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HYDROLOGY OF LAKE ATHABASCA: PAST, PRESENT AND FUTURE

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ABSTRACT

Lake Athabasca (7780 km^2) in Alberta, Canada, is an important hydrological feature in the Mackenzie River system with unique reversing flow channels and biologically-rich deltas. A task force was formed in 1971 to study Lake Athabasca, the Peace—Athabasca delta, and the downstream effects of Bennett Dam operation since 1968.

The hydrology and water management of Lake Athabasca are discussed, dendrochronology, meteorology, water quality and sedimentation are considered, regulated and non-regulated lake levels are simulated, and proposals for control works are described.

RÉSUMÉ

Le Lac Athabasca représente un facteur hydrologique important du réseau du Mackenzie.

En 1971, a été constitué un groupe d'étude pluridisciplinaire pour examiner le problème des conséquences de la construction du barrage Bennett (1968) sur la Paix, et proposer certaines solutions.

Ce document traite des facteurs hydrologiques relatifs au niveau du Lac Athabasca. La dendrochronologie, la météorologie, la qualité de l'eau et la sédimentation entrent dans l'examen du bilan hydrologique.

L'avenir du Lac Athabasca est étudié en fonction de la régularisation. On expose également des mesures correctives susceptibles de maintenir un niveau d'eau qui permette de sauvegarder l'écosystème du delta.

DESCRIPTION

Lake Athabasca (7780 km^2) is the third largest lake in the 1·8 million km^2 Mackenzie River drainage basin, and is the eight largest natural lake in Canada. The 340 km long lake straddles the Alberta–Saskatchewan border (110° longitude west) at 59° 10′ latitude north (Fig. 1). At the west end of the lake, deltas formed by the Peace and Athabasca Rivers have extended into the lake, creating a complex of lakes, channels and levees known as the Peace–Athabasca Delta (PAD). This delta, located in Wood Buffalo National Park, is noted for its trapping, fishing, waterfowl, wild bison herds and scenic beauty.

The Athabasca River (drainage area, 160,000 km^2) is the major tributary to Lake Athabasca, supplying 19·7 billion m^3 of water annually. The mountain fed headwaters produce a characteristic high summer flow and low winter discharge.

