PEACE-ATHABASCA DELTA

WATER MANAGEMENT WORKS EVALUATION

APPENDIX C
ANCILLARY STUDIES

PEACE-ATHABASCA DELTA IMPLEMENTATION COMMITTEE

CANADA ALBERTA SASKATCHEWAN

PEACE-ATHABASCA DELTA
WATER MANAGEMENT WORKS EVALUATION

APPENDIX C
ANCILLARY STUDIES

A Report Prepared Under the PEACE-ATHABASCA DELTA IMPLEMENTATION AGREEMENT

Peace-Athabasca Delta Implementation Committee

CANADA ALBERTA SASKATCHEWAN

April 1987

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LETTER OF TRANSMITTAL

April 14, 1987

Mr. John Simpson, P.Eng.
Chairman
Peace-Athabasca Delta Implementation Committee
Alberta Environment
9th Floor Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5K 2J6

Dear Mr. Simpson:

Re: Peace-Athabasca Delta Water Management Works
Evaluation - Appendix C - Ancillary Studies

Please find enclosed within this appendix three reports that have been produced on behalf of the Peace-Athabasca Delta Implementation Committee. These are:

1. Evaluation of Test Fishways on Riviere des Rochers in the Peace-Athabasca Delta - Final Report.

2. Technical Feasibility Study of the Quartre Fourches Control Structure in the Peace-Athabasca Delta.

3. Assessment of Creed Creek.

The first report was produced in support of the committee's evaluation of the performance of the existing weirs. The latter two reports are independent studies done to evaluate the likely impact of either a control structure or the increasing diversion of water from the Embarras River on lakes Mamawi and Claire.

The conclusions are:

1. It is possible to construct a functional fishway at the Riviere des Rochers weir. However, further fisheries and hydraulic evidence is necessary to establish whether or not a fishway is needed.

2. A control structure on the Quartre Fourches is technically feasible; however, it would aggravate the effects the Creed Creek diversion is having on lakes Claire and Mamawi. The restriction on outflow capacity would cause lake levels to be higher than both the natural and existing situation.

3. The capacity of Creed Creek is growing and could potentially divert 100% of the Embarras River flow or 10% of the Athabasca River directly into lakes Claire and Mamawi. If Creed Creek continues to grow at its present rate, summer and winter water levels will exceed the existing and natural conditions. Also, the recession of peak summer water levels will take longer which could have consequent ecological implications.

On behalf of the committee I would like to thank S.B. Smith Environmental Consulting Ltd.; Prairie Farm Rehabilitation Administration; and Technical Services Division, Alberta Environment for their assistance, expertise and interest in the work of the committee.

Yours truly,

Walter Harris
Executive Secretary
Alberta Environment

AGRICULTURE CANADA

PRAIRIE FARM REHABILITATION ADMINISTRATION

ENGINEERING SERVICE

A TECHNICAL FEASIBILITY STUDY OF THE QUATRE FOURCHES CONTROL STRUCTURE IN THE PEACE-ATHABASCA DELTA

PREPARED FOR

THE PEACE-ATHABASCA DELTA IMPLEMENTATION COMMITTEE

Regina, Saskatchewan
August, 1986

Prepared by: G.D. McPhail

Reviewed and
Submitted by: R.R. Weinberger

Agriculture Canada

Prairie Farm Rehabilitation Administration
Administration du Rétablissement agricole des Prairies

Our File: 928/8P21

Motherwell Building
1901 Victoria Avenue
Regina, Saskatchewan
S4P OR5

August 20, 1986

Mr. John Simpson, Chairman
Peace-Athabasca Delta
Implementation Committee
Alberta Environment
9th Floor, Oxbridge Place
9820-106 Street
Edmonton, Alberta
T5K 2V6

Dear Mr. Simpson:

Re: Quatre Fourches Control Structure
Peace-Athabasca Delta

Our Design Division has completed this study under the Terms of Reference dated August 4, 1984, and we are pleased to submit the final report "Technical Feasibility Study of the Quatre Fourches Control Structure in the Peace-Athabasca Delta", dated August, 1986. Twenty-five copies are being forwarded at this time.

A substantial part of the work involved the investigation of numerous control scenarios, in which the modeling was carried out by Mr. Don Farley of Environment Canada. This proved to be a difficult and lengthy phase of the study, and his assistance in this area is gratefully acknowledged.

As well, the continuing advice and guidance of the Implementation Committee over the course of the work was appreciated.

Yours truly,

for A.F. Lukey
Director, Engineering Service, PFRA

GDM/ps

SYNOPSIS

This report presents an evaluation of the technical feasibility of constructing a gated control structure on the Quatre Fourches Channel, which is the outlet of Mamawi Lake in the Peace-Athabasca Delta. The purpose of the control structure would be to restore water levels in the Delta lakes. The evaluation was undertaken by the Prairie Farm Rehabilitation Administration at the request of the Peace-Athabasca Delta Implementation Committee.

The Peace-Athabasca Delta is one of the most important waterfowl nesting and staging areas of North America; it is the largest boreal delta in the world, and is the traditional hunting, fishing, and trapping grounds of the local people. A major component of the Delta's hydrologic system is the perched basins surrounding the lakes of the Delta, which have traditionally been refilled by periodic flooding of the Delta during the mid-summer peak water levels.

Commencing in 1968, the W.A.C. Bennett Dam began to regulate the flow of the Peace River for hydroelectric generation. This regulation reduced the mid-summer flood discharge down the Peace River, which historically has acted as a hydraulic dam on the outlet channels of the Delta lakes and has served as a source of inflow to the Delta through overland flooding along its banks during flood stage. Subsequently, water levels throughout the Delta decreased drastically, the long term consequences of which were feared to be catastrophic to the Delta. To restore the regime of the Delta to a state similar to that experienced prior to regulation of the Peace River, the inter-governmental Peace-Athabasca Delta Implementation Committee was established to oversee remedial measures. Two control weirs, one on the Rivière des Rochers and one the Revillon Coupé outlet channel were constructed in 1976. These weirs have

contributed significantly to water level restoration; however, perched basins adjacent to the Delta lakes have not been flooded as frequently since the construction of the Bennett Dam.

In response to recent concerns expressed by the local people over the drying-up of perched basins within the Delta, in August of 1984 the Implementation Committee requested PFRA to examine the technical feasibility of constructing a gated control structure on the Quatre Fourches Channel for the purpose of restoring water levels in the Mamawi Lake and Lake Claire portion of the Delta lakes to their natural regime.

The present study developed a control structure configuration that would meet the study objectives of restoring water levels in the perched basins surrounding Mamawi Lake and Lake Claire based on the present hydrologic conditions in the delta. Structure components were sized by trial and trend using historic hydrologic data and computer simulations of various structure configurations. The simulations were conducted for PFRA by Environment Canada using the one-dimensional hydrodynamic model of the Delta developed in the late 1970's by Alberta Environment and Environment Canada.

During the course of the study, it became apparent that the recent development of a natural diversion channel from the Embarras River to Mamawi Lake, called Creed Creek, is a significant contributor to the flow into this portion of the Delta. Since the formation of Creed Creek in 1982, its growth in flow capacity has accelerated to a level where it presently diverts about 4.5 percent of the Athabasca River flow directly into Mamawi Lake. The diversion appears to have the potential to capture the entire Embarras River discharge, amounting to about 10 percent of the Athabasca River flow. The effects of this diversion are to raise and sustain the water levels in Mamawi Lake and Lake Claire, and the associated perched basins of the Delta.

Computer simulations of the Delta performed for scenarios with and without the diversion, and with and without various structure configurations, confirmed that the potential benefits that could be derived by incorporating a structure in the Quatre Fourches Channel diminish as the diversion grows. Simulations for the existing natural channel indicate that at the present rate of diversion, there is an undesirable time lag in receding water levels during the fall and winter months compared with simulations performed without the diversion. A gated control structure on the outlet channel of Mamawi Lake could be operated to raise and improve the peak summer water levels to more closely approximate those resulting prior to construction of the W.A.C. Bennett Dam, but the structure would not be able to improve the time lag associated with receding water levels. A control structure having a gated width of 60 m could effectively restore peak summer water levels and attain the present receding water levels thereby mitigating the effects of the Peace River regulation, assuming diversion through Creed Creek at the present rate. Such a structure would have a capital cost of about $7,000,000, with an expected annual operating and maintenance cost of about $70,000.

Because the natural Creed Creek diversion is increasing in magnitude and indications are that it will continue to grow, any type of structure on the Quatre Fourches will result in a restriction to the recession of high water levels in the Delta lakes.

ACKNOWLEDGEMENTS

The Prairie Farm Rehabilitation Administration wishes to acknowledge the contribution made to this study by Mr. Don Farley, Water Management Systems Division, Environment Canada, Ottawa. The computer model simulations for this study were conducted under his direction.

Others who contributed to the preparation of this report include Mr. Gerry Morton and Mr. Mike Kowalchuk of the Water Planning and Management Branch of Environment Canada, Mr. Scott Flett and the staff of Alberta Environment at Fort Chipewyan.

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1.0 INTRODUCTION

1.1 Background To The Study

In December of 1967, construction of the W.A.C. Bennett Dam on the upper Peace River in British Columbia reached its final stages and the Peace River began to be regulated to produce hydroelectric power. The following summer, mid-July lake levels in Lake Athabasca and the surrounding Peace-Athabasca Delta (see Figure 1) were about 1.3 m less than the 157 year long-term average of 209.92 m. These low summer water levels continued in 1969, 1970, and 1971, with the average peak levels lying 0.82 m below the long-term average. These peak water levels are extremely important to the hydrologic system of the Delta lakes since much of the Delta consists of perched basins, which are basins or small lakes periodically recharged by only the summer peak water levels, and in the absence of this flooding would gradually dry up. By 1971, these decreased flood levels had resulted in 50 182 hectares of mud flats becoming exposed in the Delta, with plant succession already visible. Local residents as well as concerned scientists, engineers, and economists became convinced that the Delta was an "ecological disaster" in the making, and that some wildlife were in danger of depletion, and the main livelihood of those who fished and trapped in the area was being threatened. In response to the public concern and interest in the Delta, the governments of Canada, Alberta, and Saskatchewan established the Peace-Athabasca Delta (P.A.D.) Project Group in January 1971 to determine and assess the causes and effects of the reduced water levels in the Peace-Athabasca Delta.

Based on preliminary assessments by ecologists which indicated that permanent plant succession could occur if low water levels continued past 1972, a temporary dam was built in the fall of 1971 on the Quatre Fourches Channel, which is the outlet of Lake Mamawi, to temporarily flood the Claire-Mamawi complex of the Delta lakes. The dam was intended to provide the project group with some time to formulate a long-term solution to restore the Delta water levels while preventing permanent succession from occurring on much of the Delta. The Quatre Fourches Dam was to be removed once the long-term solution was initiated, as the dam was a substantial barrier to fish migration. As well the dam blocked the flow of water into the Delta lakes from Lake Athabasca, which was suspected of having serious long-term consequences to the composition of the flora and fauna of the lakes.

In 1973 the P.A.D. Project Group completed a report of its findings which contained ten recommendations, among which was the recommendation to construct a submerged weir control structure on the Rivière des Rochers, and to remove the Quatre Fourches Dam. Following public hearings the three governments signed the Peace-Athabasca Delta Implementation Agreement on September 16, 1974.

Under the terms of the Agreement a Peace-Athabasca Delta Implementation Committee was established to implement the recommendations of the Project report, including the construction of the Rivière des Rochers control weir and the removal of the Quatre Fourches Dam. The Prairie Farm Rehabilitation Administration (PFRA) was chosen to design and prepare the contract documents for the weir, as well as supervise the construction. PFRA recommended construction of a control weir on the Revillon Coupé, which branches off Rivière des Rochers and joins the Peace River, and this recommendation was accepted by the P.A.D. Implementation Committee. Construction work for the two weirs began in June 1975 and concluded in March 1976. In 1975 the contractor (Alpine Construction Company Limited) also removed that part of the Quatre Fourches Dam lying above elevation 205.74 m, and placed the rockfill into an adjacent disposal site. This completed the partial breaching of the dam, which Parks Canada had attempted with only limited success in the summer of 1974.

The purpose of the two control weirs was to restrict the outflow on two of the three main channels flowing from Lake Athabasca to the Peace River, thus attempting to simulate the natural backwater effect that the Peace River flow, in its unregulated state, had on the Lake Athabasca outlets during the mid-summer period. The weirs were to largely restore the mean peak water levels on Lake Athabasca to the natural peak levels but were not expected to completely restore the range in water levels that Lake Athabasca experienced prior to regulation of the Peace River.

In June 1983, two technical subcommittees to the P.A.D. Implementation Committee were formed to assess the effectiveness of the Rivière des Rochers and Revillon Coupé weirs. The Hydrology Subcommittee was to examine the actual performance of the weirs and to determine their effectiveness in restoring the natural hydrologic cycle to the Delta system, while the Biological Subcommittee was to examine the effectiveness of the weirs in restoring the natural ecosystem. In June 1985 the Hydrology Subcommittee submitted its report, in which it concluded that on average the weirs have been quite effective in restoring the natural maximum water levels in the Delta Lakes, and only slightly less effective in restoring the mean and minimum water levels.

The preliminary results of the Biological Subcommittee's work were used in establishing performance criteria for the proposed Quatre Fourches Control Structure discussed in this report.

1.2 Present Study

In July 1984, members of the Implementation Committee met with the Fort Chipewyan Trappers Association to discuss the trappers' concerns over the perched basins surrounding Lake Claire and Mamawi Lake, many of which had been dry since 1980. The Trappers Association proposed that a gated control structure be constructed at Dog Camp on the Quatre Fourches Channel, the site of the temporary dam placed in 1971 and removed in 1975 (see Figure 2). The control structure would be operated so as to raise the water levels in the Claire-Mamawi lakes to their natural (i.e. pre-Bennett Dam) hydrologic regimes, thus reflooding the surrounding perched basins and improving fur production.

On August 1, 1984 the Implementation Committee requested PFRA to conduct a technical feasibility study of the proposed control structure. The Terms of Reference (Appendix A) direct PFRA to assemble and review all background information on the previous Quatre Fourches Dam, prepare a feasibility-level design and cost estimate, and to evaluate the effectiveness and impacts of the structure using Environment Canada's one-dimensional hydrodynamic model of the Delta system.

This report presents the findings and conclusions reached by PFRA on the technical feasibility and effectiveness of the Quatre Fourches Control Structure.

2.0 EVALUATION OF THE PROBLEM

Prior to designing and modeling a structure capable of satisfactorily restoring the Delta lakes hydrologic system to its natural state, it was first necessary to understand the problem and the complex hydrologic system which currently exists on the Delta.

2.1 Hydrologic System of the Delta Lakes

The key to water levels in the Peace-Athabasca Delta is Lake Athabasca, the level of which generally fluctuated about 1.8 m between its winter minimum and its midsummer peak prior to regulation of the Peace River, and which now fluctuates about 1.2 m under the existing conditions. The lake has four main sources of inflow: the Athabasca River, the Fond du Lac River, the Lake Athabasca watershed, and the Peace River.

The Athabasca River has a watershed of 158 800 km^2 which rises in the Rocky Mountains and, like most mountain rivers, has a high summer discharge with very low winter flows.

The Fond du Lac River has a watershed of 86 000 km^2 with its headwaters in the Canadian Shield in Saskatchewan, and has a relatively stable discharge with little change from season to season due to the routing effect of the lakes through which it drains.

The Lake Athabasca watershed, excluding the above rivers, has an area of 16 830 km^2 draining into its southern shore, 7 250 km^2 draining into the north shore, and 20 980 km^2 which drain into Lakes Claire and Mamawi and then into Lake Athabasca. These areas generally provide little but highly variable runoff.

The Peace River is not a direct tributary to Lake Athabasca, but historically it has frequently discharged some of its water into the Lake during periods of high flow or as a result of ice jams which cause the river stage to rise high enough to flow into the Lake. Prior to regulation of the Peace River the volume of water added to Lake Athabasca from the Peace River averaged about 10% of the total annual volume fluctuation of the Lake.

The fluctuations in lake levels observed on Lake Athabasca are due to the interaction between the four basic sources of inflow, and the three outflow channels, Rivière des Rochers, Revillon Coupé, and Chenal des Quatre Fourches, all of which discharge into the Peace River. The flow in the three outlet channels is largely determined by the relative difference in water levels between Peace River and Lake Athabasca. Historically, the mid-summer peak levels in Lake Athabasca have occurred when the high summer flows on the Peace River have raised the water level at the confluences of the Peace and the Lake Athabasca outlet channels, thus effectively damming the outlets of Lake Athabasca. When the operation of Bennett Dam began to regulate the Peace River discharges, the resulting mid-summer levels in the Peace River at the confluence of the Lake Athabasca outlet channels became considerably less than the natural long-term average, and the outflow from Lake Athabasca was not influenced by the backwater effect, thus increasing the outflow and subsequently lowering the water level of the Lake. The Rivière des Rochers and Revillon Coupé control weirs were intended to approximately simulate the natural damming which had occurred prior to regulation of the Peace River.

The levels of the Delta lakes, Lake Claire and Mamawi Lake are greatly dependent upon the level of Lake Athabasca. The Delta lakes receive water from five major sources: the Birch River, the McIvor River, Lake Athabasca, and overland flooding from the Peace River (through the Baril or Claire River) and/or the Athabasca River (through the Embarras River - Creed Creek diversion). With the regulation of the Peace River, the overland flooding from the Peace has for the most part been eliminated, although overland flooding could still occur as a result of a sufficiently severe ice jam or flood on the Peace River.

The Delta area receives an average of 320 mm precipitation per year, but the mean annual evaporation for the Delta lakes is estimated to be about 400 mm. As evaporation is generally greater than precipitation during the ice-free period, it follows that unless the Delta lakes periodically flood the surrounding perched basins a persistent reduction in the water levels of the basins will occur.

2.2 1980-1984 Water Levels in the Delta

The maximum, minimum, and mean annual water surface elevations for Lake Athabasca, Lake Claire, and Mamawi Lake for the 1980-1984 period as well as the 1960-1984 period are presented in Table 1. The values are based on simulations performed by Environment Canada using the one-dimensional hydrodynamic model of the Delta for the natural hydrologic conditions, which is defined to be with Bennett Dam and the control weirs not in place, and the existing conditions, in which Bennett Dam, Rivière des Rochers, and Revillon Coupé weirs are in place. As previously documented in the Hydrology Subcommittee's report, the results of the simulation model correspond closely to the measured values for the real Delta hydrologic system and were deemed to be of acceptable veracity for this study.

From Table 1, it can be seen that during the 1980-1984 period the water levels throughout the Delta were considerably lower than the long-term natural water levels, with Mamawi and Claire having mean annual peak elevations 0.64 m and 0.75 m lower in 1980-1984 than in the period 1960-1984. It is the peak levels which determine the extent of flooding of the perched basins once the lake levels reach the basins threshold elevation, and any decrease in peak level results in a considerable decrease in the areal extent of the perched basins flooded. It should be noted that for both periods, the mean peak elevations produced by the existing conditions average about 0.15 m less than would have occurred under natural conditions.

2.3 Restoring Natural Water Levels to the Delta

Restoring the natural peak water levels of the Delta lakes can only be accomplished by either increasing the inflow or decreasing the outflow.

Increasing inflow into the Delta lakes, although not included as a study item in the Terms of Reference for the study, has become a significant factor affecting the conclusions of this study. A natural channel, called the Creed Creek diversion, has formed in the recent past. This channel connects the Embarras River to Mamawi Lake and allows a portion of the Athabasca - Embarras River flows to enter directly into the Delta lakes. The effects of the increased volume of inflow into the Delta lakes and the continued growth of the channel are discussed in detail in Section 3.3 of the report.

Controlling the outflow from the Delta lakes in order to restore the natural peaks can be accomplished by the construction of a gated structure and overflow weir across the Quatre Fourches outlet channel at Dog Camp. Generally speaking, the structure would be operated in such a fashion that the gates would be closed during the spring or early summer period to reduce outflow from the Delta lakes and then opened fully in late summer to discharge the excess storage from the lakes.

3.0 EVALUATION OF THE PROPOSED CONTROL STRUCTURE

The Terms of Reference state that the control structure on the outlet channel of Mamawi Lake should be located at Dog Camp. The site has several characteristics which would facilitate construction of the proposed structure, as are described in the following section.

3.1 Site Description

In October, 1984 representatives from the PFRA Design and Geology Divisions visited Dog Camp to perform a site reconnaissance.

The Quatre Fourches area is characterized by generally flat deltaic-alluvial sediment topography with occasional relief provided by resistant bedrock knolls and low hills which rise up to 30 m above the flood plain. At the Dog Camp site, bedrock outcrops of granite and granite-gneiss form the base of the south bank of the channel and the island located just north of the centre of the Quatre Fourches Channel. The north bank consists of clayey and/or sandy silt but 180 m north of the bank a weakly foliated granite and granite-gneiss bedrock outcrop rises above the floodplain. Bedrock appears to lie just below ground surface 60 m north of the channel bank, being covered with only a thin veneer of silt.

Conversations with local people as well as the contract plans for the original Quatre Fourches Dam indicate that the channel north of the island is underlain by silt up to 13 m deep, while the south channel contains up to 6 m of soft silts. During the construction of the original Quatre Fourches Dam, extensive settlement of the silt foundation was expected and observed. It is expected that the removal of the rockfill above elevation 205.74 m in 1975 should have left significant quantities of rockfill on the channel bottoms. The underlying silt is unlikely to experience significant additional settlement during construction of the proposed control structure, since the height of the two dams will be similiar.

3.2 Conceptual Design of the Control Structure

The proposed control structure consists of a gated control section founded on the rock island in the center of the Quatre Fourches Channel, with a rock fill dam extending from each bank out to the centre gated section. The gated width is effectively limited to that of the rock island since the silt layers overlying the bedrock in the channel beds are compressible and would not be suitable for a rigid concrete structure. Each gate would be supported by concrete piers. Abutments with rounded wingwalls connecting the concrete structure to the rock fills would reduce hydraulic losses through the structure. Vertical lift gates or radial gates with a motorized hoisting system would be required to perform the constant adjustments necessary to simulate natural conditions. Possible gate operating policies are discussed in Section 5.3.

The embankment portion of the proposed control structure would be comprised of rockfill obtained from blasting at either of the granitic bedrock outcrops located adjacent to the structure or from the removal of the rock island which forms the foundation for the control section. Since the duration of required impoundments is expected to be less than two months per year, seepage losses through the rockfill are not expected to warrant special seepage control measures.

Because of evidence of the extensive flooding observed in the past and the very flat relief of the surrounding floodplains, the embankment portion would be designed to withstand flow overtopping, thus effectively serving as a rock overflow weir during extreme flood events. The initial top of dam elevation for the simulations was selected to equal the 1960-1981 simulated natural mean peak elevation at Mamawi Lake of 210.0 m plus an additional 0.3 m to provide for some wave runup and wind setup.

As demonstrated in the subsequent discussions of the modelling results, the elevation selected for the top of dam is entirely capable of achieving and sustaining the required natural peak elevations. Little effort was made to optimize this elevation, since the rock embankment costs would be a small proportion of the overall project costs.

The proposed control structure would have facilities for both fish and boat passage around the control structure. Because the volume of flow through the fishway would be quite small, the flow was not included in the simulations.

3.3 One-Dimensional Hydrodynamic Model

Due to the extremely complex hydrologic regime of the Delta, the one-dimensional hydrodynamic model of the Delta was utilized to evaluate the effects of a control structure on the Delta lakes as recommended in the study Terms of Reference. This model was also used by the Hydrology Subcommittee to facilitate its evaluation of the effectiveness of the existing control weirs.

In 1978 Environment Canada and Alberta Environment cooperated to adapt Environment Canada's one-dimensional (1-D) hydrodynamic model to simulate the gradually varied unsteady flow conditions in the network of lakes and multiple river channels which comprise the Delta. The structure and formulation of the model are fully described in the document "Environment Canada One-Dimensional Hydrodynamic Model Computer Manual" by Water Planning and Management Branch, Inland Waters Directorate, Environment Canada.

The model uses a finite-difference scheme to integrate the St. Venant equations (for conservation of mass and momentum of fluid flow) over a wide range of transient flows and conditions. The model is readily structured to accomodate bridges, dams, and weirs or any other structure capable of being described by equations or curves, and thus was ideally suited to this study. The required input includes residual inflow records for Lake Athabasca, Athabasca River, Birch River, Peace River, Slave River as well as cross-sections of the different rivers, channels, and lakes comprising the network. For this study, the model computed the flows and water surface elevations throughout the network on a two-hour time interval for the years of record examined in the simulations.

Several significant modifications were made to the hydrodynamic model for this study which resulted in differences in the model from that used by the Hydrology Subcommittee in their investigations. The most important of these modifications are presented below:

a) Artificial Perched Basin

To simulate the water volume loss from the system which occurs when the threshold elevations of the perched basins are reached and the basins fill with water, an artificial perched basin was added to the nodal network of the model. This artificial basin was intended to function as an indicator of the effects of the perched basin storage and was based on the extremely limited data presented in Section I of the Ecological Investigations of the P.A.D. Project (Volume 2), from which two composite cross-sections representative of the storage-elevation characteristics were derived and input to the model. Based on this data, the perched basins account for less than 5% of the available water storage on the Delta, and thus the volume loss associated with filling the basins is usually quite small.

b) Embarras River Diversion: Creed Creek

On a site reconnaissance of the Dog Camp site in October 1984, PFRA learned that a natural diversion channel from the Embarras River to Mamawi Lake was diverting considerable flow into the Delta lakes. This channel was extensively developed in 1982 by a flood on the Athabasca River, which produced corresponding floods on the Embarras River, which is a distributary of the Athabasca River and flows into Lake Athabasca. Alberta Environment commenced monitoring of the diversion flows in August 1982 and has continued monitoring to date. Since the measured discharges indicated that the Creed Creek flows (as the diversion is now named) were quite significant in relation to the total inflow to the Delta lakes, the Creed Creek diversion was incorporated into the model. For the initial phase of modelling the control structure, Environment Canada used the measured data for 1982 to 1984 to derive a regression relationship between the Athabasca River flow and the Creed Creek diversion flows out of the Athabasca River into Mamawi Lake, with the diversion discharge being a function of the Athabasca flows rather than the hydraulic properties of the diversion channel itself. As the regression analysis indicated that the diversion capacity of Creed Creek virtually doubled from 1982 to 1984, the second phase of model simulations used a range of diversion scenarios to explore the consequences of this diversion and to determine the sensitivity of the gated control width to the assumed scenario. The diversion scenarios for the second phase of simulations resulted from discussions between the Implementation Committee and PFRA in September 1985, and are presented in Figure 3.

c) Control Structure

The inclusion of the control structure into the model network required a model routine different from that used previously. It was not possible to duplicate the mathematical regression equations used to simulate the Rivière des Rochers and Revillon Coupé weirs since they would not readily accommodate an operating policy for the gates. To expedite the modelling of the structures, an existing routine developed by Environment Canada for a flood study at Truro, Nova Scotia was used to model the structure. The formulation and assumptions of the routine are fully described in "Documentation for the Breach Subroutine to be used with the One-Dimensional Hydrodynamic Model" by Water Planning and Management Branch, Inland Waters Directorate, Environment Canada, August 1984.

The Breach routine permits flow to go over a dyke or dam embankment as well as through a culvert or an aboiteau (i.e. a one directional drain). This routine was ideally suited to modelling the control structure since the rock dam overflow portion could be modelled as embankment overflow, while the gated portion of the structure was modelled as either a box culvert or a box aboiteau when only one way flow was desired. As the model is solved serially, the parameters for the Breach routine could be altered from time period to time period, thus allowing the gated width (or conduit size) to be altered or the conduit altered to an aboiteau which only allows flow from Lake Athabasca to Mamawi Lake, thus simulating gate operation. Making use of this property, a simple and crude operating policy could be incorporated into the model simulations to assess the responsiveness of the delta system to gated control. The inclusion of a more sophisticated operating policy would have required considerable effort by Environment Canada personnel and would have significantly delayed the results. Given the uncertainty as to what would constitute an acceptable operating policy as well as the delays associated with incorporating it into the model, it was felt that a crude approximation of a policy could provide sufficient information to evaluate the structure's true effectiveness under gated operation. Possible operating policies for the proposed structure are discussed in more detail in Section 5.3 of this report.

d) Flow Dampening at Dog Camp

A flow dampening routine for the control structure was added to the model by Environment Canada to moderate unrealistic flow fluctuations observed during the initial model simulations. This routine restricts the rate of change that the flow can undergo between time steps and was based on an assessment by Environment Canada of the physical characteristics of the Quatre Fourches Channel.

This routine influenced flows only during an extremely short period of time, thus the total volume of water affected was quite small and would have negligible impact upon the simulated water levels. The alternate solutions for these fluctuating flows would have been to either decrease the solution time increment or increase the number of mesh points near the structure, both of which would have required extensive work with little or no apparent gain in solution veracity.

It should be noted that all of the analysis and discussions of this report are based on the results of the simulations for the various structure alternatives, the accuracy of which is dependent on that of the hydrodynamic model. Given the complexity of the hydrologic system of the Delta lakes, a mathematical model of the system offers the only feasible method of evaluating the effects of any control structure on the water levels of the Delta. The results of the model have been verified previously by Environment Canada, and were found to correspond closely to those measured in the real Delta lakes hydrologic system for the natural and existing hydrologic conditions. It must also be noted that whereas interpretations of the model results are the responsibility of PFRA, PFRA is dependent on Environment Canada for the validity of the overall model results.

3.4 Results of the First Phase of Simulations

All of the modelled structures consisted of a rock-fill embankment flanking a centrally located gated control section located on the rock island in the middle of the Quatre Fourches Channel.

To assess the responsiveness of the Delta system to a gated control section, the simulations made use of the Breach model routine which allowed flow from Mamawi to Lake Athabasca to be stopped for several months, while still allowing Lake Athabasca-to-Mamawi flows. This operating policy was intended to serve as a crude rule curve for the control structure model to examine the impact of such a policy on the Delta.

Preliminary calculations based on the amount of storage available in the Delta lakes, the duration of the natural peaks, and the expected minimum water levels suggested that a gated control width in the order of 40 metres should provide acceptable receding water levels once the peak was attained if some delay could be tolerated. Since the time lag of the receding water levels was impossible to predict due to the complex nature of the hydrologic regime of the Delta, gated control widths ranging from 12 m to 60 m were simulated to determine the system's responsiveness and sensitivity to the gated width. The results of the first phase of simulations were used to aid in the identification of an optimal control width, which would then be modelled in more detail in the second phase of simulations. This iterative procedure was made necessary by the considerable time required to set up the model, run the simulations, and evaluate the results.

The simulation period covered the years from 1970 to 1981 in order to evaluate the results under both high lake levels and sustained low lake levels in the Delta. This period had several years of high levels followed by quite low lake levels, thus allowing a good overall assessment of the effects of a structure in the real dynamic hydrologic regime with its constantly varying conditions, while reducing the computer time required by simulating only 12 of the 22 year period (i.e. 1960-1981) available at that time.

All of the structures modelled assume that Bennett Dam and the existing control weirs of Rivière des Rochers and Revillon Coupé remain in place and act concurrently with the proposed structure.

The Creed Creek channel was modelled by a regression relationship established on the basis of the flow diverted and the flow of the Athabasca River for several Creed Creek flows measured in 1982, 1983, and 1984. This non-linear relationship represented the diversion of about 2.25% of the Athabasca River flows into Mamawi Lake through Creed Creek, and was applied throughout the entire period of simulation.

The pertinent details of the alternate structures modelled in the first phase of simulations (designated Structures 1 to 9) are presented in Table 1, while a brief qualititative assessment of each is presented below. The water levels produced by the alternate structures as well as for the natural and existing hydrologic conditions are graphically presented in Figures 5 through 16 of the report. For the majority of the structures, the Delta lake levels are represented by the water levels of Mamawi Lake only, since the water levels on Lake Claire correspond closely to those experienced by Mamawi. As the impact of the structures on Lake Athabasca water levels proved to be relatively insensitive to either the gated width or the duration of impoundment, only the Lake Athabasca water levels produced by Structures 1, 2 and 7 are presented.

a) Structure 1 was a channel constriction with an uncontrolled opening 40 m wide. This structure produced water levels in Mamawi Lake and Lake Claire very close to those produced by the existing control weirs, but in some years a significant peak increase (+.15 m) was observed as well as slightly increased minimum water levels. The structure did not generally attain the peak water levels achieved under natural conditions, and produced significantly higher minimum water levels with the receding water levels occurring significantly later than for natural or existing conditions in some years.

   Structure 1 generally had little impact upon the existing water levels in Lake Athabasca, however in some years the structure decreased the peak water levels by up to 0.15 metres. The natural water levels generally have greater peak and lower minimum water levels than those produced by either the existing weirs alone or in combination with Structure 1.

b) Structure 2 was identical to Structure 1 physically, but during May, June and July the control section allowed water to flow only from Lake Athabasca to Mamawi. On Mamawi and Claire, this structure produced peak water levels above the existing and natural levels, and was able to fully restore the natural peak in the year 1981, unlike either of the existing weirs or Structure 1. In general the minimum water levels produced corresponded closely to those of Structure 1 or the existing weirs, except for one period in which the simulation indicates a minimum level signficantly in excess of that of Structure 1. This appears to have resulted from overachievement of the natural peak levels in the preceding summer by the crude rule curve. The receding limb of the hydrographs resulting from Structure 2 lags behind the natural and existing conditions by several days.

The structure had little impact upon water levels of Lake Athabasca, except that in some years the structure decreased the peak water level by up to 0.15 metres. In general the water levels were similar to those produced by Structure 1.

c) Structure 3 had a gated control width of 40 m which allowed only Lake Athabasca to Mamawi flow during May, June and July and was identical to Structure 2, except that the crest elevation of the rock dam/weir was raised from an elevation of 210.3 to 210.6 metres. Throughout the Delta system, the water levels produced were virtually identical to those resulting from Structure 2. Based on this simulation there was little apparent gain from increasing the crest elevation, as Structure 2 demonstrated that the base case crest elevation of 210.3 metres was capable of overachieving the natural peak levels.

d) Structure 4 was identical to Structure 2 except that the period of one-way flow from Lake Athabasca to Mamawi was extended by an additional month to be from May 1 to August 31. This operating policy resulted in considerable overachievement of natural peak levels throughout the simulation period, while the subsequent minimum water levels were considerably higher than either the existing or the natural minimum levels. It is apparent from the results that 4 months of gate closure was not required nor desired.

e) Structure 5 consisted of a rock dam with a gated control section 12 m wide which allowed only one-way flow from Lake Athabasca to Mamawi for the period of May, June and July, and unregulated flow for the remainder of the year. On Mamawi and Claire the structure produced peak water levels considerably above the natural peaks. Associated with these excessive peak levels were large increases in the minimum water levels on the Delta lakes, ranging from 0.05 to 0.8 metres above the levels produced by the existing conditions alone, which are themselves higher than those for natural conditions. Because of these increases in minimum levels and the time lag in the receding water levels which accompanied them, the structure and its operating policy was judged to be unsuitable. To determine the extent to which the operating policy was responsible for these unsatisfactory levels, a simulation (designated as Structure 9) of the physically identical structure with only 2 months of gate closure was subsequently modeled.

f) Structure 6 had a gated control width of 24 metres which allowed flow only from Lake Athabasca to Mamawi during the period of months of May, June and July, and unregulated flow the remainder of the year. The structure produced water levels on Mamawi and Claire virtually identical to those produced by Structure 2, with only a slight increase in the minimum water levels during a few years of the simulation period. Some time lag between the receding water levels produced by Structure 6 and the existing levels was observed.

The effect of Structure 6 upon the Lake Athabasca water levels is similar to that of Structure 2, which generally had little impact on the levels except that a decrease in peak water levels by up to 0.15 m was observed in several years.

g) Structure 7 had a gated width of 60 m, and was operated such that only Lake Athabasca to Mamawi Lake flow was allowed during May, June and July, with the control width being open the remainder of the year. The structure produced peak water levels on Mamawi and Claire virtually identical to those of Structure 2, while the minimum and receding water levels closely correspond to those produced by the existing weirs alone.

