PRAIRIE PROVINCES WATER BOARD

THE EFFECT OF LAKE DIEFENBAKER

ON

FLOOD FREQUENCIES AT THE PAS

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TERMS OF REFERENCE

At the 36th meeting of the Prairie Provinces Water Board, it was agreed that the Board Secretariat would make a review of the effect of the South Saskatchewan River Reservoir (Lake Diefenbaker) on the river flows at The Pas (Minute 36-10).

This report outlines the studies conducted during the course of the above review.

SYNOPSIS

Because the storage and operation of the South Saskatchewan River Reservoir (Lake Diefenbaker) might considerably affect the 1% to 5% floods at The Pas, and because this effect has a direct bearing on the proposed development in the Pasquia area, upon the Board's directive (Minute 36-10), the Secretariat has investigated the effects of Lake Diefenbaker on the flood frequencies at The Pas.

According to this study, based on a simplified system-analysis approach, the existing operation of Lake Diefenbaker would reduce the Annual and the May to October flood peaks at The Pas in the 1% to 2% flood frequency range, 10% to 15% respectively, and it would effectively reduce the April to May flood peaks at The Pas in the 1% to 2% frequency range by at least 26%.

PREFACE

The purpose of this study was to investigate the effect of Lake Diefenbaker on the flood frequencies at The Pas and to produce a new set of frequency curves at The Pas that would reflect the regulatory effect of Lake Diefenbaker.

A simplified system-analysis approach was adopted in this study. Two sets of stream flow records were obtained at The Forks for the period 1911-1963. One set consisted of the recorded stream flows; the other set included the regulatory effects of Lake Diefenbaker. The area from The Forks to The Pas was treated as an individual system. Within this system, Cumberland Lake, and the existing channel storage in the Pasquia area, were recognized to have the greatest flood-modifying effects.

A relationship between Cumberland Lake levels and The Pas recorded stream flows (excluding local inflow effects) was established, resulting in the development of a stage-discharge curve for Cumberland Lake; through analysis of major flood events within the system, the corresponding effective storage-capacity curve for Cumberland Lake was developed.

Both sets of flows obtained at The Forks were routed through Cumberland Lake. These routed flows and the recorded stream flows at The Pas, formed the basis in identifying the local runoff into the system, and they were also used in the reconstruction of those flows at The Pas that have been influenced by the regulatory effect of Lake Diefenbaker.

Frequency curves for the April to May, the May to October, and for the Annual Peaks were obtained on log-normal plots for both the recorded stream flows at The Pas, and for the stream flows that were modified by the regulatory effects of Lake Diefenbaker. These frequency curves, shown in Fig. 8, formed the basis for identifying the effects of Lake Diefenbaker on the flood flows at The Pas.

This study was conducted by PFRA Hydrology Division. Routings of recorded and regulated stream flows were completed by M. Mowchenko. Statistical analyses were conducted by W. G. Salway. The effective storage-capacity curve was developed by B. Abrahamson. This report was written by L. K. Szojka.

The kind cooperation of the Saskatchewan Water Resources Commission and the Manitoba Department of Mines and Natural Resources is gratefully acknowledged.

AVAILABILITY OF DATA

Streamflows at The Pas are the result of the contributions of the North and South Saskatchewan Rivers meeting at their confluence known as "The Forks," and the local inflows downstream of The Forks to The Pas. Metered flow records of local inflows from The Forks to The Pas, excepting Carrot River, are generally sparse. However, long-term stream flow records that are useful exist on the Saskatchewan River at:

5GG001	North Saskatchewan River at Prince Albert	1910-60
5HG001	South Saskatchewan River at Saskatoon	1911-62
5KJ001	Saskatchewan River at The Pas	1913-61

Relatively short-term lake level data from 1953-61 are also available at 05KH002 Cumberland Lake.

PROCEDURE

General

In addition to the stated terms of reference of this study, Mr. T. E. Weber, Member of the Prairie Provinces Water Board, requested that in the study of natural flow frequency reduction at The Pas due to Diefenbaker Reservoir, no consideration should be given to the other reservoirs that are in the process of being built or planned to be built (see Minute 38-24). In view of the above request, and after considering the existing available data, it was decided that the 1913-1961 recorded stream flows of the Saskatchewan River at The Pas, Saskatoon and Prince Albert, would be used as the basis of this study.

