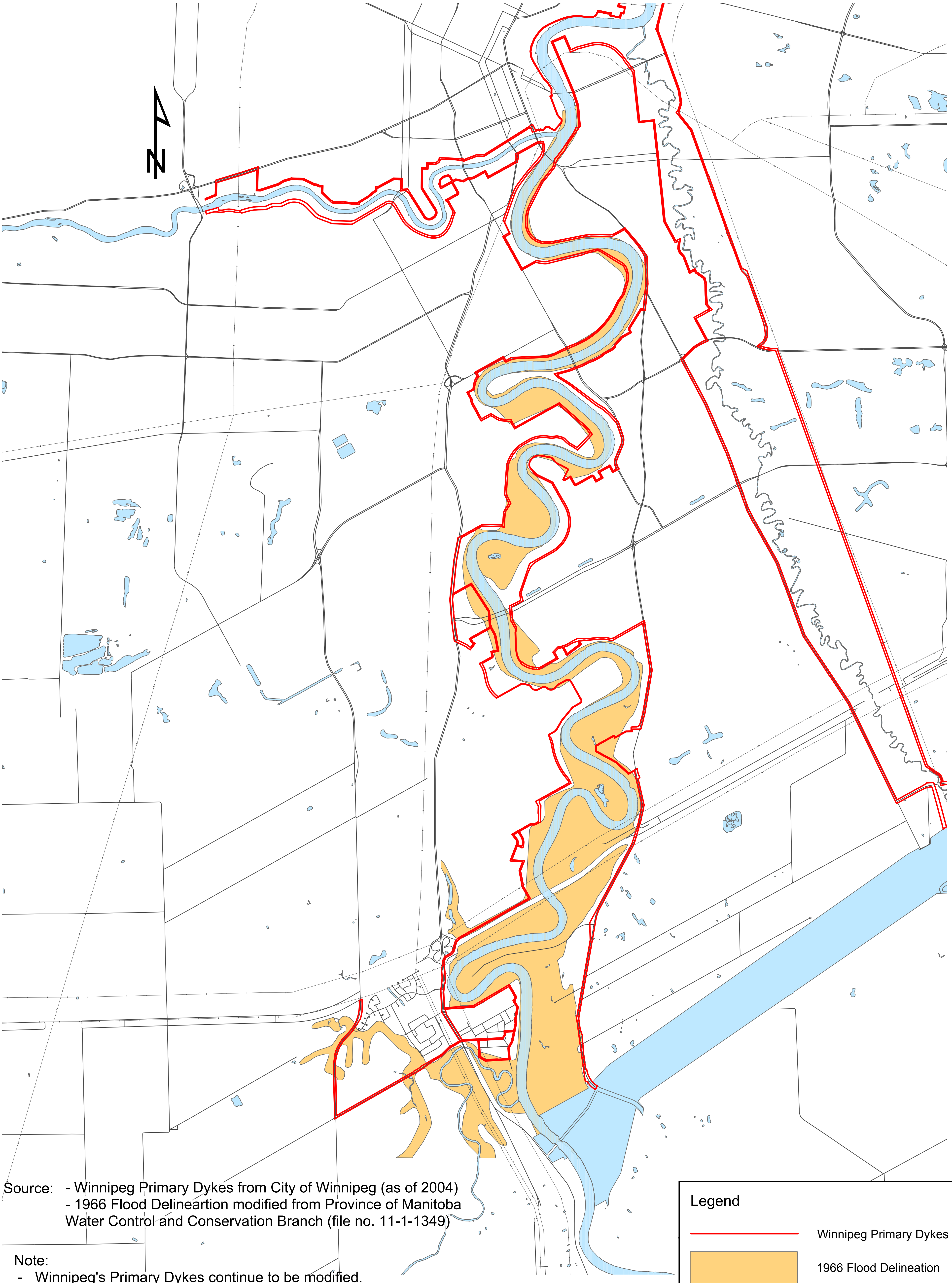

Source: - Winnipeg Primary Dykes from City of Winnipeg (as of 2004)
- 1966 Flood Delineartion modified from Province of Manitoba Water Control and Conservation Branch (file no. 11-1-1349)

Note:
- Winnipeg's Primary Dykes continue to be modified. An examination of this figure relative to Figure 2-12 indicates that some of the flooded areas in 1966 are now protected by primary dykes.
- In 1966 the Red River Floodway was only 75% completed. An earth dyke existed on the southerly extension of St. Mary's Road preventing the Red River flows from going further eastward.

FIGURE 2-13
1966 Flooded Area Map of Winnipeg

ACRES

Similar to 1950 flood, river stages and meterings were recorded along the Assiniboine and Red River. This information is documented in a report by Long (1971).

2.3 Review of 1950 and 1966 Water Level Profiles

Table 2-2 provides a summary of peak water level stages for the 1950 and 1966 floods as documented by Clark (1950) and Long (1971) in their reports. A third dataset was added for May 29, 1950, which had a comparable James Avenue stage to that of 1966. Note that in 1966, data from April 15 (JAD 26.17 ft) was chosen for analysis purposes, versus April 14 (JAD 26.24 ft) the actual peak day on the river. April 15 was chosen because up until that day, stages were still rising significantly (i.e., 0.60 ft rise between April 13 and April 14 at James Avenue) while on April 15 water levels had stabilized near the peak. The second reason for choosing April 15 is that all water levels as reported by Long (1971) are point measurements, except for James Avenue stage which was the recorded mean for the day.