The structure's effect upon Lake Athabasca water levels is similar to that produced by Structure 2.

h) Structure 8 had a gated width of 60 m which was closed during May, June and July except for Lake Athabasca to Mamawi flow, but the gate invert was raised by 0.5 m to elevation 206.5 m to determine the structure's sensitivity to a variation in invert elevation. The structure produced peak levels on Mamawi and Claire which were virtually identical to Structure 2, while the minimum and receding water levels did not correspond to those of the existing weirs as closely as did the levels produced by Structure 7. The structure's effects upon Lake Athabasca were similar to those produced by Structure 2.

i) Structure 9 had a gated width of 12 m which was closed during May and June except for Lake Athabasca to Mamawi Lake flows, and was unregulated for the remainder of the year. As previously mentioned, Structure 9 was modelled to determine whether the large increase in minimum water levels observed for Structure 5 was due to insufficient discharge capacity through its 12 m of gated width, or if the overachievement of the natural peak levels under the operating policy provided an excessive volume to discharge within the required time, thus raising the winter/spring water levels of the following year.

The peak water levels produced in Mamawi and Claire were slightly lower than those of Structure 5 but the minimum levels were approximately equal to those of Structure 5, still considerably greater than for either the existing or natural conditions. Based on these results, it was determined that the discharge capacity of the 12 m gated width was insufficient to achieve the existing minimum levels in the Delta lakes.

The criteria used to examine the results of the first phase of the simulations and to select the preferred gated width was refined as the simulation results were received. The initial criteria was for the structure to achieve the natural peak water levels on the Delta lakes without significantly affecting the existing minimum water levels, which were already higher than under natural conditions. As the simulation results became available it was noted that while the modelled structures could attain the required peak and minimum water levels, they often produced receding and minimum water levels which ocurred significantly later in the year than under the natural or existing conditions. Discussions with the Implementation Committee and the Biological Sub-committee revealed that this was an undesirable effect. These discussions resulted in revised criteria in which the structure would be required to attain the natural peak and existing minimum water levels, but would not delay the receding or minimum water levels beyond those of the existing conditions. Since constricting the outlet channel to a 40 m width (i.e. Structure 1) produced a slight delay in receding water levels, it was apparent that the control structure width had to be somewhat greater to reduce these flow lags. Structure 7, which had a gated width of 60 metres, appeared to produce satisfactory minimum and receding water levels. In this simulation, the gates were closed for 3 months, which resulted in overachievement of natural peaks in some years which would then induce a delay in the receding water levels as the excess volume was discharged. This overachievement and delayed outflow made it difficult to fully assess the suitability of the structure without additional simulations.

Examination of the total inflow volumes to the Mamawi Lake - Lake Claire system revealed that the Creed Creek diversion flows from the regression relationship comprised a significant proportion of the total inflow, ranging from 5% to 15% over the simulation period. The diversion relationship used for Structures 1 to 9 assumed that the diversion channel capacity was in a steady state, while the regression analysis of the measured flows in each year indicated that the channel was very dynamic and had doubled its discharge capacity in 3 years. As the channel bed consists primarily of erodible alluvial deposits, the channel capacity will be greatly dependent upon the future flows down the Athabasca River and the response of the diversion channel regime to those flows. Since it was possible that the Creed Creek inflows could significantly influence the water levels in the Delta Lakes, additional simulations were required to determine the sensitivity of the lake levels to future variations in the discharge capacity of the channel. Due to the uncertainties involved in forecasting a long-term stable diversion channel capacity and the paucity of available data, the Implementation Committee supplied PFRA with a range of 5 diversion discharge relationships (designated as Curves A to E), the upper bound of which diverted 50% (Curve A) of the Athabasca River through Mamawi Lake while the lower bound diverted 4.5% (Curve E). These relationships are presented in Figure 3.

3.5 Results of the Second Phase of Simulations

Due to the uncertainty surrounding the future discharge capacity of the Creed Creek diversion and the significance of the volumes diverted to the Delta lakes, a second phase of simulations was performed. These simulations were to assess the sensitivity of the Delta lake water levels to the Creed Creek diversions. Hydraulic acceptability for the proposed Quatre Fourches Control Structure would require that both the natural peak and existing minimum water levels be attained while the receding water levels were to coincide with those produced by the existing hydrologic system.

The second phase of simulations modelled five basic control structure alternatives which had gated widths ranging from 48 to 104 m. These were designated as Structures 10, 20, 30, 40, and 50 in order of increasing gated width. The minimum gated width of 48 m was based on an examination of the Mamawi Lake water surface elevations produced by a 40 m wide channel constriction, i.e. Structure 1, which revealed that the 40 m wide opening produced a significant delay or time lag in the receding water levels for several years. These biologically unacceptable flow delays can only be mitigated or eliminated through increasing the gated width of the control structure, and thus the minimum gated width was increased to 48 m.

The maximum gated width of 102 m, designated Structure 50, represented the approximate physical upper bound for a gated control structure founded on the bedrock island at Dog Camp. Increasing the gated control width beyond this approximate limit would, in all probability, add substantially to the cost of a structure at this site.

It should be noted that the alternatives designated as Structures 10 to 50 did not include any period of gate closure or operating policy, since the intent was to merely establish the minimum width of control structure that can best match the existing receding and minimum water levels. Based on the results from the first phase of simulations it was evident that the desired maximum water levels could be readily achieved through judicious operation of the gates.

To examine the response of the receding water levels of the Delta system under an operating policy which prevents overachievement of the natural peak water levels, two control structures, designated Structures 60 and 70, with gated widths of 60 m and 72 m were simulated using the simplistic operating policy of closing the gates to Mamawi outflow for the month of May in the two years having the greatest difference between the peak levels produced by the natural and existing conditions, which are 1972 and 1981. The intent of these two simulations was to restore the natural peak water levels without significantly overachieving peak levels, and then compare the receding water levels to the existing conditions to assist in the selection of the optimum gated width.

To determine the impact of the Creed Creek diversions on the water levels produced by the existing hydrologic system alone, the second phase of simulations modelled the natural existing Quatre Fourches outlet channel without any control structure at Dog Camp. This alternative was designated as Structure 80.

Because of the uncertainty as to the long-term stability of the Creed Creek diversion, each of the eight alternatives (Structures 10 to 80) were to be simulated for a range of Creed Creek diversion capacities, with Bennett Dam and the control weirs on Rivière des Rochers and Revillon Coupé in place for all simulations. In addition to using each of the five Creed Creek diversion relationships (represented by Curves A to E on Figure 3), each of the structures was to be simulated with no Creed Creek diversion into Mamawi Lake in the event that it was decided to close the diversion at some future date. Because of concerns over the large number of runs and the computer and analysis time that would be required, it was decided to reduce the number of scenarios to be simulated and the eight alternative structures were simulated with only a single Creed Creek diversion relationship which constantly diverts 15% (Curve C) of the Athabasca River flow into Mamawi Lake. To examine the sensitivity of the water levels to the assumed diversion scenario, three additional simulations of the control structure having a 60 m gated width were performed using a diversion of 4.5% (Curve E), 25% (Curve B), and 10% (Curve D) of Athabasca River flow into Mamawi Lake. These simulations were designated as Structures 21, 22, and 23 respectively. The natural channel was also modeled using a diversion relationship of 10% and 4.5% of the Athabasca River flows, and these simulations were designated as Structure 83 and 84 respectively.

All of the alternatives examined were simulated with Bennett Dam and the existing control weirs in place, and the simulation period was extended by two years to run from 1970 to 1984.

The pertinent details of all of the structures modelled in the second phase of simulations are presented in Table 3, and a brief qualitative assessment of the effect of each structure is presented below. The water levels produced by the alternate structures as well as for the natural (with no diversion) and the existing conditions (control weirs in place with no diversion) are presented in Figures 17 to 29 of the report. Similar to the first phase of simulations, the water levels of the Delta lakes are represented by Mamawi Lake only, since the water levels of Lake Claire correspond closely to those produced on Mamawi. The Lake Athabasca water levels are relatively insensitive to the gated width, but are affected by the Creed Creek diversion as can be seen from the results of Structure 83, and the natural and existing conditions.

a) Structures 80, 83 and 84 (natural channel only)

The simulation designated as Structure 80 should be considered to be the existing conditions in the event of the Creed Creek diversion continuing to degrade until it diverts 15% of the flow of the Athabasca River into Mamawi Lake, since Structure 80 is the natural outlet channel without any control structure on it. The simulation designated Structures 83 and 84 are identical to 80, except that only 10% and 4.5% of the Athabasca River flows were diverted through Creed Creek to Mamawi Lake. The diversion produced peak and minimum water levels considerably in excess of the natural (with no diversion) and the existing (weirs in place with no diversion) water levels on both Mamawi Lake and Lake Claire, while the receding water levels were considerably delayed from those of the existing conditions. The overall increase in water levels of about 0.5 m for Structure 80, 0.3 m for Structure 83, and 0.15 m for Structure 84 appears to be entirely attributable to the diversion discharge. As shown in Figure 28, the overall water level increases appear to be roughly proportional to the rate of diversion. The extreme sensitivity of the Delta lake water levels to the diversion through Creed Creek was subsequently confirmed by the results of the simulations designated as Structures 20, 21, 22, and 23.

b) Structures 20, 21, 22, and 23

To evaluate the sensitivity of the Delta lake water levels to the rate of diversion through Creed Creek, a structure with a fully open 60 m gated width was simulated using four Creed Creek diversion scenarios designated Structure 20, 21, 22, and 23. Structure 20 used the diversion relationship represented by Curve C, which constantly diverted 15% of the Athabasca River into Mamawi, Structure 21 diverted 4.5% (Curve E), Structure 22 diverted 25% (Curve B), and Structure 23 diverted 10% (Curve D) of the Athabasca River flows into Mamawi. A comparison of the results of the four simulations (see Figure 19) reveals that the overall Delta lake water levels are greatly affected by the rate of diversion through Creed Creek, and the water level increases appear to be almost directly proportional to the assumed rate of diversion.

It should be noted that since the increase in water levels appears to be roughly proportional to the rate of diversion down Creed Creek, and since the existing conditions are defined as having no diversion down Creed Creek, then it is unlikely that any simulation of a control structure which incorporates a diversion through Creed Creek would produce water levels which correspond to the defined existing conditions. This implies that no structure modelled during the first phase of simulations would have been able to match the existing minimum and receding water levels, as required by the criteria of acceptability, since all of the simulations of the control structures included a diversion down Creed Creek equivalent to about 2.25% of the Athabasca River flow, while the defined existing conditions do not include any diversion.

When the water levels of the Delta lakes resulting from a control structure with a 60 m gated width are compared to those produced by the natural channel and the existing weirs for the diversion rates of 4.5%, 10% and 15% (see Figures 20 and 29), the maximum, minimum, and receding water levels for the control structure are virtually indistinguishable from those of the natural channel alone, thus indicating that the 60 m gated width is sufficient to prevent any significant deviation from the "existing" water conditions when the existing conditions are redefined to include the Creed Creek diversion, which was the stated criteria of hydraulic acceptability of a suitable structure. It should be noted that existing conditions with some Creed Creek diversion are considerably different than existing conditions with no Creed Creed diversion, as was stated previously.

Additional simulations would be required to rigorously determine the optimal gated width of a suitable control structure, but based on our analysis of the limited number of simulations completed to date, a gated width of 60 m appears to be sufficient to satisfy the defined criteria of hydraulic acceptability. This criteria requires that the structure be capable of producing minimum and receding water levels which do not significantly deviate from those produced by the existing control weirs alone, while being able to restore the natural peak water levels to the the Delta Lakes through judicious gate operation.

It should be noted that there appears to be an anomaly in the water levels on Mamawi Lake produced by Structure 21 in the years 1982, 1983, and 1984. During these years the minimum water levels produced are considerabley (+1.0 m) below either the natural or existing water levels and do not appear to be realistic. This decrease in water levels would require further investigation to provide an explanation.

c) Structures 10, 30, 40, and 50

All of these structures produced peak and minimum water levels considerably in excess of the natural and existing water levels, but as previously discussed, this is apparently entirely due to the Creed Creek diversion rate of 15% used for the simulation of these structures. Structure 10 with its fully open 48 m gated width produced receding water levels which significantly lagged behind those of Structure 80 which, as has been previously stated, can be considered as representative of the "existing" conditions should the Creed Creek channel grow to divert 15% of the Athabasca River into Mamawi Lake. Given that the 48 m gated width was inadequate if the diversion rate grows to 15%, and a 40 m gated width was inadequate for a diversion rate of 2.25%, it appears that the adequacy of gated width is relatively insensitive to the diversion rate used since for both diversion rates, a 60 m gated width appears to be capable of matching the minimum and receding water levels produced by the existing control structures alone.

Structures 30, 40, and 50 have sufficient gated width to produce Delta lakes water levels virtually indistinguishable from each other or that of Structure 80.

d) Structures 60 and 70

The simulations designated Structures 60 and 70 included a crude operating policy which eliminated outflow from Mamawi Lake for the month of May in 1972 and 1981 only, which are the two years having the greatest difference between the existing and natural peak levels. The closure period of only one month was used to increase the existing peak levels up to that of the natural levels without significantly overachieving the natural peak levels.

The Delta lake water levels produced by Structure 60 are virtually indistinguishable from those of Structure 70, and both are generally indistinguishable from that of Structure 80 except during the two years of gated operation. During the years of 1972 and 1981, the operating policy increases the peak levels produced but has little impact upon the minimum or receding water levels following the peak level, which indicates that judicious gate operation can increase peak levels without inducing a significant delay or increase in the water levels which follow the attainment of the desired peak water level.

A note of caution should be applied to the interpretation of the results of the second phase of model simulations discussed above, as it is possible that the large increases in water levels observed in the simulations of the Delta lakes may decrease the elevation difference between the diversion channel inlet on the Embarras River and its outlet on Mamawi Lake, which may decrease the discharge of Creed Creek. The degree to which this backwater effect from the Delta lakes may reduce the diversion discharges cannot readily be determined from the model simulations completed to date since all of the simulations use either a fixed percentage of the Athabasca River flow (Structures 10 to 84) or a regression relationship (Structures 1 to 9) which determines the flow diverted from the Athabasca River on the basis of the magnitude of the Athabasca River flow, rather than using the hydraulic properties of Creed Creek. The hydrodynamic model could be modified to include the actual hydraulic properties of the diversion channel at some future date, should the Implementation Committee wish to determine the significance of this backwater effect on the simulation results.

3.6 Selection of a Suitable Gated Width

Based on the results of the second phase of simulations it is apparent that if the Creed Creek channel continues to grow, then at some level of diversion the natural outlet channel itself would appear to have insufficient discharge capacity to prevent excessive water levels from developing on the Delta lakes. Further simulations would be required to define this threshold diversion value but, based on the results of this study, it appears to lie between 4.5% and 10% of the Athabasca River flow. At a diversion rate greater than this value, any control structure on the outlet channel would be useless since the water levels produced by the existing wiers acting concurrently with the increased diversion are considerably greater than under the defined "natural" conditions. Should the diversion achieve a stable discharge capacity approximating that observed in the period 1982, 1983, and 1984 through either natural or artificial means, then a control structure having a gated width of about 60 m appears to be capable of controlling the water levels of the Delta lakes to more closely correspond to those experienced prior to construction of Bennett Dam.

3.7 Documentation of the Simulations

The simulation results are recorded on several magnetic tapes currently stored at the Regina office of the Water Management and Planning Branch of Environment Canada in the care of Mr. Mike Kowalchuk. Graphical and tabular outputs can be obtained from these tapes should it become necessary to further examine the results of the simulations.

4.0 THE PROPOSED CONTROL STRUCTURE

If the Creed Creek diversion channel achieves a stable discharge capacity approximating that observed in the period 1982, 1983, and 1984 through either natural or artificial means, then a control structure with a gated width of 60 m appears to be capable of fully restoring the natural peak levels without significantly affecting the existing minimum and receding water levels.

4.1 Design and Layout of the Sturcture

The layout and design of the proposed control structure are illustrated in Figure 4, and are described below:

4.1-1 Gated Control Section

The gated portion of the proposed control structure is divided into 10 bays with a total clear width of 60 m. Each bay contains a 6 m wide by 4.3 m high radial gate operated by a powered hoist. The gated portion of the structure consists of a concrete base slab and piers which are founded on the bedrock outcrop island located just north of the centre of the Quatre Fourches Channel at Dog Camp. A rounded wing-wall at each abutment adjoining the rock fill dam would reduce hydraulic losses through the structure and thus maximize the discharge capacity. The gates would be designed to withstand water pressures in both directions.

For ease of operation and to facilitate remote telemetric control, the gate hoists would be electrically powered by an on site generator driven by either a propane-powered gas engine or a diesel equipped with a fuel heater to facilitate cold weather operation should it be required. It is expected that the gates would be raised above water level prior to freeze up. The power plant and the gate controls would be located in a service building on the north abutment.

The gate hoists and all mechanical components would be located on the top of the piers at an elevation of 212.1 m, or 1.0 m above the maximum peak water level on Mamawi Lake of 211.1 m as determined from the simulated natural conditions for the period 1960 to 1984. The simulated value was used since there is little available historical data for peak water levels on Mamawi Lake. The service building would also be located above this elevation on the north abutment.

The hydraulics of the gated section are very similar to that of a broad-crested weir since the Quatre Fourches Channel substantially deepens upstream and downstream of the bedrock outcrop island. This results in a hydraulically efficient structure that maximizes the discharge capacity for the gated width.

No energy dissipation measures such as a stilling basin or baffle blocks would be required to protect the channel bed against scour from excessive exit velocities, since the gated section is seated on the rock outcrop and the natural channel deepens considerably on either side of the structure providing natural stilling pools.

The gated section would be located on the north side of the bedrock island so as to take advantage of a natural rock ledge which reduces the amount of rock excavation required for placing the concrete base slab and piers. Based on the visible portion of the island, the bedrock appears to offer a very good foundation for the control works. Adversely oriented bedding planes in the bedrock could be strengthened with conventional foundation treatment such as rockbolts or grouted anchors should such planes be encountered during excavation for the base slab.

A suitable source of fine aggregate was not located in the immediate vicinity of the site. Coarse aggregate could be obtained by processing the rock quarry wastes. Alternatively, suitable coarse and fine aggregate could be supplied from the provincial stockpile in Fort Chipewyan. The cement would be delivered to the site either on winter ice roads or by barges in the summer. Concrete would probably be batch mixed on site.

The excavation of the rock island and the placement of the concrete for the control structure can readily be performed only after dewatering, which requires the construction of a cofferdam around the work area.

4.1-2 Cofferdam for the Gated Section

A cofferdam of rock fill and local silt would be required prior to excavation of the rock from the island. This cofferdam could be constructed by end dumping rockfill supplied from the rock outcrop located north of the channel, working from the north bank across and then around the required work area. The cofferdam would serve as an access road to the rock island work area and portions of the cofferdam would later be incorporated into the main embankment of the rockfill overflow weir.

It is not planned to provide a high load capacity bridge over the control section because of the high costs associated with its construction and the inaccessibility of the site. Because of this, the construction sequence would require completion of the rock embankment on the south side prior to the removal of the cofferdam from the flow path of the control structure, since the cofferdam itself will provide access for the heavy construction equipment required. For such a sequence to be feasible, the removal of the cofferdam from the flow path of the control structure must occur quite soon after final river closure to prevent excessive water levels on Mamawi Lake, and possible overtopping of the cofferdam.

4.1-3 The Rockfill Dam

The rockfill portion of the control structure extends from both sides of the gated section to the banks of the channel, and will incorporate portions of the cofferdam constructed to dewater the gated control work area. The dam portion was designed to withstand flow overtopping during extreme flood events on the Delta lakes, and has a crest elevation of 210.3 m. The dam would be constructed of rock fill obtained by blasting at either of the bedrock outcrops adjacent to the channel at the dam axis, and from the rock excavated from the island. The rock appears to be relatively hard and durable but is moderately to highly fractured with an average joint spacing of 0.3 m to 0.6 m. Trial blasting would be required to verify that the large sizes required to insure stability of the rockfill during overflow flood stages are available.

Three factors favour use of the north bedrock outcrop for the majority of the fill: it was the source of rockfill for the 1971-1975 Quatres Fourches Dam, and as such has a developed quarry face; the lack of stripping and clearing required to expose the bedrock; and the apparent good condition of the original haul road. However, the ability of the north quarry to produce rock of sufficient size for armouring the overflow section is questionable. The size of rock that could be produced from a quarry on the south side of the river is unknown. Significant stripping and clearing would be required to develop a quarry at the southern bedrock outcrop. Both sources should be subjected to test blasting programs prior to final design.

The dam would be constructed by end dumping the rock fill and progressing across the channel width, in a manner similiar to that of the cofferdam. Since the 1971-1975 Quatre Fourches Dam was of roughly the same height and much of its rock fill still remains on the channel floor, the underlying silt is unlikely to experience the same magnitude of settlement during construction of the proposed structure as was observed during construction of the original dam.

As the north bank of the river is comprised of consolidated silt, riprap protection both upstream and downstream of the rockfill overflow section will be required to prevent the development of a washout cutoff channel at this abutment.

4.1-4 Boat and Fish Passage around the Structure

Although it is realized that both the boat passage and the fishway are extremely important components of the structure, little time was spent on the details associated with their incorporation into the structure since changes in their design details would not significantly affect the total project cost. The boat passage would consist of a motorized rail and cart tramway system located on the north abutment of the river. The fishway would be of reinforced concrete construction, with location and size to be determined later in consultation with experts associated with the design and operation of such structures.

4.2 Estimated Cost of the Structure

4.2-1 Capital Costs

The unit costs for the components of the proposed structure were derived by examination of the costs from construction of previous control structures in the region, as well as construction of recent works of similiar nature. The remoteness of the site and the difficulty of access have been reflected in the unit costs selected, however it must be emphasized that because of the uncertainties inherent to the bidding process, these costs can only be regarded as preliminary order of magnitude costs.

Construction material quantities were developed from three channel cross-sections supplied to PFRA by Alberta Environment, one taken on the dam axis and one each upstream and downstream of the dam axis. These cross-sections indicate that in the region of the island, the two arms of the channel undergo considerable change which makes estimates of both rock excavation and fill quantities of limited accuracy.

The uncertainties inherent in the unit costs and quantity estimates, as presented in Table 4, are reflected by the large contingency and engineering costs included in the capital cost estimate of $7 000 000 (1986 dollars).

4.2-2 Operating and Maintenance Costs

Annual operating and maintenance costs for a structure of this nature have been generally found to be in the order of 0.75% of the capital cost of the structure, or about $60 000 per year. The cost of either a local operator or the facilities for remote operation would be in a addition to this cost, but this cost is expected to be quite small and should be less than $10 000 per year.

5.0 CONCLUSIONS

5.1 Creed Creek Diversion

Based on the second phase of simulation results (i.e. Structures 10 to 84), the water levels on the Delta lakes appear to be quite sensitive to the diversion flows in Creed Creek. If the diversion channel continues to increase in discharge capacity, as it presently appears to be doing, then a control structure on the Quatre Fourches Channel would not restore the hydrologic regime of the Delta lakes to that of natural conditions. Any control structure which further reduces or delays the outflow would only increase the deviation of the hydrologic regime of the Delta lakes from that experienced prior to the impoundment of Bennett Dam. It should be noted that the development of this diversion channel and its resulting impact on the Delta lakes could be viewed as a natural process which is changing what is presently thought of as the natural hydrologic regime.

At low Creed Creek diversion flows similiar to those experienced in the period 1982 to 1984, a structure on the Quatre Fourches would provide some desirable increase in the water levels of the Delta lakes; however, as the capacity of the Creed Creek diversion expands and flows through the diversion increase, the benefits of a control structure on the Quatre Fourches would decrease until, at some point, the structure becomes a restriction to the recession of the high water levels in the Delta lakes.

5.2 Quatre Fourches Control Structure

In the event the Creed Creek diversion channel achieves a stable discharge capacity approximating that observed in the period 1982, 1983, and 1984 through either natural or artificial means, then a gated control on the outlet of Mamawi Lake would help the Delta lake water levels to more closely correspond to those experienced prior to construction of Bennett Dam. While additional simulations would be required to rigorously determine the optimal gated width of a satisfactory control structure, the results of the simulations to date indicate that a control structure with 60 m of gated width appears to be capable of restoring the natural peak water levels without significantly increasing the minimum water levels nor delaying the receding water levels beyond those of the existing conditions. This structure has an estimated order of magnitude capital cost of $7 000 000, with an annual operating and maintenance cost expected to be about $70 000.

5.3 Operating Policy

The true effectiveness of any control structure on the outlet channel of Mamawi Lake will be greatly determined by the manner in which the gates are operated. Achieving the desired water levels of natural peak and existing minimum and receding water levels would be extremely difficult since the operation of the gates would require some method of predicting these target levels. The present hydrodynamic model is capable of simulating the hydrologic system and can examine the effects of variations in the system using the historic flow information input into the model, but it is not capable of predicting future conditions. Such a model for predicting future conditions is a prerequisite for successful operation of a control structure, since the ever-changing hydrologic conditions of the Delta require a dynamic operating policy to successfully re-establish the natural water levels to the Delta lakes.

It must be noted that it is entirely possible that an operating policy could evolve to favour a single purpose, such as only reflooding perched basins, or a policy could be devised to mitigate the consequences of an event which has certain adverse impacts.

6.0 RECOMMENDATION

Prior to any decision to proceed further with a control structure on the Quatre Fourches, the long term effects of the Creed Creek diversion will have to be assessed and some policy for control or non-control of its development will have to be made and implemented . The success of any control structure requiring operator intervention to restore "natural" water levels to the Delta will require development of a predictive model for determining future water levels so that controls can be operated in an attempt to achieve those levels. Because of difficulties that can be foreseen in the development of such a model it is suggested that if the control structure concept is to be carried further, the model should be developed first and tested to insure that it operates to the satisfaction of the Committee.

TABLE 1

1980-1984 DELTA LAKES WATER LEVELS

LAKE	REGIME	PERIOD	WATER SURFACE ELEVATIONS (metres)					
			MAXIMUM		MEAN ANNUAL		MINIMUM	
			$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
ATHABASCA	NATURAL	1960-1984	209.75	.67	208.67	.44	207.90	.30
	NATURAL	1980-1984	208.88	.37	207.89	.33	207.45	.18
	EXISTING	1960-1984	209.72	.48	209.06	.33	208.08	.25
	EXISTING	1980-1984	209.03	.23	208.51	.11	208.08	.13
MAMAWI	NATURAL	1960-1984	209.94	.56	209.08	.31	208.41	.20
	NATURAL	1980-1984	209.30	.39	209.65	.12	208.19	.10
	EXISTING	1960-1984	209.81	.52	209.19	.28	208.70	.10
	EXISTING	1980-1984	209.16	.27	208.78	.12	208.56	.07
CLAIRE	NATURAL	1960-1984	210.0	.55	209.17	.29	208.62	.11
	NATURAL	1980-1984	209.35	.32	208.80	.12	208.73	.06
	EXISTING	1960-1984	209.82	.52	209.22	.29	208.73	.12
	EXISTING	1980-1984	209.20	.27	208.82	.13	208.58	.07

NOTES:

1. All values based on simulations of natural (ie pre-Bennett) and existing conditions, with no diversion flow through Creed Creek.
2. $\bar{X}$ = mean, S = standard deviation

TABLE 2

PERTINENT DATA FOR FIRST PHASE OF SIMULATIONS

STRUCTURE DESIGNATION	OPERATION PERIOD	ROCK DAM		GATED PORTION		
		WIDTH m	CREST ELEV m	WIDTH	GATE OPERATION	INVERT ELEV m
1	Jan 1-Dec 31	145	210.3	40	OPEN	206.0
2	Aug 1-Apr 30	145	210.3	40	OPEN	206.0
	May 1-Jul 31	185	210.3	40	CLOSED	206.0
3	Aug 1-Apr 30	145	210.6	40	OPEN	206.0
	May 1-Jul 31	185	210.6	40	CLOSED	206.0
4	Sep 1-Apr 30	145	210.3	40	OPEN	206.0
	May 1-Aug 31	185	210.3	40	CLOSED	206.0
5	Aug 1-Apr 30	173	210.3	12	OPEN	206.0
	May 1-Jul 31	185	210.3	12	CLOSED	206.0
6	Aug 1-Apr 30	161	210.3	24	OPEN	206.0
	May 1-Jul 31	185	210.3	24	CLOSED	206.0
7	Aug 1-Apr 30	125	210.3	60	OPEN	206.0
	May 1-Jul 31	185	210.3	60	CLOSED	206.0
8	Aug 1-Apr 30	125	210.3	60	OPEN	206.5
	May 1-Jul 31	185	210.3	60	CLOSED	206.5
9	Jul 1-Apr 30	173	210.3	12	OPEN	206.0
	May 1-Jun 30	185	210.3	12	CLOSED	206.0

NOTES:

1. For all cases the gated portion (ie. the conduit for the Breach routine) had a length of 35 m, a slope of 0.0%, and a top elevation of 211.5 m.
2. Rock Dam width varies with gate closure to prevent the gated width from being included in the calculation of both the weir overflow discharge and the gated width discharge when the gates are fully open. (a requirement for correct use of the Breach Routine)
3. Gate closure prevents only flow from Mamawi Lake to Lake Athabasca, still allows reverse flow.
4. For all cases Creed Creek diverted about 2.25% of the Athabasca River flow into Mamawi Lake, as determined from a regression relationship derived from the 1982, 1983, 1984 measured flows.

TABLE 3

PERTINENT DATA FOR SECOND PHASE OF SIMULATIONS

STRUCTURE DESIGNATION	OPERATION PERIOD	ROCK DAM WIDTH m	GATED PORTION		DIVERSION	
			WIDTH m	GATE OPERATION	CURVE	% of ATHA. R
10	Jan 1-Dec 31	137	48	OPEN	C	15.0
20	Jan 1-Dec 31	125	60	OPEN	C	15.0
21	Jan 1-Dec 31	125	60	OPEN	E	4.5
22	Jan 1-Dec 31	125	60	OPEN	B	25.0
23	Jan 1-Dec 31	125	60	OPEN	D	10.0
30	Jan 1-Dec 31	113	72	OPEN	C	15.0
40	Jan 1-Dec 31	101	84	OPEN	C	15.0
50	Jan 1-Dec 31	83	102	OPEN	C	15.0
60	Jan 1-Apr 30	125	60	OPEN	C	15.0
	May 1-May 31 (1972, 1981 only)	185	60	CLOSED	C	15.0
	May 1-May 31 (Except 1972, 1981)	185	60	OPEN	C	15.0
	June 1-Dec 31	125	60	OPEN	C	15.0
70	Jan 1-Apr 30	113	72	OPEN	C	15.0
	May 1-May 31 (1972, 1981 only)	185	72	CLOSED	C	15.0
	May 1-May 31 (Except 1972, 1981)	113	72	OPEN	C	15.0
	June 1-Dec 31	113	72	OPEN	C	15.0
80	NATURAL CHANNEL ONLY				C	15.0
83	NATURAL CHANNEL ONLY				D	10.0
84	NATURAL CHANNEL ONLY				E	4.5

NOTES:

1. For all cases, gated portion had a length of 20 m, a slope of 0.0%, an invert elevation of 206.0, and an obvert elevation of 211.5, while the rock dam had a crest elevation of 210.3 m.

2. Rock Dam width varies with gate closure to prevent the gated width from being included in calculating both the weir overflow discharge and the gated width discharge when the gates are fully open. (a requirement for correct use of the breach routine)

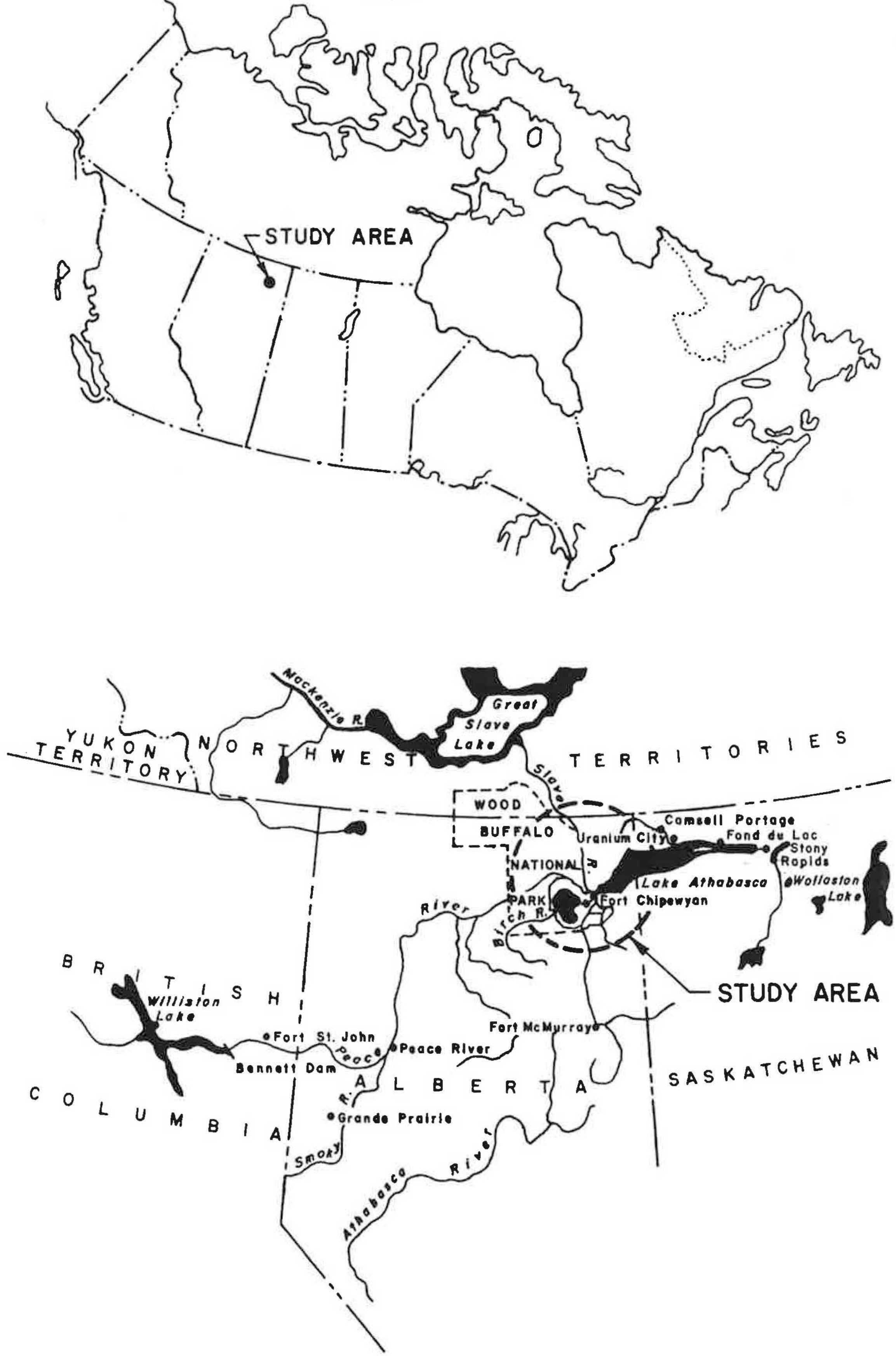
3. Gate closure prevents only flow from Mamawi Lake to Lake Athabasca, still allows reverse flow.

4. Creed Creek diversions based on scenarios represented by Curves A to E, which constantly divert a given proportion of the Athabasca River into Mamawi Lake.

