Prepared for:

MANITOBA WATER COMMISSION
WINNIPEG

Prepared by:

NORTHWEST HYDRAULIC CONSULTANTS LTD.

September 1980

REVIEW OF OPERATIONAL PROBLEMS WITH THE RED RIVER FLOODWAY

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SUMMARY

The report was commissioned in order to investigate certain specific questions on Red River flood control operations, as raised in an overall review of the floodway system conducted by Acres Consulting Services Ltd. These questions concern the effect in 1974 of inaccuracies in operating data for Inlet Control Structure gates, subsequent adjustments to the operational calculations, and complaints from upstream residents about flood control operations generally.

It is concluded that the effect of errors in gate control data in 1974 was to raise upstream water levels above allowable 'state of nature' levels, by an amount not exceeding 2 feet. It is further concluded that the present operational system is adequately achieving a 'state of nature' with respect to upstream levels.

Recommended improvements to the present system include preparation of an up-dated manual of operations and development of a computer system for flood control.

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ACKNOWLEDGEMENTS AND CREDITS

Thanks are expressed to the following persons for their cooperation and assistance in providing information and responding to numerous questions:

Mr. T.A. Crosier, acting chairman, and Messrs. A. Scarth, J. Anarson and H. Einarson of Manitoba Water Commission.

Mr. T.E. Weber, director, and Messrs. N. Mudry and J. Toye of Manitoba Water Resources Branch.

Mr. W.R. McKay, regional manager, and Messrs. R. Carson, B. Bodnaruk and J. McPherson of Acres Consulting Services Ltd., Winnipeg.

Mr. R.G. Boals, asst. regional chief, and Messrs. J. Way and J. Wedel of Water Survey of Canada, Winnipeg.

The report was prepared by C.R. Neill of Northwest Hydraulic Consultants Ltd. and reviewed by A.L. Charbonneau.

1. INTRODUCTION

1.1 Reason for Study

The Red River Floodway System was constructed by federal-provincial agreement in the 1960's to alleviate flooding in Winnipeg. In 1980, the Manitoba Water Commission conducted enquiries into the operation of the system since operations started in 1969, and received a number of complaints and briefs from upstream residents alleging mismanagement of the system by Manitoba Water Resources, particularly with reference to the flood of 1974.

Acres Consulting Services Ltd. was retained by the Commission to review the operation of the Floodway together with the associated Shellmouth Reservoir and Portage Diversion on the Assiniboine River system, A series of specific questions was posed to Acres regarding the effects of the floodway and its operations. One specific question was:

"Does operation of the control gates violate the intended principle of not raising upstream water levels above the state of nature?"

The resulting Acres report of June 1980 concluded that the intended principle had been violated in 1974 and 1976, as a result of errors in gate operation graphs supplied by Acres to Manitoba Water Resources in 1967. Because of their company's involvement in the problem, Acres recommended that their analysis of the error and its effects on water levels "be reviewed and reported upon by a disinterested party or agency".

1.2 Terms of Reference

Following discussion with the Commission, terms of reference for the present review were agreed as follows:

1. To investigate the effects of errors in control graphs for Inlet Control Structure gates, as recently reported by Acres and by Water Resources, on upstream flood levels in 1974.

2. To investigate whether any additional factors caused upstream flood levels in 1974 to exceed a 'state of nature' or to be excessively high compared to similar floods before or since, as alleged in briefs to the Commission.

3. To investigate whether present operating data and procedures are achieving a 'state of nature' with respect to upstream flood levels, and if not to explain why.

4. To comment on any aspects of operational procedures requiring improvement, providing comments can be sufficiently backed up by evidence.

These terms of reference somewhat exceed those implied by Acres' recommendation. The Commission considered that in order to respond to the concerns of upstream residents, it was necessary to go beyond the question of the error in control gate data prior to 1977.

1.3 Investigations Conducted

On 29 July 1980 Mr. C.R. Neill of Northwest Hydraulic Consultants visited the Inlet Control Structure and Floodway inlet site in company with Mr. Arnold Crosier, Acting Chairman of the Commission, then met with the Commission to discuss the overall problem and terms of reference. He then met with Messrs. W.R. McKay, R. Carson, B. Bodnaruk and J. McPherson of Acres Consulting Services. The next day he met with Messrs. R.G. Boals, J. Way and J. Wedel of Water Survey of Canada, and later with Messrs. T.E. Weber, N. Mudry and J. Toye of Manitoba Water Resources. All organizations were extremely cooperative in answering questions and supplying relevant data and documents.

The present report is based essentially on analysis of documents and on meetings outlined above. No field investigations or interviews with residents have been conducted.

2. OPERATIONAL POLICY AND PROCEDURES

2.1 Operational Policy for Floodway System

The Red River Floodway System can be considered to consist mainly of the Floodway, which by-passes part of the Red River floods around Winnipeg, together with Shellmouth Reservoir and Portage Diversion, which reduce flood peaks reaching Winnipeg from the Assiniboine River (Figure 1). The hydraulic interactions between these components are rather complex, so that it is not easy for the public to comprehend the logic of flood control operations or to follow the chain of calculations which determines the operation of the control gates on the Red River just downstream of the floodway inlet.

The floodway system is intended to be operated normally according to a policy of not raising flood levels upstream of the inlet above natural conditions, defined as the levels that would have obtained had the floodway system (including Assiniboine River components) not been in operation. This policy, which we understand was enshrined in the original agreements, is stated in a 'Program of Operation'[1] prepared by Manitoba Water Resources in 1970 and in a report published by Manitoba Water Commission in 1974[2]. The floodway is not intended to be operated to reduce flood levels upstream of the inlet, even although this might be possible to a limited

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[1] "Red River Floodway Program of Operation". Unpublished typescript dated March 1970.

[2] "A review of provincial procedures and plans for flood protection and flood fighting". Manitoba Water Commission, Dec. 1974.

degree under certain flood conditions. Under emergency conditions, if the design flood of 169,000 cfs were exceeded, upstream water levels would exceed natural levels, but these circumstances are very unlikely.