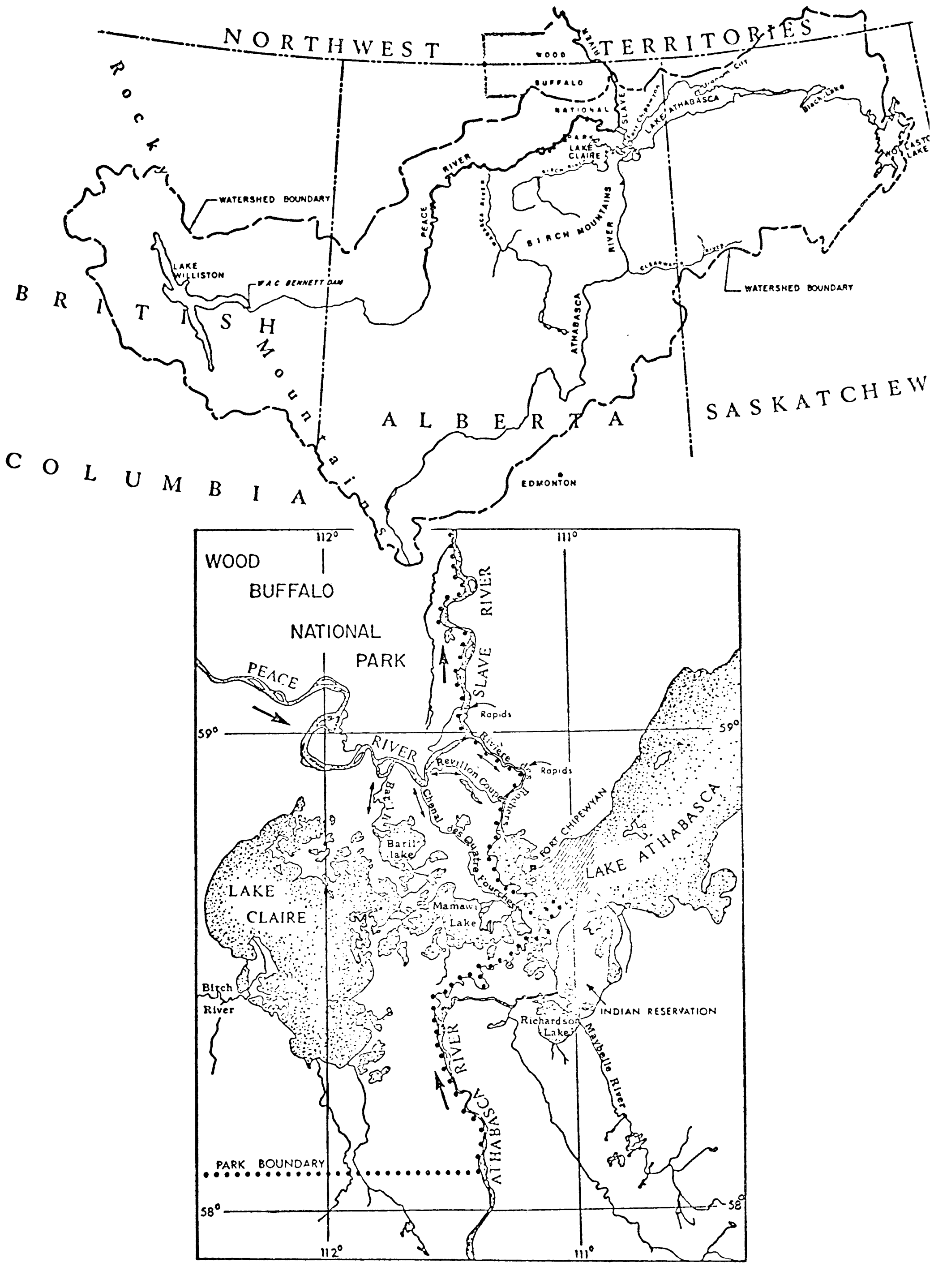


Fig. 1 — Lake Athabasca and the Peace–Athabasca Delta.

The Fond du Lac River (drainage area, 86,000 km^2) drains portions of the Canadian Shield, and has a relatively stable mean flow of 9·6 billion m^3 annually. An additional 24,000 km^2 area contributes to local inflow to Lake Athabasca proper, and another 21,000 km^2 area drains into lakes Mamawi, Claire and Baril, in the delta.

The Peace River (drainage area, 306,000 km^2) is not a direct tributary to Lake Athabasca, but is connected to it by three main channels named Rivière des Rochers, Chenal des Quatre Fourches and Revillon Coupé. These channels normally drain Lake Athabasca, but may carry reversed flow into the lake when Peace River levels exceed Lake Athabasca levels, (Fig. 2). This unique feature supplies life-sustaining flood waters to the delta, and permits natural regulation of Slave River flows.

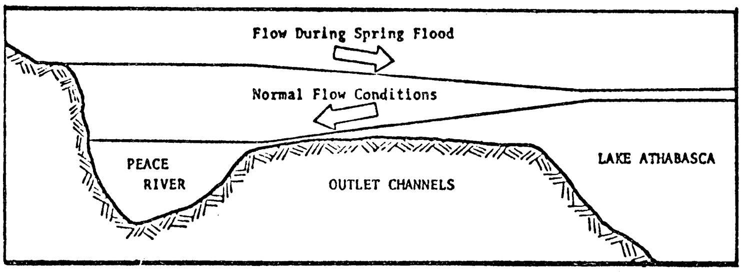


Fig. 2 — Flow in outlet channels.

