharge exceeded the capacity of the Diversion and the excess downstream flow from a flow of that magnitude would have produced stages in Winnipeg near the level of the primary dykes. With the Floodway operating slightly above desired capacity, virtually any increase in the Assiniboine flow entering Winnipeg would have required either raising the city's primary dyke system (which would have increased the magnitude of the emergency measures enormously, endangered more properties, and increased the number of evacuations) or diverting more water through the Floodway, causing flooding of even more properties in the backwater zone. With the negligible inflow of the Assiniboine, virtually the entire 1997 peak flow was from the Red River and the assumptions about the water gradient south of the confluence on which the normal operating rules for the Floodway were seriously compromised. Stages of 24.5 ft in central Winnipeg (which allowed for 2 ft. of freeboard) translated into relatively higher equivalent stages in south Winnipeg, coming within inches of overtopping the secondary dykes in St. Norbert (Manitoba Natural Resources 1997d).

The second mitigating factor was the favourable weather which prevailed after the blizzard. From April 7 to the flood crest at Winnipeg on May 4, precipitation at Winnipeg was only 70% (c.20 mm) of normal. A major rainstorm (30 mm) on May 6-8 came after the river had crested and had little effect on river stage, although it did cause sewer backup and damage to some Winnipeg homes. The greatest weather hazard came from strong (50-70 kph) south winds on several days when stages were near their crest. Waves and setup on the 2000-km^2 "lake" elevated downwind water levels and threatened the integrity of many dykes.

In the valley south of Winnipeg, ring dykes had been elevated to 3-4.5 ft above peak stages. With continuous monitoring and maintenance, the dykes held and little damage occurred within these communities. Individually dyked buildings in the predominantly rural area outside the ring dykes, however, fared less well. Almost a year after the crest (April 20, 1998) 5,247 private and 69 municipal damage and compensation claims had been filed (Siroka 1998). With slightly more than 50% of claims settled, $116 million had been paid out ($61.4 million to private owners and $54.6 million to municipalities). Published figures for expenditures on emergency measures, cleanup, and repair of roads and bridges exceed $120 million. When other costs such as uncompensated damage, lost income and business, donated goods and services, reestablishment of businesses, interest on lines of credit to municipalities, stabilizing damaged riverbanks in Winnipeg etc. are included, the ultimate costs of the flood may reach $500 million. Spurred by Canadian media attention, several national fund-raising campaigns raised c.$20 million to assist victims beyond official governmental compensation.

Damage severity increased downstream, being greatest in the Rural Municipality of Ritchot immediately south of Winnipeg where two communities suffered particularly heavy losses. Ste. Agathe (population 500) was not protected by a ring dyke, relying on a combination of road and railway embankments, some permanent dykes, and emergency dykes. This defence failed on April 29 when water washed out a section of temporary dyke and flooded much of the town. Grande Pointe is a residential community of 150 homes one km south of the Floodway and thus outside of its protection. On May 1-2, as flow upstream of the Floodway was nearing its peak, dykes around c.125 homes were overtopped.

A notable feature of Red River floods is their long duration. The large volume of storage within the valley which causes a gradual buildup to the peak also extends the recession limb over several weeks after the crest. In 1997, flow did not fall below minimum flood stage between Emerson and St. Adolphe until May 25-29, four weeks after the peak; at most locations, the river was above minimum flood stage for a total of 36-40 days. Thus the danger from dyke fatigue, leakage, waves, wind setup, and adverse weather required vigilance for some time after the crest passed.

Evacuees began returning to some regions on the margins of the flooded area on May 3-5 but the long recession delayed re-entry to most communities and homes near the river. Emerson was not re-occupied until May 12, 3 weeks after evacuation began and as late as May 15, 12,000 people remained evacuated (Manitoba Natural Resources 1997c). Most of these were permitted to return beginning on May 17. In Winnipeg, where the majority of evacuations were precautionary, most evacuees were resettled by May 15.

Discussion

The 1997 flood raised (or resurrected) a number of broad issues, including such immediate concerns as the level and timing of damage assistance, the management of emergency measures, and the precision of forecast stage information on which dyke building in the valley was based.