Based on the recorded stream flows of Saskatoon and Prince Albert from 1913 to 1961, two sets of stream flows were produced at The Forks:

1. Recorded Stream Flows
2. Regulated Stream Flows

The Recorded Stream Flows at The Forks were obtained by adding the recorded stream flows at Saskatoon to the recorded stream flows at Prince Albert on a day-to-day basis. No consideration was given in this study to lag times from Saskatoon to The Forks.

The Regulated Stream Flows at The Forks were obtained by routing the Saskatoon recorded stream flows through Lake Diefenbaker and by adding the routed flows on a day-to-day basis to the Prince Albert recorded stream flows.

Operation of Lake Diefenbaker

The effect of Lake Diefenbaker on the Stream Flows at The Forks, is directly related to the operational procedure of Lake Diefenbaker. While a multitude of operational procedures are possible, and numberous possible workable solutions are in existence, for the purposes of this study, a single operational procedure has been adopted that is now known to be followed at the Dam Site.

At Lake Diefenbaker, power is produced during the winter months. Consequently, the reservoir is gradually drawn down from a late summer FSL of 1,827 to elevation 1,790 by the first of April. In the case of flood inflows, the water level in the reservoir is expected to be allowed to rise to 1,827, beyond which time the spillway gates would commence to rise with the rise in water level. While it is possible to produce power during a major flood event, for the purposes of this study, it was assumed that there would be no releases specifically for power, nor would there be any releases through the Qu'Appelle system, during a flood event.

The Simplified System Approach

Considering the area from The Forks to The Pas as a system, shown in Fig. 1 and Fig. 2, was a matter of necessity. With the available data, it was possible to study the system, without giving too much consideration to the various factors within the system.

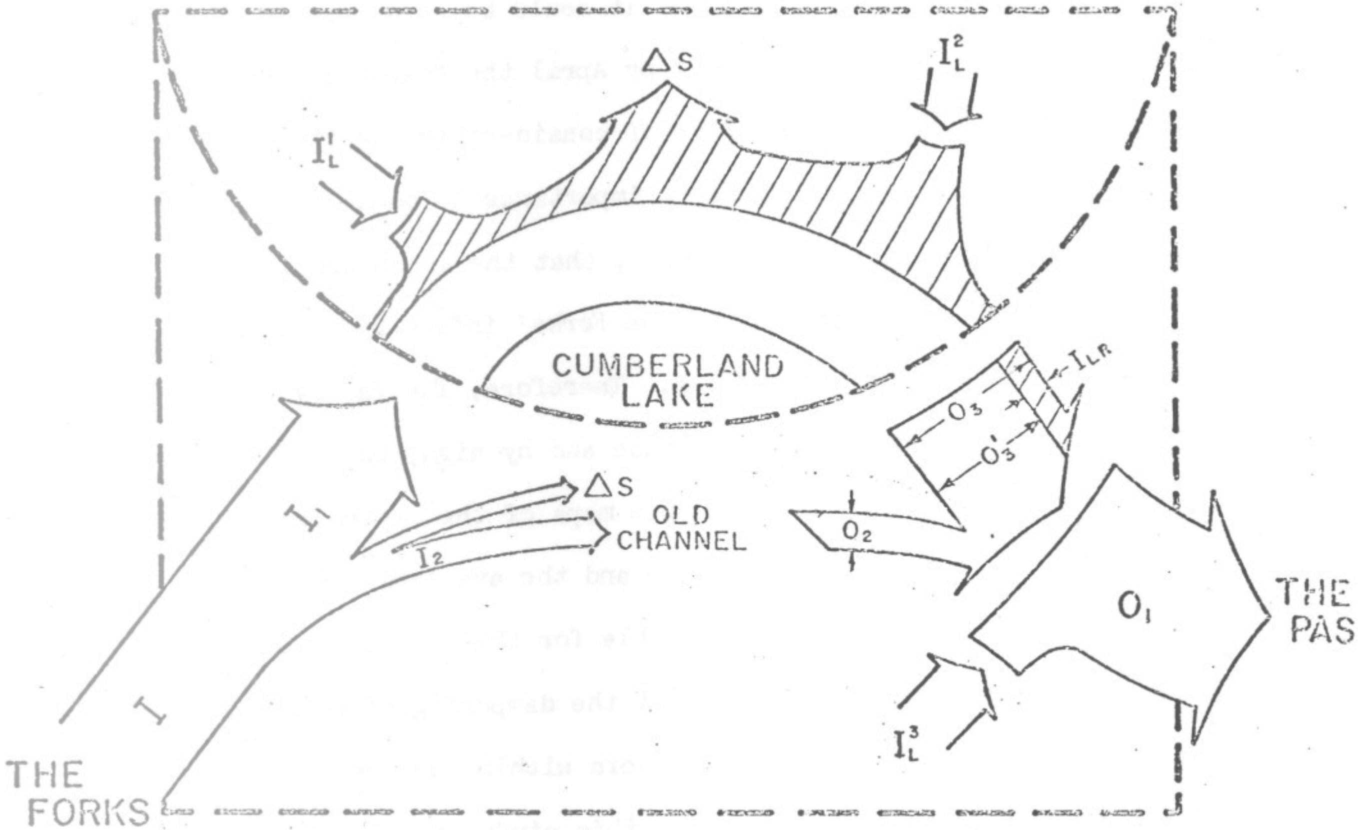
The flow data recorded at The Pas, reflect the behaviour of the whole system. Therefore, the recorded flows at The Pas required a close study.