In 1974, allegations were made at public hearings that the policy had been violated during the 1974 flood. The above-mentioned Commission report of 1974 stated:

> "With regard to the Red River Floodway Inlet Structure, it was alleged that the structure was operated so that water levels were higher south of the structure than they would have been in a 'state of nature' and that a lowering of the gates would have helped the area south of the inlet structure. The Commission in examining these points is convinced that the level at the inlet control structure was maintained at or below the levels that would have occurred in a 'state of nature'. The Floodway was designed to give protection to Winnipeg and should be operated in such a manner so as to provide a maximum of protection without violating the 'state of nature' criteria."

As will be shown, the Commission's conviction regarding levels was not quite justified. Briefs submitted to public hearings in 1980 reiterate assertions regarding violations of the policy, particularly in April 1974, and raise the possibility of legal action. These briefs are considered further in Section 3.2.

2.2 Operational System

Figure 1 shows a diagrammatic map of the river and floodway system, with the location of some of the key gauges used to determine discharges and water levels. When the river level at the floodway inlet rises above the floodway floor level of 750 feet elevation, part of the Red River flow starts to pass down the floodway. For a given condition in the Red River upstream, the proportion of Red River flow passing down the floodway can be increased by raising the gates on the Inlet Control Structure, thereby reducing the proportion that would otherwise pass through Winnipeg.

In practice, during flood periods when by-passing becomes necessary, the level of the gates is determined by a series of calculations designed to establish the 'state of nature' water level at the floodway inlet, as called for by the operating policy. When this water level is destermined for a given point in time, the gates are adjusted until it is attained, the water level being checked by river gauges. Because under natural conditions the river level is subject to backwater effects from the confluence of the Red and Assiniboine Rivers, the 'state of nature' calculations have to take into account not only the portion of flow passing down the floodway, but also the inflow from the Assiniboine that would have occurred had Shellmouth Reservoir and Portage Diversion not been present. For this reason, it can be somewhat misleading to compare the operational results of different floods on upstream levels: two floods of equivalent severity on the Red River upstream of Winnipeg may, when controlled strictly according to policy, produce rather different upstream levels, simply because runoff conditions in the

Assiniboine River are different. For an upstream Red River discharge of 70,000 cubic feet per second, (roughly equivalent to the 1974 flood), the difference in upstream levels due to different conditions in the Assiniboine can amount to over 2 feet, higher levels of course resulting from higher flows in the Assiniboine system.[1]

It is interesting to note that the hydraulic design of the floodway system has certain psychological consequences. Because of the high level of the floodway floor relative to the river bed, under moderately high flood conditions the control gates have to be raised in order to divert enough water down the floodway to relieve Winnipeg significantly. Upstream residents, observing a substantial drop in water levels across the Inlet Control Structure, tend to perceive this gate operation as artificially or unnecessarily raising the flood levels they experience. Provided that operating policy is strictly observed, this perception is basically incorrect. However, because operating policy says nothing about rates of change, it is possible under some conditions for upstream levels to rise faster than would have occurred naturally, even although 'natural' levels are at no time exceeded.

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1 The basic chart of these relationships, included in the Program of Operation (1970) as Figure 8, and otherwise described as file no. 11-5-1103, appears to show lower upstream levels for higher Assiniboine River contributions. This is because the upstream level is plotted against combined discharge downstream of the Assiniboine confluence. An alternative, more easily grasped presentation of the same data is shown as Figure 3 herein.

Figure 2 shows diagrammatically some of the key elevations in the vicinity of the floodway inlet that will be referred to subsequently.

2.3 Hydraulic Calculations and Assumptions

The method utilized to calculate and set the 'natural' (or 'state of nature') flood level upstream of the Inlet Control Structure at any point of time has five essential components, as follows:

1) Calculate the ('natural') contribution of the Assiniboine River to the Red River flood in Winnipeg, that is, the Assiniboine discharge that would have entered the Red River had the flood control system on the Assiniboine not been in operation.

2) Determine the discharge in the floodway, and the Red River discharge downstream of the floodway inlet.

3) Calculate the total 'natural' discharge in the Red River below the mouth of the Assiniboine.

4) Estimate the 'natural' water level at the floodway inlet corresponding to 3) and 1).

5) Determine the gate setting to achieve 4).

Each of these components will now be explained in more detail, on the basis of the writer's interpretation of the Program of Operation (1970) and subsequent modifications. It should be noted here that a unified document describing the present system does not seem to be available.

2.3.1 Calculation of 'Natural' Discharge Contribution from Assiniboine River

In calculating the 'natural' discharge from the Assiniboine River, it is necessary to discount the effects of Shellmouth Reservoir, Portage Diversion and flood retention dikes along the lower Assiniboine. The procedure is as follows:

1) Gauged flows in the Portage Diversion and in the Assiniboine River downstream of the diversion are added together.

2) The above sum is augmented to discount actual flood regulation by Shellmouth Reservoir*.

3) The resulting figure is reduced to allow for overflows that would have occurred under natural conditions below Portage.

4) The resulting figure is augmented to allow for certain inflows below Portage, not included in measured flows used in 1) above.

Step 2, according to the Program of Operation (1970), was to be accomplished by the use of a single-curve graph relating natural to reduced peak discharges at Portage. We understand, however, that this

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* We understand that it is actually possible for Shellmouth Reservoir to be operated in such a way as to increase downstream flows, requiring a reduction rather than an augmentation at this point.

curve is not in fact used, and that the effect of Shellmouth Reservoir in any particular flood is determined by routing calculations. In the case of the 1974 flood our understanding is that the effect of the reservoir was virtually zero.

Steps 3 and 4 are accomplished by the use of single-curve graphs derived from earlier studies by PFRA and by the Province before 1962. These graphs presumably represent the averages of relationships that in fact vary from one flood to another. Apparently they are judged adequate for the purpose of estimating the Assiniboine River's 'natural' contribution. This point is discussed further in Section 2.4, Comments on Calculation Procedures.