TABLE 4

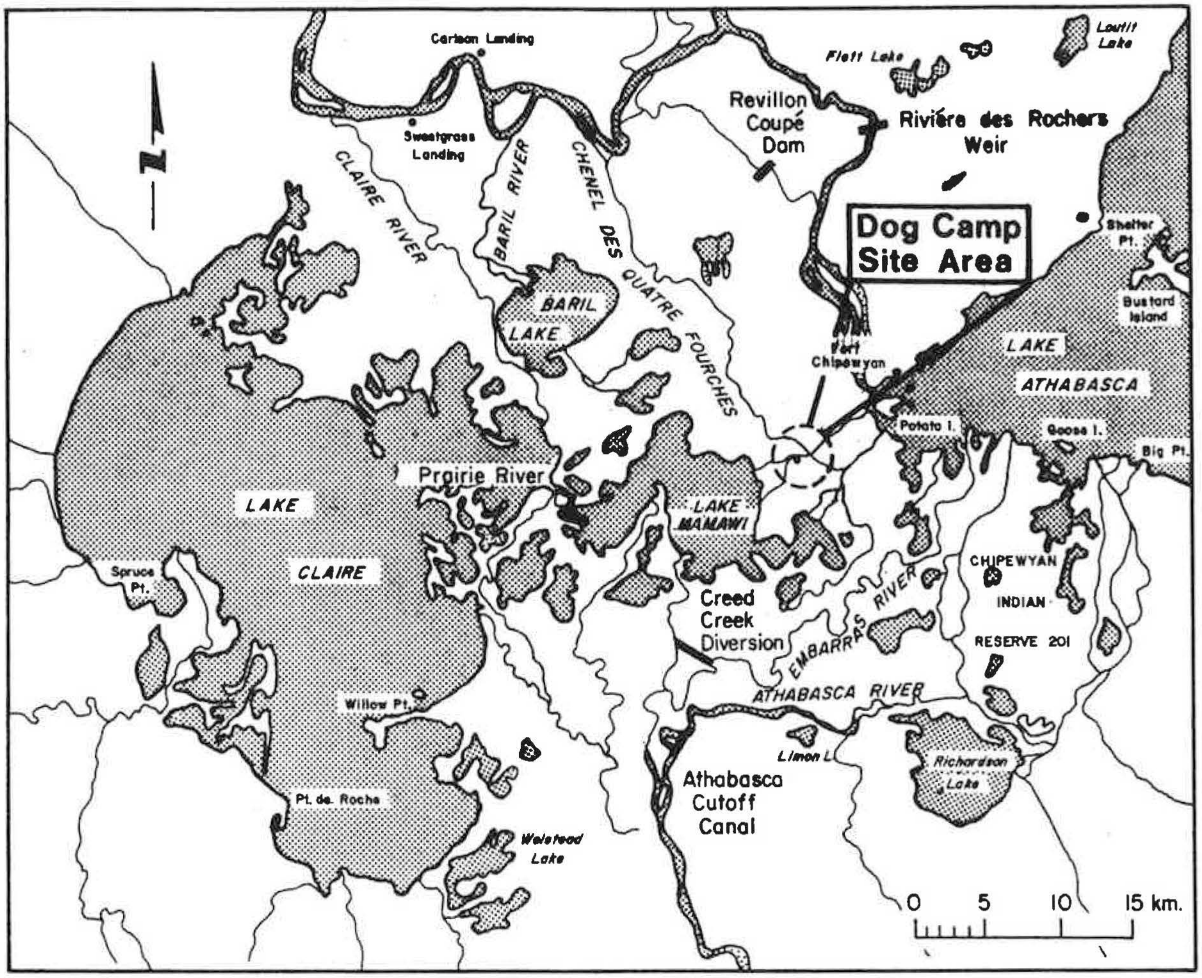
COST ESTIMATE FOR PROPOSED STRUCTURE WITH 60 m GATED WIDTH

ITEM	UNITS	UNIT PRICE $ 1986	QUANTITY	EXTENSION $ 1986
MOBILIZATION	L.S.	300 000.00	1	$ 300 000
CARE OF WATER	L.S.	370 000.00	1	370 000
ROCK EXCAVATION	M^3	75.00	19 500	1 463 000
EMBANKMENT	M^3	30.00	9 300	279 000
CONCRETE	M^3	750.00	950	712 000
GATES AND HOIST	EACH	120 000.00	10	1 200 000
SERVICE BUILDING	L.S.	25 000.00	1	25 000
POWER SUPPLY	L.S.	50 000.00	1	50 000
BOAT TRAMWAY	L.S.	150 000.00	1	150 000
FISH PASSAGE	L.S.	200 000.00	1	200 000
MISCELLANEOUS	L.S.	25 000.00	1	25 000
SUB TOTAL				4 774 000
CONTINGENCIES				1 313 000
ENGINEERING				913 000
TOTAL COST				7 000 000

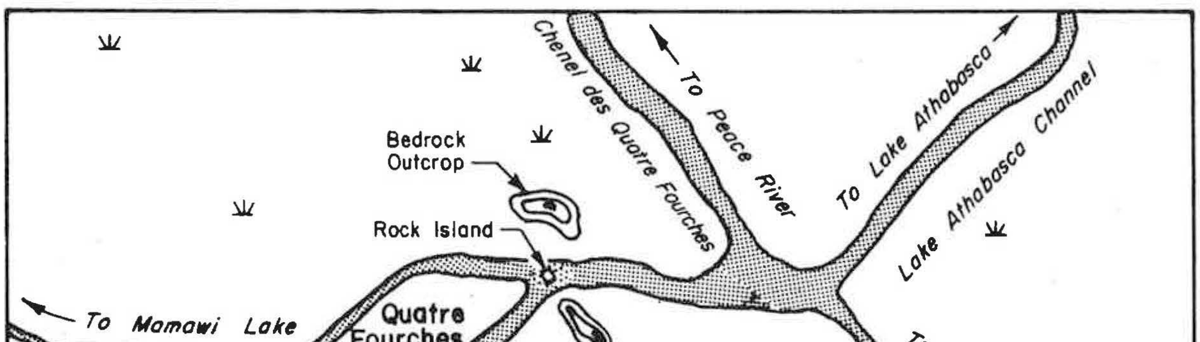


QUATRE FOURCHES CONTROL STRUCTURE STUDY AREA

Figure 1



PEACE - ATHABASCA DELTA



DOG CAMP SITE

Figure 2

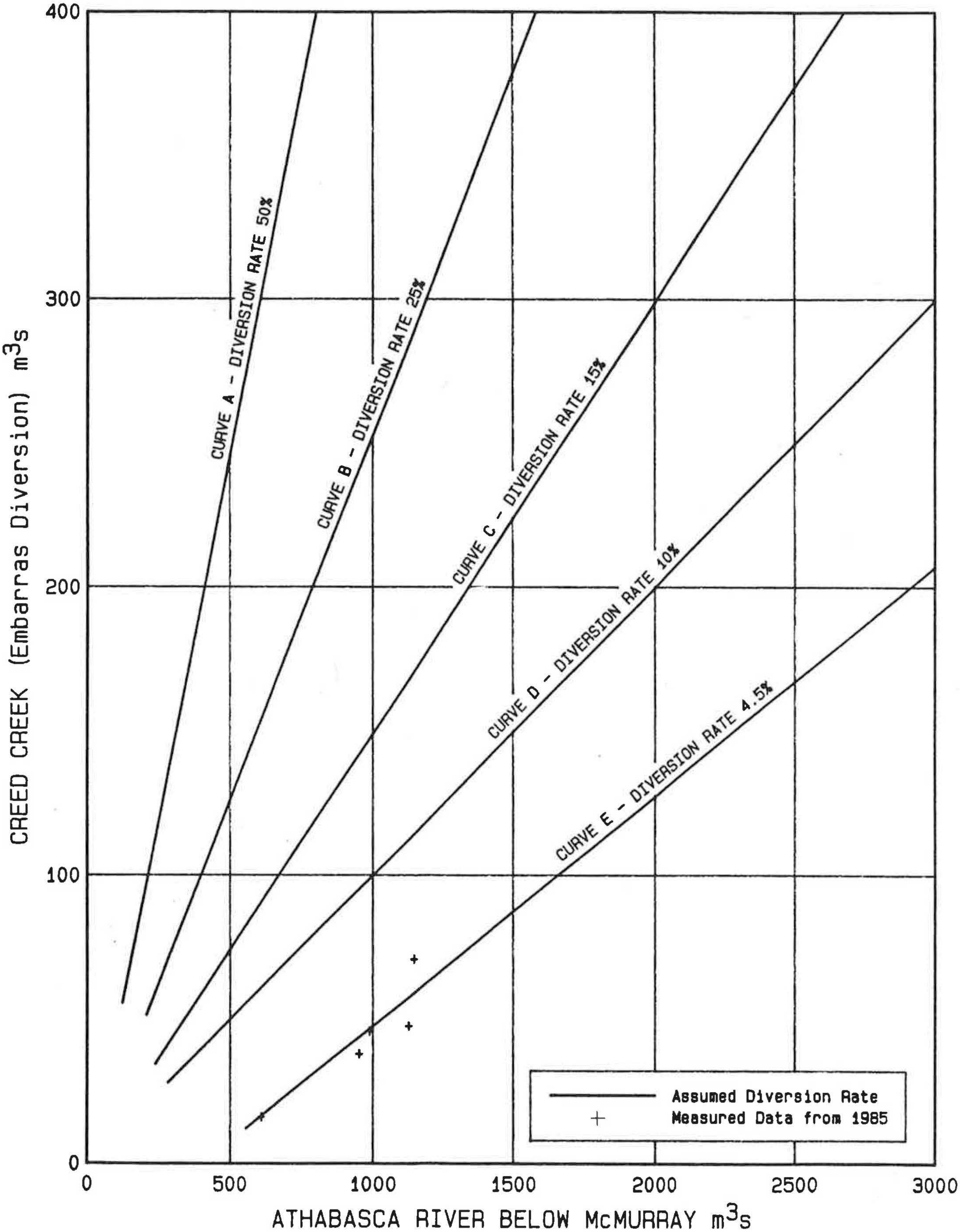
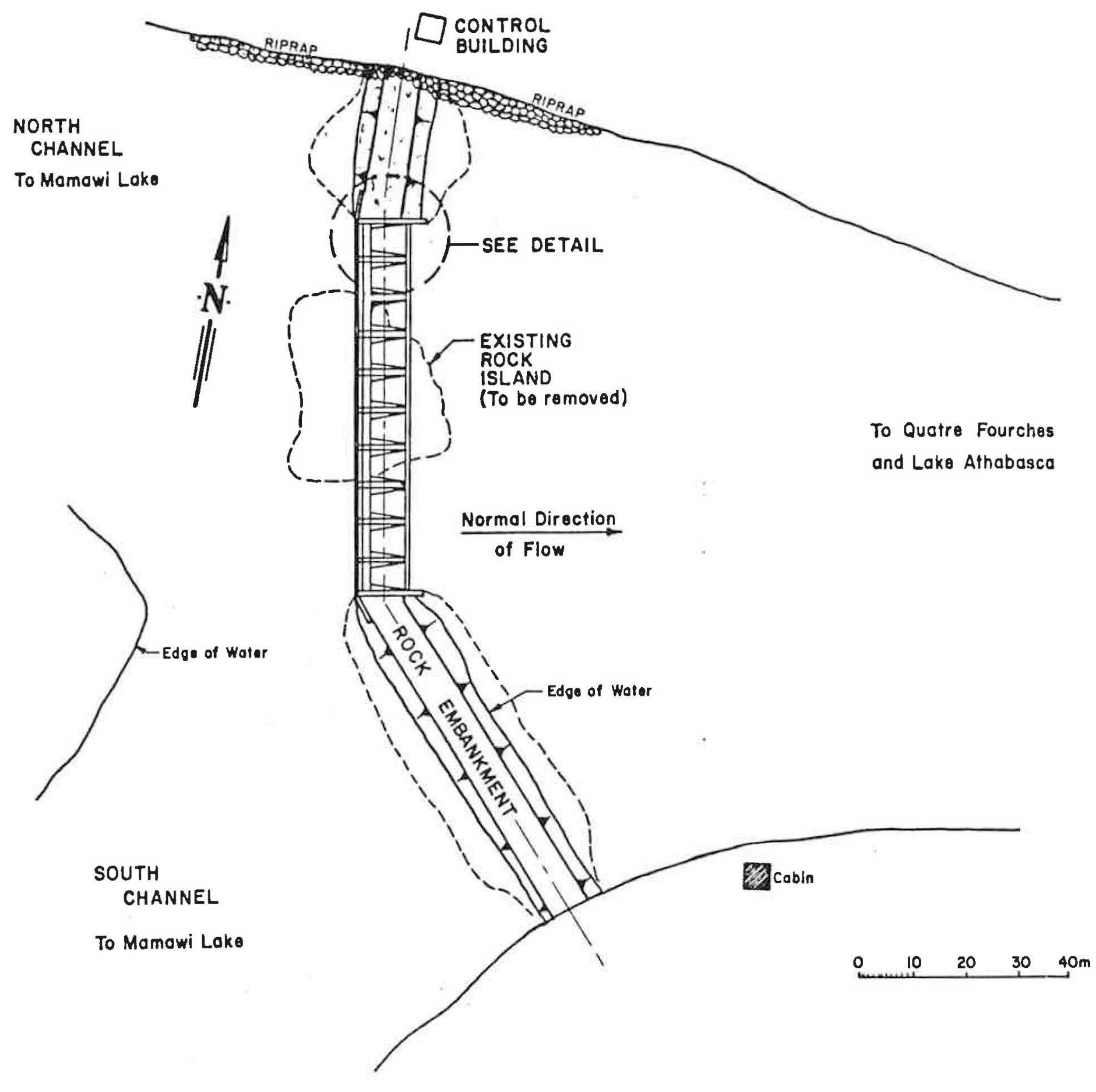
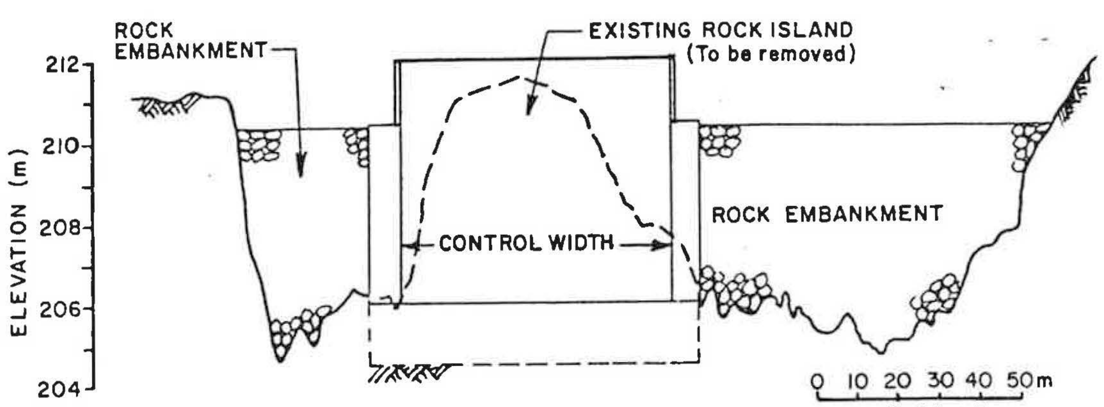


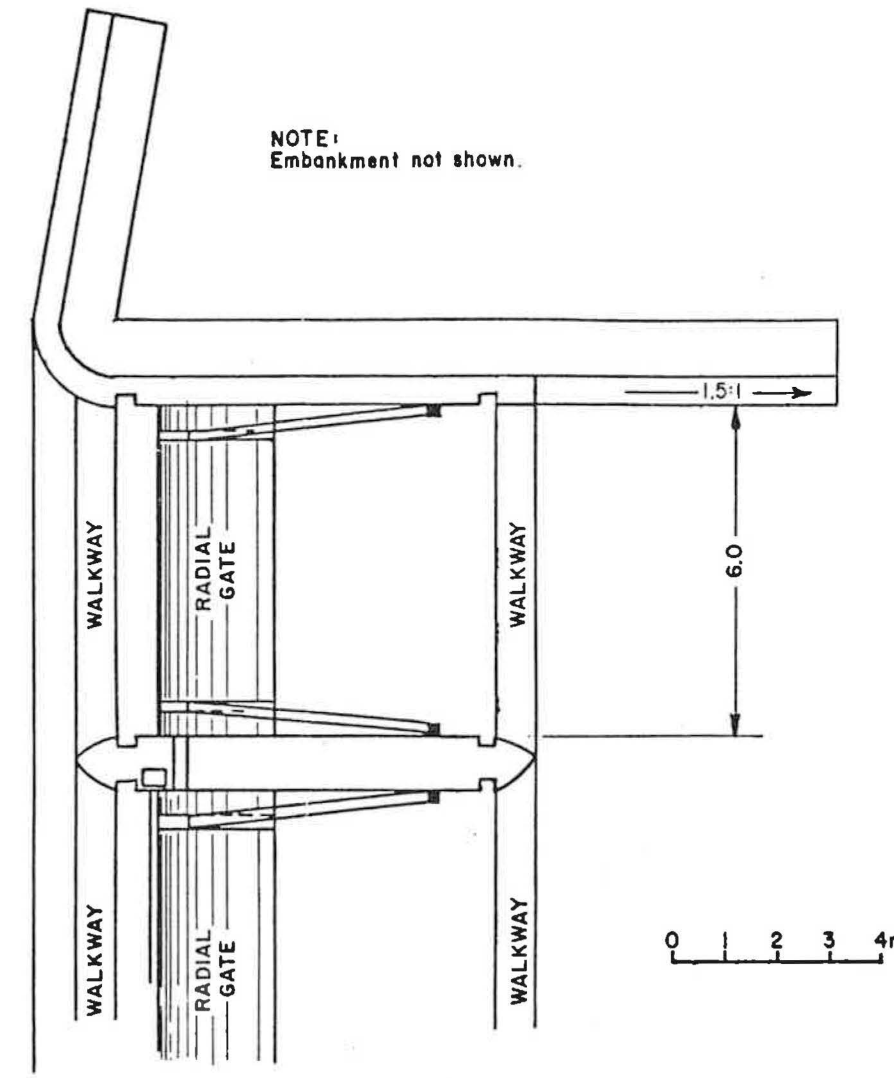
FIGURE 3 - CREED CREEK DIVERSION SCENARIOS



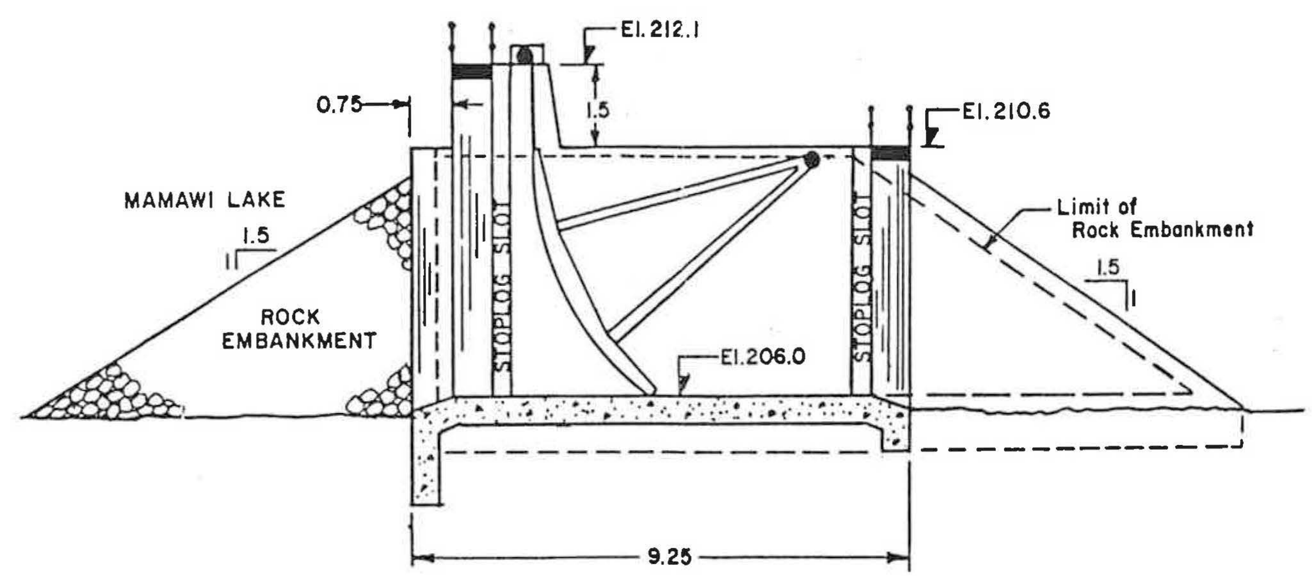
LAYOUT OF QUATRE FOURCHES CONTROL STRUCTURE



℄ PROFILE



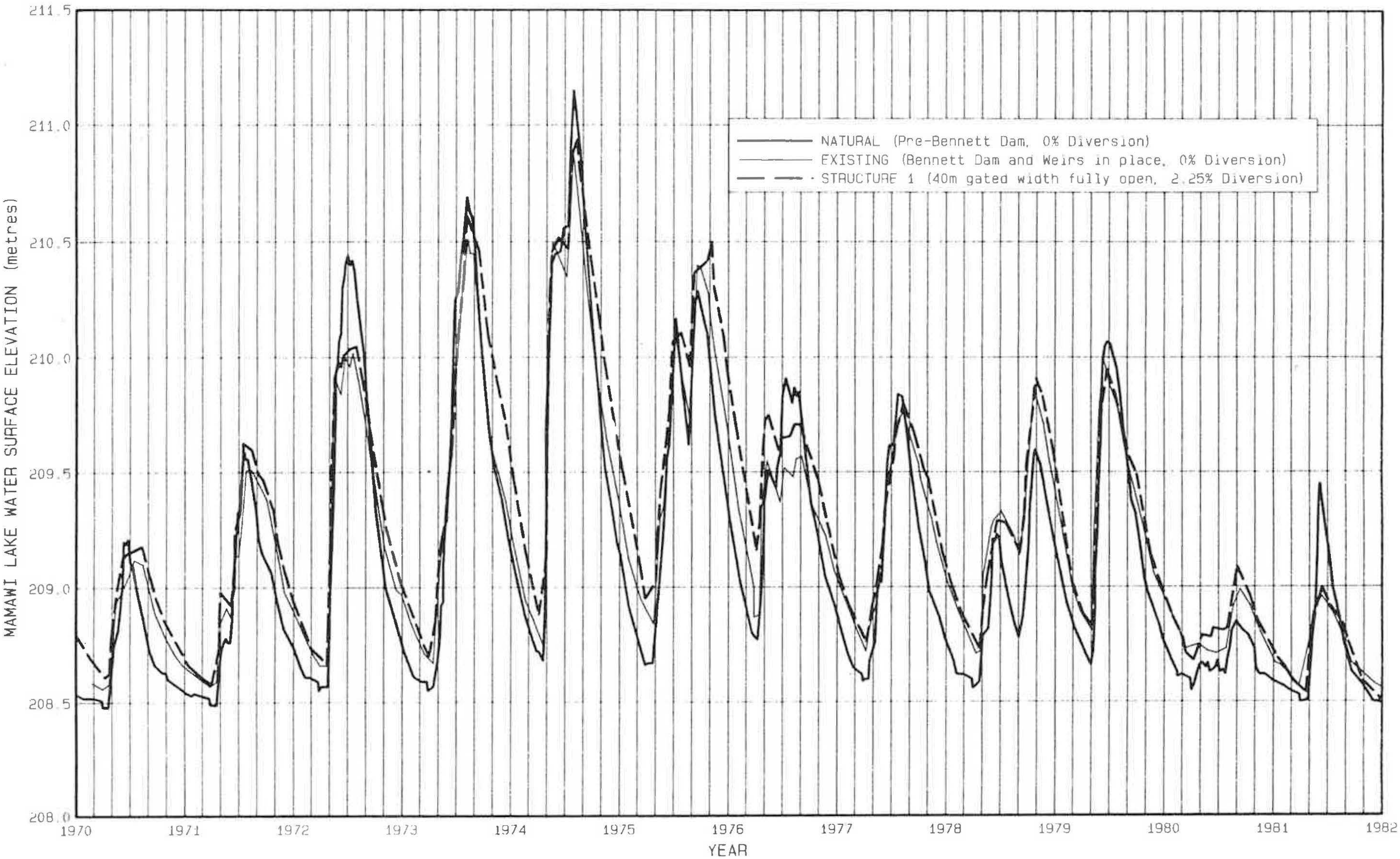
PLAN OF NORTH ABUTMENT



SECTION

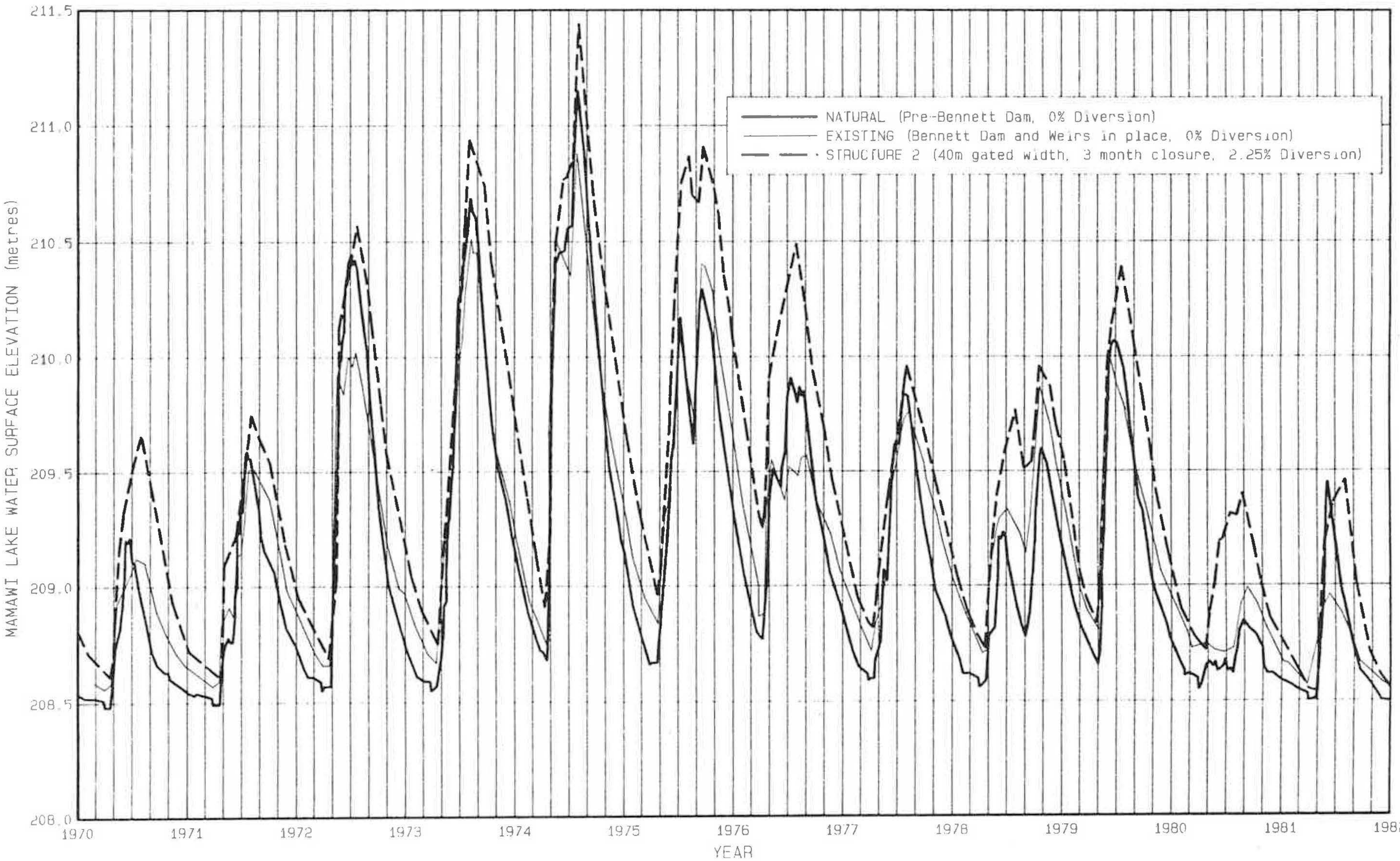
DETAILS OF GATED CONTROL STRUCTURE

FIGURE 4



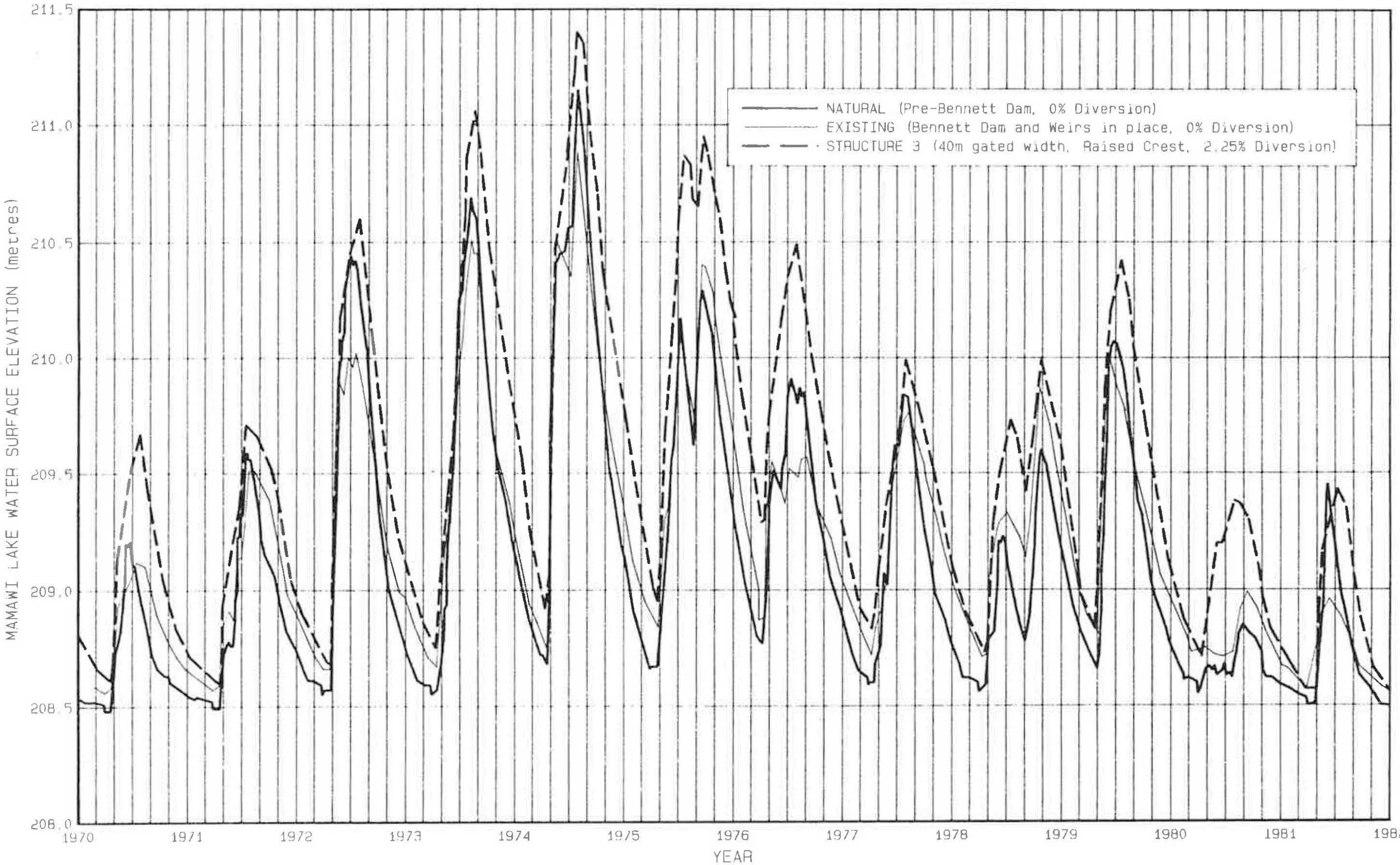
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 5



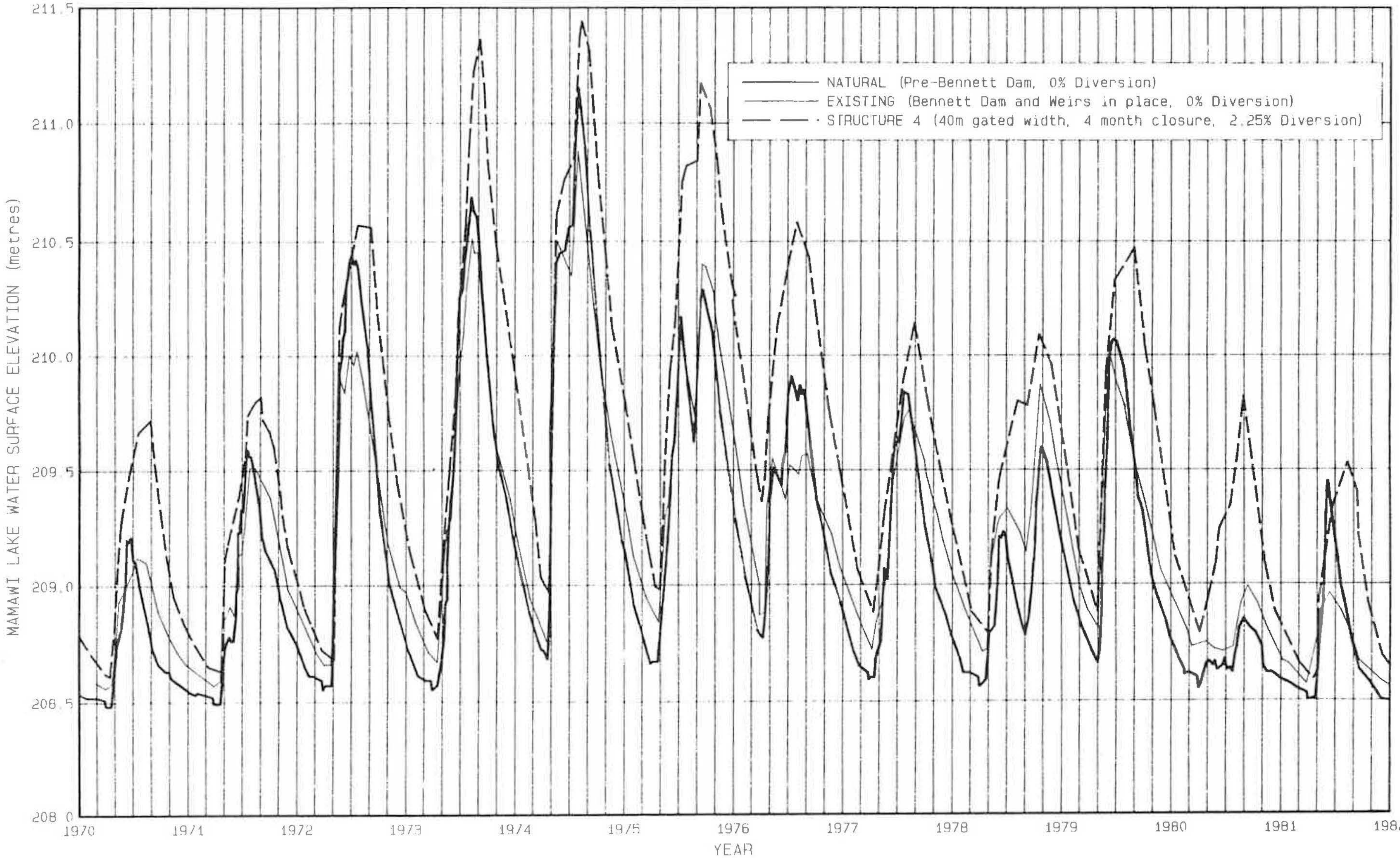
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 6