Table 2.2
Selected River Stages from 1950 and 1966 Red River Floods

	River Centre-line distance (km)[1]	May 19th, 1950 @ noon		May 29th, 1950 @ 8 am		April 15, 1966 @ peak		Absolute Difference Between Bridge Losses (A - B)
		stage[2,3] (ft)	drop thru bridge x-sec	stage[2,3] (ft)	drop thru bridge x-sec (A)	stage[2,4] (ft)	drop thru bridge x-sec (B)	
Ft. Garry Municipal Hall	71.28	35.49		31.53		28.99		
Elm Park Bridge u/s	64.43	33.53		29.33		28.99		
Elm Park Bridge d/s	64.42	33.39	0.14	29.19	0.14	28.45	0.54	0.40
Norwood Bridge u/s	58.21	31.15		27.21		26.89		
Norwood Bridge d/s[5]	58.20	30.93	0.22	27.08	0.13	26.83	0.06	0.07
Provencher Bridge u/s	57.14	30.81		26.96		26.83		
Provencher Bridge d/s	57.13	30.29	0.52	26.49	0.47	26.54	0.29	0.18
CNR Bridge u/s[7]	56.60	30.18		26.40		26.33		
CNR Bridge d/s	56.59	29.74	0.44	26.18	0.22	26.33	0.00	0.22
James Ave pumping stn	56.37	30.30		26.40		26.17		
CPR Bridge u/s	54.54	29.33		25.71		25.43		
CPR Bridge d/s	54.53	29.27	0.06	25.70	0.01	25.43	0.00	0.01
Louise Bridge u/s	54.06	28.72		25.20		25.13		
Louise Bridge d/s	54.05	28.62	0.10	25.10	0.10	25.01	0.12	0.02
Redwood Bridge u/s	52.46	28.12		24.75		24.31		
Redwood Bridge d/s	52.44	28.08	0.04	24.70	0.05	24.11	0.20	0.15
North City Limits	50.87	26.99		23.53		23.97		
Bergen Cutoff u/s[6]	47.80	26.14		22.84		23.30		
Bergen Cutoff d/s[6]	47.79	26.07	0.07	22.75	0.09	23.23	0.07	0.02
Gauge #3 -Middlechurch[6]	42.99	24.06		20.95		21.01		

1 - distance calculated from HEC-RAS and geo-referenced map (see Appendix B, Table B1)
2 - stage relative to James Ave datum
3 stage data from Clark (1950)
4- stage data from Long (1971)
5 - "downstream #2 gauge
6 - based on 1 water level reading per day
7 - interpolated data for May 29th, 1950 for upstream gauge

file: Analysis of 1950 and 1966 Flood Data.xls

2.3.1 Bridge Losses

Prior to evaluating individual bridge losses, an assessment was made of the overall slope of the water surface profile to determine what effect, if any, it might have on the calculation of localized bridge losses. Over the 23.5 km distance between Ft. Garry Municipal Hall and Bergen Cutoff the water level drops 9.35 ft, with 1.59 ft of that drop attributed to losses through the 8 bridges (Table 2.2). Based on a net drop of 7.76 ft (i.e., minus bridge losses) the slope of the river is calculated at about 0.10 ft per 1000 ft (approximately ½ ft per mile). While Clark (1950) does not record the actual location of the upstream and downstream gauge, if it is assumed that the gauges had a separation of 200 ft then the drop between the gauges due to normal water surface profile could potentially be 0.02 ft. Differentials this small would be difficult to detect given some of the inaccuracies inherent in gauge board reading, therefore it can be concluded that river slope is insignificant in the bridge loss calculation.

Table 2.2 provides a calculation of bridges losses for the 2 flood years; the losses which are higher than normal have been shaded to assist in the following discussion.

In 1950, high bridge losses were observed for the Provencher and CNR bridges (adjacent bridges) both at the peak and on the recession limb. At the peak, bridge losses were in the range of 0.52 ft for Provencher and 0.44 ft for the CNR Bridge and 0.22 ft for the Norwood Bridge. While some of the losses for the Provencher and Norwood Bridges can be attributed to a portion of the bridge superstructure being submerged and creating additional losses, not all of the loss can be attributed to this factor. In the case of the CNR Bridge, the deck is well above the 1950 flood level (Appendix C) and the piers are relatively efficient, therefore other factors are responsible for the large losses, which may include datum errors and/or unaccounted hydraulic factors such as local scour, back eddies or gauge siting issues. Modelling should be able to determine how much of the bridge losses can be attributed to normal hydraulic losses and what portion of the loss could be attributed to other unexplainable factors that cannot be modelled.

The losses through the Norwood Bridge of only 0.22 ft at the peak may be lower than expected. Losses may be moderated somewhat by the inflow of the Assiniboine River just below the Norwood Bridge potentially causing a backwater effect.

A number of bridge sites were accumulating debris floating down the river. Free Press (1950) and Winnipeg Tribune (1950) photo supplements show examples of debris against the bridges, such as a house colliding with the Elm Park Bridge and having to be removed by dynamite. Figure 2-9 shows an example of debris accumulated against the Norwood Bridge. If a significant amount of debris collects at the bridges this may cause elevated stages.

In 1966, the bridge with the highest loss is the Elm Park Bridge at 0.54 ft (versus only 0.14 ft in 1950). While some of the higher losses in 1966 could be attributed to all the flow going through the river section and not overland as it did in 1950 (see Figure 2-10 and Section 2.1), the loss in 1966 is larger than expected for a bridge with a centre pivot pier similar to the Louise and Redwood bridges (Appendix C). Close examination of the daily stages at this bridge show that the water level differential was relatively constant on the rising limb of the hydrograph until April 10 where the differential grew to 0.50 ft over a period of 3 days of the hydrograph and remained relatively constant on the falling limb of the hydrograph to April 26 well below the April 10 stage. The data does not support a gauge re-location error (which would have appeared instantaneously) or gradual increasing bridge pier hydraulic losses due to higher flows. Why the Elm Park Bridge shows a large differential in 1966 is unresolved.

Table 2.2 also shows the absolute difference for the bridge losses between May 29, 1950 and April 15, 1966 where flows are relatively the same. Those bridges with large variations such as Elm Park and CNR likely have differences attributable to other factors than bridge hydraulic factors. The bridges with the largest differential between the two years are Elm Park, CNR and to a lesser degree Provencher. The difference in Provencher at 0.18 ft is approaching the expected accuracy of these types of readings.