Reasonably high Peace River levels also retard outflow from Lake Athabasca, thereby sustaining lake water levels. Main inflow Peace River to Lake Athabasca averaged 1·2 billion m^3 annually during the 1960 to 1967 period.

Because of this feature, Lake Athabasca exhibits annual water level fluctuations of as much as 3 m, with 1·7 m being the mean annual fluctuation.

The Problem

In December, 1967, closure of the Benett Dam on the Peace River commenced, creating the world's sixth largest man-made reservoir, which effectively regulated the Peace River 1170 km upstream from Lake Athabasca. In 1970, after three years of low Lake Athabasca levels, public attention focussed on the Peace–Athabasca Delta. Eminent scientists expressed concern that regulation of the Peace River was depriving the lake and delta of essential flood waters, and that ecological changes threatened to disrupt the delta permanently. Others claimed that the reduced water levels were a natural part of the hydrological cycle, and that the low water levels were a relatively temporary phenomena which had occurred naturally in the past.

Consequently, an interdisciplinary government task force was formed in 1971 with a budget of $1·5 million and 18 months to study the problem and recommend possible solutions. Some of the objectives of the study group were to identify the specific components causing the reduced water levels, to determine what could be done to remedy the situation, and to forecast the probable side effects of possible remedial works.

The Study

All available lake data back to 1930 were compiled and correlated to produce the post-1930 portion of the water level record represented in Fig. 3. A time frequency analysis of the data produced the stage duration curves shown in Fig. 4. Tree ring cores were sampled and analysed to obtain a very good correlation relating water level to tree growth. This dendrochronology study extended the long-term lake level record back to 1910, as illustrated in Fig. 3. The extrapolated lake levels correspond satisfactorily with observations recorded by early explorers in the area.

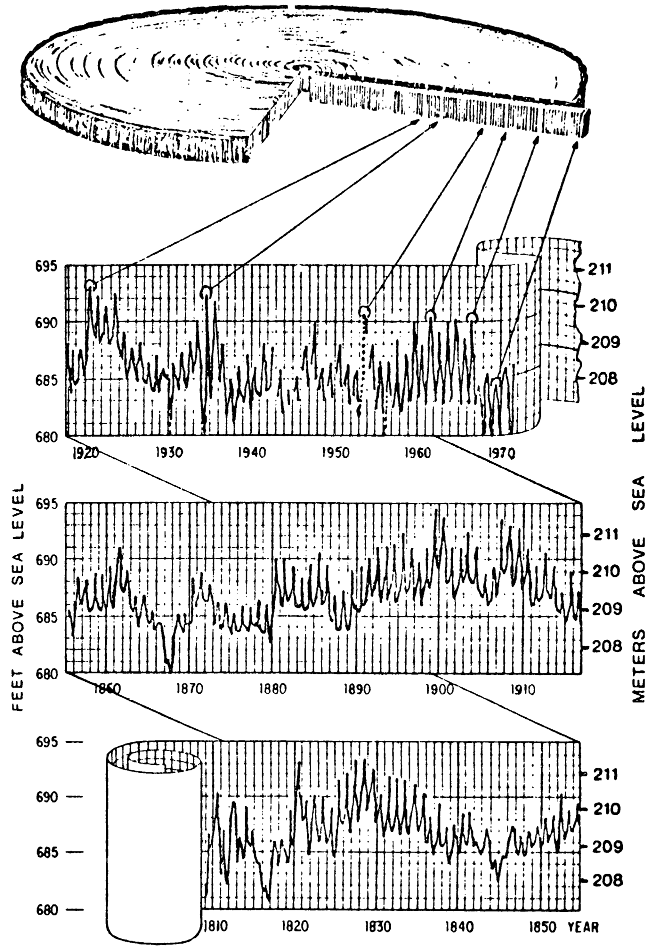


Fig. 3 — Water levels of Lake Athabasca from 1810 to 1970, estimated from tree-ring data.

