Canada Alberta Northwest Territories

Northern River Basins Study





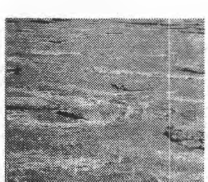




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 43

HYDRAULIC MODELLING OF THE PEACE-ATHABASCA DELTA

UNDER MODIFIED AND NATURAL FLOW CONDITIONS






DATE DUE

Prepared for the
Northern River Basins Study
under Project 1151-B1

by

B. Aitken and R. Sapach,
Water Planning and Management Branch,
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NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 43

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
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(Dr. F.J. Wrona, Ph.D., Science Director) — 26 July 94 (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair) — 19 Sept 94 (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
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(Lucille Partington, Co-chair) — Sept. 15, 1994 (Date)

(Robert McLeod, Co-chair) — Sept. 15, 1994 (Date)

HYDRAULIC MODELLING OF THE PEACE-ATHABASCA DELTA UNDER MODIFIED AND NATURAL FLOW CONDITIONS

STUDY PERSPECTIVE

> ***Related Study Questions***
>
> *10. How does and how could river flow regulation impact the aquatic ecosystem?*

Construction of the Bennett Dam in British Columbia in 1967 has altered the natural flow patterns of the Peace River. This effect is felt most immediately downstream of the dam, but also in the Peace - Athabasca Delta, almost 2000 km downstream. To counteract the effects of the dam on the delta several weirs were constructed in the early seventies. A weir was constructed in 1972 at the outlet of Lake Mamawi, but was removed several years later. In 1974, two weirs were constructed at Rivière des Rochers and Revillon Coupé that are still operating. To model the effect of the dam and weirs on water levels in the delta, Environment Canada's One-Dimensional Hydrodynamic Model was used. Previously this had been done up to 1984. The purpose of this project was to extend that analysis to 1990. Several flow scenarios were modelled: 1) natural (no dam), 2) with dam, and 3) with dam and weirs (Rivière des Rochers and Revillon Coupé). The modelling results showed that mean and maximum water levels of delta lakes have declined due to operation of the dam, while minimum water levels were relatively unaffected. In general, the dam operation has raised mean monthly water levels in delta lakes and along river channels in the winter, and lowered them in the summer, compared to the natural situation. This could cause problems for perched basins in the delta that need to be flooded every three to five years to maintain the health of their critical ecosystem.

The report also found that the weirs have raised minimum and mean Lake Athabasca and Lake Mamawi water levels significantly above natural conditions and returned the mean and minimum Lake Claire levels to near natural conditions. However, the range of water level fluctuations is reduced. One limitation of the model was that it could not accurately simulate freeze-up and breakup events. This was reflected in an analysis of accuracy for those times of the year. In particular, breakup can be a very important time of the year for recharging perched basins.

Results of this modelling exercise show changes in water levels at different locations in the delta due to dam operation and can be used to compare flooding frequencies for various parts of the delta. A next step would be to construct a contour map of the delta to model exactly how these changes in water levels have affected and could affect the recharge of the perched basins.

REPORT SUMMARY

The construction of the Bennett Dam in British Columbia, which was completed in 1967, altered the natural fluctuations of spring peaks and fall-winter low flows downstream on the Peace River in Alberta. The altered flow regimes had major implications for the ecosystem of the Peace-Athabasca Delta as water levels were increased in the winter and decreased in the summer.

Since 1968 low water levels on Lake Athabasca and the two largest delta lakes, Claire and Mamawi, have been of concern to many people. In 1972 the Peace Athabasca Delta Biological Monitoring Committee released a report which outlined many options for dealing with the low water levels. The options spanned the range from a 'let nature take its course' option to an intensive water management option for individulal sub basins. Intense water management is contrary to National Parks policy and 80% of the Delta lies within Wood Buffalo National Park. It was felt that the minimum that must be done would be to restore the water levels on Lake Athabasca in order to re-establish the ecological conditions in the delta which occurred under natural conditions. The construction of a weir on the outlet channel of Lake Mamawi in 1971 and 1972, its removal several years later, and the construction of two additional weirs on the Rivière des Roche and Revillon Coupè have all been attempts to restore the water level regime of the delta to what it was prior to the construction of Bennett Dam on the Peace River.

This modelling exercise, partially funded by the Northern River Basins Study (see Terms of Reference in Appendix A), is an attempt to assess the effect of the weirs and Bennett Dam on the delta water levels during the period 1985 - 1990. This work was originally requested by the Peace-Athabasca Delta Implementation Committee in 1991, but funding and staff were not available. At that time the water levels in Lake Athabasca were low and it was not clear whether the weirs were not functioning properly or if the low water levels were caused by low flows coming from the upper Peace and Athabasca river basins. It was felt that the additional six years of modelled data could be used to determine if the weirs were still functioning. The work had started in 1992. In 1993, the Northern River Basins Study Board agreed to fund the remainder of this work.

The model used for the simulations is the Environment Canada One-Dimensional Hydrodynamic Model. The One-Dimensional model can describe gradually varied unsteady flow conditions in a network of lakes and multiple river channels. It also has the capacity to simulate control structures such as weirs and can accommodate reversing flows. By considering the principles of Conservation of Mass and Conservation of Momentum, the model employs a finite difference scheme to apply the St. Venant equations. The model, however, has problems with rapidly varying flow. Therefore, the data generated for freezeup and breakup periods are suspect. Also, the water storage that occurs when the natural levees around the perched basins are overtopped is not included in the model configuration. Both of these problem areas are being investigated under another study being administered by Parks Canada.

The results are presented in the form of water level plots and monthly maps that quantitatively show areas that are affected by the weirs and dam. As well, tables of mean lake levels that allow the results of this study to be compared to previous Peace-Athabasca Delta Implementation Committee work are presented.

The effects of the Bennett Dam are greatest along the Peace River and decline in magnitude with distance into the delta. In general, the effect of Bennett Dam was to increase winter water levels and to decrease summer levels.

The weirs have restored the peak annual water levels on the large delta lakes to what they were prior to the Dam being built but in so doing have also raised the mean and minimum water levels above what whey would have been under natural conditions. The weirs have their greatest effect on water levels in the delta immediately upstream of the weirs. This effect diminishes with distance upstream from the weirs. Temporally, the weirs have their greatest effect in the winter and spring.

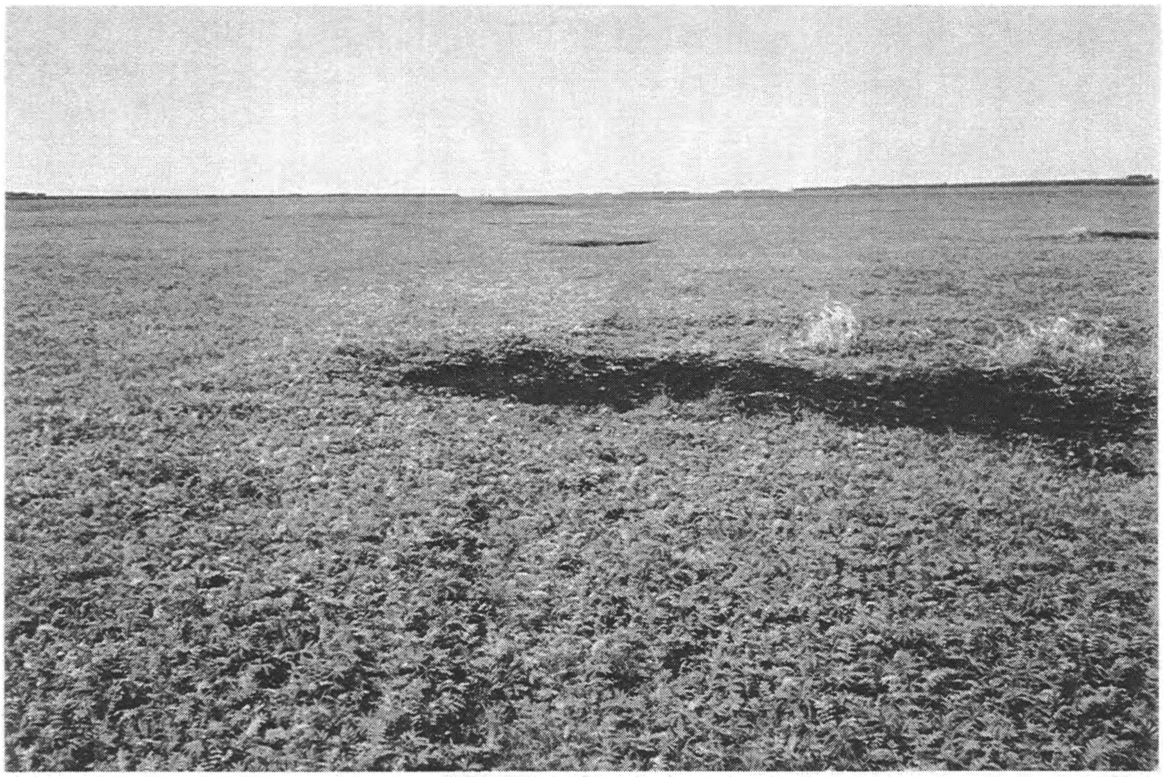


Photo #1 A large meadow near Lousey Creek. The dark patches are Buffalo wallows.

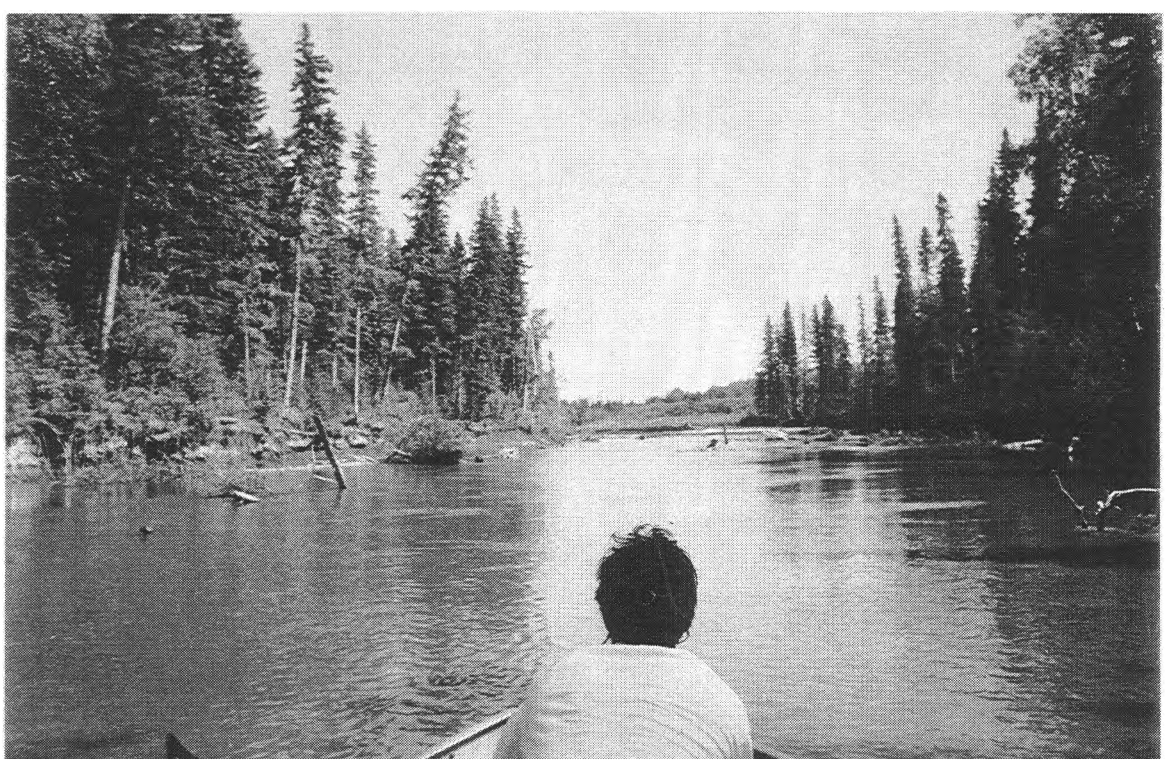


Photo #2 Cree Creek break through to Mamawi Creek. The steep banks and fallen trees indicate that the channel is actively eroding.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

ACKNOWLEDGEMENTS

The authors wish to thank the following people for their contributions to this project. Mr. Hanson Cheng of the Economics and Conservation Branch, Conservation and Protection, Hull, is acknowledged for his time spent in training and his advice on running and calibrating the One-Dimensional Hydrodynamic Model. The staff of Wood Buffalo National Park including Wardens S. Kato and M. Peterson are recognized for their insight into the delta and its varying habitat. Mr. M. Gilchrist, Water Planning and Management, Regina, is greatly thanked for his graphics which help to make the complex changes to the delta regime more understandable. Ms. B. Lyons, Queen's University Engineering student, for the many hours of data manipulation and paper work required to pull together the Appendices of this report.

1.0 INTRODUCTION

The Peace-Athabasca Delta consists of the Athabasca, Peace, and Birch River deltas, with the major lakes being Claire, Baril, Mamawi and Richardson. Active and inactive water courses, scattered across the delta, join these lakes and rivers (Figure 1).

The topographic relief in the Delta rarely exceeds one metre above the normal water surface resulting in meadows of sedges and grains that will disappear if there is any permanent change in water levels (Farley and Cheng 1986). The lakes in the delta generally have a thick growth of submerged or emergent vegetation.

Aside from the major lakes, there are basins with rims higher than surrounding the lakes and bottoms lower than the natural levees of the water courses. These 'perched basins' will dry out if they are not replenished every 3 - 5 years by a flood (Farley and Cheng 1986).

About 80% of the Peace-Athabasca Delta lies within the Wood Buffalo National Park. In the northern part of the park, outside of the delta, nests the world's entire population of non-captive breeding Whooping Cranes. Other wildlife in the park includes 255 bird species, 44 species of mammals, and 18 fish species. The perched basins, when full, support significant numbers of migratory waterfowl, and other wildlife

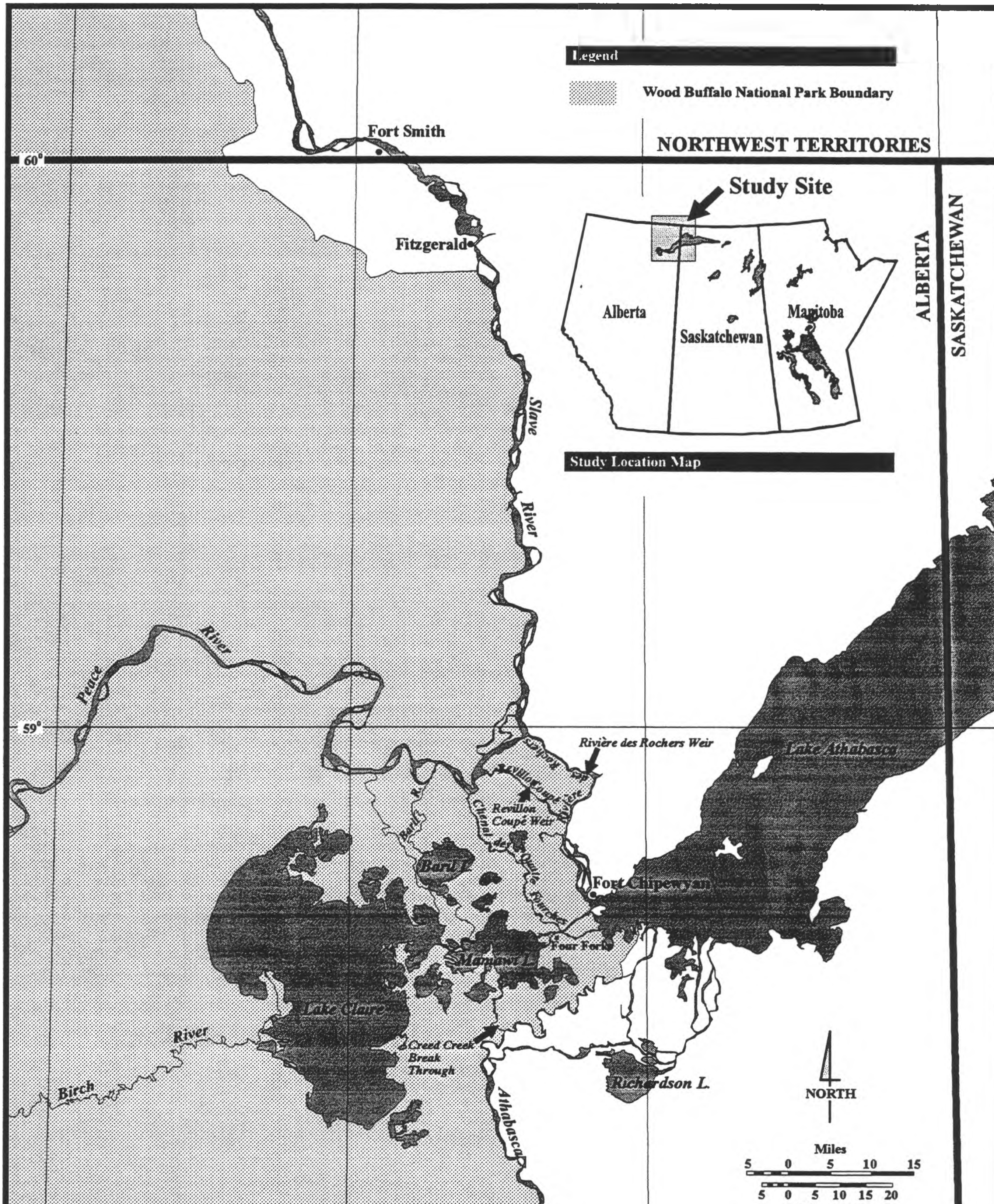


Figure 1: Peace-Athabasca Delta - Basin Map

The first people to call the Peace-Athabasca Delta home were the Chipewyan, Beaver, and later, the Cree. The 1780's saw the first Europeans in the area with the establishment of a fur trading post at Fort Chipewyan which soon became the centre of trade in the area. The highly competitive fur trade in the area arose between the XY Company, the North West Company, and the Hudson's Bay Company. The North West company absorbed the XY Company in 1804 and was itself absorbed by the Hudson's Bay Company in 1821. Roman Catholic Missionaries began arriving in the Peace-Athabasca Delta area in 1847 and were followed by surveyors from the Geological Survey of Canada in 1875. As the fur trade dwindled and economic forces, such as the Klondike Gold Rush in 1898, the Alberta Great Waterways Railway in 1920 and mining in Uranium City in 1953, appeared elsewhere, the importance of the area changed. No longer was the delta an end point, but rather a stopping place *en route* to other locations.

Constuction of the W.A.C. Bennett Dam was completed in 1967 near the headwaters of the Peace River for power generation by BC Hydro. The dam effectively dampened the yearly fluctuations of the Peace River, resulting in significant impacts on the Peace-Athabasca Delta. During the filling period of the dam, low water levels caused severe reduction in the area of surface water. More recently, (Jaques 1990) indicated a major change in vegetation and an increase in the succession from meadows of sedges and grasses to willows. In the 1970's the Peace-Athabasca Delta Study Group completed a study that assessed water level problems in the Delta. Many options were examined (Environment Canada, 1971) which spanned the range from intensive management of each individual basin to accepting the premature ageing of the delta. It was felt that intensive management of the delta would be contrary to National Parks Policy. It was therefore proposed that the minimum action should be to restore the water levels of Lake Athabasca in order to re-establish the ecological conditions in the delta, which occurred under nature. The options were ranked and the submerged rockfill weir was considered to be the most viable solution. Therefore, two rock filled weirs on Revillon Coupè and Rivière des Rochers, were built in an attempt to restore the low water levels of the delta to a more natural state.

The purpose of this study is to determine the effects of the Bennett Dam and the rock filled weirs on the water level regime of the Peace-Athabasca Delta and in addition, to improve the model calibration and to extend the modelling period from 1985 to 1990. The One-Dimensional Hydrodynamic model, which was used for the 1960-1984 period (Alberta Environment 1985), is utilized for this purpose by simulating water levels with and without the Bennett Dam and rock filled weirs in place. Comparisons are made and conclusions drawn. The results of this study will be used by the Northern River Basins Study, Parks Canada, the people of Fort Chipewyan, and other residents of the delta.

2.0 PREVIOUS STUDIES

From a review of previous studies, the following reports were found to be most relevant to the hydraulic modelling focus of this report. Brief descriptions are provided for each report.

Environment Canada; Peace-Athabasca Delta Project: **The Problems, Proposals, and Action Taken**; Canada, Alberta, Saskatchewan, December, 1971.

This report, intended for use by the general public, gives an overview of the Delta and Delta projects. The subjects include: objectives and strategy, investigations under way, ecological considerations, the people of the Delta, hydrology, dendrochronology, geology, recommendations and government action.

Peace-Athabasca Delta Project Group. **The Peace-Athabasca Delta - A Canadian Resource; Summary Report, 1972**, Canada-Alberta-Sakatchewan, 1972.

This reports describes the setting of Lake Athabasca, hydrology, ecology and social aspects of the Peace Athabasca Delta. Alternative solutions for raising the minimum water levels are presented. The legal framework and government co-ordination are also discussed.

The Peace Athabasca Delta Project Group; **The Peace-Athabasca Delta Project: Technical Report**; Canada, Alberta, Saskatchewan, Edmonton, Alberta, 1973.

This is a comprehensive report on the physical, social, economic, ecological, and political aspects of the Delta. The major topics discussed are: history of the area, Bennett Dam, project investigations, hydrological regime, biological regime, Fort Chipewyan and the region, geology, water quality, navigation, environmental change, impact on future lake levels, remedial measures, legal aspects of interprovincial waters and intergovernmental coordination. Volume 2 contains the ecological investigations. Topics include: succession, the status of waterfowl, muskrat, moose, bison, goldeye, trout, walleye, vegetation and topographical maps. Volume 3 contains the support studies: A History of Fort Chipewyan and the Peace-Athabasca Delta Region, A Socio-economic Study of Fort Chipewyan and the Peace-Athabasca Delta Region, Peace-Athabasca

Legal Framework Study, Peace-Athabasca Study of Socio-Economic Characteristics of Fort Chipewyan and A Recreation and Tourism Study of Lake Athabasca and Environs.

Farley, D.W., Aggarwal, A., Draper, D.W.; **Peace-Athabasca Delta Hydraulic Model**; Ottawa, Ontario, June 10th, 1974.

This report provides simulation results assuming hypothetical regulation schemes on the Peace and Athabasca Rivers for the original and five alternative weir designs at the Little Rapids site on the Rivière des Rochers.

Sydor, M., of Environment Canada, DeBoer, A., of Alberta Environment, Cheng, T, of Environment Canada; **Developing a Mathematical Flow Simulation Model for the Peace-Athabasca Delta**; March 1979.

This report reviews the development of mathematical models for simulating natural conditions in the Peace-Athabasca Delta and indicates the applicability of the latest one dimensional hydrodynamic model in evaluating present and future influences in the Delta. The technical study and simulation results are given for specific case studies.

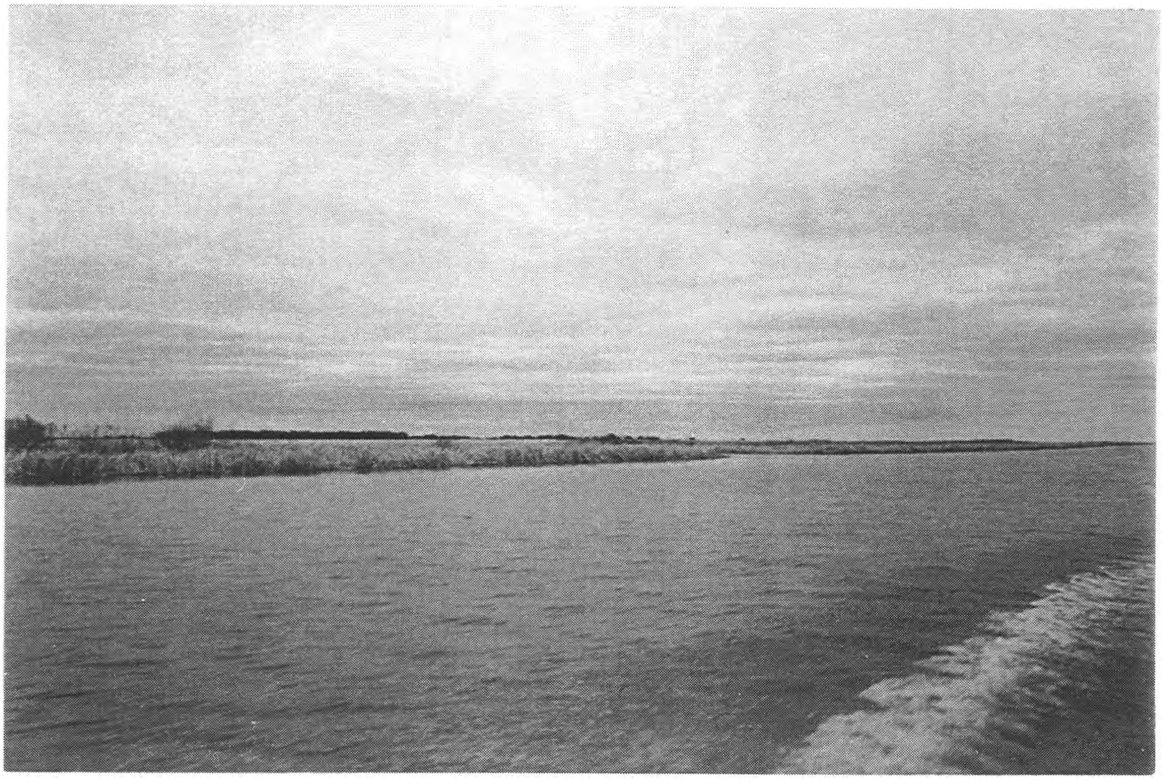


Photo #3 Lake Claire at the Prairie River outlet.

Photo #4 The Athabasca River near the 27th Baseline.

Smith, S.B., of S.B Smith Environmental Consultants Ltd.; **Monitoring Studies on the Peace-Athabasca Delta 1975 -1982**; Alberta Department of Environment; Edmonton, April 1982.

This report deals primarily with the conditions on the delta between 1975 and 1982. Particular reference is made to the water levels in the delta after the weirs were constructed. The report contains information pertaining to the water regime, water quality, and ecology of the delta. Figures include: the Peace Athabasca and Fond du Lac drainage basins, Peace-Athabasca Delta, Water levels and related events for the Peace-Athabasca Delta 1962-1982, and Plant succession as a result of hydrological regimes of increasing and decreasing water levels. Tables include: Percent of years in which Lake Athabasca summer maximum water levels were exceeded for two time periods, 1935-1967 and 1968-1981.

Water Management Systems Division, Environment Canada; **Documentation Manual of Network Configuration and Cross-Sections for 1-Dimensional Hydrodynamic Model of the Peace-Athabasca Delta Region and the Slave River**; Hull, Quebec, Revised August 1983.

A detailed report, "Developing a Mathematical Flow Simulation Model for the Peace-Athabasca Delta", was released in March, 1979. Between 1979 and 1983 additional and more extensive data were collected. The additional data were intended to increase the accuracy and resolution in model simulations and to extend the model network to include downstream developments on the Slave River, and overflow during extreme events between the delta lakes, on Baril Lake and on the Peace River.

Alberta Environment, Environment Canada, Department of Fisheries and Oceans; **An Evaluation**

or the Performance of the Rivière des Rochers and Revillon Coupè Weirs in the Peace-Athabasca Delta; The Peace-Athabasca Delta Implementation Committee; June 1985.

This study examines the hydrologic performance of the weirs. The appendix contains: the Peace-Athabasca Delta One-Dimensional Hydrodynamic Model Network, reach node connectivity schematic, reach node connectivity description, simulated water levels and discharge hydrographs and tables for regulated flows and water level with and without the Rivière des Rochers and Revillon Coupè Weirs in place, and for natural condition (no dam - no weirs), simulated hydraulic head at Rivière des Rochers Weir Site under natural conditions and for Bennett Dam regulated flows, with or without weir, and table of computed Lake Athabasca residual inflows. The Water Planning and Management Branch of Environment Canada generated data sets for scenarios in an attempt to assess the impacts of Bennett Dam, the Rivière des Rochers and Revillon Coupè weirs on the water levels in the delta. The data generated covered the period 1960 - 1984. This time frame spanned a period of natural flow conditions (1960 - 1967); the initial filling period (1968-1971); a period of the Bennett dam operation (1972-1974); and a period of Bennett Dam operation and the delta levels also being affected by the weirs (1975-1984).

Alberta Environment, Environment Canada, Department of Fisheries and Oceans; **Supplement No.1 to An Evaluation or the Performance of the Rivière des Rochers and Revillon Coupè Weirs in the Peace-Athabasca Delta**; The Peace-Athabasca Delta Implementation Committee; October 1985. This report extends the period of model simulation from January 1, 1982 to December 31, 1984. (see above).

Garner, L.A., Fonstad, G.D.; **Assessment of Creed Creek Diversion**; Alberta, February, 1986.

Creed (Cree) Creek is a natural diversion channel that allows water from the Embarras River to flow into a tributary of Mamawi Creek. This diversion was not documented until the flood of 1982, when the River Engineering Branch, Alberta Environment began monitoring flows. This report includes the monitoring done after 1982 and provides an assessment of the Creed Creek Diversion describing channel development and future growth.

Peace-Athabasca Delta Implementation Committee; **Peace-Athabasca Delta Water Management Works Evaluation**; Canada, Alberta, Saskatchewan, April, 1987.

This report is separated into five volumes. The first volume is the final report. The second volume, Appendix A - Hydrological Assessment provides a description and discusses limitations of the Stanley Model (Peace Athabasca Delta Project Group 1973). It contains information on the application as well as data produced by the One-dimensional Hydrodynamic Model. Comparisons with previous studies are also included. The third volume, Appendix B, is the Biological Assessment. This appendix assesses the performance of the Rivière des Rochers and Revillon Coupè Weirs from a biological perspective. Topics include: a biological monitoring program, quantitative analyses, simulation of wild life habitat, success of the weirs in restoring biological communities and recommendations. The fourth volume is the Ancillary Studies, which includes three reports: Evaluation of Test Fishways on the Rivière des Rochers in the Peace-Athabasca Delta - Final Report, Technical Feasibility Study of the Quatre Fourches Control Structure in the Peace- Athabasca Delta and an assessment of Creed Creek. The final volume is a status report for the period 1974-1983. It summarizes the activities of the Implementation Committee during

this period.

Water Management Systems Division, Water Planning and Management Branch, Inland Waters Directorate Environment Canada; **Peace-Athabasca Delta Hydrodynamic Modelling Study: Reassessment and Recalibration of the Rivière des Rochers and Revillon Coupè Mathematical Formulation**; Ottawa, Ontario, August 7th, 1991.

The reassessment and recalibration of the mathematical formulation for the Rivière des Rochers and Revillon Coupè Weirs is based on data received from Alberta Environment in their draft report, "Recalibration of the Weir Formulae at the Peace-Athabasca Delta"(Alberta Environment 1991). The regression fit was improved by as much as 50%. This report contains the weir formulation for free flowing and submerged conditions, methodology dealing with outliers, and the findings and conclusions for both the Rivière des Rochers and Revillon Coupè analysis.

These studies have adressed the impacts of the Bennett Dam and the rock filled wiers on the delta's water levels. It has generally been concluded that the dam is the cause of the altered flow regime and potentially adaptive ecosystem change. The wiers cannot return the flow regime of the delta to pre-dam conditions, but they have restored peak water levels. The study that follows continues the previous work and, in addition, attempts to make qualitative assesments of the impacts of the weirs and dam on a monthly basis.

3.0 ONE-DIMENSIONAL HYDRODYNAMIC MODEL

3.1 General Description

The One-Dimensional Hydrodynamic Model has been applied to unsteady state channel network flow and is based on gradually varied unsteady flow theory. This model utilizes the St. Venant equations in the form of an implicit one dimensional finite difference scheme (Water Planning & Management 1988). It has the ability to incorporate structures such as weirs, bridges, rapids and gated control structures. The advantage of the model is that it solves transient flow conditions in rivers and tidal estuaries for divided flow or multiple channel situations where conventional steady state routing models cannot be applied.

The original version of the computer manual for the One-Dimensional Hydrodynamic Model is dated March 1973 and was developed at the Massachusetts Institute of Technology (Water Planning & Management 1988). Since then modifications and additions to the program by Environment Canada staff have been made as a result of applications to river systems such as the St. Croix, St. Lawrence, Fraser, Red, Souris and Boyne rivers.

Figure 2 schematically shows the linkages between the various programs and data sets that combine to make a model of a water course. This configuration consists of three distinct phases, which are the Preparation, One-Dimensional, and Means programs. The preparation phase combines static and dynamic data. That is to say, cross section data, roughness, and so on, are combined with the level and flow data to create one input file. The One-Dimensional

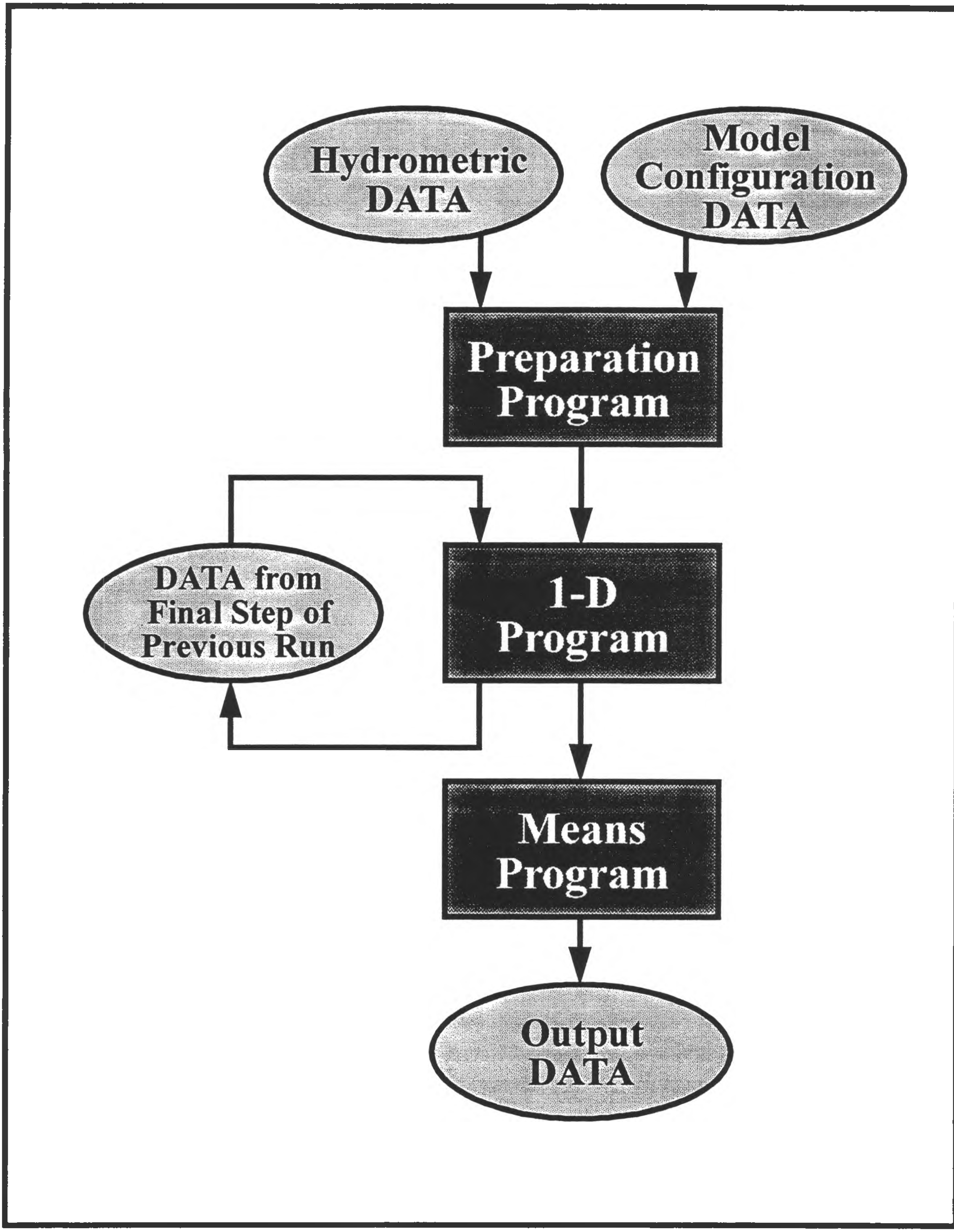


Figure 2: One-Dimensional Model - Component Interactions

Hydrodynamic Model uses this file as input along with the results from the run of the time period immediately prior to the present run, in order to maintain continuity. The Means program takes the results from the One-Dimensional Hydrodynamic Model, which is for each mesh point and time interval, and produces daily averages for specified locations.

3.2 Application to the Peace-Athabasca Delta

The volume of outflow from Lake Athabasca and the delta is a function of the water levels of the Peace River and the delta. Under normal conditions, the delta discharges water to the Peace River, but when Peace River water levels are sufficiently high, the Peace River water flows into the delta. This complex situation is the reason that a dynamic model, like the One-Dimensional Hydrodynamic Model is being used in this study. Figure 3 is a schematic of the complex reach-node network used to model the delta.

3.2.1 Modelled Scenarios

Water levels in the delta have been influenced by three distinctly different flow regimes (Figure 4). The three regimes include 1) 'existing conditions', which is regulated flow on the Peace River combined with a modified outflow from the delta due to construction of weirs on the outflow channels, 2) regulated flow on the Peace River only, and 3) natural flow. Modelling of water levels for these three regimes over a common time period of 1985 - 1990 was performed to assess the influence of the Bennett Dam, and the Rivière des Rochers and Revillon Coupé weirs on the delta water levels.

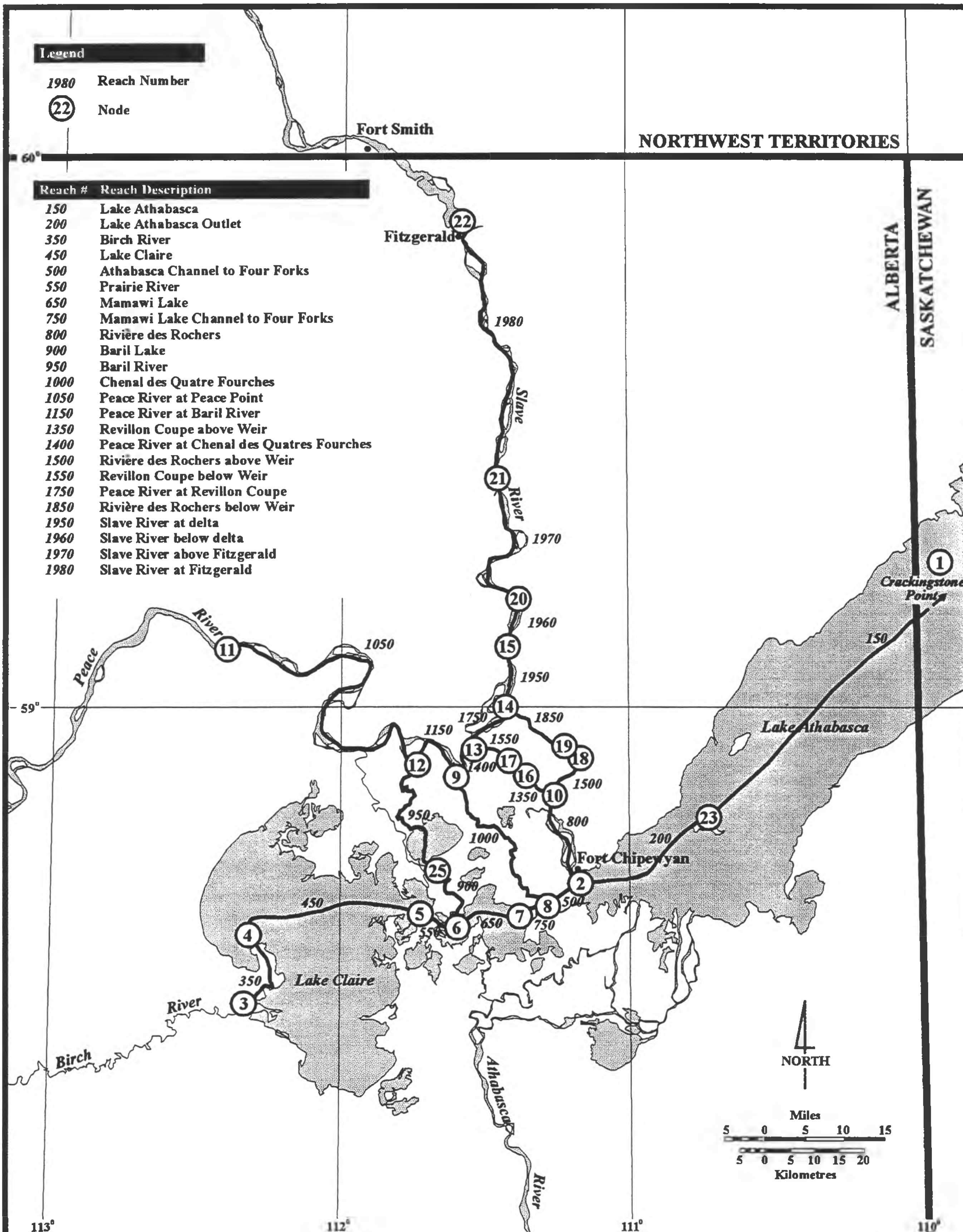


Figure 3: One-Dimensional Model Reach-Node Connectivity

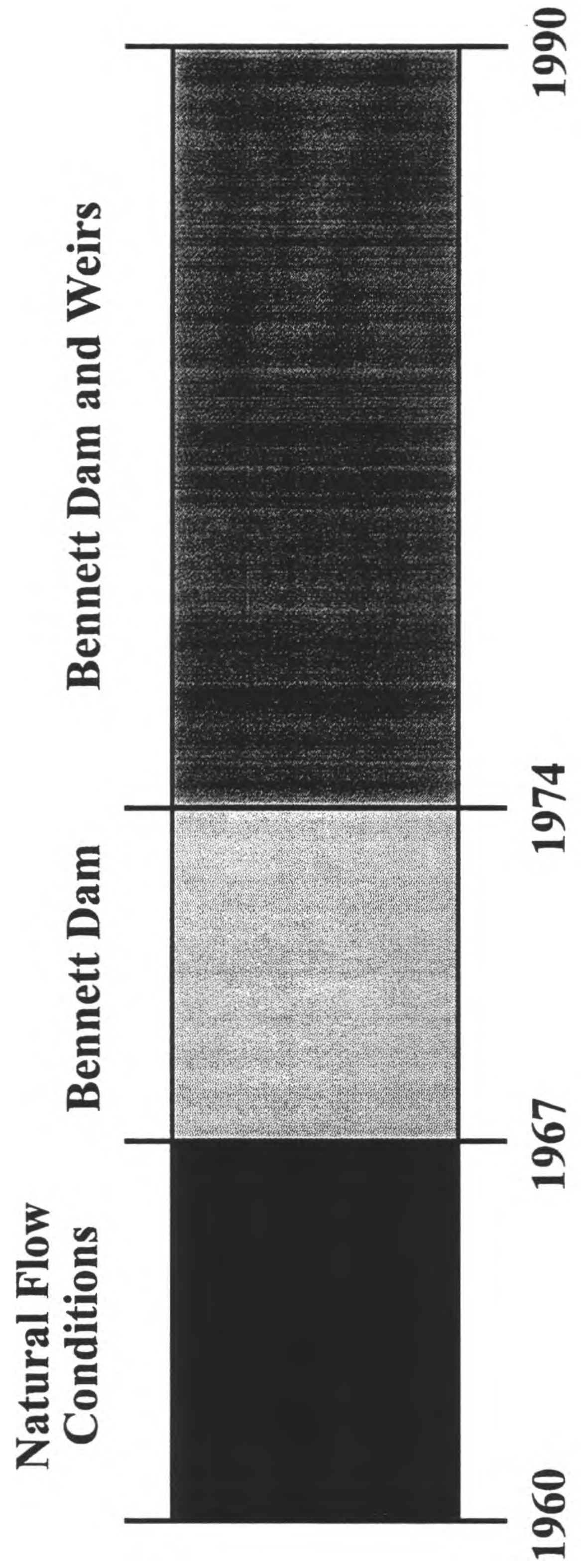


Figure 4: Flow Regimes of the Peace-Athabasca Delta

The first model scenario is the 'existing condition' run and is the calibration of the model's simulated values to measured water levels in the delta. This scenario was previously called the Residual Inflow or RI scenario. The model runs were used to produce an inflow file for Lake Athabasca for use in the other scenarios. The inputs for this set of runs include recorded discharge data for the Peace, Slave, Birch and Athabasca rivers, shown in Figure 5, as well as water level data for Lake Athabasca. During the calibration runs, Manning's 'n' values were adjusted on the delta reaches until a good agreement was achieved between the simulated and recorded water levels at the delta hydrometric stations. The 'n' values never had to be adjusted outside the normal range for the type of channel being considered. This scenario generated water levels and discharges for each node in the model. This model also uses weir flow equations developed by Environment Canada to simulate the existing weirs. These results were used for comparison with the following two scenarios.

The second or 'no weirs' scenario is produced by removing the weir subroutine from the model configuration. This produces water levels similar to what they would be if the rock filled weirs were removed. This scenario is used to determine the amount of influence that the weirs are having on channel water levels.

The final scenario, called the 'no weirs - no dam' or natural flow scenario, uses the same model configuration as the 'no weirs' scenario. The difference between these two is that the 'no weirs - no dam' scenario replaces the recorded Peace River flow with a calculated natural flow. The natural flow is generated by using a modified SSARR model called SIMPAK (Opseth 1990).