Overall, except for the losses through the Norwood Bridge and Provencher bridge of about ¾ of a foot at the peak in 1950, the losses through the other bridges are relatively minor (if it assumed that there are unexplained gauge errors in 1950 for the CNR bridge and in 1966 for the Elm Park Bridge). The recent reconstruction of the Norwood Bridge and Provencher Bridge with hydraulically efficient piers will significantly reduce the losses at these two locations.

Since the 1960's, 6 new bridges have been built: South and North Perimeter, Chief Peguis, Disraeli Freeway, St. Vital and Bishop Grandin, all these bridges have narrow, hydraulically efficient piers as well as large unobstructed openings between the bridge abutment and water edges providing additional flow area during floods. It is probable that the new bridges will add very little additional staging to the river during flood periods.

2.3.2 Water Level Profile

Figure 2-14 shows a plot of several water level profiles from Middle Church (just north of the Perimeter Highway) to Norwood Bridge using water level

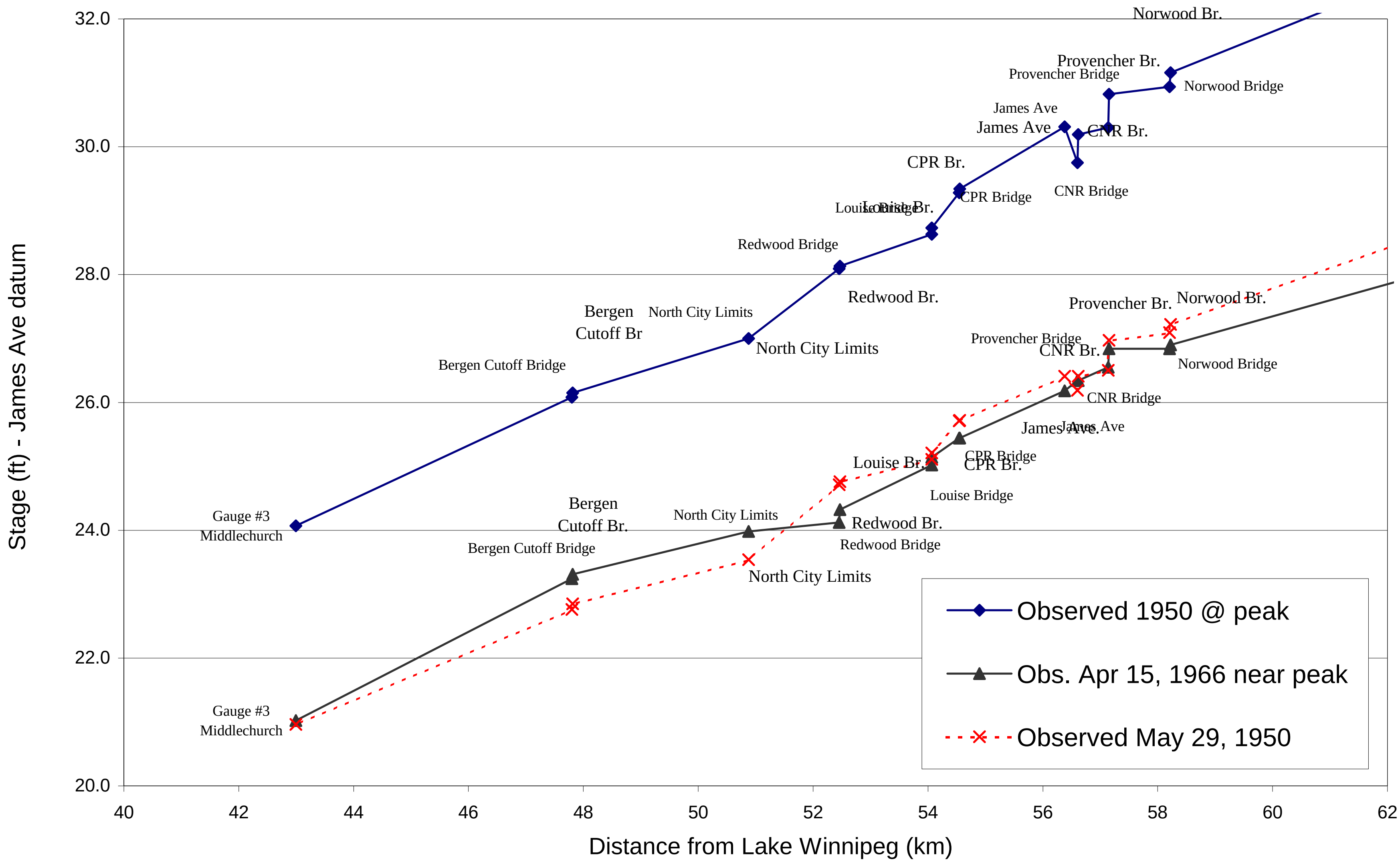

Figure 2-14
Comparison of Water Level
Profiles for 1950 and 1966 Flood

data from Table 2.2. This plot shows the profile of the 1950 and 1966 flood at the peak and at a lower stage in 1950 that corresponds to the 1966 peak levels.

Examination of the 1950 peak profile shows that there is a progressive rise in water levels moving upstream except for the James Avenue to Provencher Bridge section of the river. While it has been previously indicated that there are potential datum errors for the CNR Bridge it is uncertain in examining the profile whether an adjustment should also be made to the James Avenue level and/or the downstream Provencher Bridge level. At a lower river stage, i.e., May 29, 1950 the differential in the James Avenue/CNR Bridge reach of the river reduces significantly but it is still present somewhat.

Comparing both the peak April 15, 1966 and May 29, 1950 profile shows gauge/datum differentials between the two years. Starting from the downstream Middle Church gauge and progressing upstream, profiles are crossing each other and there are slope change differentials between the stations. From a modelling perspective, the only practical approach to resolve these differences is to compute the water level profile and use the modelling to provide additional information on the reliability of a given stage.