From the inspection of the 1913-1961 Saskatchewan River recorded stream flow hydrographs of The Pas, and in particular the stream flow hydrographs for 1953 to 1954 (see Fig. 3), it could be seen that peak flood flows occurred either in the April to May, or in the May to October time period. Therefore, the flood regulatory effects of Lake Diefenbaker were studied considering the April to May, and May to October time periods, in addition to the annual peaks. Also, from inspection of these hydrographs shown in Fig. 3, it could be seen that the flows receded to a relatively low level by April the following year, even if the summer recorded peaks were of considerable magnitude.

What is considered of major importance in connection with The Pas recorded hydrographs, is to note, that the sharp weekly flow increases that are so evident on The Forks' inflow hydrographs, are completely dampened by the system. Therefore, The Pas hydrographs are characterized by a wide time base and by high, but rounded, flood peaks. From inspection of available maps of the system (see Fig. 2), it can be seen that Cumberland Lake and the available channel storage in the system, are chiefly responsible for this complete dampening effect. While it is recognized that the dampening effect is the result of a multitude of inter-related factors within the system, it was possible, strictly for the purposes of this study, to view the regulatory effect only, without giving too much consideration as to how this dampening effect has occurred within the system.

With the recorded stream flow hydrographs available at The Forks, at The Pas, and with the available Cumberland Lake levels, it was possible to assess the regulatory effect of Cumberland Lake and the existing channel storage. Also, it became possible to identify the order of magnitude of local runoff into the system.

It is advantageous here to refer to a flow diagram of the considered system, shown hereunder:



THE CONSIDERED SYSTEM

Sketch #1

In reference to Sketch #1, page 9, the following points need to be noted:

1. The inflows to Cumberland Lake (I_1) are increased by the local runoff (I_L^1 and I_L^2). Consequently the outflow from Cumberland Lake can be considered as consisting of two parts: inflow I_1 routed (O_3^1) and local runoff ($I_L^1 + I_L^2$) routed (I_{LR}). Therefore,

$$O_3 = O_3^1 + I_{LR} \qquad (1)$$

2. The stream flows at The Pas, (O_1), consist of the outflows from Cumberland Lake and the old channel ($O_2 + O_3$), plus the unrouted local runoff, I_L3.