2.3.2 Determination of Actual Discharges in Floodway and in Red River Downstream of Floodway Inlet

The floodway discharge is determined by reading the water level at a gauging station and converting to discharge by means of a single-valued stage-discharge curve.

The Red River discharge downstream of the floodway inlet has usually been determined by reading the water level upstream of the Inlet Control Structure, the level of the tops of the gates, and the water level downstream. The discharge is then read from a chart which graphs an equation originally derived from model testing in 1967 or thereabouts: this relates gate discharge to upstream head and to the difference between upstream and downstream water levels, as is normal for a weir affected by backwater.

This latter operation is the main reason for errors in operation that occurred in 1974 and 1976. It is not essential that the Red River discharge be measured at the Inlet Control Structure, since there are river gauges elsewhere from which reasonable estimates can be made. As the Acres report of June 1980 states, however:

> "When the Floodway and control structure came into operation in 1968, the Water Resources Branch chose to use the control structure as a metering device. This made the level of the gate lip critical as it served to meter the flow through the structure. The error in the graph showing gate lip elevation versus cylinder position, and the use of this graph to determine the gate lip level, resulted in an overestimate of the natural river flow. This overestimate of natural flow in turn called for a higher upstream water level than the real or correct flow would have justified and the gates were raised accordingly."

The reasons for this use of the control structure have been probed further with Acres and Water Resources personnel. Apart from the convenience and accuracy of using a weir or gate overflow, if properly calibrated, as a flow measuring device, there were other considerations: at other measurement sites, stage-discharge curves were found to be unreliable because of backwater effects, and use of these sites for flood operations would therefore have required several time-consuming velocity meterings across the channel every day. Taking account of practical difficulties in flow measurement, it does appear that for

operational purposes it is technically appropriate to meter the Red River flow by use of the control structure gates.

The question then arises of how an error in gate data was allowed to persist for several years. Firstly, it appears that there was a lack of communication between Water Resources and Acres. Water Resources rightly state that the erroneous gate control data were supplied by Acres in 1967, but Acres claim they did not know the data were to be used to meter the flow. Although the error was essentially discovered by Water Resources field surveys in the fall of 1974, no action was apparently taken to alter operational procedures until 1977. Acres state that discovery of the error was never communicated to them, and that they had suggested a field check of the gate control data when supplying these in 1967.

There is a further complication, in that some written statements refer to two different sources of error. The first is the above-mentioned mistake in Acres' graph relating top-of-gate elevation to setting of the operating cylinder inside the control house. The second is the fact that the equation relating discharge to top-of-gate elevation (and downstream water level) was based on model tests. Water Resources claim that subsequent field checks did not fully support the model-based equation, and that use of the latter was in fact favourable to upstream interests in 1974, thereby partially compensating for the gate setting error. More attention is given to this point in Section 3.3.

2.3.3 Calculation of Combined 'Natural' Discharge in Red River Downstream of Assiniboine River

This is calculated as the sum of:

- Assiniboine River 'natural' discharge
- Floodway discharge
- Red River discharge at Inlet Control Structure
- Local inflow below Inlet Control Structure

Derivation of the first three items has been explained above. The last is partly measured (LaSalle River) and partly estimated, but is relatively unimportant.

2.3.4 Estimation of 'Natural' Water Level at Floodway Inlet

In estimating the water level at the floodway inlet corresponding to the calculated 'natural' discharges (with all flood control systems discounted), reliance is placed on hydraulic relationships derived from pre-floodway data. The procedure is as follows:

1) The calculated Assiniboine 'natural' discharge is compared against the calculated combined 'natural' discharge* on a correlation graph, to determine whether the Assiniboine contribution is 'minimum', 'average', or 'maximum'. The correlation graph is based essentially on 1931-61 data.

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*By combined discharge we mean the discharge in the Red River downstream of the Assiniboine.

2) The water level at the floodway inlet is then read against combined 'natural' discharge (downstream of the Assiniboine), on a chart which shows three curves corresponding to 'minimum', 'average' and 'maximum' Assiniboine River contributions. In Figure 3 we have re-plotted part of the information on this chart, to show water level at the floodway inlet against Red River discharge alone, with the same separation of curves according to Assiniboine River contribution. This form of plotting demonstrates more clearly the influence of the Assiniboine River contribution on the stage-discharge relation in the Red River upstream.

2.3.5 Setting of Inlet Control Structure Gates

The required gate elevation to achieve the 'natural' upstream water level is calculated by using the previously-mentioned graph relating upstream head to discharge and drop across the structure. The required cylinder rise is then read from a gate control graph, errors in which were mentioned in Section 2.3.2.

A follow-through of the calculation procedure outlined in the Program of Operation (1970) indicates that at this point the previously discussed error in the gate control data would come into play again and introduce an additional error in water level. However, we understand that the calculation is used only to approximate the gate setting and that the gate is subsequently adjusted so that the actual water level achieved at the floodway inlet meets the target level. This point is raised again in Section 2.5.

2.4 Comments on Calculation Procedures

Being previously unfamiliar with the floodway system, we found considerable difficulty in following through the logic of the calculation procedure from the documents provided. The chain of calculations appears at first sight to be rather indirect and therefore vulnerable to human errors. It is not possible within the scope of the present study to investigate in depth the reliability of some of the graphs utilized, particularly those used to calculate the 'natural' Assiniboine discharge and its effect on 'natural' levels upstream of the floodway inlet. On the basis of the graphs provided, the calculated upstream levels are not particularly sensitive to the calculated Assiniboine discharge, therefore there is probably no reason for concern on this point. For example, under moderate flood conditions, an error in classifying the Assiniboine contribution as 'average' rather than 'minimum' would affect upstream levels by about 1 foot (see Figure 3).

It appears that no use is made in flood operations of the combined discharge gauge on the Red River at Lockport, downstream of the floodway outlet. Since this gauge sums several actual flows of interest, it would seem to offer some advantages over the series of gauges used for various components.