Some of the strongest criticism concerned the operation of the Floodway. Flow into the Floodway is created elevating the upstream water level of the Red River and normal operating rules limit this upstream elevation to that which would have occurred with no control measures (i.e. in the absence of the Floodway, Assiniboine Diversion and Shellmouth Dam). In several previous floods, property owners in this affected area claimed that the control structure had created higher-than-natural water levels upstream. Predictably, the controversy was renewed in 1997 when for the first time it was necessary to divert more than 60,000 cfs to maintain stages within Winnipeg at design level. Beginning on May 1, upstream water levels were raised by about 0.5-1.0 ft[4] above the design or “natural” stage to increase Floodway discharge to 65,100 cfs. This decision was taken to provide 1 ft additional freeboard on the city dykes, to reduce the possibility of storm sewer backup, and to prevent overtopping of secondary dykes in the southern part of the city (Manitoba Water Resources 1997d).

After Grande Pointe suffered major damage, the May 3 headline in the *Winnipeg Free Press* proclaimed “Suburbs Sacrificed to Spare Winnipeg”. While the small artificial elevation of water level upstream may have been a minor contributing factor to the flooding of these properties, many of the assertions of residents of the upstream zone misrepresent the hydrological circumstances and the gravity of the situation. For example, the President of The 768 Association, representing the residents of Turnbull Drive immediately south of the Floodway control structure, offered the following critique of the operation of the control system:

> When one reviews the 1997 flood and in particular compares its progress to both the 1996 and 1979 floods... it is difficult not to conclude that the 1997 flood was made far worse than it should have been because of the operation of the control gates... Within 3 days of activating the control gates the flood waters south of the gates were approaching the historic 1950 levels... Most profound to me, was the degree by which the 1997 flood deviated from the pattern of the 1979 flood... Since >80% of the flood waters come from the ... (United States), and since during the time of the flood there was no significant precipitation, and since much of the local runoff had preceded the crest period,

> one would anticipate a similarity between the 1979 and 1997 floods. That similarity simply does not exist. (Hunter 1997)

The similarity Hunter felt should have occurred didn't because the hydrologic circumstances in 1997 were so different from those of 1979. As was noted above, the delay in significant melt for 10 days after the blizzard caused severe runoff to be generated simultaneously over the entire basin. In contrast, the severity of the 1979 flood was primarily the result of heavy rainfall in the United States portion of the basin during the snowmelt period. In 1997, levels equalling 1979 and/or 1950 were produced by "local or regional" runoff. The 1979 stage was surpassed at Emerson and Letellier on April 23, at St. Jean a day later, and by the morning of April 25 (about 3 days after the beginning of operation of the control gates), 1979 levels had been reached or exceeded along the entire Manitoba section of the river, 5-10 days before the arrival of the main body of water from the United States. By the morning of April 26, discharge at the Floodway entrance was slightly greater than the peak 1979 discharge and the crest was still 9 days away. Thus, Hunter's statement that "much local runoff preceded the crest period" ignores the fact that this "local" runoff was by itself capable of producing 1979 levels and initiating the operation of the floodway. Although the control gates were indeed raised very rapidly from April 22 to April 24, this was a response to the rapidly rising stage complicated somewhat by ice problems; actual stages during the period closely followed the computed natural stages until April 27 (Figure 6, Manitoba Water Resources 1997d). Thereafter, for the reasons noted above, stage was 0.5-1.0 ft above natural until May 7.

A more fundamental issue, however, is the fact that many of these buildings in the upstream "backwater" zone post-dated the beginning of Floodway construction and their presence compromises the most effective operation of the structure designed to protect the adjacent city of 650,000. This problem will continue to arise in future floods unless long-term policies for building in this area (including more strict and carefully enforced land-use regulation) are implemented. Within Winnipeg, numerous buildings

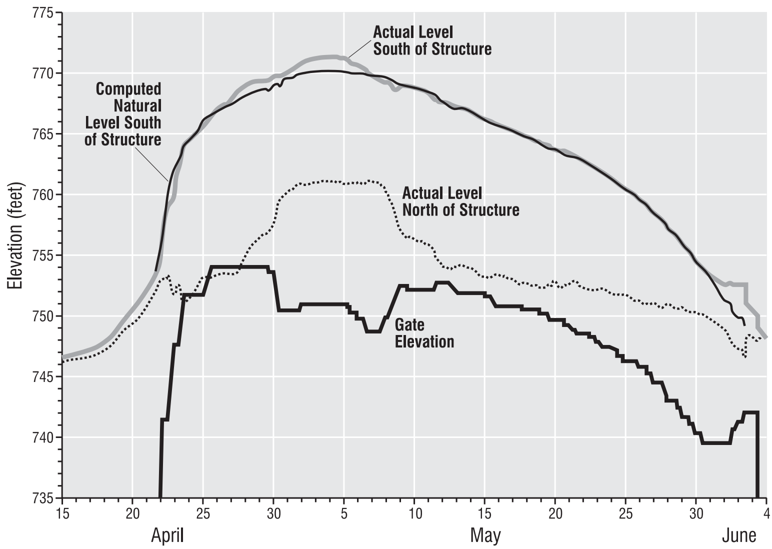

Figure 6: *Actual and computed natural stages north and south of the Floodway and at James Avenue, and control structure gates elevations (after Manitoba Water Resources 1997d).*

which required dyking were located within the flood hazard zone where again, more strict land-use control within the flood hazard zone will be necessary to reduce the need for future emergency measures.