$$\text{Thus, } O_1 = (O_2 + O_3) + I_L3 \qquad (2)$$

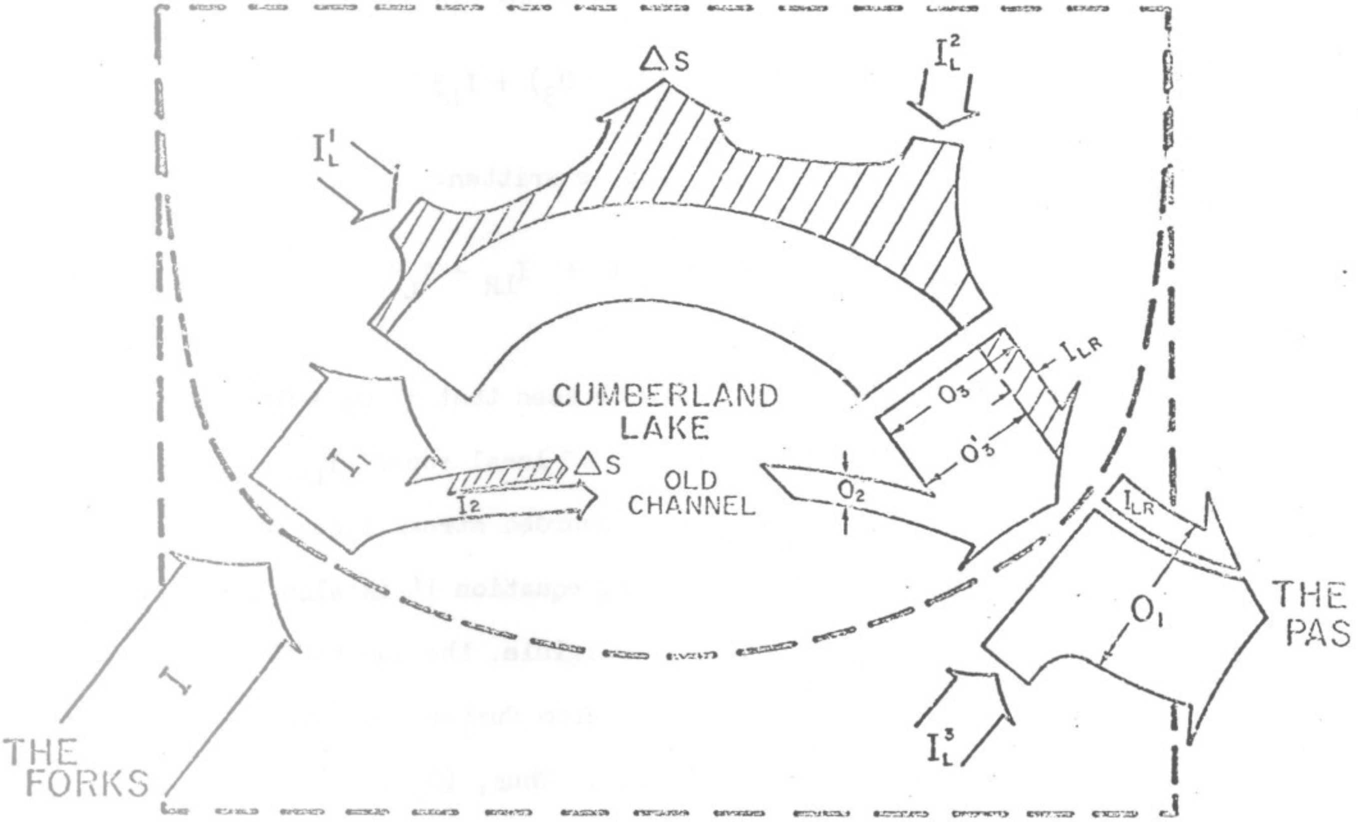
which equation can also be written:

$$O_1 = (O_2 + O_3^1) + I_{LR} + I_L^3 \qquad (3)$$

From equation 3 it can be seen that if $O_2 + O_3^1$ are identifiable, then the magnitude of local runoff $I_{LR} + I_L^3$ can be separated from The Pas recorded stream flows and can be identified. From the preceding equation it is also evident, that when local runoff is negligible, the sum total of the flows out from the old channel and from Cumberland Lake should equal the recorded flows at The Pas. Thus, $(O_2 + O_3^1)$ is equal to or less than the recorded stream flows at The Pas.

3. I_1 is modified through Cumberland Lake storage; I_2 is modified through channel storage in the old channel.
4. While the inflows to the old channel change from day to day considerably, the channel storage in the old channel would tend to dampen this change. Therefore, the outflows from the old channel are expected to recede relatively slowly.

In view of these points, the system was further simplified, as shown in Sketch #2. Therefore, the whole problem, as shown in the following flow diagram, became a routing and hydrograph separation and synthesization problem.



THE SIMPLIFIED SYSTEM

Sketch #2

A discharge-capacity curve of Cumberland Lake in terms of The Pas recorded flows that were without local runoff, $(O_1 - (I_{LR} + I_L^3))$, was obtained. An effective storage-capacity curve, based on lake level data and on the recorded major inflows (I), was developed. The inflows to the system were routed through a theoretical reservoir. Since the recorded inflows, I, at The Forks, were free from local runoff when routed through the reservoir, the routings produced outflows $(O_2 + O_3^1)$ that were also free from local runoff $(I_{LR} + I_L^3)$. The routed flow $(O_2 + O_3^1)$ was subsequently lagged and subtracted from the recorded hydrographs at The Pas (see Fig. 7). Thus, the local runoff into the system, that is, $(I_L^3 + I_{LR})$, was obtained.