While the water surface profile on April 15, 1966 and May 29, 1950 are relatively close, as a result of selecting a date in 1950 where the James Avenue stage was similar to that of 1966 stage, the discharges are not. The metered discharge for May 29, 1950 was 84,600 cfs, versus the April 15, 1966 metering of 88,500 cfs (Table 2.3). While some of the 4,000 cfs differential might be attributable to normal metering error or potentially hysteresis with the 1950 metering (although none has been observed with the 1950 data) it appears that the main reason for the flow discrepancy is attributable to metering differences between 1950 and 1966 as discussed in the next section.
The flat stage between Provencher and Norwood bridges is probably due to a number of cumulative factors including the staging that occurs at Provencher and the backwater effect from flow input from the Assiniboine River (Table 2.1).

2.3.3 Flow Measurements

Flows estimates during the 1950 and 1966 floods were based on meterings taken at the Water Survey of Canada (WSC) gauge at Redwood Bridge (Station No. 05OJ001). During the 1966 flood, forecasters noted a considerable shift to the right in the rating curve of the Redwood Bridge, giving stage reductions of almost two feet (Flood Forecasting Committee, 1966). (Rating curves are plotted with stage on the y-axis and flow on the x-axis, a shift in the right for the rating curve means that for a given stage the channel is conveying a higher discharge.) While potential explanations for the shift were given in the April 12, 1966 meeting notes, "it was concluded that it would be desirable to investigate this phenomenon in an endeavour to ascertain the reasons for it".

Figure 2-15 shows the Redwood Bridge meterings of 1950, 1956 and 1966 and the Redwood Bridge rating curve as illustrated in Long (1971). This figure clearly shows that the 1950 meterings appear as outliers on this rating curve and that the rating curve is "force fitted" to the highest stage for 1950. Also shown on the curve is a third order polynomial fit of the 1950 data and the 1956 and 1966 data.