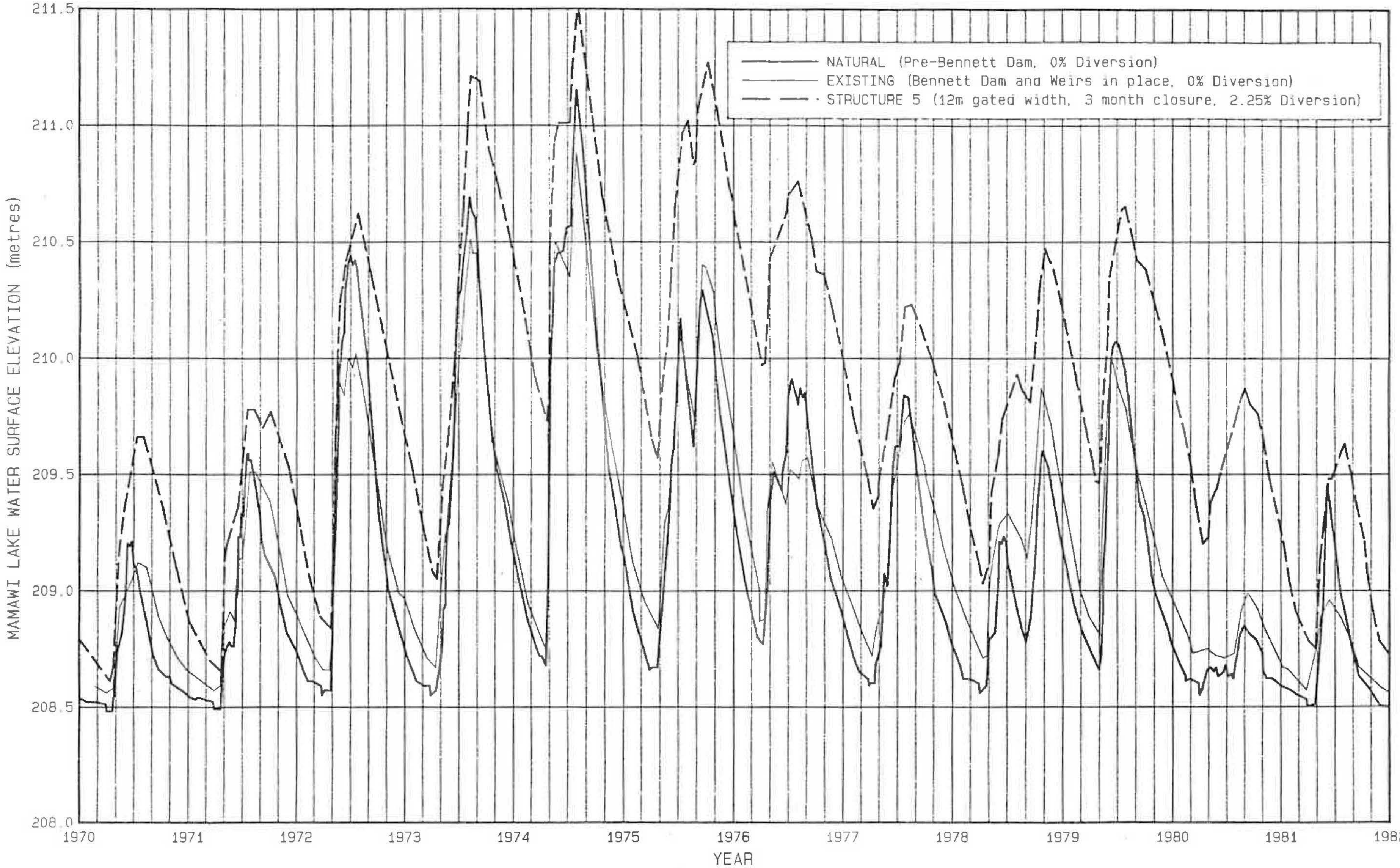
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 7



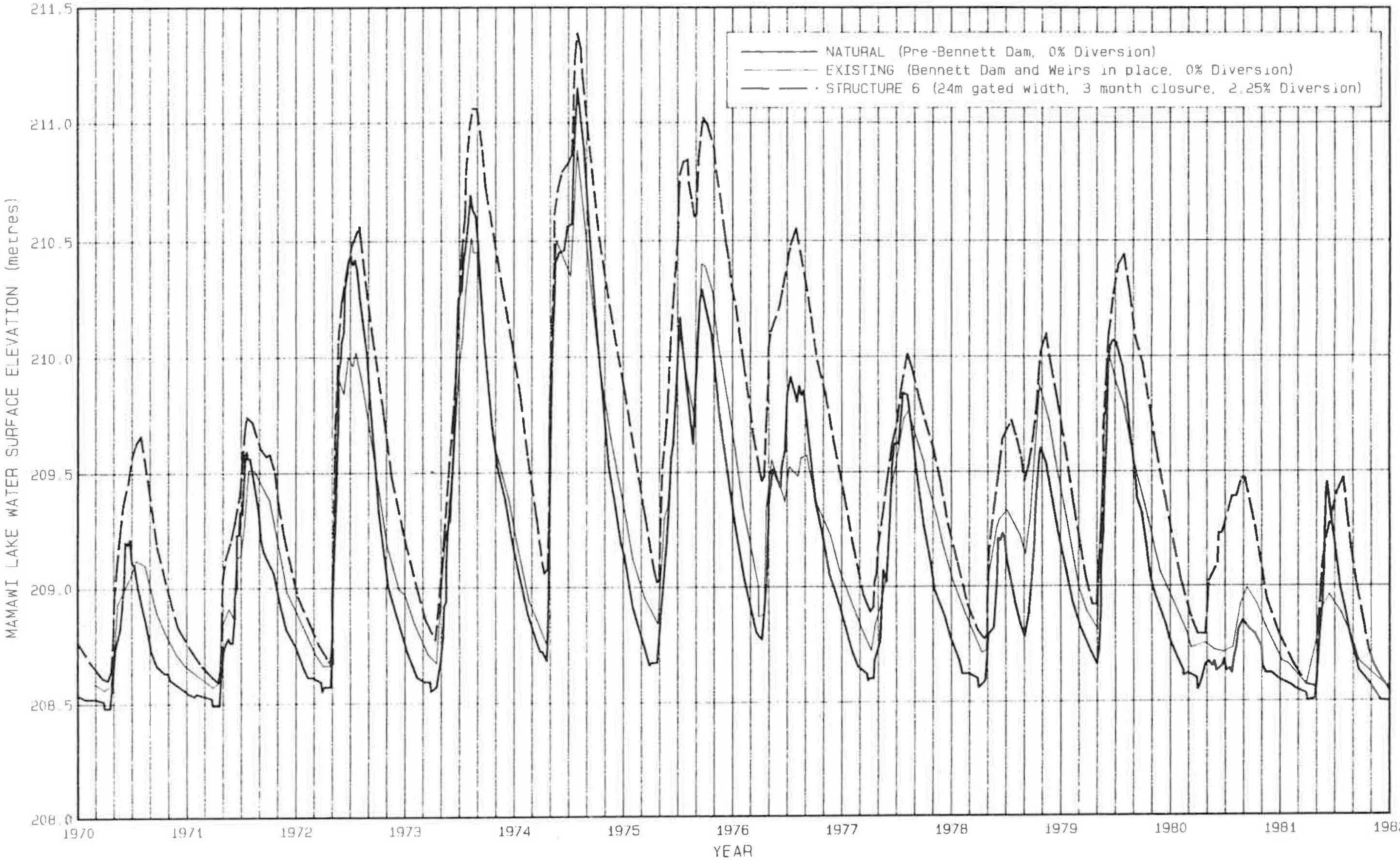
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 8



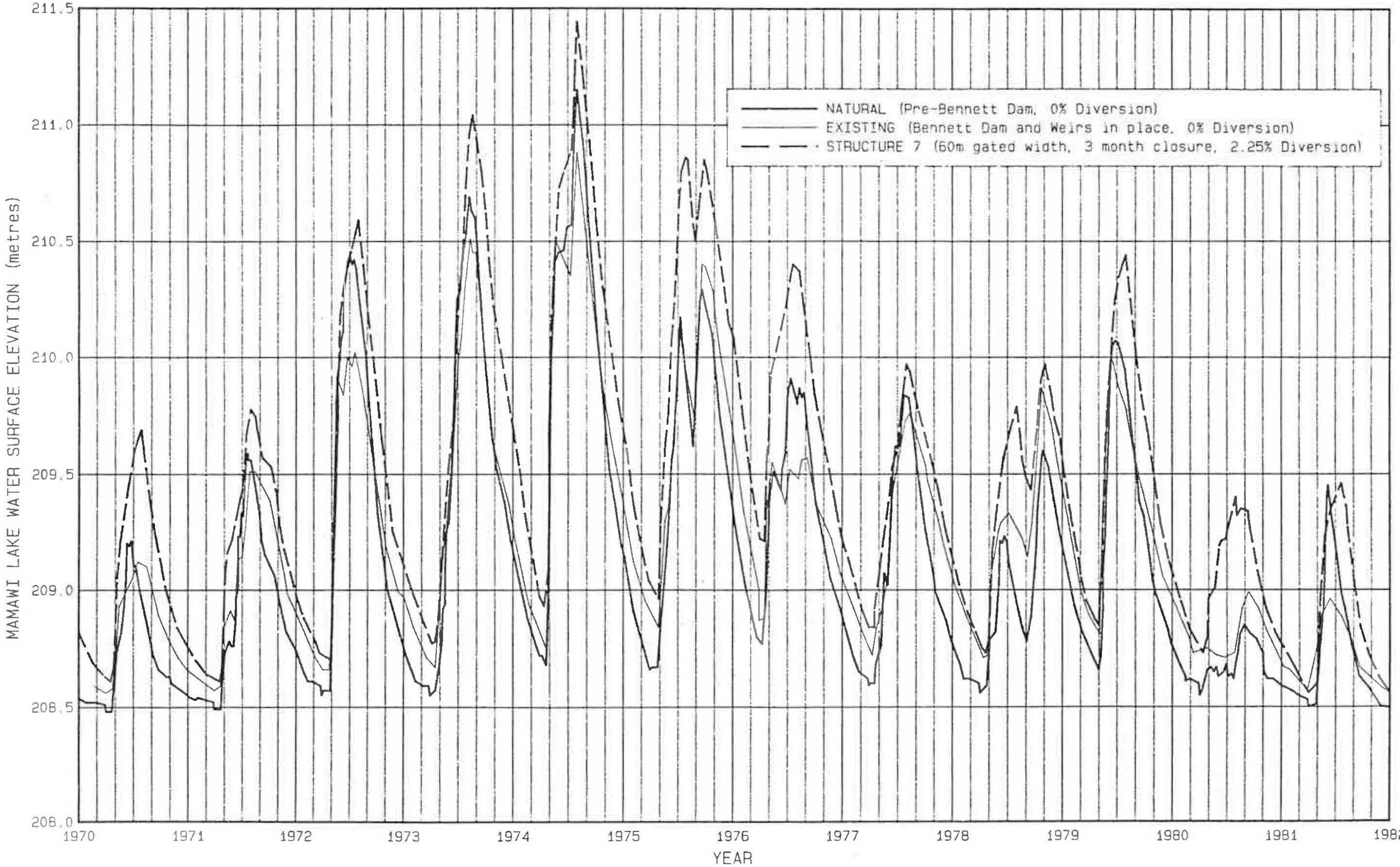
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 9



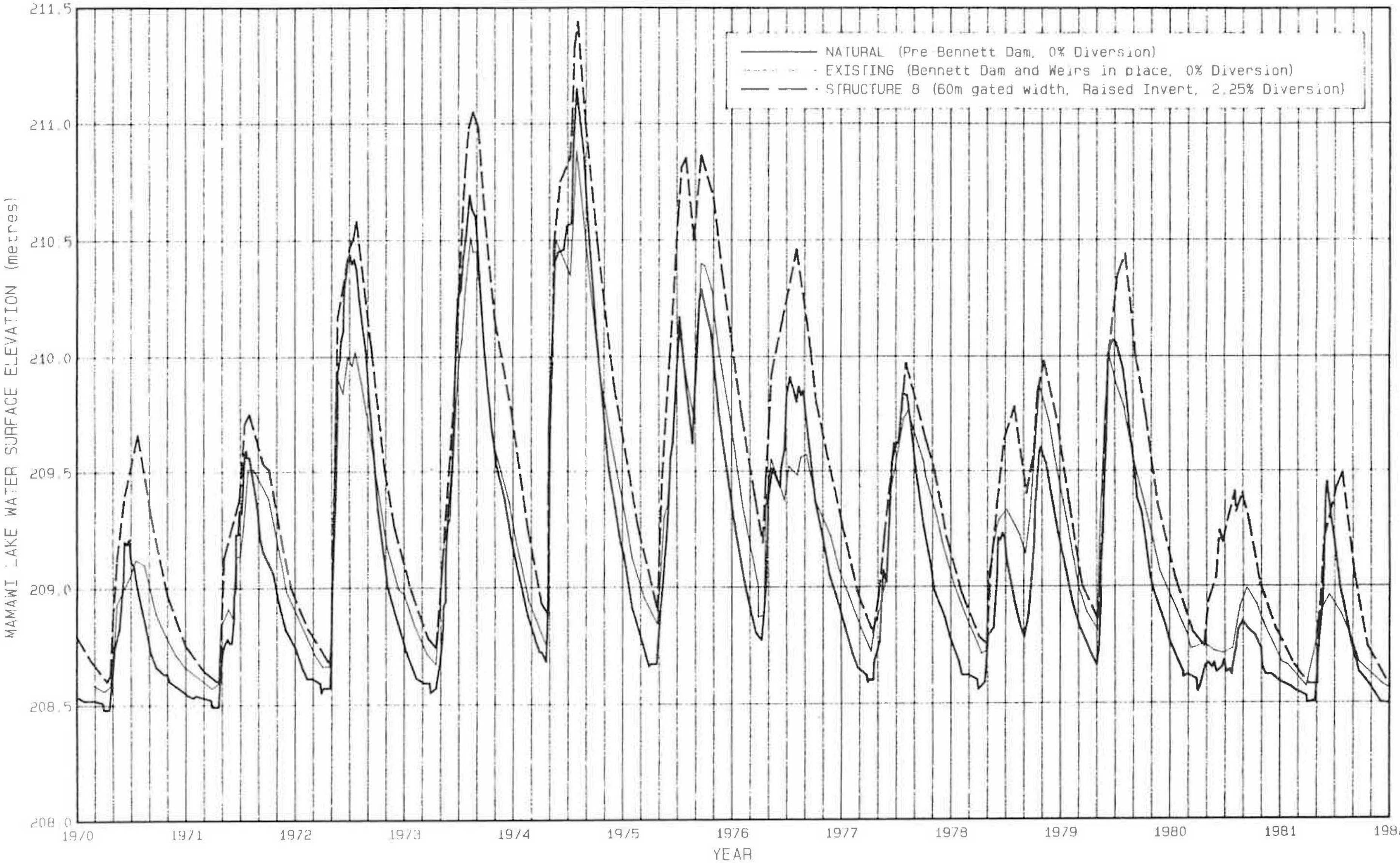
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 10



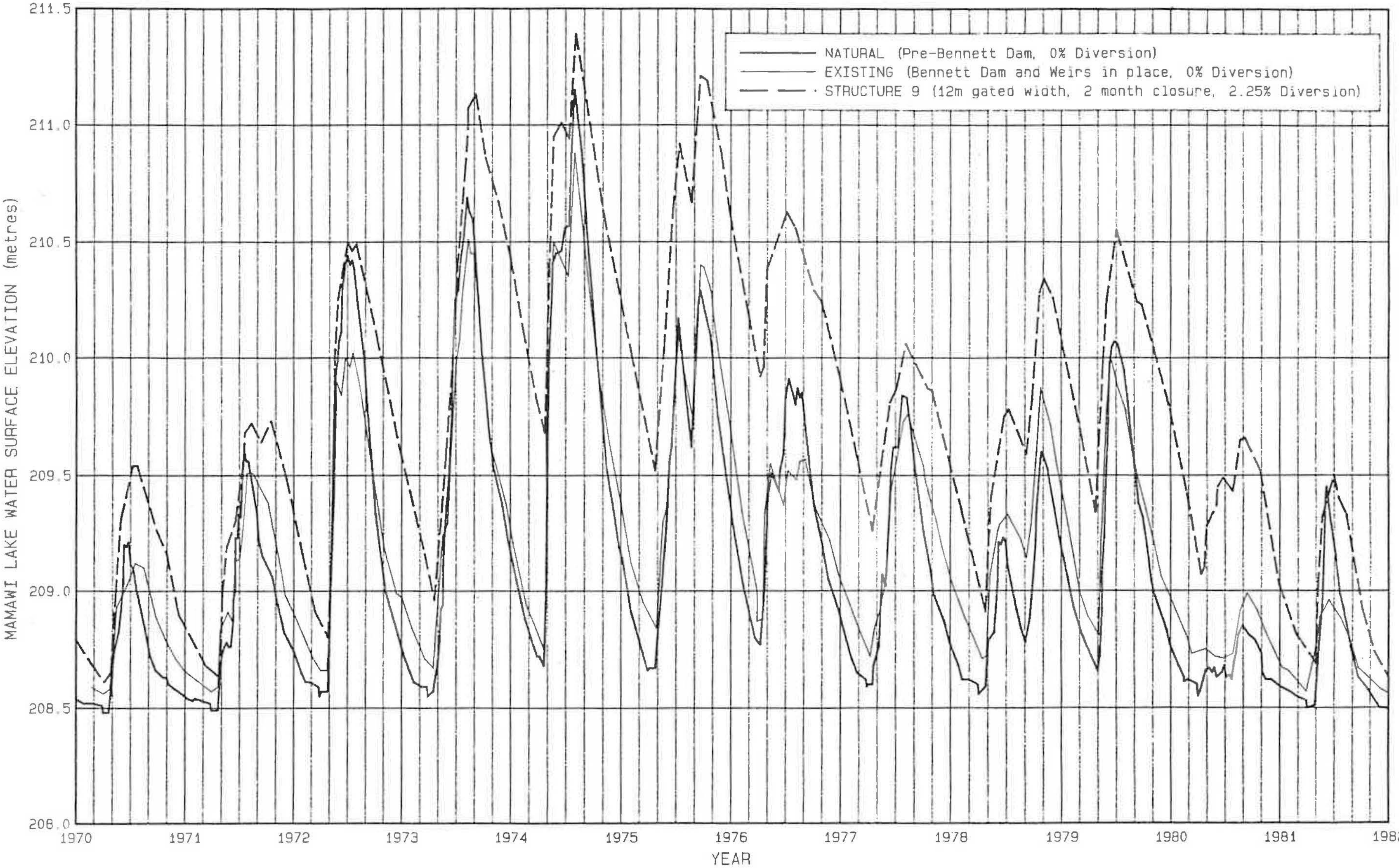
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 11



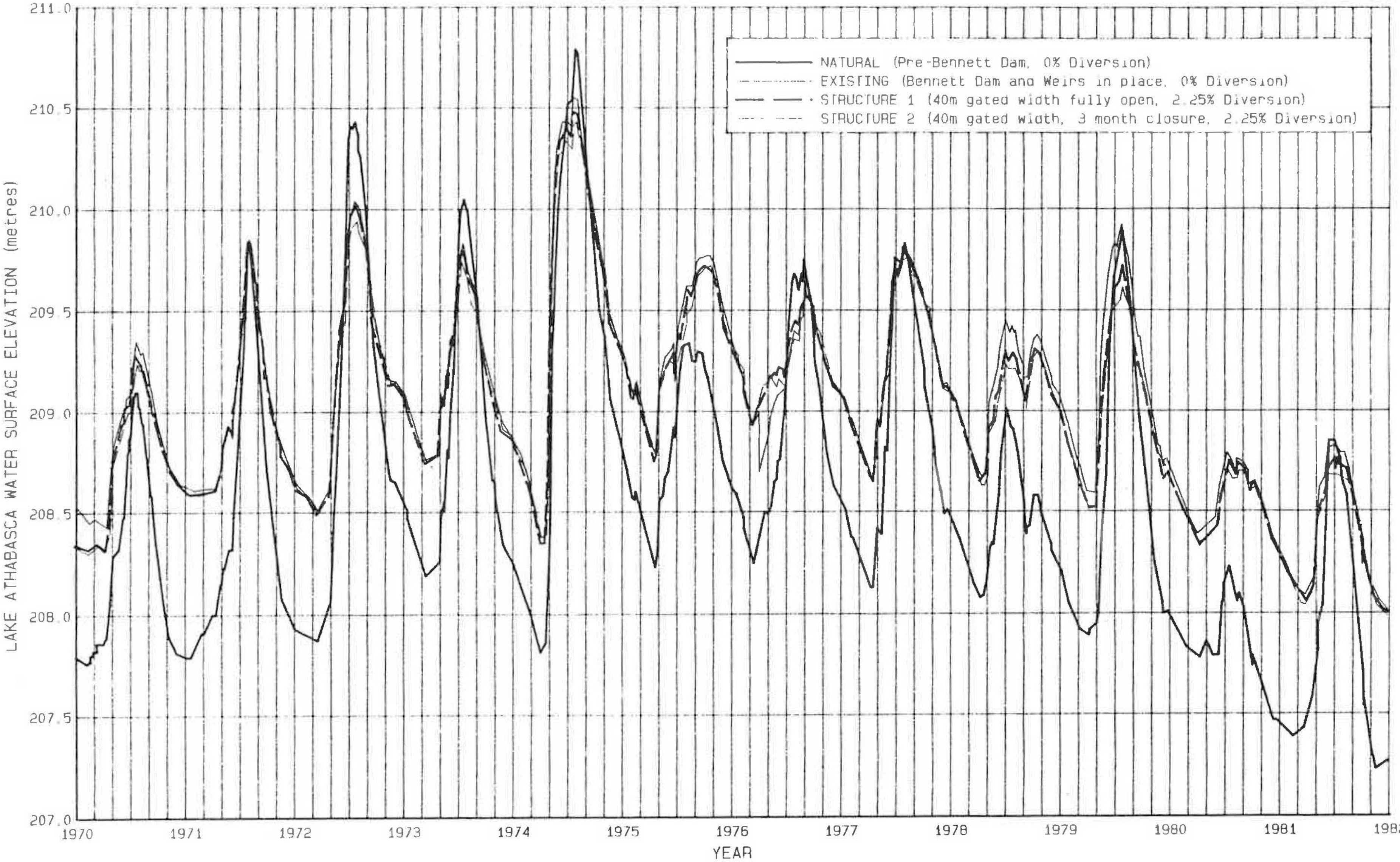
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 12



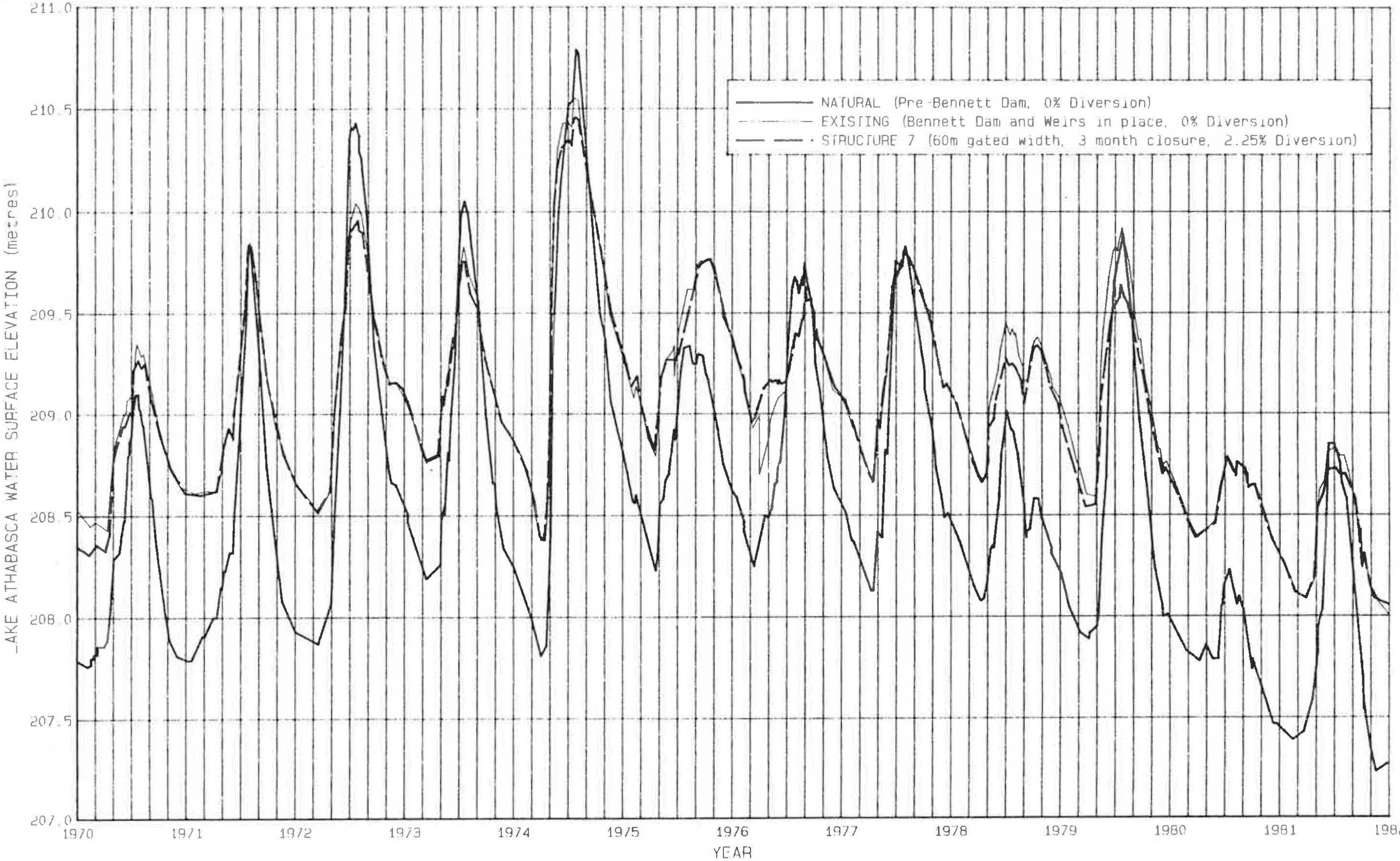
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 13



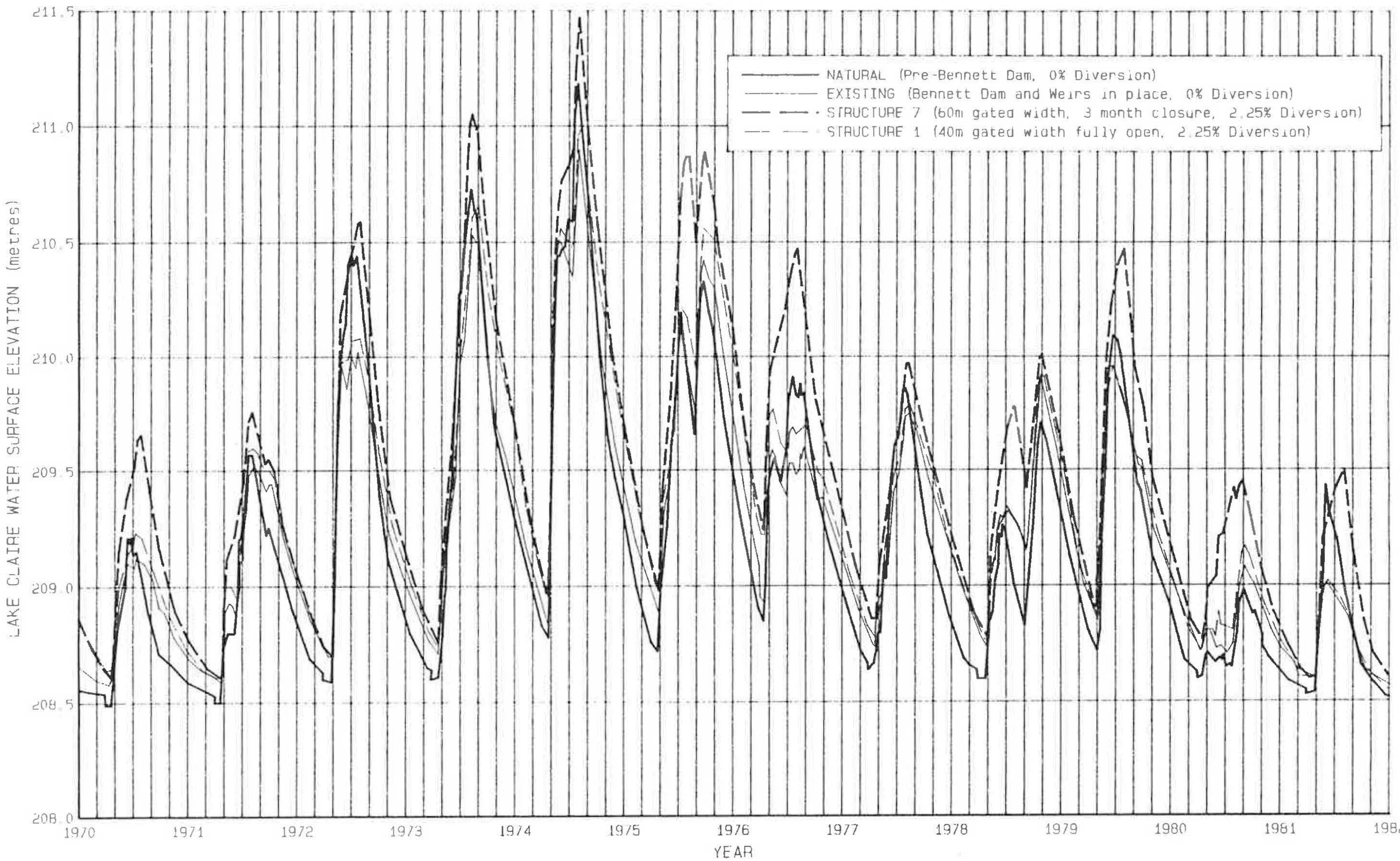
SIMULATED WATER LEVELS FOR LAKE ATHABASCA

FIGURE 14



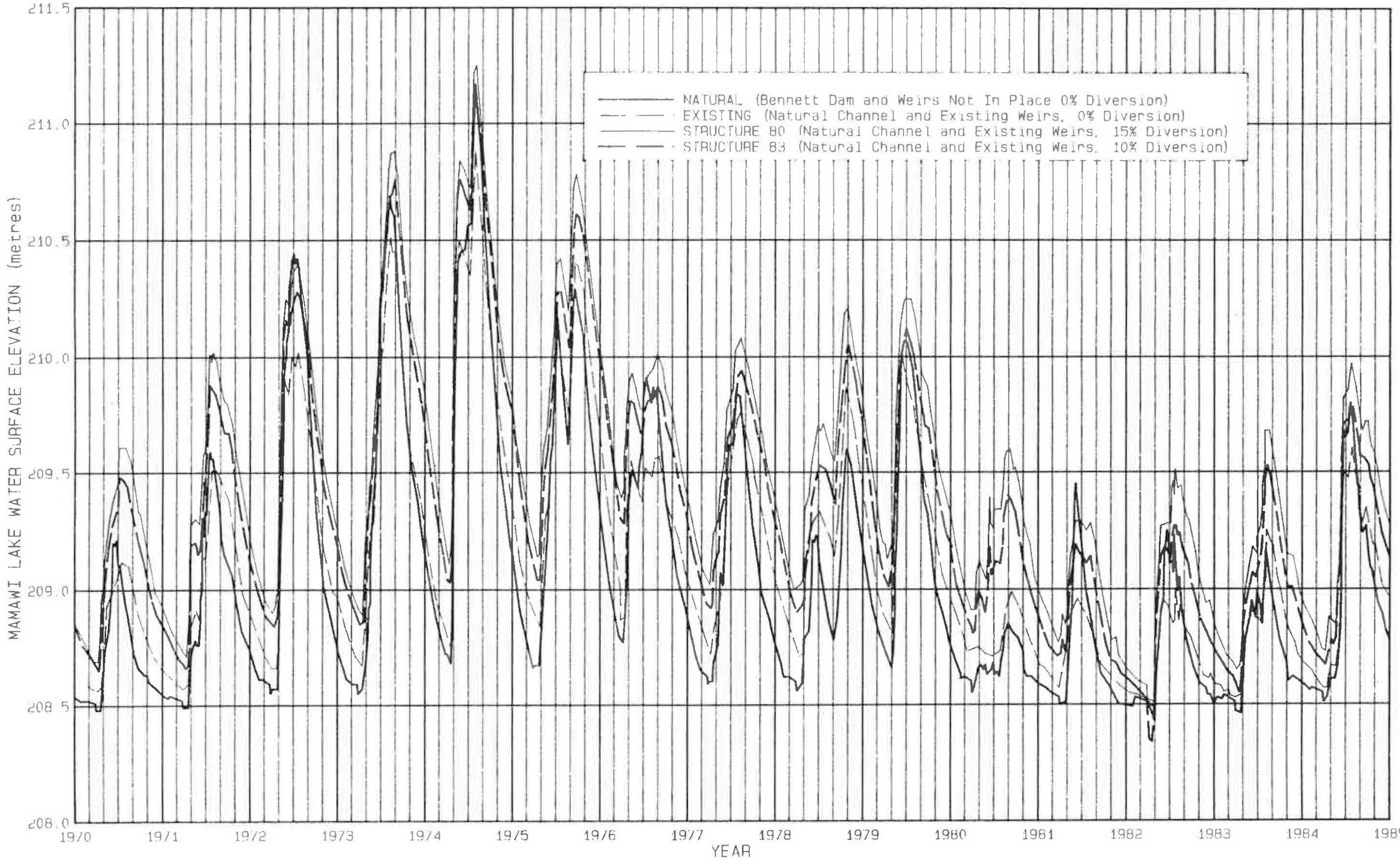
SIMULATED WATER LEVELS FOR LAKE ATHABASCA