Stream discharge data were compiled and correlated, and ungauged inflow was estimated to provide the surface water inflow components of the water budget. Outflow from Lake Athabasca was computed as the difference between Slave River and Peace River recorded flows, and a mathematical model was derived relating lake and river levels to gross outflow. Mean annual precipitation was computed as 23 cm, and mean annual evaporation was calculated to be 40–46 cm. A series of groundwater wells and observation of isolated ponds showed

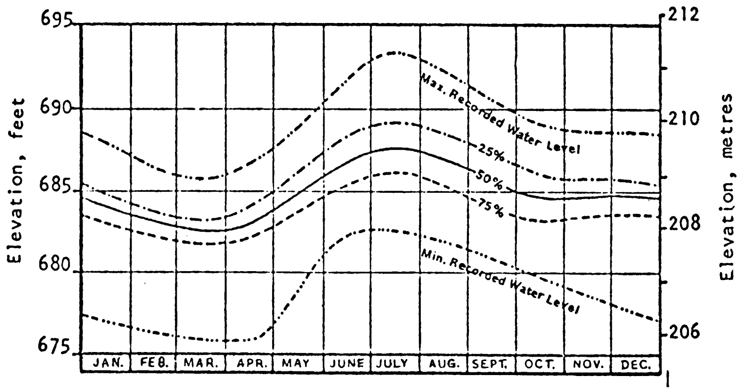


Fig. 4 — Lake Athabasca stage–duration curves, 1930–1970.

groundwater seepage to be small relative to the magnitude of the other components, so the seepage component was ignored. Wind-caused seiches of the magnitude of 1 m were observed, which had to be allowed for in the model. Also, an intensive stream discharge measurement and sediment sampling programme was instituted to better define the actual distribution of flow within the delta channels. It was observed that under certain conditions, Chenal des Quatre Fourches could be flowing from Peace River to the lake, while at the same time, Rivière des Rochers could be flowing from the lake to the Slave River.

Water samples were also taken to determine any trends in water quality changes in the delta lakes. In conjunction with the hydrological programmes extensive ecological and sociological studies were conducted.

Results

A thorough reconnaissance showed that several possibilities existed for remedial works. Figure 5 summarizes the major alternatives considered.

As a temporary measure to restore natural water levels in the delta lakes, a small rockfill dam costing $200,000 was constructed in late 1971, on the Mamawi Lake outflow channel to retard outflow, but permit inflow during Peace River flooding.