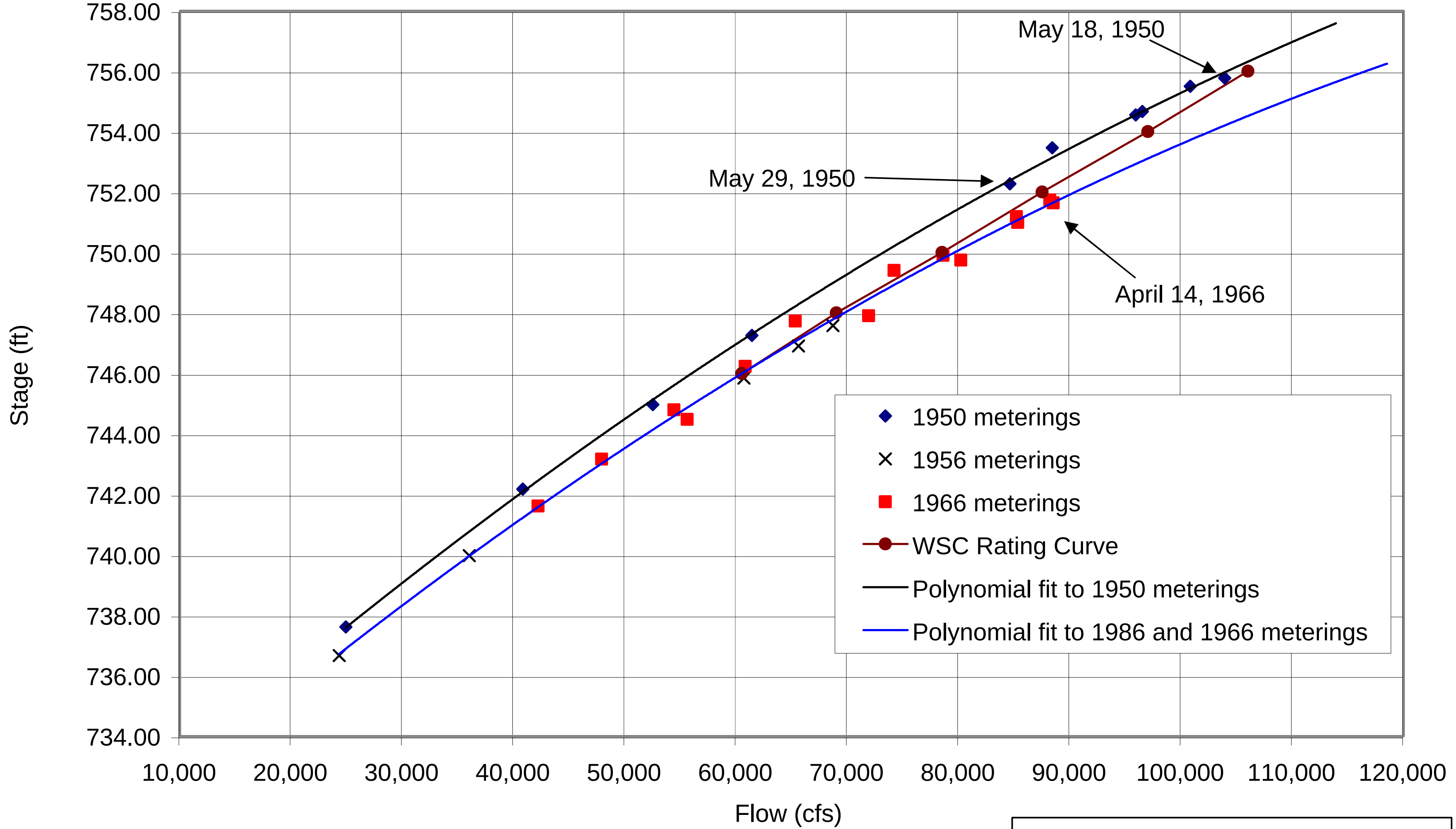

FIGURE 2-15
Redwood Bridge Rating Curve

Table 2.3
Redwood Meterings from 1950, 1956 and 1966 Floods

Date	Area (ft^2)	Velocity (cfs)	Discharge (cfs)	Gauge Height (ft)
08-May-50	16,770	5.27	88,400	753.47
10-May-50	17,500	5.51	96,500	754.67
12-May-50	18,000	5.59	100,800	755.50
18-May-50	18,200	5.71	103,900	755.77
25-May-50	17,200	5.56	95,900	754.55
29-May-50	16,300	5.20	84,600	752.27
06-Jun-50	13,600	4.51	61,400	747.26
09-Jun-50	12,590	4.17	52,500	744.97
13-Jun-50	11,100	3.67	40,800	742.17
21-Jun-50	8,930	2.79	24,900	737.61
25-Apr-56	13,900	4.72	65,600	746.91
27-Apr-56	14,500	4.74	68,700	747.58
04-May-56	13,500	4.50	60,700	745.85
15-May-56	10,200	3.53	36,000	739.97
05-Jun-56	9,120	2.66	24,300	736.67
04-Apr-66	10,400	4.06	42,200	741.61
06-Apr-66	11,800	4.77	55,600	744.48
09-Apr-66	14,700	5.25	71,900	747.91
11-Apr-66	15,200	5.47	80,200	749.75
13-Apr-66	15,600	3.94	85,300	750.99
14-Apr-66	16,200	5.43	88,200	751.74
15-Apr-66	16,300	5.43	88,500	751.64
18-Apr-66	16,000	5.32	85,200	751.19
21-Apr-66	16,000	5.32	78,600	749.91
22-Apr-66	14,900	4.98	74,200	749.41
25-Apr-66	14,700	4.45	65,300	747.73
27-Apr-66	12,900	4.71	60,800	746.23
29-Apr-66	12,400	4.40	54,400	744.79
02-May-66	11,300	4.23	47,900	743.16

Source: Clark (1950) and Long (1971)

file: Analysis of 1950 and 1966 Flood Data

The Redwood Bridge metering and water level station was operational from 1912 until 1977 and miscellaneous discharge measurements continued from time to time until 1982; this latter data has not been published. The Redwood Bridge site is less than an ideal site for meterings; the metering section is interrupted by three concrete piers and one centre concrete pivot pier (see Section C8, Appendix C). The pivot pier has a diameter of 27 ft and under normal summer water levels represents 5% of the total river width. Large eddies and areas of backwater are apparent in the vicinity of the pivot pier and to a lesser extent around the three other piers under higher flows. Likely with the high flows in 1950 the eddies and backwater effects would have been more pronounced, however this does not explain why some of the 1950 meterings that correspond to similar stages in other years plot off the curve (Figure 2-14).

According to MacKay (1998) as a result of the apparent shift in the Redwood Bridge rating curve and questions with regard to the accuracy of flow measurements, WSC agreed to undertake a study to assess the possible reasons for an apparent shift in the rating curve.

WSC carried out an extensive review of the Redwood Bridge metering data as documented in a report by Long and Wagner (1970). Part of their investigation focused on the "standard" soundings taken at the metering section to define the river cross section. The standard sounding approach is an approach used in flow metering where a bottom sounding is taken initially, a table of depths is determined for each "vertical" slice and then the standard sounding table is used as the basis for subsequent flow meterings without having to resound the river. In the case of the 1950 Redwood Bridge meterings a standard sounding was taken on May 12 and was used for two previous meterings and all subsequent meterings for the year except for three. (Note that by May 12 water levels were stabilizing near the peak, on May 12 James Avenue was at 29.80 ft JAD, on May 19 the river peaked at 30.30 ft JAD, only 0.5 ft higher.)

Long and Wagner (1970) found in examining the 1950 standard soundings that this sounding was shallower in the centre and in the more critical parts of the metering cross-section relative to soundings in prior years, and after the 1950 flood. The authors note that even a sounding taken in early 1951 after a period of low flows and potential sediment deposition was deeper than the 1950 sounding. There appears to be no physical explanation of why the metering section would be shallower during the 1950 flood, if anything it would be likely be deeper due to scour around the bridge piers. If it is assumed that there was a measurement error in the May 12, 1950 sounding and the cross-section should actually be deeper, the result is that the majority of the computed meterings for 1950 would be higher.

Another notable difference between the 1950 meterings and the 1966 meterings is the location of the gauge for measuring water levels. Up until

1957 a chain gauge was located on the upstream side of the pivot pier (Section C8, Appendix C). In 1957 this gauge was replaced with a wire weight gauge. The new gauge was installed forty-four feet west of the old chain gauge location. Long and Wagner (1970) indicate they are uncertain what effect if any that this change may have had. Given the "pillow effect" in front of the centre pier there were likely differences between the water levels between the two years.

According to MacKay (1998), he states that,

> *"The conclusions of the investigations as reported in the aforementioned report [i.e., Long and Wagner] was that the 1950 measurements should be corrected, and the rating curve modified. The peak discharge was corrected to 105,000 cubic feet per second (CFS), form [from] the 103,600 previously reported".*

In review of the Long and Wagner (1970) report, the authors do not make a definitive conclusion as reported by MacKay (1998). The authors do provide three alternatives for estimating the discharge at Redwood called Method A, Method B and Method C. The rating curve shown in Figure 2-15 is based on Method C, which estimates the discharge at about 104,000 cfs. Recommendations are made in the Long and Wagner (1970) on how to improve on discharge measurements such as establishing a cableway downstream of the Redwood Bridge and taking accurate soundings before and immediately after a spring run-off. As indicated in the introduction to this section the Redwood gauge was decommissioned in 1977 in favour of Lockport metering station located downstream of the Floodway Outlet. The Lockport gauge was established in 1960.

Following the decommissioning of the Redwood metering station a rating curve was developed by Manitoba Water Resources for James Avenue. Since a metering section does not exist at this site, a rating curve has been constructed by using historical James Avenue water level data from City of Winnipeg records that date back to 1908 and historical and more recent meterings conducted at other locations. With the opening of the Red River Floodway in 1969, peak flows at James Avenue have typically been 55,000 cfs or less, except for 1997 when flows reached about 75,000 cfs (Table 2.1). However, as noted in Section 2, a backwater condition occurs on the river as a result of significant discharges from the floodway outlet, this suggests that the high end of 1997 meterings may have been backwater affected.

Examination of Figure 2-15 shows that there are two points from 1950 that fall within the same range of meterings as 1966 that is: 61,400 cfs on June 6, 1950; and, 84,600 cfs on May 29, 1950 (Table 2.3). If it is assumed that the stage is correct then the adjusted discharge required for these two meterings to fall on the rating curve would be 65,860 and 88,710 cfs respectively or an adjustment of 7.3% and 4.9%.