The 1997 flood also refocussed attention on the question of land drainage in the Red River Valley, an issue which was raised after the 1979 flood but which quickly died away during the subsequent drier period of the 1980's. Beginning early in the century, extensive artificial drainage of agricultural land in the valley has been effective in speeding the spring drainage of agricultural land and in draining wetlands for agriculture. It may also, however, have intensified runoff and increased effective drainage area by transforming non-contributing into contributing area. The increased incidence of flooding in the last 30 years has drawn attention to the drainage ditches as a possible contributing factor; while they are not the cause of major floods, their cumulative impact in exacerbating flood levels needs to be re-examined.

Not all consequences of the flood are negative. Every flood has left its own legacy of improvement in the region's ability to cope with its greatest natural hazard. The 1950 flood led to the construction of the basic control measures, focussing on Winnipeg. After the 1966 event, the ring dykes around valley communities were added to the infrastructure. The 1974 flood initiated discussion of flood-proofing and institutional measures without which the effectiveness of the structural measures would be gradually eroded. Finally, the 1979 flood led to an increase in the design standards for dykes within the valley, triggered the dyking and flood-proofing programme, and reinforced the need for institutional measures. The 1997 flood will produce a similar improvement in flood preparedness and further reduce the damages from future floods. Many new earth dykes will become permanent and the improvement of the community and individual dykes will provide greater protection. More strict land-use control and enforcement will further reduce the need for future emergency measures. The first steps in this direction were announced in July 1997. Under a joint Provincial and Federal programme similar to that implemented after 1979, community ring dykes will be improved, new ring dykes will be constructed (eg. around Ste. Agathe and Grande Pointe) and individuals will be assisted in permanently dyking, elevating, or relocating buildings to 2 ft (0.6 m) above the 1997 level at an estimated cost of $50 million (Manitoba Government Information Services 1997). The City of Winnipeg has also announced plans to increase the secondary dyke system, isolate health care facilities from the sewer system, improve pumping capacity, control urban drainage, and extend the regulation of land use.

Perhaps the most important legacy is the heightened general awareness of the hazard. The flood educated the public regarding the functioning of the control system and will undoubtedly ease the acceptance of the need for future expenditures, land-use regulation, and other damage-reduction measures. Understandably, the greatest media attention was devoted to the drama of the emergency response and the victims' losses. With some reflection, however, the biggest story of the 1997 flood was probably what didn't happen— the widespread flooding and wholesale evacuation of Winnipeg. The damages such an event would have entailed are difficult to envisage but would have been many billions of dollars. On a smaller scale, the undamaged ring-dyked communities and individual buildings throughout the valley were less newsworthy than the devastation suffered by Ste. Agathe, Grande Point and the many buildings whose dykes proved insufficient. Nevetheless, the fact that the flood control and damage prevention measures averted perhaps 95% of the damages that would otherwise have occurred (and virtually 100% of the damages they were designed to prevent) demonstrated the effectiveness of the programme of flood control and flood proofing which has been evolving in Manitoba over the last 50 years.

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End Notes

[1].Although SI units are normally preferable, local convention during the flood in media reports, published data and most discussions was to state stage and discharge in Imperial units. Since these units are so engrained in local usage, even within the professional hydrologic community, this convention has been followed in this paper. Thus stage is given in feet and discharge is given in cubic feet per second. All other data are given in SI units.

[2].Stages for the Red River in Winnipeg are stated in feet above the normal winter ice level at James Avenue, in central Winnipeg just downstream of the confluence with the Assiniboine. This reference elevation has been defined as 727.57 feet above sea level.

[3].The capitalized term "Floodway" used in this paper refers to the official name of the diversion channel around Winnipeg and should not be confused with the more general usage elsewhere to designate a specific portion of the floodplain.

[4].Existing rating curves (dating from the 1950's and 1960's) indicated that stage was about 1 ft above "natural" but the 1997 experience suggested that these curves yielded stages which were about 0.5 ft too low. Thus it was estimated that the "excess" elevation was only 0.5 ft above "natural" (Manitoba Natural Resources 1997d)