2.5 Theoretical Effect of Error in Gate Control Graph

To test the effect of the erroneous gate control graph used before 1977, we have assumed the following figures, which do not correspond to any particular flood event:

Red River discharge upstream of floodway inlet	80,000 cfs
'Natural' Assiniboine River contribution	30,000 cfs
Local inflows	negligible
Combined 'natural' discharge	110,000 cfs

Calculations strictly according to the Program of Operation (1970) give the following results, using the correct gate control curve:

Required water level at floodway inlet	766.0 ft
Corresponding floodway discharge	43,000 cfs
Structure discharge (by difference)	37,000 cfs
Corresponding top of gate elevation	753.8 ft

We shall now assume that the inflowing Red River discharge is unknown, and that the structure discharge is calculated using the wrong gate control curve, then used in determining the required water level at the floodway inlet. It is necessary to assume an initial water level at the time the gate setting is read: this will be taken as 764.5 ft. Actual figures are then as follows:

Corresponding floodway discharge	37,000 cfs
Actual structure discharge (by difference)	43,000 cfs
Corresponding top of gate elevation	750.7 ft
Corresponding cylinder rise (by correct curve)	24.7 ft

Using the wrong gate control curve, figures are calculated as follows:

Top of gate elevation	749.3
Calculated structure discharge	48,000 cfs
Calculated total natural discharge downstream of Assiniboine confluence	115,000
Required water level at floodway inlet	766.7 ft

At this point, due to use of the wrong gate control curve, a target level has been established at the floodway inlet that is 0.7 ft too high. Further use of the wrong curve to establish the required gate setting to achieve this target would lead to an additional error, as follows:

Floodway discharge for above target level	46,000 cfs
Required structure discharge (by difference)	39,000 cfs
Required top of gate elevation	754.0 ft
Corresponding cylinder rise (using wrong curve)	32.4 ft

This is the cylinder rise that would be set. The actual results would then be as follows:

Top of gate elevation (by correct curve)	756.8 ft
Head upstream of gate	10.8 ft
Water level at floodway inlet	767.6 ft
Floodway discharge	49,000 cfs
Structure discharge	31,000 cfs

Thus use of the erroneous graph for gate setting would produce an additional 0.9 ft of error in the water level, making it 1.6 ft too high in total.

The advantage of making this calculation with hypothetical figures is that it avoids the uncertainty surrounding certain data for the 1974 flood. Since, however, the assumed figures are in the same general range as those for the 1974 flood, it seems reasonable to conclude that the error in 1974 is unlikely to have exceeded 1.6 ft, even assuming no gate adjustments to match achieved water level to target water level.

3. OPERATIONS IN 1974 FLOOD

3.1 Relationship of 1974 Flood to Other Notable Floods

Some of the key discharges and water levels in the 1974 flood are compared with those of other notable floods in Table 1.

An important feature of the 1974 flood was the high ratio of Assiniboine River flow to Red River flow. Under natural conditions, the 1974 combined discharge at Lockport, just downstream of the floodway outlet, would have been about 103,000 cfs, of which about 30,000 cfs would have been supplied from the Assiniboine River; however, the Portage Diversion in fact drew off more than half of the Assiniboine River contribution. In terms of combined peak discharge at Lockport, the 1974, 1950 and 1979 floods would all have been similar under natural conditions, but the proportion of combined Lockport flow supplied from the Assiniboine would have been about 30% in 1974, against 10% in 1950 and 15% in 1979.

3.2 Contentions by Upstream Residents

The above-mentioned differences in the Assiniboine River contribution go far to explain apparent anomalies in water levels commented upon in briefs submitted to the Commission by A.W. Hilger, T. Lasko and the Red River Valley Flood Control Coalition. It is instructive to analyze these anomalies as follows:

(i) A.W. Hilger alleges that controlled water levels upstream of the Inlet Control Structure were 6 feet higher in 1974 than natural levels in 1948, although flows in the Red River upstream were similar. So far as we are able to determine, the actual difference was about 5 feet. The relevant discharge figures are approximately as follows:

	Red River (upstream)	Assiniboine River	Combined
1974	66 000	30 000 ('natural')	96 000
1948	63 000	7 000 (actual)	70 000

Use of the hydraulic relationships graphed in the Program of Operation indicates that on the basis of the above figures, 'natural' upstream water level should have been nearly 4 feet higher in 1974 than in 1948. The actual situation is slightly complicated by local inflows not listed above and by the effects of the previously-discussed gate control error, which will be discussed more fully in Section 3.3.

(ii) T. Lasko suggests that the control gates have been operated since 1969 to raise upstream water levels above natural conditions. He asks why there had to be a drop of 18 feet across the Inlet Control Structure in 1974 although water levels in Winnipeg were only at normal summer levels. Mr. Lasko's figure for the drop across the structure is essentially correct (Figure 2). As shown in Table 1, the 1974 maximum level in Winnipeg was only 744.5, as in the considerably smaller flood of 1969, and over 2 feet lower than in the flood of 1979 which was roughly equivalent to that of 1974. His contention that the gates were unnecessarily high in 1974 therefore seems to have some justification. In 1979 the drop across the structure was only about 12 feet.

(iii) The Red River Valley Flood Control Coalition allege that the upstream flood of 1974 was "created solely by the mismanagement and raising of the floodway gates", and make comparisons between 1974 and 1979. They imply that the 1979 flood was more serious than that of 1974, yet upstream water levels were not significantly higher. Reference to Table 1, confirms that maximum upstream levels were similar, and that the upstream Red River flow at Ste. Agathe was in fact much greater in 1979. The combined 'natural' flow downstream of the Assiniboine, however, as approximated by actual combined flow at Lockport plus Portage Diversion flow, was about the same in 1974 and 1979. Therefore the allowable upstream levels, according to the floodway operating policy, would have been similar in the two years. Graphs in the Program of Operation indicate that the allowable 1979 level could have been approximately one foot higher than was actually attained.