In the separation and identification of local runoff, the development of Cumberland Lake stage-discharge curve, shown in Fig. 4, the effective storage-capacity curve of Cumberland Lake, shown in Fig. 5, and the assessment of lag time of the flood peaks at The Pas, played an important part.

Cumberland Lake Stage-Discharge Curve

For six years of records (for the open season from May to October), Cumberland Lake levels were plotted versus The Pas recorded flows. From Cumberland Lake to The Pas, the stream flows were lagged two days(1) and the levels and flows were plotted accordingly. All stream flow data plotted in a band, shown on Fig. 4. It was considered that the scatter of plots (within a 5,000 cfs to 15,000 cfs range)

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(1) Numbers in brackets refer to references listed on page 17.

was chiefly the result of local runoff. It was further considered that if the minimum envelope curve is taken from the plot, the attained curve will be free from local runoff. A similar procedure was used to derive the April flow relationship, also shown on Fig. 4.

Development of the Effective Storage-Capacity Curve

With the stage-discharge relationship developed for Cumberland Lake, and with the Cumberland Lake levels and the natural inflows given, the effective storage-capacity curve, shown on Fig. 5, for Cumberland Lake, was derived. Note that in deriving the effective storage-capacity curves for Cumberland Lake, all the known inflows I_1 were used and the best fit to the possible storage-capacity curves was adopted.

Lag Times

All the April to October recorded stream flows of The Forks from 1916-61 were routed through the system. In the routing, the developed stage-discharge curves and the effective storage-capacity curves were used. At the outset of the routing, the lake level for each year was established on the basis of the recorded April stream flows at The Pas (see Fig. 4). The routed and the recorded stream flows at The Pas were studied and compared. Since there were a multitude of flood peaks, where the local runoffs were negligible, and at those flood peaks the routed flows had to be equal to and in phase with the recorded flows, a lag-time-to-peak relationship was developed for the purposes of this study. For the purposes of local runoff identification, the routed recorded* flows were advanced according to the lag

* As designated on page 6.

times indicated in the following table:

TABLE 1

Discharge Equal or Less Than	Routed Flows Advanced
20,000 cfs	10 days
65,000 cfs	9 days
100,000 cfs	8 days

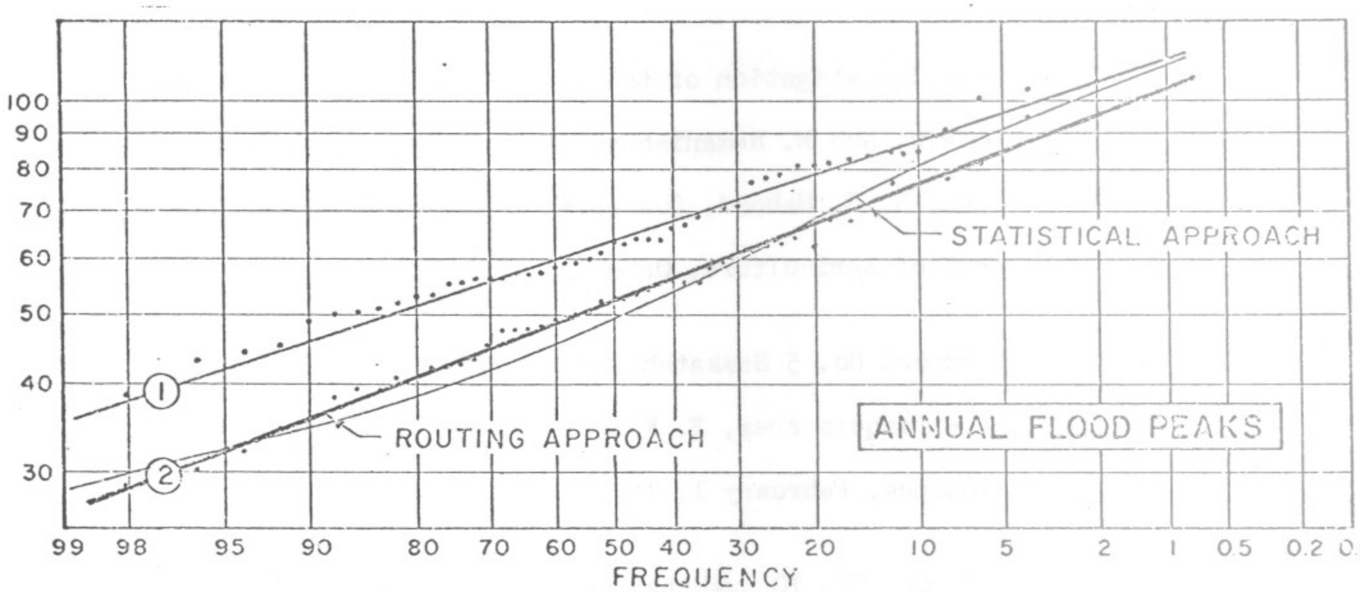
Where the local runoffs were negligible, the agreement of the flood peaks provided a check on the developed curves. Additional checks have been obtained through comparison of the generated levels of Cumberland Lake (see Fig. 6) with the Cumberland Lake levels estimated by the Saskatchewan Water Resources Commission[2]. Once the routed hydrographs have been advanced according to the established relationship (shown in Table 1), they were then subtracted from The Pas recorded stream flows (see Fig. 7). Therefore, the total local runoff for each year of record into the system was identified.