FIGURE 15



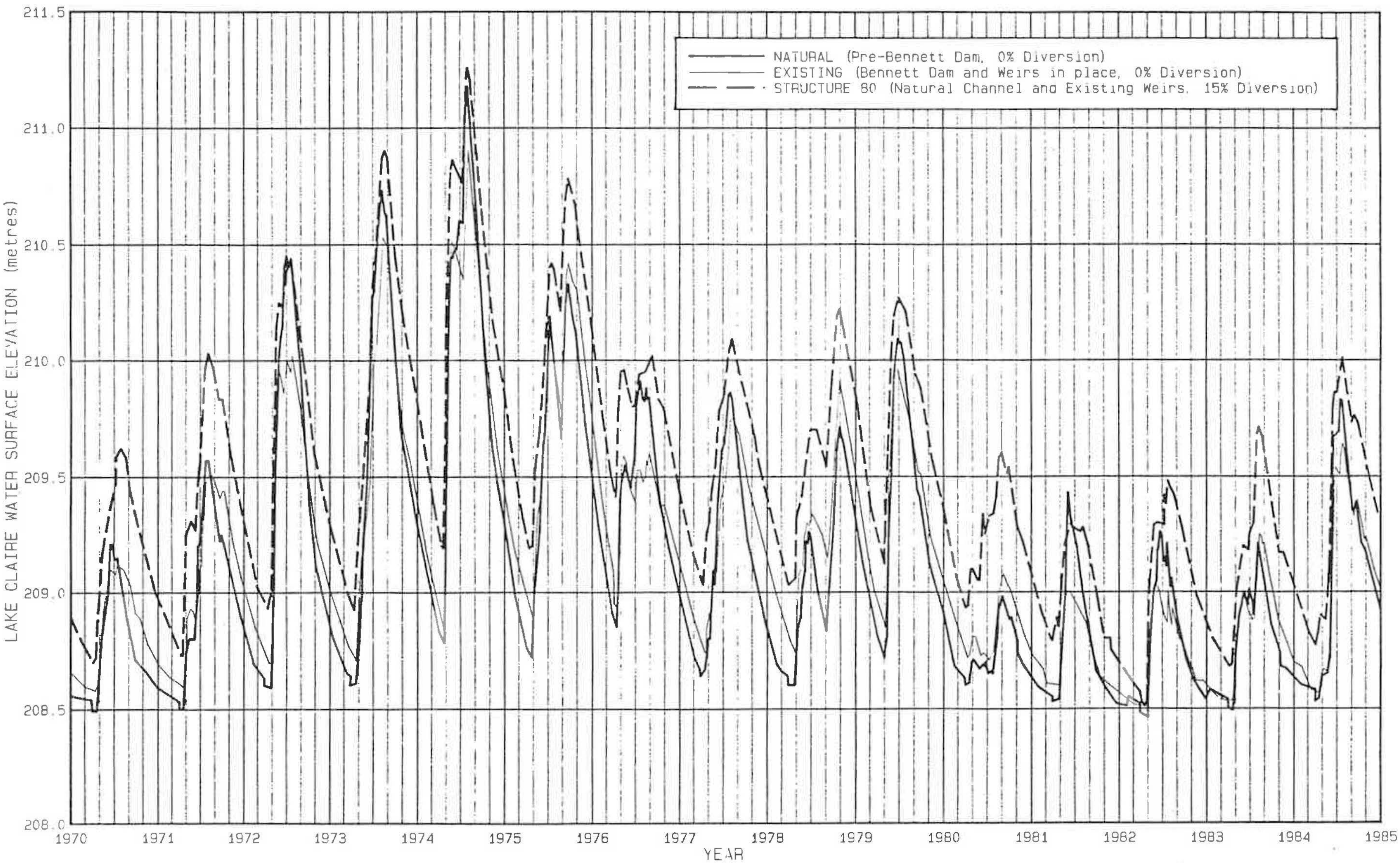
SIMULATED WATER LEVELS FOR LAKE CLAIRE

FIGURE 16



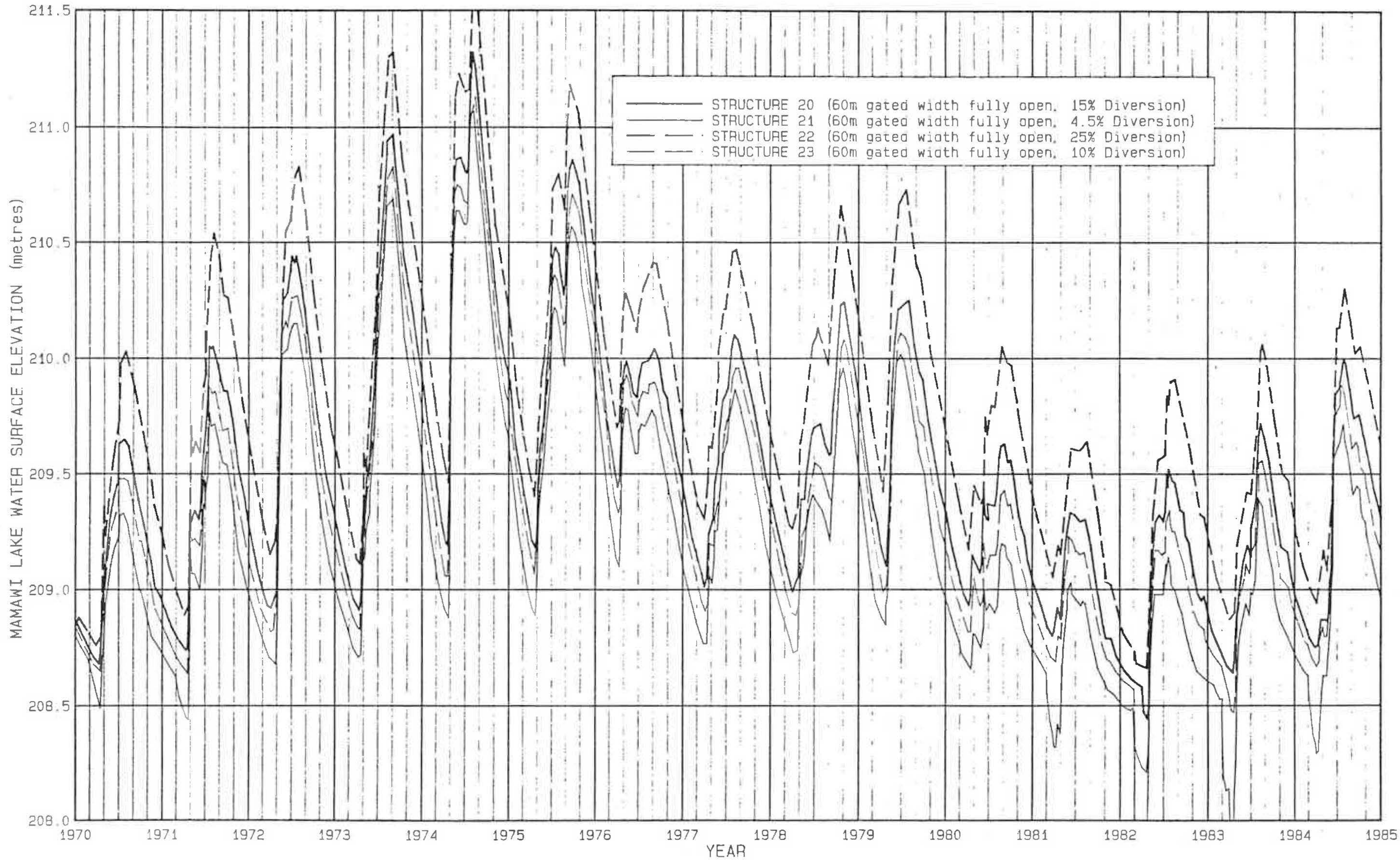
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 17



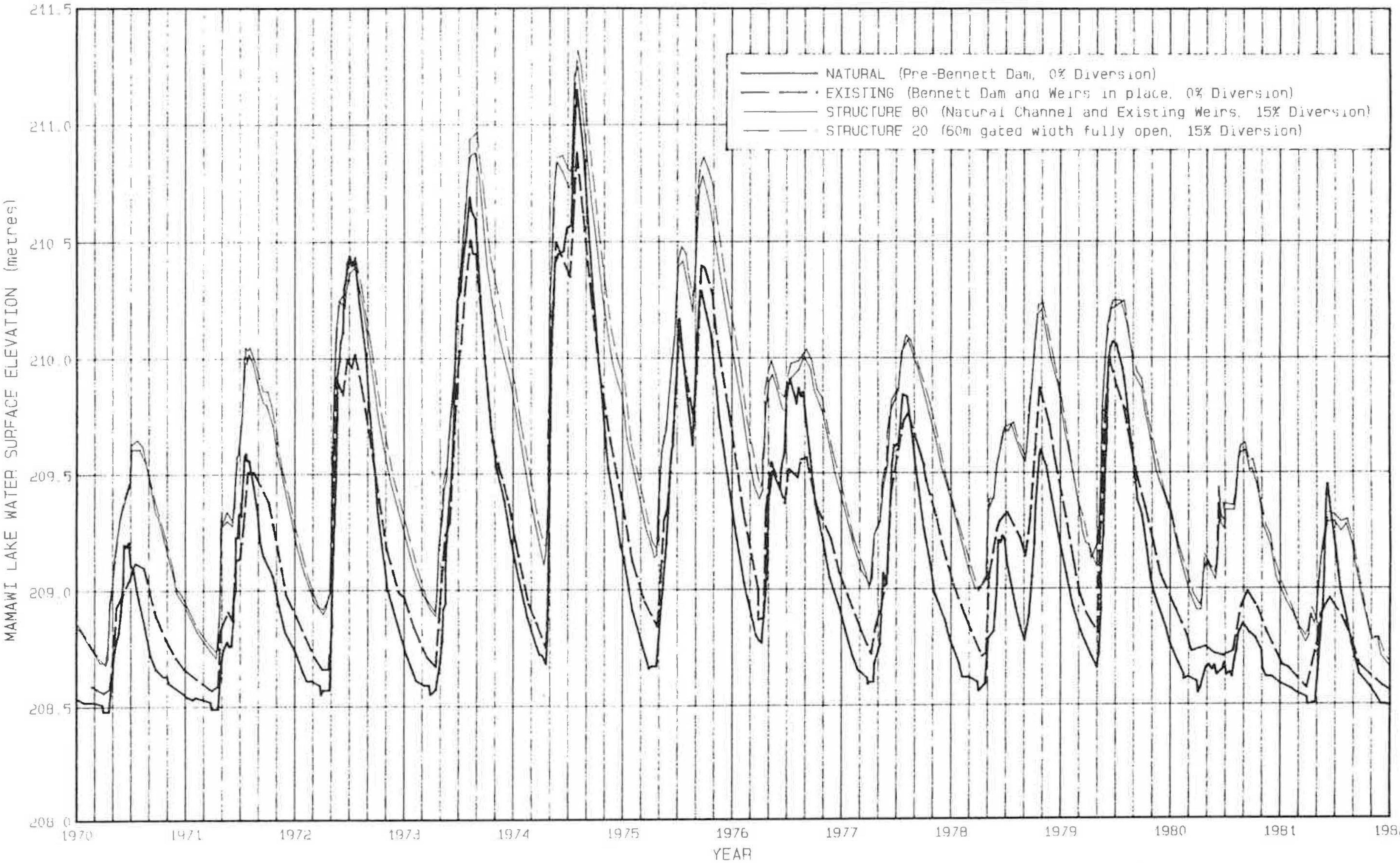
SIMULATED WATER LEVELS FOR LAKE CLAIRE

FIGURE 18



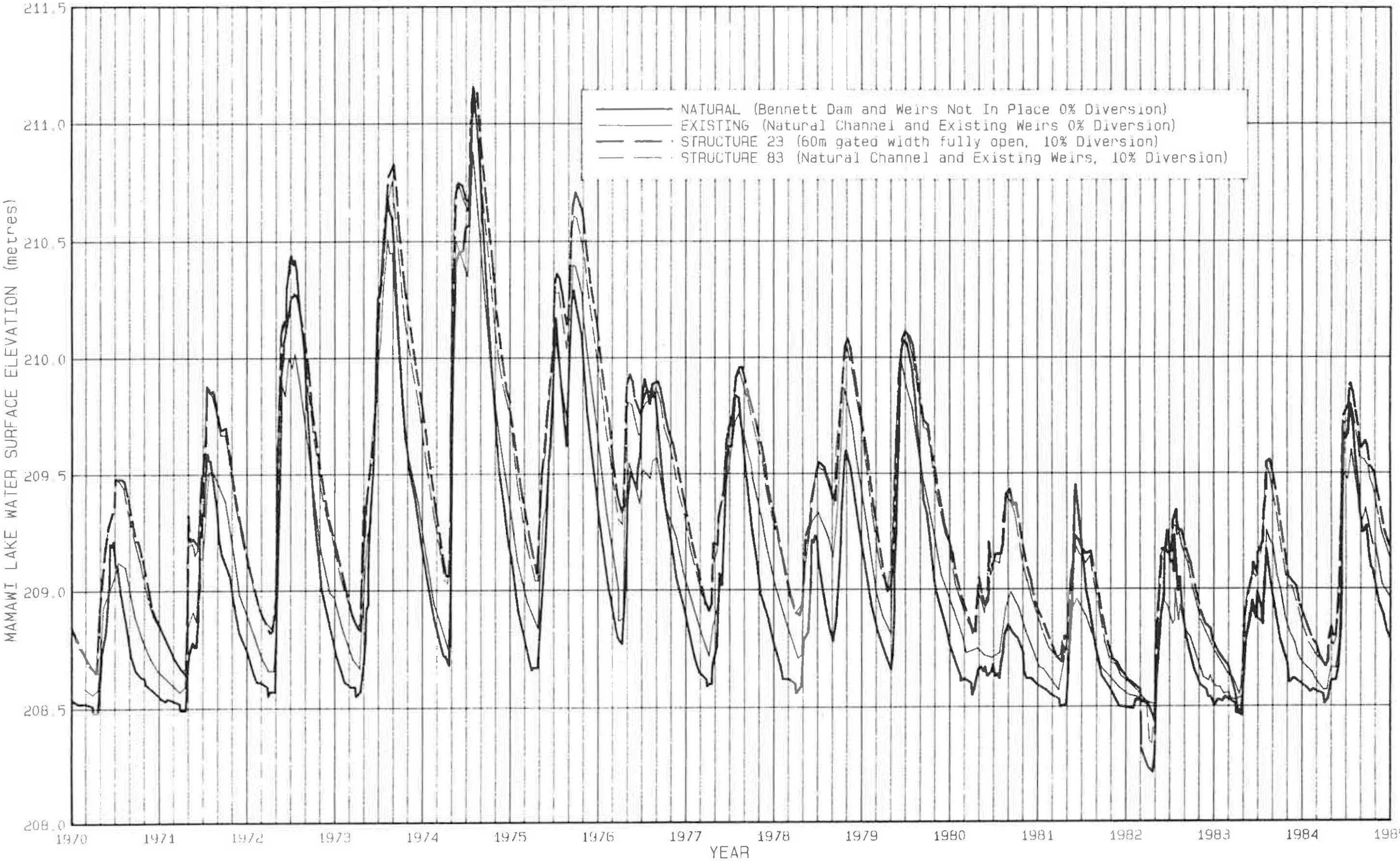
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 19



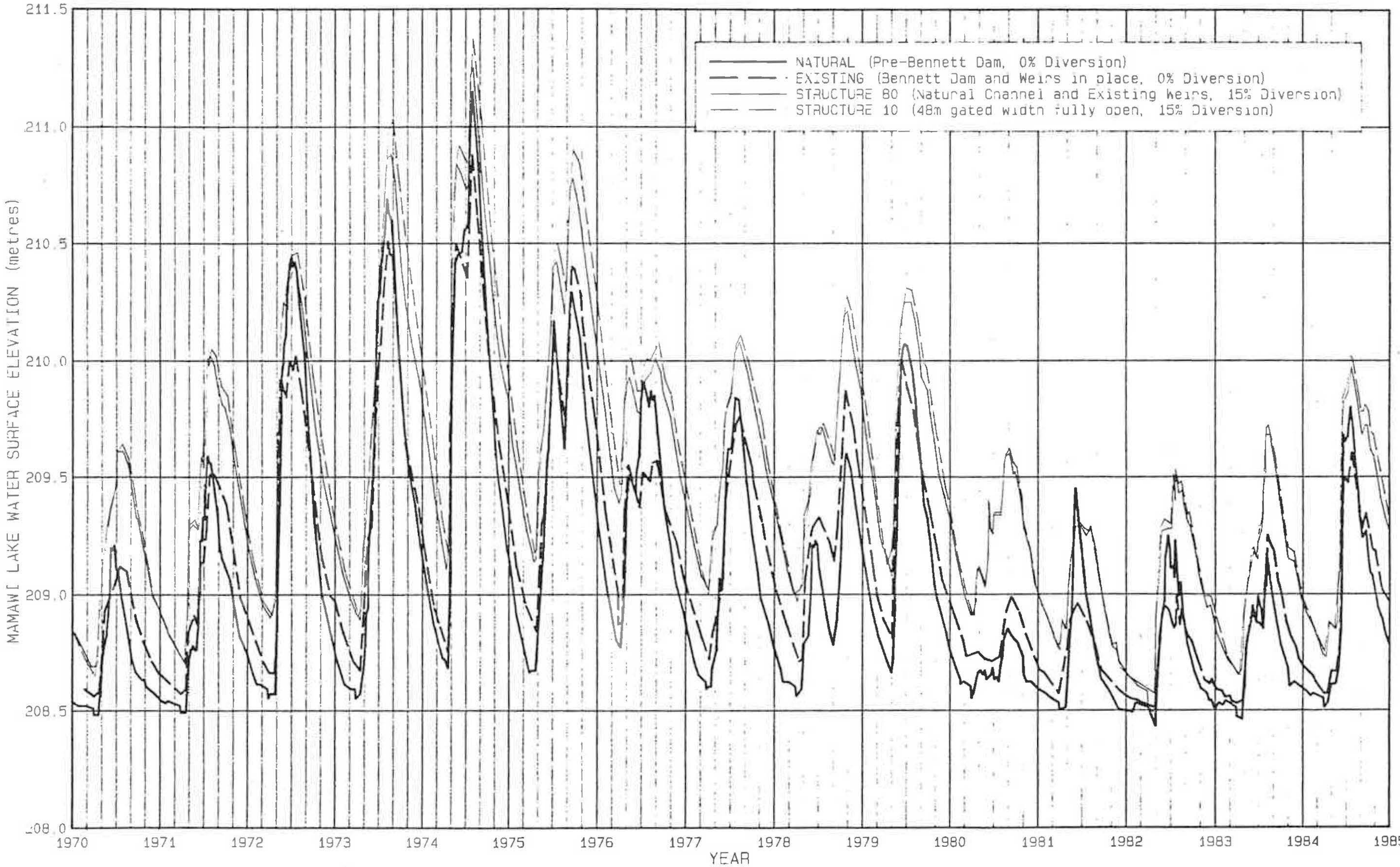
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 20



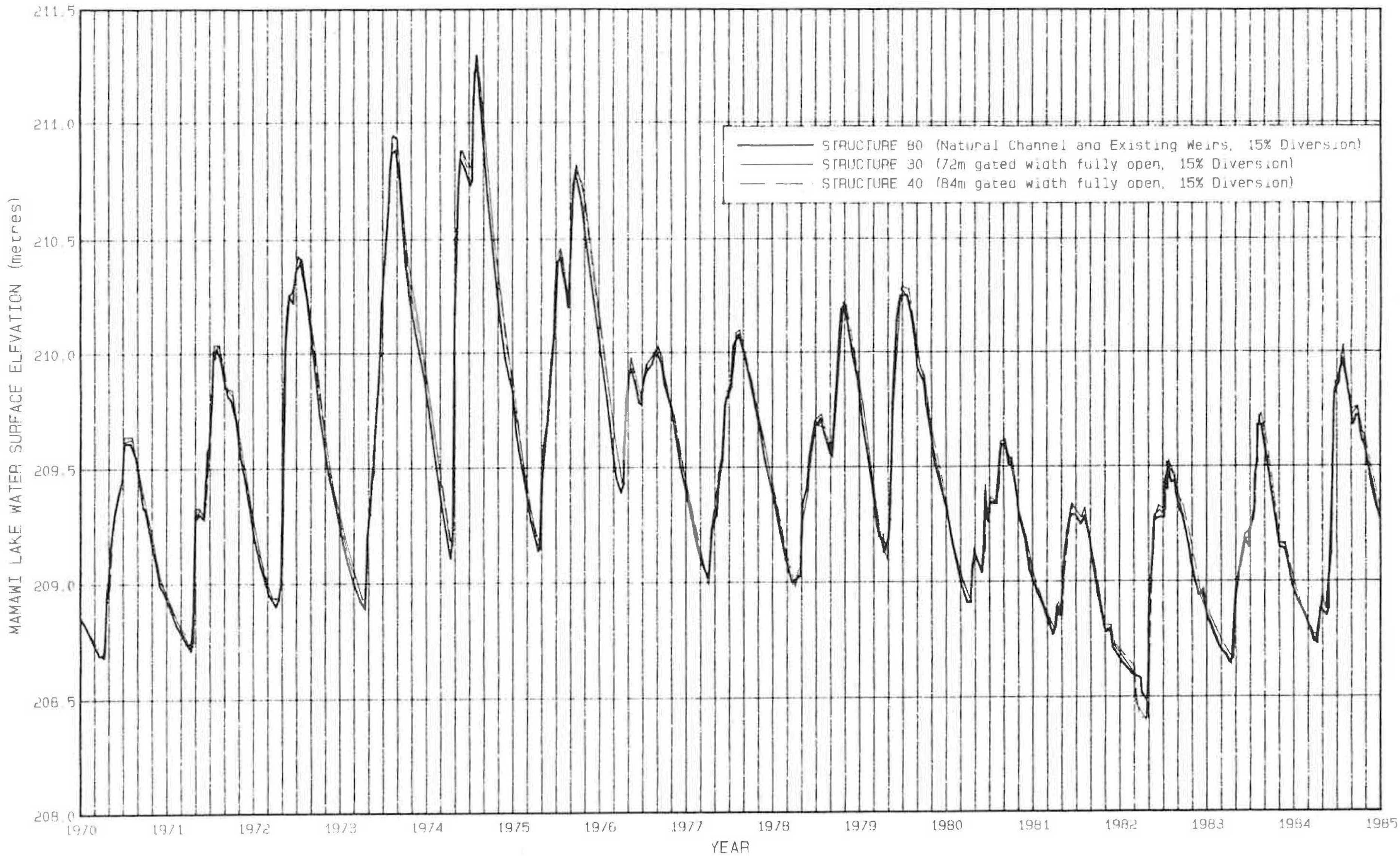
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 21



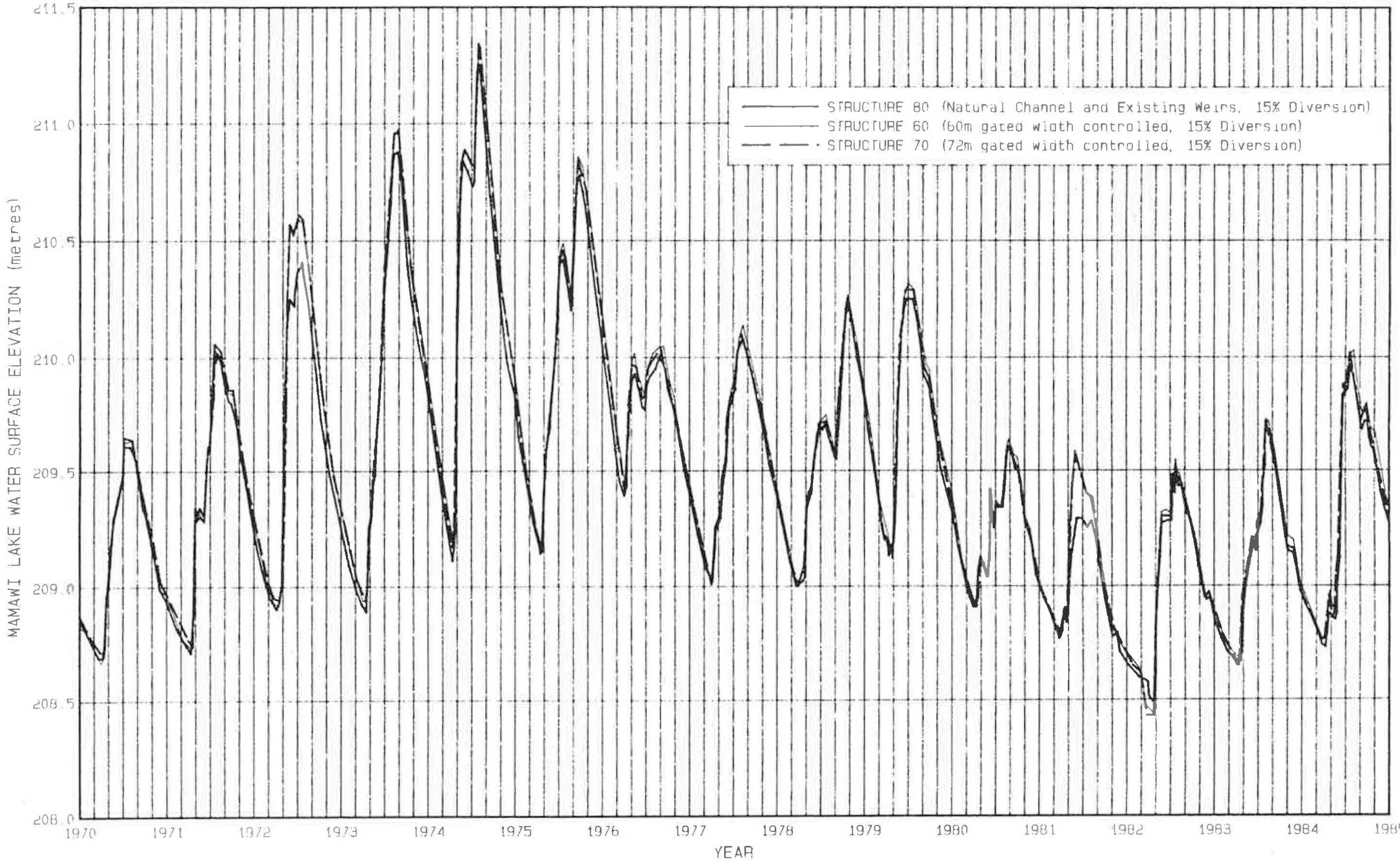
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 22



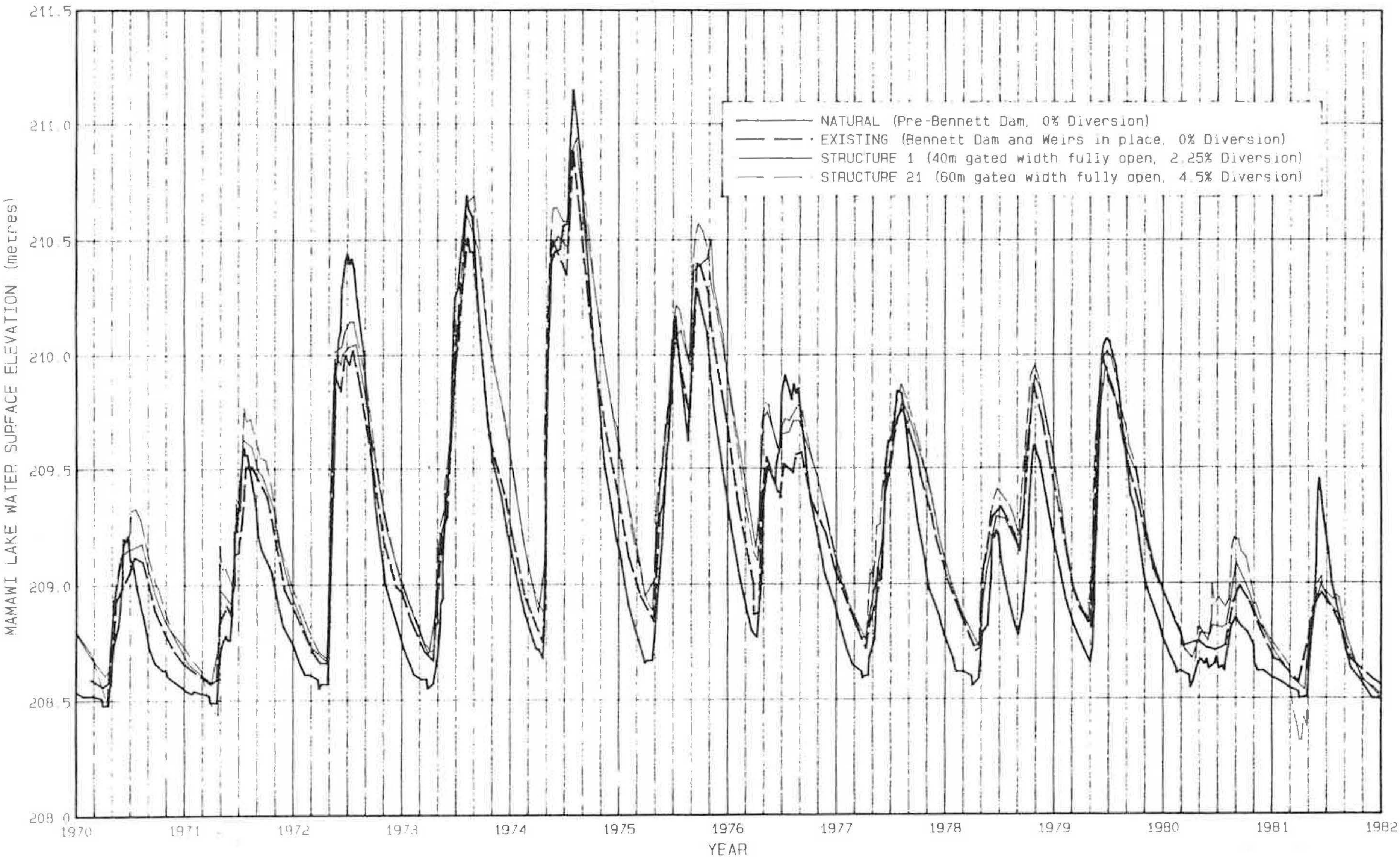
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 23



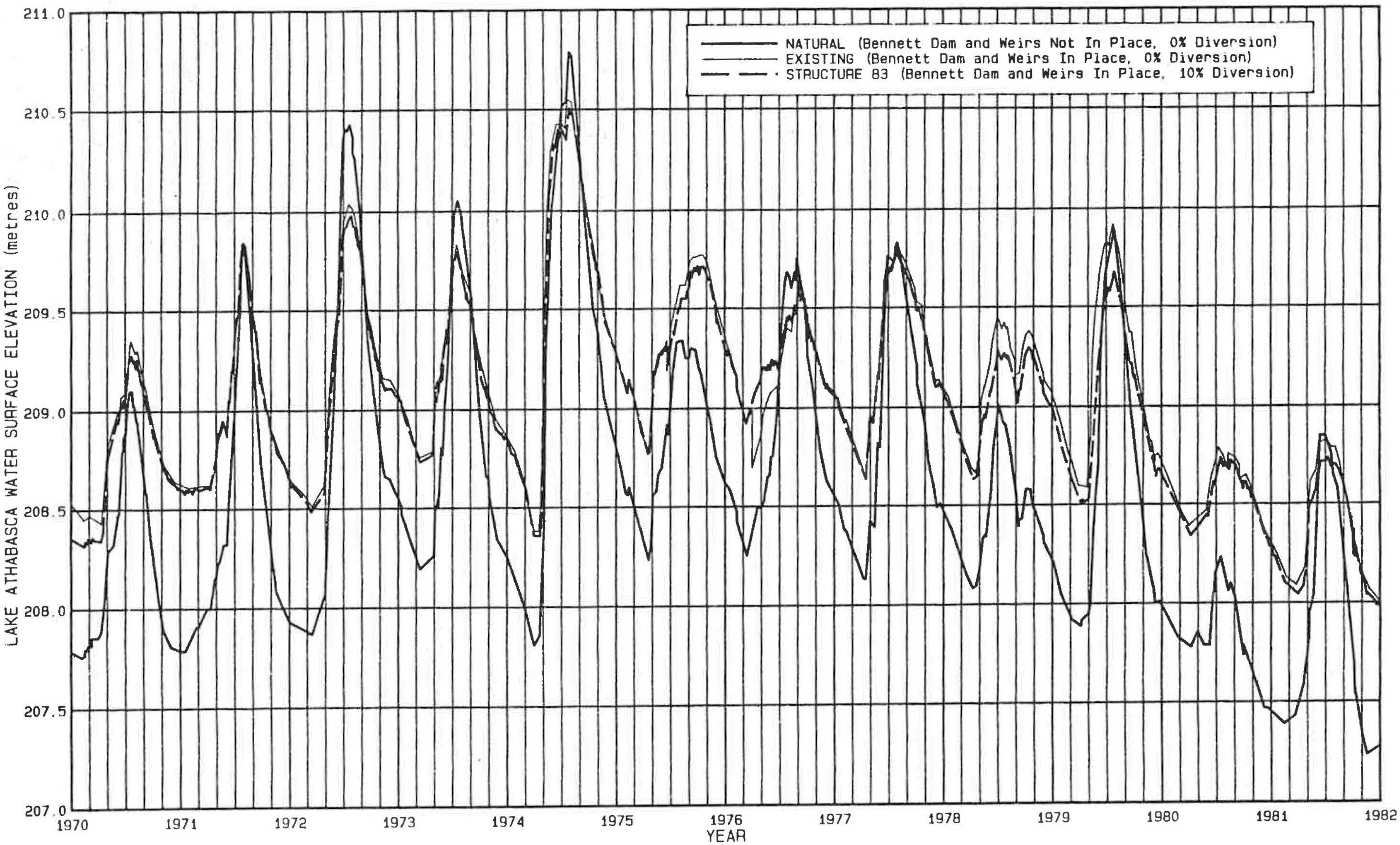
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 24



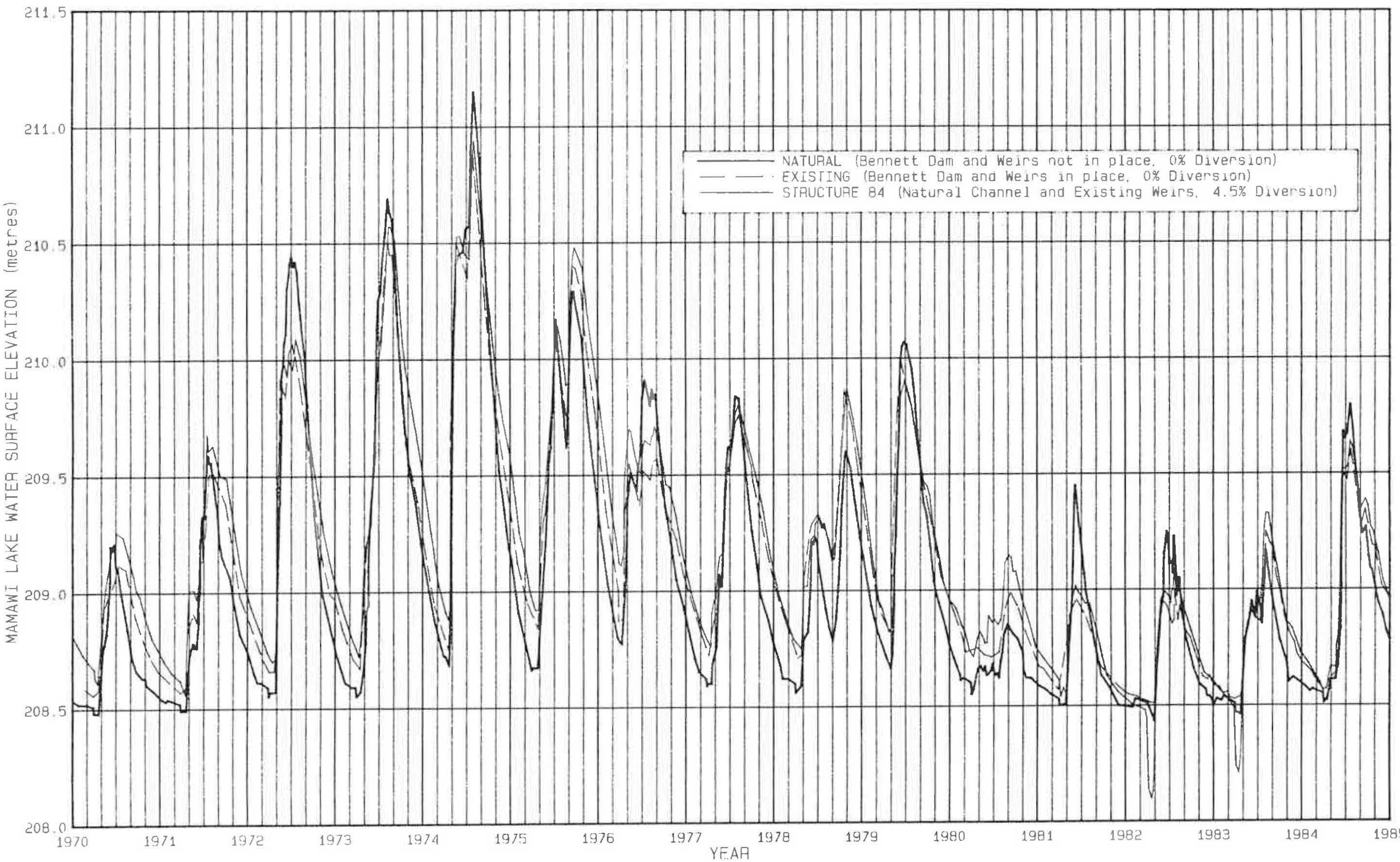
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 25



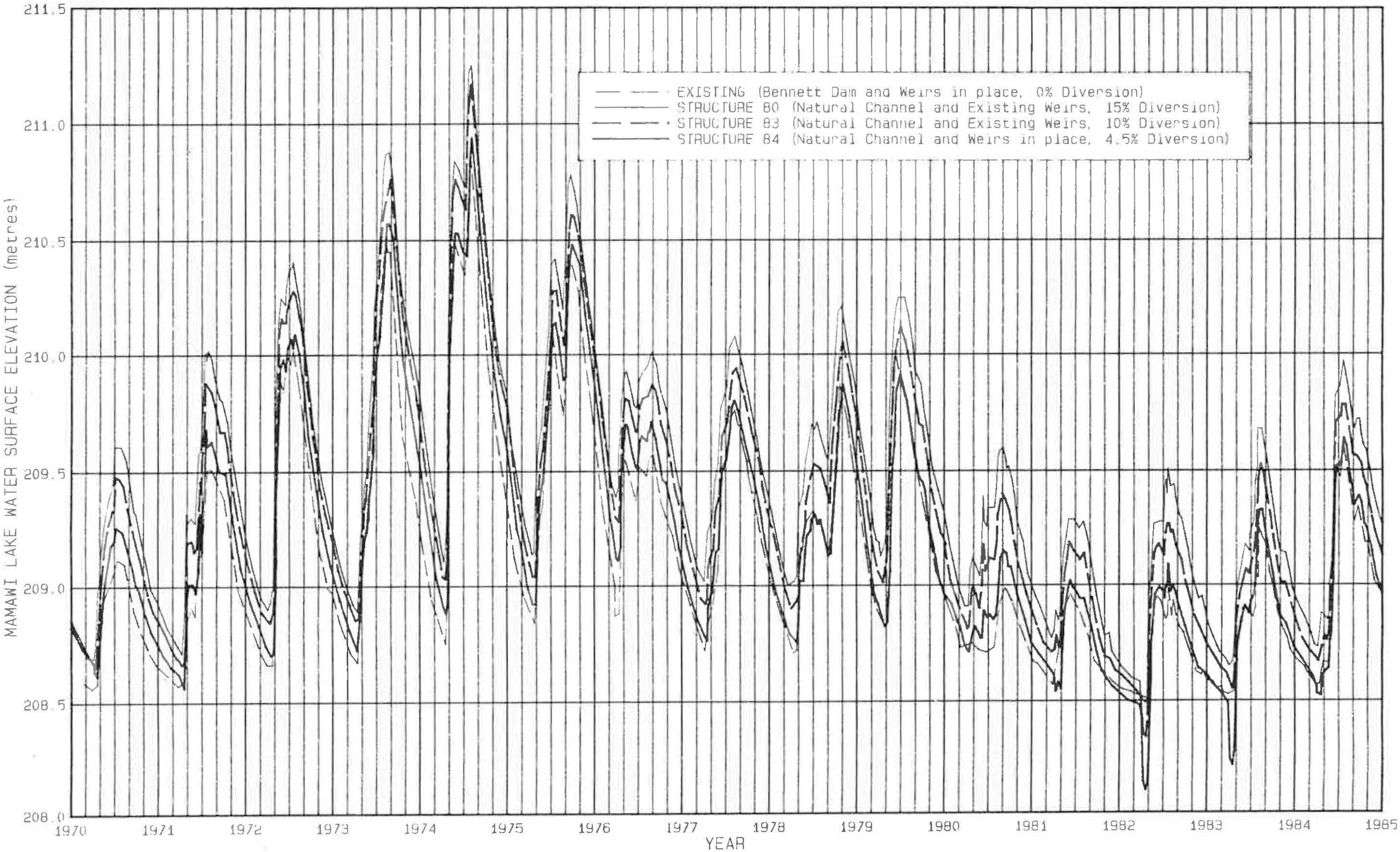
SIMULATED WATER LEVELS FOR LAKE ATHABASCA