The Coalition brief makes a number of comparisons of flows and water levels between 1974 and 1966. These refer only to the Red River upstream of Winnipeg, and overlook the effect of Assiniboine River flows in determining gate settings according to the operating policy. The effect of this has already been discussed.

The case made by the Flood Control Coalition appears to be essentially a case against the operating policy, rather than against the operations themselves. Basically, their contention seems to be that in order to afford Winnipeg a reasonable degree of protection, it was not necessary in 1974 to raise the gates so high and divert such a large proportion of Red River flow down the floodway channel.

3.3 Actual Effect of Error in Gate Control Graph

According to the June 1980 report by Acres Consulting Services Ltd., the effect of the gate control graph error (see Sections 2.3.2 and 2.5) was to produce an upstream level approximately 2.1 feet higher than the correct 'natural' level allowed by operating policy. Their estimate of the correct level is 762.8 feet, and their quoted figure for the actual maximum is 764.9 feet. (According to published Water Survey of Canada data, the maximum was 764.6 feet on April 24, but this was an average for the day).

According to a statement provided to the Commission by Mr. T.E. Weber, Director of Water Resources Branch, Water Resources estimate that the gate error led to an excess water level of approximately 1.8 feet. The two organizations therefore agree that the maximum upstream water level on April 24, 1974 was approximately 2 feet higher than it should have been. This is not far out of line with calculations we have shown in Section 2.5, which apply the erroneous graph to hypothetical flow figures that are comparable with the actual 1974 figures. Note, however, that the calculations in Section 2.5 assume no re-adjustment of the gates after initial setting.

An independent check of the 1974 situation using certain actual flow figures indicates that the actual excess in upstream water level may not have been as great as estimated by Acres and Water Resources. In this check, the graphs in the Program of Operation that relate levels at the floodway inlet to combined 'natural' discharges have been accepted as valid, but combined 'natural' discharge has been estimated by a different approach. The calculation is as follows (refer to Figure 1 for locations).

Actual combined discharge at Lockport, April 25 (Red R. + floodway + Assin. R)	88,000 cfs
Add Portage Diversion, April 24	17,000
Est'd 'natural' flow at Lockport, April 25	105,000
Deduct local inflow below Redwood Bridge - allow	2,000
Est'd 'natural' flow at Redwood Bridge	103,000
Corresponding 'natural' level at floodway inlet	764.6 ft

This rather simplistic calculation therefore indicates that the maximum water level achieved in 1974 was at most a few inches above the allowable maximum. The main difference from Acres and Water Resources' method is that the above calculation utilizes the combined discharge from the Water Survey of Canada, gauge at Lockport. Mr. J. Toye of Water Resources states that they do not use this gauge because of uncertainty as to its reliability, but Mr. J. Way of Water Survey claims that it is quite reliable at discharges in excess of 22,000 cfs.

A review of Water Resources' daily calculation sheets for 1974 shows that in fact the peak combined 'natural' discharge utilized in their calculations was about 103,000 cfs on April 25. This figure was arrived at in part by use of the erroneous gate control graph. Its agreement with our estimate given above, based on the Lockport gauge, suggests that in fact there were other compensating errors as has been suggested by

Water Resources. One compensating error, mentioned previously in Section 2.3.2, was that the coefficient in the gate discharge equation, which had been based on model tests, was apparently too low. The result is that the head over the control gates was over-estimated because of the error in the gate operating graph, but the discharge coefficient was under-estimated, the two errors partly cancelling out in calculating the gate discharge.

3.4 Conclusion Regarding Upstream Flood Levels in 1974

Our conclusion is that a significant margin of uncertainty surrounds all figures for maximum combined 'natural' discharge in 1974. We consider that the excess in the upstream water level certainly did not exceed 2 feet, and may have been considerably less. Although we have not been in a position to verify the basic river hydraulic relationships embodied in Figure 8 of the Program of Operation (otherwise described as File No. 11-5-1103, Dec. 1965), we have no reason to doubt its validity within reasonable limits.

Whatever the exact excess in flood level due to the gate error in 1974, it was not the main cause of noted differences between 1974 levels and levels in other comparable Red River floods. A major cause was the high Assiniboine River flood in 1974, which under natural conditions would have produced a rise of several feet, in the area of the floodway inlet, above levels due to the Red River alone.

4. EFFECTS OF PRESENT OPERATIONAL PROCEDURES

4.1 Adjustment of Calculations After 1974 Operations

As previously noted in Section 2.3.2, evidence of an error in the gate operation curve first surfaced in the fall of 1974, but action was not taken until 1977. This was partly because various checks on calculated discharges did not indicate any serious error in floodway operations.

For 1978 and 1979 operations, a corrected gate operation curve was used, as well as an adjusted discharge coefficient based on field data over a number of floods since 1969. As previously noted, these two corrections partly cancel out, the net effect on targeted upstream levels being quite small, generally one foot or less.

A further complication is that according to Water Resources, field data from the 1979 flood more or less support the original Acres discharge coefficient and not the adjusted version. The question of the gate discharge equation is therefore still unsettled. It is our understanding that the adjusted value is still in use. The question is not critical, since various checks are now made of total discharge using river gauges.

4.2 Results of 1979 Flood Operations

Briefs complaining about 1974 operations appear to imply that 1979 operations were acceptable.

According to the Acres report of June 1980, the peak upstream level in 1979 was about 0.9 feet below the allowable 'natural' level.

A simplistic calculation according to the method of Section 3.3 roughly confirms Acres' conclusion.

4.3 Conclusion Regarding Present Procedures

We conclude that present operating data and procedures, as modified since the 1974 flood, are satisfying the operational policy of not exceeding a 'state of nature' with respect to upstream flood levels, provided that the basic hydraulic relationships embodied in Figure 8 of the Program of Operation (1970) are valid.

