97/14

Robert H. Clark, P. Eng.
Charles D. D. Howard, P. Eng.
John N. MacKenzie, P. Eng.

December 9, 1997

North Ritchot Restoration Committee
P.O. Box 147
St. Norbert, Manitoba
R3V 1L5

Attention: **Robert Starr, Chairman**
Technical sub-Committee

Dear Sir:

Re: **Report on 1997 Red River Floodway Operations**

The principle behind the original concept of the Red River flood control system was that levels upstream from the Floodway would not exceed the levels which prevailed prior to construction of these works ("natural" levels). Experience in at least three past floods shows that this has not been achieved in practice. Upstream residents have experienced additional flooding because of these facilities. Furthermore, the operation of the Floodway has increased their risk of being flooded during future extreme events.

The following more detailed conclusions were reached:

1. The original rating curve for Redwood bridge was a key factor in determining the design parameters for the Red River Floodway. Table 5 of the 1984 Program of Operation contains a stage-discharge rating which lies to the right of the original curve, indicating a change in the hydraulic control. The new rating shows a significantly higher discharge for levels at and above those reached in 1997 at the gauge near James Avenue Pumping Station. If this curve has changed in the manner indicated, the City of Winnipeg is now afforded greater protection from very high floods.

2. Flooding upstream from the Inlet Control Structure exceeded "natural" levels during the 1997 flood. A figure plotted by the Water Resources Branch of Manitoba Natural Resources for the Manitoba Water Commission shows that south of the Inlet Control Structure flooding was sustained approximately 72 hours at 1.5 feet above the "natural" level. In the Grande Pointe area, this corresponds to at least 1.9 feet above the "natural" level.

3. Table 5 in the 1984 Program of Operation is for the gauge at the James Avenue Pumping Station. The first line in Table 5 is the stage-discharge rating for present conditions; the second line purports to be based on the rating used in the design of the Red River Floodway. At the peak discharge reached in the 1997 flood, there is a significant difference between the values obtained from Table 5 and the values from the "Report on Investigations into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area, Appendix D". The difference in ratings corresponds to approximately two feet of difference in the calculated maximum 1997 "natural" level upstream from the Floodway inlet. In other words,

the flooding upstream from the Floodway inlet might have been 3.5 feet above "natural" level and, in the Grande Pointe area, 3.9 feet above "natural" level.

4. In the 1984 Program of Operation, "natural" levels are based on the revised rating curve for the James Avenue Pumping Station and a rating curve developed in 1953 for the Red River at the location of the Floodway inlet. It may be reasonable to adjust the rating curves based on additional data acquired since 1953, but it is not clear why one curve was adjusted without adjusting the other.

5. For several miles upstream from the Inlet Control Structure, the backwater from the Inlet Control Structure raised water levels above natural levels. This exacerbated the overflow from the Red River. A backwater analysis would show how far upstream and how much the water surface was affected by an additional 1.5 feet in level at the Inlet Control Structure.

6. The backwater from the Inlet Control Structure affected the river's sloping water surface profile for some distance upstream where the river levels were well above the level at the inlet. The overland flow from the river into these upstream areas, i.e. Grande Pointe and Avonlea Road, was increased during the 1997 flood because of the operation of the control structure.

7. Wind effects during the 1997 flood on the west dyke and its extension towards Brunkild increased the water levels above "natural". This fact is not considered in the Program of Operation.

8. The Seine River now contributes more to flooding upstream from the Floodway than it did before the construction of the Seine diversion. Before construction of the diversion, a large portion of the Seine River flood flows entered the Red River in downtown Winnipeg - the areas upstream from the Floodway inlet indirectly were affected slightly by backwater. Now, the diverted Seine River flood flows directly affect levels above the Floodway inlet. This fact is not considered in the Program of Operation.

9. The method of calculating "natural" flows and the degree of compliance with "natural" levels is incomplete. It does not consider the effect of wind setup on the Brunkild and west dykes, the diversion from the Seine River, or the potential effect of accumulated errors in measurement. Thus, a calculated "natural" level is an approximation which will always underestimate the effect of the flood control facilities on the residents upstream from the Floodway inlet.

Yours very truly,

Robert H. Clark, P.Eng. Charles D. D. Howard, P.Eng. John N. Mackenzie, P. Eng.

North Ritchot Restoration Committee

Report on the

1997 Red River Floodway Operations

December 18, 1997

Robert H. Clark, P. Eng. Charles D. D. Howard, P. Eng. John N. Mackenzie, P. Eng.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The Red River Floodway was the major factor in protecting the City from the 1997 flood. But immediately upstream of the inlet to the Floodway, the high water levels caused considerable damage. The upstream homeowners now are trying to understand the way in which the operation of the Red River Floodway Inlet Control Structure gates might affect their homes in the future. This is important to them because it may determine what they should do to protect themselves from losses during future floods.

The 1980 report of the Manitoba Water Commission concluded that the backwater from operation of the Red River Floodway may have caused water levels upstream during the floods of 1974 and 1976 to exceed the levels specified in the Program of Operation for the Inlet Control Structure. The September 1997 submission to the Manitoba Water Commission by the Water Resources Branch showed that the upstream levels were again excessive during the 1997 flood.

The upstream homeowners have been led to expect that the upstream water levels caused by operation of the Floodway would be within limits specified in the Program of Operation. The City of Winnipeg probably expects that the Floodway will be operated to provide the City with the maximum possible protection during floods.

1.1 The Technical Review

This review was conducted by three professional consulting engineers: Robert H. Clark, Charles D. D. Howard, and John N. MacKenzie. All are former residents of Winnipeg, with professional experience in hydrology and water management in Manitoba and well aware, first hand, of the importance of the Winnipeg flood control system.

Robert H. Clark was an advisor for thirty years on Federal Government policies regarding water resources, and served on the Souris-Red Rivers Engineering Board of the International Joint Commission, and on eleven Federal-Provincial Engineering Boards dealing with Canadian rivers. He directed the hydrology and hydraulic studies of the Red River Basin Investigation carried out by the Federal Government from 1950 to 1953. This investigation studied many alternatives for controlling Red River floods, including the floodway scheme which exists today. He was President of the Technical Commission for Hydrology of the World Meteorological Organization from 1976 to 1984. He holds degrees in Civil Engineering from McGill University. He is retired and resides in the Toronto area.