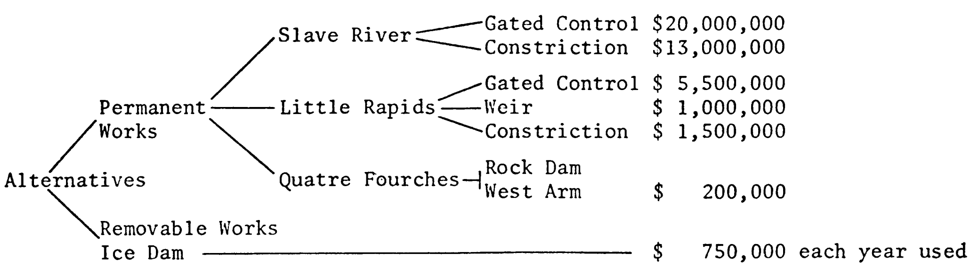
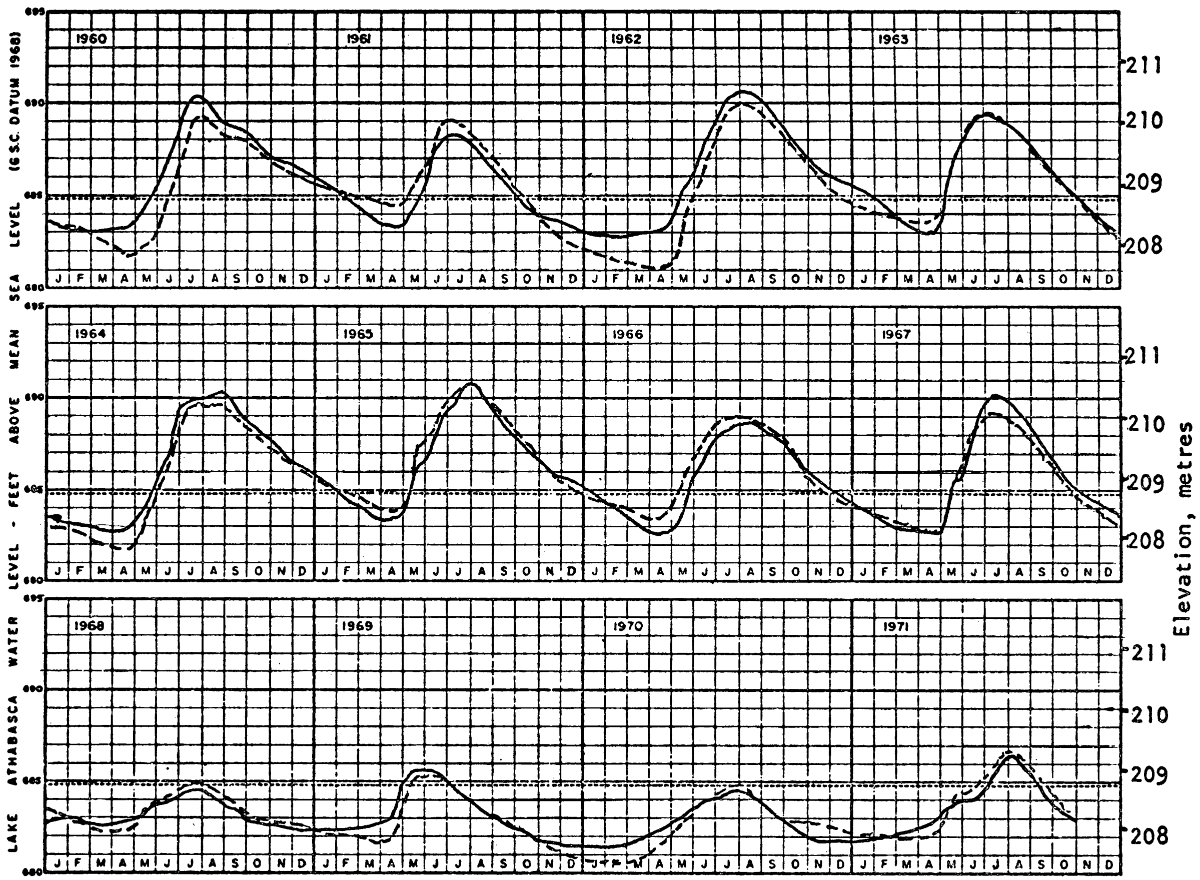


Fig. 5 — Alternatives considered for remedial works on Lake Athabasca.



—— Hydrograph of observed lake levels (smoothed)
---- Hydrograph of simulated lake levels

Spring 1972, brought substantial local inflow as well as ice jams causing overbank flooding of the Peace River. In addition, early summer rain storms on the Peace and Athabasca Rivers produced above normal flow which fortunately restored adequate lake levels. However, such a combination of circumstances cannot be expected to occur each year.

The idea of using cryopiles or thermosiphons to freeze solid a section of the outflow channel and thereby create a seasonal ice dam was tested in a pilot study on the Rivière des Rochers during the period January–March 1972. The innovative field tests proved that this concept is feasible but does not appear practical as a permanent water level control measure.