5. POSSIBLE IMPROVEMENTS TO OPERATIONAL PROCEDURES

In reviewing the operational problems discussed above, it has seemed to us that there is a case for some changes to the operational system to improve comprehensibility and flexibility. We offer the following suggestions for improvements:

5.1 Operational Manual

In the course of discussions with Acres and Water Resources staff, we discovered that the Program of Operation (1970), supplied to the Commission in response to a request for information, was not in all respects a correct description of the current system for operational calculations.

We recommend strongly that a clear and correct description of the current method of calculation and operation should be prepared. This should include the following features:

- a key map showing the location of all discharge and water-level gauges utilized in flood operations;

- profiles of the Red and Assiniboine Rivers showing water levels in notable floods, including 1974 and 1979;

- an explanation of the technical background and basis for all charts and graphs;

- some indication of the margins of uncertainty surrounding certain data, and of the sensitivity of calculated levels to these uncertainties;

- an explanation of why data from certain gauges are preferred and others discounted.

5.2 Computational System

We note that operational calculations during floods are still being performed by a manual-graphical system that is time-consuming, admits the possibility of reading errors and arithmetical mistakes, and has only a limited capability for checks and comparisons.

We recommend development of an interactive computer program or series of programs for flood operations, that would include the following features:

- display of all gauge data simultaneously or sequentially at frequent intervals;

- calculation of discharges and of required levels and gate settings by alternative methods;

- short-range forecasts of flows and levels at various points resulting from proposed operations;

- evaluation of alternative operational sequences;

- simplicity of operation.

In undertaking or commissioning development of such a system, consultations should be held with persons or agencies experienced in computer-based operation of river systems.

5.3 Instrumentation

From discussion with Water Resources personnel, we concluded that operations could be facilitated by improvement of the gauge system, mainly towards instantaneous reading of discharges from key river gauges. Automation of instrumentation is desirable to obtain full advantage from a computer-based operational system.

It has not been satisfactorly explained to us why data from the Lockport gauge on the Red River are not utilized as a check in flood operations. The Lockport gauge (Figure 1) sums Red River plus floodway plus Assiniboine River flows.

5.4 Interpretation of Operational Policy

The operational policy as enunciated in Section 2.1 introduces a basic difficulty in relation to objections from aggrieved parties, in that the 'state of nature' referred to is determinable only by calculations based on imperfectly known relationships that existed prior to 1969. It seems only right that where uncertainty exists (except in emergency), the benefit of the doubt should be given to upstream interests. Such in fact appears to have been the case in 1979 operations.

It would be possible to build into a computer program the capability for expressing all input and output quantities in terms of an estimated value plus or minus a figure representing uncertainty.

There may be a case for reviewing from its origins the basic hydraulic relationship between river discharges and upstream levels embodied in file no. 11-5-1103. We have no reason to believe, however, that such a review would result in any significant change in favour of upstream interests.

6. SUMMARY OF CONCLUSIONS

(i) The error in control graphs for Inlet Control Structure gates, as recently reported by Acres and Water Resources, resulted in upstream flood levels exceeding a 'state of nature' in 1974. The excess height, in our opinion, was certainly not more than 2 feet, and may have been considerably less.

(ii) We are satisfied that present computational and operational procedures are adequate to achieve a 'state of nature' with respect to upstream flood levels, provided that the basic river hydraulic relationships plotted in 1965 are valid for describing the pre-floodway state.

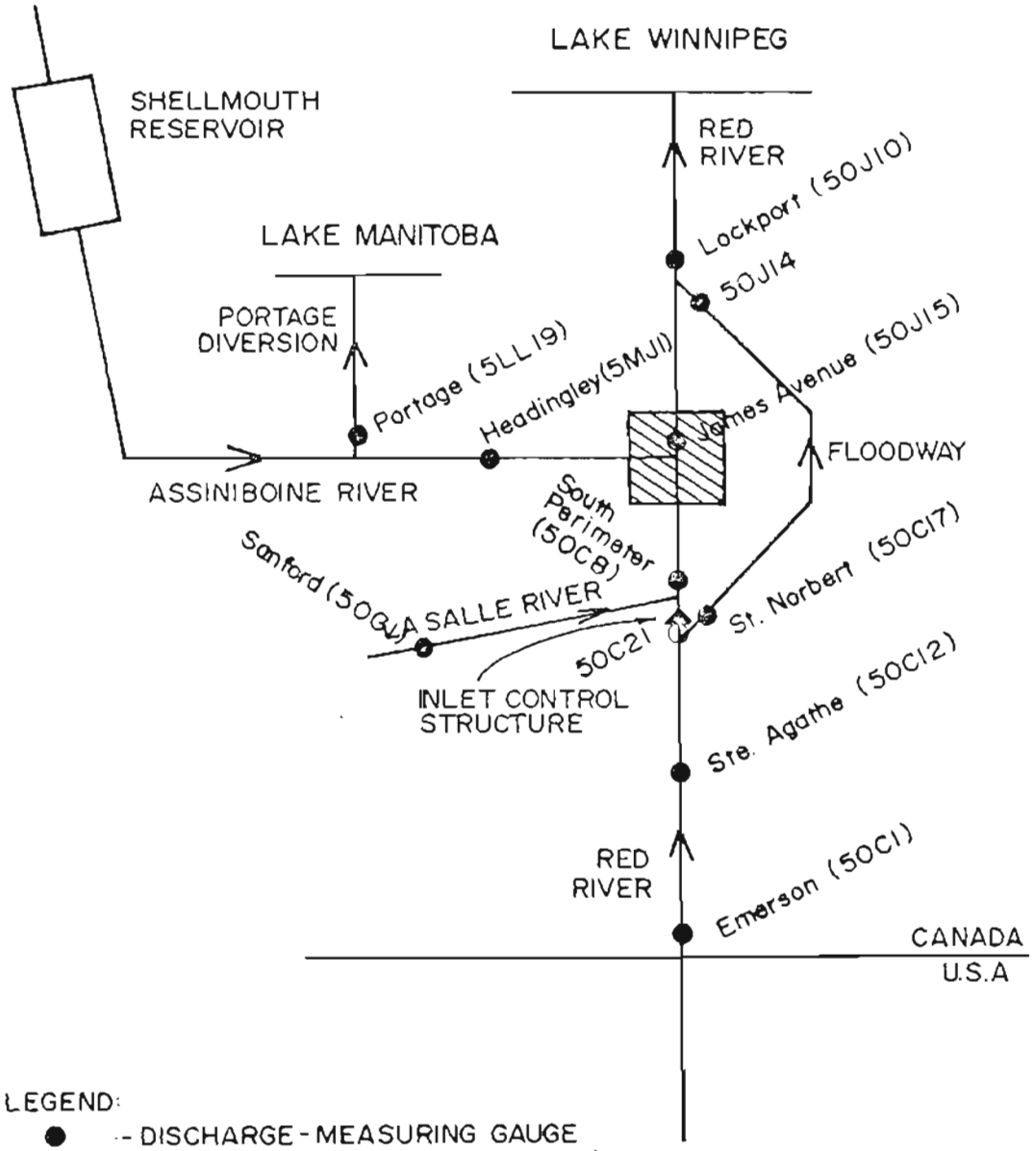
(iii) We consider that operational procedures require improvement mainly in two directions: firstly, preparation of a clear up-dated manual describing the calculations and operations and explaining the technical basis of all the hydraulic relationships utilized; and secondly, development of a series of computer programs for flood control, together with such improvements in instrumentation as are necessary to provide an efficient computer-assisted system.