Charles D. D. Howard is a consulting engineer with an active international practice including assignments for the World Bank, the United Nations, and for many hydroelectric utilities and water utilities in Canada and the United States. He serves on many professional technical committees and is a member of the Water Science and Technology Board of the United States National Academy of Sciences. He holds degrees in Civil Engineering from the University of Alberta and from the Massachusetts Institute of Technology. He resides in Victoria, B.C.

John N. MacKenzie has many years of experience as a consulting engineer and early in his career he was employed by the Manitoba Water Resources Branch, the Manitoba district of the Water Survey of Canada, and Manitoba Hydro. He holds degrees in Civil Engineering from the University of Manitoba. His home is in Victoria B. C.

1.2 Historical Perspective

Severe floods have been experienced in the vicinity of Winnipeg since the earliest days of settlement in the area. In 1826, the peak discharge may have exceeded 225,000 cfs, almost four times the capacity of the natural river channel at that time. In 1852, it probably reached 165,000 cfs, and caused hardship for most of the 3500 people in the region. In 1861, the discharge reached 125,000 cfs in this area, which was largely rural at the time.

In 1879, investigations for the coming Canadian Pacific Railway advocated avoiding the site of the new City of Winnipeg because of the dangers of future floods. The 1882 flood of 79,000 cfs and the 1916 flood of 71,000 cfs put portions of the City of Winnipeg under water. The next major event was the flood of 1948 which reached a peak of 69,000 cfs.

In 1950, the City was flooded when the river overtopped the dykes and the discharge reached 103,600 cfs. In July of 1950, the Greater Winnipeg Dyking Board was established. The resulting dykes provided capacity through the City for about 71,000 cfs (the 1948 flood), with approximately three feet of freeboard. Today, according to the revised rating curve for the Red River at the James Avenue Pumping Station, the dykes provide the Red River with a capacity of 77,000 cfs.

In late 1950, the Federal Government set up the Red River Basin Investigation. The 1953 report of that investigation, with its technical Appendices A to H, was titled, "Report On Investigations Into Measures For The Reduction of the Flood Hazard in the Greater Winnipeg Area". This study was the basis for the present system of flood control structures and channels.

1.3 Flood Management Facilities

The City of Winnipeg now receives considerable flood protection through the operation of a combination of flood control facilities which, together with the capacity of the dyking system through the City, provide a combined nominal capability of approximately 169,000 cfs.

There are four major flood control facilities.

The first is the Shellmouth reservoir on the upper Assiniboine River. Shellmouth operations can reduce flows into the Red River at Winnipeg by approximately 7,000 cfs.

The second facility is the diversion to Lake Manitoba from the Assiniboine River at Portage La Prairie. It was designed to divert up to 25,000 cfs out of the Red - Assiniboine river system.

The third facility is the Red River Floodway and its related hydraulic control structures and dykes. This diversion channel is designed to carry approximately 60,000 cfs around Winnipeg without exceeding water elevation[1] 770.25 ft. at the inlet. There is no control structure on the entrance to the Floodway. The discharge entering the Floodway is determined by the levels in the adjacent Red River. The levels are controlled by a two-gate structure in the river immediately downstream from the Floodway intake channel. The position of these gates determines the level of the Red River at the Floodway inlet and thus the discharge that is diverted from the river into the Floodway.

A fourth facility is the Seine River Diversion to the Red River several kilometres upstream from the Floodway inlet. A small portion of flood flows in the Seine River is diverted directly into the Floodway through four large culverts. Low flows continue to flow into Winnipeg through a small inverted syphon under the Floodway, but the discharge in the syphon is too small to have any influence on flood operations.

Under natural conditions, the Seine River contributed flood flows to the Red River between the James Avenue Pumping Station and Redwood Bridge, causing slight backwater effects, i.e. increases in water levels upstream from its junction with the Red River. As part of the flood control system, most of the Seine River flood flow now is diverted directly to the Red River upstream from the Floodway inlet. The Seine River diversion reduces levels in the City but now adds directly to the levels upstream of the Floodway.

1.4 Purpose and Scope of this Report

The Consultants were requested to provide an objective, scientific assessment of the 1997 operation of the Red River Floodway and the related flood control structures. The Terms of Reference are described in the September 9, 1997 letter from the Chairman of the North Ritchot Restoration Committee which state:

1. Review from its origins the "Rules of Operation" of the Red River Flood presented in the report entitled "Red River Floodway Program of Operation", July 1970, and the basic hydraulic (stage-discharge) relationships;

2. Assess both the current intent and implementation of the "rules of operation" and their relationship to the original intent of the operation of the Red River Floodway in not raising water levels upstream of the Floodway above the "state of nature";

3. Comment on the feasibility of investigating any additional factors such as the construction of the Brunkild dyke, breaching of the Avonlea Road and other roads that may have caused

[1] All water elevations are relative to G.S.C. datum. River stages at Redwood Bridge and at James Avenue Pumping Station are relative to City of Winnipeg datum. Elevations and stages are in feet.

a negative impact on flood fighting efforts and water levels so as to exceed a "state of nature" upstream of the Floodway;

4. Comment on the extent of "artificial flooding" (i.e. maximum water levels exceeding the "state of nature"), if any, immediately upstream of the Floodway Control Structure including Grande Point and extending to Ste. Agathe;

5. Review the overall operational flood control for the Red River in 1997, including operation of the Floodway, flood forecasting, drainage practice upstream of Winnipeg, operation of the Shellmouth Reservoir and operation of the Assiniboine River Diversion, and provide an opinion as to any areas where flood operations could potentially have been improved.

6. After discussion and review with the Technical Committee, should any further detailed technical analysis be deemed necessary (e.g. overland modelling), the information required will be identified and gathered to carry out the detailed technical analysis.

Conclusions expressed herein are based on a visit to the sites of the control facilities and some of the flooded homes, an office study of the available information, discussions with some of the officials involved in gathering data and operating the flood control facilities, and the experience of the Consultants.

2.0 THE RULES OF OPERATION

The Cost-sharing Agreement dated May 28, 1962, between the Governments of Canada and of the Province of Manitoba for the construction of the Red River Floodway required that the Province submit a plan of operation for approval by Canada. Specifically, Section 20 of that Agreement states:

"1. The province will submit to the federal Minister for approval prior to the completion of the Floodway,

(a) a program for control and operation of the Floodway under routine conditions and emergency conditions, and

(b) a program for the establishment and maintenance of hydrometric and rain gauges and snow surveys in the Red River basin.