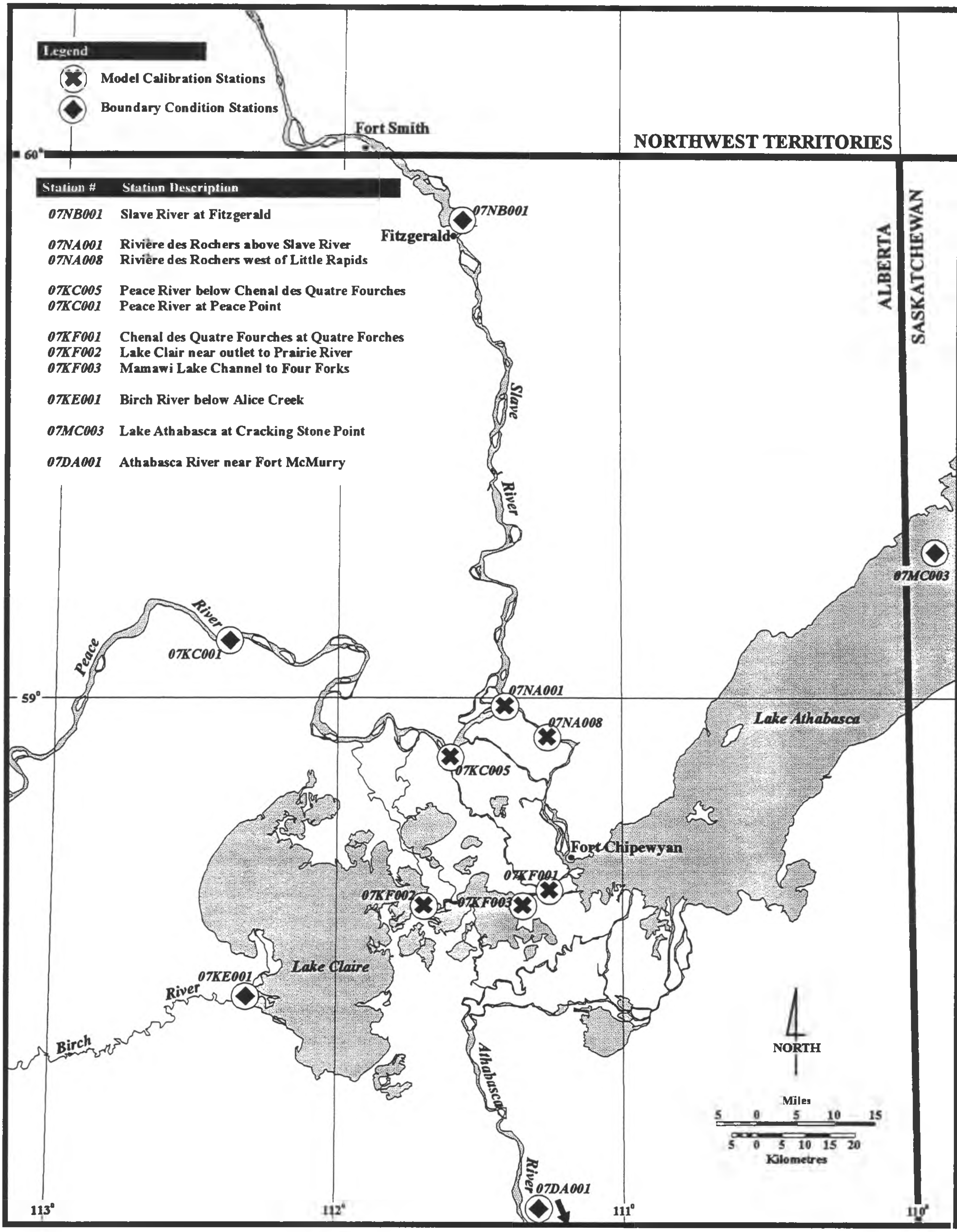


Figure 5: Location of Hydrometric Stations

SIMPAK first determines natural flow at Hudson Hope by adding or subtracting the change in storage of Williston lake reservoir to the recorded flows. Local inflows from Hudson Hope to Peace Point were calculated by determining the difference between the recorded flows from these two stations. This local inflow file takes into account the storage and release of water caused by freezeup, breakup and any temporary inaccuracies in the flow data caused by rapidly varying ice conditions. The local inflows and the natural flow at Hudson Hope were routed downstream to result in natural flows at Peace Point. The 'no weirs - no dam' scenario generates water levels and flows at each node in the delta and can be compared with the outputs from the calibration scenario to determine the effects of Bennett Dam.

3.2.2 Model Set-up and Boundary Conditions

The Peace-Athabasca Delta One Dimensional Model requires cross-sectional data to create and connect nodes within reaches. This reach-node connectivity, as seen in Figure 3, is assumed and operated to function in one dimension. In addition, channel roughnesses and ice thicknesses are input from monthly files. The remainder of the required input data fulfils the boundary conditions. These data are in the form of flows or elevations at each boundary node. Table 1 shows the boundary condition data type. Figure 5 shows the locations of the boundary condition stations.

Table 1
Boundary Conditions

Location	Data Type		
	Scenario 1 'Existing Codition'	Scenario 2 'No Weirs'	Scenario 3 'No Dam & no Weirs'
Peace River at Peace Point	Adjusted Recorded Discharge	Adjusted Recorded Discharge	Natural Flow Discharge
Birch River	Recorded Discharge	Recorded Discharge	Recorded Discharge
Lake Athabasca at Crackingstone Point	Recorded Level	Discharge from Calibration Run	Discharge from Calibration Run
Athabasca River at Fort McMurray	Recorded Discharge	Recorded Discharge	Recorded Discharge
Revillon Coupè and Rivière des Rochers	With weirs discharge Routine	No weirs discharge Routine	No weirs discharge Routine
Lake Claire and Mamawi Lake	Evaporation	Evaporation	Evaporation
Inflows along Peace and Slave River at the Delta	Discharge as a Percentage of Recorded Birch River Discharge	Discharge as a Percentage of Recorded Birch River Discharge	Discharge as a Percentage of Recorded Birch River Discharge

3.2.3 Model Improvements

Model improvements include consideration of the Embarras River breakthrough, modified weir routines, and ice thickness data.

First, the Embarras River break-through is considered. During previous high water events on the Athabasca River, water backed up the Cree Creek Channel and spilled into the Mamawi Creek drainage basin (Garner and Fonstad 1986). After several repetitions of this spilling, the height of land between the creeks was eroded to the point that flow continously passed from the Athabasca River into Mamawi Creek via Cree Creek. An estimate of 6.5% of the Athabasca

River's flow is used in this modelling exercise. This estimate is based on recent discharge measurements taken on both rivers. Future model updates should refine this value, since there is some indication that at lower flows the break through carries a larger percentage of the discharge.

By 1991, additional stage and discharge data were gathered above and below the weirs by Alberta Environment. A new mathematical formulation for flow over the weirs was incorporated into the 1-D model (Water Management Systems Division 1991) . The report suggests that the new formula improves the regression by up to 50% (Farley and Cheng 1986).

Also, by 1991 Alberta Environment had collected sufficient ice thickness data for use in the model. The data were collected on lakes Mamawi, Claire and Athabasca. The ice routine in the model uses an average monthly ice thickness for each month for the period between November to April. Prior to this study the channel roughness values were adjusted to simulate the change is resistance to flow caused by varying ice thicknesses.

3.2.4 Calibration and Verification

Calibration of the model consisted of varying Manning's 'n' roughness values and adjusting flow data for Peace River at Peace Point (see subsequent discussion regarding the quality of Peace Point data). Adjustments were made until the model output compared closely with the recorded data for Slave River at Fitzgerald. A further verification was achieved by visually comparing simulated and recorded data for the other recording stations in the delta. Differences between calibrated and recorded data is summarized as root mean squares of the differences. Table 2 provides a measure of the model's accuracy at those locations for the time period indicated. The values are plus or minus the value shown.

Table 2

Model Accuracy (± metres / water levels)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Chenal des Quatres Fourches	N/A	N/A	N/A	N/A	0.1	0.1	0.2	0.2	0.2	0.2	N/A	N/A	0.2
Prairie River	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2
Mamawi Lake Channel to Four Forks	0.1	0.2	0.3	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.1	0.3
Riviere des Rochers below Weir	0.4	0.2	0.2	0.9	0.8	0.2	0.1	0.1	0.2	0.3	1.1	0.5	0.5
Slave River at Delta	0.5	0.3	0.4	0.9	0.6	0.1	0.2	0.2	0.3	0.4	1.2	0.6	0.5
Peace River at Chenal des Quatre Fourches	0.4	0.3	0.2	0.7	0.5	0.3	0.2	0.2	0.3	0.3	1.1	0.3	0.4
Slave River at Fitzgerald	0.4	0.4	0.2	0.3	0.4	0.4	0.2	0.3	0.2	0.3	0.3	0.3	0.3

There are high root mean squares for several stations during certain times of the year (Table 2). These values reflect the model's inability to accurately simulate ice freezeup and breakup. Also, parameters such as ice thickness and rate of formation or melting, are highly variable from year to year. The data that are required to accurately simulate these conditions is not collected due to the prohibitive safety risk and associated cost. The most apparent disadvantage is that the model may not predict breakup affected water levels that are high enough to recharge perched basins in the spring.

The One-Dimensional Hydrodynamic model operates on the principle of conservation of mass. This means that total inflow to the model network must be equal to the total outflow. This is not the case with the Peace River recorded data. In a previous modelling exercise (Alberta Environment 1985), it was decided that to maintain a water balance in the model, the Peace Point data would have to be adjusted. Peace River at Peace Point flows were adjusted because winter streamflow data from that hydrometric station is, at best, suspect. The difficulty in obtaining accurate discharge measurements, for daily streamflow computation, due to the presence of slush and frazil ice has resulted in numerous adjustments to the published records, some up to 61.7% (Spitzer 1988). Further adjustments calibrate the model were minor. A plot of recorded vs adjusted data is shown in Figure 6. Percent adjustments (Table 3) are similar in magnitude to those in the previous work carried out for the Peace-Athabasca Delta Implementation Committee.

Table 3
Yearly Mean Flows at Peace Point

Year	Adjusted Flows (m^3/s)	Recorded Flows (m^3/s)	Percent Difference
1985	2175	2032	+6.6
1986	1849	2106	-12.1
1987	2607	2353	+9.5
1988	2382	2301	+3.3
1989	2204	2086	+5.3
1990	2350	2244	+4.5
		Mean	2.85

Differences between the simulated calibration data and recorded data are due to potential accuracies in:

- measured hydrometric data;
- weir discharge relationships for Rivière des Rochers and Revillon Coupè
- topographic input and model representation
- estimated local inflows based on Birch River flows
- assumptions of the presence of an ice cover and its thickness on a monthly basis
- calibrated roughness coefficients (Manning's n)

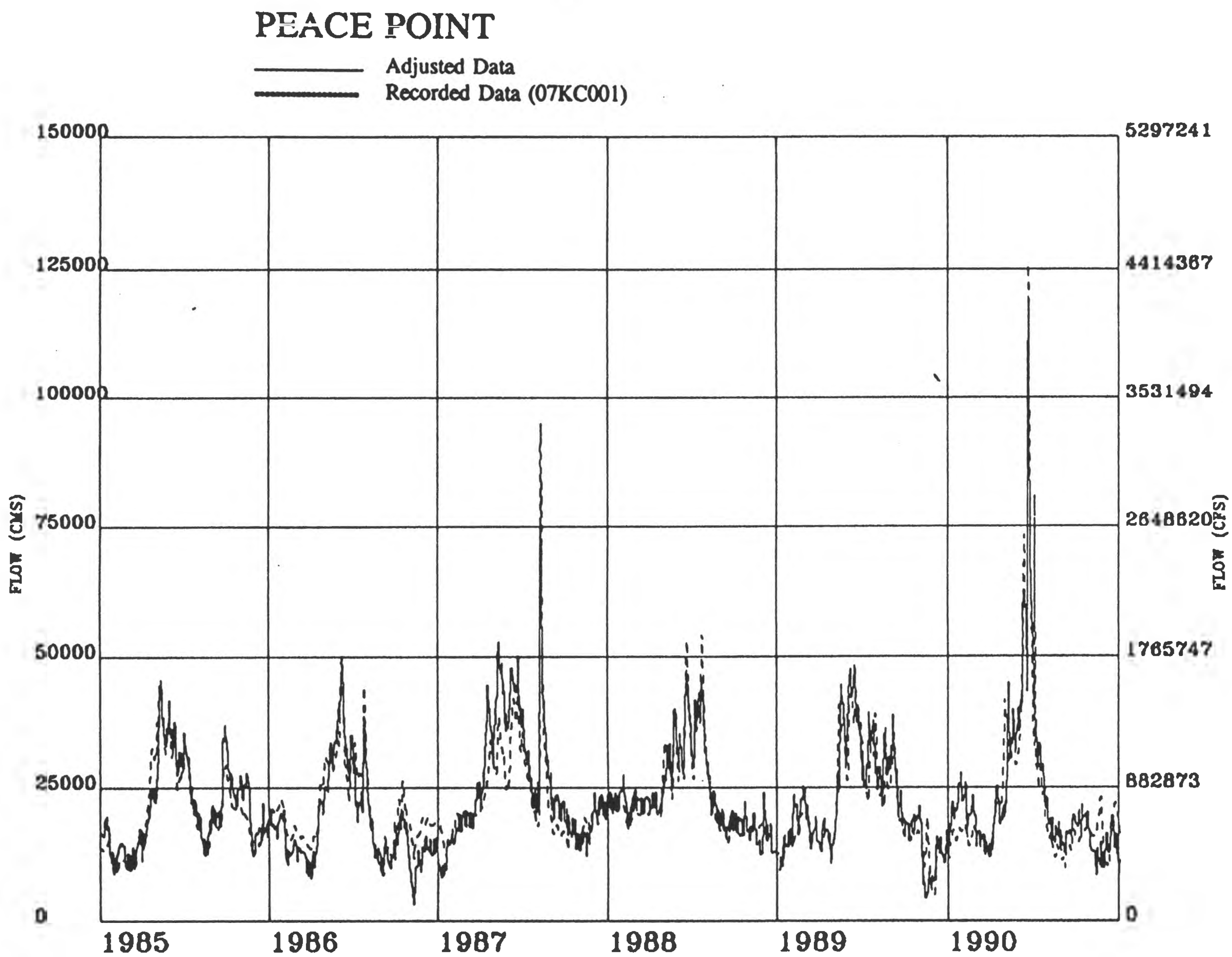


FIGURE 6: Comparison of Recorded and Adjusted Flows at Peace Point

- evaporation estimates for the delta lakes (excluding Lake Athabasca).
- variations in Lake Athabasca levels due to factors such as wind setup.

Furthermore, deltas result from dynamic sediment deposition and erosion, and are always changing. Cross-sectional data (topographic input), approximates the physical characteristics of the area and the cross sections change over time in a direct relationship with sedimentation or erosion of the delta. This annual sedimentation and erosion is why the model must be recalibrated on a yearly basis.

4.0 ANALYTICAL METHODOLOGY

Comparison of two flow scenarios for the determination of an effect first requires the consideration of what effects are to be studied and what effects are to be blocked out. Each test was performed for each month for all the years studied. For example, the test for January uses data from January of each year, for the study period. By so doing, seasonal and month to month variation are blocked out. However, year to year fluctuations are not blocked out since the tests use data from all years. A final test uses all data from each station.

The sample data were evaluated for the statistical appropriateness of the type of test to be conducted. First, since the models have varying boundary conditions, and internal configurations, the samples are considered to be independent. Also, the models are for the same study area and period, which supports the assumption that the variances from any month are similar between scenarios and normally distributed. Finally, the samples are taken from distinct populations.

Therefore, the unpaired t-test was employed using a 99% confidence interval. The tests were done for each node. The effects of the dam, weir, and weir plus dam were determined. If a significant difference occurred, the mean difference is reported. If no significant difference occurred, the mean difference was reported to be zero.

5.0 RESULTS AND DISCUSSION

5.1 Lake Levels

Tables of minimum, maximum and mean lake levels are presented so that the reader may draw comparisons between this and the previous study (Alberta Environment, 1985). The tables are printed in the same format and include the results of the previous study.

5.1.1 Lake Athabasca

The long term mean and standard deviation of the minimum, maximum and mean annual water levels for Lake Athabasca for all three scenarios are virtually identical to the previous simulation for the 1960 to 1984 period. The annual maximum water level (Table 4) of Lake Athabasca would be reduced by the effect of the Bennett Dam by approximately 0.5 m. The weirs have returned the maximum Lake Athabasca water levels to what they would have been naturally. The minimum water levels (Table 5) were essentially unchanged by the Bennett Dam. The weirs have increased the minimum water levels by approximately 0.5 m. The annual mean water levels (Table 6) of the lake were slightly (0.2 m) reduced by the effect of the Bennett Dam. The weirs have increased the mean level of Lake Athabasca by 0.4 m above natural conditions.

Table 4
Annual Maximum Lake Athabasca Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	210.43	209.67	210.00
1961	209.83	209.13	209.66
1962	210.57	209.87	210.34
1963	210.19	210.06	210.43
1964	210.47	209.60	210.03
1965	210.63	210.00	210.38
1966	209.99	209.41	209.97
1967	210.49	209.69	210.14
1968	209.43	208.78	209.33
1969	209.18	209.02	209.55
1970	209.12	208.74	209.35
1971	209.85	209.37	209.85
1972	210.44	209.82	210.04
1973	210.07	209.54	209.81
1974	210.80	210.15	210.56
1975	209.35	209.27	209.75
1976	209.78	209.30	209.63
1977	209.85	209.32	209.82
1978	209.03	208.76	209.44
1979	209.93	209.27	209.90
1980	208.26	208.01	208.77
1981	208.88	208.20	208.80
1982	209.02	208.30	209.07
1983	209.00	208.68	209.27
1984	209.25	208.64	209.22
1985	209.32	208.94	209.39
1986	209.86	209.06	209.62
1987	209.18	208.77	209.27
1988	209.66	208.89	209.36
1989	209.61	209.05	209.54
1990	210.13	209.31	209.72
Mean	209.73	209.18	209.68
S.D.	0.61	0.53	0.44

Table 5
Annual Minimum Lake Athabasca Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	208.15	208.08	208.32
1961	208.20	207.99	208.64
1962	208.13	207.98	208.72
1963	208.15	207.92	208.45
1964	208.14	208.08	208.69
1965	208.32	208.20	208.68
1966	208.09	207.93	208.44
1967	208.09	208.02	208.57
1968	208.11	207.96	208.61
1969	207.81	207.76	208.54
1970	207.79	207.76	208.43
1971	207.81	207.79	208.59
1972	207.89	207.88	208.50
1973	208.20	208.23	208.73
1974	207.82	207.90	208.35
1975	208.25	208.31	208.75
1976	208.25	208.48	208.69
1977	208.14	208.15	208.64
1978	208.08	208.12	208.66
1979	207.91	207.85	208.55
1980	207.47	207.44	208.28
1981	207.24	207.08	207.95
1982	207.30	207.20	207.97
1983	207.61	207.51	208.06
1984	207.63	207.61	208.12
1985	207.88	207.89	208.36
1986	207.86	207.93	208.37
1987	207.76	207.67	208.38
1988	207.72	207.74	208.23
1989	207.90	207.87	208.30
1990	208.01	207.83	208.54
Mean	207.93	207.88	208.46
S.D.	0.27	0.29	0.22

Table 6
Annual Mean Lake Athabasca
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	209.12	208.70	209.14
1961	208.83	208.47	209.13
1962	209.17	208.77	209.40
1963	209.06	208.80	209.42
1964	209.19	208.75	209.33
1965	209.28	208.93	209.46
1966	209.02	208.70	209.32
1967	209.00	208.63	209.28
1968	208.53	208.25	208.92
1969	208.38	208.28	208.96
1970	208.23	208.12	208.81
1971	208.46	208.32	208.97
1972	208.88	208.68	209.16
1973	208.82	208.73	209.14
1974	209.23	209.04	209.52
1975	208.84	208.85	209.33
1976	208.87	208.87	209.18
1977	208.86	208.66	209.25
1978	208.45	208.38	209.11
1979	208.59	208.38	209.12
1980	207.86	207.76	208.54
1981	207.83	207.59	208.34
1982	208.04	207.74	208.46
1983	208.03	207.86	208.54
1984	208.21	208.00	208.65
1985	208.43	208.23	208.81
1986	208.61	208.33	208.91
1987	208.36	208.17	208.74
1988	208.40	208.14	208.69
1989	208.61	208.39	208.93
1990	208.67	208.39	208.96
Mean	208.64	208.42	209.02
S.D.	0.40	0.37	0.31

Table 7
Annual Maximum Lake Claire
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	210.11	209.36	209.69
1961	209.64	208.91	208.37
1962	210.28	209.60	210.04
1963	210.01	208.84	210.16
1964	210.46	209.67	209.99
1965	210.98	210.48	210.76
1966	208.71	209.04	209.67
1967	210.22	209.50	210.02
1968	209.96	209.64	209.78
1969	209.99	210.03	210.14
1970	209.23	208.96	209.13
1971	209.59	209.21	206.53
1972	210.46	209.93	210.04
1973	210.72	210.46	210.55
1974	211.17	210.67	210.92
1975	210.33	210.28	210.44
1976	209.92	209.67	209.72
1977	209.86	208.35	209.76
1978	209.70	209.67	209.92
1979	210.08	209.74	209.97
1980	208.98	208.96	209.07
1981	209.44	208.92	209.00
1982	209.27	208.97	209.03
1983	209.21	209.07	209.26
1984	209.83	209.53	209.64
1985	210.55	210.56	210.55
1986	210.19	210.11	210.15
1987	210.53	210.52	210.54
1988	210.58	210.49	210.51
1989	210.41	210.40	210.41
1990	210.23	210.02	210.05
Mean	210.02	209.66	209.80
S.D.	0.57	0.62	0.83

5.1.2 Lake Claire

The long term mean and standard deviation of the minimum, maximum and mean annual water levels are virtually unchanged by adding the additional six years to the data set. The maximum annual water levels for Lake Claire (Table 7) are lowered by 0.36 m by the effect of the Bennett Dam. The weirs increased the maximum levels to 0.22 m below natural conditions. A reduction of 0.22 m in the peak delta water levels would mean that on average 18% fewer of the perched basins would get flooded (Peace-Athabasca Delta Project Group, 1973).

Table 8
Annual Minimum Lake Claire Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	208.78	208.66	208.80
1961	208.61	208.54	208.77
1962	208.52	208.50	208.68
1963	208.72	208.61	208.83
1964	208.57	208.55	208.74
1965	208.76	208.64	208.88
1966	208.69	208.62	208.84
1967	208.55	208.51	208.73
1968	208.71	208.68	208.82
1969	208.56	208.57	208.67
1970	208.48	208.49	208.58
1971	208.50	208.50	208.60
1972	208.59	208.58	208.69
1973	208.60	208.58	208.71
1974	208.77	208.74	208.83
1975	208.73	208.67	208.89
1976	208.86	208.87	208.94
1977	208.64	208.61	208.75
1978	208.59	208.57	208.74
1979	208.70	208.69	208.85
1980	208.61	208.59	208.70
1981	208.52	208.52	208.56
1982	208.45	208.40	208.51
1983	208.49	208.41	208.54
1984	208.53	208.52	208.57
1985	208.97	208.92	209.06
1986	208.94	208.91	209.02
1987	209.08	208.99	209.13
1988	209.05	208.98	209.06
1989	209.08	209.03	209.11
1990	209.03	208.84	209.04
Mean	208.70	208.65	208.79
S.D.	0.19	0.17	0.17

The minimum annual Lake Claire levels (Table 8) are virtually unchanged by either the effects of the Bennett Dam (-0.05 m) or the effects of the weirs (+0.09 m).

The mean annual water levels (Table 9) were lowered slightly (0.18 m) by the effects of the Bennett Dam and raised insignificantly above natural conditions (0.04 m) by the weirs.

5.1.3 Mamawi Lake

The addition of the six years of data also made little difference to mean or standard deviations of

Table 9
Annual Mean Lake Claire
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	209.34	208.91	209.23
1961	209.00	208.65	209.06
1962	209.25	208.91	209.29
1963	209.23	209.04	209.44
1964	209.38	208.98	209.33
1965	209.52	209.22	209.55
1966	209.14	208.82	209.28
1967	209.31	208.98	209.37
1968	209.31	209.18	209.34
1969	209.04	209.00	209.17
1970	208.73	208.67	208.84
1971	208.94	208.78	209.04
1972	209.34	209.12	209.32
1973	209.47	209.35	209.50
1974	209.82	209.61	209.83
1975	209.53	209.46	209.67
1976	209.38	209.26	209.40
1977	209.14	208.92	209.25
1978	209.03	208.96	209.25
1979	209.28	209.10	209.38
1980	208.75	208.71	208.84
1981	208.75	208.64	208.71
1982	208.74	208.61	208.71
1983	208.76	208.70	208.82
1984	209.01	208.93	209.03
1985	209.36	209.29	209.36
1986	209.45	209.29	209.44
1987	209.45	209.35	209.46
1988	209.58	209.48	209.56
1989	209.52	209.41	209.54
1990	209.48	209.21	209.41
Mean	209.23	209.05	209.27
S.D.	0.28	0.27	0.27

Table 10
Annual Maximum Mamawi Lake
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	210.11	209.38	209.69
1961	209.64	208.91	209.37
1962	210.28	209.62	210.04
1963	210.01	209.84	210.16
1964	210.46	209.58	209.99
1965	210.97	210.47	210.75
1966	209.71	209.05	209.67
1967	210.22	209.46	210.01
1968	209.93	209.56	209.74
1969	209.95	209.99	210.11
1970	209.24	208.90	209.13
1971	209.63	209.24	209.53
1972	210.46	209.90	210.03
1973	210.68	210.43	210.53
1974	211.16	210.66	210.91
1975	210.27	210.25	210.42
1976	209.92	209.60	209.67
1977	209.85	209.32	209.76
1978	209.55	209.57	209.88
1979	210.07	209.71	209.96
1980	208.75	208.83	208.99
1981	209.50	208.86	208.95
1982	209.28	208.87	209.01
1983	209.18	209.02	209.25
1984	209.79	209.44	209.58
1985	208.97	209.69	209.76
1986	210.05	209.60	209.82
1987	209.73	209.48	209.63
1988	210.25	209.96	210.05
1989	210.08	209.87	209.95
1990	210.24	209.66	209.80
Mean	209.93	209.57	209.81
S.D.	0.53	0.48	0.47

the minimum, maximum, or mean annual water levels of Lake Mamawi.

The maximum annual water levels of Lake Mamawi (Table 10) were reduced by the effects of the Bennett Dam by 0.36 m. The weirs have returned the mean annual maximum levels to

Table 11
Annual Minimum Mamawi Lake
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	208.73	208.64	208.77
1961	208.57	208.51	208.74
1962	208.50	208.49	208.66
1963	208.64	208.58	208.78
1964	208.55	208.53	208.71
1965	208.70	208.58	208.83
1966	208.62	208.57	208.80
1967	208.52	208.50	208.70
1968	208.62	208.61	208.77
1969	208.54	208.56	208.65
1970	208.14	208.48	208.57
1971	208.14	208.49	208.59
1972	208.24	208.56	208.67
1973	208.26	208.57	208.69
1974	208.55	208.67	208.76
1975	208.46	208.62	208.84
1976	208.64	208.79	208.87
1977	208.32	208.59	208.71
1978	208.27	208.56	208.71
1979	208.39	208.63	208.81
1980	208.34	208.57	208.68
1981	208.18	208.50	208.55
1982	208.10	208.40	208.51
1983	208.12	208.42	208.53
1984	208.21	208.51	208.55
1985	208.73	208.66	208.60
1986	208.03	207.96	208.52
1987	208.57	208.36	208.73
1988	208.09	208.49	208.73
1989	208.50	208.41	208.71
1990	208.69	208.50	208.88
Mean	208.42	208.53	208.70
S.D.	0.22	0.13	0.10

Table 12
Annual Mean Mamawi Lake
Water Levels

Year	Water Levels (in metres)		
	Natural	Regulated	Regulated and Weirs
1960	209.32	208.87	209.21
1961	208.97	208.64	209.04
1962	209.24	208.89	209.28
1963	209.18	209.01	209.41
1964	209.36	208.95	209.31
1965	209.48	209.18	209.53
1966	209.10	208.78	209.26
1967	209.27	208.93	209.34
1968	209.23	209.07	209.27
1969	208.98	209.95	209.13
1970	208.63	208.64	208.82
1971	208.83	208.74	209.01
1972	209.25	209.08	209.29
1973	209.39	209.31	209.46
1974	209.72	209.55	209.79
1975	209.40	209.40	209.62
1976	209.25	209.19	209.35
1977	209.04	208.87	209.22
1978	208.88	208.89	209.21
1979	209.14	209.02	209.33
1980	208.57	208.66	208.79
1981	208.64	208.61	208.69
1982	208.59	208.59	208.69
1983	208.61	208.67	208.79
1984	208.86	208.86	208.98
1985	209.08	208.99	209.11
1986	209.07	208.88	209.18
1987	209.11	208.99	209.20
1988	209.17	209.10	209.24
1989	209.21	209.07	209.29
1990	209.26	208.96	209.23
Mean	209.09	208.98	209.20
S.D.	0.28	0.29	0.25

approximately 0.1 m below natural conditions.

The minimum annual water level on Lake Mamawi (Table 11) was increased by the effects of the Bennett dam by 0.11 m. The weirs have raised the minimum levels by 0.28 m above natural conditions.

The mean annual water levels (Table 12) were decreased by 0.1 m due to the effects of the Bennett Dam. The weirs have raised the mean annual water level approximately 0.1 m above natural conditions.

5.2 Spatial and Temporal Effects

The following discussion is based only on the monthly mean data for the period 1985 to 1990. The spatial and temporal effects discussed in each section are best understood when read in conjunction with viewing the corresponding appendix of figures. Since the model cannot simulate the effectsof dynamic ice breakup the comparison of results for early spring are somewhat tenuous. The overall decription for each effect is based on an analysis which utilized the annual mean data for the 1985 - 1990 period.

5.2.1 Effect of Weirs on Present Conditions

The numerical results of this analysis are displayed in Table 13 and Appendix F. These figures and table indicate what change there would have been in the mean monthly water levels if the weirs had not been built. A positive number indicates that the weirs have raised the water levels. Spatially, the weirs have their greatest effect upstream of the weirs along Rivière des Rochers and Revillon Coupé. The increases caused by the weirs decrease with distance into the delta, upstream of the weirs and up to the lakes.

Temporally, the weirs increase water levels in all parts of the delta during the winter. The weirs release water slower than natural so the lakes are still draining in the winter, which explains why the Peace and Slave River water levels are higher as well. This becomes negligible in July and continues as such until December.

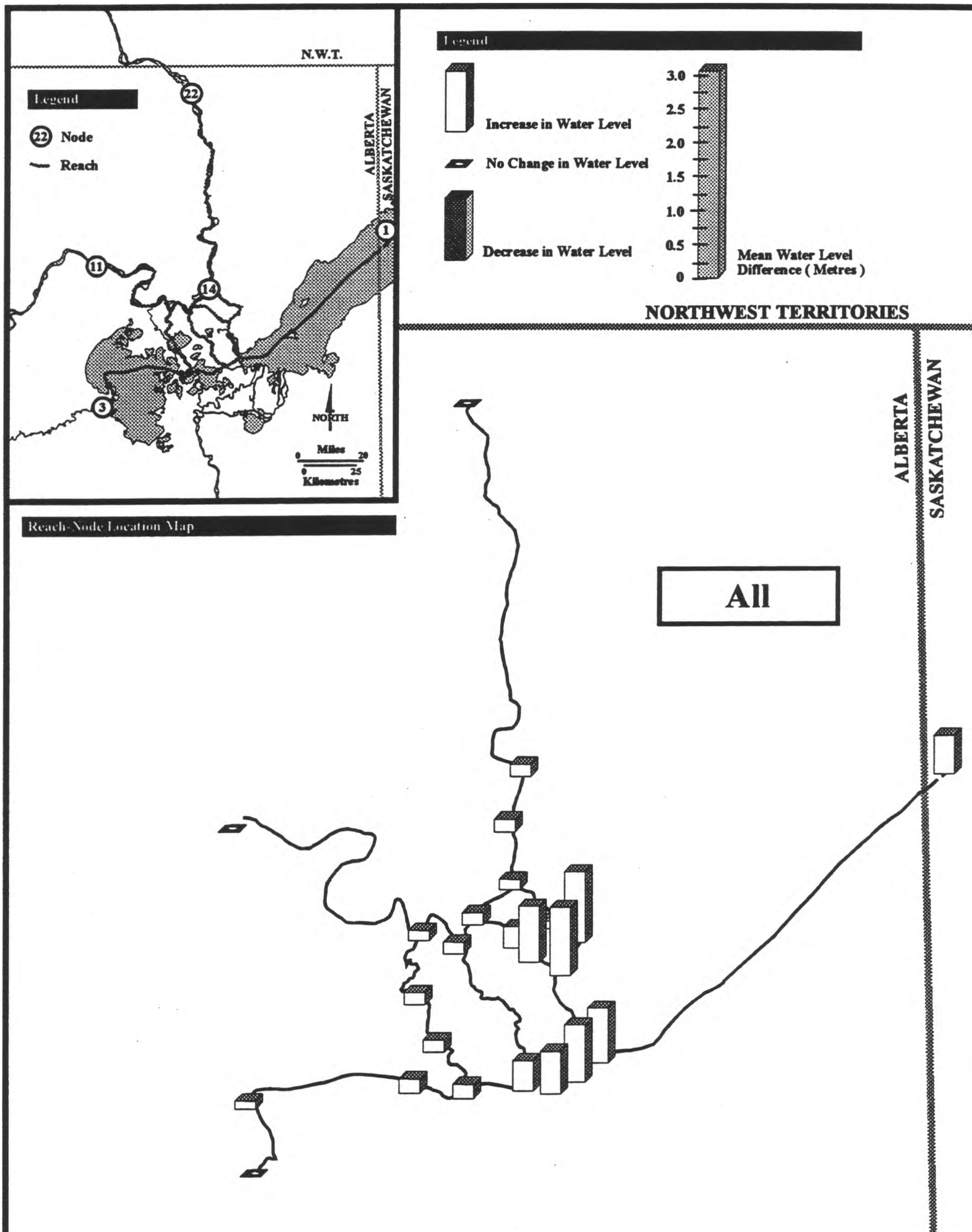
Table 13
Water Level Mean Difference : Effect of Weirs on Present Conditions
(metres)

Location(Reach No.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Lake Athabasca(150)	0.6	0.6	0.5	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.7	0.6
Lake Athabasca Outlet(200)	1.0	1.1	1.3	0.9	0.5	0.5	0.5	0.6	0.7	0.9	1.0	0.9	0.8
Birch River(350)	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Lake Claire(450)	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1
Athabasca Channel to Four Forks(500)	1.0	1.1	1.3	0.9	0.5	0.5	0.6	0.7	0.8	1.0	1.2	1.0	0.9
Prairie River(550)	0.2	0.3	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.2
Lake Mamawi(650)	0.2	0.3	0.3	0.2	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.2	0.2
Mamawi Lake Channel to Four Forks(750)	0.0	0.4	0.3	0.2	0.2	0.1	0.2	0.3	0.3	0.4	0.7	0.6	0.4
Riviere des Rochers(800)	1.1	1.1	1.4	1.0	0.6	0.6	0.7	1.0	1.2	1.3	1.5	1.0	1.0
Baril Lake(900)	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.2	0.2
Baril River(950)	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.2	0.2
Chenal des Quatre Fourches(1000)	0.7	0.6	0.7	0.5	0.4	0.3	0.5	0.6	0.8	0.9	1.1	0.7	0.6
Peace River at Peace Point(1050)	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peace River at Baril River(1150)	0.2	0.2	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2
Revillon Coupe above Weir(1350)	0.7	0.6	0.8	0.6	0.4	0.4	0.7	1.1	1.3	1.4	1.4	0.6	0.8
Peace River at Chenal des Quatres Fourches(1400)	0.3	0.3	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2
Riviere des Rochers above Weir(1500)	1.1	1.0	1.3	1.0	0.7	0.6	0.8	1.0	1.3	1.4	1.5	1.0	1.1
Revillon Coupe below Weir(1550)	0.5	0.5	0.6	0.5	0.3	0.3	0.2	0.0	0.0	0.1	0.2	0.5	0.3
Peace River at Revillon Coupe(1750)	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.3	0.2
Riviere des Rochers below Weir(1850)	0.4	0.4	0.5	0.0	0.0	0.2	0.0	0.0	-0.1	0.0	0.0	0.4	0.1
Slave River at delta(1950)	0.3	0.4	0.4	0.0	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.2
Slave River below delta(1960)	0.4	0.4	0.5	0.0	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.2
Slave River above Fitzgerald(1970)	0.4	0.4	0.6	0.0	0.2	0.2	0.0	0.0	0.0	0.0	-0.2	0.4	0.2
Slave River at Fitzgerald(1980)	0.0	0.0	0.7	0.2	0.1	-0.2	-0.1	0.0	-0.1	0.0	-0.8	0.2	0.0

As shown in Figure 7, the weirs increase water levels in all parts of the delta with the effects being greatest immediately upstream of the weirs and decreasing with distance upstream of the weirs. Lake Athabasca is also significantly affected by the weirs, leaving other areas experiencing similar but smaller effects.

5.2.2 Effect of Weirs and Bennett Dam on Natural Conditions

The results of this analysis are shown in Table 14. Illustrations in Appendix G illustrate the spatial and temporal variations discussed in this section. These figures and table indicate the change in water level caused by the combined effects of the weirs and Bennett Dam. This is the condition that exists today. A positive number indicates that the water levels are higher than natural.



Effect of Weirs on Present Conditions - All (Figure 7)

Table 14

Water Level Mean Difference : Effect of Weirs and Bennett Dam on Natural Condition (metres)

Location(Reach No.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Lake Athabasca(150)	0.5	0.5	0.5	0.4	0.4	0.0	-0.2	0.0	0.2	0.4	0.6	0.6	0.3
Lake Athabasca Outlet(200)	1.4	2.1	2.1	1.6	0.4	0.0	-0.2	0.0	0.3	0.6	0.8	1.1	0.9
Birch River(350)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Claire(450)	0.0	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.1	0.0	0.0	0.0	0.1	0.0
Athabasca Channel to Four Forks(500)	1.6	2.1	2.2	1.7	0.5	0.0	-0.2	0.0	0.4	0.7	1.0	1.3	0.9
Prairie River(550)	0.1	0.3	0.3	0.1	0.0	-0.1	-0.2	-0.1	0.0	0.1	0.1	0.1	0.1
Lake Mamawi(650)	0.1	0.3	0.3	0.1	0.1	-0.1	-0.2	-0.1	0.0	0.1	0.2	0.1	0.1
Mamawi Lake Channel to Four Forks(750)	0.9	0.8	0.6	0.2	0.1	-0.2	-0.2	-0.1	0.0	0.2	0.4	0.7	0.3
Rivière des Rochers(800)	2.3	2.8	2.8	2.2	0.5	-0.2	0.0	0.4	0.9	1.2	1.5	1.8	1.3
Baril Lake(900)	0.1	0.1	0.1	0.1	0.1	-0.1	-0.2	-0.1	0.0	0.1	0.1	0.1	0.0
Baril River(950)	0.1	0.1	0.1	0.1	0.1	-0.2	-0.2	-0.1	0.0	0.1	0.1	0.1	0.0
Chenal des Quatre Fourches(1000)	1.6	2.1	2.0	1.0	0.2	-0.4	-0.3	0.0	0.4	0.6	0.9	1.3	0.8
Peace River at Peace Point(1050)	2.8	3.1	2.7	2.4	-0.5	-2.2	-1.1	0.0	0.8	1.0	0.8	2.4	1.0
Peace River at Baril River(1150)	2.4	2.8	2.5	2.1	0.0	-1.6	-1.0	-0.3	0.3	0.6	0.4	2.0	0.8
Revillon Coupe above Weir(1350)	2.3	2.7	2.7	2.1	0.2	-0.8	-0.2	0.6	1.2	1.5	1.6	1.9	1.3
Peace River at Chenal des Quatres Fourches(1400)	2.3	2.7	2.5	2.0	0.0	-1.4	-0.9	-0.3	0.3	0.5	0.4	1.9	0.8
Rivière des Rochers above Weir(1500)	2.3	2.8	2.8	2.2	0.6	-0.3	0.0	0.5	1.0	1.3	1.5	1.9	1.4
Revillon Coupe below Weir(1550)	2.2	2.6	2.4	1.9	0.0	-0.9	-0.7	-0.4	0.0	0.2	0.4	1.8	0.8
Peace River at Revillon Coupe(1750)	2.2	2.6	2.4	1.9	0.0	-1.2	-0.8	-0.3	0.2	0.4	0.3	1.8	0.8
Rivière des Rochers below Weir(1850)	1.8	2.4	2.2	1.3	0.0	-0.8	-0.9	-0.6	-0.2	0.0	0.0	1.4	0.5
Slave River at delta(1950)	1.9	2.4	2.2	1.3	0.0	-0.9	-0.8	-0.4	0.0	0.2	0.0	1.5	0.6
Slave River below delta(1960)	2.0	2.6	2.3	1.4	0.0	-1.0	-0.9	-0.4	0.0	0.3	0.0	1.6	0.7
Slave River above Fitzgerald(1970)	2.2	2.7	2.4	1.5	0.0	-1.1	-1.0	-0.4	0.0	0.3	0.0	1.7	0.7
Slave River at Fitzgerald(1980)	1.1	1.4	1.2	0.7	0.0	-0.9	-0.8	-0.2	0.0	0.0	-0.7	0.7	0.2

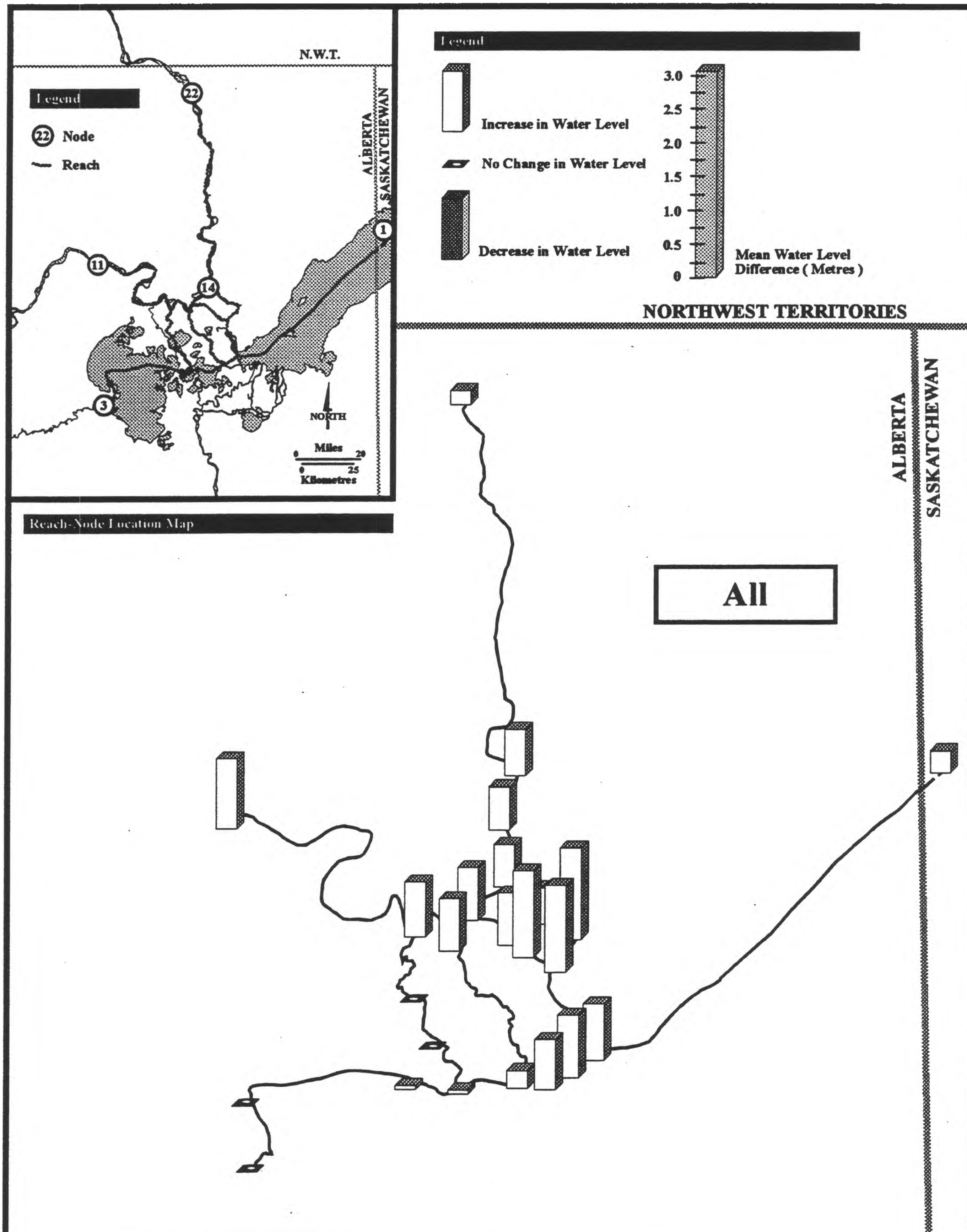
Several spatial variations are evident. The greatest effects from the weirs and the dam are visible along Revillon Coupê, Rivière des Rochers, Chenal des Quatre Fourches, Peace River and the Slave River. Additionally, the effects decrease with distance down the Slave River and with distance into the delta up to the weirs. At the weirs, the effects are suddenly increased followed, again, by a gradual decrease into the delta. The effects in the lakes are generally small or, in other words, the effects are small beyond the Rivière des Rochers and Chenal des Quatre Fourches.