(iv) Although terms of reference did not extend to operational policy, we offer the comment that there may be a case for reviewing and amplifying policy to allow, in certain circumstances, an apportionment of flood-control benefits between upstream and downstream interests. Improvements in the operational system might make some such modification more acceptable to downstream interests.

TABLE 1 - KEY DISCHARGES AND WATER LEVELS IN 1974 AND OTHER FLOODS

YEAR	APPROX. DATE OF PEAK	DISCHARGES (APPROX.) IN CFS					MAXIMUM WATER LEVELS IN FT.			NOTES
		RED RIVER @ EMERSON	RED RIVER @ STE AGATHE	RED RIVER @ LOCKPORT	ASSIN. R. @ HEADINGLEY	PORTAGE DIVERSION	ABOVE INLET CONTROL STRUCTURE	BELOW INLET CONTROL STRUCTURE	AT JAMES AVE.	
1948	April 27	52 000	60 000(?)	-	7 000	zero	759.5(?)	?	750	Prior to floodway.
1950	May 11	94 000	95 000(?)	105 000	10 000	zero	767	-	758	Prior to floodway
1966	April 15	62 000	66 000	90 000	10 000	zero	762.5(?)	-	751.6	Floodway under construction
1969	May 2	52 000	52 000	77 000	20 000	zero	?	?	744.5	Floodway in operation
1974	April 25	42 000	50 000	88 000	5 000	15 000	764.6	748.1	744.5	Floodway in operation
1979	May 8	81 000	81 000	98 000	9 000	6 000	764.9	752.6	746.7	Floodway in operation

Note: Figures quoted are approximate, for purposes of comparison only, and have been taken from a variety of sources.



LEGEND:

- ● - DISCHARGE-MEASURING GAUGE (WATER SURVEY OF CANADA NO.)
- ○ - STAGE-MEASURING GAUGE

NOTES: - NOT ALL GAUGES ARE SHOWN.
- LA SALLE RIVER IS VARIOUSLY REFERRED TO AS SALE RIVER, RIVIERE SALE, ETC.
- SOUTH PERIMETER GAUGE IS ALSO REFERRED TO AS RED RIVER AT ST. NORBERT