2. After receiving of such a program by the Federal minister, the Province will put into effect such programs in accordance with the time schedules contained in the programs in a manner satisfactory to the Federal minister,

3. Any change which the Province may desire to make in the programs submitted in accordance with subsection (1) hereof shall be submitted to the Federal Minister for approval."

The Program of Operation was developed in 1970 and revised in 1984. Presumably the Program of Operation has been approved by the Federal Government.

The Red River Floodway is operated to provide maximum protection for the areas downstream of the Inlet Control Structure without adversely affecting interests upstream. The Program of Operation (1984) lays out the procedure for accomplishing this:

> "the water levels upstream of the Inlet Control Structure shall be maintained at the elevation which would have obtained under natural conditions"

Exceptions to this basic operating procedure are set out in the Program of Operation under "Initial Gate Settings", "Gate Shut Down Sequence", and "Emergency Operation".

> "The water surface elevation to be maintained upstream of the Inlet Control Structure is dependent upon the combined discharges of the Assiniboine and Red rivers which would have obtained under natural conditions. These discharges can be computed by following the procedures outlined in the computation sheet (Form 2) or by running the computer program. The basic data required for each computation are:
>
> (a) Discharge of the Portage Diversion with a two day lag

(b) Gauge height of the Assiniboine River at Headingley

(c) Water surface elevation of the Red River upstream and downstream of the inlet control structure

(d) Inlet Control Structure gate elevation

(e) Gauge height of the Red River at James Avenue, City Datum

(f) Water surface elevation of the Lasalle River upstream and downstream of P.T.H No. 75

(g) Sturgeon Creek local inflows"

The Program of Operation provides a procedure for calculating the "natural" discharge of the Red River, and of the Assiniboine River. The accuracy of the calculated "natural" discharges is affected by measurement errors and uncertainties resulting from several sources:

1. Calculations of routing flow through the Shellmouth Reservoir and in the Assiniboine River system,

2. Estimates of the overbank flow from the Assiniboine into the LaSalle River and hence to the Red River downstream of the Floodway Inlet Control Structure,

3. Changes in surface features such as dykes and roads which affects the shape of the hydrograph of the Red River and the influence of winds on levels (setup),

4. Location of the Seine River diversion,

5. The reported change in the rating curve for the Red River near the James Avenue Pumping Station, which indicates a substantial change in the hydraulic control downstream from this location.

As reported elsewhere (Acres Consulting Services, Ltd., June, 1980), errors in measurement alone "would certainly be more than ...0.5 feet, plus or minus" in the calculated "natural" levels upstream from the Floodway Inlet Control Structure.

The concept of maintaining estimated "natural" levels above the Floodway has the theoretical advantage that property owners immediately upstream of the Floodway would not be placed at greater risk during floods less than or equal to the design flood. However, as shown by experience with Floodway operations, this is not always a practical concept.

Considering the stakes involved, it might be logical and safer to accept the fact that the operation of the Floodway is guided by minimizing the potential overall flood damages, and the risk of flood damages from errors in operation. In fact, this may have been a consideration during floods when estimated upstream "natural" levels were exceeded in 1974, 1976 and in 1997 (Acres, June, 1980; Manitoba Natural Resources, Sept. 1997).

2.1 Alternative Operating Criteria

Two alternative methods of operation were previously considered (Canada, 1953). The first is the approach currently documented, i.e. the Floodway would operate to maintain natural levels above the diversion throughout the flood. To assist in the determination of the "natural" levels, a chart in the report shows the relationship between the total natural flow at Redwood Bridge and the levels above the Floodway intake channel. The total natural flow at Redwood Bridge includes the "natural" inflow from the Assiniboine River.

As discussed above, a technical weakness in this approach lies with determining what the "natural" levels would have been in the absence of all of the control works on the Assiniboine and Red Rivers. Another weakness has been the inability of the Province to operate according to the Program of Operation. This issue is serious for the residents above the Floodway, several of whom lost their homes by a margin of a few inches during the 1997 flood.

The second alternative previously considered has the goal of controlling a portion of the natural valley storage upstream from the Floodway inlet. This would reduce the maximum flood levels for some floods. It would keep levels in Winnipeg within the capacity there, and would reduce upstream levels to below "natural" during the earlier stages of the flood.

The suggestion was made previously (report of Manitoba Water Commission, November 1980) that alternative methods of operation should be investigated, but no such study has been made to date (letter from Water Resources Branch of Manitoba Natural Resources to Ritchot). As a minimum, a study should be made to determine the optimal capabilities and commitments by government for actually operating the facilities according to a plan. The study could also determine the range of flood events by which the second alternative could safely maintain the river below "natural" levels, upstream and downstream of the Inlet Control Structure, and the management strategies that would be needed to limit or to mitigate potential erosion at the lower stages.

3.0 DATA SOURCES

During floods, the river levels from the gauges are collected by both Water Resources Branch of Manitoba Natural Resources and by the Water Survey of Canada. During the 1997 flood, the Water Resources Branch of Manitoba Natural Resources used some of these water level observations to estimate the corresponding discharges since the data were not processed by the Water Survey of Canada.

During the Consultants' visit to the office of the Water Survey of Canada on October 9, 1997, it was learned that not only the 1997 but also the 1996 discharge calculations had yet to be completed. According to Water Survey of Canada staff, the main reason for this delay is that considerable manual effort is required to make the conversion from the measurements of water level to the determination of discharge. According to the Water Survey of Canada, this is a fairly complex process because the data must be checked for consistency, the correct rating tables established, and backwater adjustments must be noted.

The Water Survey of Canada in Manitoba does not appear to have the resources to provide timely information on river and Floodway discharges. The Consultants were told that since January 1, 1997, the Water Survey of Canada has experienced a 40 percent cutback in staff, and during the 1997 flood, its office facilities were relocated across the city to another building. The staff reduction delayed the processing of important water data and the office relocation was a major interruption that should have been avoided at such a critical time.

The Atmospheric Environment Service of the Federal Government provides weather data that supports river forecasting as a flood progresses. During the 1997 flood, some of the measurement stations were temporarily removed (i.e. at Emerson) to protect them from the rising water. In anticipation of floods, these instruments should have been located so that their data would be available when needed.

The Federal Government should consider its commitment and its vested interests in ensuring that adequate resources and expertise are available so that the various flood facilities will be operated and maintained (see Section 2.0) according to the intent of Article 20 of the Federal-Provincial Agreement with respect to the construction and operation of the Floodway.