The water levels in all parts of the delta are higher than natural conditions in the winter because releases from Bennett Dam causes higher than natural flows on the Peace River and thus a slowing of flow from the delta compared to natural conditions. As discharge from the Peace River decreases, so do the water levels in the delta until May when little or no effect exists except an increase immediately downstream of the weirs. Lower than natural flow onl the Peace River during the summer allows the water levels in the delta to drop rapidly to below natural conditions. The weirs significantly reduce draining of the delta caused by the dam on the upstream side of the weirs by decreasing the rate of flow from the delta, thereby increasing the water levels. The water levels gradually increase with respect to natural conditions, although still lower than natural for the rest of the summer until August. During the fall, water levels everywhere, except Rivière des Rochers and Revillon Coupè upstream of the weirs, have small or no visible effects. The levels gradually increase until the typical winter effects are in place.

Figure 8 shows that the combined effect of the weirs and Bennett Dam have caused higher water levels than natural in the delta except on the Baril River, Baril Lake, Lake Claire, and the Birch River. The effects decrease with distance down the Peace and Slave rivers and with distance into the delta up to the weirs. Also, the weirs significantly raise the water levels in Revillon Coupè, Rivière des Rochers, and Chenal des Quatre Fourches. The weirs effects decrease with distance into the delta to where the effects are small in the delta lakes.

5.2.3 Effect of Bennett Dam on Natural Conditions

The effects of the Bennett Dam on natural conditions are shown in Table 15. A positive number indicates that the Bennett Dam increases the water above natural conditions and a negative number indicates a decrease in the levels. Maps depicting the spacial and temporal variations



Effect of Weirs and Bennet Dam on Natural Conditions - All (Figure 8) may be seen in Appendix H.

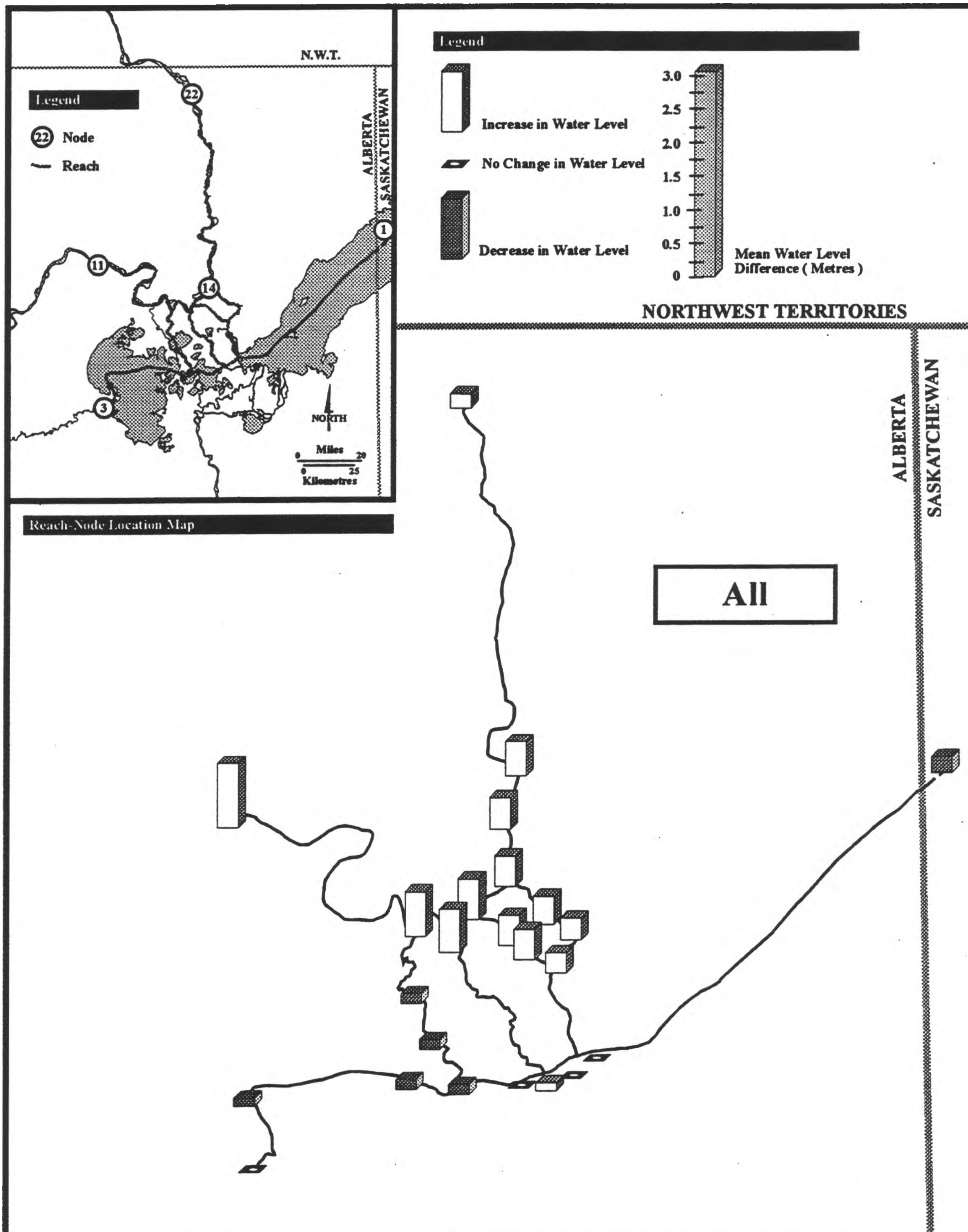
Table 15

Water Level Mean Difference : Effect of Bennett Dam on Natural Conditions (metres)

Location(Reach No.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Lake Athabasca(150)	-0.1	-0.0	0.0	0.0	0.0	-0.4	-0.6	-0.6	-0.4	-03	-0.2	-0.1	-0.2
Lake Athabasca Outlet(200)	0.4	1.0	0.8	0.7	0.0	-0.5	-0.7	-0.6	-0.4	-0.3	-0.2	0.2	0.0
Birch River(350)	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	-0.1	-0.1	-0.1	0.0
Lake Claire(450)	-0.1	-0.1	-0.1	0.0	0.0	-0.1	-0.3	-0.3	-0.2	-0.2	-0.1	-0.1	-0.1
Athabasca Channel to Four Forks(500)	0.6	1.1	0.9	0.8	0.0	-0.5	-0.7	-0.6	-0.4	-0.3	-0.2	0.3	0.0
Prairie River(550)	-0.1	0.0	0.0	-0.1	0.0	-0.2	-0.3	-0.3	-0.3	-0.2	-0.1	-0.1	-0.1
Lake Mamawi(650)	-0.1	0.0	0.0	0.0	0.0	-0.3	-0.4	-0.4	-0.3	-0.2	-0.1	-0.1	-0.2
Mamawi Lake Channel to Four Forks((750)	0.0	0.5	0.3	0.0	0.0	-0.3	-0.4	-0.4	-0.3	-0.3	-0.3	0.0	0.0
Riviere des Rochers(800)	1.2	1.7	1.4	1.2	0.0	-0.8	-0.8	-0.6	-0.3	-0.2	0.0	0.8	0.3
Baril Lake(900)	-0.1	-0.1	-0.1	0.0	0.0	-0.3	-0.4	-0.4	-0.3	-0.2	-0.1	-0.1	-0.2
Baril River(950)	-0.0	-0.0	-0.1	0.0	0.0	-0.3	-0.4	-0.4	-0.3	-0.2	-0.1	-0.1	-0.2
Chenal des Quatre Fourches(1000)	0.9	1.5	1.3	0.5	-0.1	-0.7	-0.8	-0.6	-0.4	-0.3	-0.1	0.6	0.1
Peace River at Peace Point(1050)	2.8	3.1	2.7	1.9	-0.5	-2.2	-1.2	0.0	0.8	1.0	0.8	2.4	1.0
Peace River at Baril River(1150)	2.1	2.6	2.3	1.7	-0.3	-1.7	-1.1	-0.3	0.3	0.5	0.4	1.7	0.7
Revillon Coupe above Weir(1350)	1.6	2.1	1.8	1.4	-0.2	-1.2	-0.9	-0.4	-0.1	0.0	0.2	1.2	0.5
Peace River at Chenal des Quatres Fourches(1400)	2.0	2.4	2.2	1.6	-0.3	-1.5	-1.0	-0.3	0.2	0.4	0.4	1.6	0.6
Riviere des Rochers above Weir(1500)	1.3	1.7	1.5	1.2	0.0	-0.9	-0.8	-0.5	-0.3	-0.1	0.0	0.9	0.3
Revillon Coupe below Weir(1550)	1.6	2.1	1.8	1.4	-0.2	-1.2	-0.9	-0.4	-0.1	0.0	0.2	1.2	0.5
Peace River at Revillon Coupe(1750)	1.9	2.3	2.1	1.6	-0.2	-1.4	-1.0	-0.3	0.2	0.4	0.3	1.5	0.6
Riviere des Rochers below Weir(1850)	1.4	2.0	1.7	1.3	-0.1	-1.0	-0.9	-0.5	0.0	0.0	0.0	1.0	0.4
Slave River at delta(1950)	1.5	2.0	1.8	1.4	-0.2	-1.1	-0.9	-0.4	0.0	0.2	0.2	1.2	0.5
Slave River below delta(1960)	1.6	2.1	1.8	1.4	-0.2	-1.2	-1.0	-0.4	0.0	0.2	0.2	1.2	0.5
Slave River above Fitzgerald(1970)	1.8	2.3	1.8	1.5	-0.2	-1.3	-1.1	-0.4	0.0	0.2	0.2	1.3	0.5
Slave River at Fitzgerald(1980)	1.1	1.3	0.5	0.5	-0.1	-0.7	-0.6	-0.2	0.0	0.1	0.0	0.5	0.2

Several spatial effects may be seen. The Bennett Dam's effects are usually greatest along the Peace and Slave rivers. The effects decrease with distance down the Peace and Slave Rivers and also with distance into the delta. Also, the Rivière des Rochers, Revillon Coupè and Chenal des Quatre Fourches see greater effects than the Baril River and Baril Lake.Temporally, the spatial effects discussed above are not visible in the fall when the delta lakes are high from summer lows. The higher than natural winter water levels in the delta are a result of the higher than natural Peace River flows which slow the outflow of water from the delta and cause the levels to remain higher. As spring approaches, the Peace River flows return to near natural and the effects in the delta decrease. The effects of storage behind the Bennett Dam, which are lower water levels, are first seen in May and the effect continues to increase to a maximum in June, followed by a steady decrease. In the summer the lower Peace River flows allow the delta to drain faster than natural. During the fall, the releases from the dam increase water levels in the Peace and Slave rivers. The already depressed water levels in the delta caused by the lower than natural summer flows start to move toward natural conditions. The effect of Bennett Dam never causes water levels in the Claire or Athabasca Lakes to increase above natural levels, but it does decrease the levels. Finally, Mamawi Lake usually experiences a small lowering of water levels due to the operation of Bennett Dam.

The overall effect of the Bennett Dam shown in Figure 9, is the result of increased winter levels and decreased summer levels. This serves to decrease the amplitude of the annual water levels, the effect lessening with distance from the dam. Also, increases in water levels along the Peace and Slave rivers decline with distance down the Peace and Slave rivers and into the delta. The Bennett Dam decreases average levels in Claire, Mamawi and Athabasca lakes. Most importantly, it has to be recognized that the regulation of the Bennett Dam reduces the peak water level caused by the annual spring flooding in the delta. The mean annual level statistics do not indicate the reduction of the maximum flood levels at various locations in the delta. At this time, the ability of these peaks to fill the pearched basins is incalculable. Additionallly, it is unclear as to the effects the Bennett Dam has on the development of ice jams on the Peace River. These ice jams are also responsible for causing flood levels that fill the perched bains.



Effect of Bennet Dam on Natural Conditions - All (Figure 9)

6.0 CONCLUSIONS

1. Bennett Dam Effect on Delta Water Levels

The modelled effects of the Bennett Dam indicate that the maximum and mean water levels of the delta lakes have declined compared to natural conditions. Minimum levels have not been affected. The Dam also increased delta water levels in the winter and decreased levels in the summer.

2. Weirs have Restored Peak Water Levels

The effect of the weirs was to return the maximum levels of the delta lakes to near the natural conditions.

3. Wiers have Raised Mean and Minimum Water Levels

The weirs raised the mean and minimum Lake Athabasca and Lake Mamawi levels well above natural conditions. This means that the winter delta levels that were elevated by the effects of the Bennett Dam were further elevated by the effect of the weirs.

The weirs returned the mean and minimum Lake Claire levels to near natural conditions.

4. Effectiveness of Weirs During the 1985 to 1990 Period

The addition of the six additional years of data (1985-1990), to the 25 year period (1960-1984), did not change the mean or standard deviation of the minimum, maximum, or mean annual water levels for the three largest delta lakes. Examination of the maximum Lake Athabasca levels for the 1985-90 period indicates that the weirs have raised the water levels by 0.5 m above the regulated (dam only) scenario. This increase is similar to the average increase for the 1960-84 period.

7.0 RECOMMENDATIONS

A trend analysis should be conducted to identify and isolate any long term trends to further identify the effects of the weirs and the dam. A trend analysis of the different scenarios would indicate if any long term trend is natural or not.

The results of the water level modelling on the Peace-Athabasca Delta should be used as input into a GIS based analysis of the delta for the determination of the areas ecological sensitivity to changes in water levels.

A more detailed analysis of flow in Cree Creek should be done to determine a more accurate flow regime for the creek. This could then be used to precicely model the effects of the diversion.

Freezeup and breakup data should be collected to improve modelling of these critical periods. An improved model should also have the ability to account for the storage in the perched basins when the natural levees are overtopped.

Further studies using this model could be done to determine the size and location of any future man-made ice dams for the purpose of flooding the perched basins.

The One-Dimensional Hydrodynamic Model could be continued to be used to evaluate Northern River Basins Study scenarios as well as Atmospheric Environmental Service climate change studies.

Additional studies should be conducted to determine the magnitude, frequency and cause of floods that are required to fill pearched basins for each scenario discussed within this report.

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Water Management Systems Division, Environment Canada; **Documentation Manual of Network Configuration and Cross-Sections for 1-Dimensional Hydrodynamic Model of the Peace-Athabasca Delta Region and the Slave River**; Hull, Quebec, Revised August 1983.

Water Management Systems Division Water Planning and Management Branch Inland Waters Directorate Environment Canada; **Peace-Athabasca Delta Hydrodynamic Modelling Study: Reassessment and Recalibration of the Rivière des Rochers and Revillon Coupè Mathematical Formulation**; Ottawa, Ontario, August 7th, 1991.

Water Planning and Management, Environment Canada; **One-Dimensional Hydrodynamic Model Computer Manual**; February 1988.

APPENDIX A
Terms of Reference

NORTHERN RIVER BASINS STUDY
SCHEDULE A - TERMS OF REFERENCE
Project - Natural and Modified Flow Modelling

Agreement #930723

1. **Purpose**

To determine the effects of the Bennett Dam, Rivière des Rochers and Revillon Coupé Weirs on the flow and water level regime in the Peace-Athabasca Delta and the Slave Rivers.

2. **Rationale**

To evaluate the cumulative environmental effects of industrial developments in the Northern River Basins, a thorough understanding of the hydraulic characteristics of key river reaches is required. The Peace-Athabasca Delta, one of the largest freshwater deltas in the world, is one of these key reaches.

3. **Technical Background**

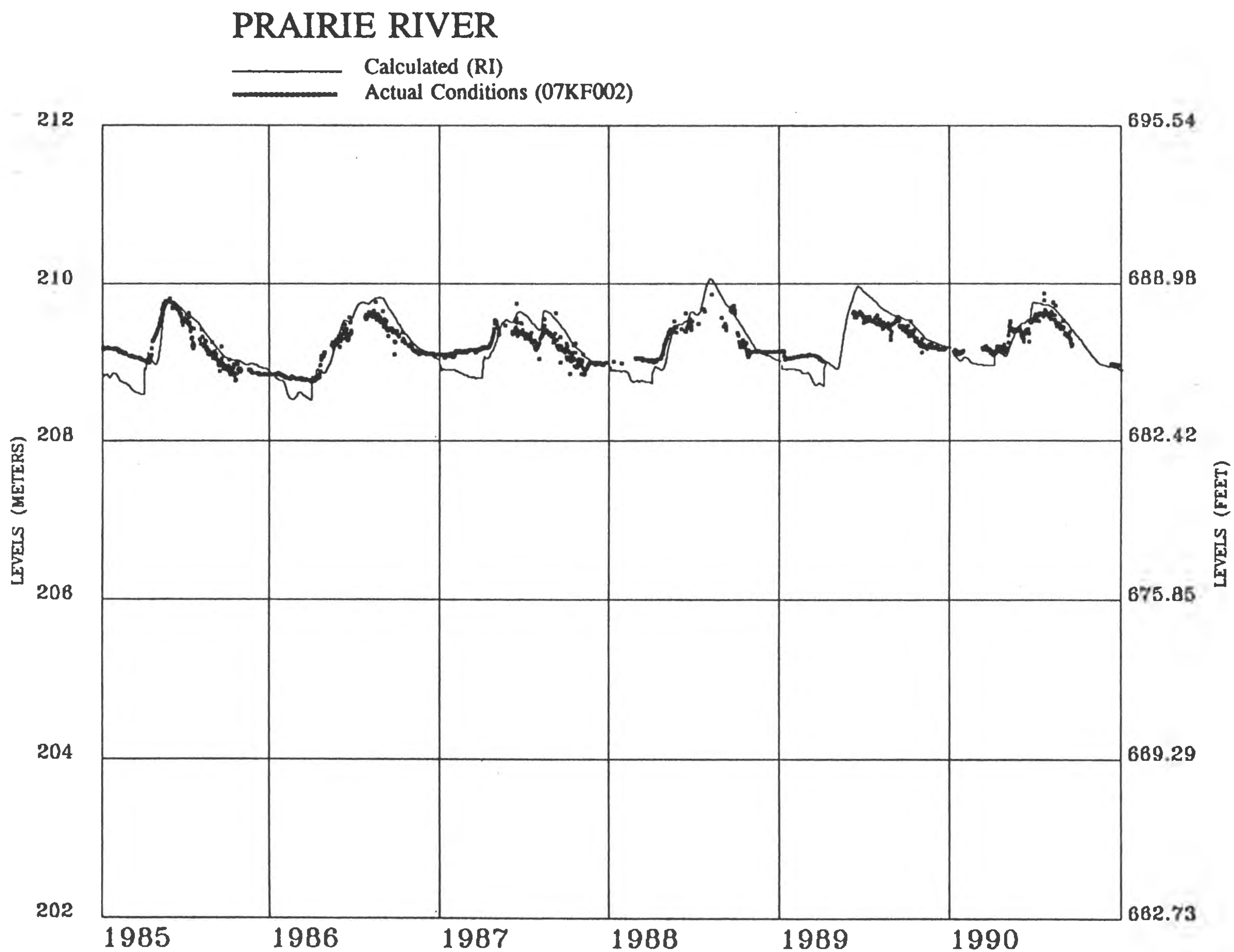
A one-dimensional hydrodynamic model which uses physical data has been developed by the Water Planning and Management Branch for the Peace-Athabasca Delta and includes portions of the Athabasca, Peace and Slave Rivers immediately adjacent to the delta. The model is currently being used to compute the natural water levels and flows with man-made works removed from the rivers. The model is also used to compute the flows and levels of the river regime with Bennett Dam and the mitigation structures in the delta in place. The amount of change to the river regime is found by comparing the natural flow system with the modified river system. The Water Planning and Management Branch, Inland Waters Directorate, Western and Northern Region, Environment Canada, Regina Office will extend the available information for the natural and modified flow regimes for the period from 1960 to 1984 up to 1990. Past modelling of the Peace-Athabasca Delta has been performed on behalf of the Peace-Athabasca Delta Implementation Committee in cooperation with Environment Canada, Inland Waters Directorate, Ottawa, Regina, and Calgary, Canadian Parks Service and Alberta Environment.

4. **Reporting Requirements**

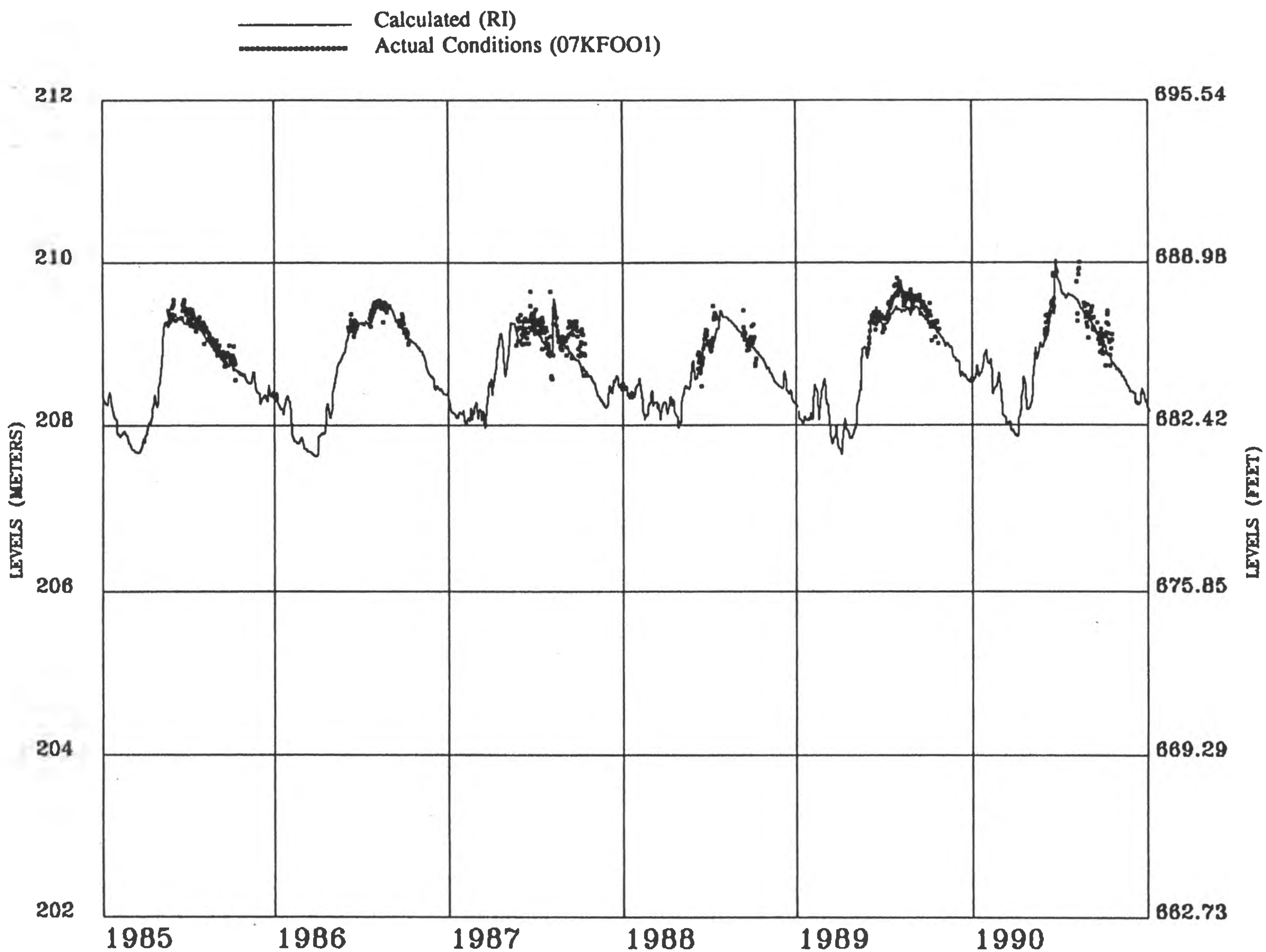
1) The contractor will provide the Northern River Basins Study Office with outlining present model calibration improvements and scenario runs.

2) The contractor will provide Five (5) cerlox bound copies, an electronic in Word Perfect 5.1 format, is to be submitted along with the final report. Data presented in tables, figures, appendices, etc. in the final report are also to be submitted in electronic form (dBase IV format preferred) along with the final letter report. The final report is to contain a table of contents, list of figures (if appropriate), list of tables (if appropriate), acknowledgements, executive summary and an appendix containing the Terms of Reference for this contract.

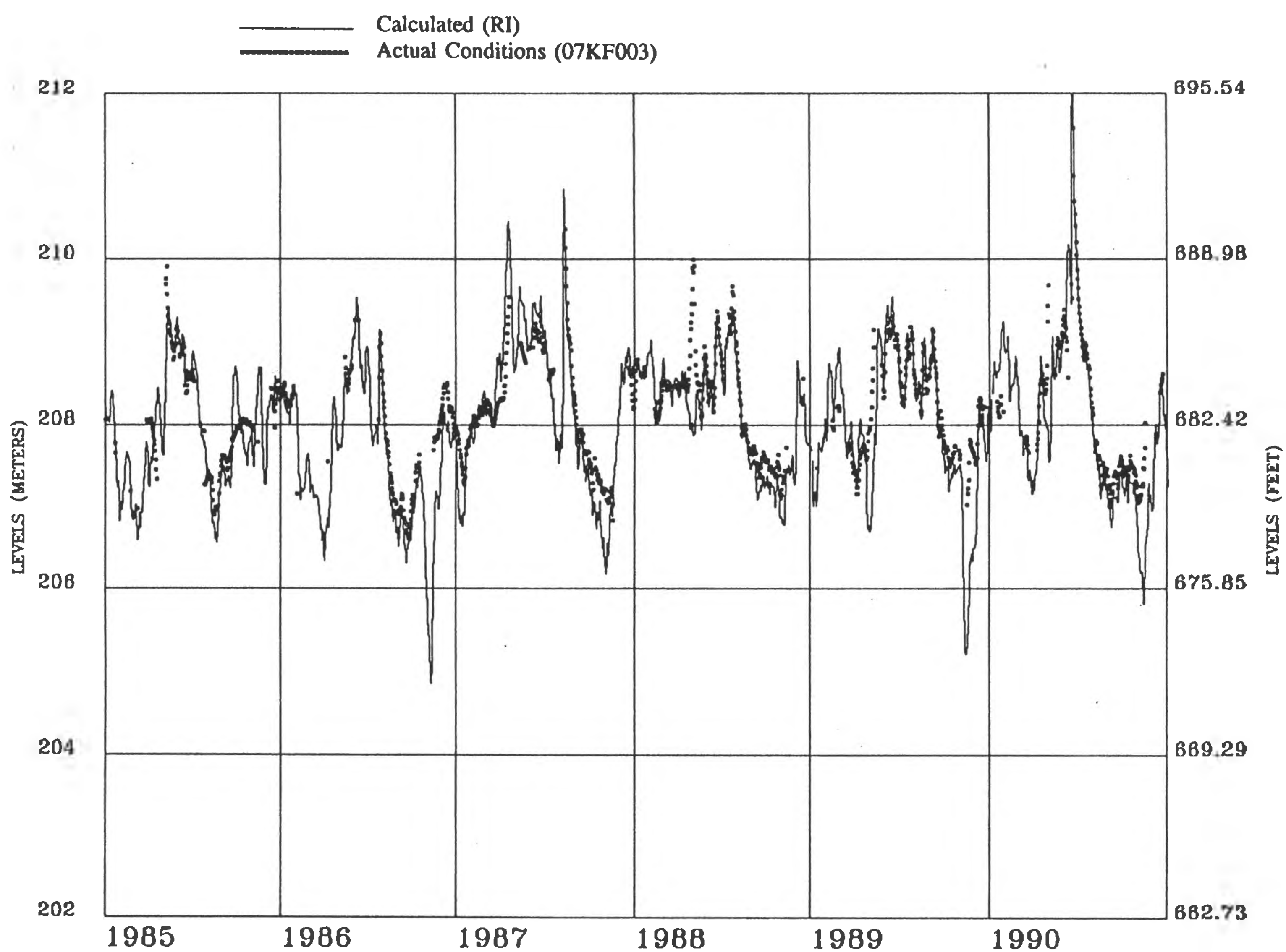
APPENDIX B.
Plots of Calibration Stations


PRAIRIE RIVER
Calculated (RI)
Actual Conditions (07KF002)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

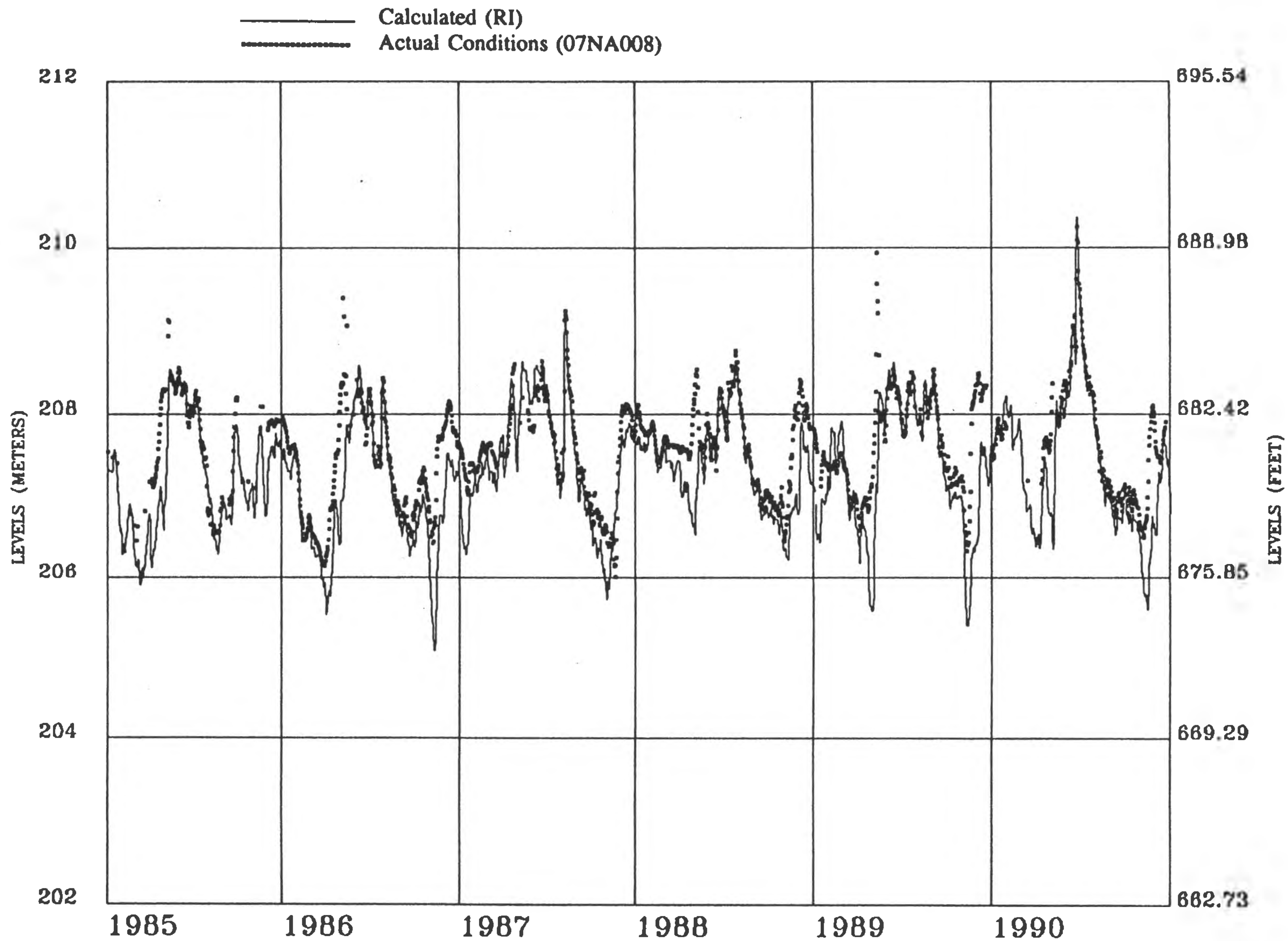
CHENAL DES QUATRE FOURCHES



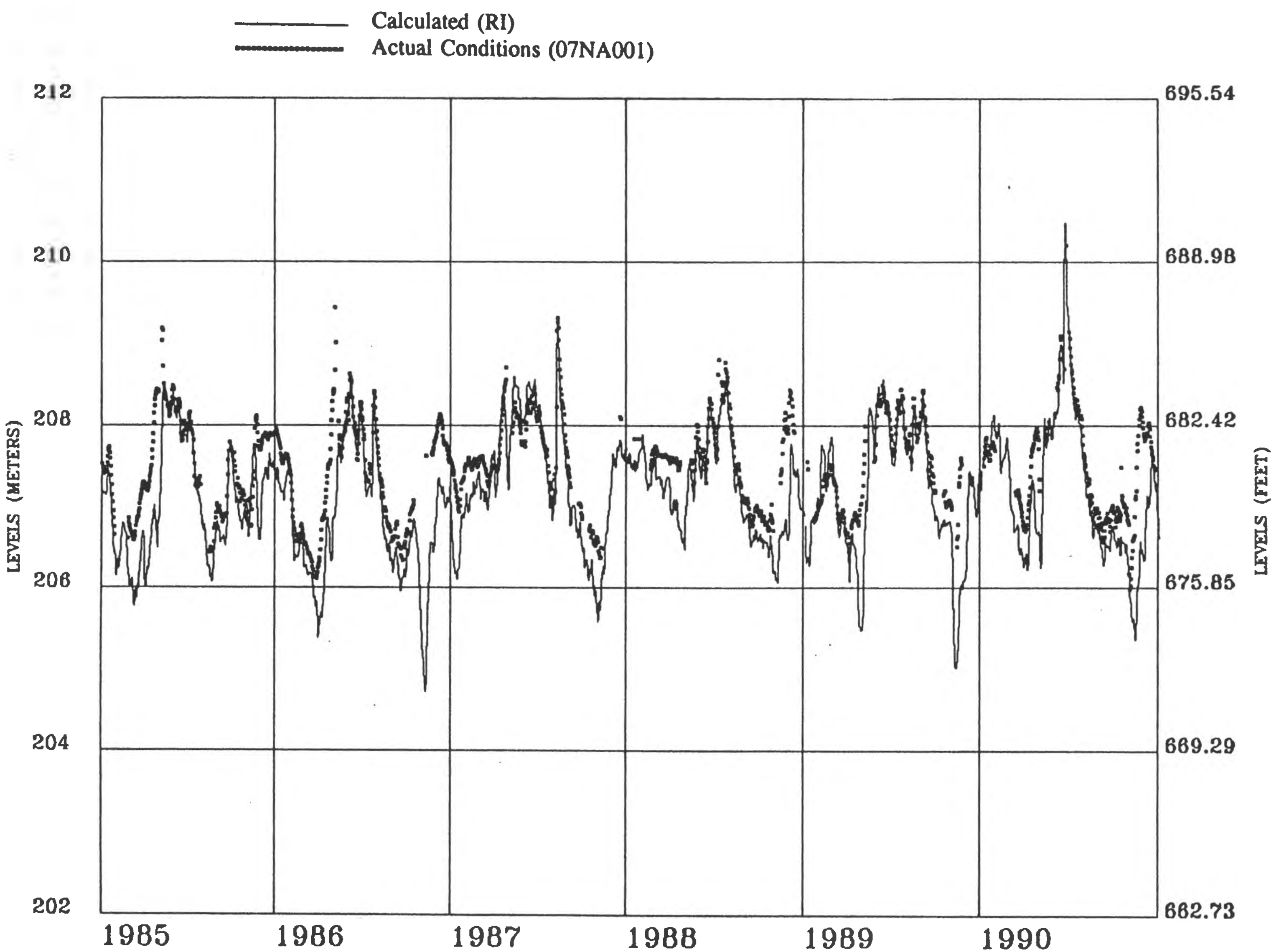
PEACE RIVER AT CHENAL DES QUATRE FOURCHES