FIGURE 26



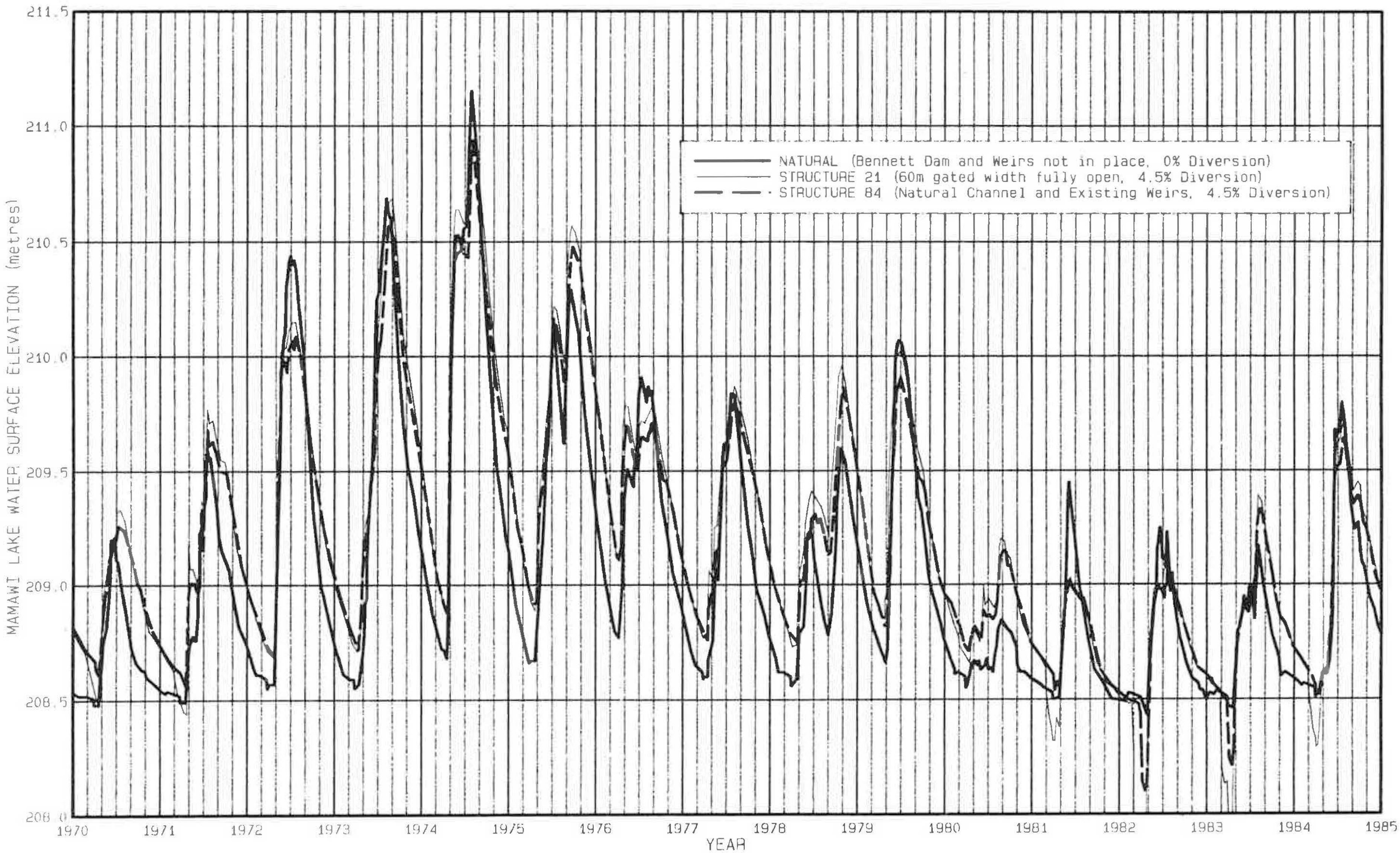
SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 27



SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 28



SIMULATED WATER LEVELS FOR MAMAWI LAKE

FIGURE 29

APPENDIX A

TERMS OF REFERENCE

1. Assemble and review all background information on the weir previously installed at Dog Camp on the Quatre Fourches including plans, geotechnical information, etc. (Note: A current cross section of the proposed weir location can be provided by Alberta Environment.).
2. Prepare a technical feasibility level design (adequate to make a decision on whether to proceed with funding, design and construction) of a gated control structure including boat passage and working fish passage for the Dog Camp Quatre Fourches site.
3. Evaluate the effectiveness of the structure in restoring natural water levels in the Lake Claire/Mamawi Lake area, and specifically the periodic flooding of perched basins. (Note: The 1-D hydrodynamic model should be used in the analysis, modelling would be undertaken by Water Management Systems Division, IWD, Environment Canada. Water levels with the structure in place should be compared to the natural conditions (pre-Bennett) and existing conditions (post-Bennett, Rochers and Coupé weirs in place).)
4. Evaluate the impacts of the structure on water levels in Lake Athabasca and Wood Buffalo National Park per the above two conditions.
5. Prepare a cost estimate for the structure (±20%).

REPORTING

1. 25 copies of a technical feasibility report should be submitted to the Peace-Athabasca Delta Implementation Committee at the conclusion of the analysis.

EVALUATION OF TEST FISHWAYS
ON RIVIERE DES ROCHERS
IN THE PEACE-ATHABASCA DELTA

FINAL REPORT

BY

S.B. SMITH
S.B. SMITH ENVIRONMENTAL CONSULTANTS LTD.

FOR

ALBERTA ENVIRONMENT
ENVIRONMENT CANADA
DEPARTMENT OF FISHERIES AND OCEANS

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1.0 INTRODUCTION

Closure of the Bennett Dam on the Peace River in 1967 had an immediate and continuing impact on water levels in Lake Athabasca, the Peace-Athabasca Delta and associated channels. Biological, hydrological and engineering studies carried out by the Peace-Athabasca Study Group (1973) resulted in recommendations that submerged weirs be constructed on two of the outlet channels from Lake Athabasca (Revillon Coupe and Riviere des Rochers) to effect partial control of outflow of Lake Athabasca to the Peace-Slave system. The weirs were designed to provide increased water levels in Lake Athabasca and the Peace-Athabasca Delta, which in turn were expected to restore and maintain suitable ecological conditions in the large areas of marshlands comprising the Peace-Athabasca Delta. The weirs on Riviere des Rochers and Revillon Coupe were completed in spring 1975 and spring 1976 respectively. The Peace-Athabasca Delta is shown in Figure 1 and Riviere des Rochers site in Figure 2.

Although the weirs may have created summer water levels in Lake Athabasca which have benefited some components of the Peace-Athabasca Delta, they have delayed or prevented fish migration upstream in the Revillon Coupe and Riviere des Rochers, depending on river levels and head difference across the weirs. Concern was first expressed in 1975 about the blockage of upstream fish migration at the weir on the Riviere des Rochers (Smith and Hammond, 1975). Studies of fish migration subsequently were initiated to determine the relative importance to fish migration of the Chenal des Quatre Fourches, Revillon Coupe and Riviere des

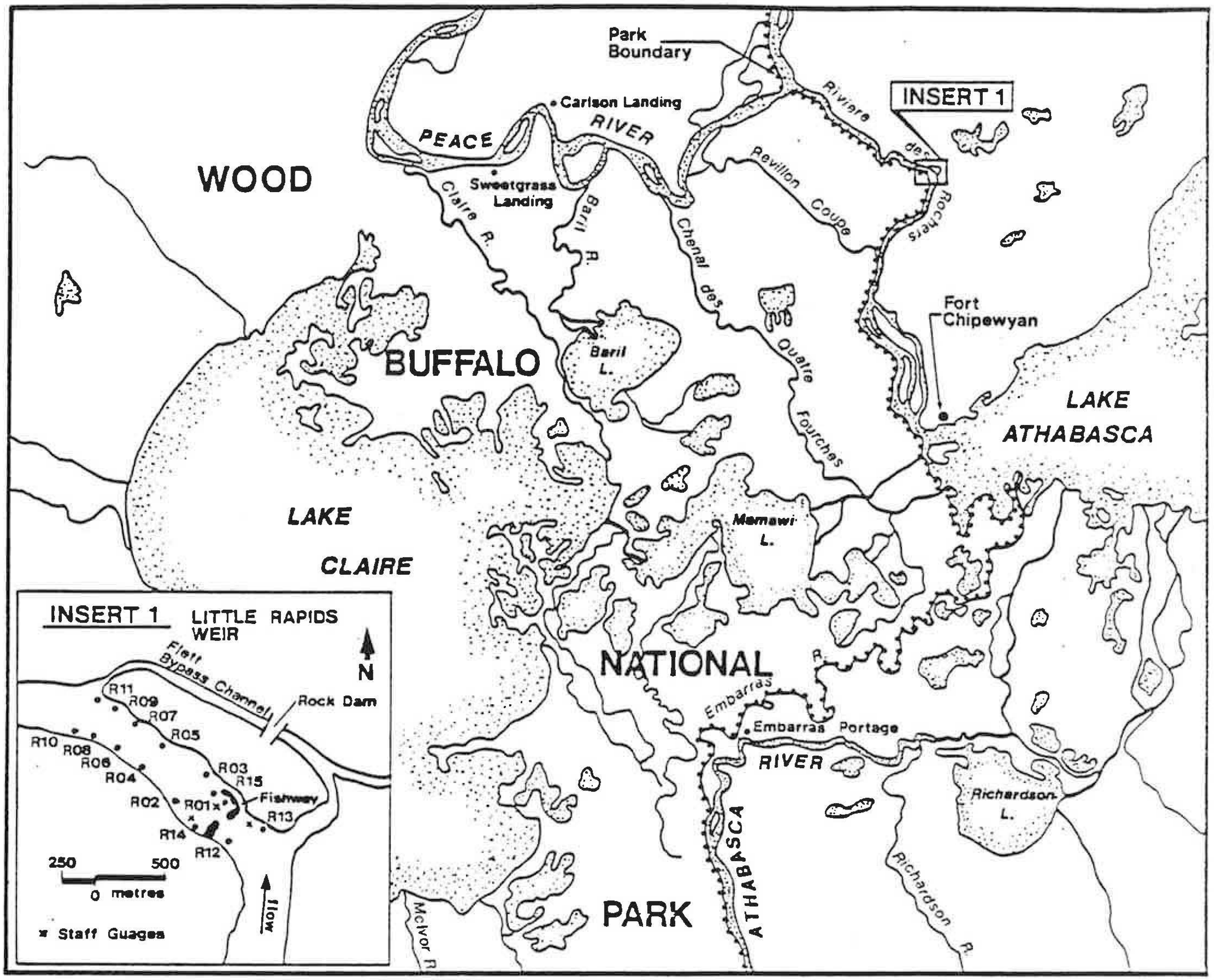

Figure 1. Peace-Athabasca Delta region, showing location of fishway test site as insert.

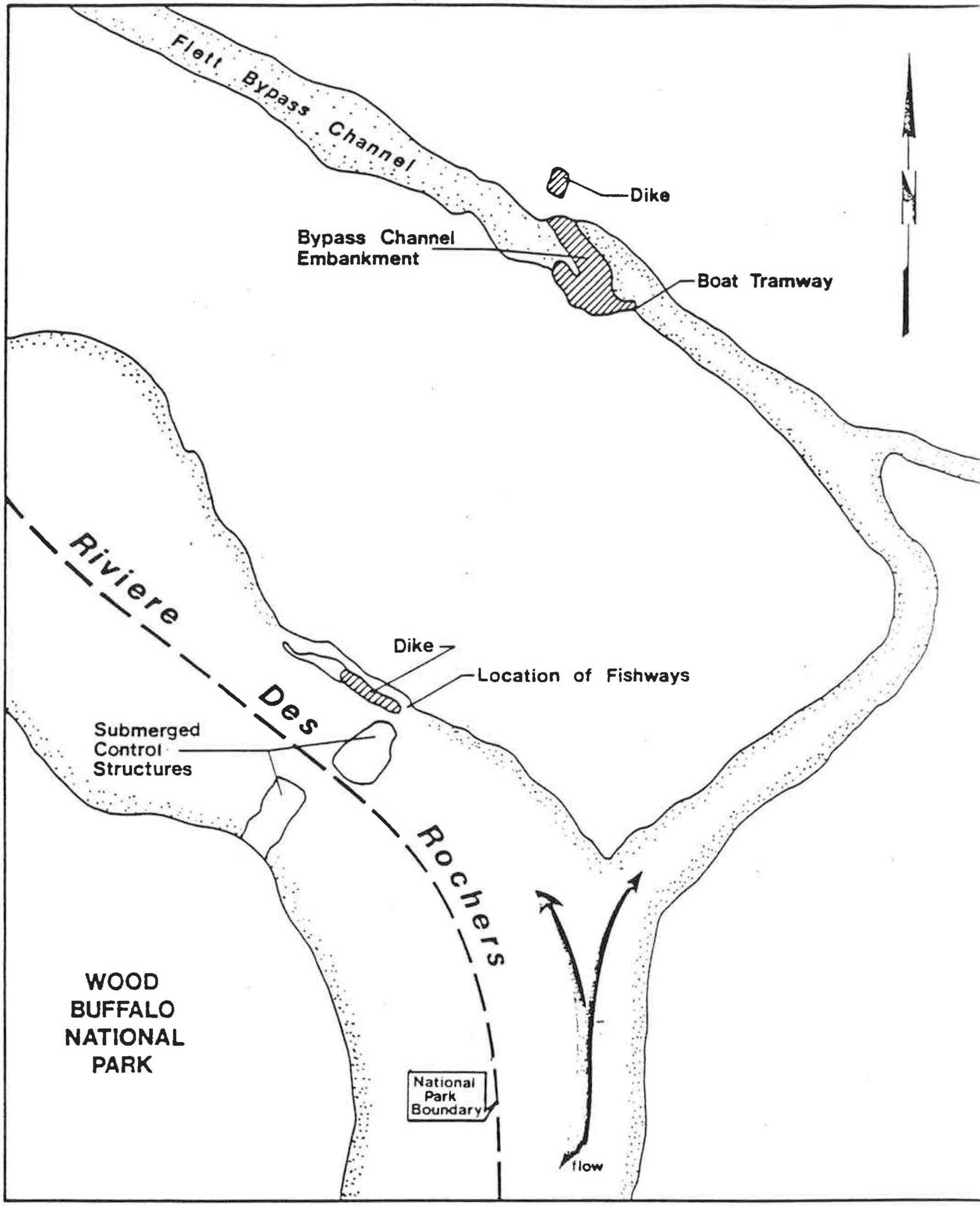

Figure 2. Riviere des Rochers weir test site. Prototype fishways are installed between dike and north bank.

Rochers, and the possible effects on fish migration of the weirs on Riviere des Rochers and Revillon Coupe. It was known from earlier studies (Kooyman, 1973; Donald and Kooyman, 1974; 1977 (a)) that goldeye and other species of fish migrated from the Peace-Slave system into Lake Athabasca and the Peace-Athabasca Delta, and that the Lake Claire and Mamawi Lake system was an important goldeye spawning area. Subsequent studies (Kristensen, 1976; 1980), (Kristensen and Summers, 1978; 1981) revealed that large numbers of fish (± 10^6) migrated from the Peace-Slave system in the three channels draining Lake Athabasca, and that up to 75% of these were blocked when head differences across the weirs resulted in water velocities preventing movement upstream. A final study (Kristensen and Parkinson, 1983) was carried out to determine migratory behavior of fish at the two weirs, and to provide data for location and engineering feasibility of fishways to pass fish over the two obstructions. These studies resulted in recommendations that two fishways (one each on left and right bank) be constructed at the weir site on Riviere des Rochers, and that one fishway be constructed at the Revillon Coupe weir.

Because it was known that water levels at the two weir sites fluctuated widely (hydrological records, Alberta Environment) hydraulic and biological data were required in order to determine the performance of fishways at the sites, before any decision could be taken as to the possible construction of permanent structures to pass fish over both the Riviere des Rochers and the Revillon Coupe weirs. In 1981 a decision was taken by Alberta Environment to construct two prototype fishways for installation and testing at the weir on Revillon Coupe. A Denil and a vertical slot fishway were fabricated in Edmonton and transported to Fort Chipewyan over the winter road in February, 1982. During the summer of 1982, attempts were made to install the prototype fishways at the Revillon Coupe weir, but high water levels and lack of suitable equipment resulted in abandonment of the Revillon Coupe weir site, and a recommendation was made to install and test the fishways in the fish bypass channel at the weir on the Riviere des Rochers. The prototype fishways were installed at the weir on the Riviere des Rochers during the winter of 1982-83. It was discovered in April, 1983, by Alberta Environment staff, that a survey error of approximately 0.75 m (2.5 feet) had resulted in an installation elevation too high to allow testing. Consequently, the prototype fishways were removed and re-installed at the correct elevation in October, 1983. Evaluation of fishway performance was deferred until the open water period in 1984.

This report summarizes work carried out between 6 May 1984 and 17 June 1984 at the installation site of the two prototype fishways on the Riviere des Rochers. Although data obtained in 1984 were severely limited because of adverse conditions in the field, comparisons with previous studies are made where possible. Comparisons are also made of the hydraulics of the vertical slot fishway with data from a study by Katopodis *et al* (1985) and of the Denil fishway with work carried out by Katopodis (1981).

2.0 METHODS

2.1 Material Assembly and Site Preparation

Commencing on 6 May 1984 a fish fence and trap were fabricated at Fort Chipewyan and transported 40 km by boat to the test site at the Riviere des Rochers weir on 9 May 1984. The fish fence and trap were installed about 50 m downstream of the lower end of the fishways. The top of the fence was 2.1 m above the water surface at the time of installation. The fish fence and trap were installed on the assumption that fish proceeding upstream in the channel would be captured, tagged and released above the fish fence, and that time from release to subsequent recapture in traps at the upper ends of the fishways would provide a comparative measure of the effectiveness of each fishway in passing fish upstream.

Coffer dams had been constructed both upstream and downstream in the channel in October, 1983, to secure the fishways against winter ice damage. On 29 April 1984 (S. Flett, personal comment) the Riviere des Rochers overtopped the lower coffer dam and flooded out the fishways from below, leaving large amounts of debris in each structure. This debris was removed and a 2.5 cm poultry wire fence was constructed across the spaces between the fishways and between the outer rock walls of the channel and the fishways, to prevent upstream fish movement past the lower end of the fishways (Figure 3).

Staff guages were installed above and below the fishways, in order to provide data on head differences above and below the structures. The leads into the fish traps at the upper end of the

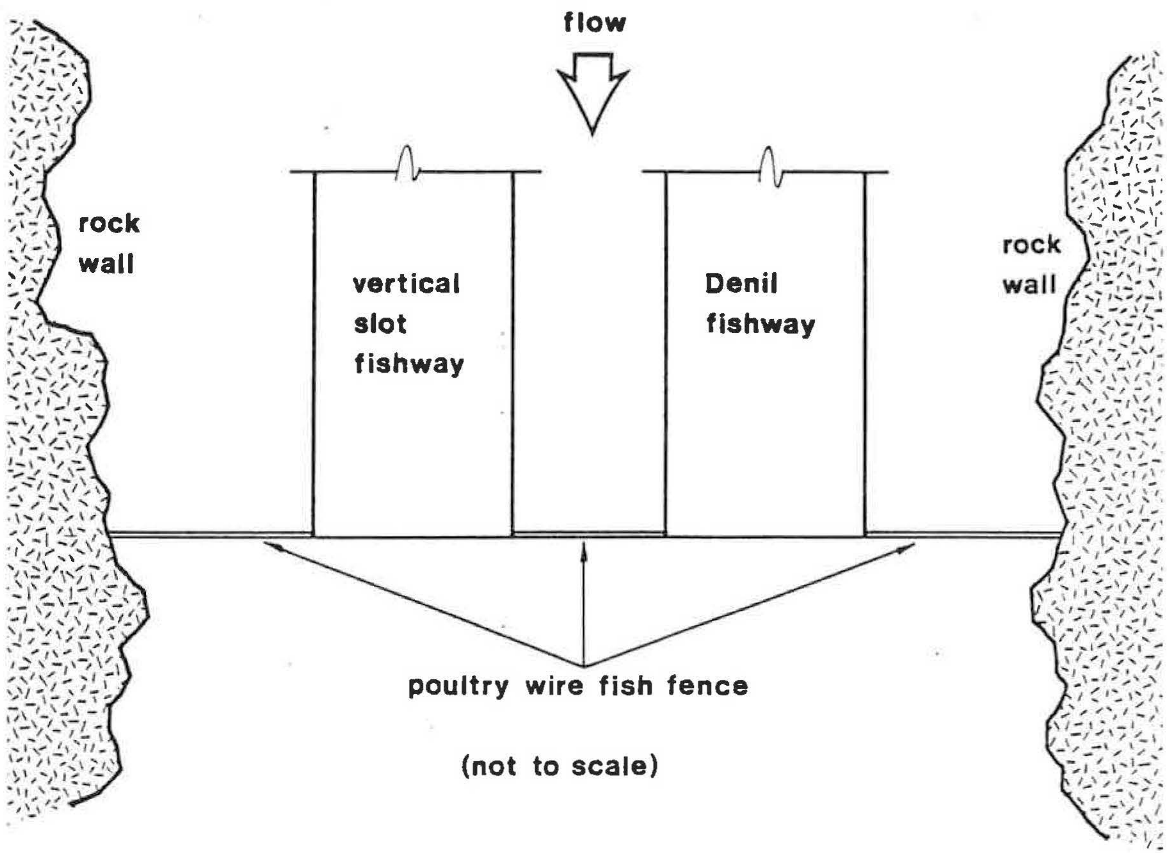

Figure 3. Schematic of fishway installation, showing location of poultry wire fish fence, to prevent movement of fish upstream, past the lower ends of the fishways.

fishways were modified to reduce the openings from 20 cm to 10 cm, since it was considered likely that fish would find the larger openings and escape downstream. Plywood extensions were used to modify the trap leads, as shown in Plate I.

The upstream coffer dam, which was estimated to contain a volume of approximately 35 m^3, was breached by digging a channel through it, and allowing the subsequent water flow to erode the dam and carry the material downstream, through the fishways, to the pool at the lower end of the structures.

2.2 Hydrology

Examination of hydrological data was confined to the period between 1 May 1984 and 15 June 1984, and for the same period in 1985. Although no data were obtained in 1985, because the fishways were damaged and never repaired to a satisfactory operational condition, the hydrological records (1984-85) will be discussed later, in relation to the necessity or otherwise for permanent fishway installations at the weir on the Riviere des Rochers and on the Revillon Coupe.

2.3 Physical and Chemical Data

Data were gathered twice daily (0800h and 2000h) on air and water temperature. Dissolved oxygen concentration and pH was determined once daily at 0800h, using a Chemetrics Model No. 0-12

Plate I. Modification of fish trap lead, by placing 4mm plywood inserts at upstream "V" opening. Aperture in "V" is reduced from 20cm to 10cm, to prevent escape of fish downstream.

dissolved oxygen test kit color comparator for oxygen and a Fisher Scientific Co. No. A-983 Alkacid tester color comparator for pH (range 6.0 pH to 8.5 pH). Turbidity was determined by use of a Secchidisc in a quiet surface area of the lower channel.

2.4 Fish

All fish ascending the two fishways were sacrificed to provide data on length, weight, sex and state of sexual maturity.

2.5 Fishway Hydraulics

2.5.1 Vertical Slot Fishway

Fishway hydraulics were determined for the slots at the lower end of each of the 5 upper pools on the vertical slot fishway, using a Model No. 625 Teledyne Gurley Pygmy Current Meter. This meter was calibrated against a Nixon Streamflow 1 cm impeller mini current meter in the T Blench Hydraulics Laboratory, Department of Civil Engineering, University of Alberta. The calibration test curve is shown in Figure 4. Because water velocities in the slots of the vertical slot fishway were expected to approximate 1 m/s (J. Parkinson, personal communication) an electronic counter was used to record the revolutions of the current meter over a 1-minute interval, rather than using earphones and counting the clicks produced by the contact on the revolving meter. Because both the

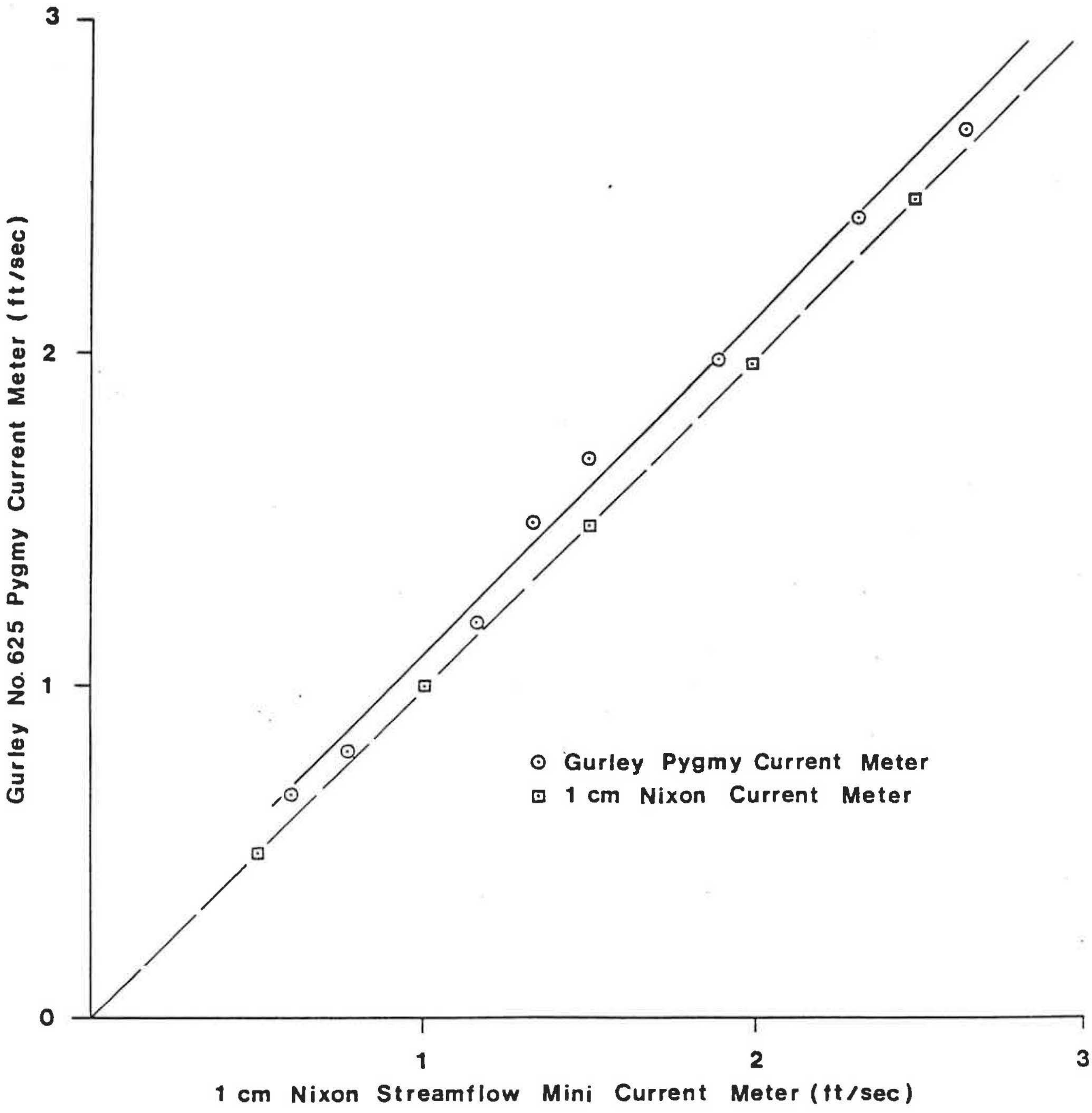

Figure 4. Calibration test curve for Gurley No. 625 Pygmy current meter, calibrated against 1 cm Nixon Streamflow Mini current meter. (test carried out at the T. Blench Hydraulic Laboratory, University of Alberta)

Gurley and Nixon current meters provide readings in feet per second, these readings were later converted to metric equivalents (1 ft/s = 30.48 cm/s).

2.5.2 Denil Fishway

Because extensive published information was available on a Denil fishway of the same scale as that installed on the Riviere des Rochers, detailed hydraulic measurements were not made within the Denil fishway. Instead, for comparative purposes, one series of measurements was made on 10 June 1984 at the same location and over the same depth range as measurements carried out on 17 May 1984 by researchers from the T Blench Hydraulics Laboratory at the University of Alberta.

3.0 RESULTS

Requirements for data collection and analyses are contained in Appendix 1. Outlined below are those portions of the project where useful results were obtained; physical conditions prevented successful achievement of most objectives, which will be discussed later.

3.1 Air and Water Temperatures

Air and water temperature were recorded daily at the Riviere des Rochers test site between 6 May 1984 and 14 June 1984. These data are shown in Figure 5.

3.1.1 Air Temperature

Air temperature was generally low between 6 May 1984 and 14 June 1984, when field studies were suspended. It might have been expected that air and water temperature would be correlated, for most of this period, but such was not the case.

3.1.2 Water Temperature

From Figure 5 it may be seen that between 6 May 1984 and 26 May 1984 water temperature at the site never rose above 3°C and

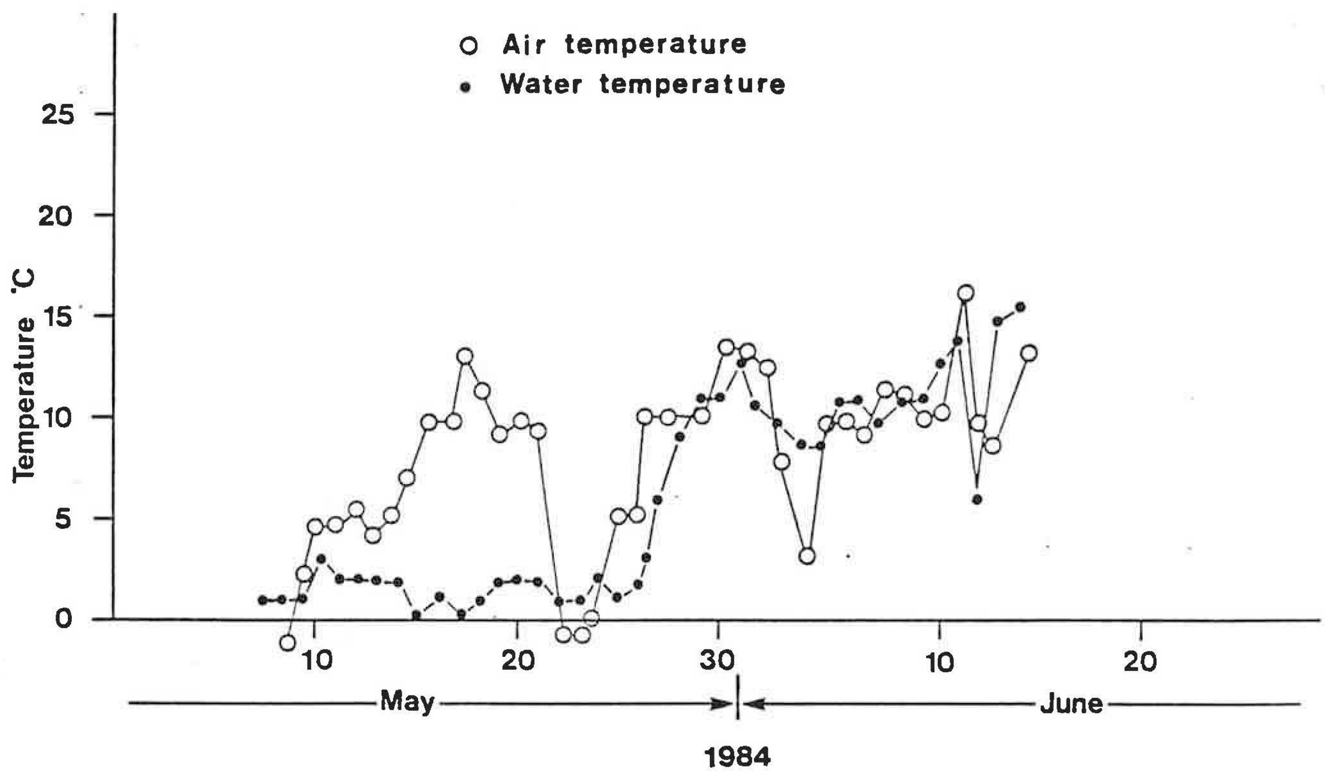

Figure 5. Air and water temperatures on Riviere des Rochers between 07 May 1984 and 13 June 1984

generally was between 0°C and .2°C. On several occassions during this period, large amounts of ice were observed passing down the main channel of the Riviere des Rochers. Between 6 May 1984 and 20 May 1984 access by boat between the test site and Fort Chipewyan was not possible because of heavy ice accumulation in the western end of Lake Athabasca and the upper 5 km of the Riviere des Rochers. The ice packed in the shallow water of Lake Athabasca and its drainage channels was presumed to be the major contributing factor to the very low water temperatures recorded at the fishway test site on the Riviere des Rochers.

3.1.3 Dissolved Oxygen

Dissolved oxygen was determined in the Riviere des Rochers at a sampling site immediately above the upstream entrance to the channel in which the test fishways were installed. At no time did the amount of dissolved oxygen drop below saturation, and was virtually constant at saturation level between 6 May 1984 and 14 June 1984.

3.1.4 Turbidity

Turbidity of water at the sampling site was high during the period between 6 May 1984 and 14 June 1984. The Secchi disc used to measure turbidity was not visible at a depth of more than 5.0 cm at any time, and generally not visible at a depth of more than 3.0 cm.

3.1.5 pH

The measurement of pH indicated a level of 6.0 for this chemical parameter. Although the colorimetric determination of pH by the method employed is somewhat crude, changes in pH of 0.5 units are easy to detect, and the results indicate very little change in pH over the period of sampling, between 6 May 1984 and 14 June 1984.

3.2 Water Levels

Water levels in the Peace-Athabasca Delta are obtained by Alberta Environment at a number of locations from recording manometers. These records for the period 6 May 1984 to 14 June 1984 and for 07 May 1985 to 13 June 1985 are shown in Figures 6 and 7.