4.0 CALCULATION OF "NATURAL" CONDITIONS

4.1 Potential Errors in Estimating "Natural" Flow

At any instant, the total flow in the Red River above the Floodway inlet is the sum of the discharge through the control structure and through the Floodway. The Floodway discharge is determined by a rating curve related to the Water Survey of Canada gauge mounted on the downstream side of the St Mary's Road bridge. Discharge calculations for this location are believed to be reliable to within a few percent.

The Inlet Control Structure discharge is based on levels determined by gauges upstream from the intake and in the tailwater area. Levels at the upstream gauge are affected by backwater from the gates. Thus, the relationship between discharge and water level includes allowance for the position of the gates. This relationship is a set of curves determined by hydraulic model studies. With the water levels at the gauges and the gate position known, the discharge through the control structure and into the Red River through Winnipeg can be read directly from the curves.

The gate position is not measured directly. Instead, it is determined by a curve which relates it to the observed position of the hydraulic actuators. The 1980 report of the Manitoba Water Commission noted an error in this curve. Consequently, there was some uncertainty in the discharges determined during previous floods. At a meeting on October 9, 1997, the Consultants were informed by Water Resources Branch of Manitoba Natural Resources that this error had been corrected.

4.2 Potential Errors in Estimating "Natural" Levels

The total flow which determines the "natural" condition is the sum of measurements made in the Assiniboine system, at the Inlet Control Structure, and within the Red River Floodway. Errors in estimating this flow are translated to errors in the "natural" levels upstream from the Floodway. At the peak stage of the 1997 flood, each one percent of error in any constituent of the "natural" flow could cause approximately ± 0.2 feet of error in the calculated "natural" level upstream of the Floodway.

The discharge obtained by applying each of the individual stage measurements to the appropriate stage-discharge relationship are probably accurate to within five percent, plus or minus. Thus, because of measurement limitations, the calculation process of the Program of Operation may have determined the "natural" level upstream of the Floodway to within the nearest foot.

For the peak flow conditions of concern, there were no direct readings during Floodway operations of "natural" levels at the location upstream of the Inlet Control Structure. "Natural" levels were determined from a rating curve developed for the 1953 Federal Government report. This rating curve was calculated by office backwater studies based on measured levels and discharges at Redwood Bridge, and the Red River channel dimensions.

In the 1997 submission to the Manitoba Water Commission, the concept is advanced that the Red River is more efficient hydraulically than indicated by the 1953 report. The backwater levels between Redwood Bridge and locations upstream from the Floodway should be recalculated and verified to determine if the river slope is actually flatter, or steeper, than determined for the 1953 report, bearing in mind that the present Floodway location is slightly further south than the location considered in 1953.

4.3 Seine River Diversions

Under natural conditions, the confluence of Seine River flood flows with the Red River was located in the vicinity of the James Avenue Pumping Station. This is no longer the case. For example, during the early stages of the 1974 flood, the diverted flows into the Red River upstream of the Floodway reached about 6,000 cfs and probably raised the upstream Red River levels during the earlier flood stages (prior to about April 25) before the Red River overflowed its banks (Floods in Manitoba, April-May, 1974, by J. A. Long, Environment Canada). Later, as the flood stage rose to overbank flow conditions, and when the maximum levels were experienced above the Floodway, there was less effect from the Seine River diversion on water levels near the Floodway inlet.

The Seine River Diversion to the Red River is not considered in the calculations outlined in the Program of Operation.

4.4 Potential Inconsistencies

There may inconsistencies in the information that is relied upon to operate the Floodway. For example, in the Submission to the Manitoba Water Commission (pp. 16-17, September, 1997) there is concern that the early studies (1950's and 1960's) compared to present conditions were based on natural water levels that were lower (at the Floodway inlet location). In the Program of Operation (1984, p. 20) compared to present conditions, the rating curves and the text indicate that, for the same discharge, the levels used earlier were a foot higher (at James Avenue). The submission notes that, "This still needs to be determined".

Another inconsistency results from using the shifted rating curve for the James Avenue location. The values in Line 2 of Table 5 of the 1984 Program of Operation are stated, at the end of the table, to be consistent with the Redwood Bridge rating curve developed for the 1953 Federal Government report. At lower discharges this is the case, but in the range of the 1997 flood peak, this is not the case. Compared to the 1953 information, Line 2 of Table 5 considerably overestimates the discharge for a given stage at James Avenue.

In 1997 the peak level, without flood control facilities, would have been 34.5 feet according to Figure 1 (following page) in the Submission to the Manitoba Water Commission, September, 1997. On line 1 of Table 5 this corresponds to a discharge of 160,610 cfs (4,548 cms), about the same as the 1852 estimated peak discharge that was calculated in the 1950's (Govt. Canada, 1953, Appendix D, Table 1, p. 8).