Development of the Regulated Hydrographs at The Pas

The regulated flows at The Forks were routed through the drainage system in the same manner as the recorded stream flows. The routed flows were advanced as the recorded flows, according to the values listed in Table 1. Finally, the local runoffs were added to the routed flows, resulting in the stream flows at The Pas that displayed the regulatory effect of Lake Diefenbaker. The obtained regulated peaks, that had Lake Diefenbaker regulatory effects included, resulted in a set of frequency curves marked with No. 2 on Fig. 8, while the analysis of the recorded peak flows at The Pas provided the other set of frequency curves shown as No. 1 on Fig. 8 for comparison. From the frequency curves of regulated flood peaks, the effect of Lake Diefenbaker on the flood peaks could be determined.

CONCLUSIONS

From this study, and in particular reference to the annual flood peaks shown hereunder, it can be seen that the peak reduction effect of Lake Diefenbaker varies from 37% to 10% from the 90% frequency to the 1% frequency. Within the 2% to 1% frequency range, the peak reduction effect of Lake Diefenbaker is equal or less than 15%. As the frequency decreases, so do the peak reducing effects.



It is of additional interest to note that the peak reduction effect of Lake Diefenbaker on the spring peaks at The Pas exceeds the effects on the annual peaks, and within the 2% to 1% frequency range a peak reduction effect of at least 26% can be expected.

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1. Flood Routing Procedure - Saskatchewan River Upper Reaches to The Pas, N. Mudry, The Highways Department, Province of Manitoba, June 16, 1952.

2. A Study of the Probable Water Level of Cumberland Lake, R. B. Godwin, Hydrology Division, Saskatchewan Water Resources Commission, May, 1968.

3. Hydrologic Investigation of the Saskatchewan River Delta Project, R. B. Godwin, and W. Nemanishen, Saskatchewan Water Resources Commission; H. E. Mahood, Conservation and Development Branch, Department of Agriculture, October, 1966.

4. Interim Report No. 5 Saskatchewan River Reclamation Project Drainage - Pasquia Area, E. Kuiper, Canada Department of Agriculture, PFRA, Winnipeg, February 1, 1954.

5. Interim Report No. 10 Saskatchewan River Reclamation Project Regime Saskatchewan River, E. Kuiper, Canada Department of Agriculture, PFRA, Winnipeg, December 1, 1955.

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APPENDIX I

Possible Approaches

A study of the flood peak reducing effect of Lake Diefenbaker at The Pas, may be approached in four distinct ways:

1. A single major event could be studied.
2. Several major events at The Pas could be considered with the assumption that the frequency of the major flood events would remain relatively constant.
3. A multitude of recorded flood events could be studied:
   (a) statistically or
   (b) using statistical and routing procedures.
4. The statistical parameters of the stream flows of the drainage basin could be established. Hydrographs based on these statistical parameters could be developed for the major contributing streams at selected points. Artificial combinations of these flow hydrographs could be used then to establish a 'Range' of peak-reducing effects of Lake Diefenbaker on the flood flows at The Pas.

These approaches vary from a relatively simple to a more complicated approach; from a relatively inexpensive to a more expensive approach.

The first two approaches, 1 and 2, are simple approaches.

Because of its simplicity, approach 2 was proposed initially, and was considered for this study (see Appendix II - A Simple Approach).

Later, during the course of the study, it was found that the basic assumption, that the frequency of the major events at The Pas remained reasonably constant, was not valid. In fact, the order of magnitude and the frequency of an event at The Pas, is very much influenced by the relative distribution of the flood flows within the Saskatchewan drainage basin. Therefore, the summation of the peak flows of the North Saskatchewan and the Routed Stream Flows of the South Saskatchewan at The Forks, did not yield the same frequency of a flood event at The Forks and eventually at The Pas, that was initially assigned to the same flood event at The Pas.