In 1984, flows in the Slave River, about 15 km below the Riviere des Rochers test site, apparently had fluctuated widely prior to commencement of the fishway study. It is known from hydrological records that water levels in the Peace-Slave system strongly affect water levels in the outlet channels from Lake Athabasca (Peace-Athabasca Delta Project, 1973). An aerial inspection of the fishway test site on 30 April 1984 by Alberta Environment had revealed that the Riviere des Rochers weir and fishways were overtopped by high water from downstream in the Riviere des Rochers. As a consequence, flow in the Riviere des Rochers had reversed, and was southward, toward Lake Athabasca. Implications of fluctuating river levels on fish movements will be

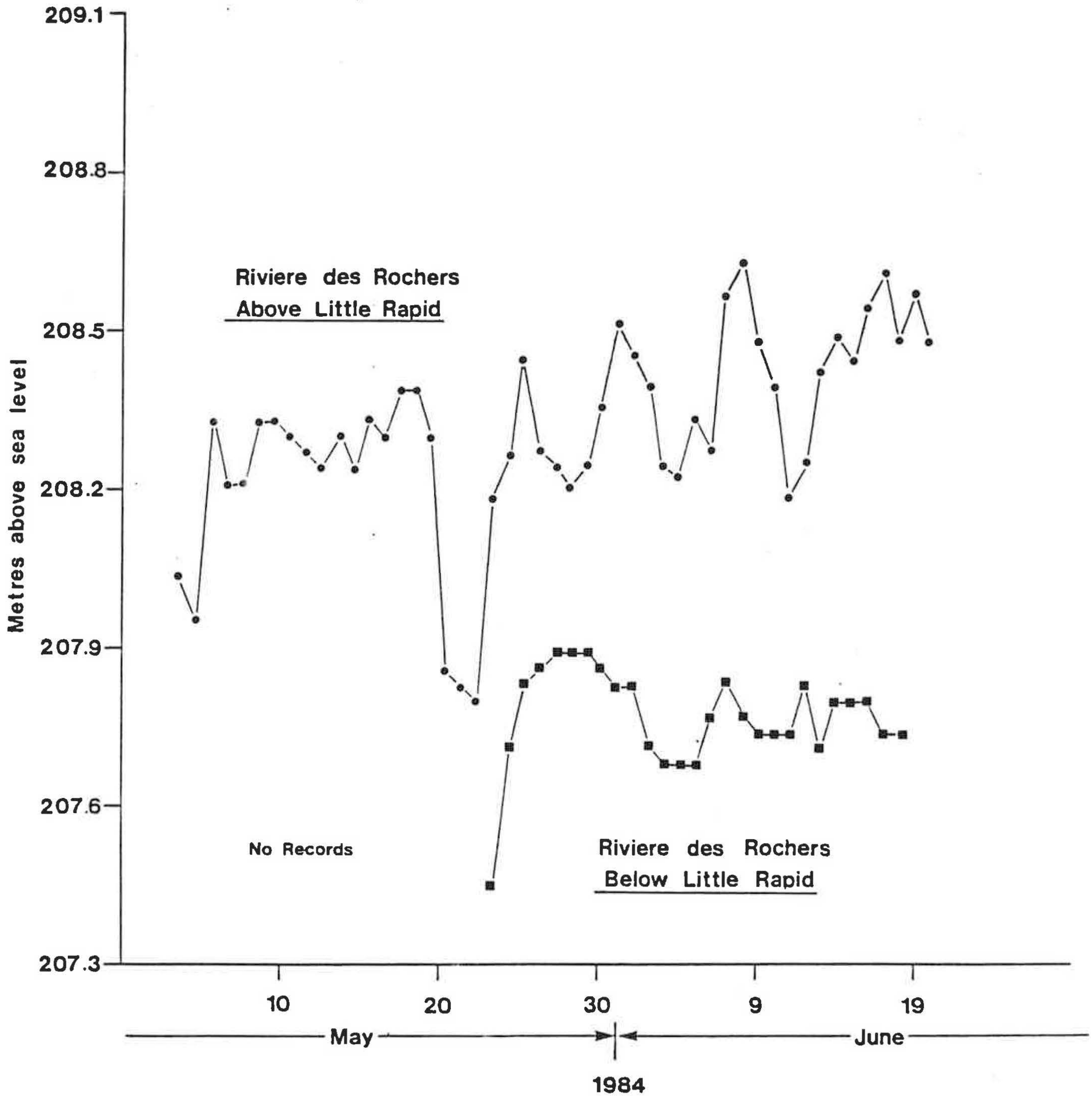

Figure 6. Water levels in Riviere des Rochers, above and below the fishway test site, between 05 May 1984 and 20 June 1984.

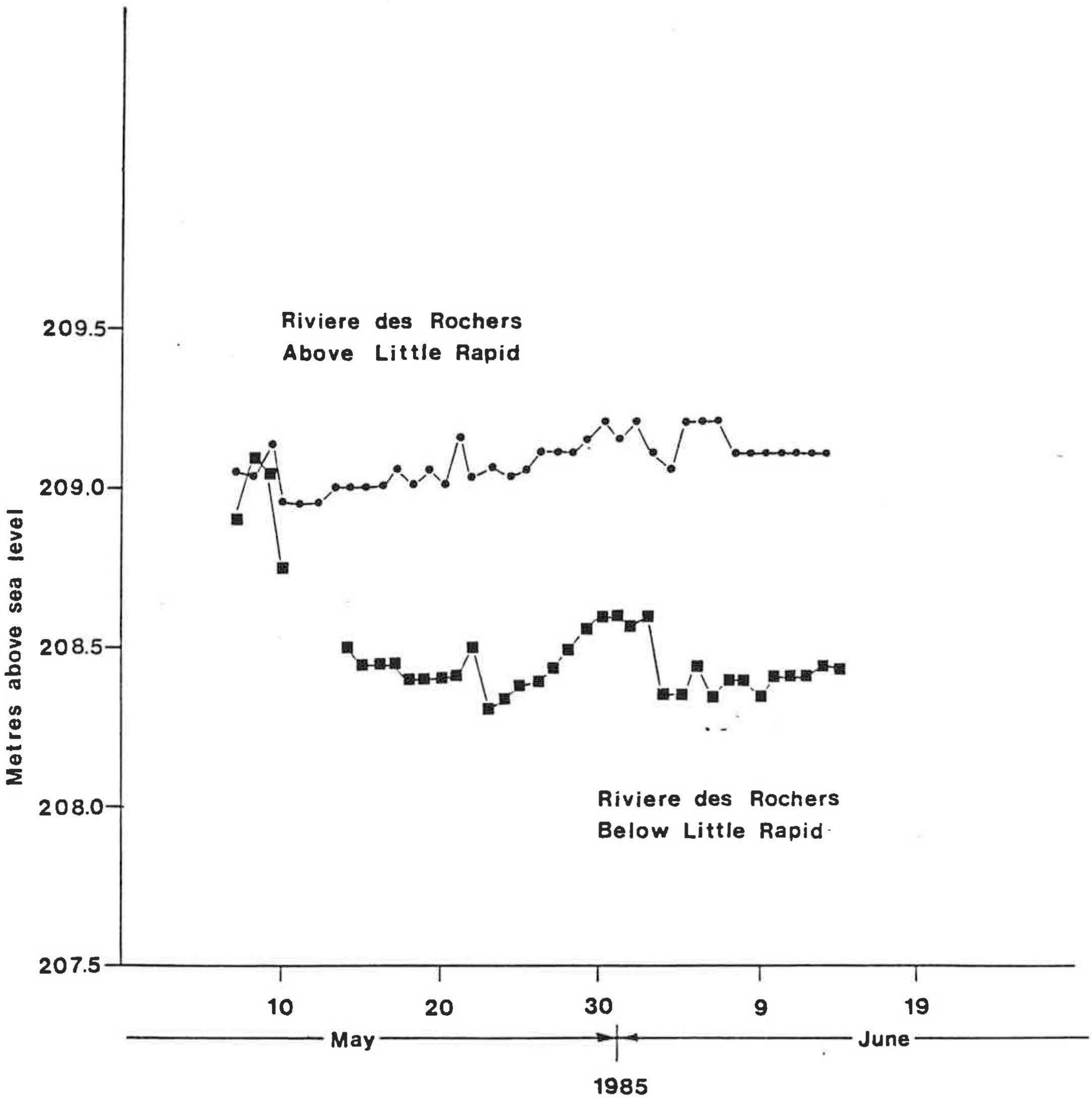

Figure 7. Water levels in Riviere des Rochers, above and below the fishway test site, between 07 May 1985 and 14 June 1985. (The test fishway installations are overtopped approximately at 208.5 m downstream elevation.)

discussed later.

Fluctuations in water levels on Lake Athabasca are reflected in similar fluctuations in water levels in the outlet channels from the lake. Ice jams in the shallow water of Lake Athabasca at the entrance to outlet channels may also affect water levels for considerable distances downstream. Between 19 May 1984 and 21 May 1984, when ice jams existed from Fort Chipewyan to a point 5 km down the Riviere des Rochers, a drop in the water level of 50 cm was observed at the fishway test site (Figure 6). It is assumed that ice jamming was the cause of this drop in water level at the site because a similar drop in water level at Fort Chipewyan was not recorded for the same period.

Another factor which may result in fluctuating water levels in outlet channels from Lake Athabasca is the occurrence of seiches (wind tides) on the Lake. From examination of hydrographs for Lake Athabasca and Riviere des Rochers (Kristensen and Parkinson, 1983) it is apparent that water levels at the test site on Riviere des Rochers are generally about 30 cm lower than at Fort Chipewyan (allowing an appropriate time for the water to reach the site) and closely approximate the pattern of fluctuation at Fort Chipewyan. The effect of a seiche on water levels in Lake Athabasca is illustrated by the hydrograph at Fort Chipewyan for the period 29 May 1984 to 01 June 1984 (Figure 8). A very strong east wind, followed by a strong west wind, produced a fluctuation in lake level between a high of 209.46 m (687.2 feet) above sea level and a low of 207.42 m (680.5 feet) above sea level. Hydrographic records for Lake Athabasca indicate that fluctuations in lake level of 2 m or more at Fort Chipewyan are not rare. The

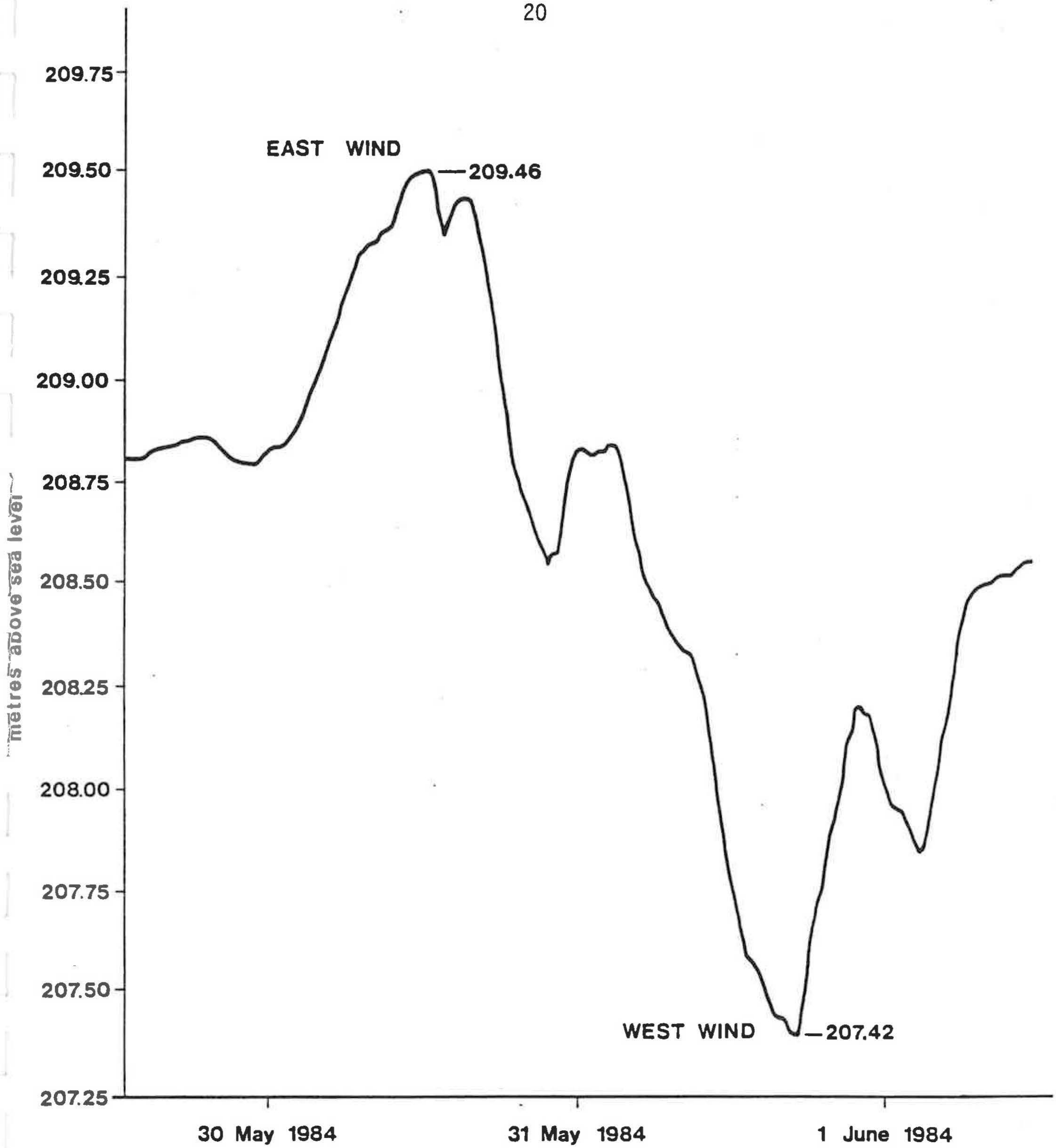

Figure 8. The effect of a seiche (wind tide) on the surface elevation of Lake Athabasca at Fort Chipewyan, Alberta.

significance of fluctuations in lake level on operation of fishways will be discussed later.

3.3 Fish

3.3.1 Fish Movements

No large movement of fish through either of the test fishways was detected during the period of observation (6 May 1984 to 14 June 1984). Only 55 fish were captured in the fishways during the entire period of operation. During most of May it would be unlikely that fish activity would be high in water temperatures ranging between 0°C and 3°C. When water temperature in the Riviere des Rochers finally rose toward the 10°C level (28-29 May) high flows in the Peace River resulted in rising water levels in the Riviere des Rochers. Between 28 May 1984 and 14 June 1984, the mean head difference across the weir on the Riviere des Rochers was seldom over 60 cm, which probably permitted upstream migration of fish across the weir. In any event, rise in water temperature was not accompanied by movement of significant numbers of fish through the test fishways.

3.3.2 Fishway Performance

Of the 55 fish captured in the fishways, 40 ascended the vertical slot fishway and 15 ascended the Denil fishway. These numbers are not considered reliable, because some fish were observed escaping downstream through the fish trap lead at the upper end of the Denil fishway, and also may have escaped in a similar fashion in the vertical slot fishway. Because of extreme turbidity of the water, it was not possible to see more than the occasional fish movement in the fishways, when fish were swimming at the surface of the water.

Examination of the very limited data pertaining to ascent of fish through the test fishways indicates than any statistical analysis of preference by fish for either the Denil or the vertical slot fishway would be pointless. Goldeye, northern pike, walleye, lake whitefish, longnose sucker and ling were captured. Of the 55 specimens captured, 26 were goldeye and 21 were lake whitefish. For goldeye, 25 of 26 specimens ascended the vertical slot fishway, and for lake whitefish, 9 of 21 ascended the vertical slot fishway. As indicated above however, no clear pattern of preference should be ascribed to fish movements through either structure. Captures of fish in the two test fishways are listed by numbers of each species in Table I.

Table I. Numbers of 6 species of fish captured in two test fishways on the Riviere des Rochers, 1984.

SPECIES	FISHWAY	
	DENIL	VERTICAL SLOT
Goldeye	1	25
Lake Whitefish	12	9
Northern pike	-	2
Walleye	-	2
Longnose sucker	2	-
Ling	2	-
Totals	17	38

3.3.2 Sex Ratio of Goldeye Captured in Fishways

Data are available from previous studies of goldeye sampled in the Peace Athabasca Delta, with which the sex ratio of goldeye captured in 1984 may be compared. Table II lists sex ratios of several samples of goldeye, and it appears as if there may have been a shift in sex ratio toward a higher percentage of females since 1977. The samples shown in Table II are relatively close to evenly balanced sex ratios for most years up to and including 1977. The samples of goldeye obtained by Kristensen and Parkinson (1980) from three sites are heavily skewed toward females. The samples of goldeye obtained from the fishways on the Riviere des Rochers in 1984 are very small, but not inconsistent with those obtained in 1980.

Table II. Sex ratios of goldeye from outlet channels of Lake Athabasca between 1947-48 and 1984.

Sample Location	Year Sampled	Percent Females
Chenal des Quatre Fourches	1947-48	57
Revillon Coupe	1977	48
Riviere des Rochers	1977	49
Chenal des Quatre Fourches	1977	42
Riviere des Rochers	1980	85
Revillon Coupe	1980	89
Chenal des Quatre Fourches	1980	71
Riviere des Rochers	1984	77

3.3.3 Size of Goldeye Captured in Fishway

Because of the small sample size of goldeye captured in the fishways, it was not possible to construct a length frequency histogram which would provide a meaningful description of size of fish in the sample. However, if the mean fork length of goldeye sampled in 1984 is compared to the large samples obtained by Kristensen and Parkinson in 1980, it may be seen that the 5325 goldeye in the 1980 study had a mean fork length of 305 mm, while the sample in 1984 had a mean fork length of 262 mm. Whether the sample of 26 goldeye obtained in 1984 was representative of the population as a whole is open to question.

3.3.4 Reproductive Condition and Age of Goldeye

Of the 26 goldeye examined for state of sexual maturity, only 3 contained gonads which weighed more than 1 gram. These 3 fish were females which were judged to be in a state of sexual maturity which would have resulted in full maturation in 1985. These 3 females were each 7 years of age. For the remainder of the sample of females (17 fish) 8 were 6 years of age; 5 were 5 years old; 2 were 4 years old; and 2 were 3 years of age. For the 6 males, 3 were 5 years old and 3 were 4 years of age.

3.4 Fishway Hydraulics

Because of a delay in receiving the Gurley Pygmy current meter, plus unsuitable water levels in the fishways, hydraulic measurements were not attempted in the fishways until 6 June 1984. Plates II, III and IV show the fishways in relation to water levels on that date. On this date also the water level in the Riviere des Rochers was such that tailwater effects began to show in lack of head differences in the lower pools of the vertical slot fishway and with the lower end of the Denil fishway under water (Plate V). On 10 June 1985, water velocities were measured in the 4 slots between the five pools of the vertical slot fishway (pool number 1 is the furthest upstream) and on the centre line of the Denil fishway. On this date, a head difference of 50 cm existed across the structures. An attempt was made to measure water velocities in the slot between pools 4 and 5, but it was obvious that these measurements would be meaningless because of tailwater effect. The velocities measured in the vertical slot fishway are shown in Table III, and for the Denil fishway in Table IV. Between 10 June 1984 and 13 June 1984 water levels continued to rise until the fishways were flooded out on 13 June 1984, when field work was discontinued (Plates VI and VII).

On 17 May 1984 researchers from the T Blench Hydraulics Laboratory, University of Alberta, measured water velocities in the slot between pools 2 and 3 in the vertical slot fishway, and on the centre line of the Denil fishway, 3 m from the upper end of the latter structure. The data from both sets of measurements are shown in Figure 9 for the vertical slot fishway and in Figure 10 for the Denil fishway. From the plots in Figures 9 and 10, it may be seen

Plate II. Fishways from downstream. Head difference across structures of 60cm on 06 June 1984

Plate III. Upper end of fishways with 60cm head difference across structures on 06 June 1984. Both fishway supply flumes are spilling.

Plate IV. Lower end of fishways with 60cm head difference across structures on 06 June 1984.

Plate V. Lower end of fishways with 60cm head difference across structures on 06 June 1984. Note difference in flow pattern below Denil fishway (far side) and vertical slot fishway.

Plate VI. Upper end of fishways flooded out. No head difference across structures on 12 June 1984.

Plate VII. Lower end of fishway instllations overtopped on 12 June 1984. No head difference across stuctures.

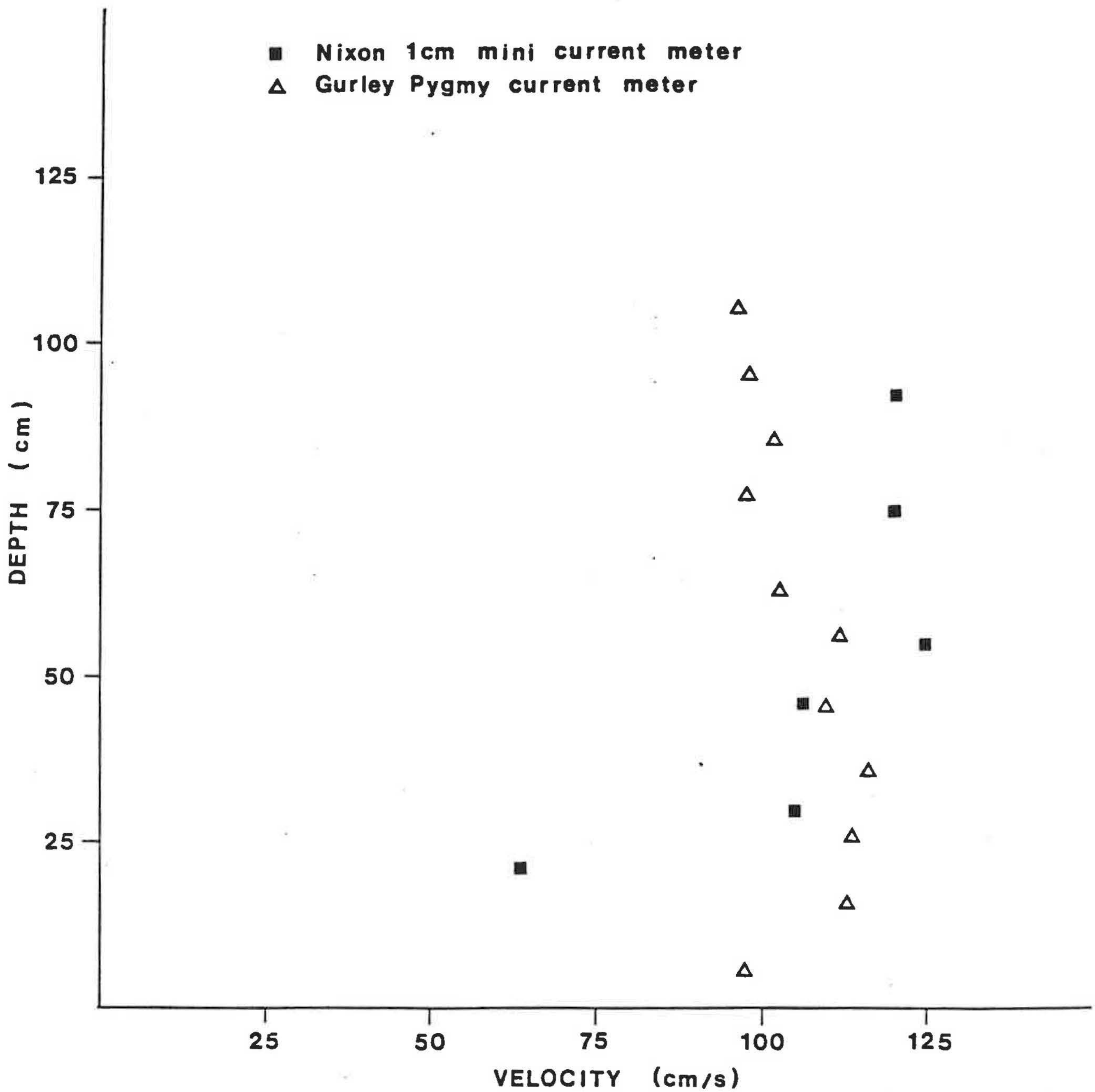

Figure 9. Velocities measured in slot between pool 2 and pool 3 of vertical slot test fishway on Riviere des Rochers, 17 May 1984 (Nixon current meter) and 10 June 1984 (Gurley current meter).

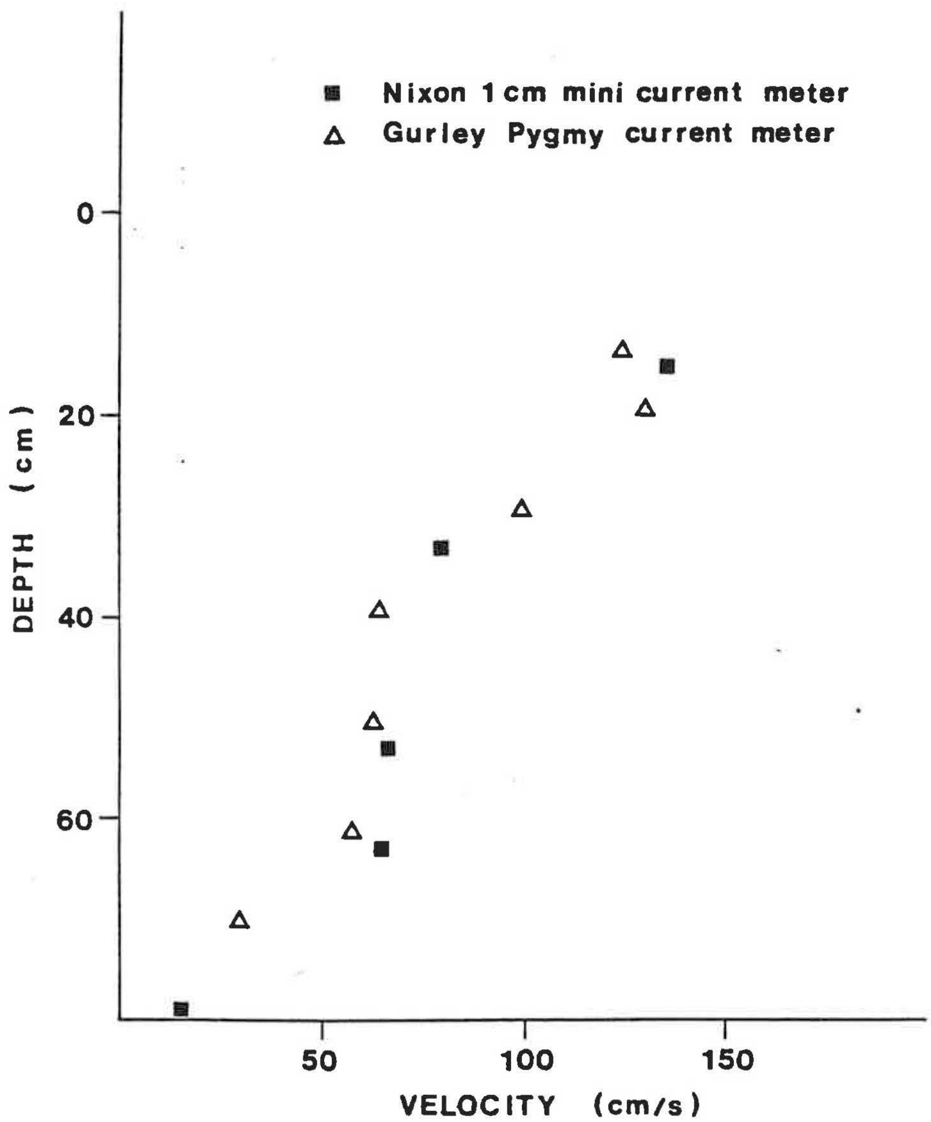

Figure 10. Velocities measured on the centre line of Denil test fishway on Riviere des Rochers, 17 May 1984 (Nixon current meter) and 10 June 1984 (Gurley current meter).

Table III. Velocities through slots between four upstream pools of the vertical slot fishway test section at the Little Rapid site on the Riviere des Rochers, 10 June 1984.

Water Depth (cm)	Velocities (cm/s) Pool 1-2	Pool 2-3	Pool 3-4	Pool 4-5
5.1	101.7	97.5	101.7	84.4
15.2	101.7	112.8	102.7	91.4
25.4	111.9	114.3	102.7	91.4
34.6	107.6	115.8	97.5	92.9
45.7	99.7	109.7	92.4	76.2
55.9	97.5	110.3	94.5	91.4
66.0	101.7	101.7	97.5	96.6
76.2	90.5	94.5	93.9	96.0
86.4	63.1	101.2	93.9	94.5
96.5	36.6	97.5	95.4	92.4
106.7	30.5	95.4	99.1	82.3
Total Depth (cm)	127	127	135	145

Note: Total water depth in slot is measured from water surface to floor of pool; velocities are recorded at regular intervals from surface. Pools are numbered from upstream to downstream.

Table IV. Velocities measured in Denil fishway test section at the Little Rapid site on the Riviere des Rochers, 10 June 1984. Measurements were made 3 m from the upper end of the fishway

Water Depth (cm)	Velocities (cm/s)
10	124.9
20	129.6
30	99.8
40	64.9
50	62.9
60	57.1
65	32.3

that there is a tendency for the Gurley Pygmy current meter to provide readings which are higher in the upper range of velocities and lower in the lower range than those recorded with the Nixon Streamflow 1 cm mini current meter. It may also be seen from Figure 9 that the readings obtained in the vertical slot fishway with the Gurley Pygmy current meter have a more compressed range of velocities than those obtained with the 1 cm Nixon mini current meter, which may indicate a slight interference with flow in the slot, caused by the larger Gurley Pygmy meter.

Data from velocity measurements carried out by University of Alberta researchers were extracted from Katopodis *et al.* (in press) with the permission of the authors. A schematic of a portion of the vertical slot fishway, showing the location of velocity measurements, is shown in Figure 11.

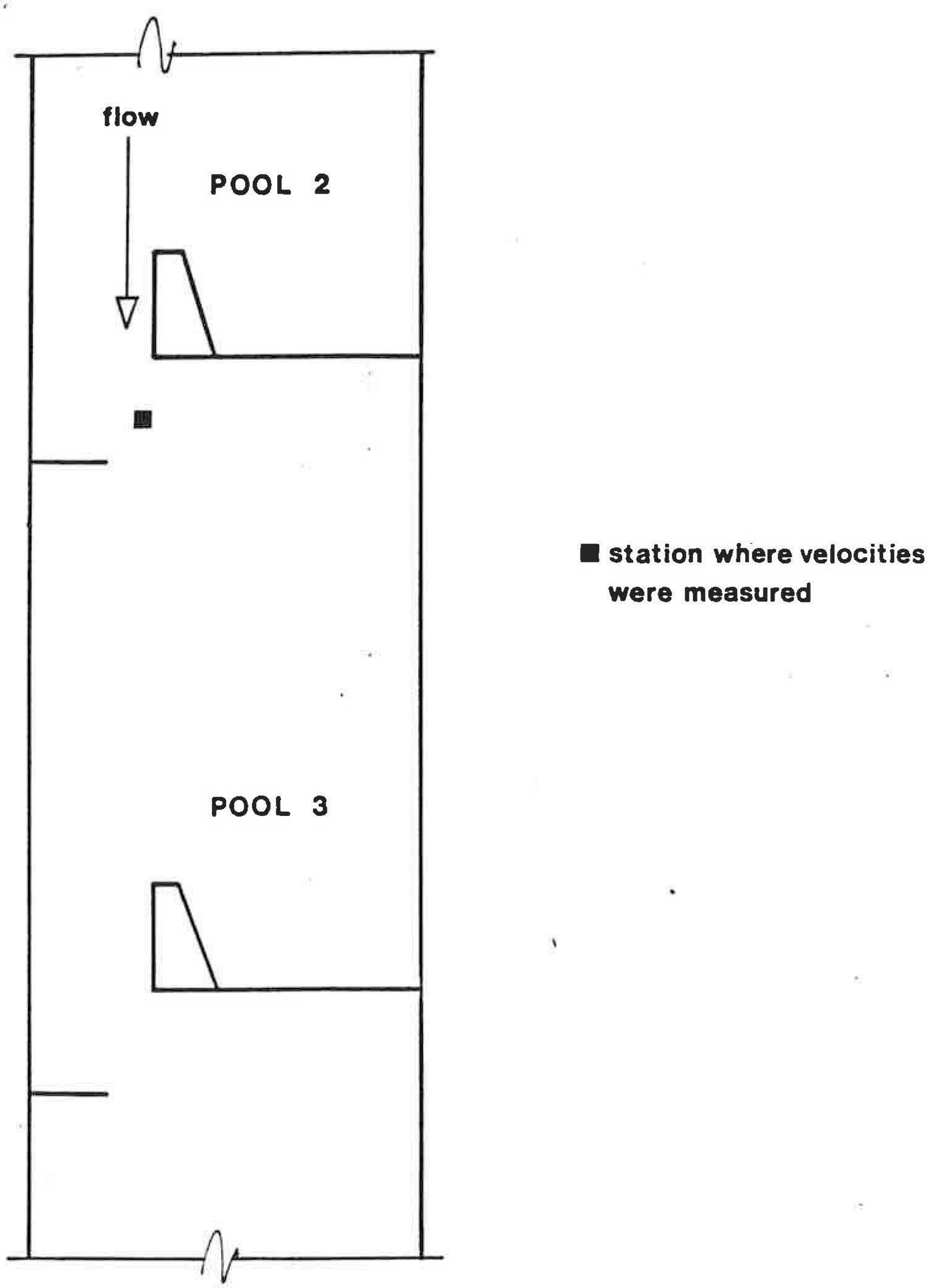

Figure 11 . Schematic of portion of vertical slot fishway, showing location of station where water velocities were measured.

4.0 DISCUSSION

The project discussed in the preceeding pages was carried out under adverse field conditions. Almost continuous flow of ice in the Riviere des Rochers, with water temperatures at the site in the 0°C - 3°C range between 9 May 1984 and 26 May 1984 very likely was the cause of lack of fish movement during this period. When the Riviere des Rochers was finally free of ice, rising water levels in the Peace-Slave River system resulted in high tailwater levels at the fishway installations. These water levels prevented experimental measurement of hydraulic performance of the two test fishways, except on a very limited basis.

The terms of reference for the study are contained in Appendix 1. Section A outlines the general objectives for the study, which, broadly speaking, was to assess the hydraulic performance of the test structures and to document the preference by fish for either structure under a variety of hydraulic conditions. These objectives could not be met because of lack of fish movement and unsuitable water levels.

Notwithstanding the occurrence of unsuitable field conditions, some data which were gathered at the project site may be useful to an assessment of fish passage at the weir on the Riviere des Rochers (and possibly also at the weir on the Revillon Coupe). With respect to dissolved oxygen, pH and turbidity, these were virtually constant throughout the period from 9 May 1984 to 14 June 1984, and indicate that they are not significantly variable with respect to fish. They are all within reported ranges for optimum conditions for fish habitat, and require no further investigation. Low temperatures likely severely restricted fish movements in the

Riviere des Rochers, but it is not known if the occurrence of low temperatures, with subsequent delay of about two weeks in fish migration would have an effect on reproductive success for species proceeding to upstream spawning areas. Both Donald and Kooyman (1974) and Kristensen and Parkinson (1983) suggest that delay in migration of goldeye to the Lake Claire-Mamawi Lake system could adversely affect the successful rearing of larval goldeye.

Water levels at the weir on the Riviere des Rochers (and Revillon Coupe) are critical to the ascent of fish from the Peace-Slave system to spawning and feeding areas in the Peace-Athabasca Delta. From previous studies, Kristensen *et al* (1976); Kristensen and Summers (1978) and Kristensen and Parkinson (1983), it is apparent that the weirs present an impediment to fish passage at head differences across the structures of about 60 cm and a total block to fish migration with a head difference of 100 cm or more. Water levels in rivers fluctuate widely, and there is no guarantee that blockage will not occur at critical times or for critical periods at either or both of the weirs. From the limited amount of data obtained on fish movement through the Denil and vertical slot fishways, it is not possible to state which of these structures would be more suitable to effect fish passage at the weirs. However in view of the comments above regarding delays which might be caused by adverse temperature or head differences across the weirs, the following would appear to be applicable:

(1) Any fishway installation should be operational over all ranges in river levels and head differences at the weirs on the Riviere des Rochers and Revillon Coupe.

(2) Fish are continually present and probably motivated by food requirements, state of maturity and environmental cues to migrate upstream from the Peace-Slave river system in outlet channels from Lake Athabasca; fish passage facilities thus should operate at all times of the year except when ice conditions preclude movement of fish.

(3) Fishways should be as maintenance-free as possible, and able to withstand ice conditions and debris.