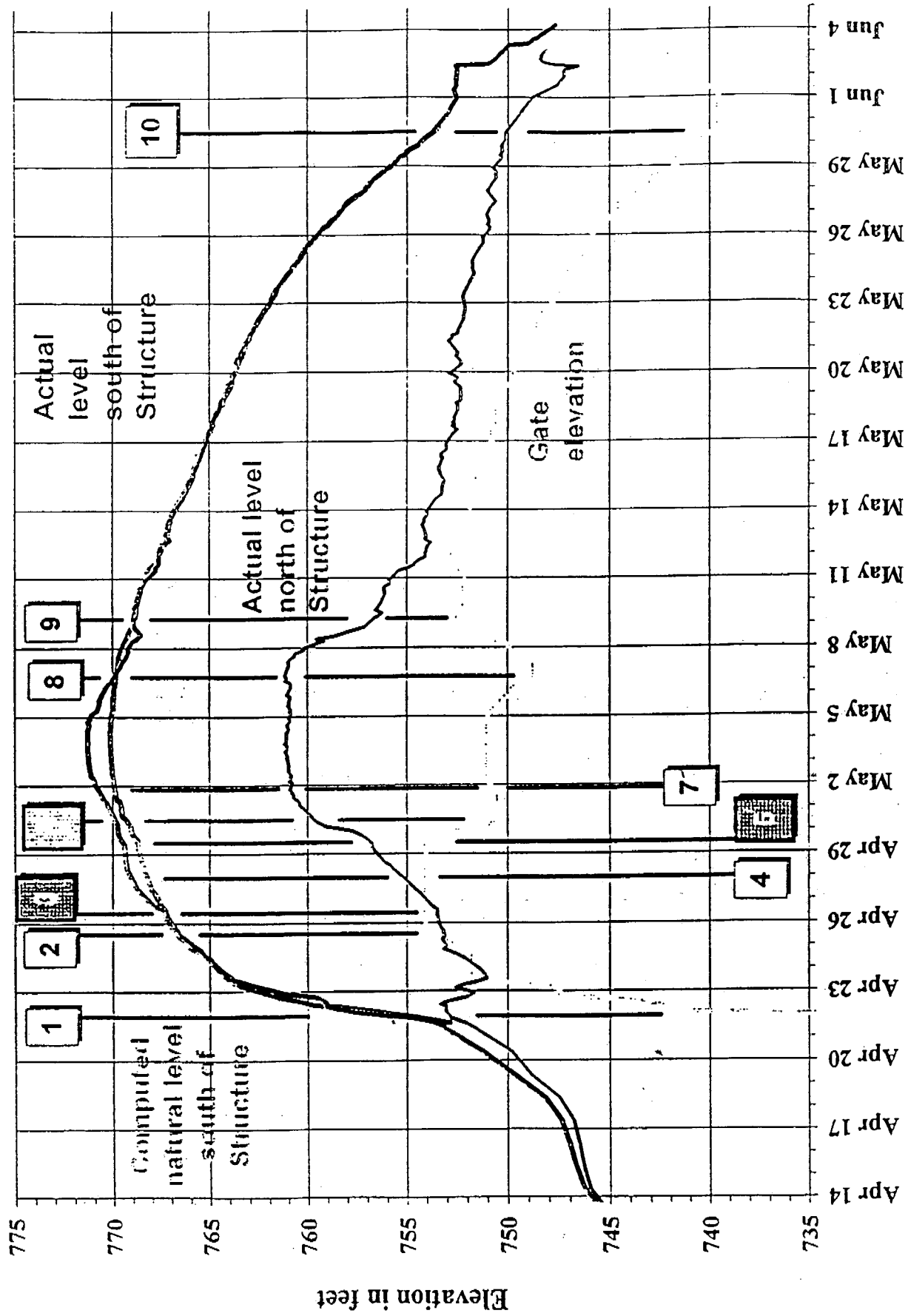

Figure 1. 1997 Flood: Red River

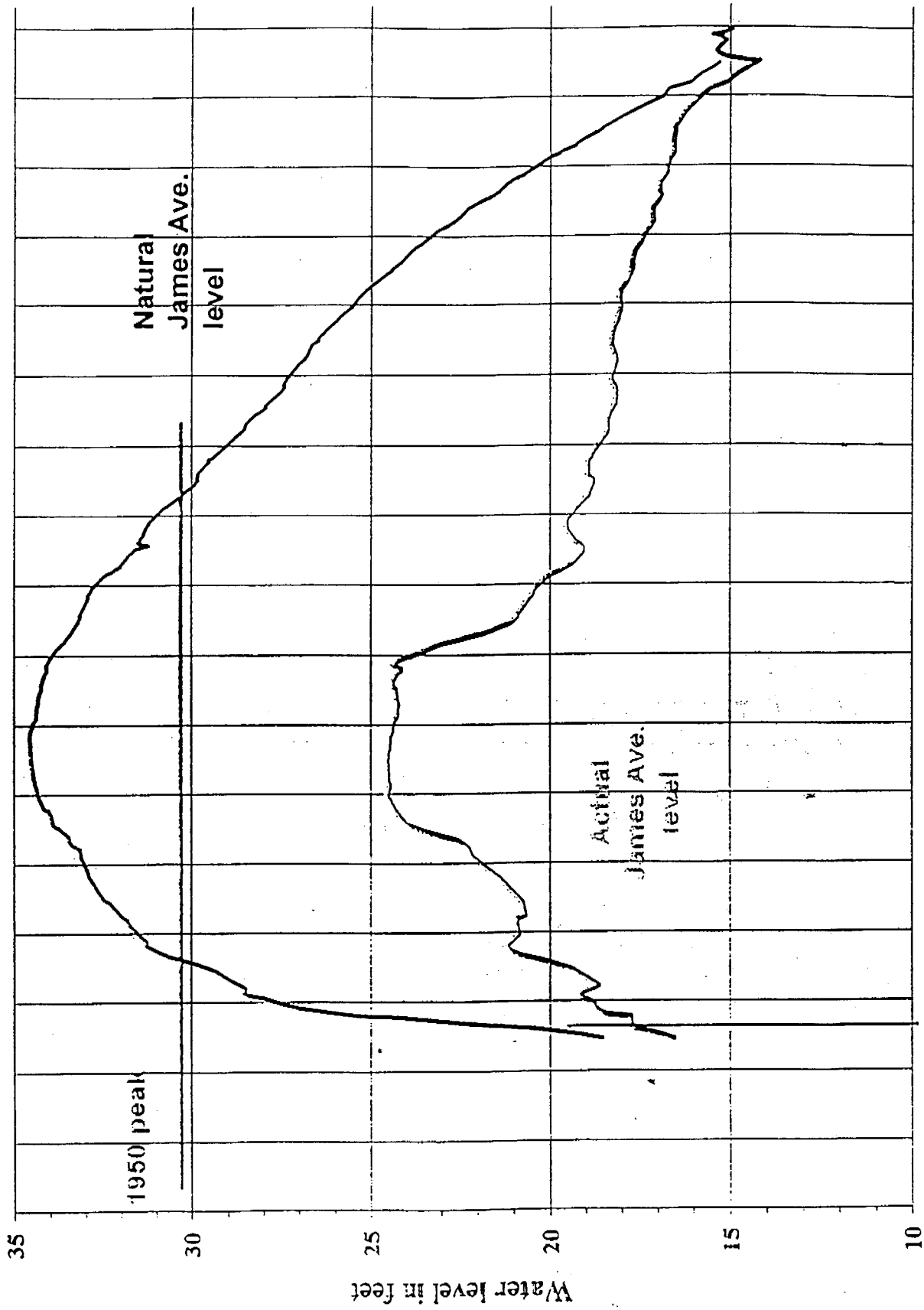

Figure 1a. 1997 Flood: Red River

Figure 1 shows that the corresponding "natural" water level upstream of the Floodway would be approximately elevation 770.0[2]. On line 2 of Table 5, the 34.5 foot stage corresponds to a discharge of about 150,000 cfs. However, based on the rating curve in the 1953 Federal Government report, the maximum discharge would have been approximately 134,000 cfs. Thus, line 2 of Table 5 does not correspond to the rating curve developed in the 1953 Federal Government investigation and included in the 1970 Program of Operation. According to Figure 10 of the 1970 Program of Operation, the water level upstream corresponding to 134,000 cfs would be elevation 768.0, or two feet lower than the "natural" water elevation 770.0 shown on Figure 1.