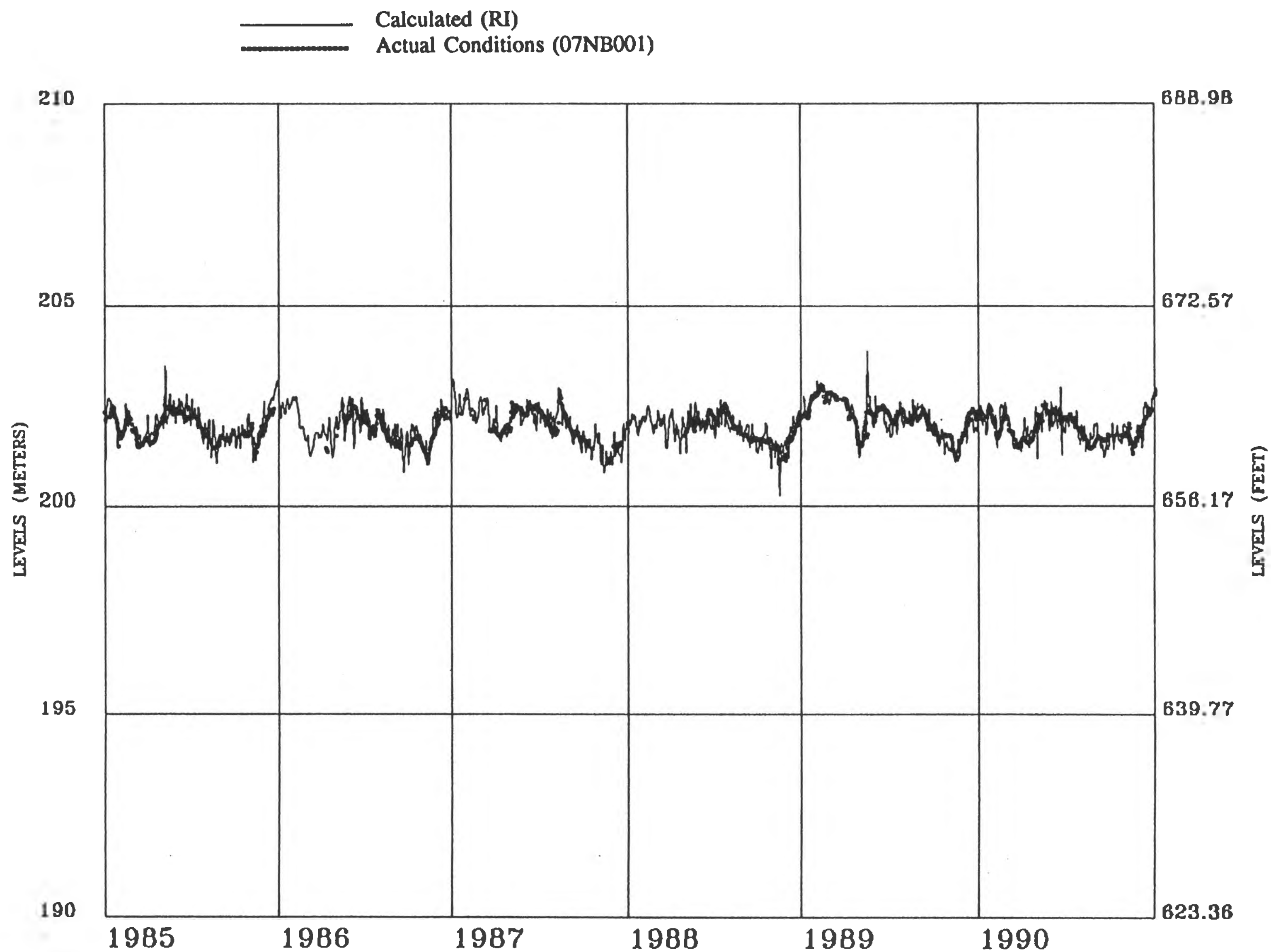
RIVIERE DES ROCHERS BELOW WEIR



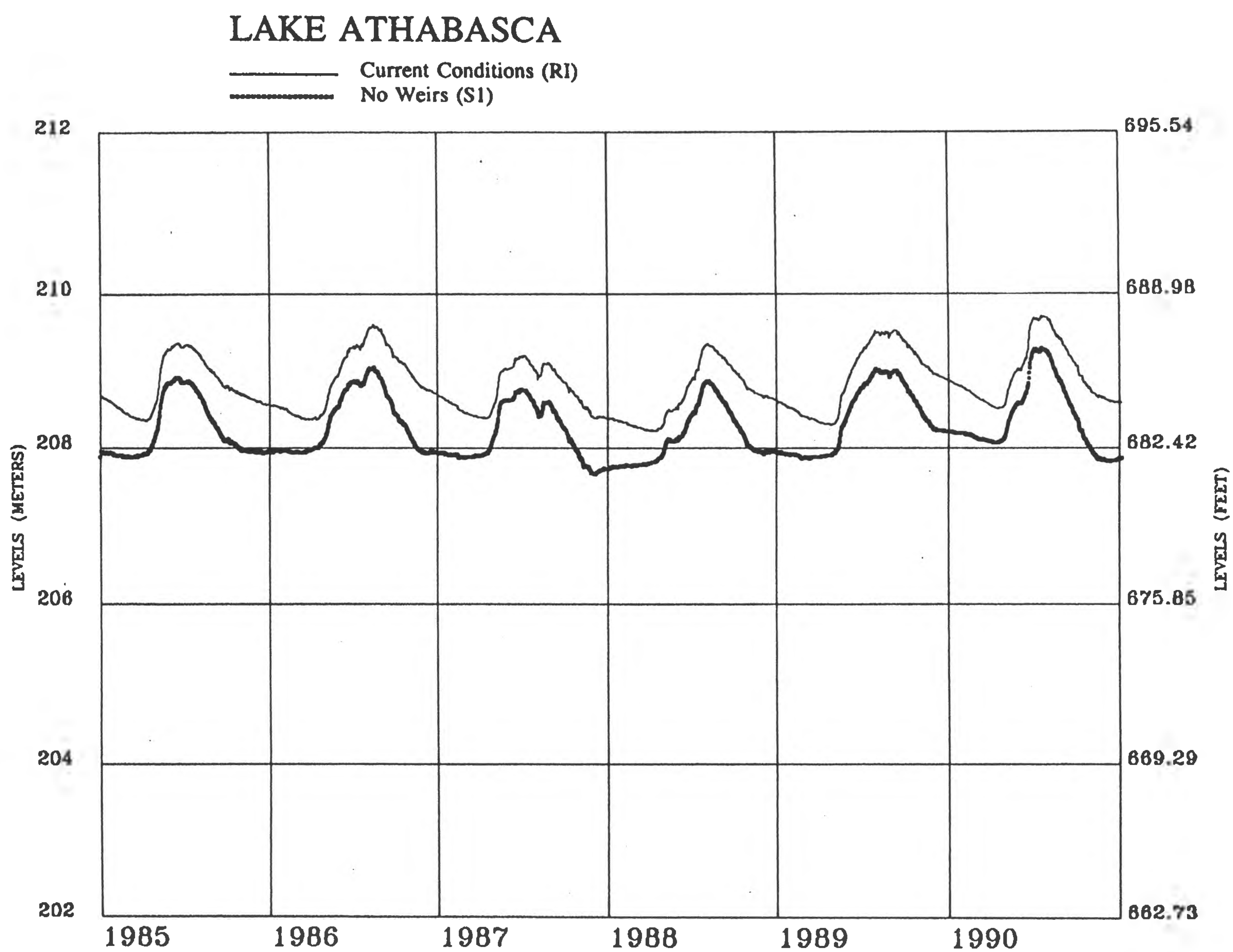
SLAVE RIVER AT DELTA

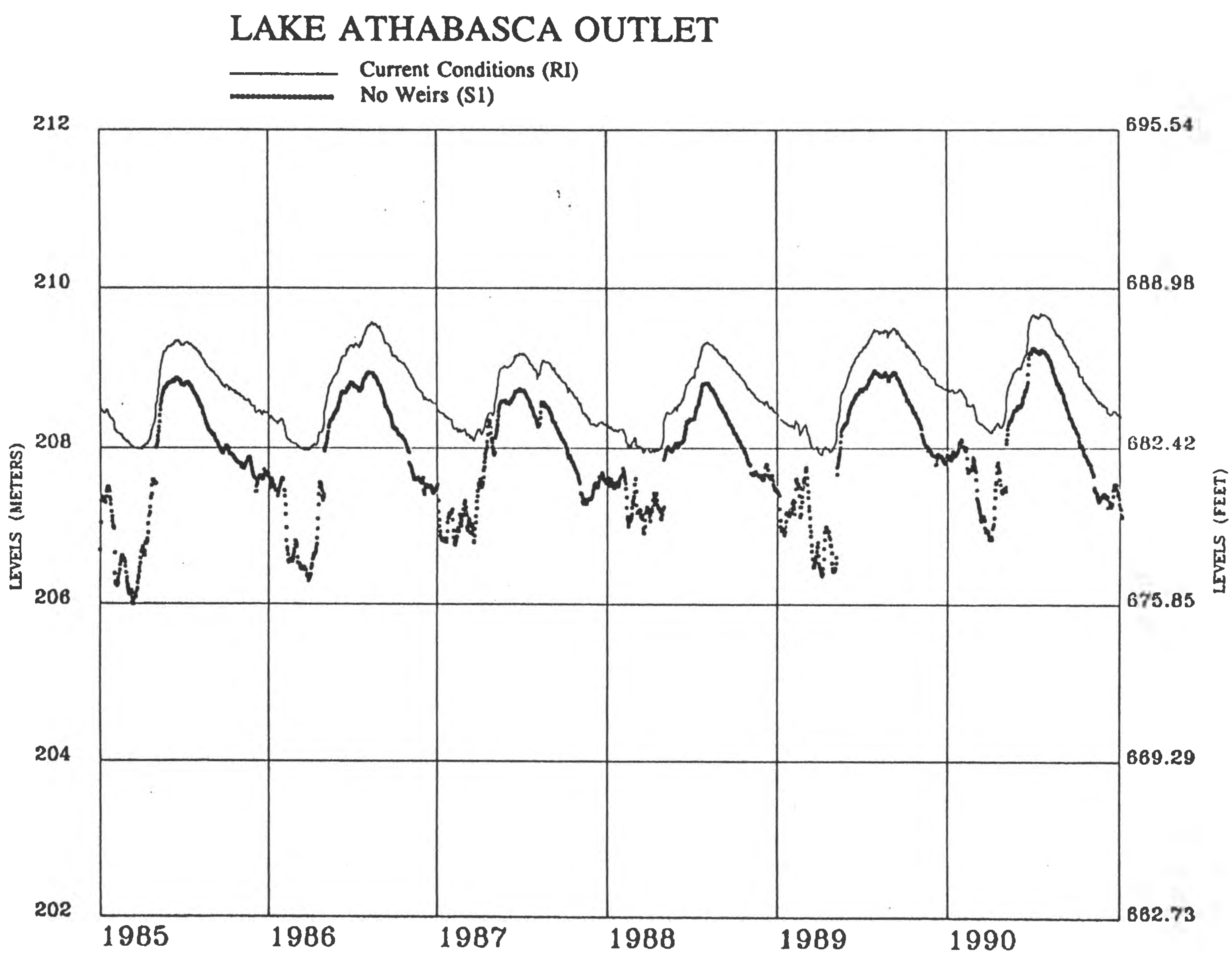


SLAVE RIVER AT FITZGERALD



APPENDIX C.
Plots of Present and No Weirs Conditions


LAKE ATHABASCA
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990


LAKE ATHABASCA OUTLET
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
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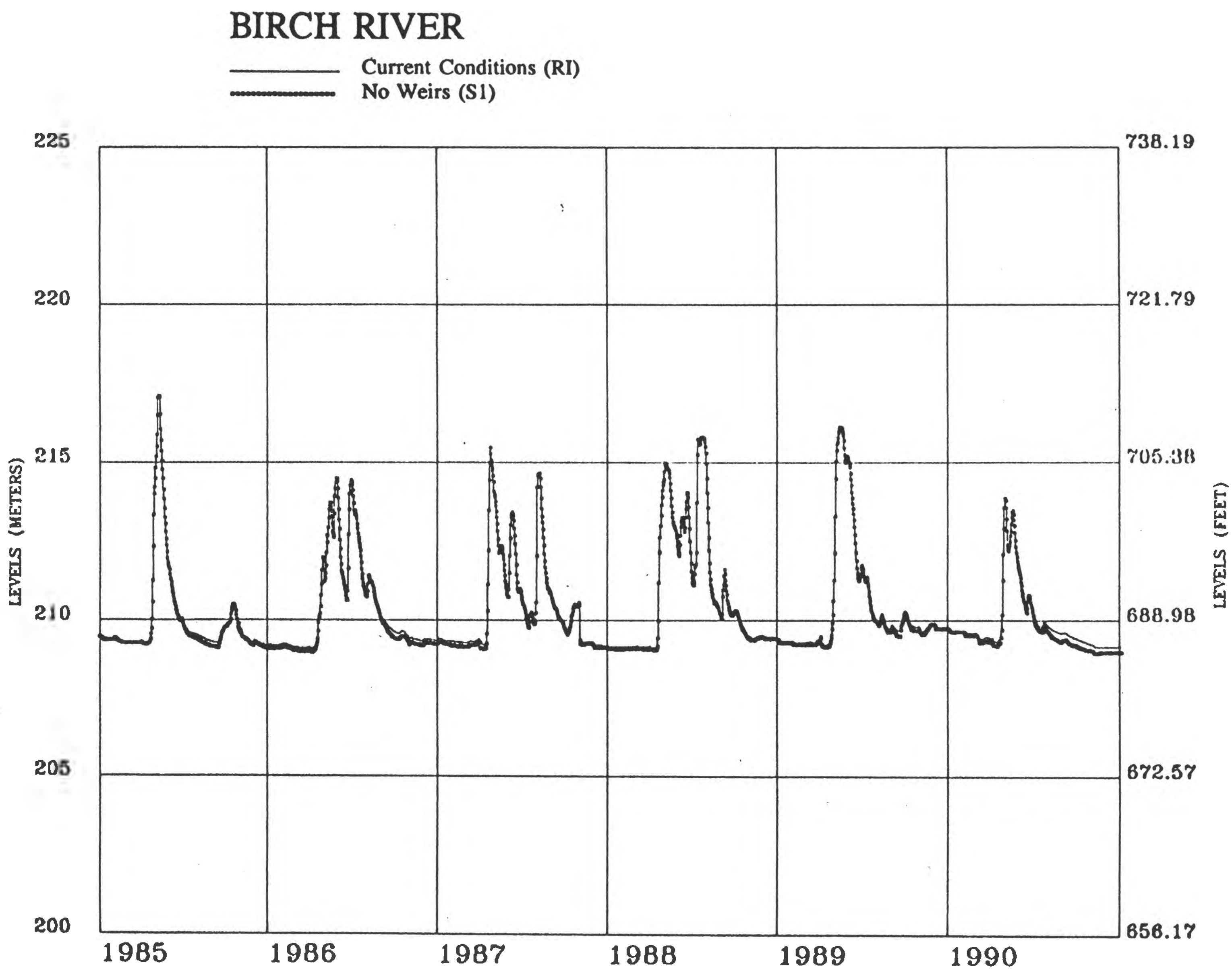
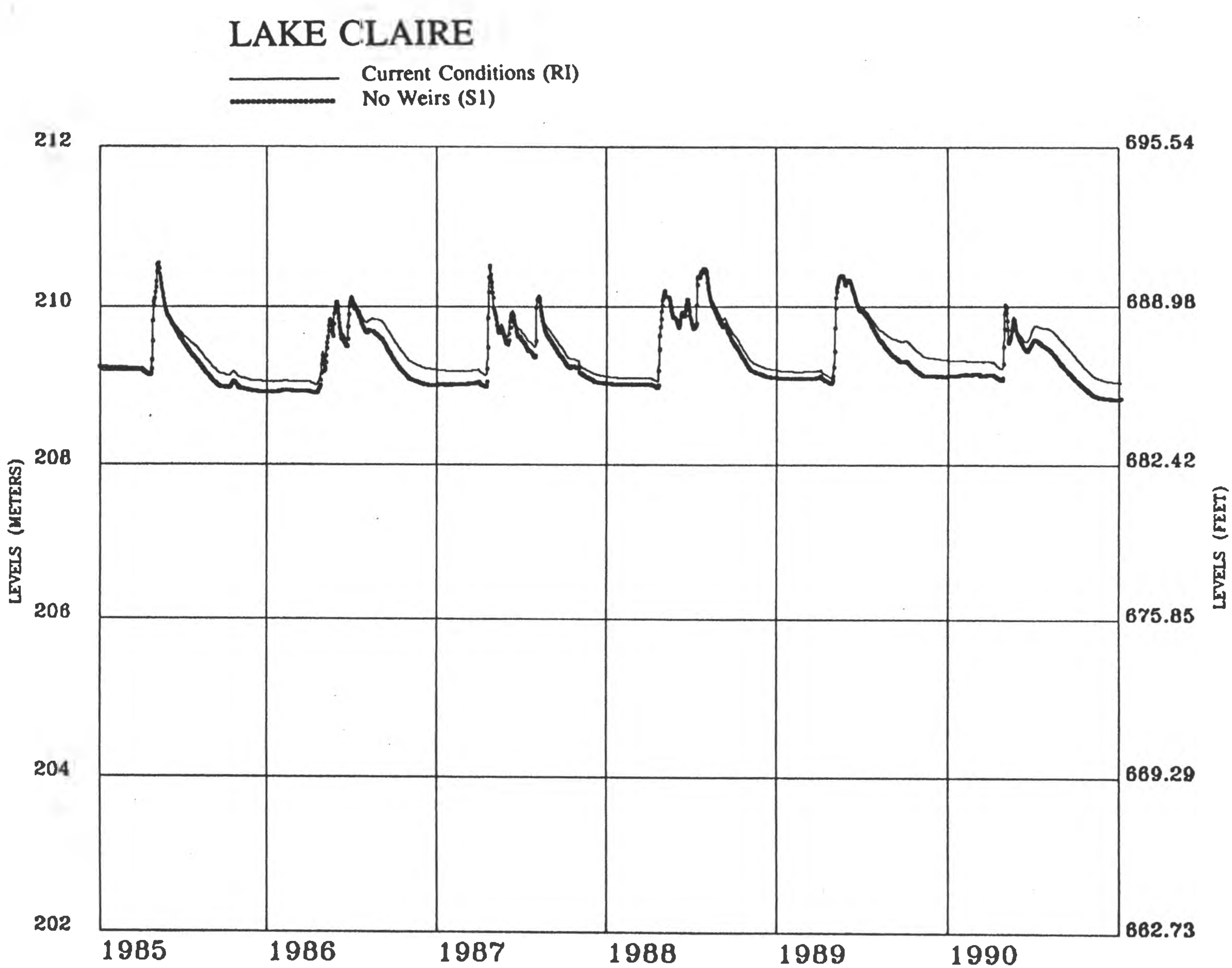
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990



BIRCH RIVER
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
225
220
215
210
205
200
LEVELS (FEET)
738.19
721.79
705.38
688.98
672.57
656.17
1985
1986
1987
1988
1989
1990


LAKE CLAIRE
Current Conditions (RI)
No Weirs (S1)
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208
206
204
202
LEVELS (METERS)
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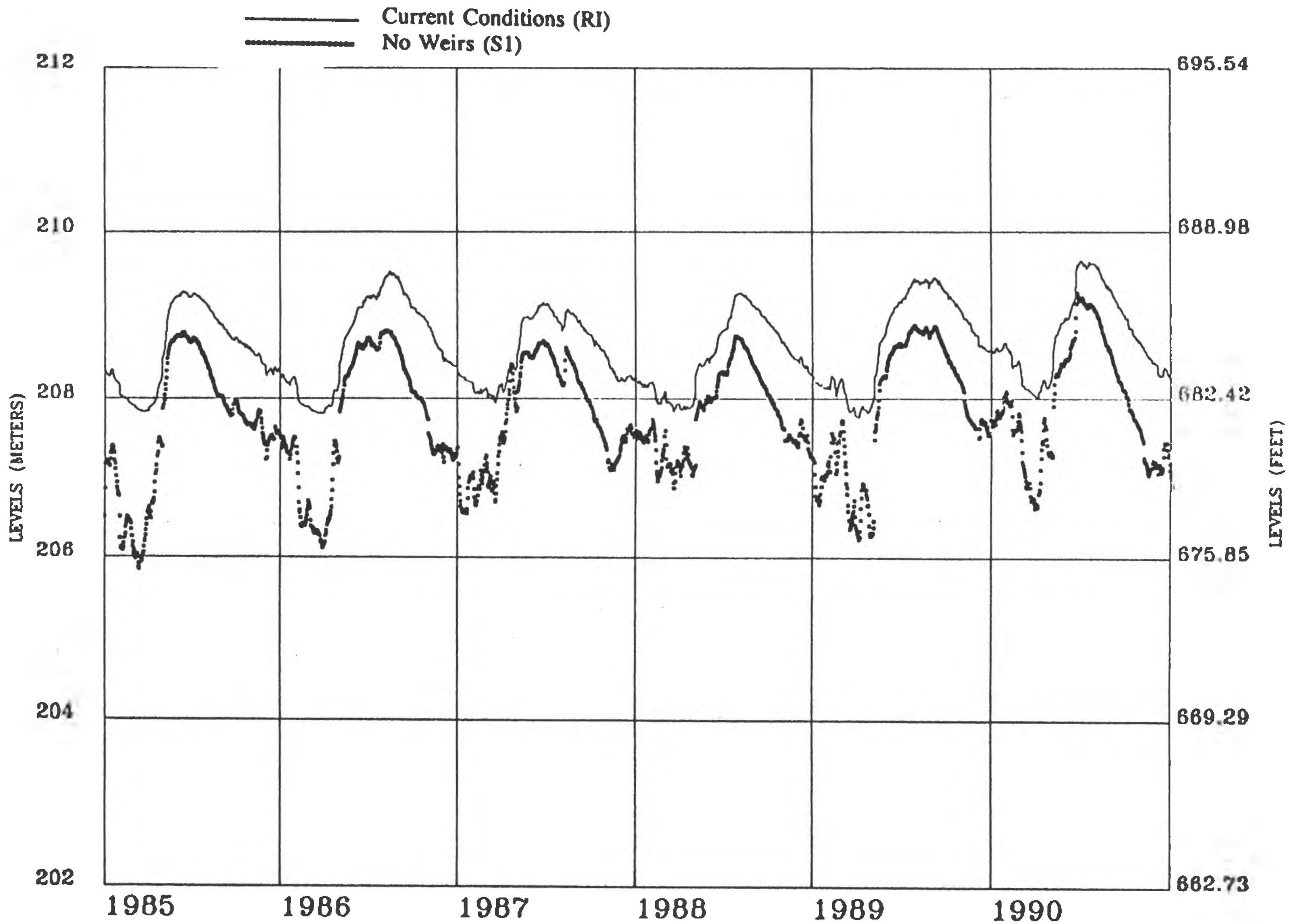
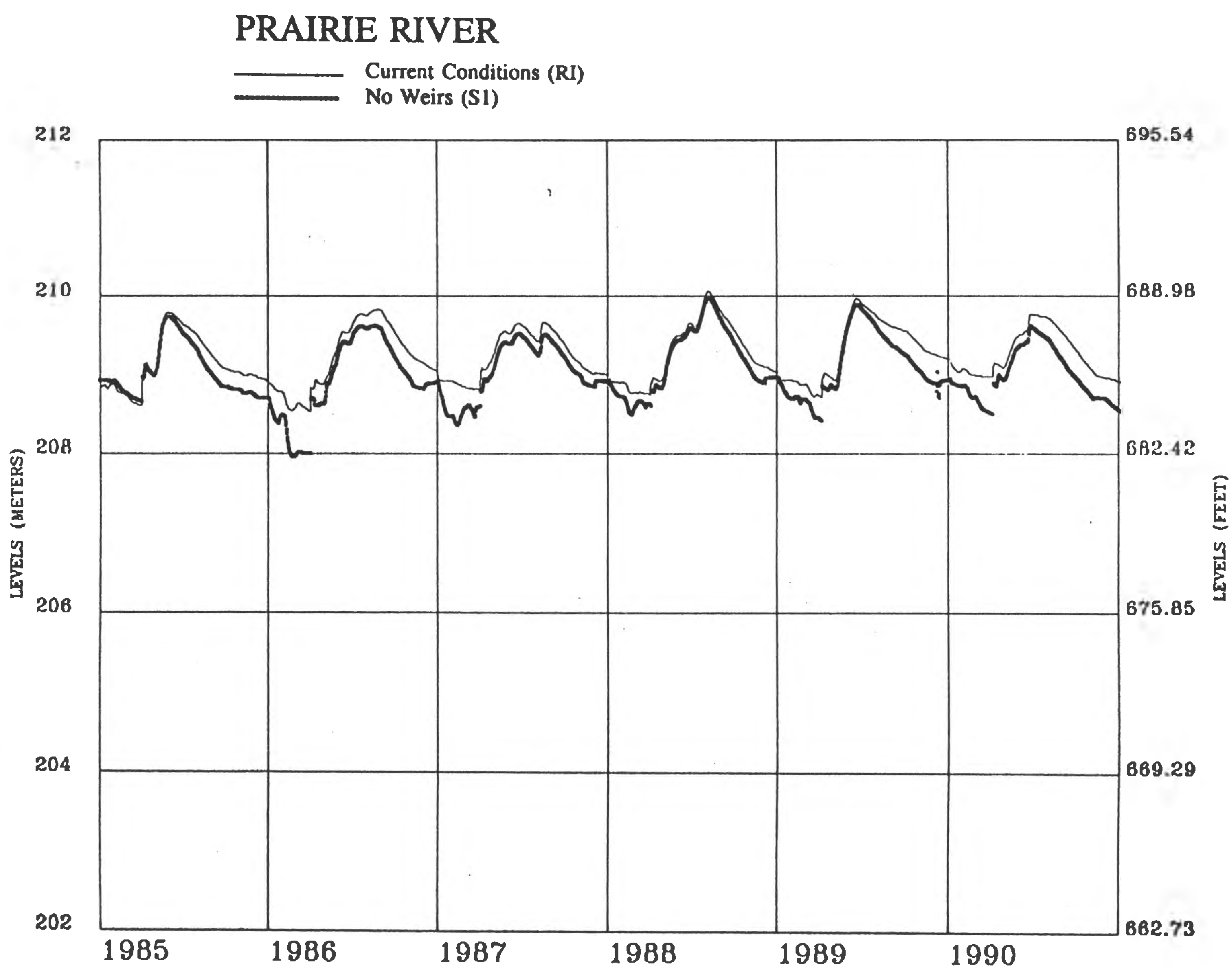
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

ATHABASCA CHANNEL TO FOUR FORKS

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Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
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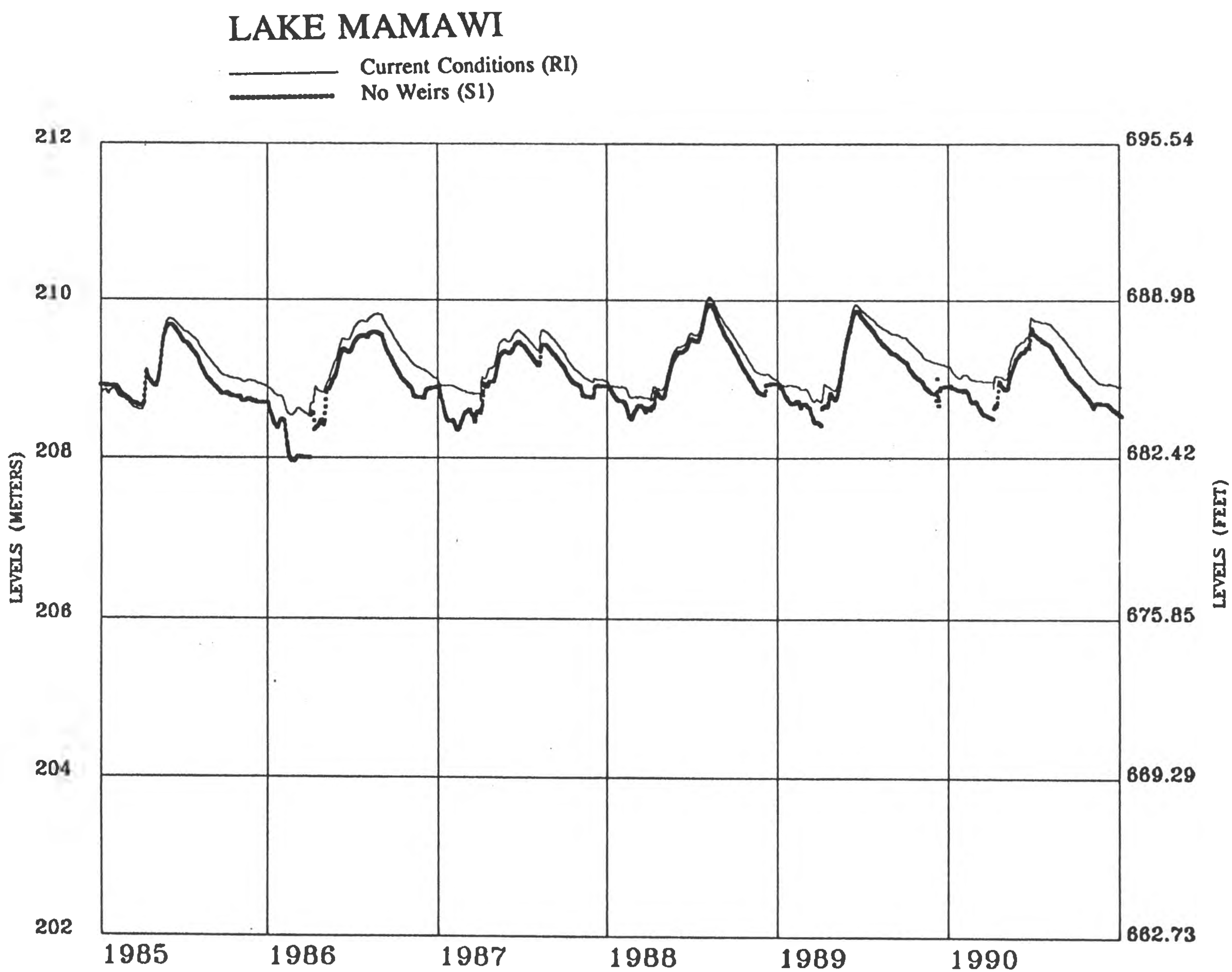
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990


LAKE MAMAWI
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
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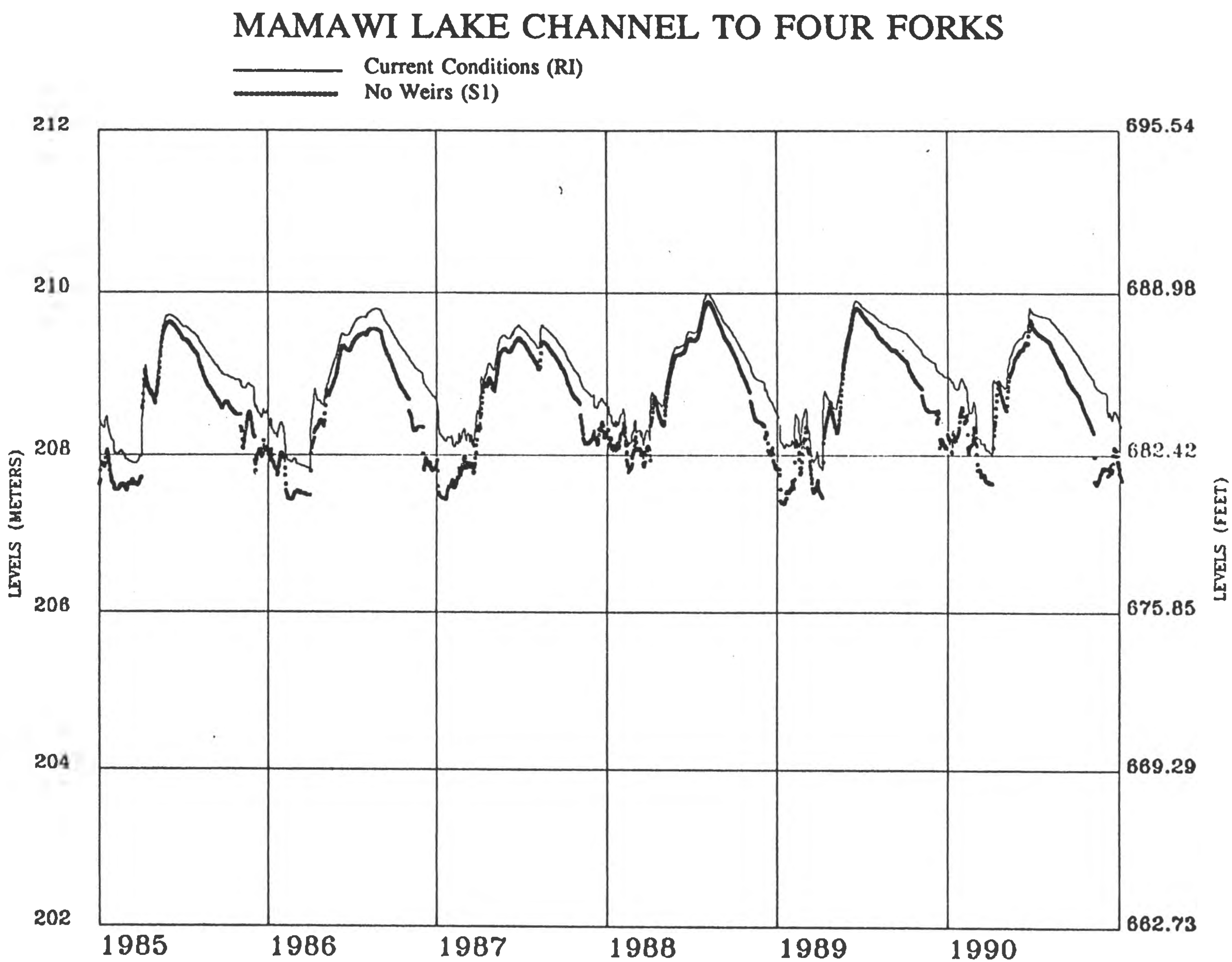
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990


MAMAWI LAKE CHANNEL TO FOUR FORKS
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
LEVELS (FEET)
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210
208
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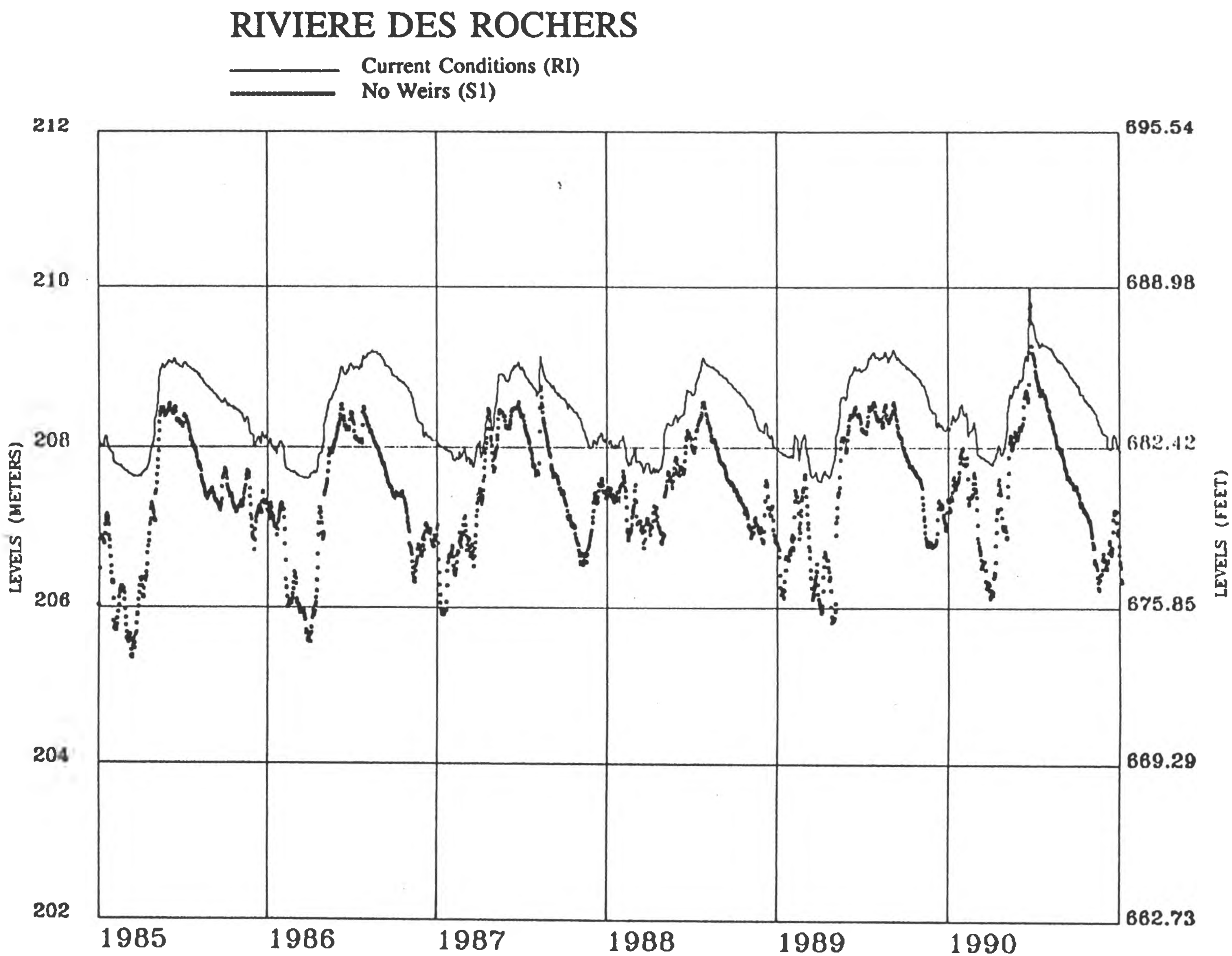
202
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990



RIVIERE DES ROCHERS
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
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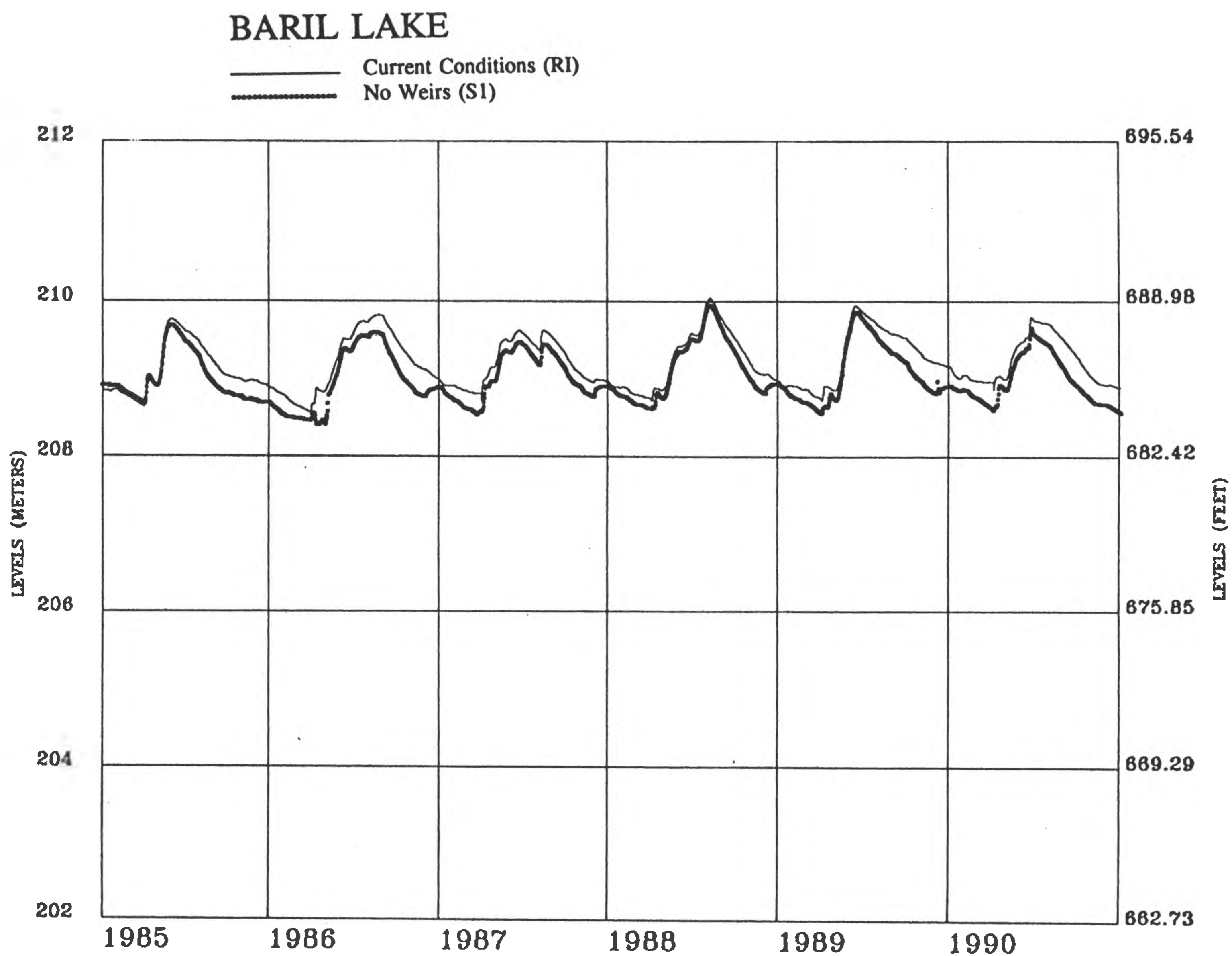
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990


BARIL LAKE
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
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682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
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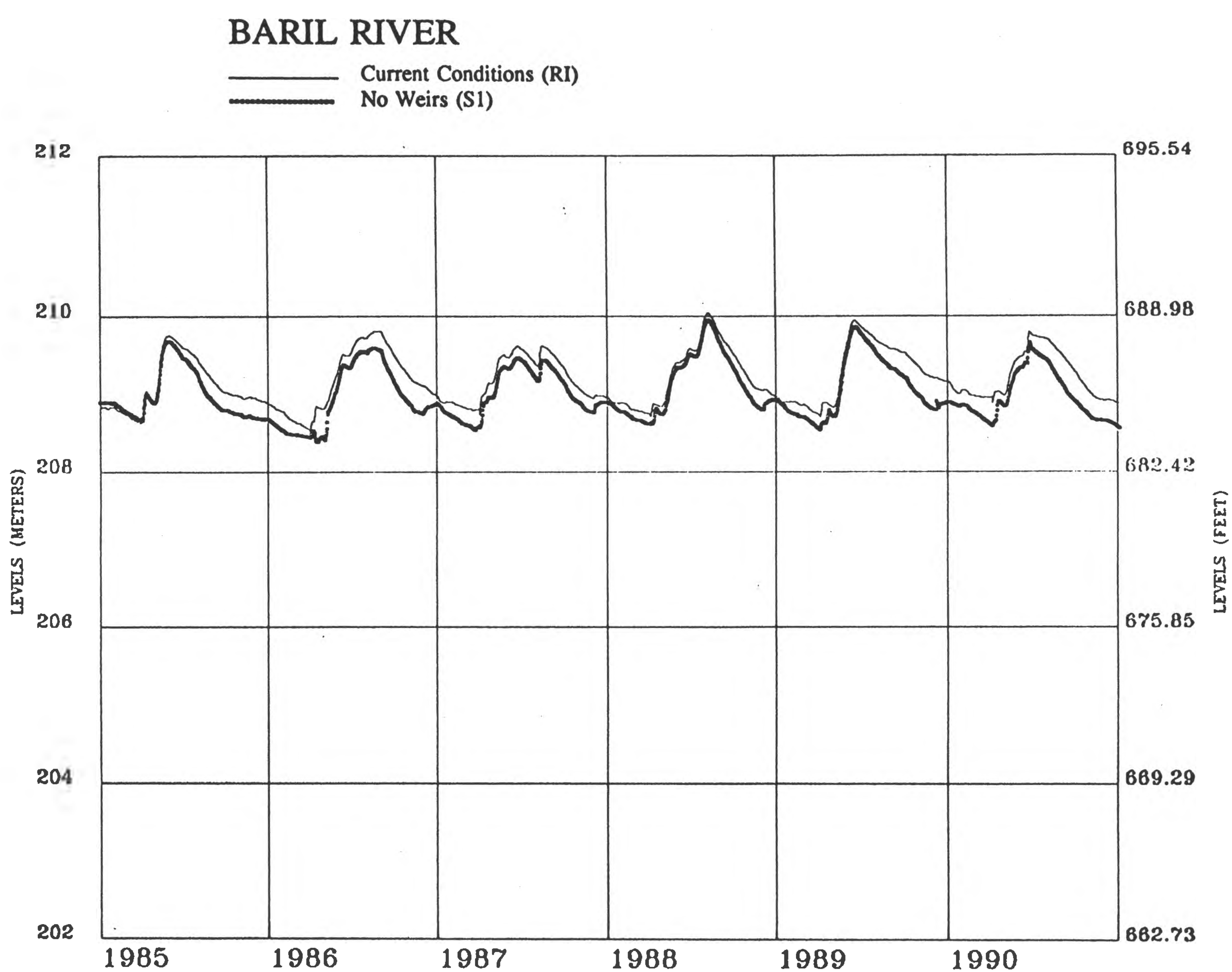
1987
1988
1989
1990


BARIL RIVER
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
LEVELS (FEET)
212
210
208
206
204
202
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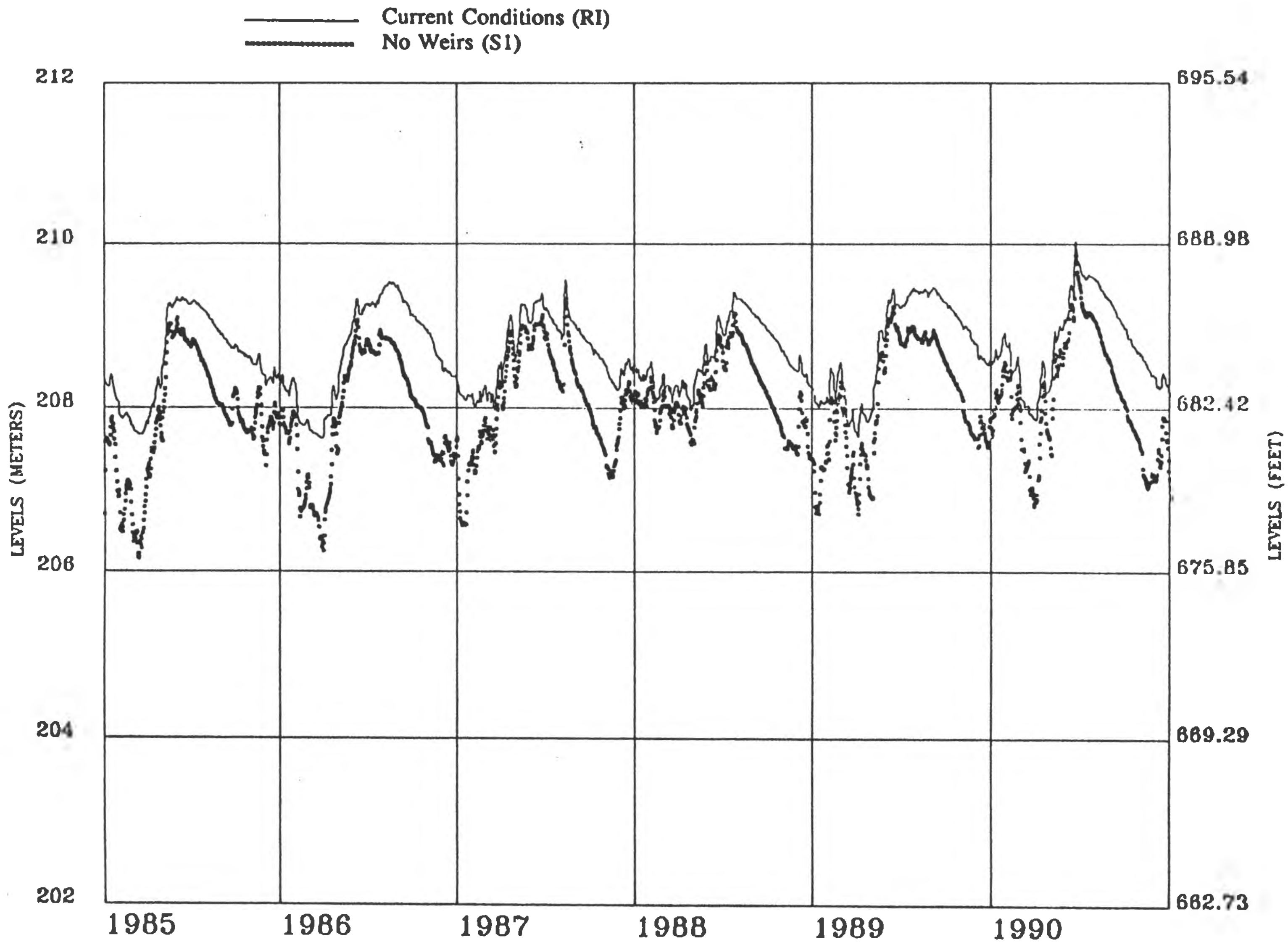
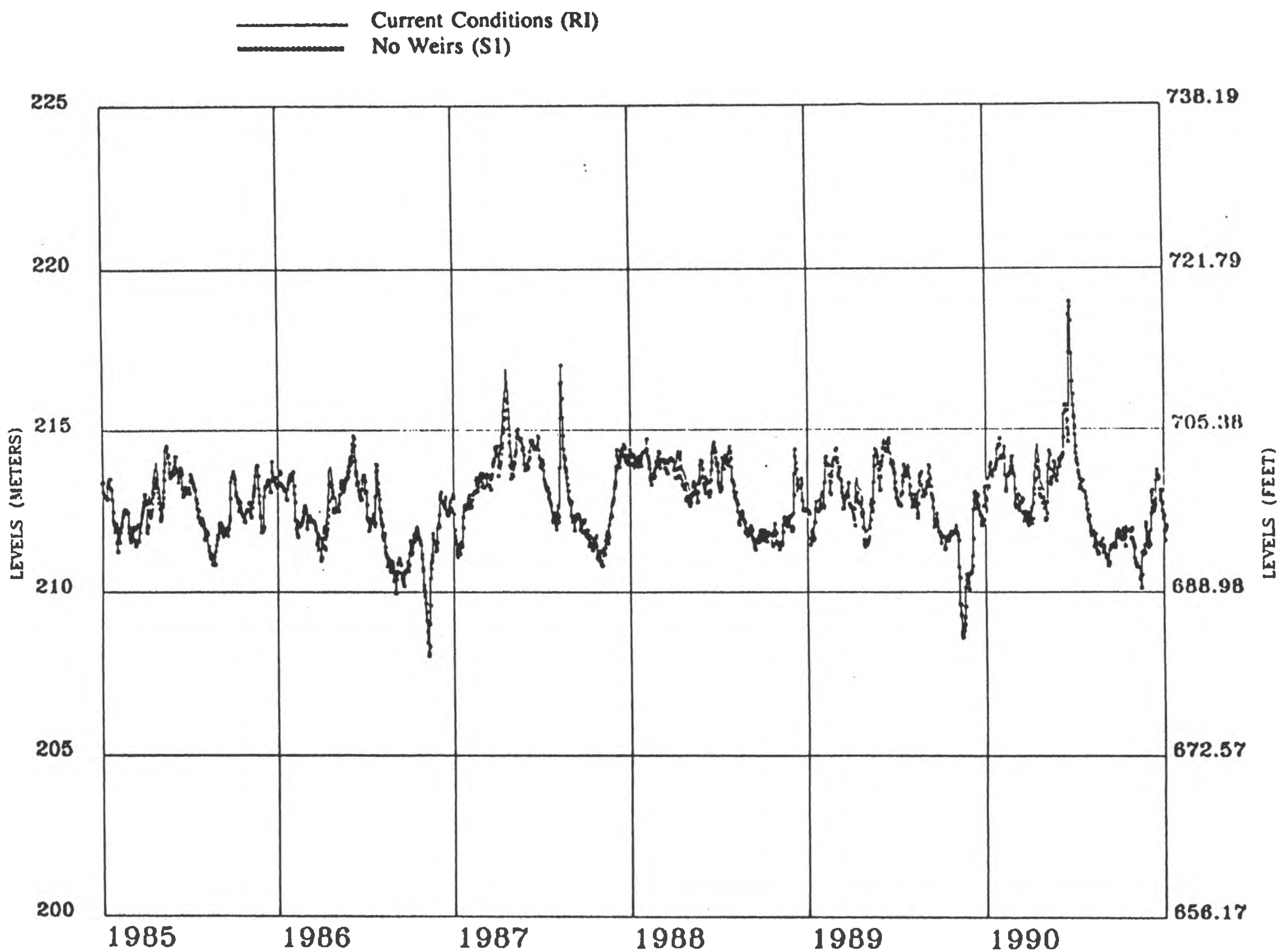
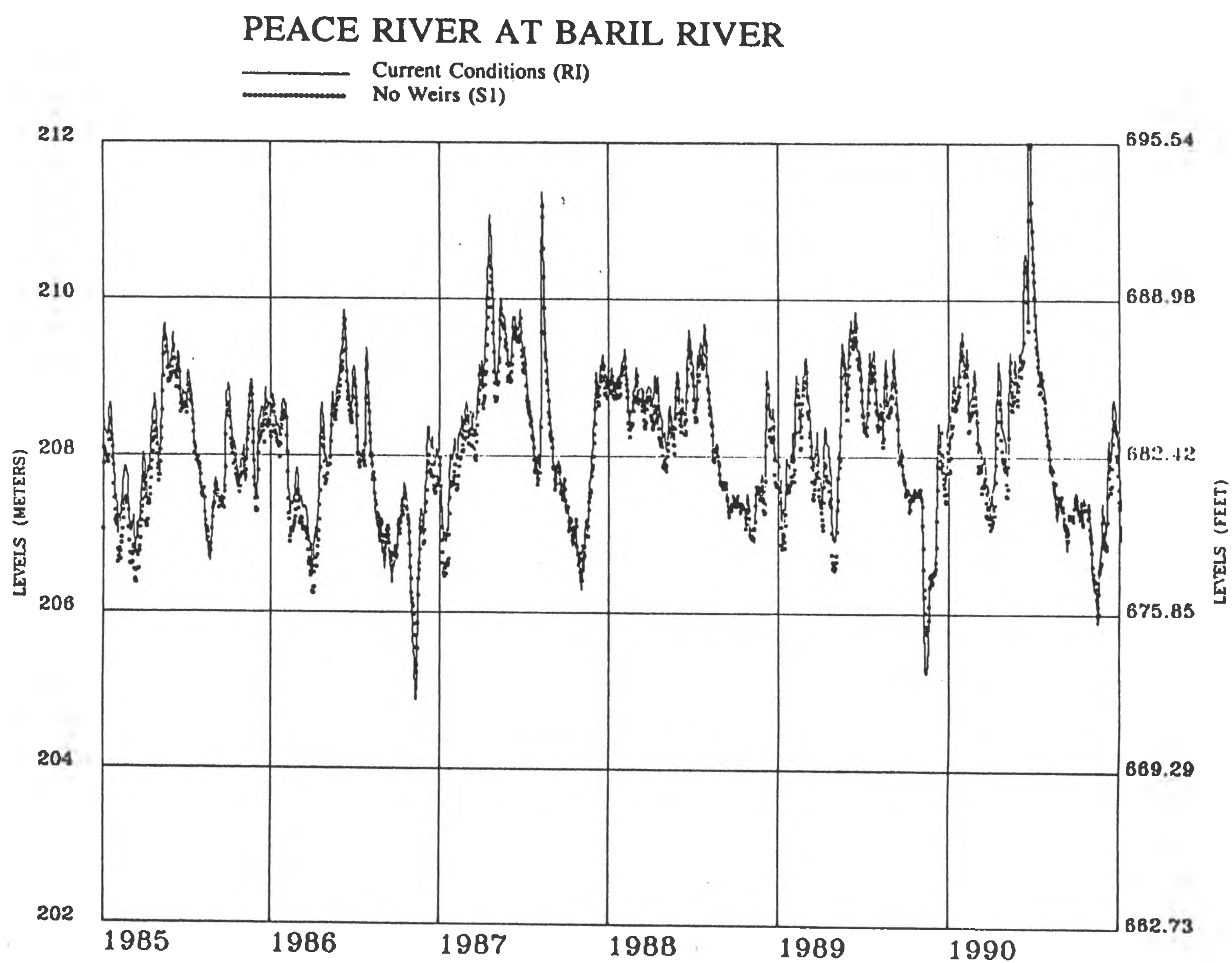
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