Figure 1

FILE: 80-430

DIAGRAMMATIC MAP OF FLOODWAY SYSTEM

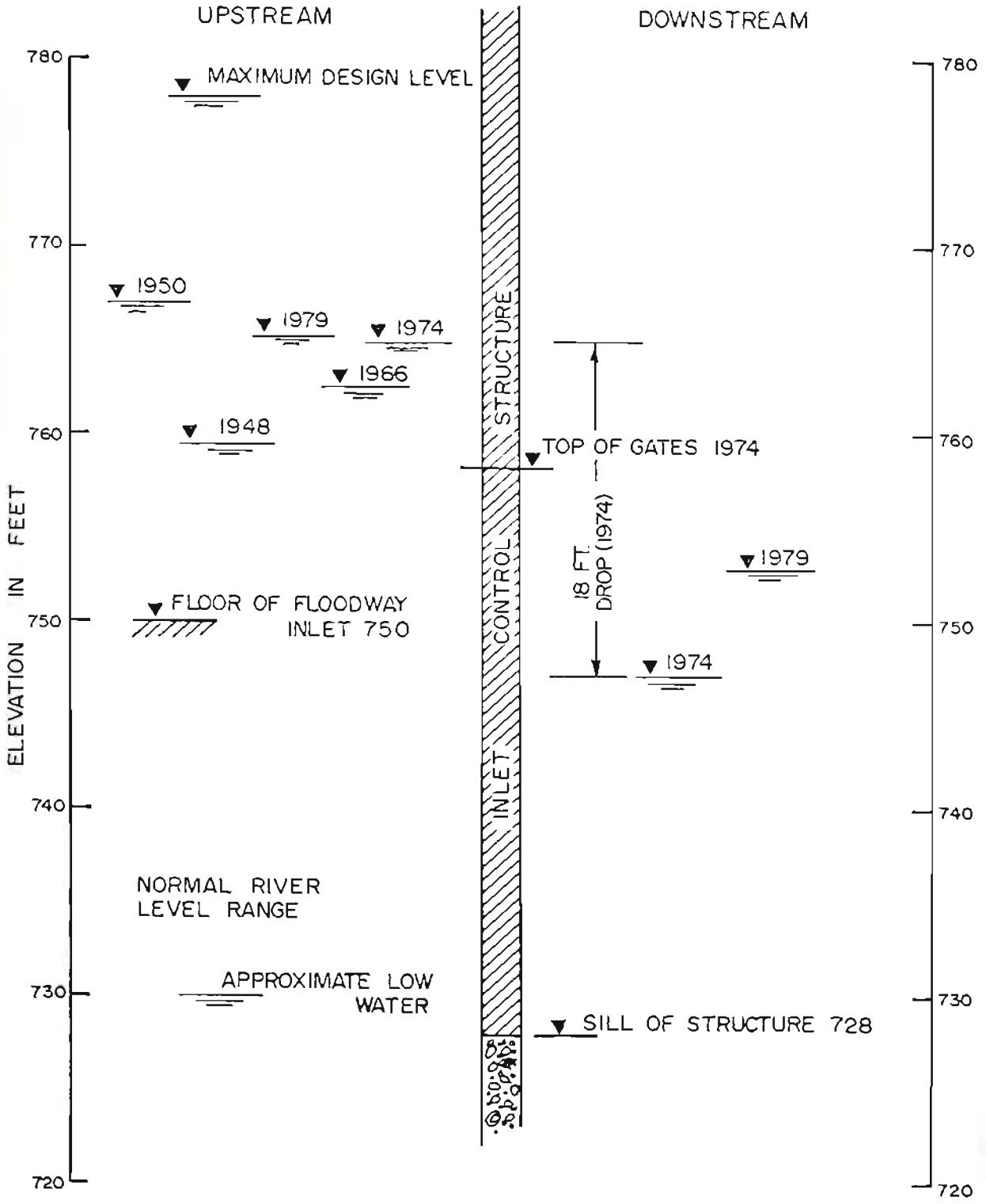


Figure 2

FILE 80-430 DIAGRAM OF ELEVATIONS NEAR INLET CONTROL STRUCTURE

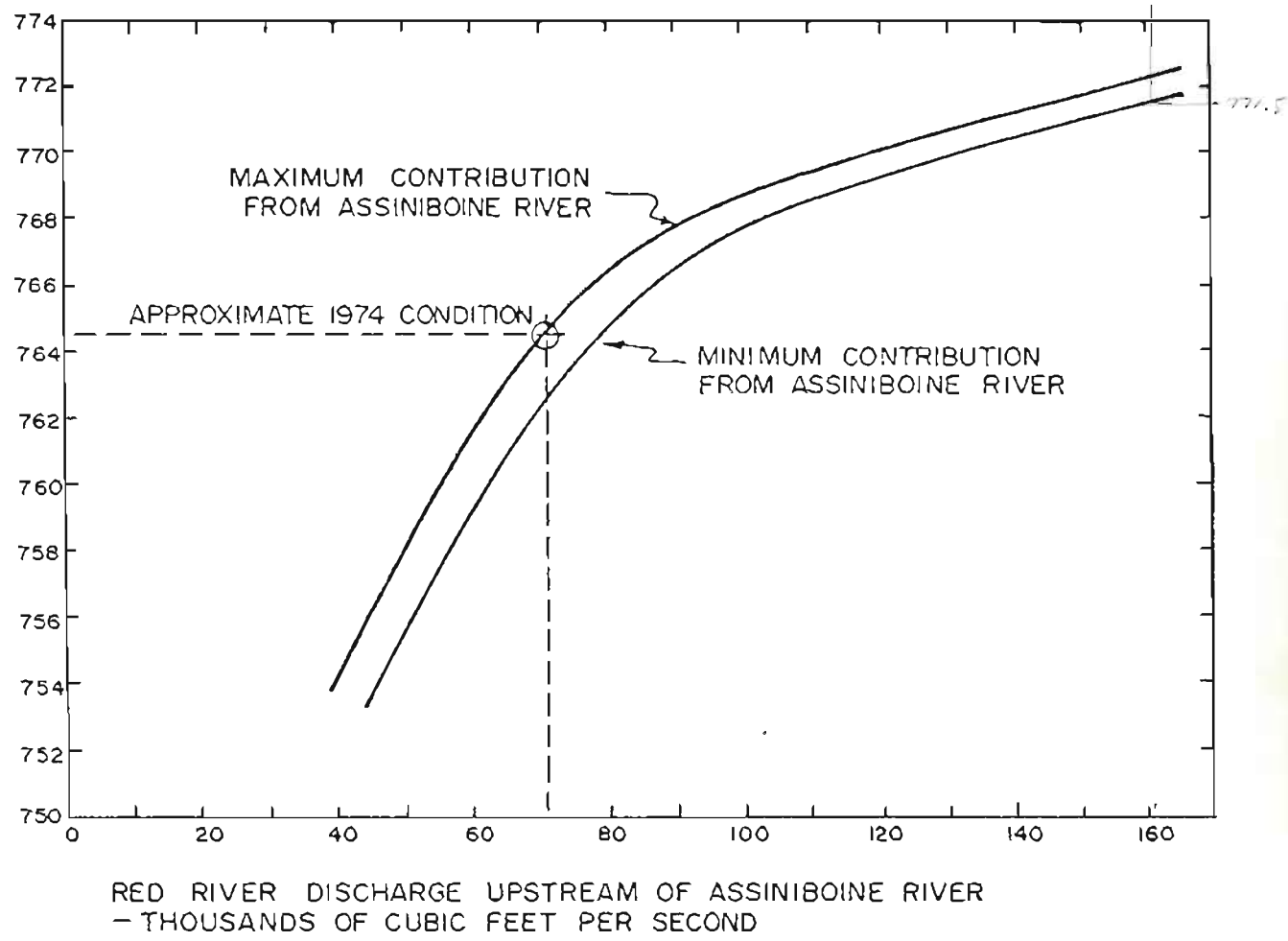


Figure 3

WATER LEVEL AT
FLOODWAY INLET VS. RED RIVER
(ONLY) DISCHARGE AND ASSINIBOINE RIVER
CONTRIBUTION, FOR NATURAL CONDITIONS

(BASED ON REPLOTTING OF DATA SHOWN
ON WATER RESOURCES CHART FILE NO. 11-5-1103)

LE:80-430