4.5 Cumulative Errors in "Measuring" Flood Flows

The preliminary value determined by the Water Survey of Canada for the **actual** maximum controlled discharge at Lockport during the 1997 flood is approximately 153,000 cfs (May 3 and 4). This is the sum of the Floodway discharge, the flow into Winnipeg through the Inlet Control Structure, the Assiniboine River inflow to the Red River, and any other local inflow.

The discharge in 1997 at the James Avenue Pumping Station peaked at approximately 80,000 cfs. Thus, most of the difference of 73,000 cfs (153,000 - 80,000) would have to pass through the Floodway. However, according to the Water Survey of Canada, the preliminary value for the maximum Floodway discharge is about 54,000 cfs. The apparent discrepancy of almost 20,000 cfs illustrates difficulties in the determination of "natural" conditions. Each 7,500 cfs of error in the natural discharge at the Floodway inlet corresponds to approximately one foot of water level in areas south of the Floodway.

153,000
16,000
16

4,000

[2]All water elevations are relative to G.S.C. datum. River stages at Redwood Bridge and at James Avenue Pumping Station are relative to City of Winnipeg datum. Elevations and stages are in feet.

5.0 LEVELS DURING THE 1997 FLOOD

5.1 Operation During the Flood

The September 1997 report to the Manitoba Water Commission sets out the rules to be followed for various high "natural" flows in the Red River. According to Operating Rule Number 1, the Inlet Control Structure is to be operated to maintain "natural" water levels at the Floodway inlet up to the design flow of 169,000 cfs in the Red River at the Redwood bridge, i.e. including the Assiniboine River flow (Plan of Operation, 1970).

Operating Rule Number 2 deals with "natural" flows on the Red River north of the Assiniboine River junction, from 169,000 cfs to 189,000 cfs. According to this rule, the control structure will be operated to maintain a water elevation 751.5 at Redwood Bridge. Water levels will be raised above "natural" levels at the inlet accordingly, to a maximum of water elevation 775.8. It should be noted that the water elevation 751.5 at the Redwood Bridge corresponds to a river stage of 25.5 feet (City datum) at the James Avenue Pumping Station.

Although the maximum discharge in 1997 was less than the design flood of 169,000 cfs, operating Rule Number 2 was used and modified to suit the actual circumstances during the flood. The City government specifically requested that the maximum water stage at James Avenue be limited to 24.5 feet for the following reasons:

1. With a river stage of 25.5 feet at James Avenue, the *theoretical* freeboard on the primary dykes would be only one foot - the actual freeboard would probably be less because of uncertainties in dyke elevations from place to place as a result of erosion and settling. There were real possibilities of overtopping from waves on windy days.

2 Many surface drains in the newer parts of Winnipeg have been designed to carry rainfall runoff directly into the Red and Assiniboine Rivers at an elevation equivalent to a James Avenue stage of 24.5 feet. If the James Avenue stage reached 25.5 feet, backflow would occur and some of this could enter the sewer system to cause basement flooding.

3. Secondary dykes in certain parts of the City, particularly those in the South End, would have been overtopped and, even with the modification to Rule Number 2, the secondary dykes in the St. Norbert area were within inches of being overtopped.

The Consultants were informed at the October 29, 1997 meeting with Water Resources Branch of Manitoba Natural Resources that, during the 1997 flood, the water level profile of the Red River within the City actually was steeper than was assumed in the 1953 investigations. Thus, if the water level at the James Avenue Pumping Station had been raised to the elevation 753.1 threshold (25.5 foot stage), the river would have been higher upstream, i.e. in the southern part of Winnipeg, than anticipated by the 1953 investigations which established the threshold level at the James

Avenue Pumping Station. The 1953 investigations are the basis for calculation of the "natural" water levels upstream of the Floodway inlet.

A river stage of 25.5 feet would have endangered the dyking and caused additional difficulties in the operation of the South End Sewage Treatment Plant (Water Resources Branch of Manitoba Natural Resources submission to the Manitoba Water Commission, September, 1997). Instead, the river stage near the James Avenue Pumping Station was not allowed to exceed 24.5 feet (water elevation 752.1), one foot lower than the threshold called for by Rule Number 1 of the 1984 Program of Operation.

The river stage at the James Avenue Pumping Station was maintained at or below 24.5 feet by diverting more water down the Floodway. This was accomplished by using the control gates to raise the water levels at the Floodway inlet.

Figure 1 and 1a are reproduced from the September 1997 Manitoba Natural Resources submission. The figure shows the estimated "natural" water levels upstream from the Floodway, compared to the water levels resulting from operation of the Floodway system. It can be seen that the observed water levels exceeded the calculated "natural" water levels at the peak of the flood over a period of approximately 72 hours. During most of this time, the water level was maintained approximately eighteen inches higher than "natural".

It may be concluded that neither the 1970 nor the revisions in the 1984 Program of Operation were followed during the 1997 flood.

5.2 Levels for Emergency Maintenance

Water Resources Branch of Manitoba Natural Resources' 1997 report to the Commission pointed out that maintenance of the Inlet Control Structure during the flood period required that water levels be raised upstream from the Floodway inlet to permit repairs to the eroding rip rap at the downstream toe of the inlet control structure.

The higher water levels also permitted repairs to the gate cylinder servomotor support beams, a problem which had been identified by an engineering consulting firm some months previously. The result was that upstream water levels at that time were raised above "natural" by about one foot. Subsequently, the gates again were raised on May 1, 1997 to keep the river stage at the James Avenue gauge from exceeding 24.5 feet.

Although the gates had to be raised to accomplish the required maintenance, this did not have to take place during the flood. Several months before the flood, during the period when the flood potential was general knowledge among water resources professionals, there was ample knowledge and time to accomplish the required maintenance.

5.3 Flooding of Grande Pointe

The Grande Pointe area is upstream of the Floodway inlet and east of the Red River. Formerly, the Seine River flood flows passed through this area and into the City of Winnipeg. Now most of the flood flows of the Seine River are diverted further upstream to the Red River. Section 4.3 discussed the tendency for higher water levels in this area, caused by moving the point of confluence of the Seine River's flood flows to a location upstream from the Floodway.