CHENAL DES QUATRE FOURCHES

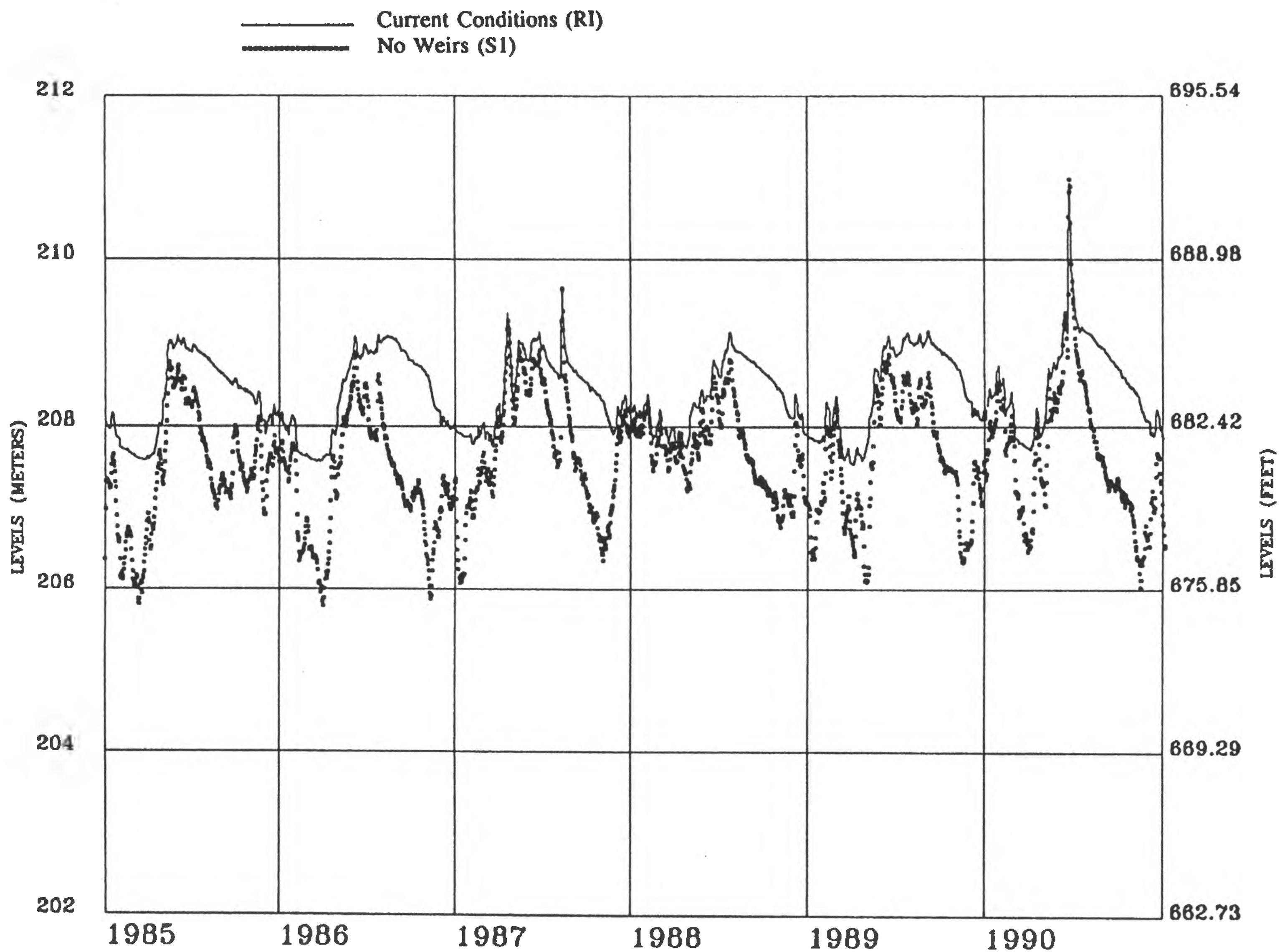


PEACE RIVER AT PEACE POINT

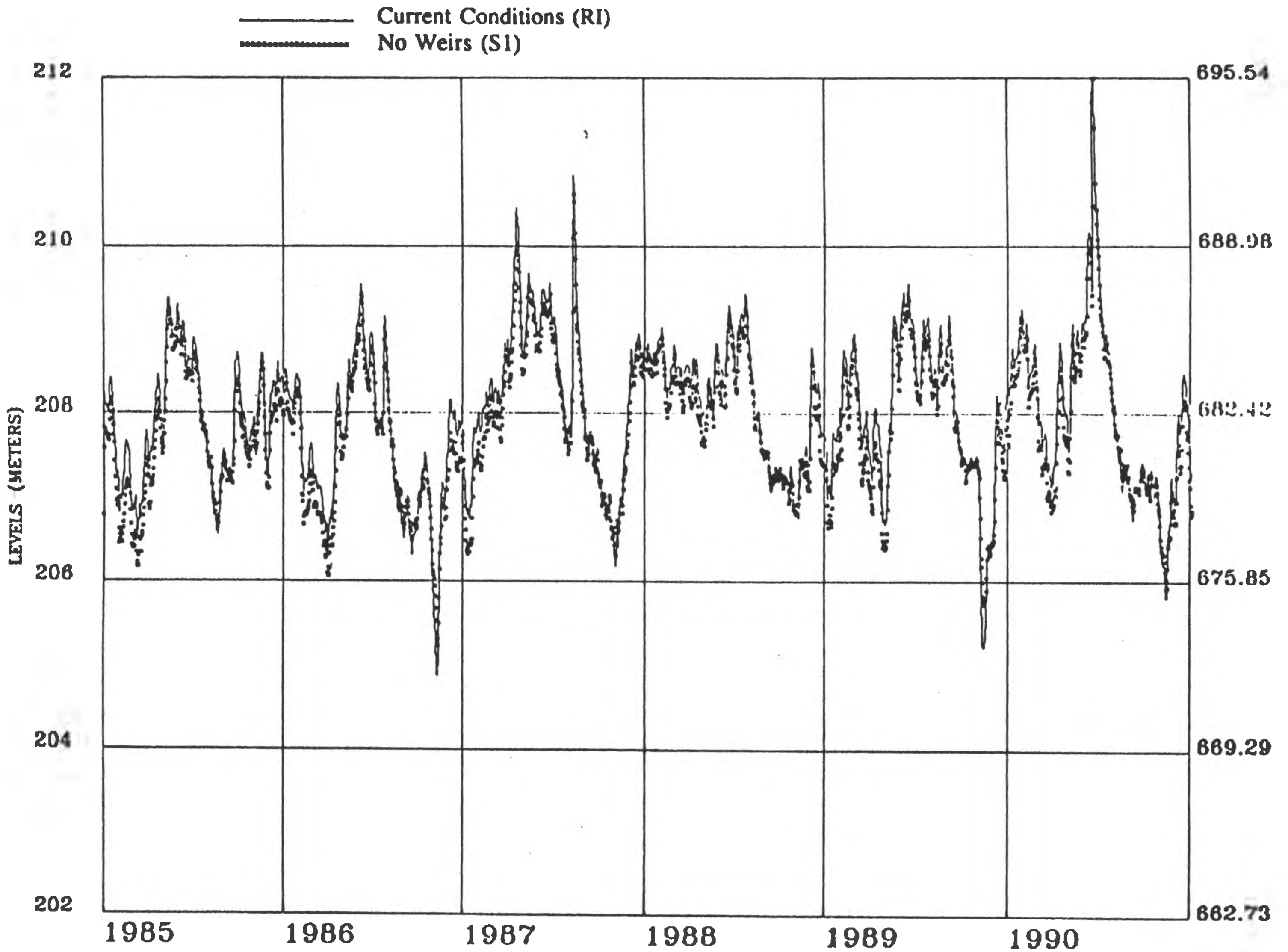


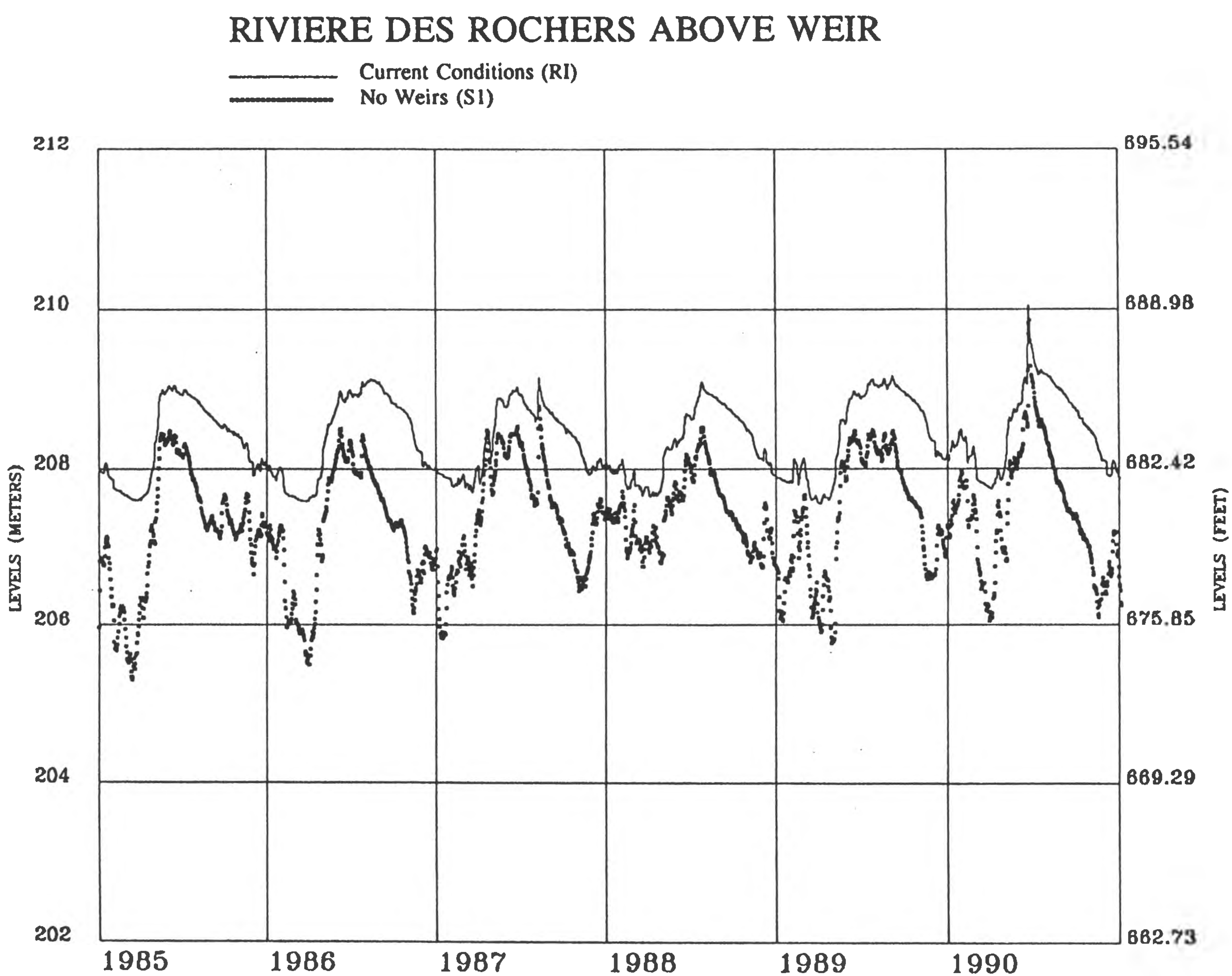

PEACE RIVER AT BARIL RIVER
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

REVILLON COUPE ABOVE WEIR

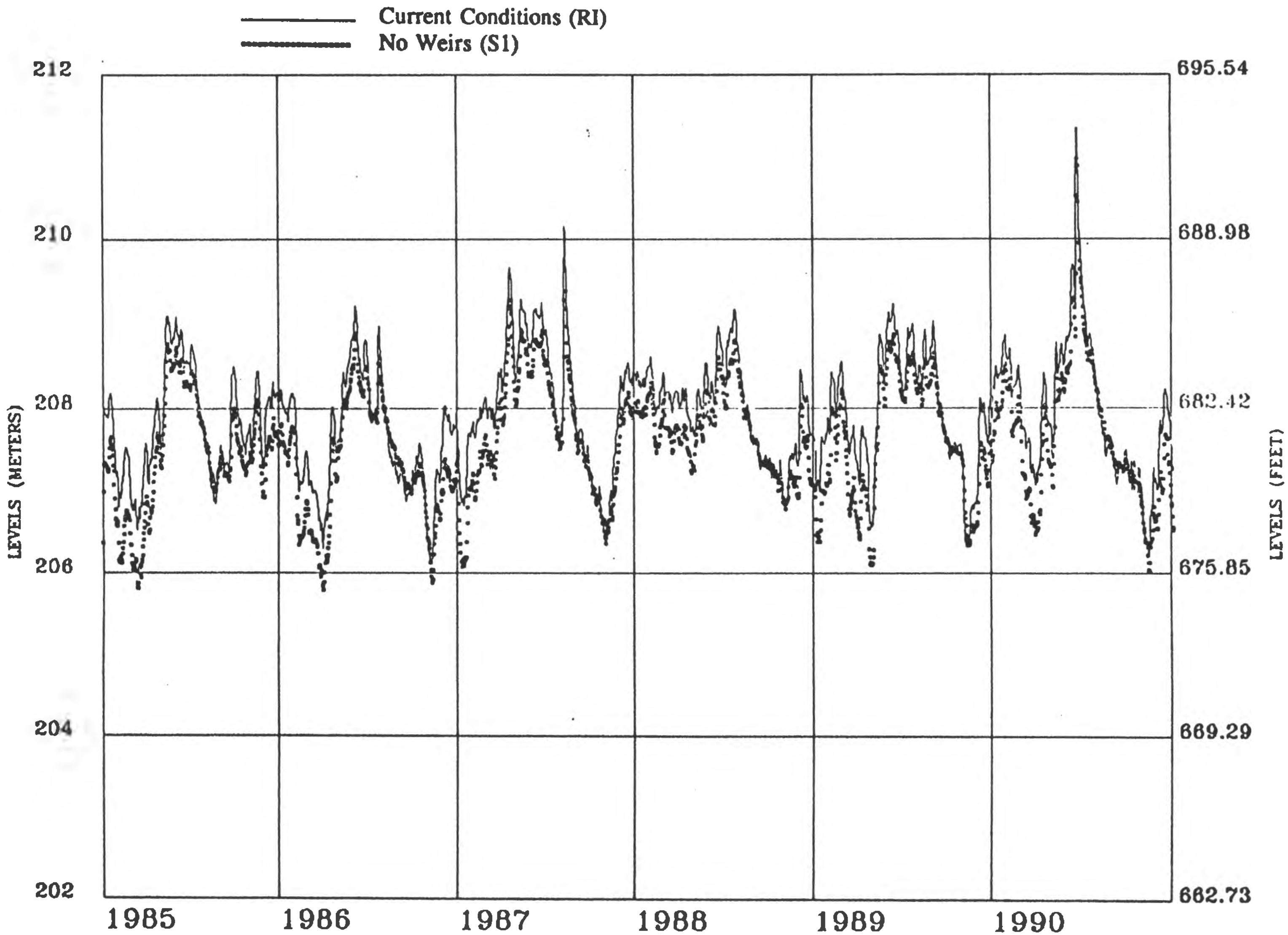


PEACE RIVER AT CHENAL DES QUATRE FOURCHES

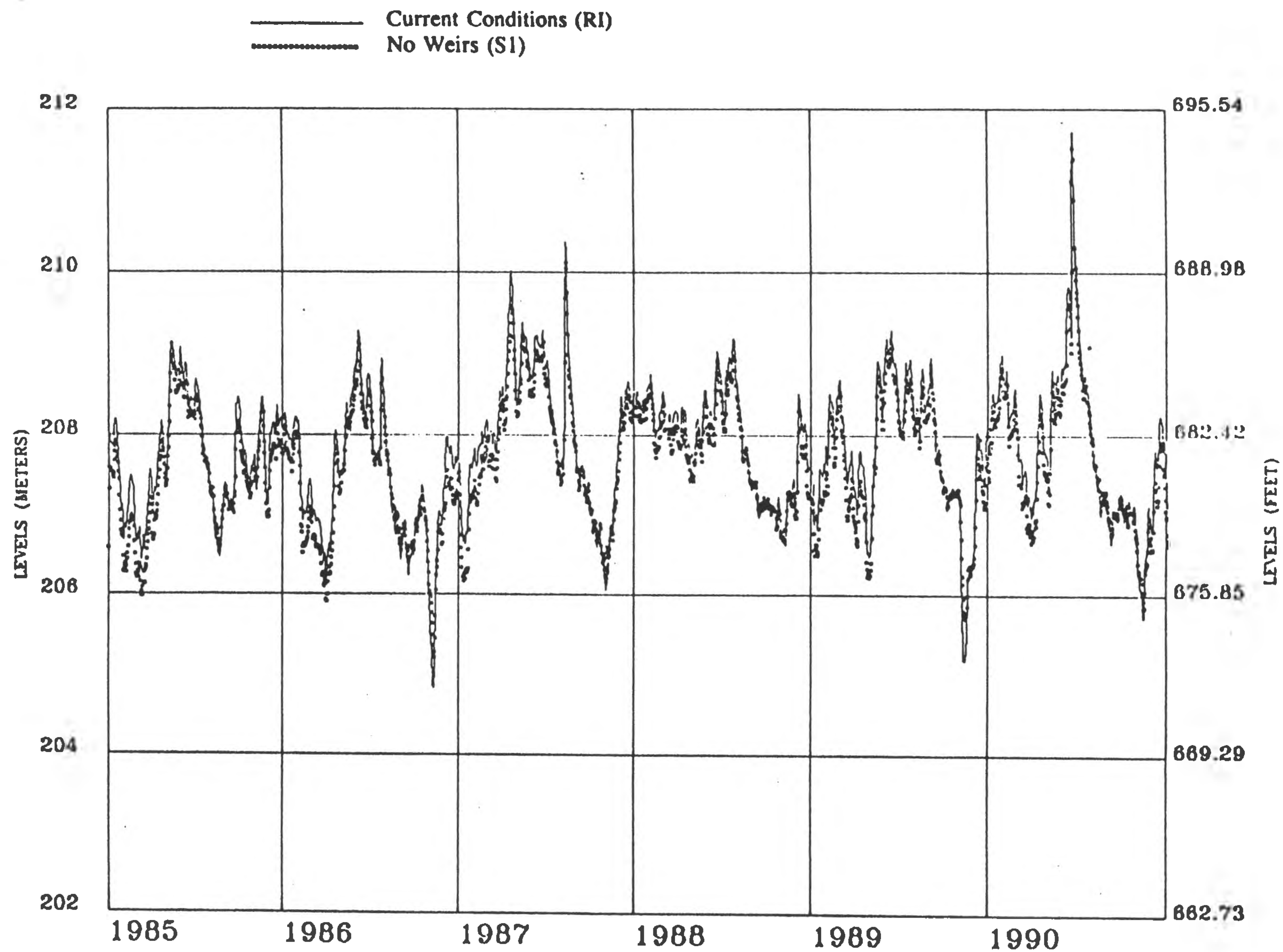



RIVIERE DES ROCHERS ABOVE WEIR
Current Conditions (RI)
No Weirs (S1)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

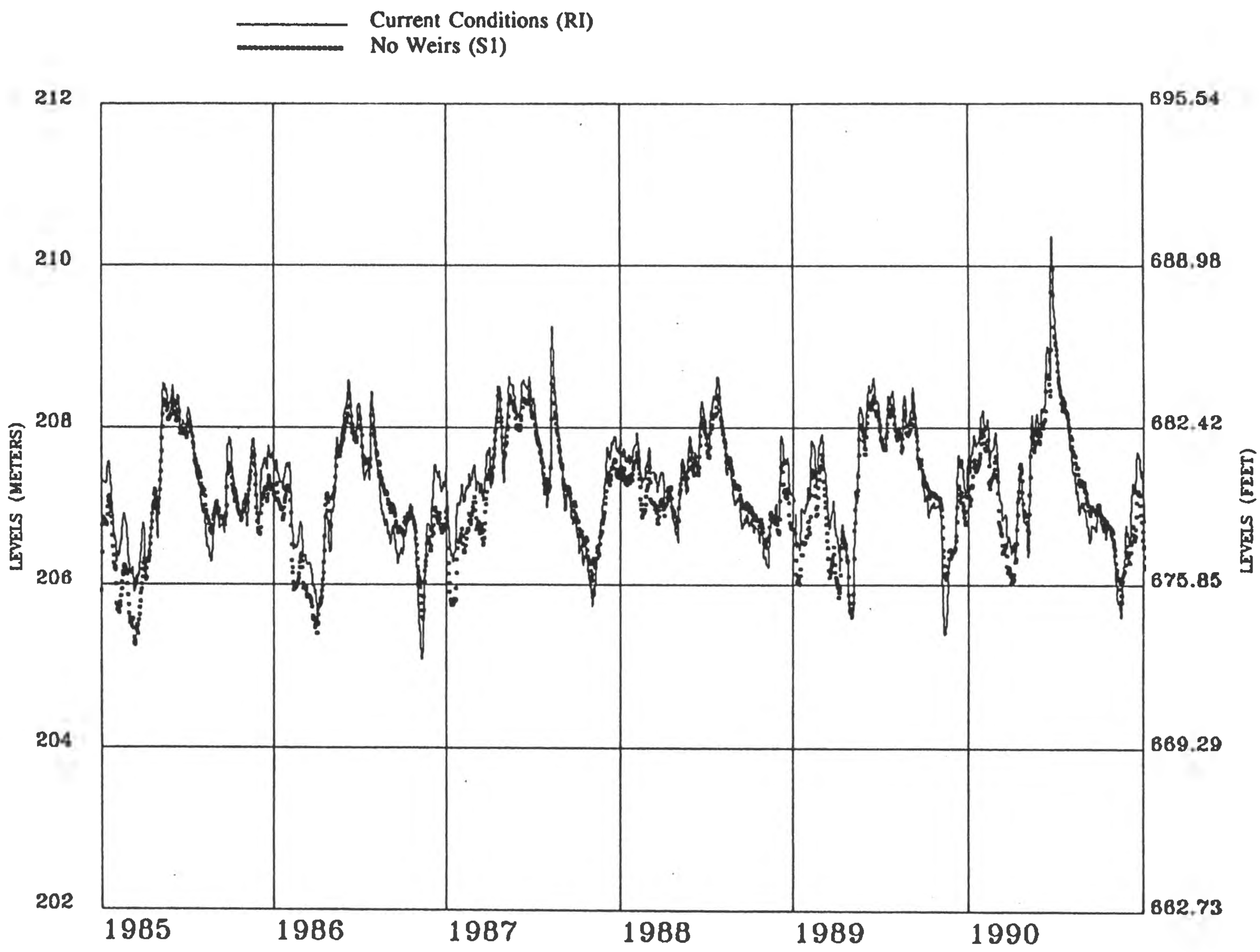
REVILLON COUPE BELOW WEIR

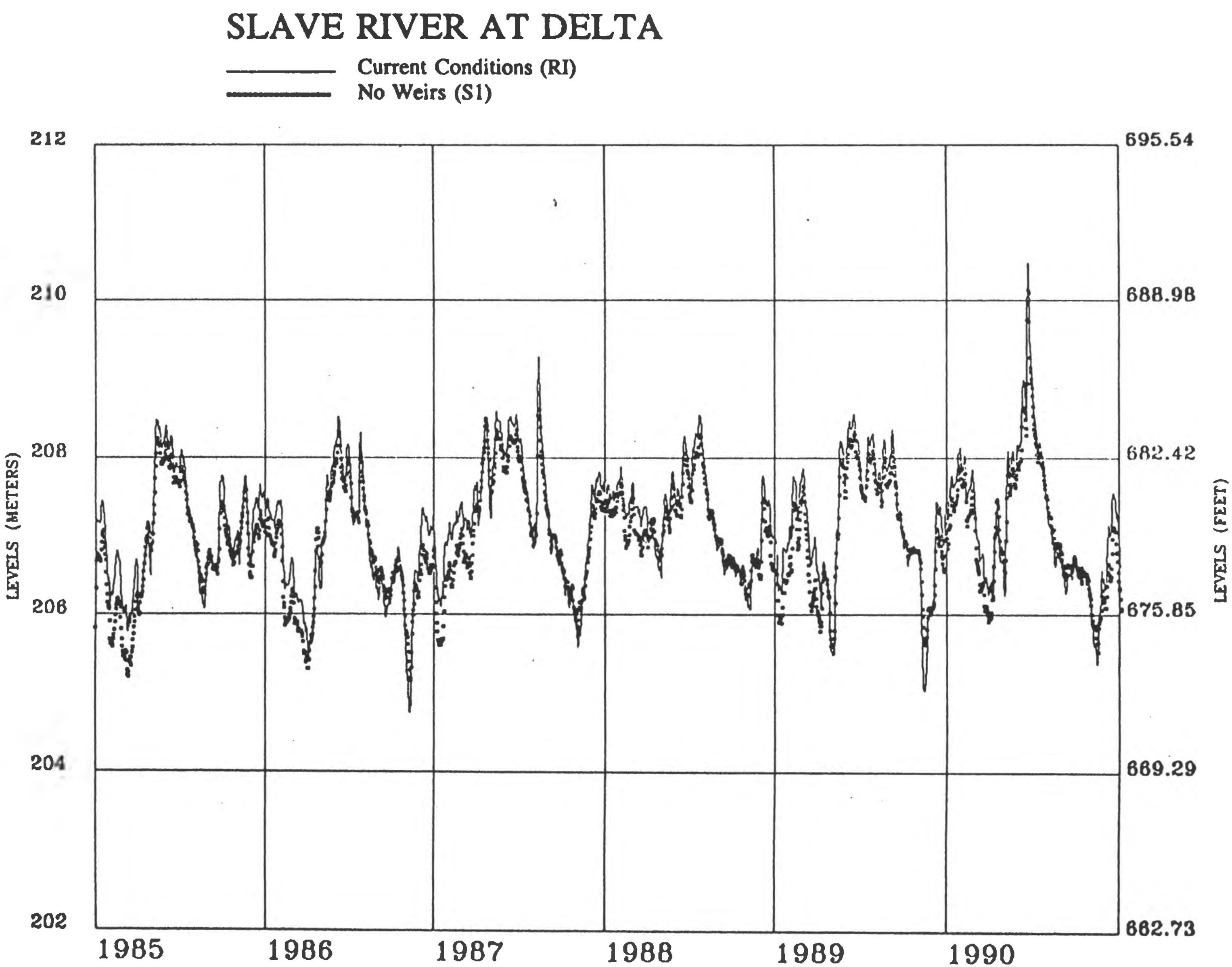


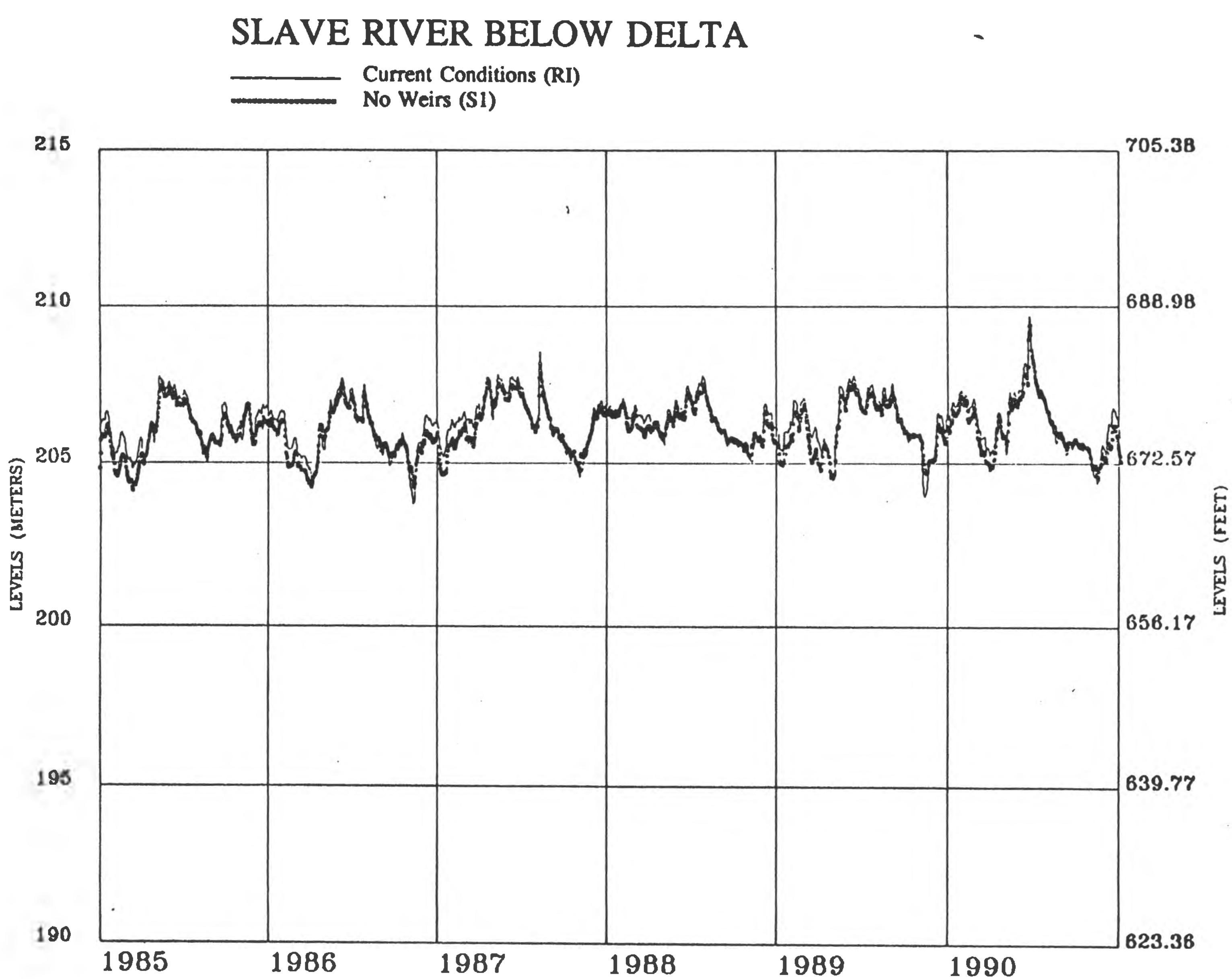
PEACE RIVER AT REVILLON COUPE



RIVIERE DES ROCHERS BELOW WEIR



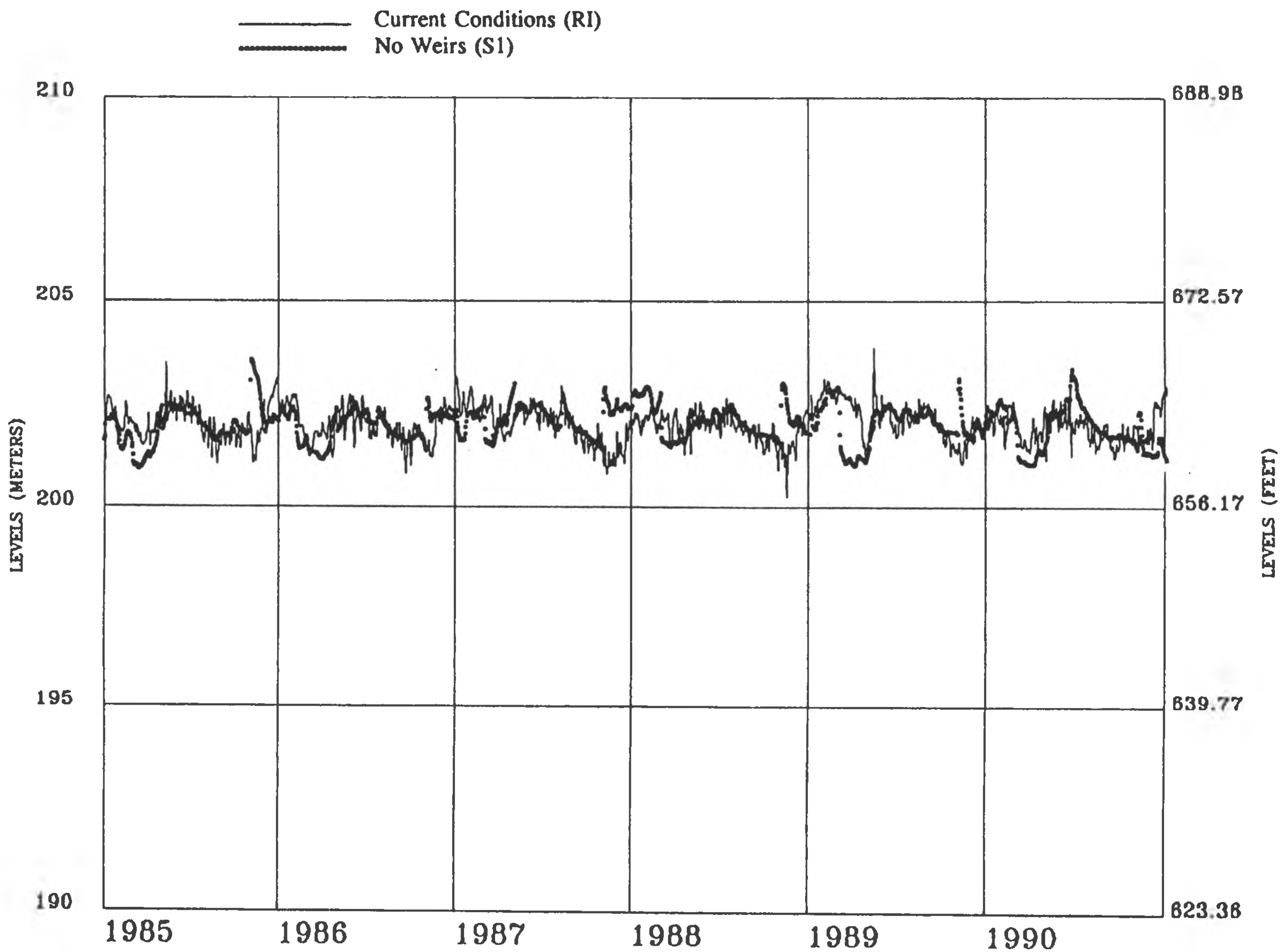

SLAVE RIVER AT DELTA
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
LEVELS (FEET)
212
210
208
206
204
202
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990



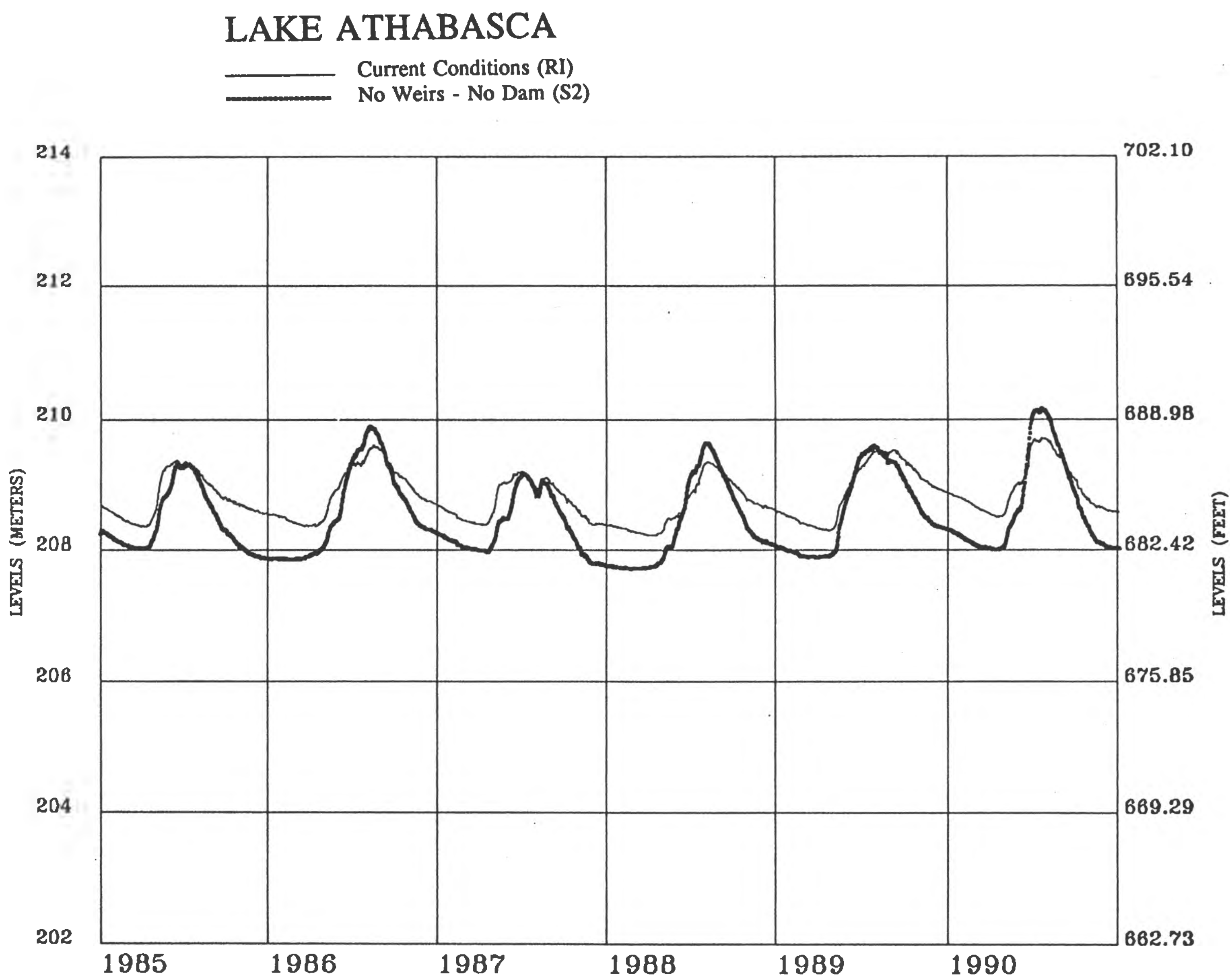
SLAVE RIVER BELOW DELTA
Current Conditions (RI)
No Weirs (S1)
215
210
205
200
195
190
LEVELS (METERS)
705.38
688.98
672.57
656.17
639.77
623.36
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

SLAVE RIVER ABOVE FITZGERALD
Current Conditions (RI)
No Weirs (S1)
LEVELS (METERS)
215
210
205
200
195
190
LEVELS (FEET)
705.38
688.98
672.57
656.17
639.77
623.36
1985
1986
1987
1988
1989
1990