One major hydrological effort on the Peace–Athabasca Delta Project study was the development of a digital mathematical model which would simulate the fluctuation of water levels in Lake Athabasca, utilizing input primarily composed of Peace, Slave, Athabasca and Fond du Lac River flows. One component of the model was designed to simulate the flow distribution in the Rivière des Rochers and Chenal des Quatre Fourches while considering Lake Athabasca and the delta lakes as a single storage unit. In order to simplify the mathematical solution, and to be consistent with available data, the intricate hydraulic network had to be represented by a model with a limited degree of complexity. The flow in each channel segment was described by an expression similar to Manning's equation, as follows:

$$Q = K\frac{(H_1+H_2)}{2} \times (H_1-H_2)^{0\cdot 5} \tag{1}$$

where Q = discharge in m^3/sec and H_1 = upstream stage and H_2 = downstream stage in metres above channel datum.

The complete model involved the solution of the channel flow equations, the continuity equations at the channel confluences, and the stage–volume and water balance equations for Lake Athabasca, using a 5-day mean to minimize negative storage balances caused by wind seiches. In addition, the simulation model provided for the inclusion of the hydraulic effect of various control works.

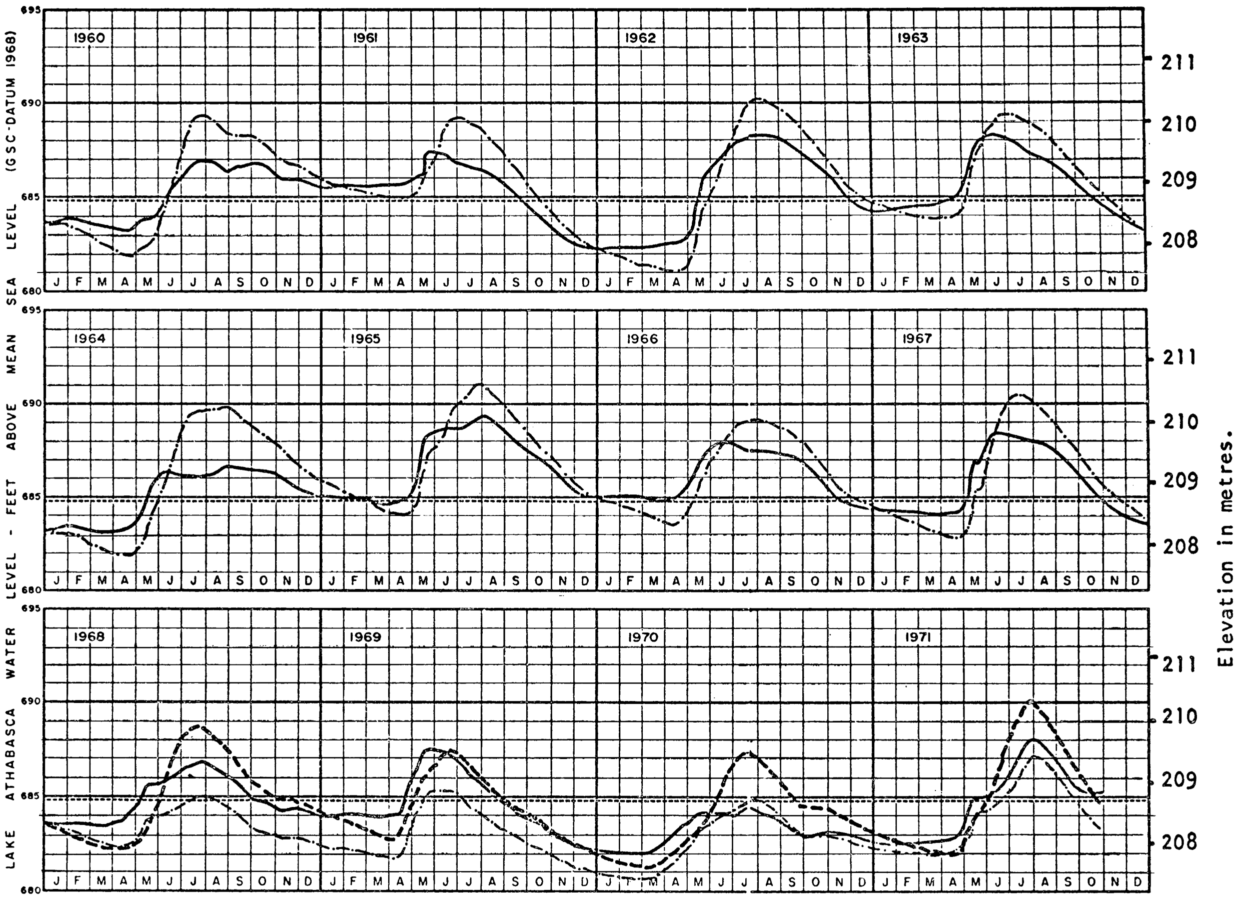
The model was calibrated using recorded streamflow and lake level data from the 12-year period 1960 to 1971 (adequate streamflow records were lacking prior to 1960) and although the model did not precisely duplicate the observed lake levels, it did simulate the important annual maximum elevations within acceptable limits (Fig. 6).