The Consultants were informed by Water Resources Branch of Manitoba Natural Resources at the October 9, 1997 meeting that the 1997 flooding in Grande Pointe was not anticipated since it had not been a problem in previous floods. Actually, the comparable flood of 1852 did inundate this area (Royal Commission on Flood Cost-Benefit, 1958).

At the height of the 1997 flood, the Red River at Ste. Agathe, several miles upstream, was at water elevation 776.4, some five feet above the water level at the Floodway intake channel. Backwater from the Inlet Control Structure extended some distance upstream and may have caused the Red River to overflow at some upstream point. Water then flowed down to the Grande Pointe area by following the topography. Levels in Grande Pointe would then be above the water elevation 771.5 level reached at the Floodway inlet, Figure 1. This was the case, since the residents and the Water Resources Branch of Manitoba Natural Resources agree that the water levels in Grande Pointe were higher, reaching at least water elevation 771.9.

5.4 Effect of Avonlea Road and the Brunkild Dyke

The Consultants were told by the residents, and by farmers in the area, that Avonlea Road was breached to release water stored behind the road and behind the east-west dyking in that area. The flow through the breach cascaded down to affect the land and private properties between the road and the Red River. This information indicates that water stored behind the road must have got there from further upstream where the river surface profile was above the elevation of the surrounding land. As discussed above, the river profile was affected by the backwater from the Inlet Control Structure, which was operated to raise water levels above "natural" levels.

The Consultants conclude, as in the case of the water levels at Grande Pointe, that the rush of water from the west that the residents say affected their homes did result to some extent from the water levels being above the "natural" level at the Inlet Control Structure.

5.5 Wind

On a river, a strong wind in the direction of the current does not raise water levels. The action of the wind on a still body of water such as a shallow lake, or on the water trapped behind the Brunkild Dyke, is to cause a surface flow in the downwind direction supported by the wind shear at the water surface. This caused water levels against the dyke to rise - the wind "setup" phenomenon that is well known on Manitoba lakes.

If the dykes had not been there, the wind-driven surface flow simply would have added to the strength of the downstream flowing river current, without causing higher water levels. The Consultants conclude that the presence of the dykes caused water levels to rise above the "natural" levels which would have been experienced in their absence.

6.0 CONCLUSIONS

The following conclusions were reached:

1. There is a reasonable technical foundation for the belief by local residents immediately upstream of the Floodway, that the Floodway has increased their risk of being flooded above "natural" levels during future extreme events.

2. The original rating curve for Redwood bridge was a key factor in determining the design parameters for the Red River Floodway. Table 5 of the 1984 Program of Operation contains a stage-discharge rating which lies to the right of the original curve, indicating a change in the hydraulic control. The new rating shows a significantly higher discharge for levels at and above those reached in 1997 at the gauge near James Avenue Pumping Station. If this curve has changed in the manner indicated, the City of Winnipeg is now afforded greater protection from very high floods.

3. Flooding upstream from the Inlet Control Structure exceeded "natural" levels during the 1997 flood. Figure 1, which is a copy of the figure plotted by the Water Resources Branch of Manitoba Natural Resources for the Manitoba Water Commission, shows that south of the Inlet Control Structure flooding was sustained approximately 72 hours at 1.5 feet above the "natural" level. In the Grande Pointe area, this corresponds to at least 1.9 feet above the "natural" level.

4. Table 5 in the 1984 Program of Operation is for the gauge at the James Avenue Pumping Station. The first line in Table 5 is the stage-discharge rating for present conditions; the second line purports to be based on the rating used in the design of the Red River Floodway. At the peak discharge reached in the 1997 flood, there is a significant difference between the values obtained from Table 5 and the values from the "Report on Investigations into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area, Appendix D". The difference in ratings corresponds to approximately two feet of difference in the calculated maximum 1997 "natural" level upstream from the Floodway inlet. In other words, the flooding upstream from the Floodway inlet might have been 3.5 feet above "natural" level and, in the Grande Pointe area, 3.9 feet above "natural" level.

5. In the 1984 Program of Operation, "natural" levels are based on the revised rating curve for the James Avenue Pumping Station and a rating curve developed in 1953 for the Red River at the location of the Floodway inlet. It may be reasonable to adjust the rating curves based on additional data acquired since 1953, but it is not clear why one curve was adjusted without adjusting the other.

6. For several miles upstream from the Inlet Control Structure, the backwater from the Inlet Control Structure raised water levels above natural levels. This exacerbated the overflow

from the Red River. A backwater analysis would show how far upstream and how much the water surface was affected by an additional 1.5 feet in level at the Inlet Control Structure.

7. The backwater from the Inlet Control Structure affected the river's sloping water surface profile for some distance upstream where the river levels were well above the level at the inlet. The overland flow from the river into these upstream areas, i.e. Grande Pointe and Avonlea Road, was increased during the 1997 flood because of the operation of the control structure.

8. Wind effects during the 1997 flood on the west dyke and its extension towards Brunkild increased the water levels above "natural". This fact is not considered in the Program of Operation.

9. The Seine River now contributes more to flooding upstream from the Floodway than it did before the construction of the Seine diversion. Before construction of the diversion, a large portion of the Seine River flood flows entered the Red River in downtown Winnipeg - the areas upstream from the Floodway inlet indirectly were affected slightly by backwater. Now, the diverted Seine River flood flows directly affect levels above the Floodway inlet. This fact is not considered in the Program of Operation.

10. The method of calculating "natural" flows and the degree of compliance with "natural" levels is incomplete. It does not consider the effect of wind setup on the Brunkild and west dykes, the diversion from the Seine River, or the potential effect of accumulated errors in measurement. Thus, a calculated "natural" level is an approximation which will always underestimate the effect of the flood control facilities on the residents upstream from the Floodway inlet.

11. During the 1997 flood, the Federal Government's Water Survey of Canada operated at reduced effectiveness because of staff cutbacks and relocation of its facilities. Emerson and a few other AES weather stations were shut down during the flood. These actions are inconsistent with the intent of Section 20 of the Federal-Provincial Cost Sharing Agreement.

BIBLIOGRAPHY

1. *Agreement Between the Government of Canada and the Government of the Province of Manitoba for Construction of the Greater Winnipeg Floodway*. Ottawa: May 1962.

2. Canadian Water Resources. *Proceedings of the Red River Valley '97 Flood Symposium, The Flood of the Century*. Winnipeg: October 1997.