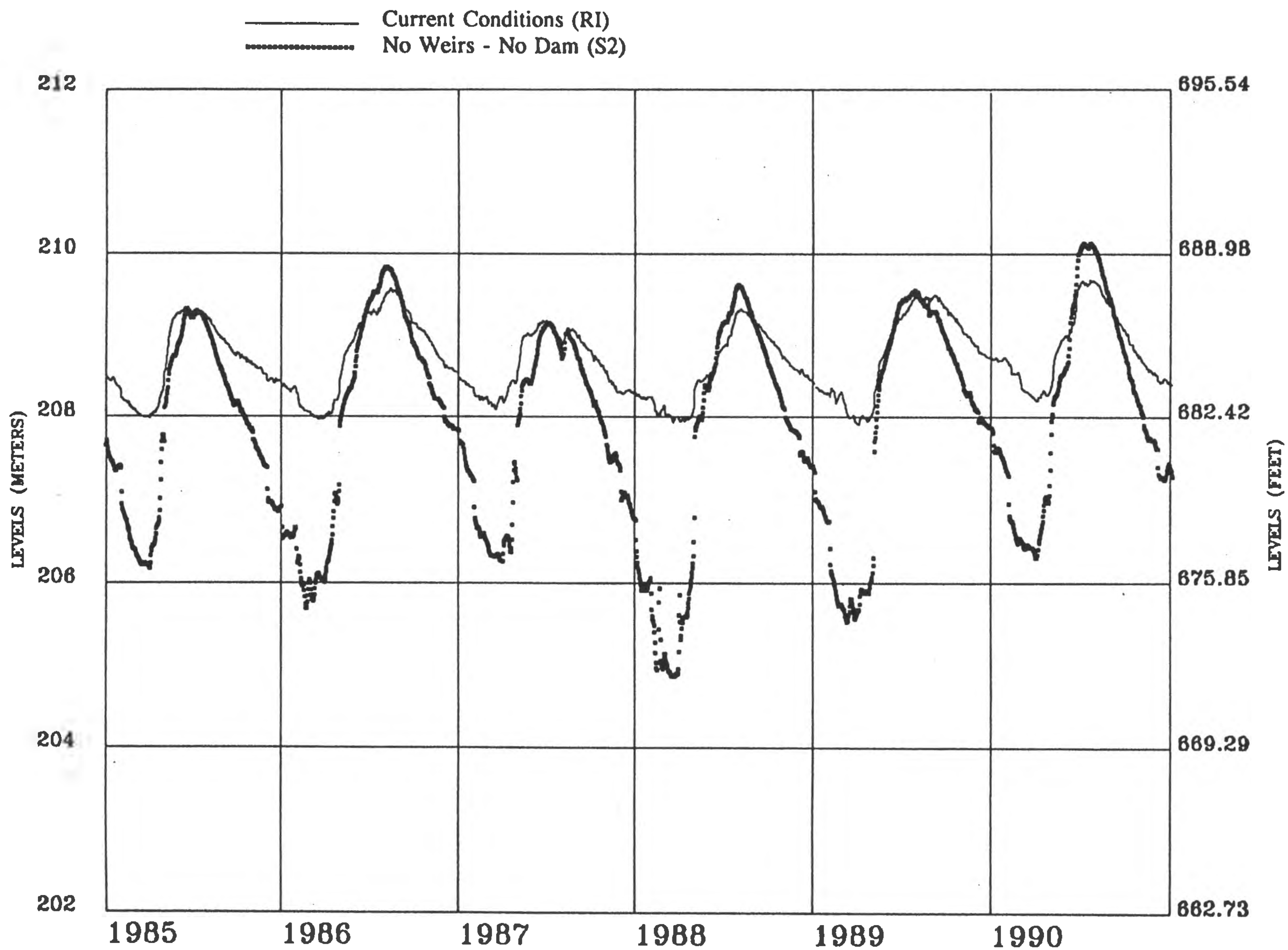
SLAVE RIVER AT FITZGERALD

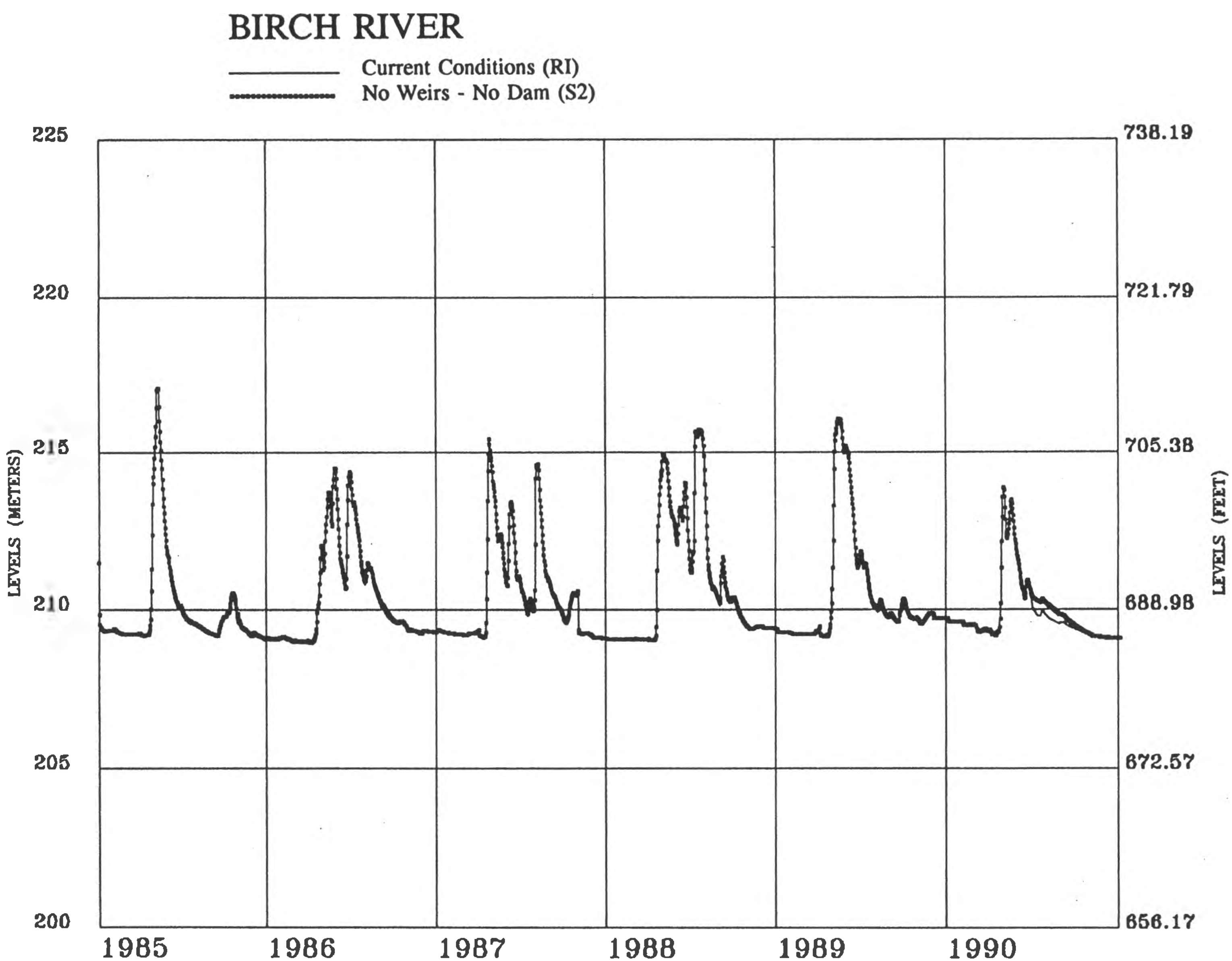


APPENDIX D.
Plots of Present and Natural Conditions

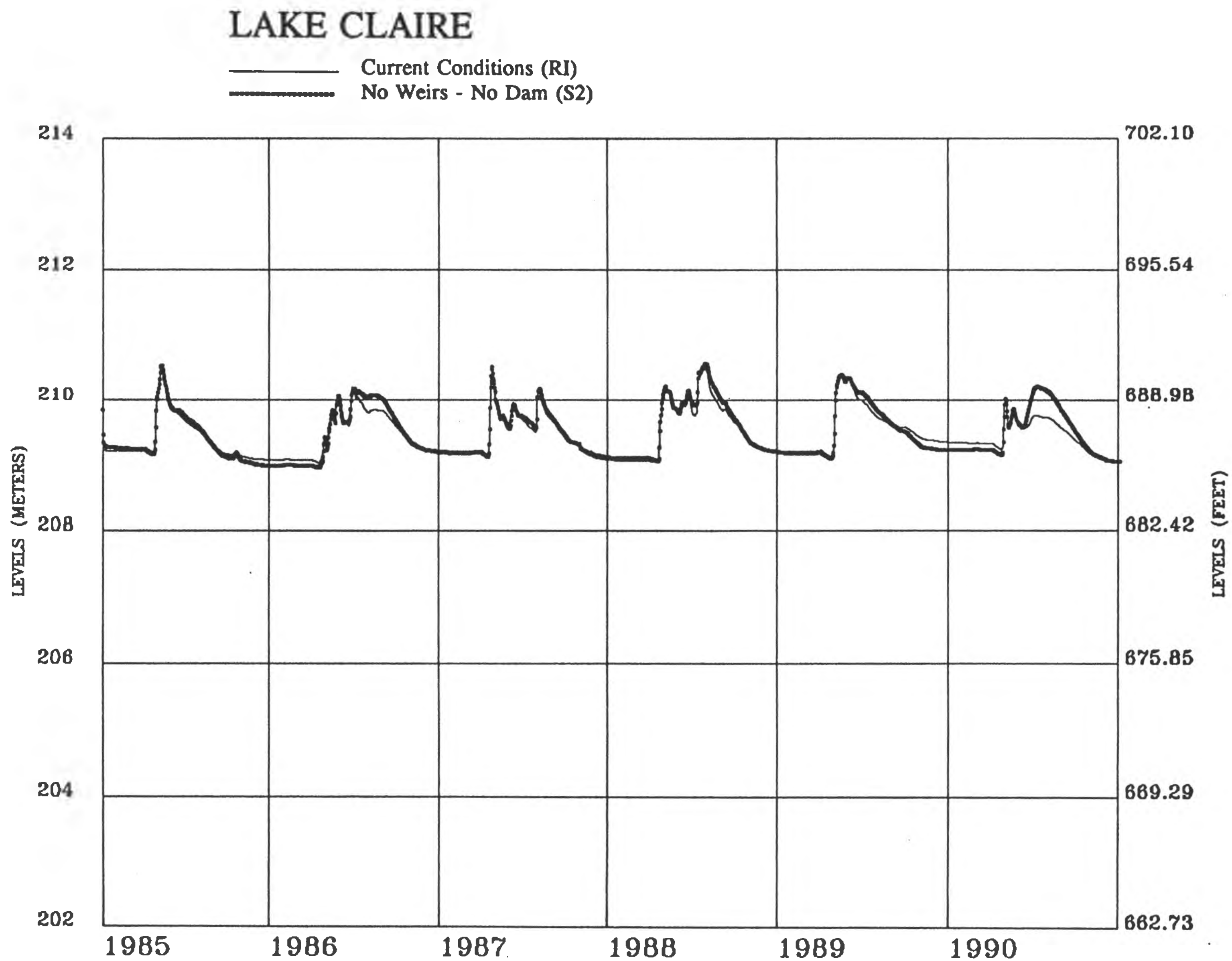

LAKE ATHABASCA
Current Conditions (RI)
No Weirs - No Dam (S2)
214
212
210
208
206
204
202
LEVELS (METERS)
702.10
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

LAKE ATHABASCA OUTLET





BIRCH RIVER
Current Conditions (RI)
No Weirs - No Dam (S2)
225
220
215
210
205
200
LEVELS (METERS)
738.19
721.79
705.38
688.98
672.57
656.17
LEVELS (FEET)
1985
1986
1987
1988
1989
1990


LAKE CLAIRE
Current Conditions (RI)
No Weirs - No Dam (S2)
LEVELS (METERS)
LEVELS (FEET)
214
212
210
208
206
204
202
702.10
695.54
688.98
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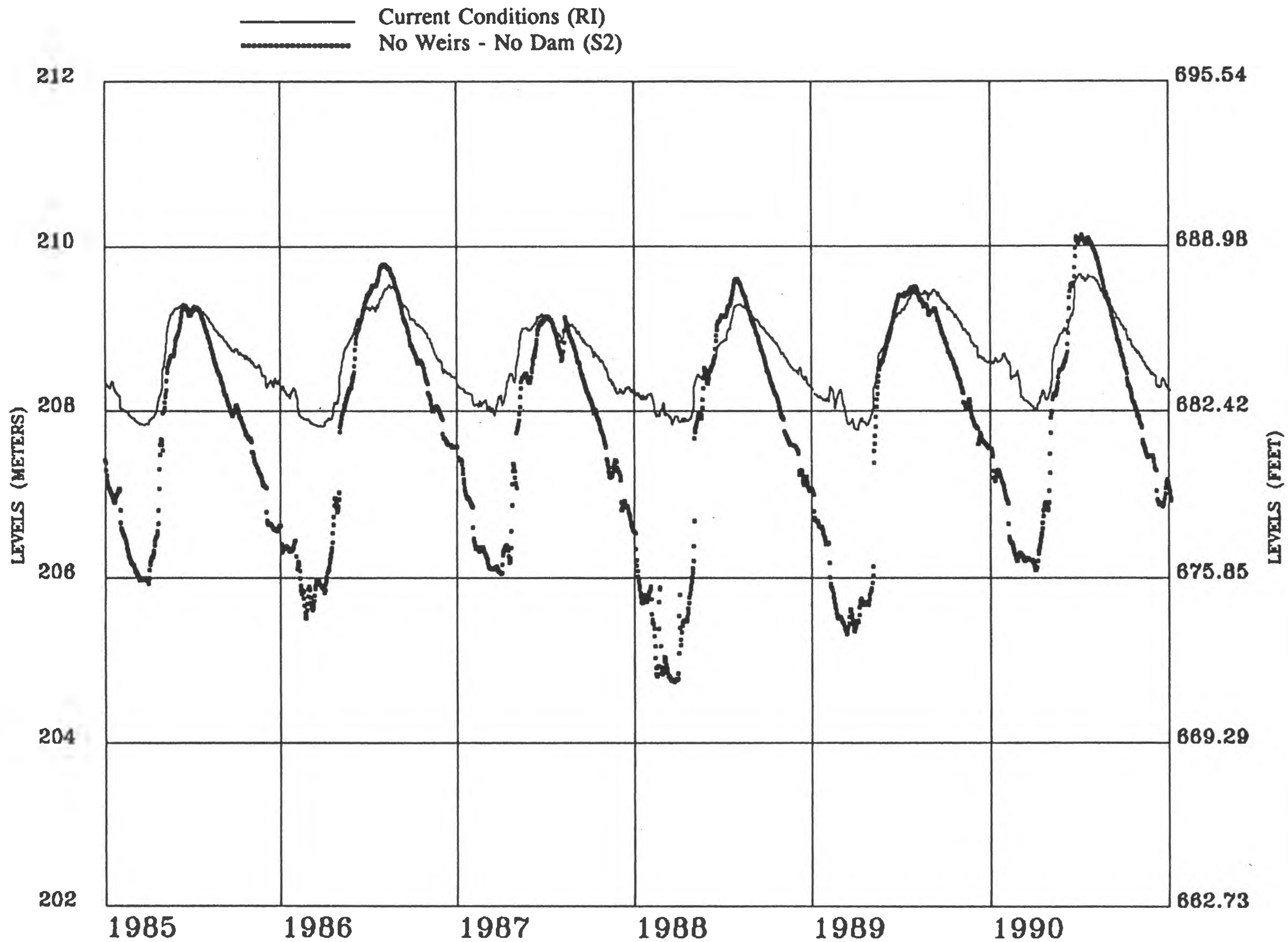
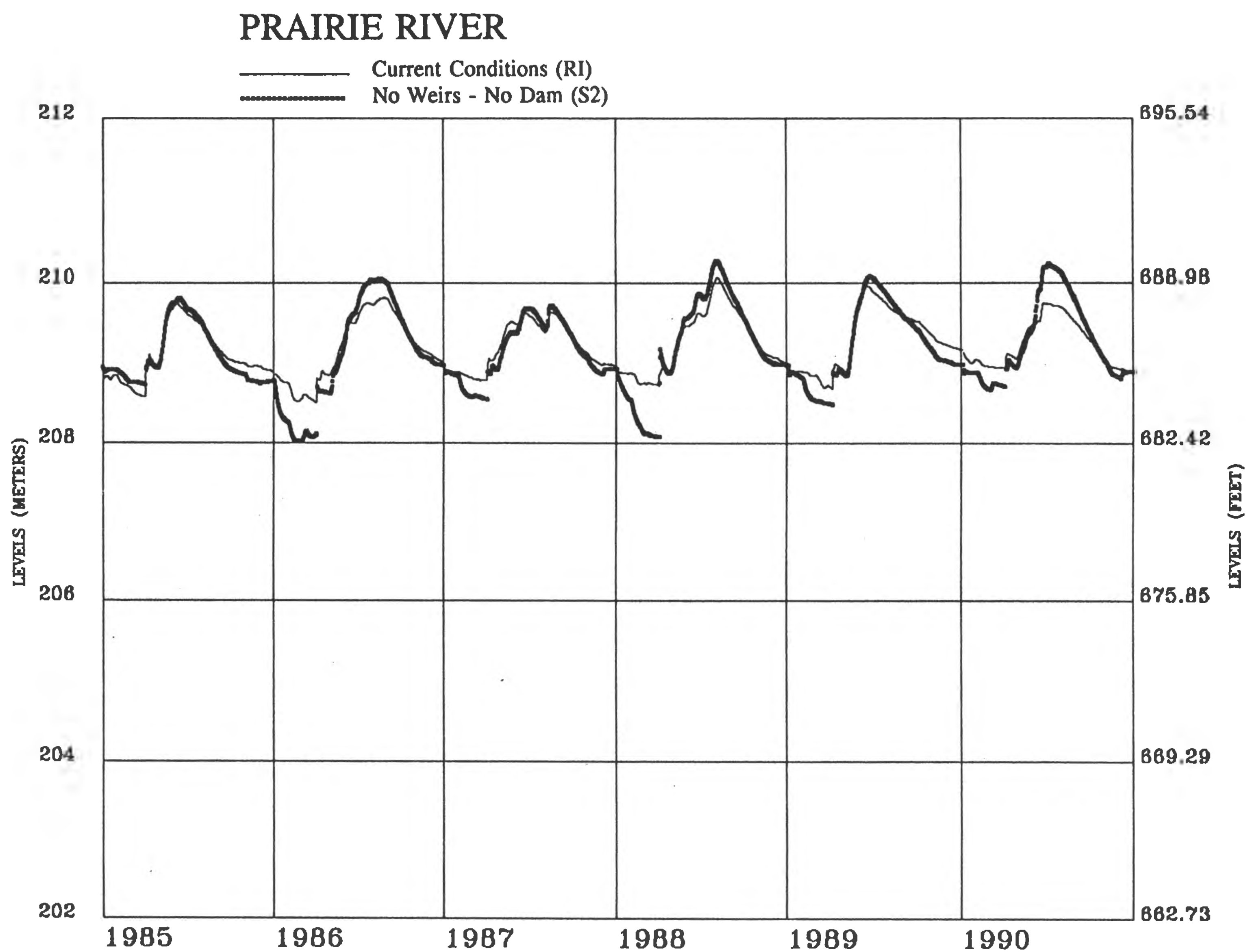
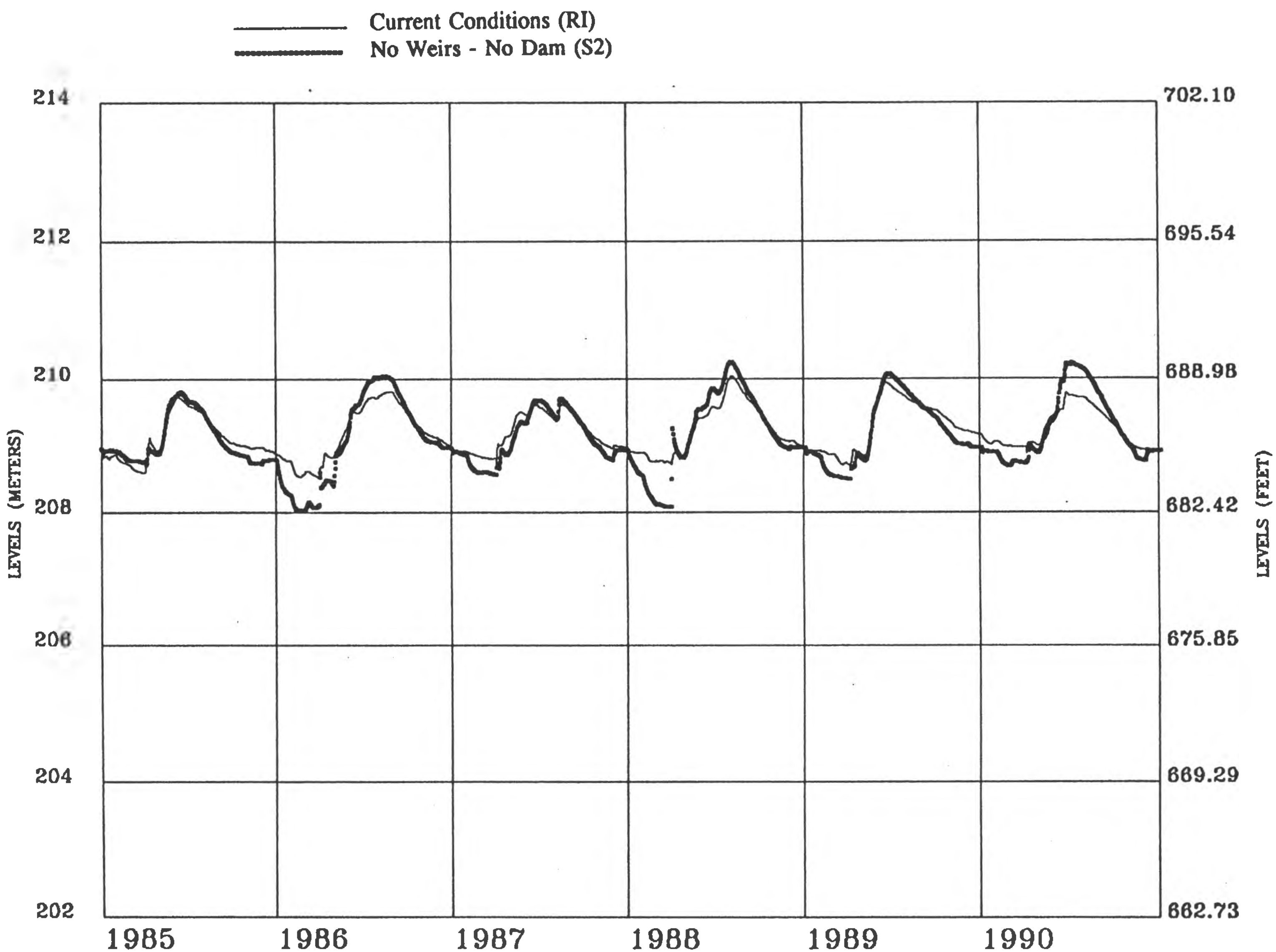
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

ATHABASCA CHANNEL TO FOUR FORKS



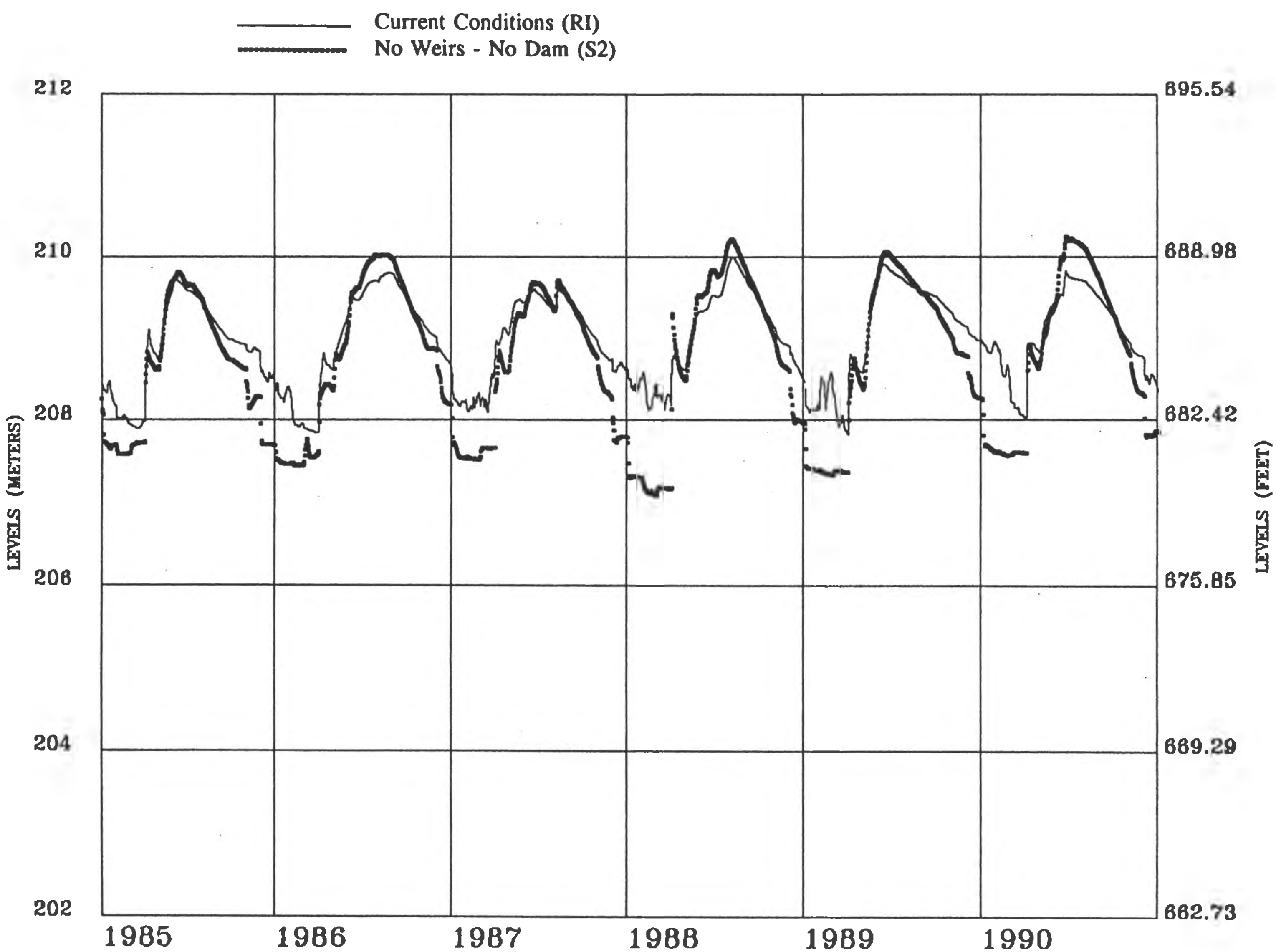

PRAIRIE RIVER
Current Conditions (RI)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

LAKE MAMAWI

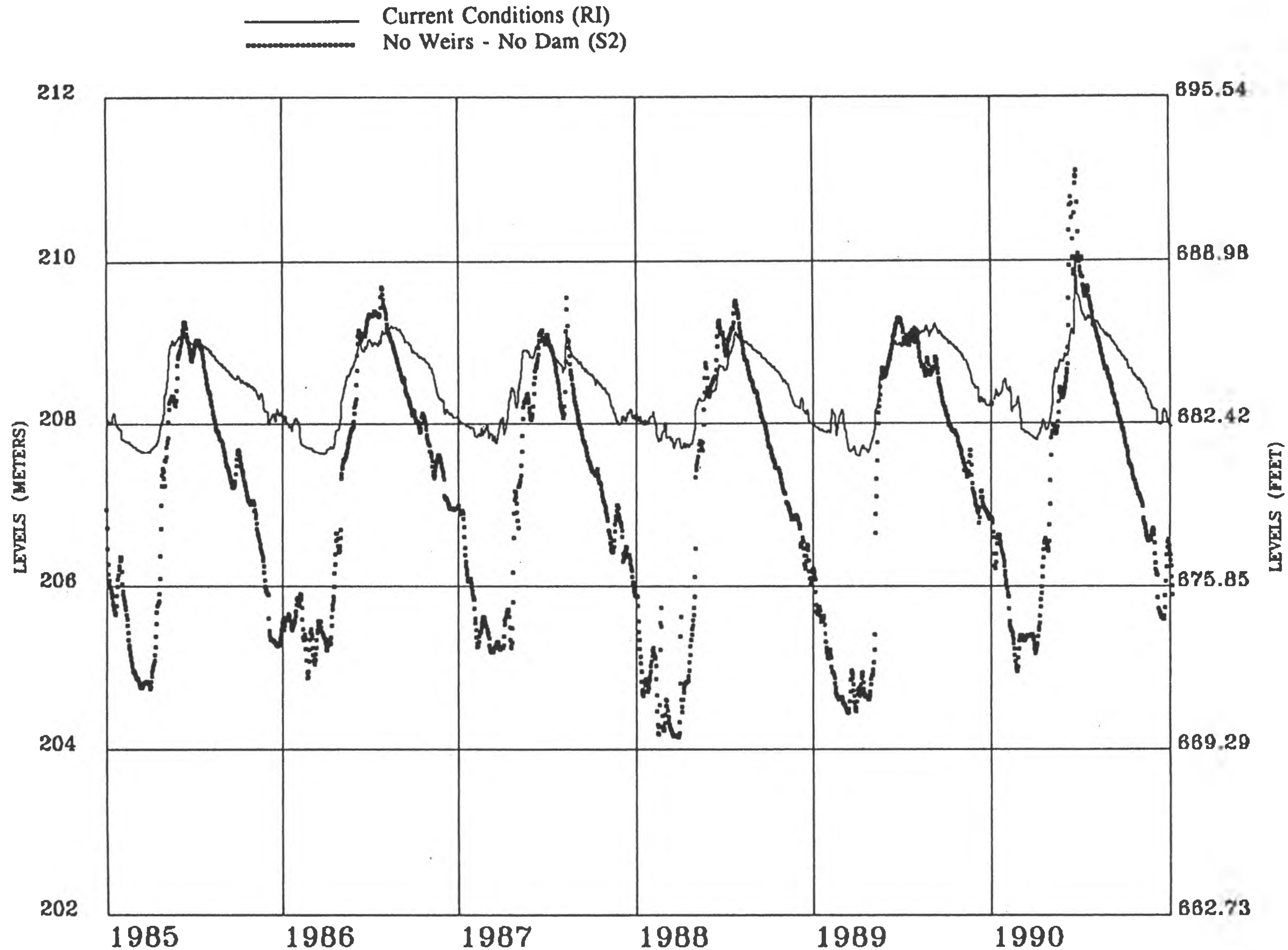


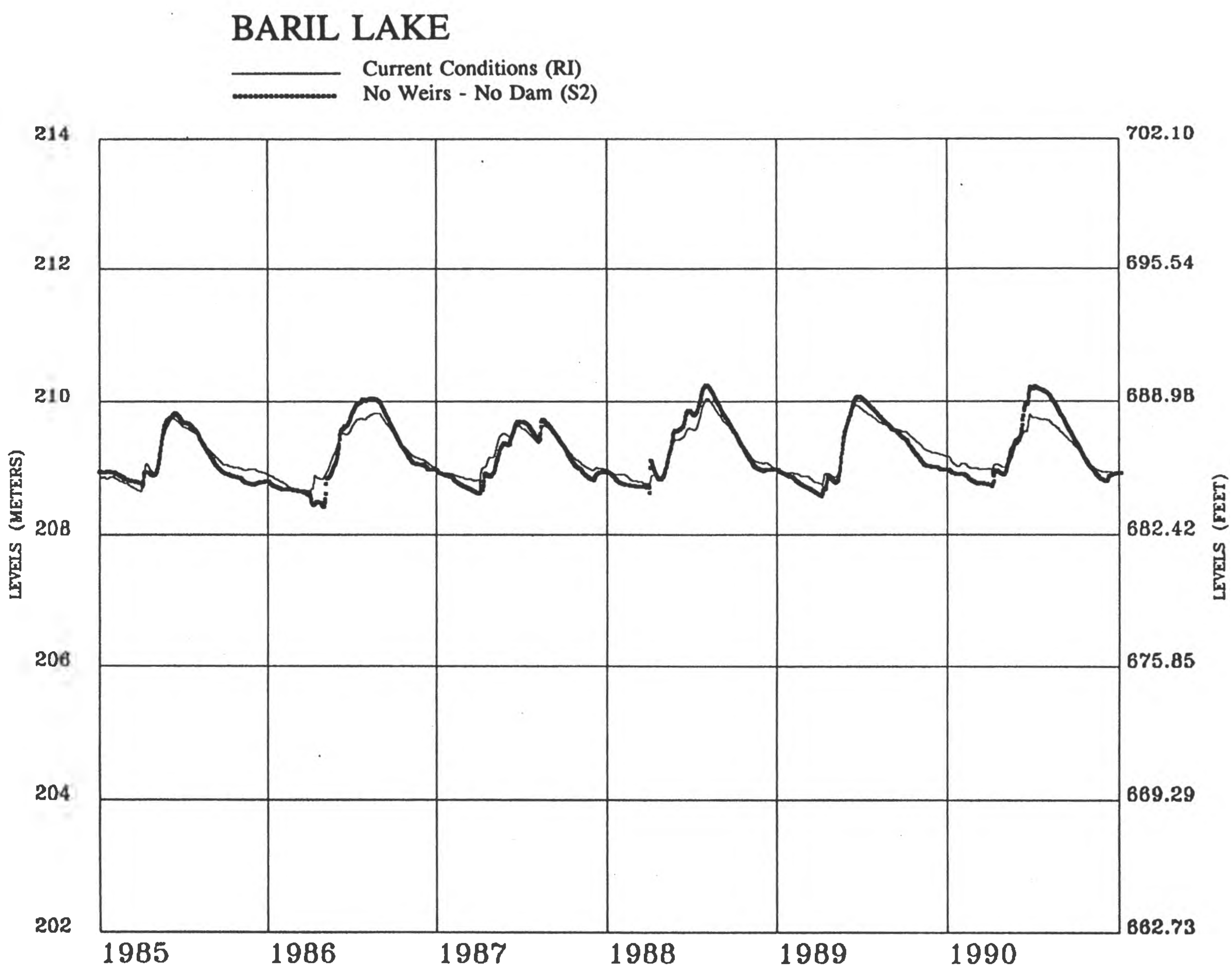
Current Conditions (RI)
No Weirs - No Dam (S2)
214
212
210
208
206
204
202
LEVELS (METERS)
702.10
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

MAMAWI LAKE CHANNEL TO FOUR FORKS



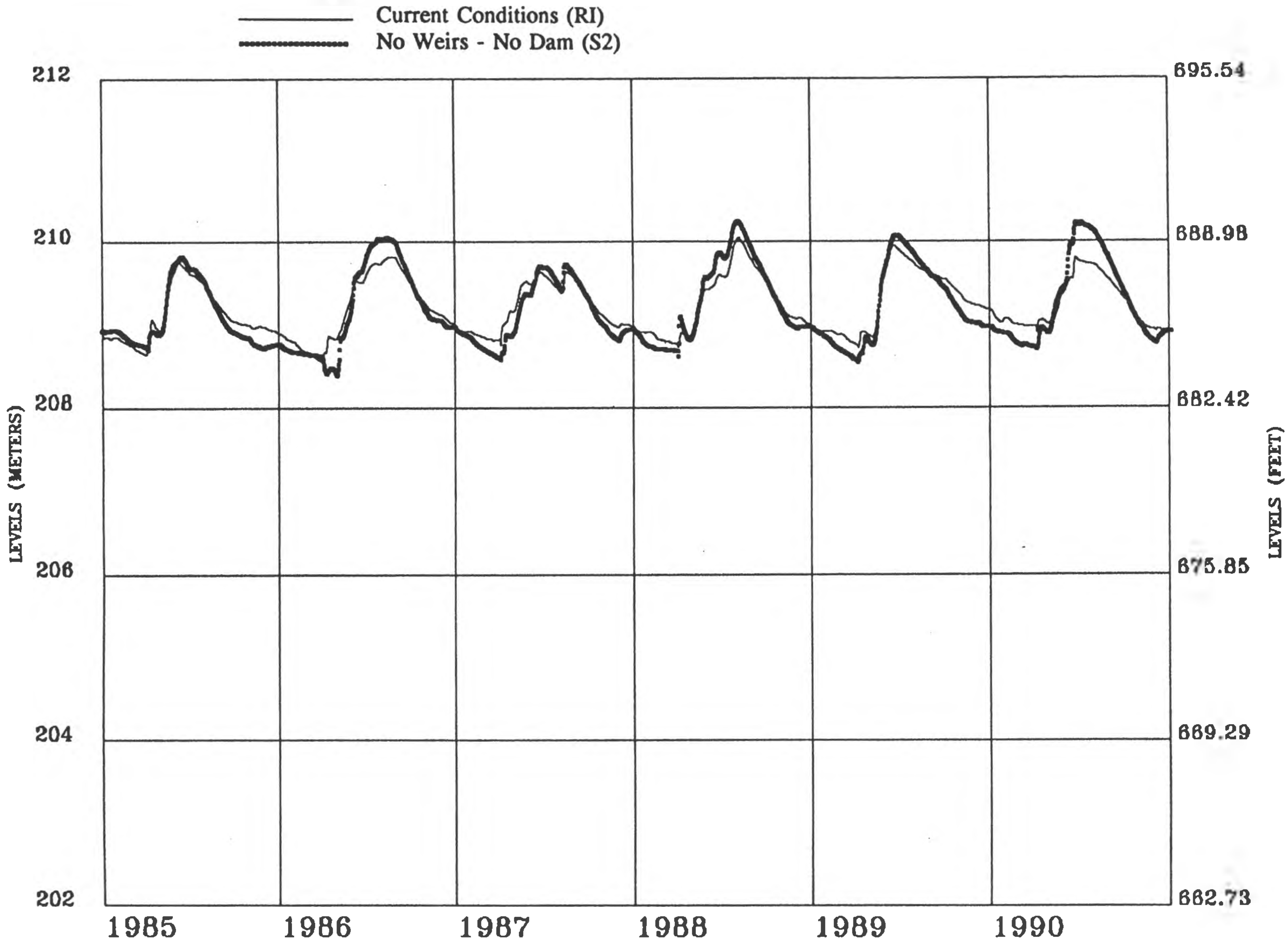
RIVIERE DES ROCHERS





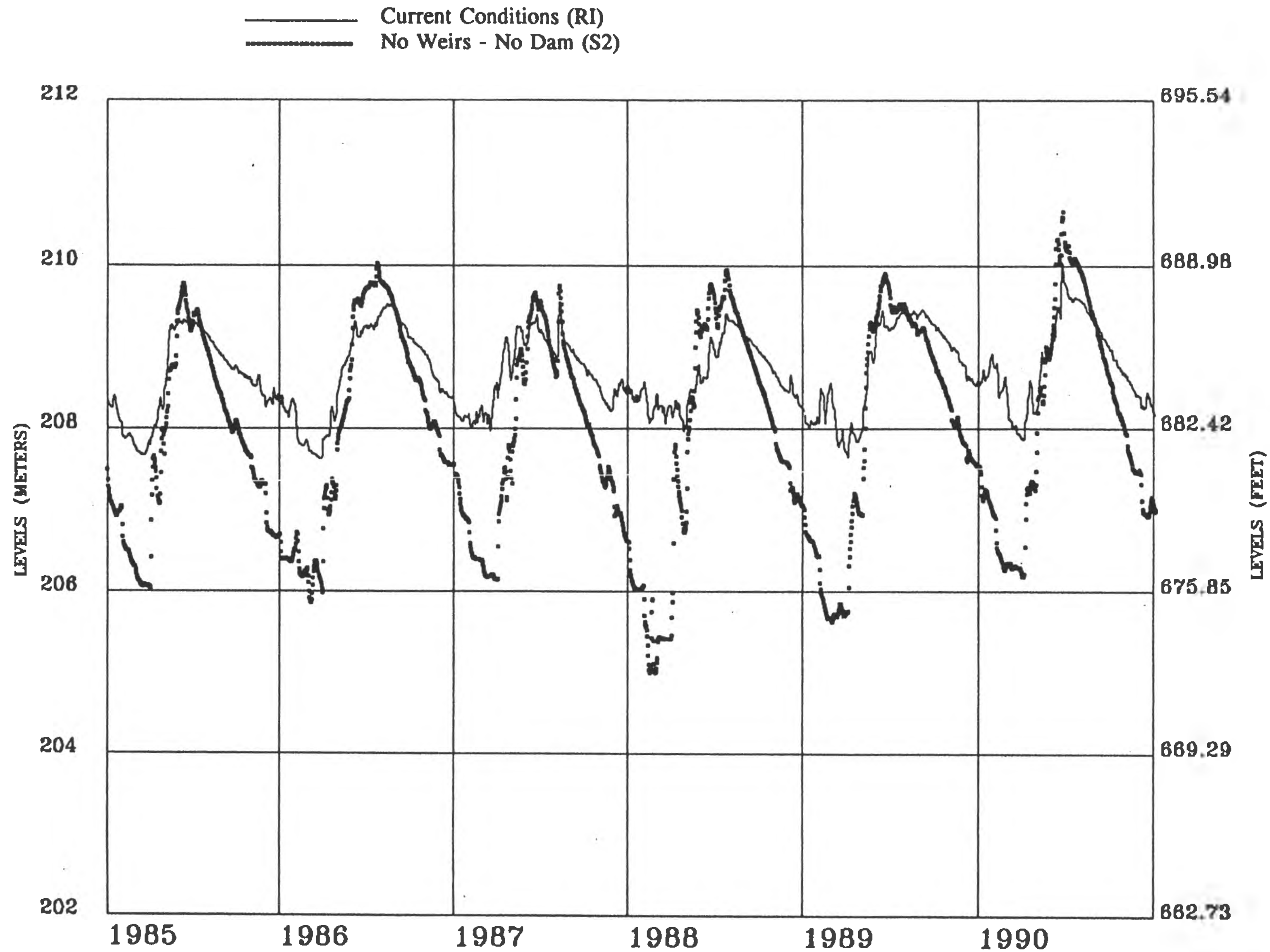
BARIL LAKE
Current Conditions (RI)
No Weirs - No Dam (S2)
214
212
210
208
206
204
202
LEVELS (METERS)
702.10
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