The study of the effect of Lake Diefenbaker according to the fourth approach, is a desirable approach, provided a range of the effects is required, or if the main concern of the study is flood forecasting. The terms of reference of this study eliminated the fourth approach. Therefore, No. 3 approach was adopted for this study. While statistical and routing procedures were used in this report, an individual statistical approach (shown in Appendix III), was used to provide a check for the annual peaks (see also Fig. 8 - Annual Peaks).

<u>Use of Available Stream Flow Data</u>

For the purposes of this study, the existing natural flow records at Saskatoon, Prince Albert and The Pas, extending from 1913 to 1961, were adopted. The adoption of these recorded stream flow records for the selected time period had the following advantages:

1. There was no need to reconstruct stream flow data.
2. The selected records were free from any effects that either Lake Diefenbaker or the Tobin Reservoir could have displayed on the natural flows since the beginning of their construction.
3. The order of magnitude of the regulatory effects would be realistic, and the effect of Lake Diefenbaker could be studied on flows that have actually occurred.
4. The effects of Lake Diefenbaker could be determined in association with the various flood frequencies at The Pas.

It was further assumed in this study, that the recorded 51 years of stream flow data used were representative of the relative distribution of the various events to which the drainage basin had been exposed.

Stage-Discharge Curve of Cumberland Lake

In the process of developing the stage-discharge curve of Cumberland Lake, a multitude of flood records were considered and eventually a single stage-discharge curve was adopted that was believed to be free of local runoff effects. It was realized, however, that the stage-discharge curve of Cumberland Lake is not necessarily constant for all the events during the open water season. It could very well differ with rising or receding flows. The stage-discharge relationship could be dependent on the order of magnitude of the floods, and on the scouring or jamming potential of various flood events. Also, in all likelihood, the stage-discharge curve could have varied with time, over the 51 years. Therefore, while it is reasonable to assume that the single curve would be sufficient for routing all the stream flow records extending over the 51 years, it is expected that the routing results would reflect some of the inherent errors of this curve. However, it is also expected that a better agreement of stream flows and lake levels is obtained for the more recent events, in the last 15 years, than perhaps in the first 15-year period.

The Storage-Capacity Curve of Cumberland Lake

It is difficult to establish the storage-capacity curve of Cumberland Lake, mainly because no proper topographical map coverage exists. The storage-capacity curve of Cumberland Lake as obtained from the Saskatchewan Water Resources Commission[3] and as shown on Fig. 5, has been found to be unsatisfactory for this study, for it did not cover the desired range of levels, nor has it produced the desired peak reduction effect at major flood events.

For the purposes of this study, therefore, an effective storage-capacity curve (shown in Fig. 5) has been derived. Here again, a single storage-capacity curve has been adopted for the study. It was well known, however, that the storage-capacity curve of Cumberland Lake, similar to the stage-discharge curve, displayed a variation, with rising and receding limb of a hydrograph. This variation in storage effects could very well be explained by considering the phenomena of: overland flow,[4, 5] sediment transport and surface and sub-surface storage. It was further observed that at the occurrence of major flood events, considerable flood peak reduction occurred and beyond critical levels, more and more storage capacity seemed to be mobilized. The attained storage capacity would persist for a considerable time period. This phenomenon is characteristic of over-land flow.

From inspection of the Effective Storage-Capacity Curve and the storage-capacity curve of Cumberland Lake by the Saskatchewan Water Resources Commission (see Fig. 5), it can be seen that the effective storage capacity is considerably larger for corresponding lake levels than is indicated by the curve provided by the Saskatchewan Water Resources Commission. While it is believed that the effective storage-capacity curve has to be larger by approximately 20% than that of the Saskatchewan Water Resources Commission curve, it would be reasonable to expect that the curves would display similar trends. Indeed, they do up to geodetic elevation 876. However, beyond elevation 878, the storage-capacity curve of Cumberland Lake is again affected, and the extrapolation of the Saskatchewan Water Resources Commission curve is not desirable beyond geodetic elevation 878.

While for simplicity, a single storage-capacity curve had to be adopted for the purposes of flood routing, it was realized that this curve, similarly to the stage-discharge curve, would not exactly represent the effective storage capacity of Cumberland Lake for the whole 51 years of record. However, as long as the curve reflects the peak reduction effect of Cumberland Lake for the last 15 years, then it is reasonable to assume that it reflects reasonably well the storage capacity of Cumberland Lake for the last 51 years.