3. Canadian Water Resources Association. *Water News Newsletter of the CWRA, Technical Bureau Supplement*. September 1997.

4. Canadian Water Resources Association. *Water News*. Volume 16, No. 1A. Anniversary Issue 1997.

5. Clark, Robert H. "Notes on Red River Floods". Dept. of Mines and Natural Resources, Manitoba. October 1950.

6. Clark, Robert H. *Summary of Existing and Potential International Waterway Problems*. Dec. 2, 1974.

7. Clark, Robert. H. *The Concept and Design of the Red River Floodway.*

8. Environment Canada Inland Waters Directorate. *Flood Damage Reduction Program, a Federal-Provincial Initiative*. Ottawa: 1978.

9. Environment Canada Inland Waters Directorate. *Historical Streamflow Summary Manitoba to 1990*. Ottawa: 1991.

10. Environment Canada Inland Waters Directorate. *Reference Index Hydrometric Map Supplement Prairie Provinces 1986*. Ottawa: 1987.

11. Environment Canada Inland Waters Directorate. *Surface Water Data Manitoba 1990*. Ottawa: 1991.

12. Environment Canada Inland Waters Directorate. *Surface Water Data Manitoba 1986*. Ottawa: 1987.

13. Environment Canada, Winnipeg Climate Centre. Station data, January to July, 1997.

14. Government of Canada, Department of Resources and Development, Engineering and Water Resources Branch, Water Resources Division. *Report on Investigations into Measure for the*

Reduction of the Flood Hazard in the Greater Winnipeg Area. Prepared by Red River Basin Investigation Water Resources Division. March 1953.
Appendix "A", Geography and Development
Appendix "B", History of Floods on the Red River
Appendix "C", Flood Runoff Analysis
Appendix "D", Flood Magnitudes and Frequencies
Appendix "E", Channel Improvements and Dyking
Appendix "F", Flood Storage
Appendix "G", Flood Diversion
Appendix "H", Assiniboine River. Prepared by Prairie Farm Rehabilitation Branch, Dept. of Agriculture.

15. Government of Canada, Department of Resources and Development, Engineering and Water Resources Branch, Water Resources Division. *Report on Investigations into Measure for the Reduction of the Flood Hazard in the Greater Winnipeg Area.* Prepared by Red River Basin Investigation Water Resources Division. October 1953.

16. Greater Winnipeg Floodway Advisory Board. Minutes of Meetings, 1965 - 1969.

17. Gulf South Research Institute. *Red River of the North Basin, Preliminary Basinwide Review Study.* Summary Report. December 1980.

18. H.G. Acres & Co. Ltd. *Red River Floodway Report on Hydraulic Model Tests of the Inlet Control Works.* Niagara Falls: January 1963.

19. H.G. Acres & Co. Ltd. *Red River Floodway Report on Hydraulic Model Tests of the Submersible Gates and the Inlet Control Structure.* Niagara Falls: March 1963.

20. Historical Floods on Red River. *Dominion of Canada Sessional Papers*, No. 123, Appendix No. 16. 1880.

21. International Pembina River Engineering Board. *Joint Investigation for Development of the Water Resources of the Pembina River Basin, Manitoba and North Dakota.* December 1964.

22. Manitoba Natural Resources. *Submission to the Manitoba Water Commission.* September 1997.

23. Manitoba Natural Resources. *Manitoba Natural Resources Submission to the Manitoba Water Commission, Background Information Concerning Manitoba Natural Resources Involvement in the 1997 Flooding of the Red River Valley.* September, 1997.

24. Manitoba Natural Resources, Water Resources, Flood Damage Reduction Section, Water Management Service. *Red River Floodway Program of Operation.* Winnipeg: October 1984.

25. Manitoba Natural Resources, Water Resources Branch. *Submission to the Manitoba Water Commission on Monitoring and Forecasting 1997 Flood Conditions in Manitoba.* (unbound papers) Sept. 18, 1997.

26. Manitoba Natural Resources, Water Resources Planning Division. *Red River Floodway Program of Operation.* July 1970.

27. Manitoba Water Commission. *A Review of Provincial Procedures and Plans for Flood Protection and Flood Fighting, Draft Report.* October 1974.

28. Manitoba Water Commission. *Review of the Red River Floodway, Portage Division and Shellmouth Reservoir.* November 1980.

29. Manitoba Water Resources Branch. *Daily Water Levels and Forecasts, Red River, April 20, 1997 to May 12, 1997.*

30. Manning, H. W., W.C. Riley, W. J. MacDonald, A. S. Beaubien, and J. McDowell. *Report of the Royal Commission on Flood Cost Benefit.* Winnipeg: December 1958.

31. McLean, Douglas L. *Flood Prevention Projects to Protect Winnipeg.* Canadian Engineer. April 1, 1920.

32. Mudry N., P. J. Reynolds and H. B. Rosenberg. *Post- Project Evaluation of the Red and Assiniboine River Flood Control Projects in the Province of Manitoba, Canada.*

33. Province of Manitoba. *The Environment Act*, Chapter 26 (Bill 26). July 1987.

34. Province of Manitoba. *Land & Water Strategy the Process Begins, Workbook on Water.* January 1989.

35. Province of Manitoba, Department of Agriculture and Conservation, Water Control and Conservation Branch. *Red River Floodway Model Tests of Inlet Transition.* Winnipeg: April 1963.

36. Province of Manitoba, Dept. of Mines and Natural Resources, Water Resources Branch. *Hydrometeorological Networks and Flood Forecasting Procedures for Operation of the Red River Floodway.* Winnipeg: October 1971.

37. Province of Manitoba, Dept. of Mines, Resources and Environmental Management, Water Resources Division. *Spring Flood Information for the Assiniboine and Red River*. February 1977.

38. Strilaeff, P.W. Environment Canada, Inland Waters Directorate, Western Region. *Floods in Manitoba April - May, 1974*. December 1974.

39. Templeton Engineering Co. *Royal Commission on Flood Cost-Benefit*. Winnipeg: December 1958.

40. Warkentin, A.A. *The Red River Flood of 1997, An Overview of the Causes, Predictions, Characteristics and Effects of the Red River Flood of the Century*. Winnipeg: July 4, 1997.

41. Yorke, Thomas H. and Russell E. Harkness. *Red River of the North Flood of 1997 - Was it the big one?* WSTB Newsletter. Volume 14, Number 3, July/August 1997.