BARIL RIVER

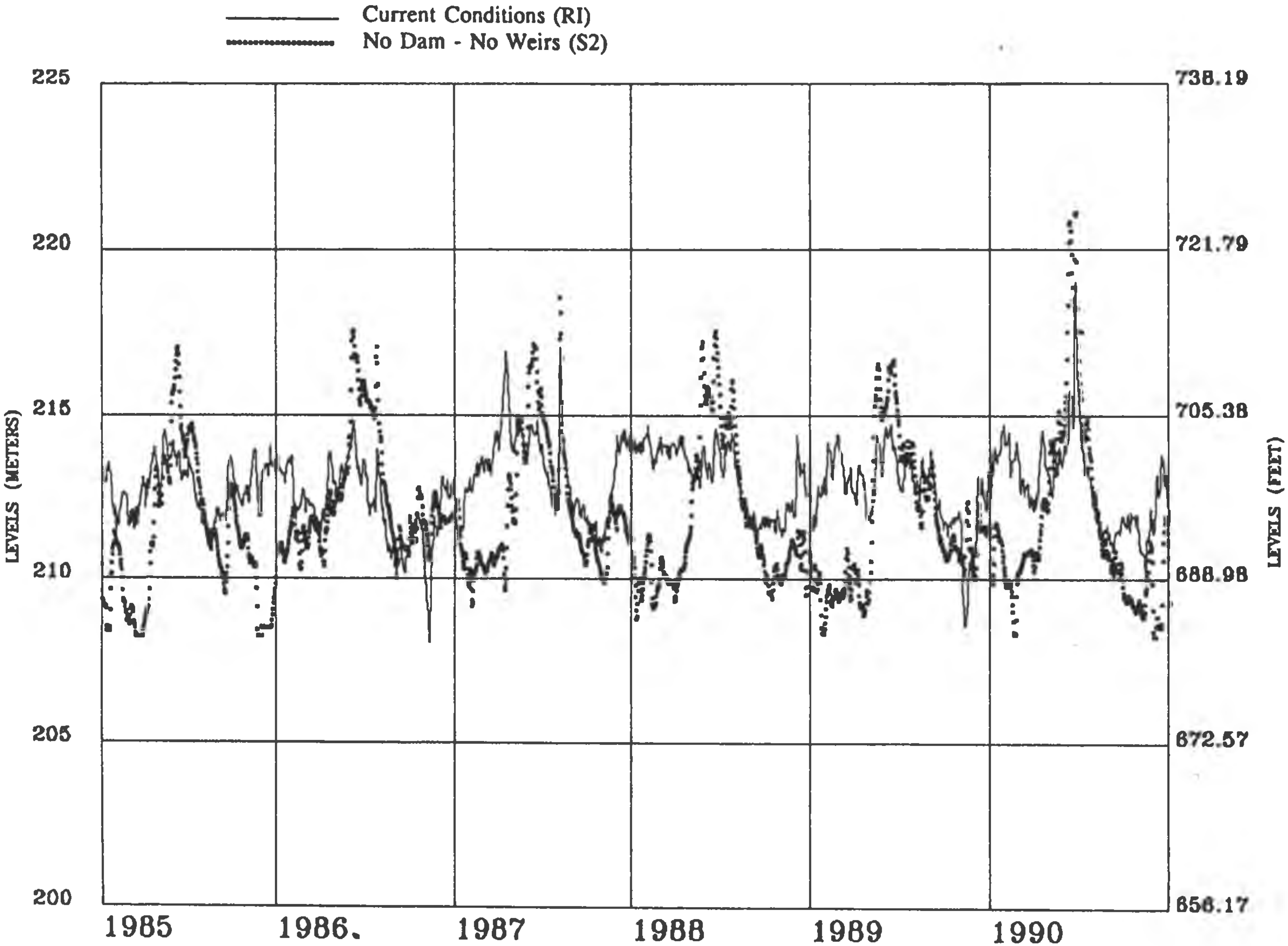


Current Conditions (RI)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

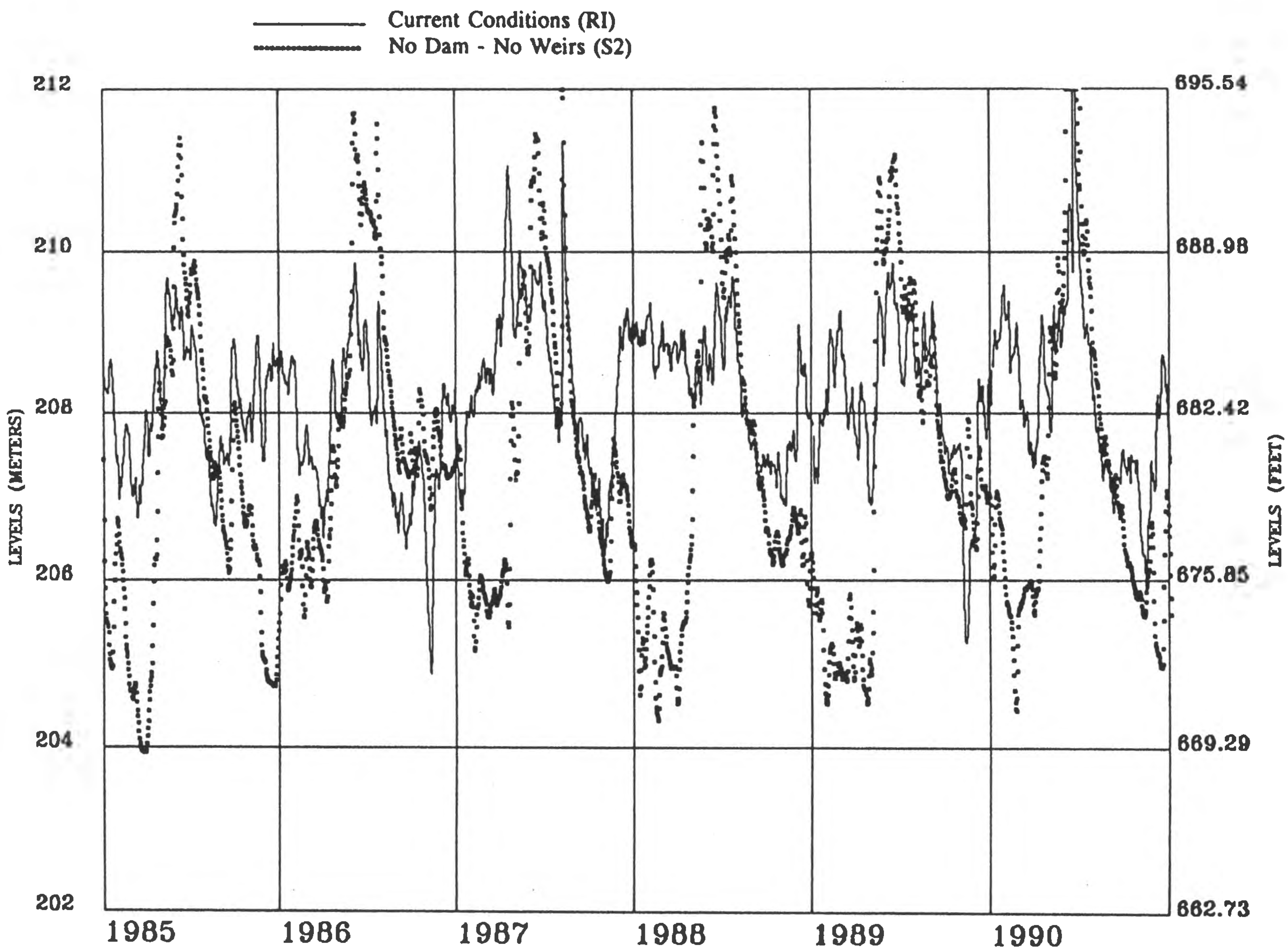
CHENAL DES QUATRE FOURCHES



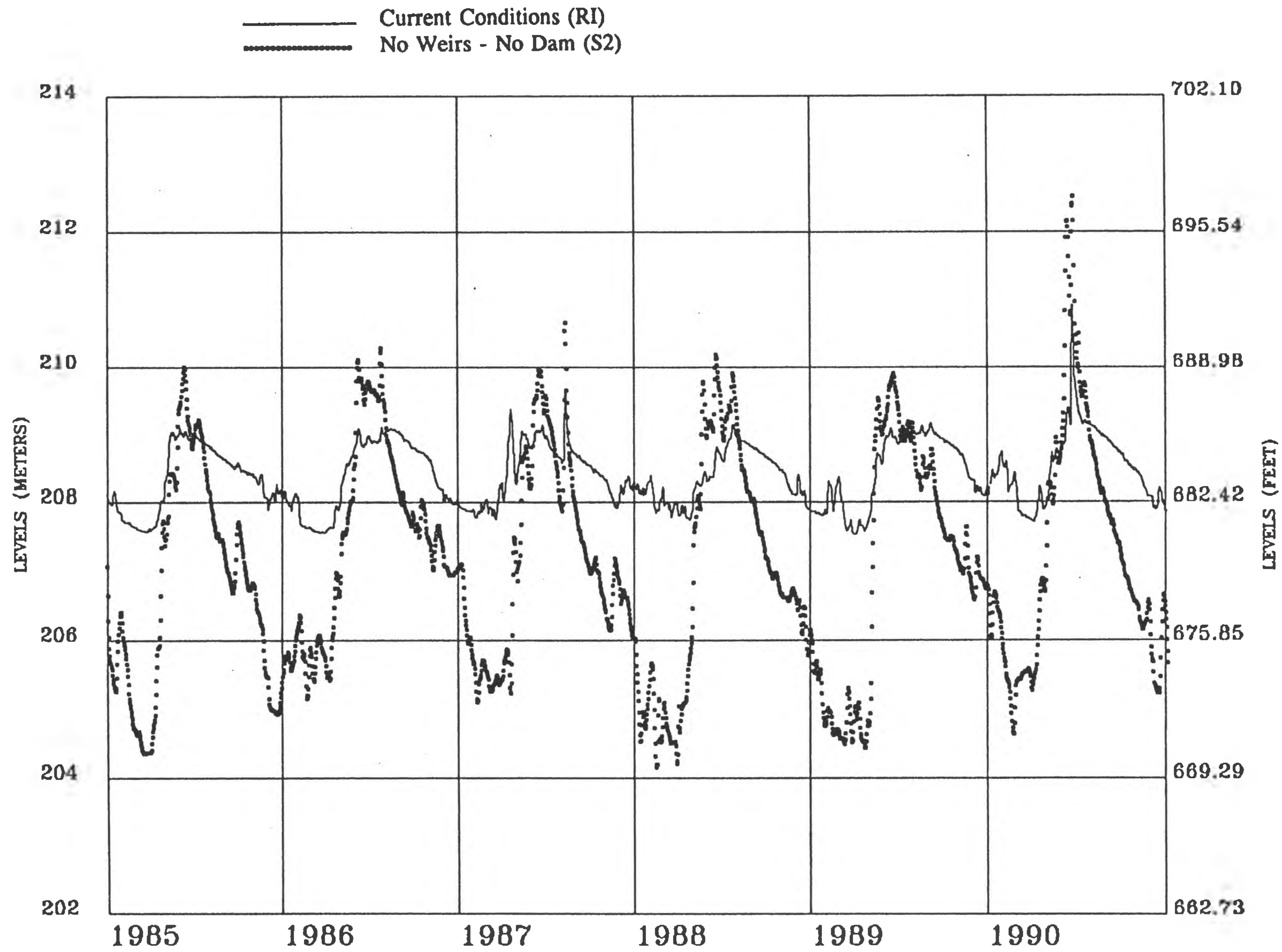
PEACE RIVER AT PEACE POINT



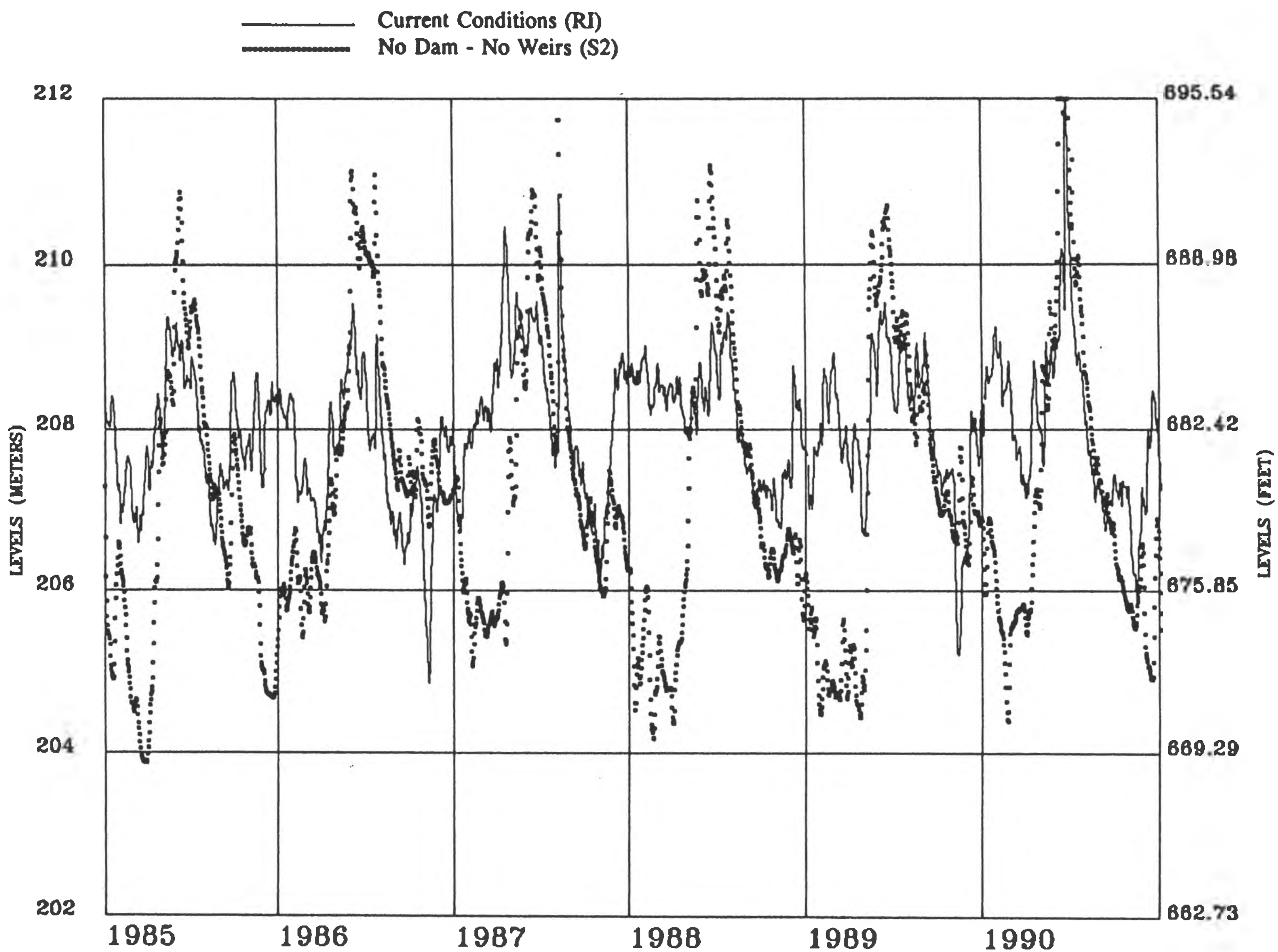
PEACE RIVER AT BARIL RIVER

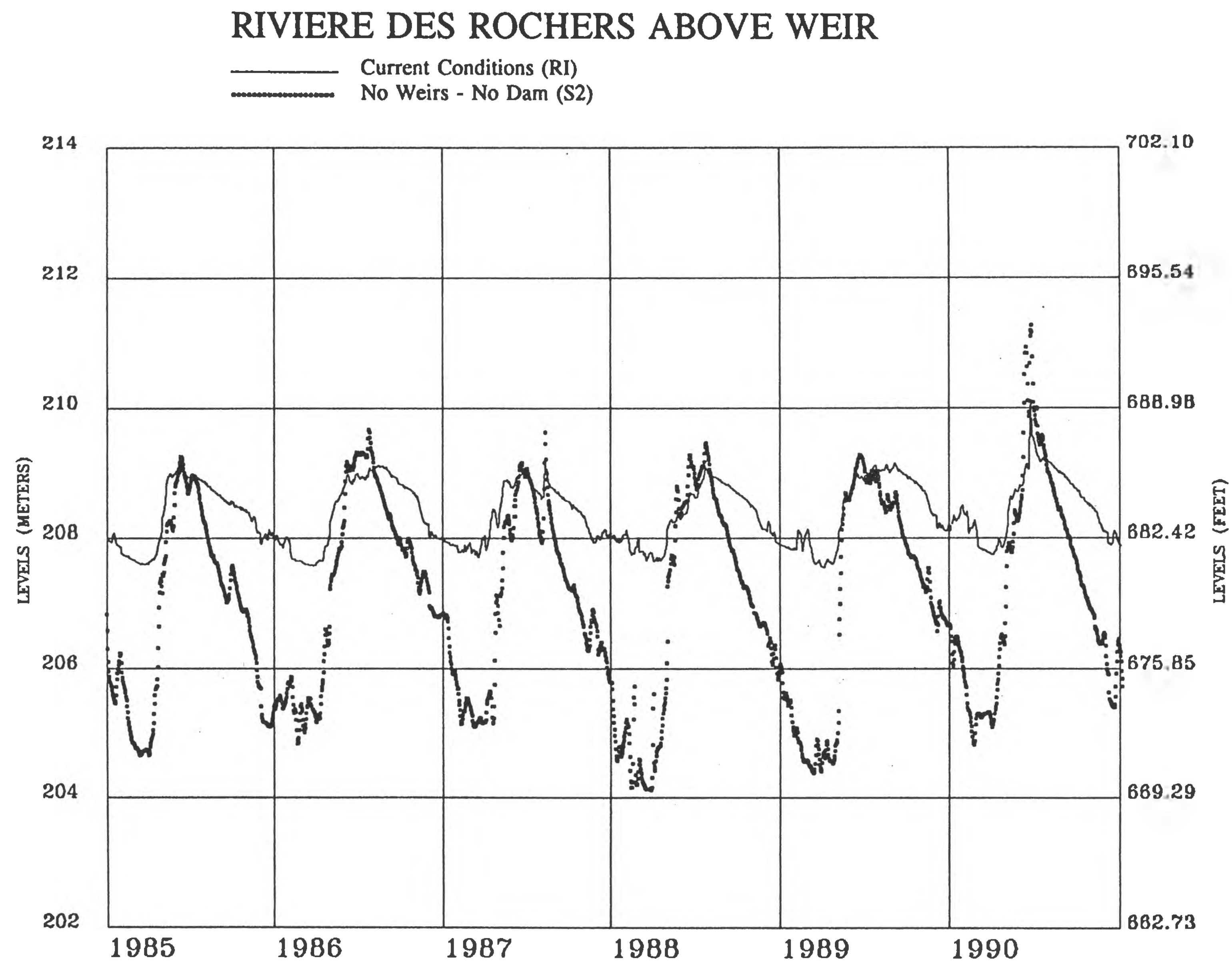


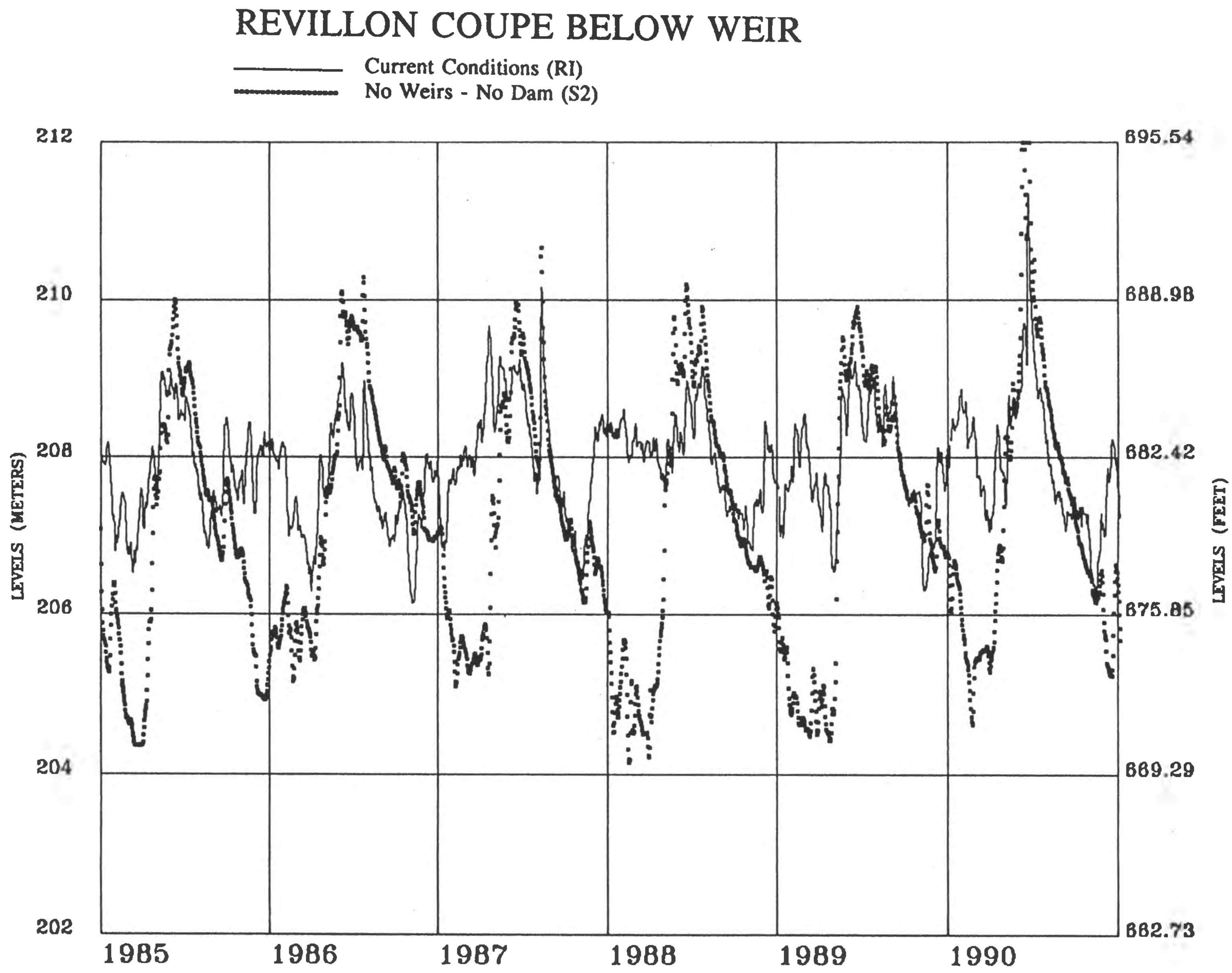
REVILLON COUPE ABOVE WEIR



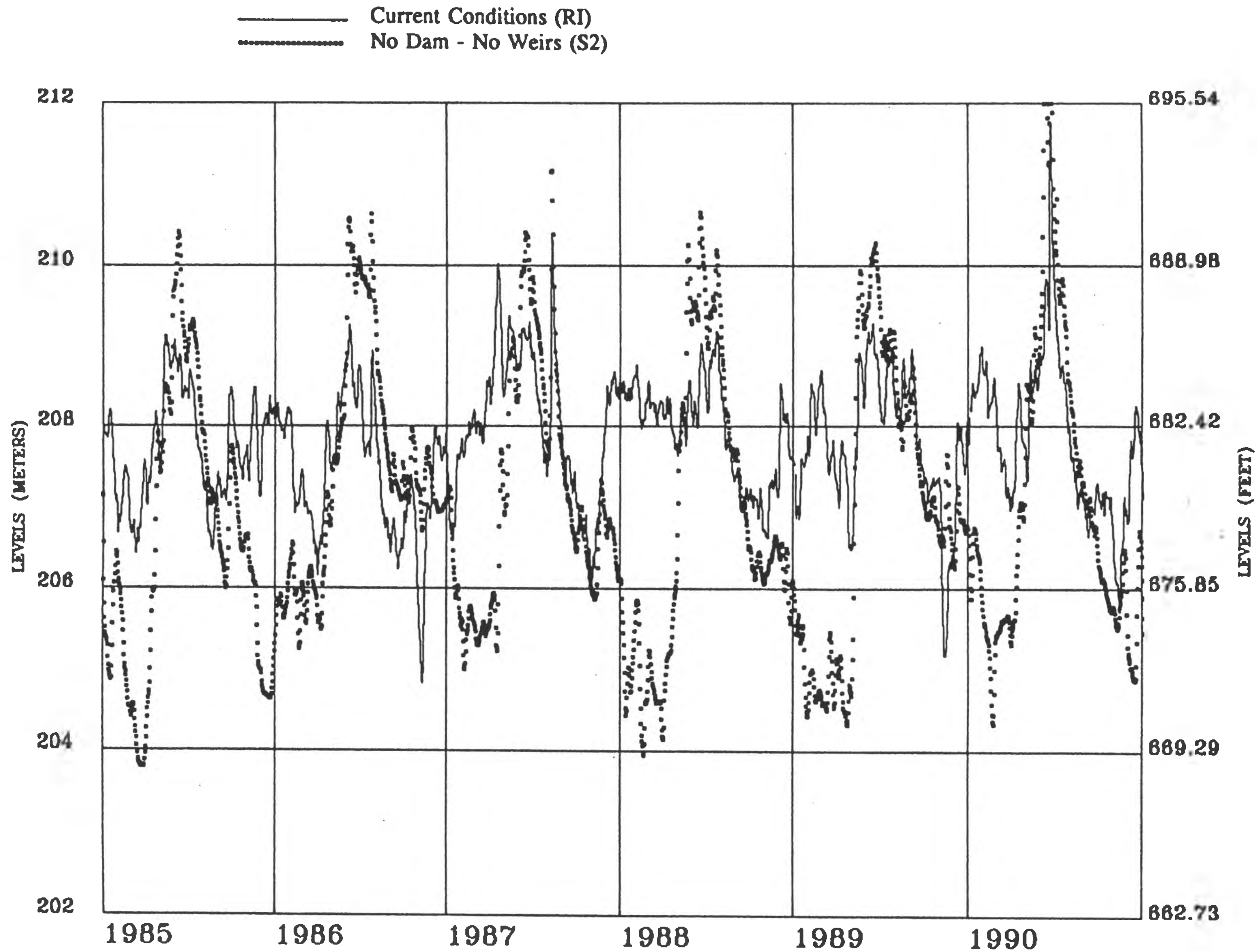
PEACE RIVER AT CHENAL DES QUATRE FOURCHES



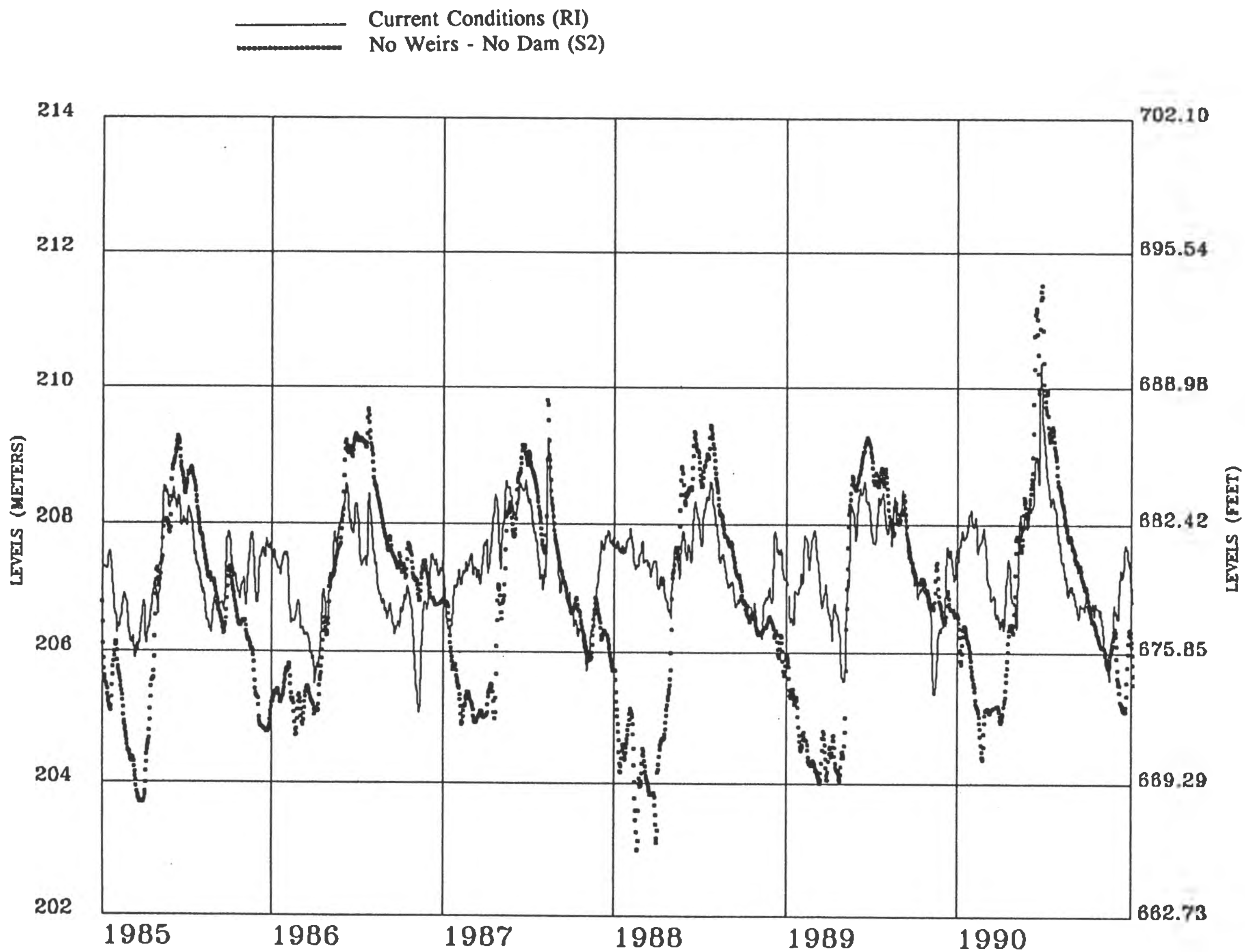

RIVIERE DES ROCHERS ABOVE WEIR
Current Conditions (RI)
No Weirs - No Dam (S2)
LEVELS (METERS)
214
212
210
208
206
204
202
LEVELS (FEET)
702.10
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990


REVILLON COUPE BELOW WEIR
Current Conditions (RI)
No Weirs - No Dam (S2)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

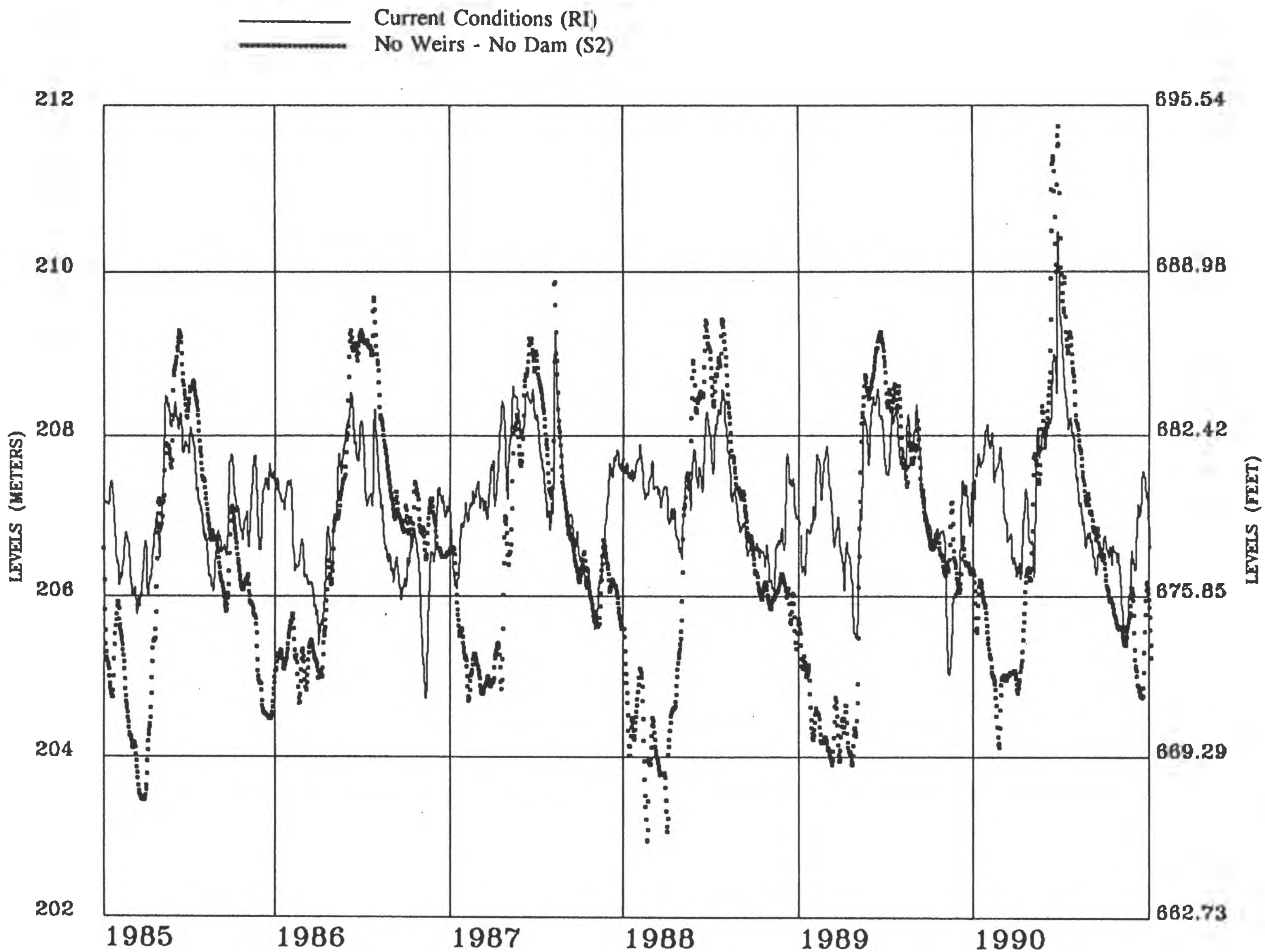
PEACE RIVER AT REVILLON COUPE

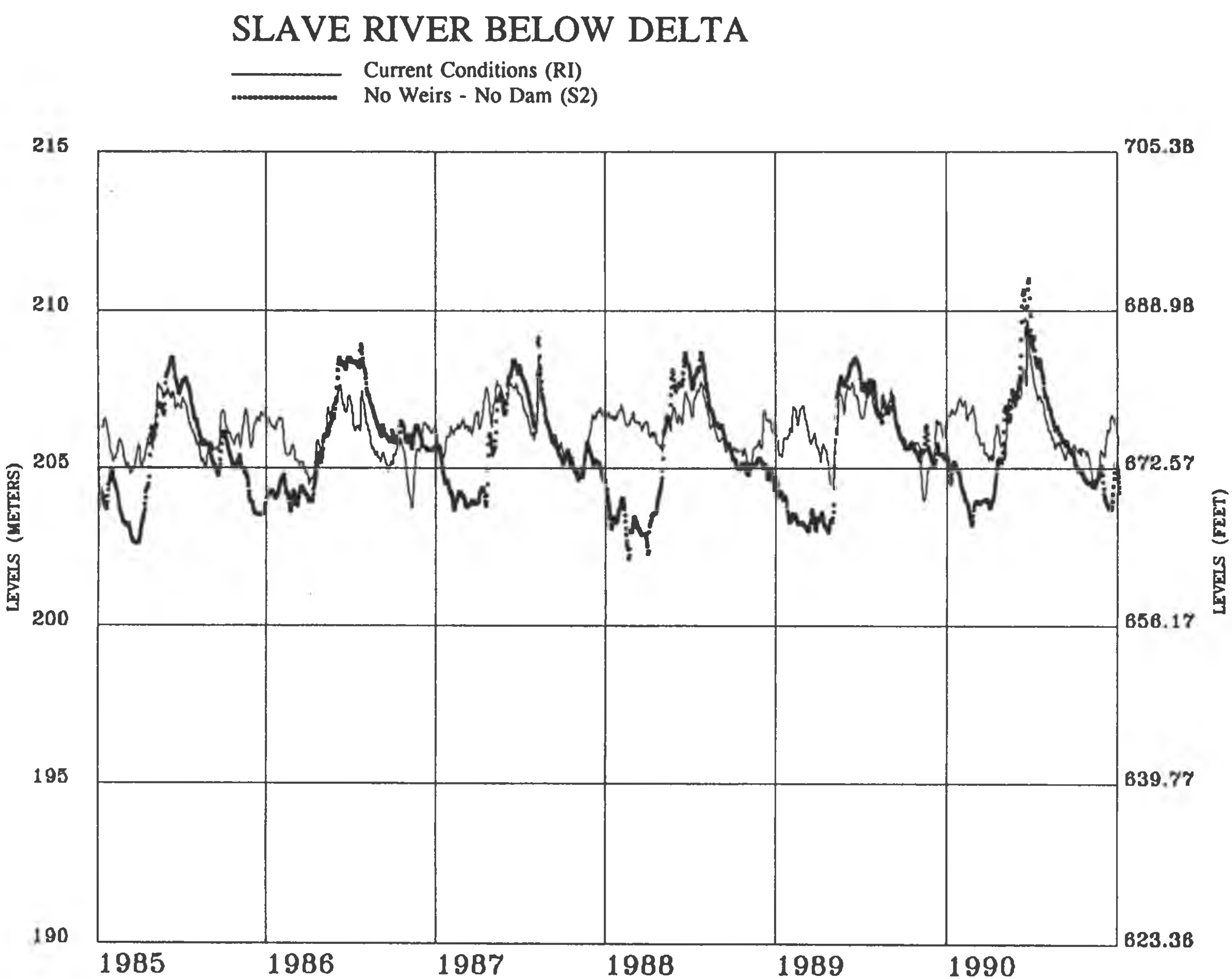


RIVIERE DES ROCHERS BELOW WEIR

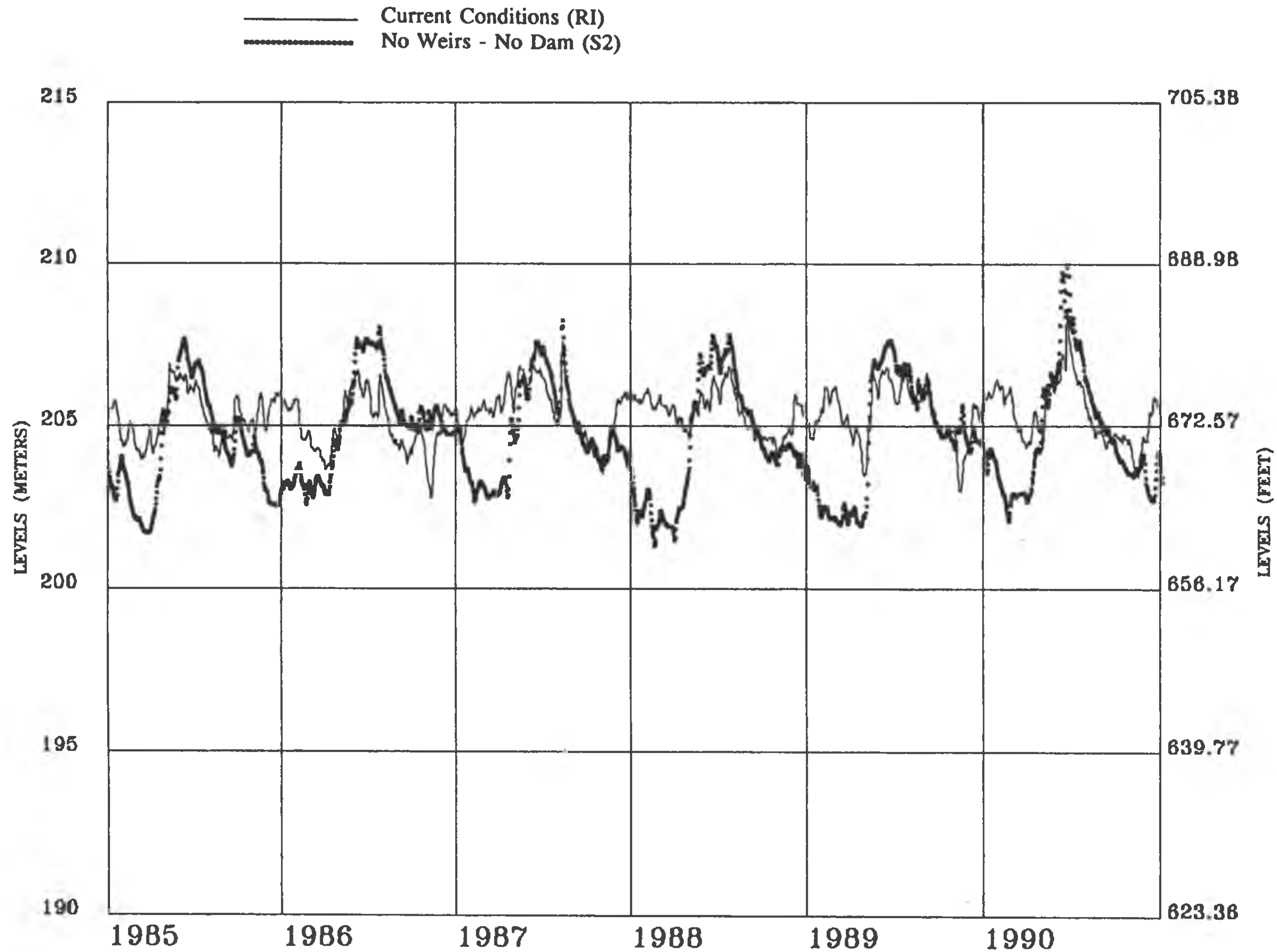


SLAVE RIVER AT DELTA

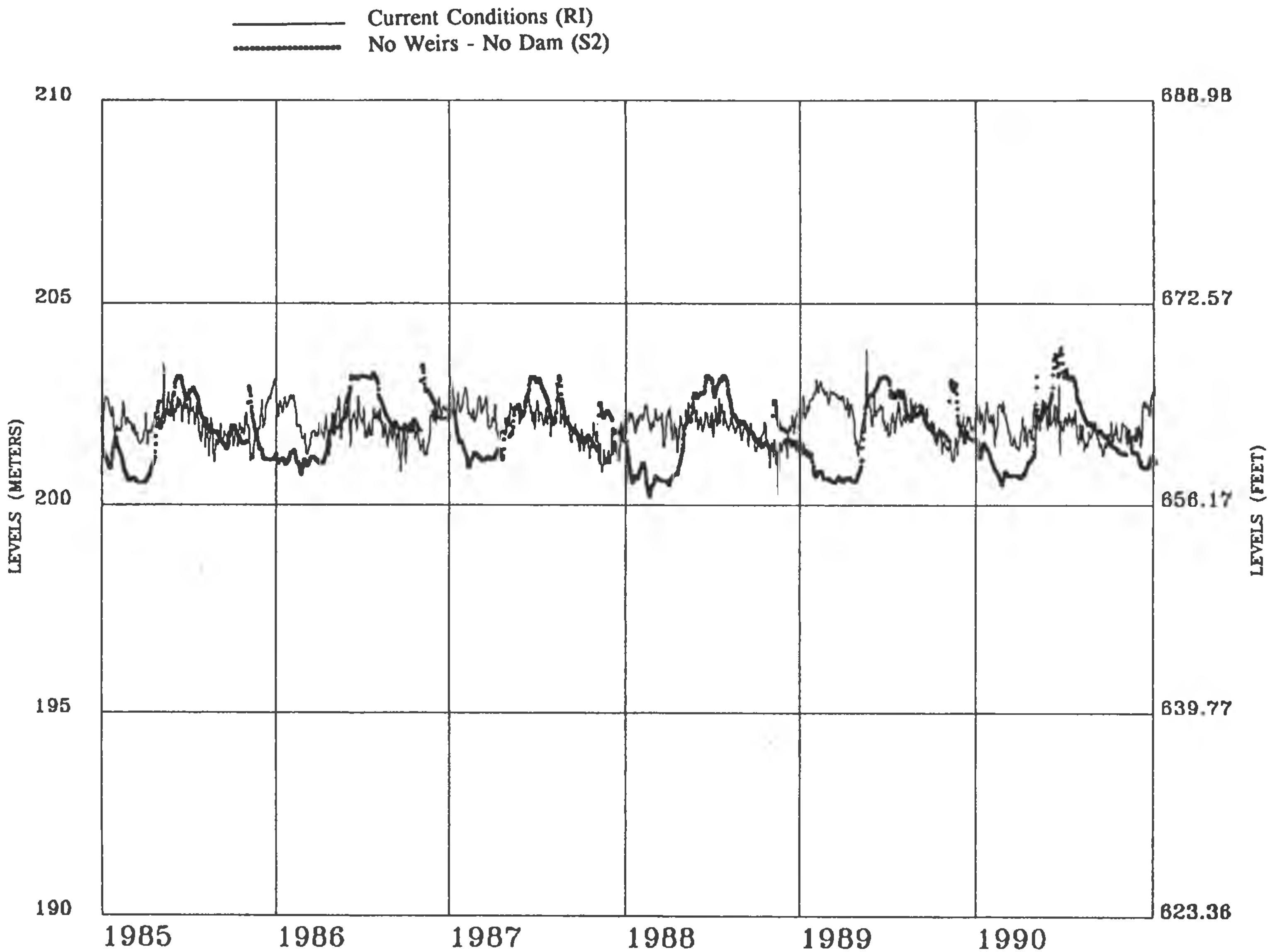



SLAVE RIVER BELOW DELTA
Current Conditions (RI)
No Weirs - No Dam (S2)
LEVELS (METERS)
215
210
205
200
195
190
LEVELS (FEET)
705.38
688.98
672.57
656.17
639.77
623.36
1985
1986
1987
1988
1989
1990

SLAVE RIVER ABOVE FITZGERALD

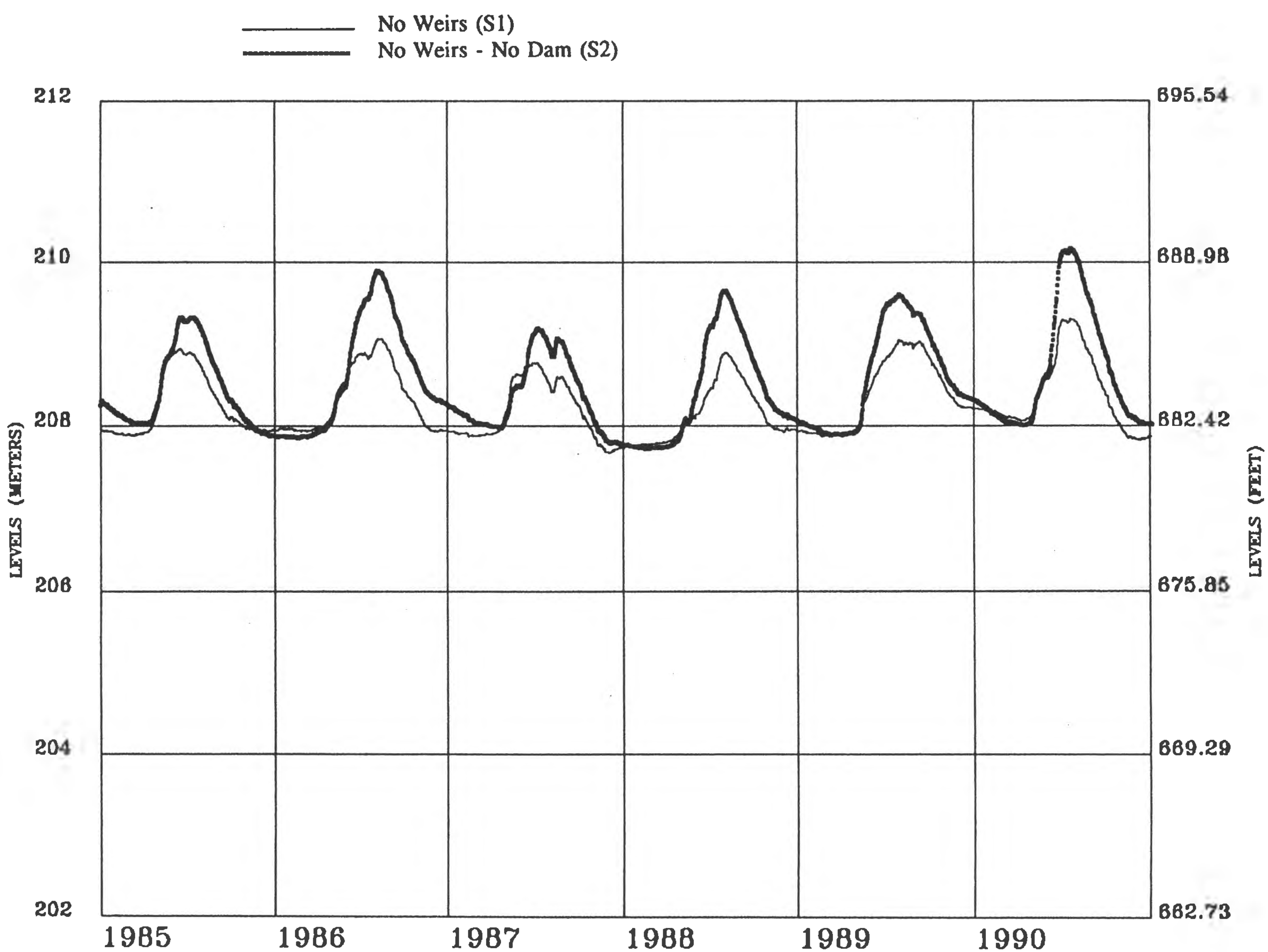


SLAVE RIVER AT FITZGERALD

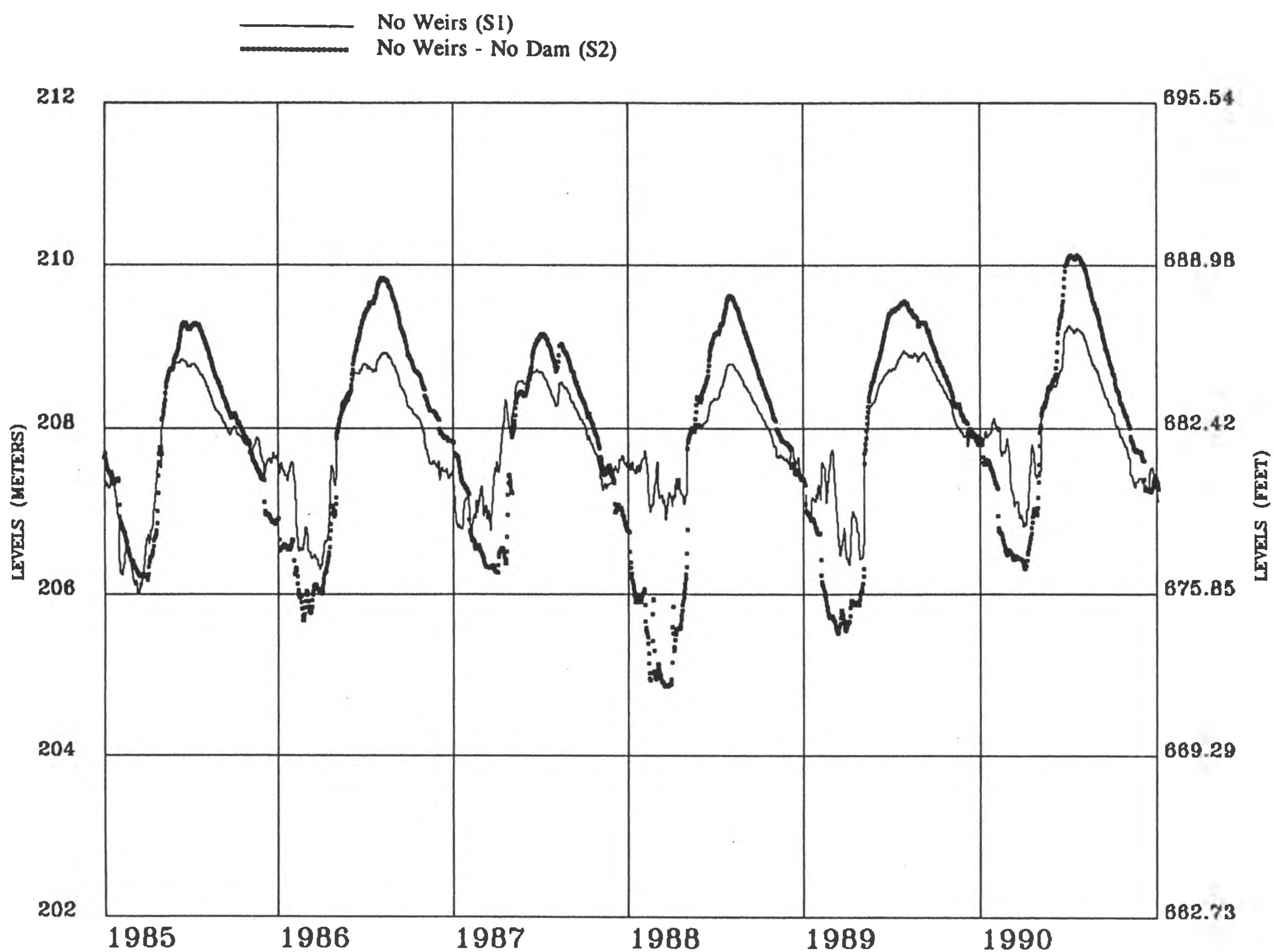


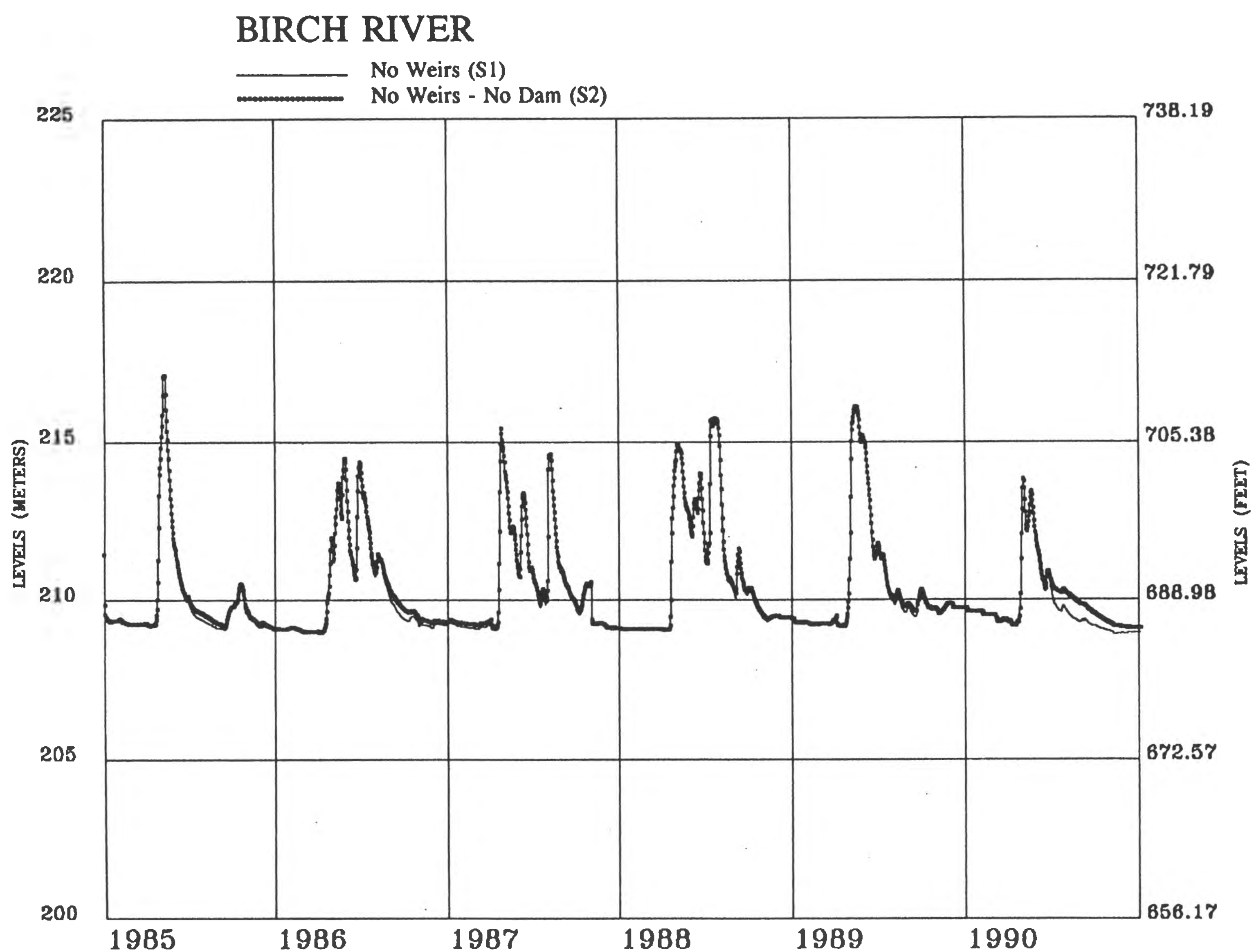
APPENDIX E.
Plots of No Weirs and Natural Conditions