With regard to the hydraulics of the two fishways, the limited measurements made in the Denil test fishway appear to agree very closely with those of Katopodis (1981) and are confirmed by measurements on site by Katopodis *et al* (in press). The measurements of velocities in the vertical slot fishway also agree reasonably well with those taken by Katopodis *et al*, on site, especially since they were taken by different people on different dates with a head difference across the structures of 10 cm between the dates of the two tests (17 May 1984 and 10 June 1984). The velocities measured in the vertical slot fishway average between 100cm/s and 120 cm/s for results obtained with the Gurley and Nixon current meters respectively.

Because of the small number of fish which ascended the test fishways, it would be speculative to assign any degree of confidence to an assessment of fishway preference, or ease of ascent. However, if the velocities in the vertical slot fishway presented a serious impediment to the ability of fish to ascend this structure, it would hardly be expected that 38 of 55 fish would ascend the vertical slot fishway in comparison to 17 speciments which passed through the Denil fishway. The velocities of 100 cm/s to 120 cm/s are suitable for "burst speed" performance of kokanee, rainbow trout and mountain whitefish (20-30 cm) in vertical slot fishway installations in British Columbia (D. Narver; personal communication). It is unlikely that goldeye, walleye, lake whitefish or pike would have difficulty ascending through the slots of a vertical slot fishway.

Biological data on goldeye captured in this study are very limited, but as discussed in Section 3.3 appear to be reasonably consistent with those from previous studies, including a strongly skewed sex ratio towards females. At least one observation, made on 20 July 1984, indicates that many thousands of immature goldeye (10 cm length range) were blocked from proceeding upstream on the Riviere des Rochers. A band of these fish approximately 0.5 m wide and approximately 100 m long, on the right bank of the main channel of the Riviere des Rochers was observed on 20 July 1984. Observations over a 30 minute period at the point where the water flows over the weir and against the right bank revealed that these small goldeye were not capable of passing the weir. No data are available on young goldeye and the possible effect of the weirs on their normal migratory behavior. Kristensen and Parkinson (1983) suggest that growth of goldeye captured while ascending the Chenal des Quatre Fourches, Revillon Coupe and Riviere des Rochers may have been reduced since 1975, because the goldeye population in the Peace-Slave river system now has reduced access for these fish to feeding areas in the Peace-Athabasca Delta because of the weirs on the Riviere des Rochers and Revillon Coupe. The small goldeye discussed above were frequently observed in the fish trap at the upstream end of the vertical slot fishway, so that they presumably could ascend this structure, although they may have descended the channel from above.

As mentioned earlier, it would be difficult to suggest that either the Denil or the vertical slot test fishway would be more effective in passing fish over weirs on the Riviere des Rochers or Revillon Coupe. If permanent fishway facilities are to be installed on the two weirs, it would seem prudent to design the major structural components in such a fashion that both Denil and vertical slot fishways could be installed in parallel. If this were done, then it would be a relatively easy and inexpensive task to evaluate fishway performance and preference by species for one structure or the other. If one fishway were to be seen as clearly superior to the other, it would be a simple matter to exchange the functional portion of the less effective structure with that which had proven to be more efficient in passing fish. It might well prove to be the case that a combination of a Denil and a vertical slot fishway could provide the best solution to passage of fish, particularly when dealing with a multi-species complex, several year and size classes, as well as differing sex ratios and states of sexual maturation.

A final consideration involves the question of whether permanent fishways are required at the weirs on the Riviere des Rochers and Revillon Coupe. It has recently been suggested that model studies of the weirs indicate a high probability for successful fish passage during the month of May. It should be emphasized however, that all the studies of fish at the weirs referred to earlier show beyond reasonable doubt that very large numbers of fish (up to 1,000,000 at a time) may be blocked from ascending the weirs both on the Riviere des Rochers and Revillon Coupe. Very little is known concerning the importance of the Peace-Athabasca Delta to young fish which apparently over-winter in the Peace-

Slave river system. The fact that many thousands of immature goldeye were observed to be blocked at the weir on the Riviere des Rochers on 20 July 1984 suggests that based on hydraulic model studies, broad generalizations concerning fish movements at the two weirs may not be supportable without direct sampling of fish over extended periods. Whenever fish have been sampled in large numbers at the weirs, the results have consistently and conclusively shown that both weirs constitute major obstacles to fish migration. In view of these facts, it would seem unwise without very conclusive evidence to abandon the proposition that permanent fishways should be installed at the weirs on the Riviere des Rochers and Revillon Coupe.

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Appendix 1.

Terms of reference - Peace-Athabasca Delta fishway evaluation of vertical slot and Denil II fishway prototype.

A. OBJECTIVES

The objectives of this evaluation are to compare the performance of insitu vertical slot and Denil II fishways which have been temporarily placed in the old "fishway rock channel or bypass" within the Riviere des Rochers site near the Peace-Athabasca Delta.

Alberta Environment, in conjunction with the Federal Department of Fisheries and Oceans and the Fish and Wildlife Division of Alberta Energy and Natural Resources, require that sufficiently detailed monitoring of fish passage be conducted in the spring and early summer of 1984 to permit evaluation of the following:

1. an assessment of the hydraulic performance of each fishway over a range of upstream and downstream water surface elevations;

2. an assessment of the comparative ascent rate of each fishway type for the fish species present under various hydraulic conditions;

3. an assessment of fish preference for the two fishways under similar head conditions and with and without the auxiliary attraction water supply pipes operating on the vertical slot fishway;

4. an assessment of which fishway or combination of fishways would be most suitable for permanent installation at the site with recommendations and justification for suitable modifications to to the designs tested; and

5. an assessment of the percent of fish of each species that successfully ascended the fishways and associated delay times in migration attributable to the fishways.

B. GENERAL STUDY REQUIREMENTS

1. The study shall commence on-site only with the consent of the client departments (Alberta Environment, abbreviated as AE, and Department of Fisheries and Oceans, abbreviated as DFO). Local break-up and water level conditions and the soundness of the installed fishways shall determine the start-up date.

2. The fishways shall be operated under test conditions for a minimum of 45 field days.

3. The fishways shall be left in an operational state upon completion of the field work.

4. The site shall be left in a tidy condition with the consultant's equipment and debris being removed from the site.

5. All permits required to conduct the study shall be the responsibility of the consultant.

6. The client departments reserve the right to make changes in study design and scheduling such as may be dictated by site or biological conditions in the field.

7. The consultant shall construct a safety railing along the fishway based upon design and material provided by AE. The purpose of the railing will be to ensure the safety of people working on the fishway monitoring program.

C. HYDRAULIC COMPONENT

1. Describe the hydraulic performance of the two fishways under various conditions of flow and various head differences.

2. Measure, record and map the water velocities and depths in the fishways under the full range of conditions experienced during the period of the monitoring. It may be necessary to simulate low head conditions by controlling inflow in the intake flumes.

3. Record the water levels daily within the fishways and upstream

and downstream at suitable locations near the fishways. Water levels within each pool of the vertical slot fishway and at five points at regular intervals over the full length of the Denil II fishway.

4. Obtain current meter readings in the timber flumes immediately upstream of each fishway at points specified on the attached drawing. Such readings shall be taken during the first week as soon as possible upon arrival on the site, on a weekly basis thereafter, and whenever headwater, tailwater or both have changed by more than 150 mm (6 inches). AE will provide advice on metering procedures.

   a. <u>Metering Procedures</u>

   i) Readings

   Readings with the proposed Pygmy Current Meter are to be taken at the points indicated on the attached sketch. Readings are to be taken at 0.2, 0.4, 0.6 and 0.8 of the water depth (D) at the centre line and at 300 mm (12 inches) left and right. Furthermore, point readings are to be taken 0.2 and 0.8 (D) at 150 mm (6 inches) from each wall.

   ii) Location

   The readings are to be taken in the four-foot wide flume portion of the installations upstream of the Vertical Slot Fishway at about Section A-A (see Drawings PEATD 0383 and 0483, sheets 2 and 3) or about 1.8 m (6 feet) upstream of Section A-A. The final selection is to be made in the field taking into account site conditions. The intent is to select a location with steady and uniform flow conditions free from local disturbances possibly associated with other elements of the installation.

   A similar location, at about the midpoint of the four-foot flume upstream of the Denil II fishway should be selected in the field, again avoiding local disturbances to flow.

   iii) Timing

   The initial reading should be taken as soon as possible during the first week on site and repeated thereafter on a weekly basis and whenever significant changes in water levels, in either headwater, tailwater or both, have occurred. A 150 mm (6 inch) change is considered significant. Readings in the vertical slot fishway shall be repeated with the auxilliary pipe closed.

iv) Alberta Environment Readings

Staff of the Technical Services Division, Water Survey, in Fort Chipewyan will periodically meter at the site for checking purposes using departmental equipment. They are prepared to advise the consultant's staff on metering procedures.

v) Velocity Estimates

The readings taken on the verticals shall be plotted, and a curve fitted to facilitate velocity distribution estimation.

vi) Discharge Estimation

The velocity estimates obtained above shall be used to determine the discharge by integrating the velocity distribution across the flow prism.

5. Record water temperatures, twice daily, and dissolved oxygen and turbidity at suitable intervals.

D. BIOLOGICAL COMPONENT

1. The consultant shall be required to construct and maintain, for the duration of the field study, a downstream fence to control fish passage including upstream and downstream traps. The fence shall be constructed at a site agreed to by the consultant and AE.

2. At the downstream fence, the consultant shall trap, tag and release fish moving upstream during the spring migration period. The fish traps shall be serviced at regular intervals to prevent prolonged confinement in the traps. If tagging appears to deter migration through the fishways it may be necessary for AE and consultant to devise an alternate tagging schedule.

3. The consultant shall regulate the flow of water through the two fishways in the initial phases of the study to maximize fish passage in both structures. When a satisfactory baseline condition has been determined the testing priority shall be to define the limitations of each fishway.

4. The vertical slot fishway shall be tested and compared to the Denil II, with and without the attraction water pipes flowing (in the vertical slot design).

5. The consultant may, in certain instances considered within the safety limits of the structures, shut one fishway off entirely and operate or test only one fishway.

6. The consultant shall estimate the daily downstream population (between the downstream fence and fishway) and the ascent delay times for each species present.

7. The consultant shall report the species, lengths, number, sex, reproduction conditions, and ascent times of the major species present.

8. Determine if additional attraction techniques such as augmented flow, turbulence or surface spray, enhances fish movement into and through the fishways.

9. The consultant shall release fish successfully negotiating the fishway, above the fishway, having first recorded the appropriate biological information.

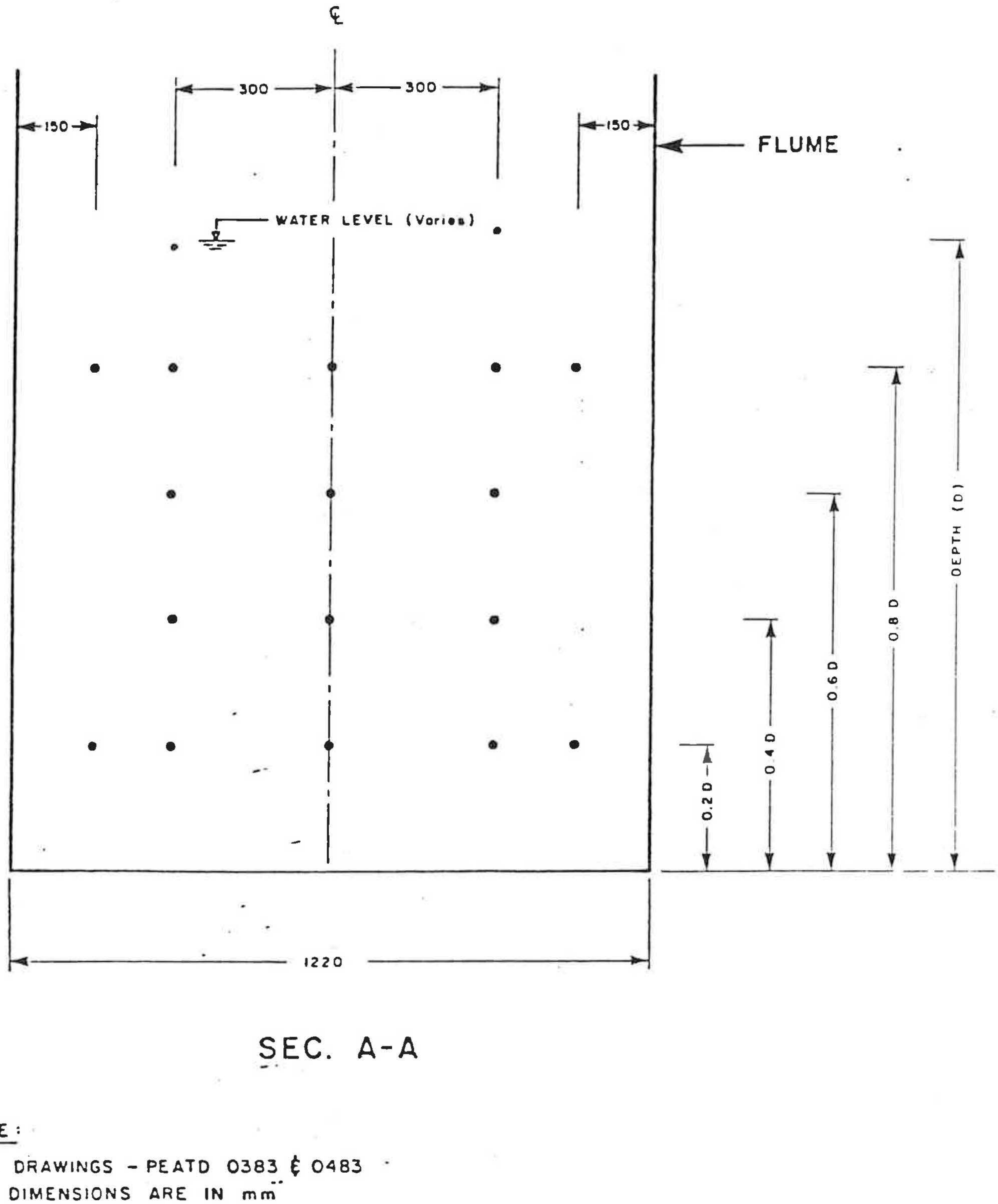
E. <u>REPORTING</u>

1. The consultant shall be responsible to inform AE of the progress of the field studies on a weekly basis. The report shall detail the numbers and types of reading and results achieved and report in brief form the significant events.

2. Upon completion of the field study, the consultant shall brief the client departments on the results achieved during the field program.

3. The draft report, due September 15, 1984, shall outline the fishway tested, the procedures followed during the tests and provide preliminary statistics and the data obtained.

4. The final report, due November 15, 1984, shall thoroughly document the entire field program and incorporate changes requested by the client departments. Upon completion, a formal presentation shall be made by the consultant to the Alberta Fishways Working Group. The consultant shall submit twelve copies of the final report, six to each client department.



SEC. A-A

NOTE:

REF. DRAWINGS - PEATD 0383 & 0483
ALL DIMENSIONS ARE IN mm

Alberta ENVIRONMENT		PEACE-ATHABASCA DELTA PROJECT
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ALBERTA DEPARTMENT OF THE ENVIRONMENT
WATER RESOURCES MANAGEMENT SERVICES
TECHNICAL SERVICES DIVISION

ASSESSMENT OF

CREED CREEK DIVERSION

Prepared by: L.A. Garner, C.E.T.
Technologist
River Engineering Branch

G.D. Fonstad, P. Eng.
River Studies Section Head
River Engineering Branch

Submitted by: M.E. Quazi, P. Eng.
Branch Head
River Engineering Branch

February 1986

ASSESSMENT OF CREED CREEK DIVERSION

A. History

The Peace-Athabasca delta is a 'birdsfoot delta' developed by the deposition of large quantities of fine sediment, which materials form relatively stable banks and levees for the various flow channels in the delta. Development of the delta occurs with either gradual lateral shifting of channels from one location to another, or bifurcation, which is the gradual or abrupt abandonment, in whole or in part, of one channel and transfer of the flow into another. The abandoned channel may then get filled by subsequent sediment deposits.

Examination of aerial photographs dating from 1950 to 1985 reveals that tributaries of Mamawi Creek extend into oxbow channel scars of the Embarras River. This indicates that the Embarras River has contributed flows directly to Mamawi Lake in the past. The present Creed Creek diversion (Figure 1) follows one of these oxbow channels to a tributary of Mamawi Creek.

In the Peace-Athabasca Delta Project Technical Report (1973) it was reported that overland flooding occurred from the Embarras River towards Mamawi Lake during the April, 1972, flood. It was also reported that "small incipient channels caused by this overbank flow were found in the banks of the Embarras River".

Development of the Creed Creek diversion channel to Mamawi Creek had not been documented prior to 1982. During the 1982 flood, the diversion channel developed extensively and a monitoring program was initiated by the River Engineering Branch upon request of the Peace-Athabasca Delta Implementation Committee.

B. Monitoring

Comparative photographs of the Creed Creek diversion for 1982 and 1985 are attached. In 1982, a program was set up by the River Engineering Branch to monitor the development of Creed Creek. The program included establishing and surveying cross sections in 1983 and 1985, as well as conducting discharge measurements on Creed Creek concurrently with discharge measurements on the Embarras River upstream of the Creed Creek diversion. The locations of the cross sections are shown on Figure 2, and a comparative plot of the surveys is given on Figure 3.

Table 1, below, is a summary of the discharge measurements conducted on Creed Creek and the Embarras River since 1982.

Table 1

Discharge Measurements
(Cubic Metres per Second)

Date	Embarras River	Creed Creek
Aug 25/82	70.7	19.0
Sept 09/82	52.5	13.2
Sept 22/82	50.2	9.87
Oct 06/82	30.6	14.2
July 07/83	162	28.2
July 20/83	192	39.0
Aug 04/83	304	56.4
Aug 22/83	81.6	16.7
June 12,15/84	310	81.0
June 26,27/84	180	53.6
July 12/84	180	50.1
July 26,27/84	101	41.3
Aug 09/84	76.7	24.7
Aug 23,24/84	55.6	20.5
Sept 19,20/84	82.1	26.9
June 13,14/85	122	49.2
June 27,28/85	74.4	44.6
July 10,11/85	112	51.3
Aug 08,09/85	35.8	16.2

C. Channel Development To Date

Hydraulic properties of the cross sections were calculated from the 1983 and 1985 surveys. A summary table of these properties, and an estimate of the mean bed elevation, is presented in Table 2 below.

Table 2

Bankfull Cross Section Hydraulic Properties

Cross Section	Area (m^2)	Top Width (m)	Hydraulic Mean Depth (m)	Mean Bed Elevation (m)
		1983 SURVEY		
1	198.4	34.8	5.70	22.31
2	141.4	33.9	4.17	23.95
3	133.5	26.0	5.14	19.76
4	78.1	23.3	3.35	23.21
5	75.3	21.0	3.58	21.99
6	92.3	30.7	3.01	20.50
Average	119.8	28.3	4.16	
		1985 SURVEY		
1	273.4	49.9	5.48	21.86
2	196.7	44.4	4.95	22.56
3	199.4	40.0	4.99	20.83
4	176.0	35.5	4.96	18.80
5	109.4	34.4	3.18	22.60
6	114.1	26.3	4.34	20.99
Average	178.2	38.4	4.65	

The average cross section top width has increased by approximately 36 percent, and the average channel depth has increased by about 12 percent. This has resulted in an increase in the average channel area of about 49 percent. The Creed Creek channel slope was calculated using a mean bed elevation at each cross section, and was found to be in the order of 0.00221 and 0.00116 metres per metre (m/m) for the 1983 and 1985 surveys, respectively. Creed Creek therefore appears to be primarily widening, though it is getting slightly deeper, appears to be incising itself deeper into the ground, and is adjusting its slope to a milder value through a process of scour and deposition within the reach under study. Channel widening with the passage of time, following an increase in the discharge in the channel, is characteristic of channels formed in fine sediments.

The relative discharge relationships for Creed Creek and the Embarras River are shown on Figure 4. It appears that Creed Creek is diverting an increasing percentage of the flow from the Embarras River as time progresses. However, because of the limited amount and narrow range of data, very little confidence can be placed in the relationships shown on Figure 4, other than to show a general trend. This is especially true for 1982 and 1985, where the range of surveyed discharges was limited.

From the evidence available it appears that the Creed Creek diversion is a gradual bifurcation process from the Embarras River, though whether or not this process will result in the total capture of the Embarras River flows remains to be seen. While Figure 4 shows that Creed Creek has been diverting an increasing percentage of the Embarras River discharges, it does not, nor can it, indicate what the final percentage might be, though 100% would be the ultimate. The final percentage of flow diverted will be governed by physical factors, notably the final hydraulic geometry of Creed Creek and its slope.

The Embarras River is one of the numerous subchannels of the Athabasca River flowing across the delta, and an analysis for these two rivers for the years 1982 to 1984, similar to that carried out above between Creed Creek and the Embarras River, shows that there is no significant change in the relationship for the amount of diverting flow.

A calculation of the bankfull discharge capacity at each cross section along Creed Creek, based upon the 1985 surveys and the determined average channel slope of 0.00116, indicates capacities ranging from 200 to 724 cubic metres per second (m^3/sec), with a reach average of 443 m^3/sec. These capacities are far in excess of the metered discharges in Creed Creek to date, indicating that in its present form, Creed Creek can accept larger diversions from the Embarras River.

D. Future Growth

Regime, as defined by Blench (Mobile-Bed Fluviology, 1969) is "... the behaviour of a channel, over a period, based on conditions of water and sediment discharges, breadth, depth, slope, meander form and progress, bar movement, etc. ... ". Thus the term 'in regime' means that over a period of time the hydraulic geometry and other stream characteristics do not change appreciably.

From the information presented earlier, i.e. that Creed Creek has been widening, flattening and deepening over the period 1983 to 1985, it is apparent that the creek is not yet 'in regime', but is in a process of regime adjustment to the increased flows being diverted into it. Therefore, analyses of Creed Creek were conducted, based upon various regime theories, to try and predict the future development of the creek channel.

The existing slope of the Embarras River was determined to be 0.00013 m/m based upon the application of a flow resistance equation to the metered discharges and surveyed cross section at the Embarras River gauging site, upstream of the developing diversion, in 1985. This slope compares favourably with slopes reported by Kellerhals, Neill and Bray (1972) of 0.00009 and 0.00018 m/m based upon surveys conducted in 1970 and an estimate of the river slope derived from available mapping, respectively. The average of these two slopes is 0.000135 m/m.

Kellerhals, et al. also give the median bed material diameter (D_{50}) for the Athabasca River at the WSC gauging station at Embarras Airport (Station 07DD001) to be 0.19 millimetres (mm). For purposes of the regime analyses which follow, it will be assumed that the D_{50} in each of the Embarras River, Creed and Mamawi

Creeks are equal to this value, since they all flow across deltaic deposits which should be more or less uniform in size.

The top width of both Creed Creek, which for purposes of this report is taken as the portion of the diversion channel contained within the ancient Embarras River channel scar (surveyed reach), and the tributary channel of Mamawi Creek which Creed Creek flows into, which can be called the 'lower' Creed Creek, are approximately the same, and in the order of 35 m, to use round figures. For this top width, a 'reverse application' of regime theory indicates that the regime discharge capacity should be in the order of 60 m^3/sec, with a regime depth of about 1.74 m and a regime slope of about 0.000195 m/m. The present channel width adequately reflects the measured discharges in the upper Creed Creek, though the discharge capacity calculated through the application of a flow resistance relationship is in excess of what regime theory indicates it should be.

Therefore, the 'upper' Creed Creek channel width should be almost completely developed (average hydraulic properties from the 1985 survey, given in Table 2), though the channel should be shallower and much flatter. That the upper Creed Creek is deeper and steeper than what regime theory indicates may indicate that the creek is degrading into the deltaic deposits to lessen its slope, hence the bankfull depth is artificially greater than what it should be. The only significant difference between the existing channel properties and regime channel properties is the slope of Creed Creek, which is significantly steeper than what regime theory indicates it should be. Therefore, Creed Creek may tend to meander or continue to degrade in order to lessen its slope.

This assessment, however, is based upon the **present** division of flows from the Athabasca to the Embarras River, and the Embarras to Creed Creek, and may not reflect the ultimate division. As indicated earlier, channel slope should be the dominant factor in the future development of the creek, and the largest single unknown at present is the slope of the lower Creed and Mamawi Creeks.

Downstream of the tributary channel, Mamawi Creek has a top width of approximately 65 m. With this top width, the regime channel capacity should be 206 m^3/sec, with a regime depth of 2.62 m and a regime slope of 0.00017 m/m. This calculated slope is close enough to that determined for the Embarras River to assume that the upper Creed Creek will flatten its slope to be in the range of from 0.00013 (Embarras River) to 0.00017 (Mamawi Creek).

If Creed Creek continues to have a steeper slope than the Embarras River, it would have a higher discharge capacity for similar channel dimensions. However, the Embarras River currently has a larger channel. Decreased flow in the Embarras River, downstream of the diversion, will cause a decrease in the sediment transport capacity. Sand bar development and some aggradation will become evident, as the sediments transported in the upper Embarras River are deposited in the reach of lower transport capacity.

The largest unknown left in the assessment of the future behaviour of Creed Creek is the measured slopes of the Mamawi and lower Creed Creeks. Depending upon their slopes, the upper Creed may not be able to continue to degrade and will have to meander to lessen its slope. This could be fortuitous, as continuing degradation in the upper Creed Creek may lead to such a large bed elevation difference between the Embarras River and the entrance to Creed Creek, that Creed Creek may be able to capture the entire flow of the Embarras River.

An event, such as an ice jam located on the Embarras River downstream of the Creed Creek diversion, would cause additional flow in Creed Creek, and the channel would develop its size accordingly, to possibly divert most of the Embarras River flow.

As the soils of the delta are easily eroded, channel slopes are the key to natural changing flow and/or channel patterns. It is recommended that monitoring continue, with additional surveys on Mamawi Creek, the lower Creed Creek and the Embarras River upstream and downstream of the Creed Creek diversion. Additional surveys would facilitate determining slopes and the monitoring of aggradation or degradation in all of the channels.

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Photo 1: Embarras River diversion to Mamawi Creek. Aerial view at confluence. August 19, 1982.

Photo 2: Embarras River diversion to Mamawi Creek. Ground view at confluence. August 17, 1982.

Photo 3: Embarras River diversion to Mamawi Creek. Ground view at confluence. August 17, 1982.

Photo 4: Embarras River diversion to Mamawi Creek. Skyline shows new channel through trees. August 17, 1982.

Photo 5: Embarras River diversion to Mamawi Creek. Looking upstream at control point near the confluence. August 17, 1982.

Photo 6: Embarras River diversion to Mamawi Creek. Looking downstream at newly formed channel. August 17, 1982.

Photo 7: Creed Creek entrance. Note instability of banks. September, 1985.

Photo 8: Downstream of Creed Creek towards Mamawi Lake. Note stability of banks. September, 1985.

Photo 9: Embarras River (lower half of photograph). September, 1985.

Photo 10: Entrance to Creed Creek. September, 1985.

Photo 11: Just below entrance to Creed Creek. Photographer standing at left bank point of Embarras River and Creed Creek. September, 1985.

Photo 12: Downstream of previous photo but above where stream contained within old banks. September, 1985.

Alberta ENVIRONMENT

CREED CREEK DIVERSION

LOCATION PLAN

SUBMITTED		DESIGNED	
DATE		CHECKED	
APPROVED		DRAWN	
DATE		CHECKED	

SCALE	1 : 250 000	SHEET	1 OF 1
DATE	JANUARY, 1986	DRAWING No.	1

MICROFILM DATE

DRAWING No.

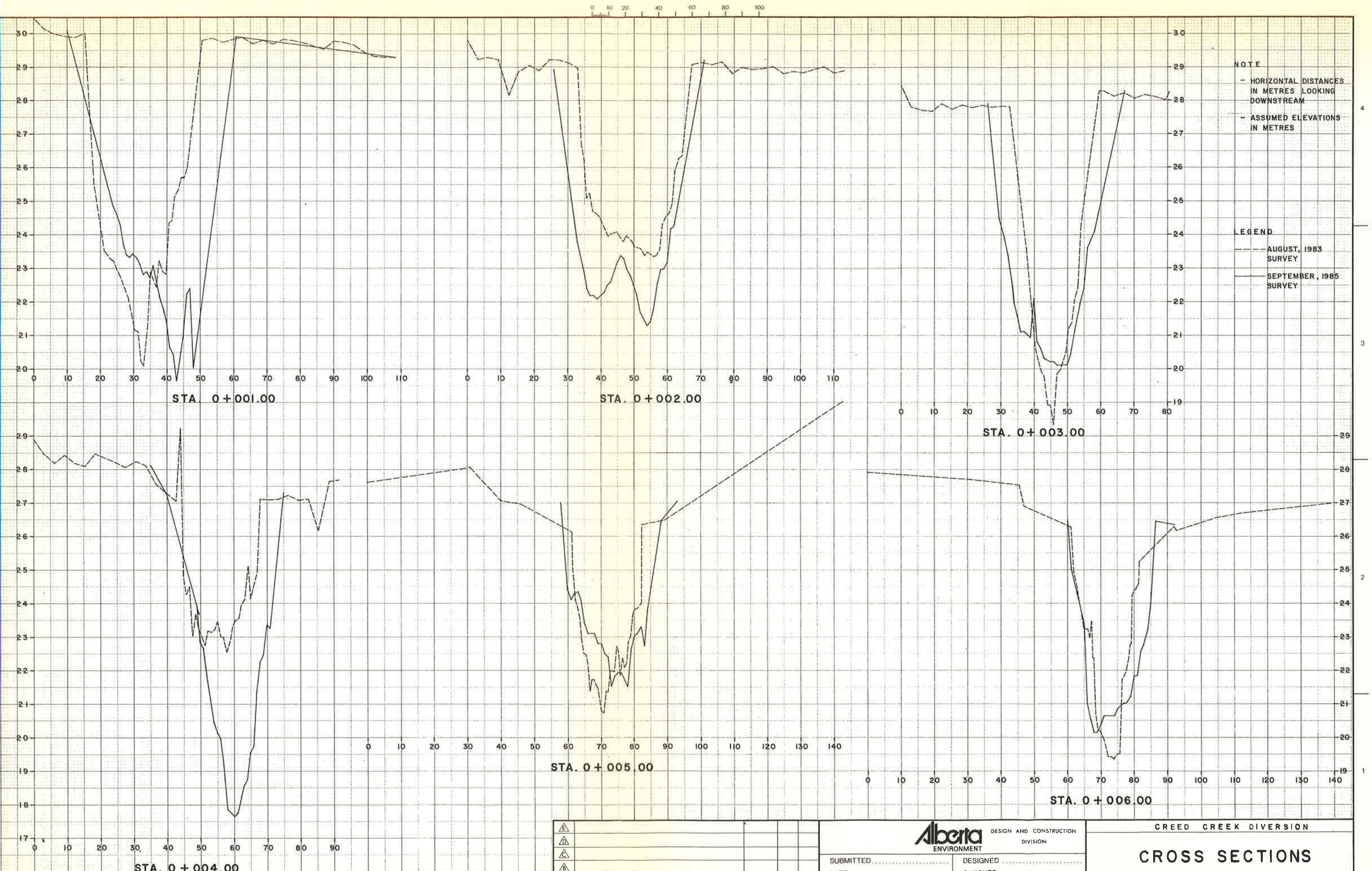
FILE No.

0 10 20 40 60 80 100

DATE OF PHOTOGRAPHY: SEPTEMBER, 1985.

Alberta ENVIRONMENT	RIVER ENGINEERING BRANCH	CREED CREEK DIVERSION
		CROSS SECTION LOCATIONS
DESIGNED	SCALE 1 : 5000	
DRAWN L. Lumbauser	DATE JANUARY, 1986	
CHECKED	SHEET 1 OF 1	**FIGURE No.** 2

P3-280 x 430



MARK	NATURE OF REVISION	DATE	ENG.	DWN.
E				
D				
C				
B				
A				

Alberta ENVIRONMENT — DESIGN AND CONSTRUCTION DIVISION

SUBMITTED ....
DATE ....
APPROVED ....
DATE ....

DESIGNED ....
CHECKED ....
DRAWN g.s.b.
CHECKED ....

CREED CREEK DIVERSION

CROSS SECTIONS

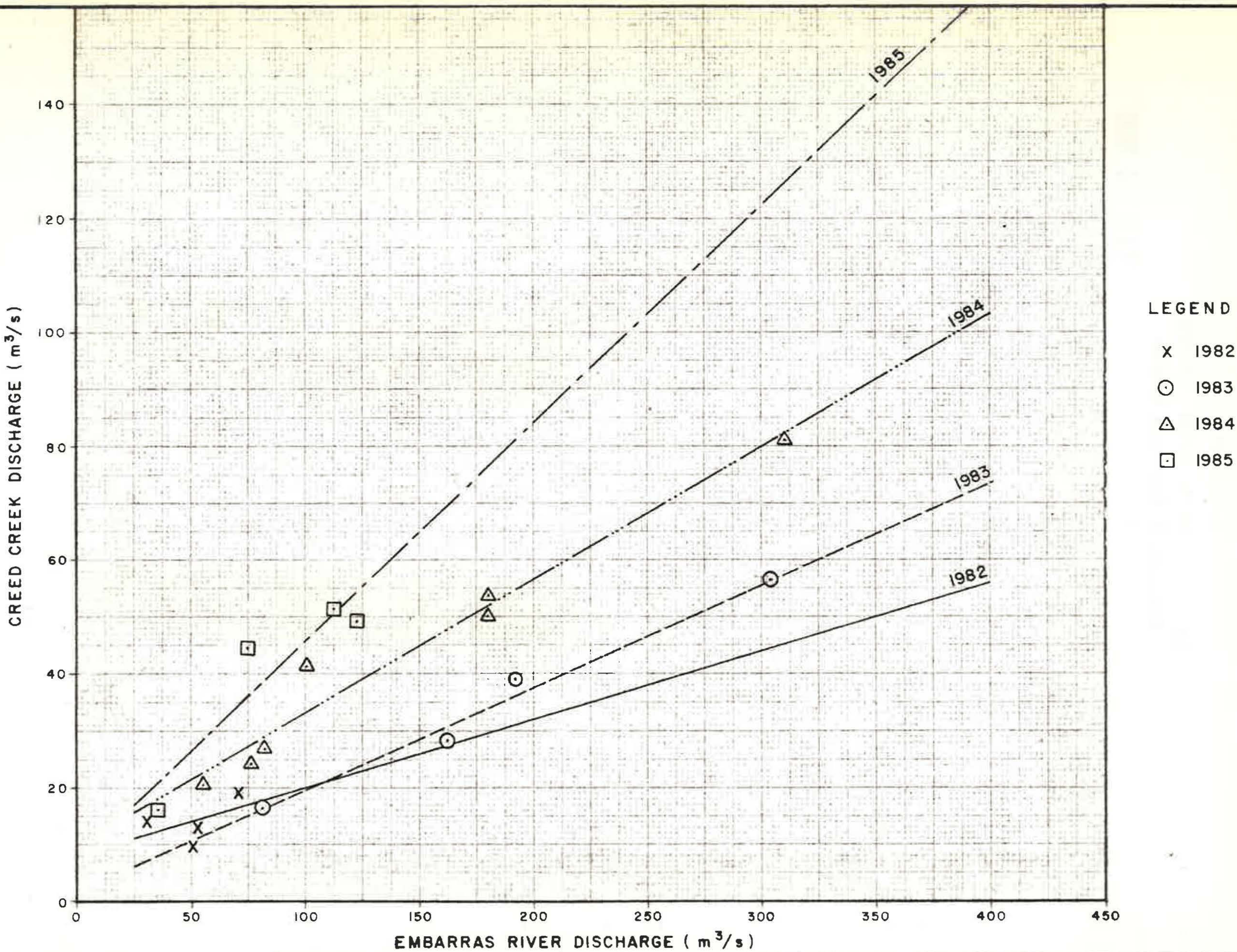
SCALE Horz. 1:500, Vert. 1:50 | SHEET 1 OF 1

DATE January, 1986 | DWG. No. 3

P1–560 x 860

FILE No [redacted] DRAWING No MICROFILM DATE

P4-215 x 280



Alberta ENVIRONMENT	RIVER ENGINEERING BRANCH	CREED CREEK DIVERSION
DESIGNED	SCALE AS SHOWN	**CREED CREEK DISCHARGE VS EMBARRAS RIVER DISCHARGE**
DRAWN g. s. b.	DATE JANUARY, 1986	
CHECKED	SHEET 1 OF 1	**FIGURE No. 4**