While the above might be a suitable technique to adjust the flows that fall within the same range as other years and corrects the metering error previously identified in Figure 2-15 (Section 2.3.2), it is not applicable to adjusting the 1950 peak. Examination of Figure 2-15 shows a third order polynomial fit of a) the 1950 data; and b) the 1956 and 1966 data combined together. A projection of the 1956 and 1966 polynomial line gives a potential discharge in the range of 116,000 cfs. Warkentin (pers. comm. 1986) has also questioned the WSC published peak discharge for 1950 and recommends that this be increased from 103,600 cfs to 108,500 cfs based on an analysis of 1966 meterings and April 4, 1950 metering at Elm Park Bridge (cf Section 2.1) and a regional analysis of flows. The 1956 and 1966 polynomial line could also be used to estimate the May 29, 1950 flow, if this curve was used the flow estimate for May 29, 1950 flow could be as high as 92,000 cfs (Figure 2-15).

Similar to the previous discussion on water level profiles (Section 2.3.2) backwater modelling can be used to assist in providing additional information on what the potential peak discharge should likely be. The approach to modelling and estimating 1950 flows is discussed later in Section 3.1.2

The upward adjustment to 1950 flows is potentially significant with respect to the backwater modelling studies done by the Red River Basin Investigations (1951 – 1953) and later by the Province in the early 60's (Appendix B2) as they were based on the original estimates of 1950 discharges at the time.

MacKay (1998) also points out some errors in the RRBI work in extending the Redwood Bridge rating curve beyond the measured flows and observed stages. MacKay concluded that the RRBI rating curve for a flow of 165,000 should be plotted about 3 feet lower than the curve plotted by RRBI. This too will have an effect on the backwater calculation for higher flows.

Because of the uncertainty in the 1950 meterings this data will not be used directly for calibration, instead the 1966 data will be used and the model extrapolated to estimate the 1950 flow.

2.4 Analysis of 1966 Flow Contributions

As indicated in Section 2.3.3 data from 1966 flood was used for calibration of the HEC-RAS model. A critical component of using the 1966 dataset for backwater calculation was the determination of whether there were any discrepancies in the daily flows on the Red River upstream and downstream of the confluence with the Assiniboine River. If large discrepancies appeared in the data, flow data from that date was not included in the calibration set.

The water level data tabulated by Long (1971) spans the time period from April 1 to May 16, with the peak occurring on April 14. As previously discussed in Section 2.3, April 15 was chosen for the peak as water levels had stabilized near the peak and the fact that James Avenue data represents daily averages while the other gauge sites represent only point measurements for the day. Measurements at the majority of the gauges generally occurred between 10:00 and 12:00 in the morning. Another aspect of the dataset (as recorded in the media coverage of the flood) was that there was significant ice jams on both the Red and Assiniboine River up until the peak and there was the ongoing necessity of removing these jams (sometimes with dynamite). Another complicating factor on the rising limb of the hydrograph was that the Assiniboine Headingley gauge was under ice backwater conditions to as late as April 16. Because of the problem with ice on the rising limb of the hydrograph, the analysis focused on examining the recession limb of the hydrograph from April 15 to May 16. This dataset covers a flow range from 88,000 cfs at the peak down to about 36,000 cfs on May 16 (at the Redwood Bridge gauge). However, as previously discussed only on those dates where there is some certainty on the flow contributions on the Red both upstream and downstream of the Forks (i.e., Assiniboine River confluence) and from the Assiniboine River would data be incorporated as part of the calibration dataset.

On the Assiniboine River, the last WSC gauging station before the river joins the Red is located at Headingley, approximately 24 km upstream of the confluence. Downstream of this gauge there are a number of tributaries, such as Sturgeon Creek, Truro Creek and Omands Creek as well as City of Winnipeg land drainage outfalls and pumping stations from the City's combined sewers. Of these tributary inflows only Sturgeon Creek had a gauge in 1966. While under most circumstances the flows from these ungauged sources would typically be small, under a flood situation these tributary inputs may not be. Therefore, under the flood situations it would be prudent to crosscheck Assiniboine River contributions using other methods.

To assist in the determination of Assiniboine flow contribution, a spreadsheet table (Table 2.4) was developed that included all the available published WSC data on the Red and Assiniboine rivers as well as supplemental meterings at non-WSC sites. As shown in Table 2.4 there was an extensive monitoring program at the South Perimeter Bridge with 20 meterings taken at the site during the 1966 flood. Also, there were unpublished miscellaneous meterings taken by the Water Resources Branch on the Assiniboine River at the St. James Bridge and at the Assiniboine Park Foot Bridge at the peak in 1966.

As shown in Table 2.4, Assiniboine River contributions were determined from:

- a back calculation of Assiniboine River contributions, **Column A** (i.e., subtraction of South Perimeter and Seine River flows from Redwood Bridge Flows);

- a summation of Assiniboine River and tributary inflows, **Column B**; and

- miscellaneous Assiniboine River meterings **Column C**.

To assist in the discussion of the data **Columns D** and **Columns E** have been created that represent the absolute difference between Columns A, B and C.