The generated Cumberland Lake levels showed reasonably good agreement with the Saskatchewan Water Resources Commission estimated lake levels and showed a good agreement with the recorded Cumberland Lake levels for the past 15 years (see Fig. 6).

Where the local runoff was negligible, and checks have been made on the flood peaks at The Pas, the flood peaks showed an agreement within 5,000 cfs. This agreement indicates that the stage-discharge curve and the Effective Storage-Capacity Curve of Cumberland Lake could reproduce major flood peaks within 5% of error. Therefore, these developed relationships could be used in flood peak forecasting for The Pas.

Finally, based on the simplified system-analysis approach and through hydrograph separation and synthesization, the frequency curves reflecting the regulatory effect of Lake Diefenbaker on the flood flows at The Pas, have been established in this study. In a separate statistical approach, developed for the Annual Flood Peaks at The Pas (included in Appendix III), a good check of the annual frequency curve for the routed flows at The Pas, has been achieved. The conclusions of the statistical approach in regard to the annual peaks were identical to the one provided in this study.

APPENDIX II

A Simple Approach

PROBLEM: To Investigate the Effects of Diefenbaker Reservoir on Natural Flow Frequencies of Saskatchewan River at The Pas

The Chairman of the Board requested the Acting Secretary to investigate this problem and report at the next meeting of the Board, Dec. 12, 1968.

In reviewing the technical side of this problem, I believe a satisfactory answer can be achieved according to the 10-step solution outlined here for your consideration and comment. It will be necessary, therefore, to:

1. Re-establish and update the natural flow peak frequency curve at The Pas.
2. Select the year of stream flow closest to the desired frequency to be investigated, (say, 2%).
3. Obtain the stream flow hydrograph of the selected year at The Pas, Nipawin, Prince Albert, Saskatoon and Lemsford.
4. Use the corresponding Lemsford hydrograph as inflow to Lake Diefenbaker and route the flow through the Lake, assuming normal operational procedure for Lake Diefenbaker.
5. Study peak reduction of hydrographs between Lemsford and Saskatoon, and between dam site and Saskatoon.
6. Reduce outflow peaks from the dam site and obtain Saskatoon stream flows.
7. Add the newly obtained stream flows of Saskatoon to the previous Prince Albert stream flows.
8. Study the Saskatchewan River stream flow peak reduction along the river at Prince Albert, Nipawin and The Pas.
9. Modify the synthesized flows and reduce peaks to obtain the modified stream flows at The Pas.
10. Compare flood peak frequency and assess if reduction is appreciable.

APPENDIX III

The Effect of Lake Diefenbaker on Flood Frequencies at The Pas

Statistical Approach

The statistical approach, as the approach taken in this report, treated the area from The Forks to The Pas as a simplified system. Flood peak correlations, shown on Fig. 9, were satisfactorily established, based on recorded stream flow data from 1913-1961, between the flood peaks at The Forks and The Pas. The correlations developed were applied to the annual peaks of the recorded stream flows at The Forks, and the frequency curve for the recorded flows at The Pas was satisfactorily reconstructed. Regulated flows at The Forks were obtained by routing the Saskatoon recorded stream flows through Lake Diefenbaker and combining the routed hydrographs on a day-to-day basis with Prince Albert recorded stream flows (see also page 6 of this report). The developed correlation between The Forks and The Pas flood peaks based on recorded stream flows was applied to The Forks regulated stream flows. Frequency curves of the Recorded stream flows and the Regulated stream flows were obtained at The Pas and they were compared.

Conclusions

Lake Diefenbaker has a strong moderating influence on flood peaks at Saskatoon, but its influence declines in proceeding further downstream. The critical factor in flood peak reduction at The Pas appears to be the extent to which the reservoir has been drawn down at the beginning of the runoff season. As expected, Lake Diefenbaker does not exercise any great moderating effect on the higher flood peaks at The Pas. Its influence is greater on flood peaks of short return periods.

The correlation between annual peaks at The Forks and The Pas appears to be satisfactory and it should now be possible to estimate the annual flood peaks at The Pas for any major flood event at The Forks.

Discussion

The statistical approach confirms the routing and statistical approach used previously in this report. Note, however, that this approach is not refined enough to be used directly in flood forecasting, but it could be used to estimate the possible annual flood peaks at The Pas.