In order to test the theory that regulation of Peace River flow was a cause of some of the reduction of Lake Athabasca levels, natural unregulated flows for the Peace River had to be computed for 1968–1971. This computed natural flow was used as input into the simulation model to produce the hydrograph of estimated lake levels assuming no regulation by Bennett Dam during 1968–1971 (heavy dashed line, Fig. 7). As well, the regulated flows that would have been released if the Benett Dam had been in operation during 1960–1971 were computed and used as input. The solid line in Fig. 7 represents the simulated lake hydrograph assuming full regulation for 1960–1971.

Using the simulation model and synthesized regulated discharges, the effects of the various proposed regulatory structures were tested to determine the most desirable control works. Ten key factors were considered in evaluating the alternatives: (1) simulation of natural lake levels, (2) fish passage, (3) navigation, (4) downstream effects, (5) operating procedures required, (6) flushing of delta lakes, (7) ice problems, (8) sedimentation, (9) effects on channel regime, and (10) costs.

Conclusions

Examination of the hydrographs given in Fig. 7 shows that regulation of Peace River flow by Bennett Dam has lowered Lake Athabasca water levels for the period 1968–1971 by the approximate difference shown between the heavy dashed line and the solid line. The estimated



LEGEND:

—·—·— Observed lake levels
– – – – Estimated lake levels assuming no effect by Bennett Dam 1968 to 1971
———— Modified lake levels assuming full operation of Bennett Dam
All Hydrographs derived from computer simulation model
.... Approximate average annual lake level (1930 to 1970)

Fig. 7 — Lake Athabasca hydrographs showing observed water levels, modified water levels and average annual water levels.

and hence are lower than the modified levels.

non-regulated lake levels were also below normal. The long-term lake levels shown in Fig. 3. indicate that considerable fluctuations have occurred in the past, under natural conditions. Therefore, it may be concluded that a combination of drought conditions and regulated flow caused the reduced Lake Athabasca levels. A study of probable future water levels indicated that additional control of the lake is recommended.

After considerable testing of the effects of the various control structures mentioned earlier, it was recommended that (1) a submerged weir control structure be constructed at the Little Rapids site on the Rivière des Rochers to restore lake levels on Lake Athabasca, and consequently on the delta, to approximate what would have occurred under historical conditions; (2) a temporary rock dam on Quatre Fourches be removed when lake levels were restored; (3) a continuing programme of monitoring discharge, sediment and water quality trends be maintained; (4) environmental impact studies be conducted on Lake Athabasca, the delta and the Slave River prior to any construction of major reservoirs, diversions or other works.

Public hearings on the proposed Little Rapids weir are scheduled for fall, 1973 to investgate public response to the remedial works plan. As well, a continuing resource monitoring programme is being carried out in the important Peace–Athabasca Delta.