As meterings on the Assiniboine River at the St. James Bridge represent the best set of flow estimates for the Assiniboine River these flows were used for calibration where data exists, i.e., April 15 to April 20. This provides a flow dataset of between 81,000 and 87,000 cfs at Redwood. As shown in Table 2.4 a comparison of the St. James Bridge meterings with the other Assiniboine River calculation methods points out some discrepancies with the data. For example on April 16 it appears that the Headingley flow estimate is about 1000 cfs too low. Similarly the flow estimate for Redwood on April 19 is in error since Column A in Table 2.4 computes a negative Assiniboine River contribution. The low flow estimate of 78,200 cfs at Redwood is as a result of a considerable drop in the Redwood stage on April 19 and then rising the subsequent day. This pattern of dropping and rising levels is not apparent in the other gauge readings including

Table 2.4

Computation Sheet to Assess Assiniboine River Contributions in 1966

1966	Back Calculation of Assiniboine R. Contributions (cfs) Redwood Br. Flows[1]	Seine River Flow Estimates[4]	South Perimeter Br. Meterings[1]	Column A Computed Assiniboine Contributions	Summation of Assiniboine Flow Contributions (cfs) WSC Headingley[2]	Sturgeon Cr. at St. James[2]	ungauged local 50%	Column B total Assiniboine River	Column C Meterings at St. James Bridge[3]	Column D Absolute Difference in Assiniboine Contributions "Col A -B"	Column E Absolute Difference in Assiniboine Contributions "Col A - C"
01-Apr					4,600	70	35	4,705			
02-Apr					4,790	90	45	4,925			
03-Apr					5,250	110	55	5,415			
04-Apr					5,850	130	65	6,045			
05-Apr					6,550	150	75	6,775			
06-Apr					7,640	164	82	7,886			
07-Apr					8,420	151	76	8,647			
08-Apr			69,900		8,830	167	84	9,081			
09-Apr					8,750	141	71	8,962			
10-Apr			72,900		8,610	159	80	8,849	6,293		
11-Apr					9,090	208	104	9,402	7,065		
12-Apr			75,300		9,990	1,030	515	11,535			
13-Apr			77,600		10,000	1,140	570	11,710	11,690		
14-Apr	87,800	1,270	76,000	10,530	10,300	1,050	525	11,875	12,574	1,345	2,044
15-Apr	87,100	1,265	76,500	9,335	7,770	805	403	8,978	9,276	358	59
16-Apr	86,300	927	76,800	8,573	6,660	611	306	7,577	8,687	997	114
17-Apr	85,600	856	76,900	7,844	6,410	669	335	7,414	7,562	430	282
18-Apr	84,800	781	77,800	6,219	5,700	465	233	6,398	6,796	179	577
19-Apr	78,200	293	78,500	-593	5,110	418	209	5,737	6,120	6,330	6,713
20-Apr	81,100	197	75,800	5,103	4,780	370	185	5,335	5,721	232	618
21-Apr	77,600	151	73,300	4,149	4,590	308	154	5,052		903	
22-Apr	76,100	119	69,400	6,581	4,480	266	133	4,879		1,702	
23-Apr	73,400	129	67,000	6,271	4,460	260	130	4,850		1,421	
24-Apr	70,700	167	62,700	7,833	4,450	314	157	4,921		2,912	
25-Apr	68,000	207			4,610	96	48	4,754			
26-Apr	64,200	115	51,900	12,185	4,760	78	39	4,876		7,308	
27-Apr	61,000	73			5,040	74	37	5,150			
28-Apr	57,300	32			5,270	33	17	5,320			
29-Apr	54,500	44	46,900	7,556	5,480	38	19	5,537		2,019	
30-Apr	52,200	68			5,560	29	14	5,603			
01-May	50,000	81			5,680	27	14	5,721			
02-May	47,700	94			5,890	39	19	5,948			
03-May	46,100	121	36,000	9,979	6,040	40	20	6,100		3,879	
04-May	45,900	261			6,360	87	44	6,491			
05-May	50,800	609			7,310	480	240	8,030			
06-May	53,400	350			7,560	367	184	8,111			
07-May	52,600	169	45,300	7,131	7,410	373	187	7,970		838	
08-May	51,700	125			7,320	116	58	7,494			
09-May	50,800	61			7,340	80	40	7,460			
10-May	48,100	57			7,380	66	33	7,479			
11-May	46,600	57			7,320	84	42	7,446			
12-May	44,200	39	36,400	7,761	7,070	102	51	7,223		538	
13-May	38,300				6,810	109	55	6,974			
14-May	37,600				6,520	81	41	6,642			
15-May	36,900				6,360	72	36	6,468			
16-May	36,200				6,190	86	43	6,319			

Notes: 1 - Source: Long (1971)
2 - Published Water Survey of Canada data
3 - Water Resource Branch data, metering all from James Ave bridge except for April 14 at Assiniboine Park Foot Bridge
4 - Seine River data: combination of review of meterings at Prairie Grove, Hwy 59 and extrapolation of Prairie Grove data
Notes:
- WSC notes the following for ice conditions: Headingley till April 16, Sturgeon Cr till April 17, Lockport till Apr 13
\- likely discrepancies in flow estimates
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Redwood. The probable flow on April 19 for Redwood Bridge based on back calculation is around 84,500 cfs. An examination of Column E shows that except for the Redwood error on April 19 the discrepancy between the Back Calculation Method of estimating Assiniboine flows (Column A) and the St. James Bridge meterings ranges between 60 and 620 cfs as shown in Column E.

To determine appropriate water level datasets beyond April 20, where there are no additional meterings at St. James Bridge the criteria for inclusion of the data for that day was that the flow differential between the different methods of calculating Assiniboine River flows had to be nominally less than 1000 cfs. Examination of Table 2.4 shows that 3 more dates can be added to the calibration dataset: April 21 – Redwood flow 77,600 cfs; May 7 – 52,600 cfs; and, May 12 – 44,200 cfs.

To determine whether some of the data between April 21 – 77,600 cfs Redwood and May 7 – 52,600 cfs could be used, a third approach was tested and that was to determine whether some of the large variances in Column E of Table 2.4 could potentially be explained by the choice of Redwood flows as shown in Table 2.5. In Table 2.5 the actual metered flow for the day at Redwood Bridge has been added to the table of computed Assiniboine River flows. Adding this row allows the calculation of a rating curve shift. By applying a pro-rated shift to the other days also results in the “absolute difference” column being substantially below 600 cfs for April 22 and April 24. Adding April 24 to the dataset with a flow of 68,200 provides a potential an intermediate flow value for calibration purposes.

The application of a shift does not provide significant change to the large absolute difference on April 26. And no additional metering data exists to examine the other dates with large discrepancies such as May 3. While other analysis techniques were examined (such as lagging flows or averaging upstream contributions, stage data anomalies, rating curves etc.), no explanation could be found for the large differences for April 26, April 28 and May 3. Potential other reasons could be variations in metering, dynamic waves moving downstream etc. Notwithstanding the fact that the data on these dates could not be resolved, the dates listed in Table 2.6 should provide sufficient data for the HEC-RAS model calibration discussed in Section 4.

Table 2.5
Impact of Applied Metered or Estimated Redwood Flows Versus Published WSC Flow

Date	Redwood Flows	Seine River Flows	S. Perim. Flows	Computed Assiniboine Contributions	Summed Assiniboine Contributions[1]	Absolute Difference	Remarks	Rating Curve Shift
21-Apr-66	77,600	151	73,300	4,149	5,052	903	published daily flow	
21-Apr-66	78,600	151	73,300	5,149	5,052	97	metered flow @ Redwood Br.	-1,000
22-Apr-66	76,100	119	69,400	6,581	4,879	1702	published daily flow	
22-Apr-66	74,200	119	69,400	4,681	4,879	198	metered flow @ Redwood Br.	1,900
23-Apr-66	73,400	129	67,000	6,271	4,850	1421	published daily flow	
23-Apr-66	71,200	129	67,000	4,071	4,850	779	applying shift to Redwood flow	2,200
24-Apr-66	70,700	167	62,700	7,833	4,921	2912	published daily flow	
24-Apr-66	68,200	167	62,700	5,333	4,921	412	applying shift to Redwood flow	2,500
25-Apr-66	68,000	207					published daily flow	
25-Apr-66	65,300	207					metered flow @ Redwood Br.	2,700
26-Apr-66	64,200	115	51,900	12,185	4,876	7308	published daily flow	
26-Apr-66	62,900	115	51,900	10,885	4,876	6008	applying shift to Redwood flow	1,300
27-Apr-66	61,000	73			5,150	5150	published daily flow	
27-Apr-66	60,800	73			5,150	5150	metered flow @ Redwood Br.	200

1 - see Table 2.4

Note: estimated rating curve shift based on observed pattern

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Table 2.6
Flow Split and Potential Dates for HEC-RAS Calibration

Date	Red River d/s of Seine R.[4] cfs	Seine R. Contribution[1] cfs	Red River u/s of Forks[2] cfs	Assiniboine Contribution[3] cfs	Assiniboine Contribution[3] % of total flow	Unaccounted for Residual[5] cfs
15-Apr-66	87,100	1,265	76,500	9,276	11%	59
18-Apr-66	84,800	781	77,800	6,796	8%	-577
20-Apr-66	81,100	197	75,800	5,721	7%	-618
21-Apr-66	78,600	151	73,300	5,052	6%	97
24-Apr-66	68,200	167	62,700	4,921	7%	412
7-May-66	52,600	169	45,300	7,970	15%	-838
12-May-66	44,200	39	36,400	7,223	16%	538

1 - flows as shown in Table 2.4

2 - metered flows at South Perimeter as shown in Table 2.4

3 - Assiniboine flows on April 15, 18 and 20 based on meterings at St.James Bridge shown in Column C, Table 2.4, flows on April 21, 24, May 7 & 12th based on summed Assiniboine R. contributions shown in Column B of Table 2.4

4 - Redwood Br. flows as shown in Table 2.4, except for April 21 & 24 which are modified flows as shown in Table 2.5

5 - Represents the remainder after subtracting all upstream flow inputs from downstream Red River flows

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2.5 Summary of Review

The following is a summary of the above information:

- the 1950 and 1966 floods represent the two highest flood years of recent record for the Red River in the City of Winnipeg. The 1997 flood is a post-Floodway flood and represents the third largest flood for Winnipeg. With the discharge of Floodway water back into the Red River north of the City there was a significant backwater effect at the north end of the City. In all three floods a significant amount of water level and flow data were collected along the river

- the 1966 flood year represents a high flood year and flooding of channel bank areas, with no significant flooding of the overbank areas at least within the urban areas of the city;

- the 1950 flood year represents a year of substantial floodplain flooding particularly upstream of the Norwood Bridge area with large areas flooded in St. Vital, as well as Riverview and portions of Fort Garry including Wildwood;

- discharge measurements for 1966 are more reliable than those for 1950. There is considerable uncertainty in the peak flow estimates for 1950 ranging from 105,000 cfs to 117,000 cfs. Modelling will be used to assist n addressing this uncertainty;

- there are larger than “normal” bridges losses for the CNR bridge in 1950, and the Elm Park Bridge in 1966 indicating other factors than just hydraulic bridge losses are likely responsible for the recorded large differences. Other potential reasons include: gauge datum errors, back eddies, debris etc.;

- even with the above noted bridge losses there are discrepancies in the water level profile for the James Avenue area in 1950 and for both the Bergen Cutoff to Redwood Bridge area for both 1950 and 1966. Modelling in this study was used to provide additional information on which of the stage data is likely in error;

- most of the bridges have relatively minor hydraulic losses ranging between 0.05 to 0.20 ft (assuming that CNR and Elm Park Bridge losses are in error).

The Provencher bridge has the largest loss, with losses greater than 0.30 feet.

Given the characteristics of the 1950 and 1966 flood years and uncertainty with the 1950 flow data, the following outlines an approach to the backwater modelling:

- the backwater model was initially calibrated to 1966 data to allow calibration of hydraulic roughness (i.e., Manning's n), as well as calibration of the channel bank areas;

- once calibrated to 1966 flows, roughness values were kept the same and flows increased to calibrate the model to observed water levels in the Lockport to James Avenue reach of the river where the majority of flow is still within channel. This technique was used to provide a peak estimate for 1950 flows. Techniques for calibrating water levels upstream of the confluence of the Assiniboine River where there was significant overbank flooding in the St. Vital and Fort Garry areas is discussed in the next section;

- for 1950 calibration purposes a "wall" was placed along Lyndale Drive in Norwood to account for the significant dyke in this area in 1950. Once the model was calibrated the "wall" or dyke was removed to represent non-dyke conditions on the river for computation of "natural" water levels.