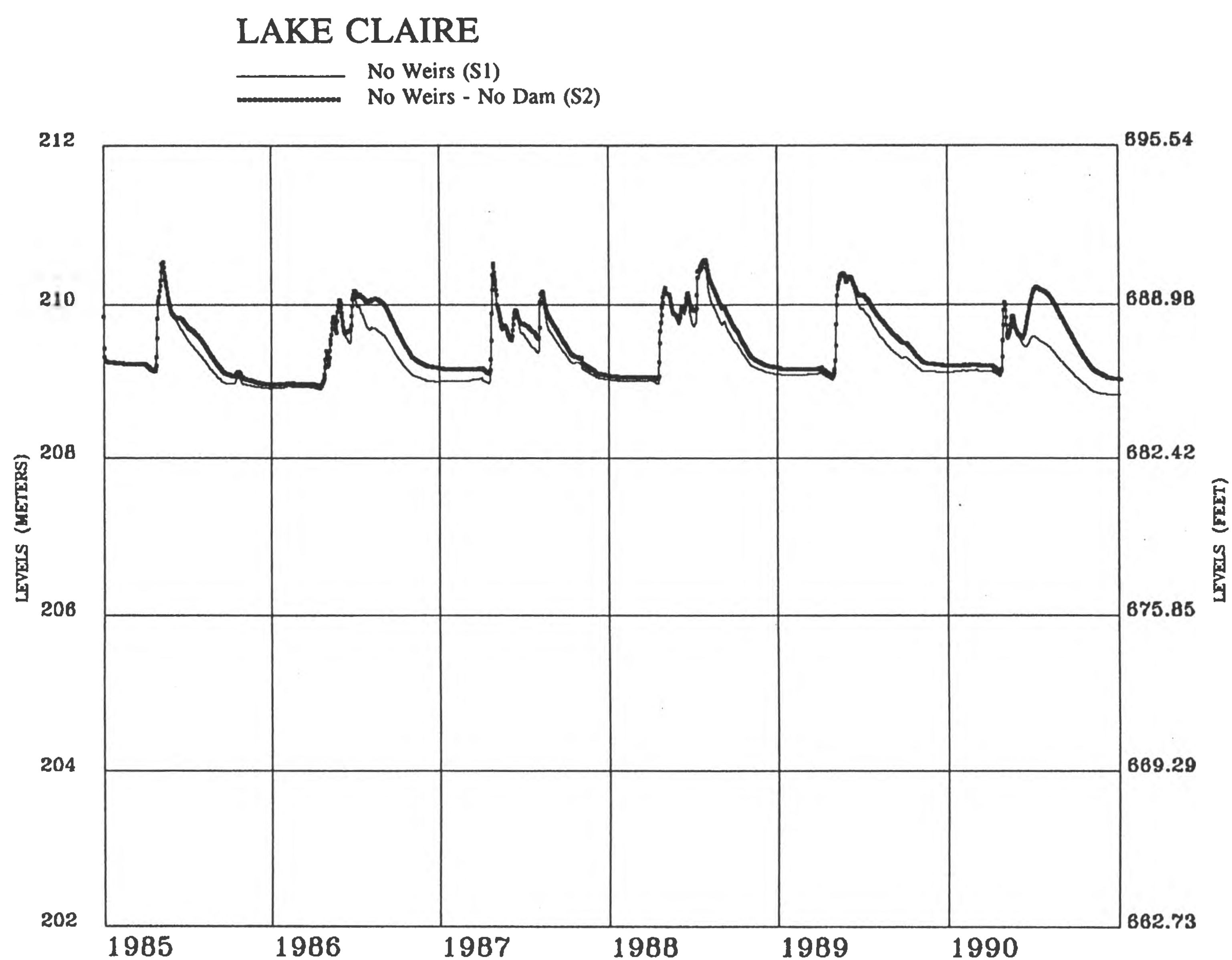
LAKE ATHABASCA

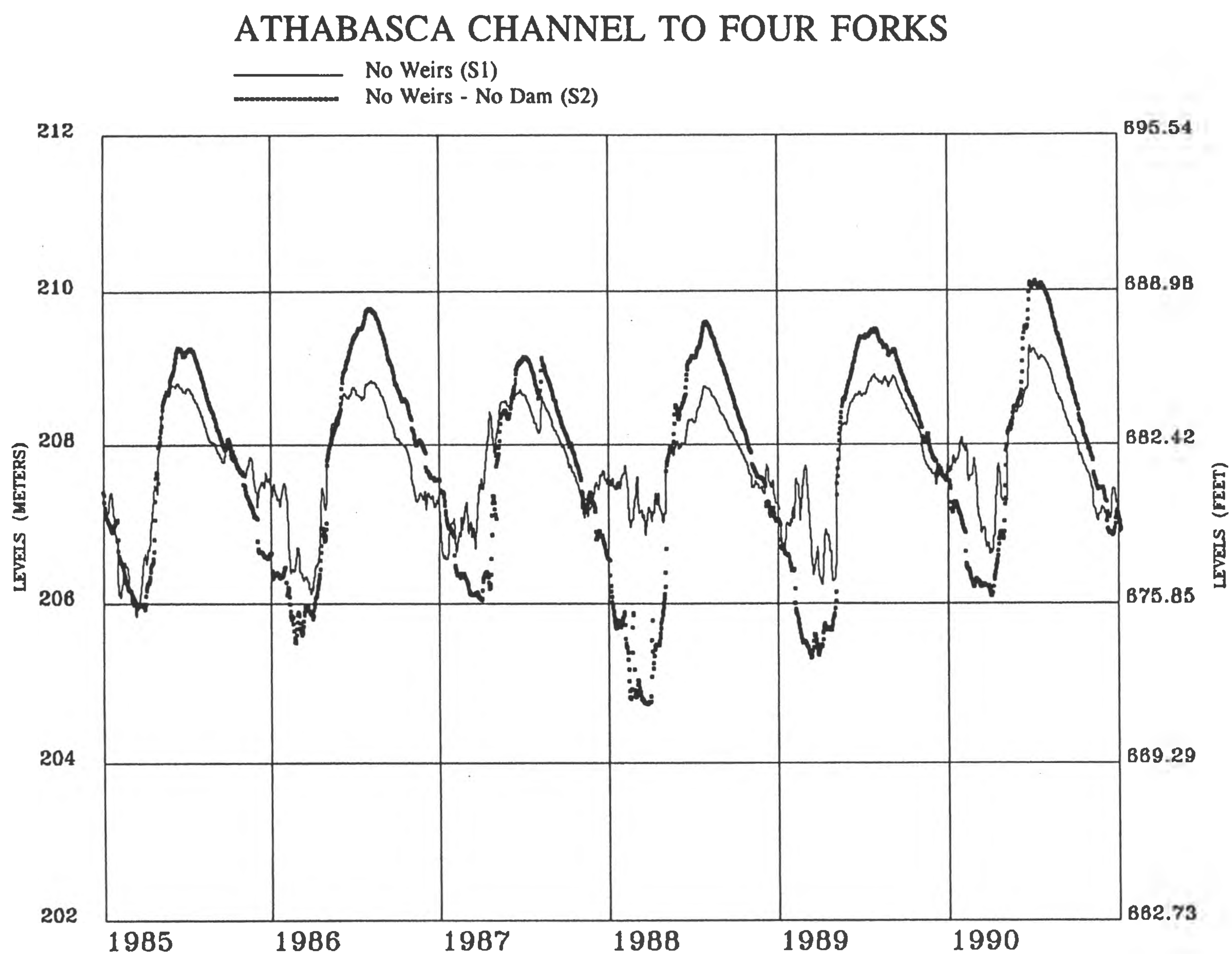


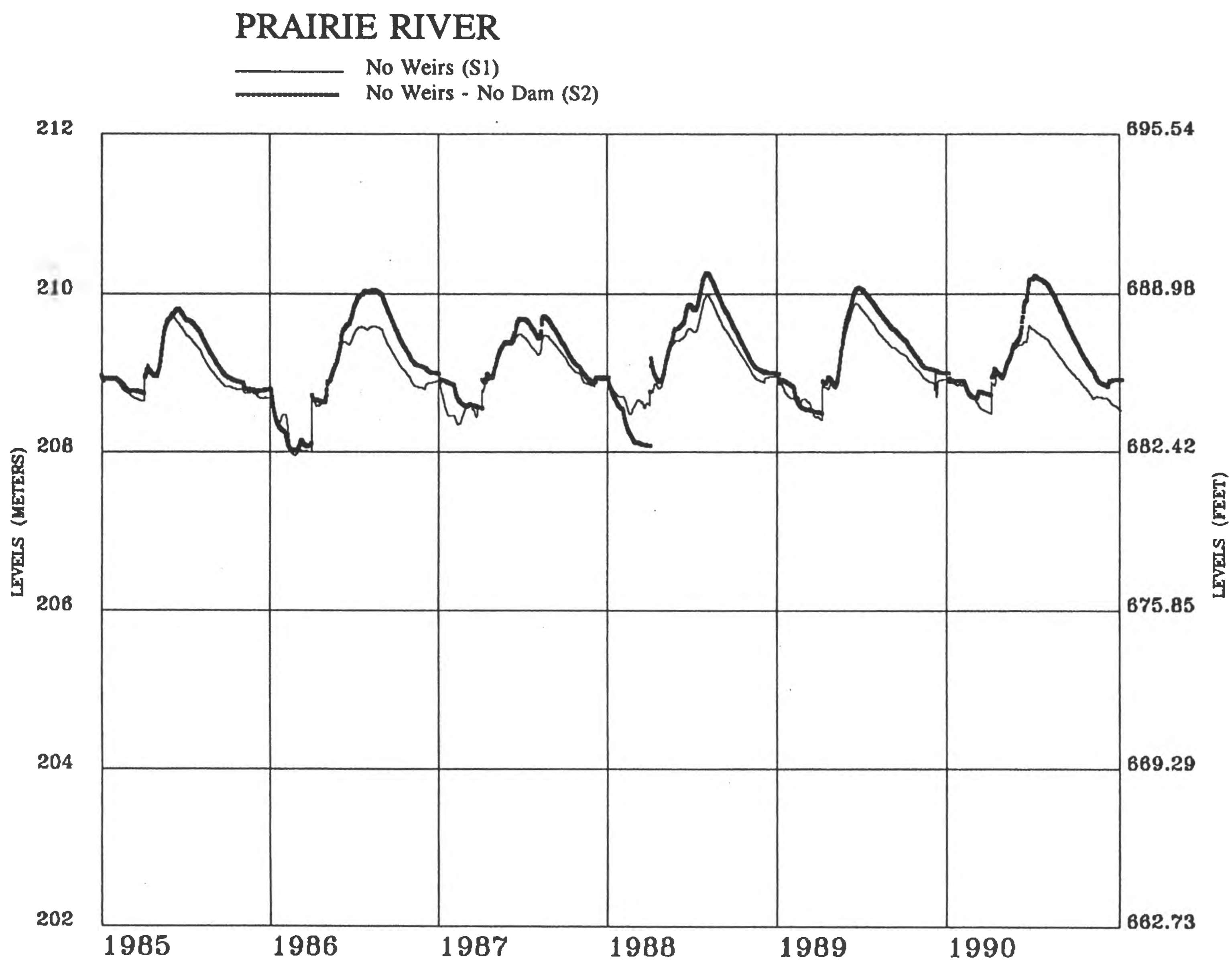
LAKE ATHABASCA OUTLET

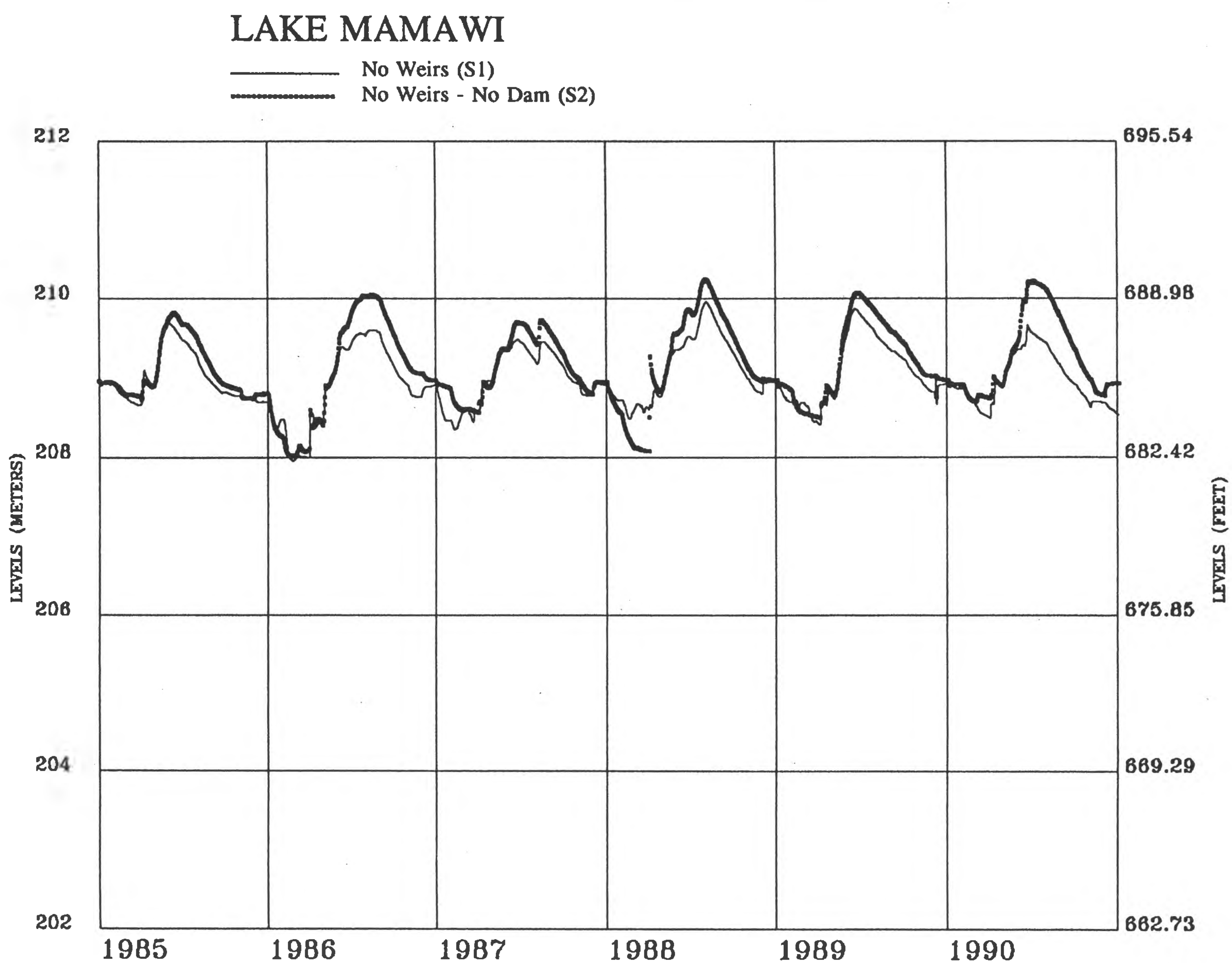



BIRCH RIVER
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
225
220
215
210
205
200
LEVELS (FEET)
738.19
721.79
705.38
688.98
672.57
656.17
1985
1986
1987
1988
1989
1990

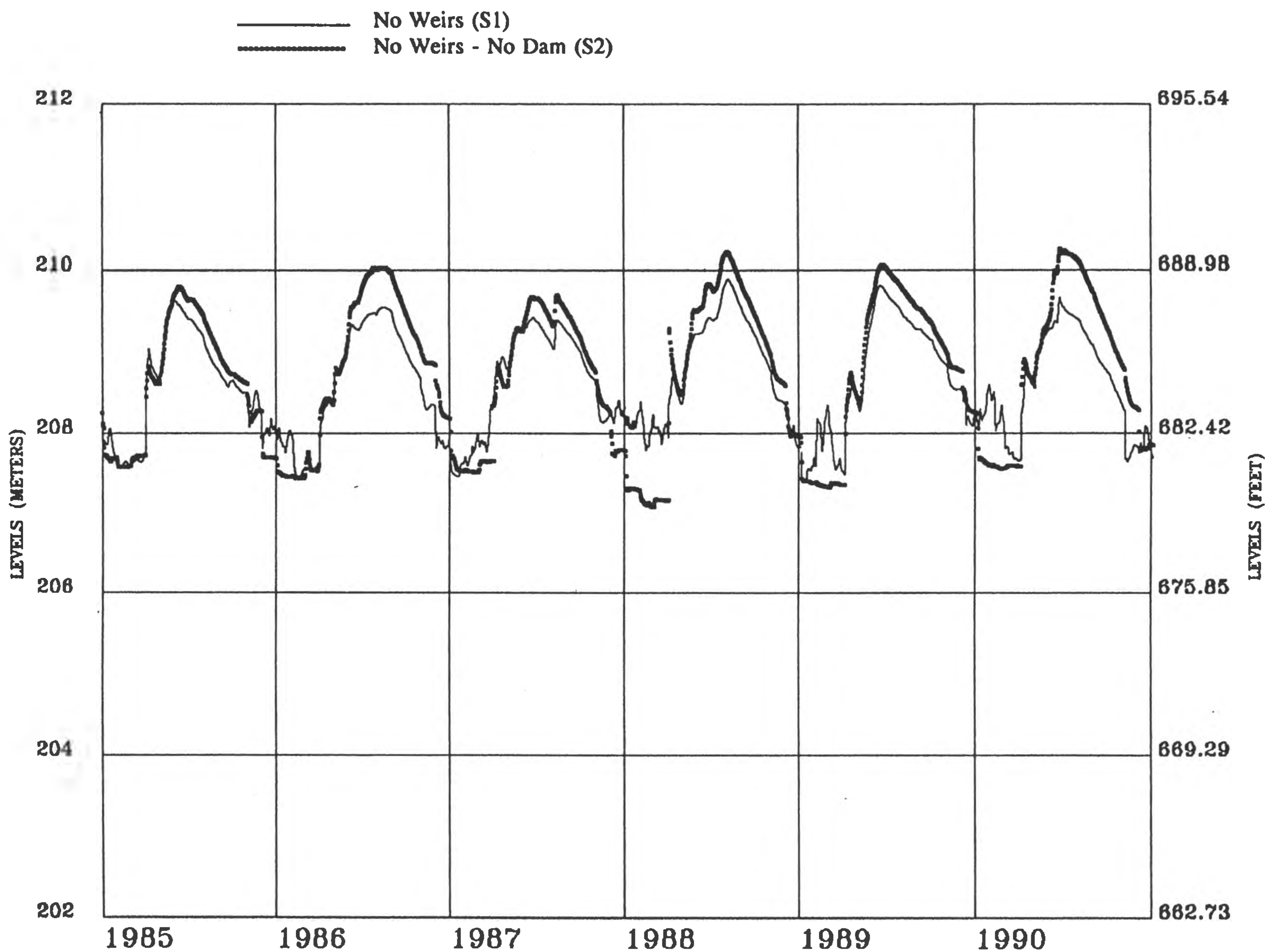

LAKE CLAIRE
No Weirs (S1)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

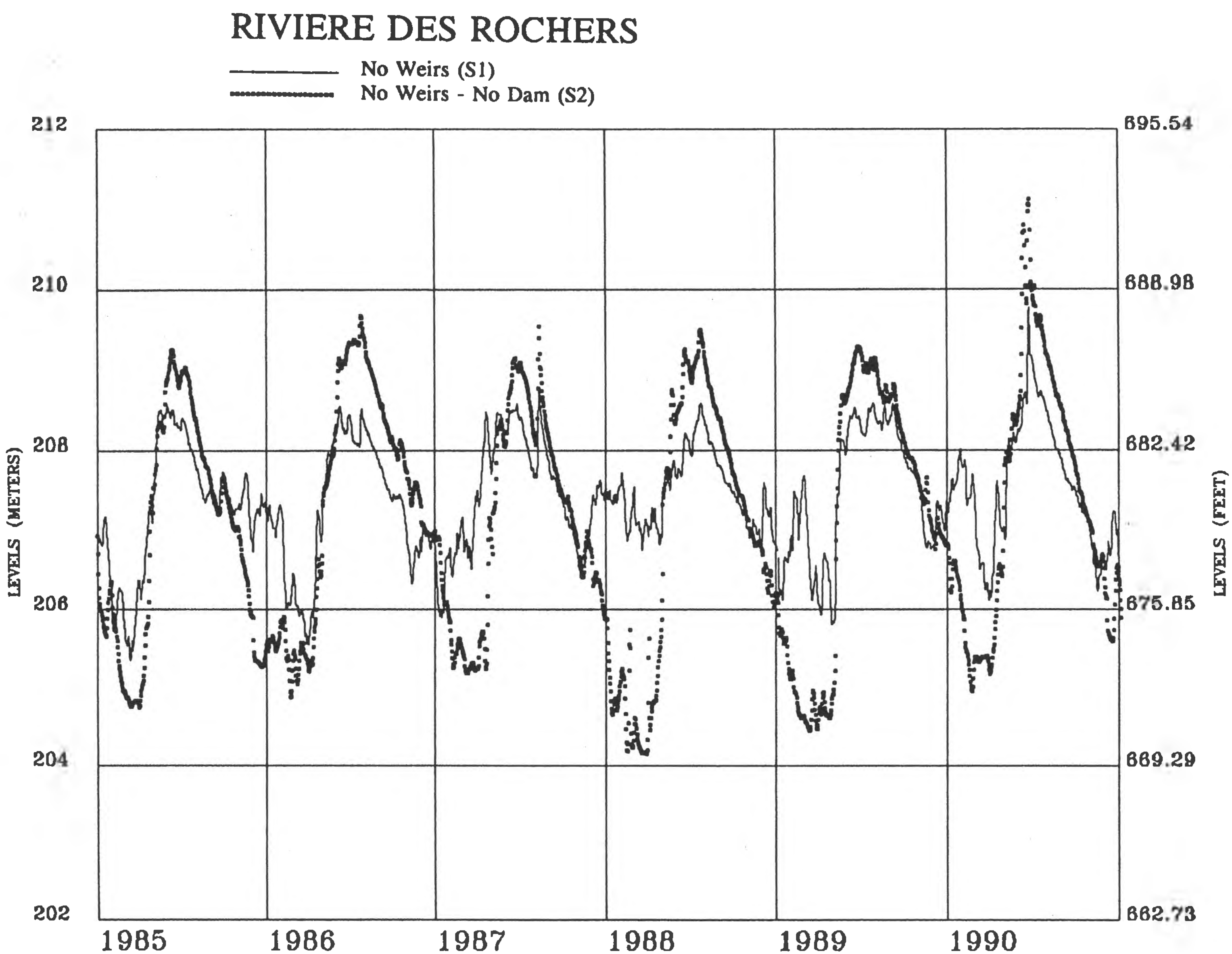

ATHABASCA CHANNEL TO FOUR FORKS
No Weirs (S1)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

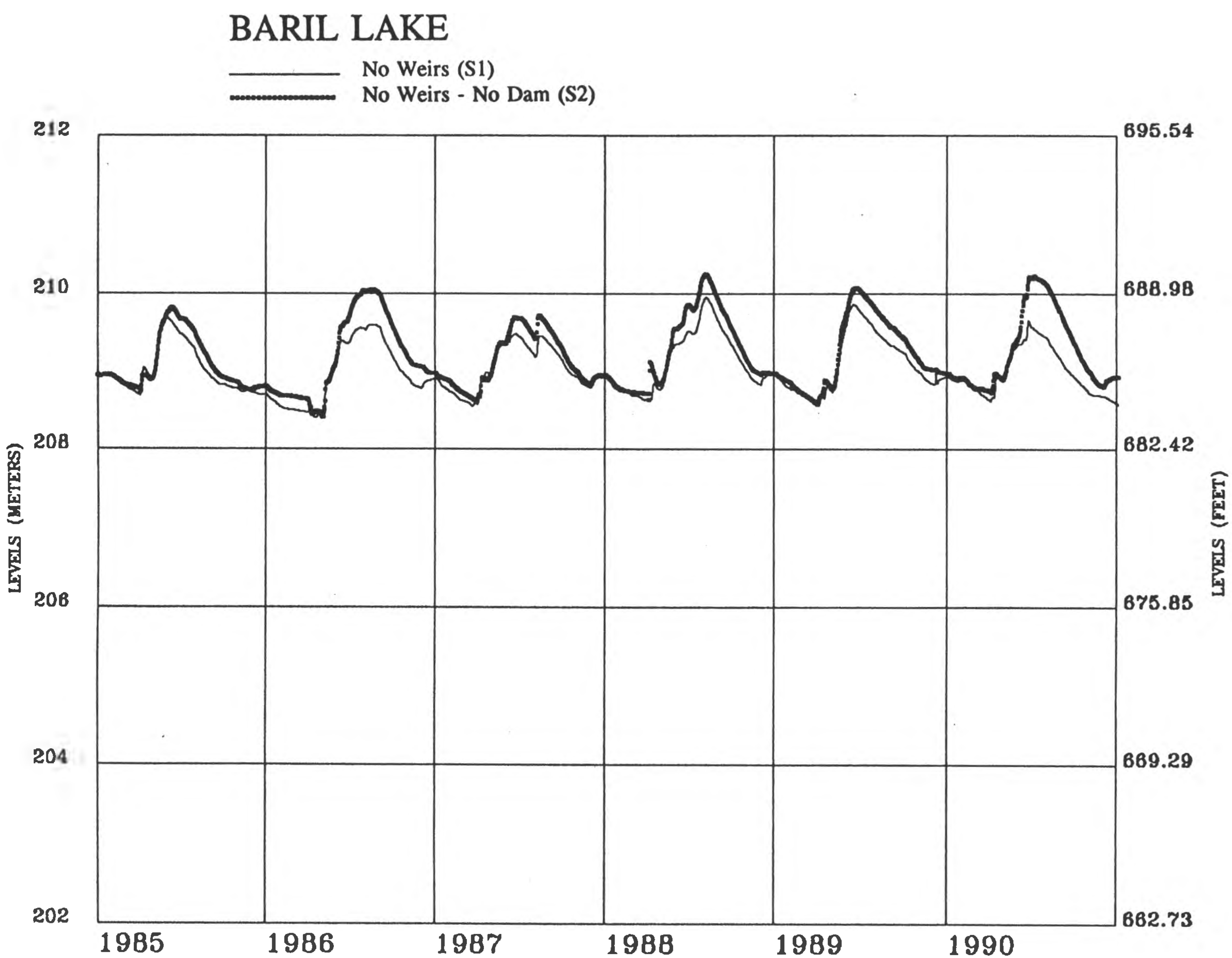

PRAIRIE RIVER
No Weirs (S1)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

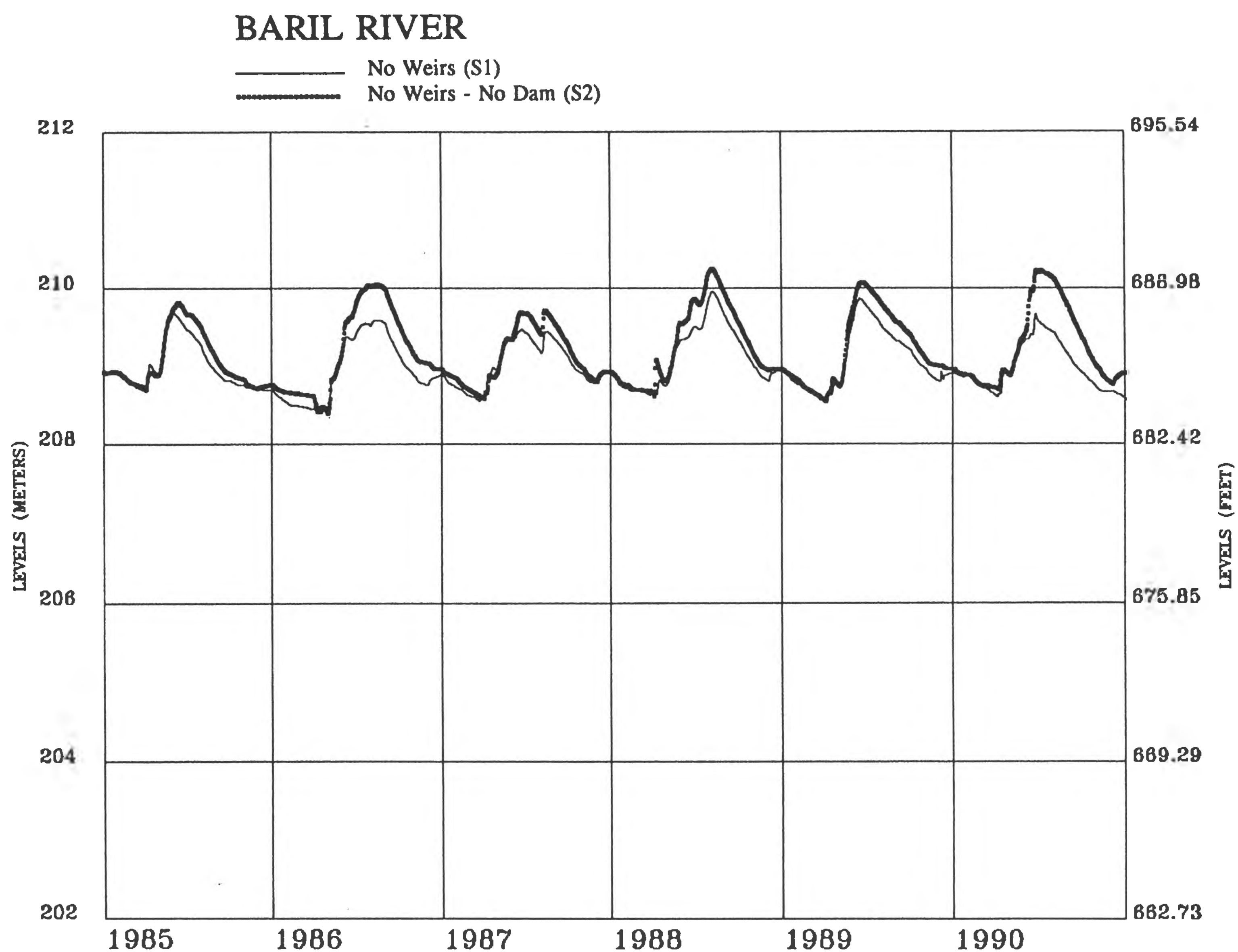

LAKE MAMAWI
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

MAMAWI LAKE CHANNEL TO FOUR FORKS



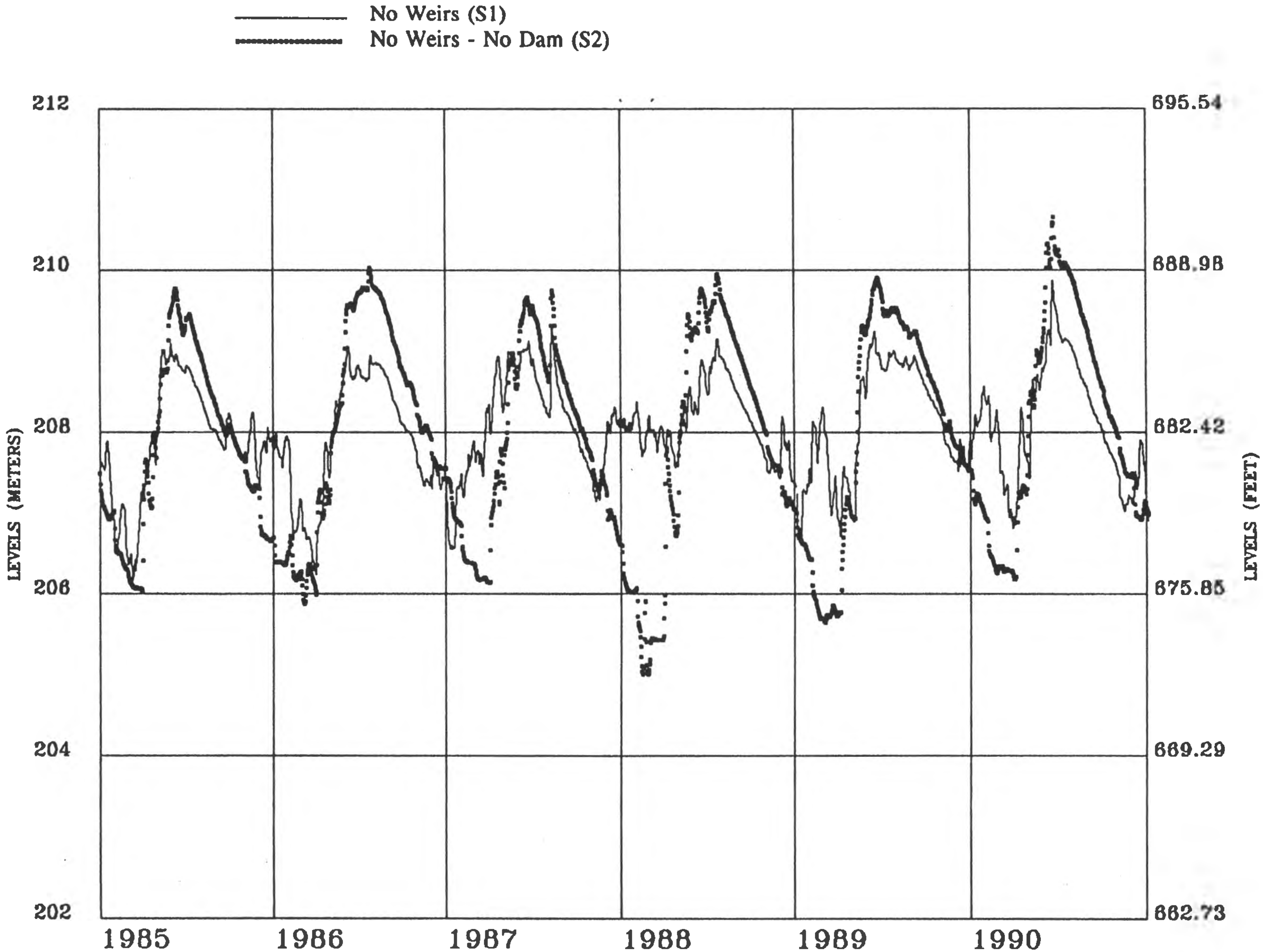

RIVIERE DES ROCHERS
No Weirs (S1)
No Weirs - No Dam (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990


BARIL LAKE
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

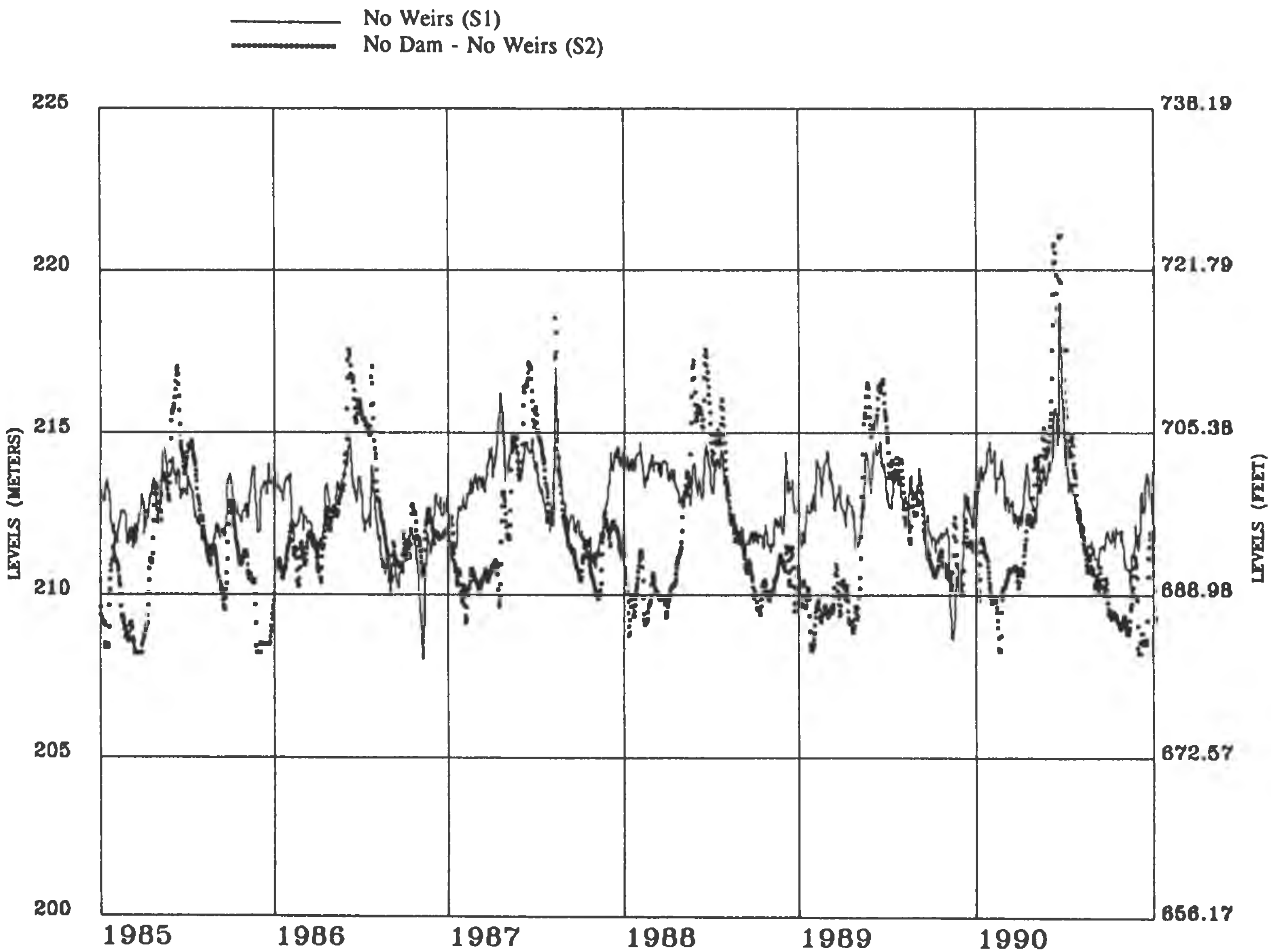


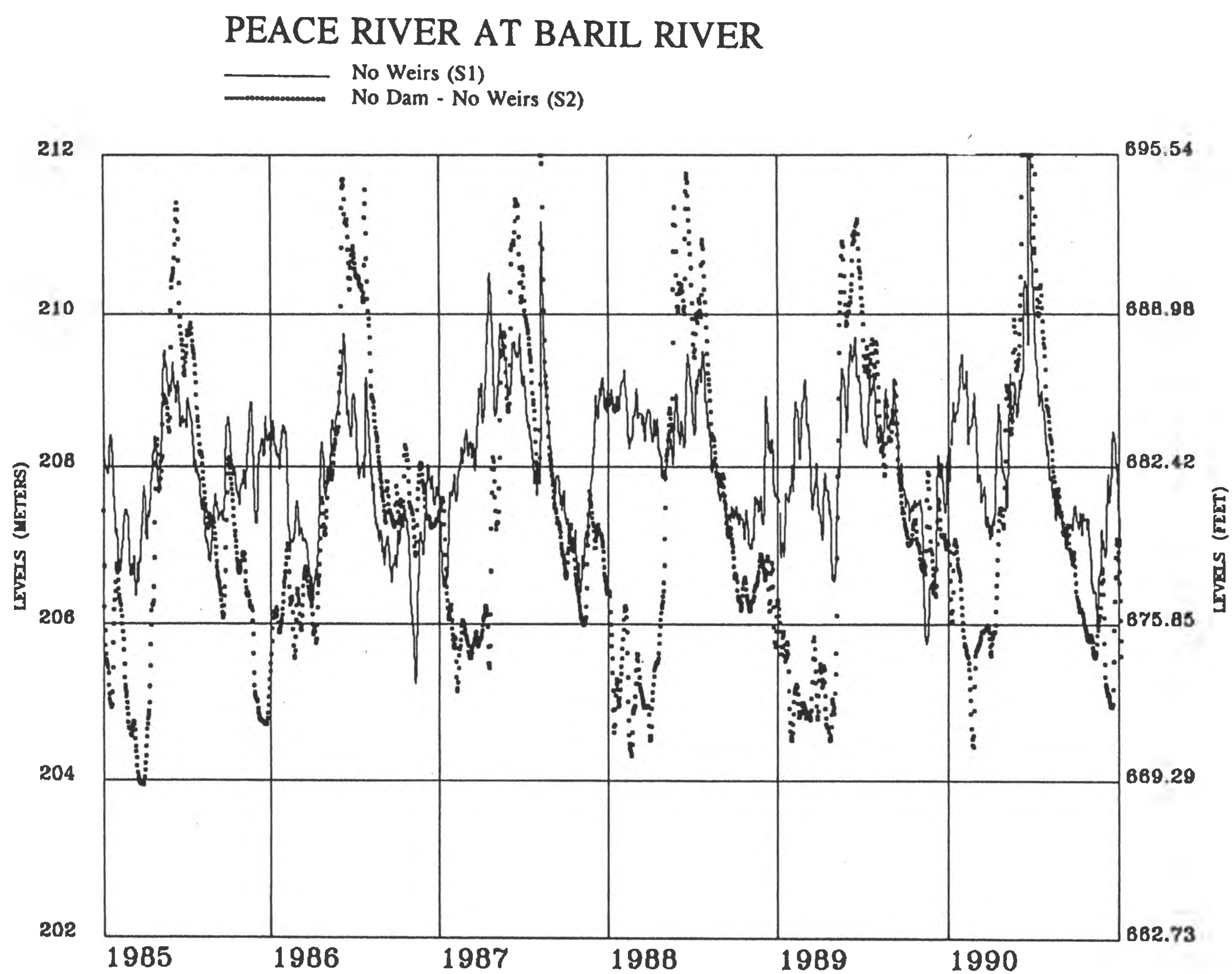
BARIL RIVER
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
212
210
208
206
204
202
LEVELS (FEET)
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

CHENAL DES QUATRE FOURCHES

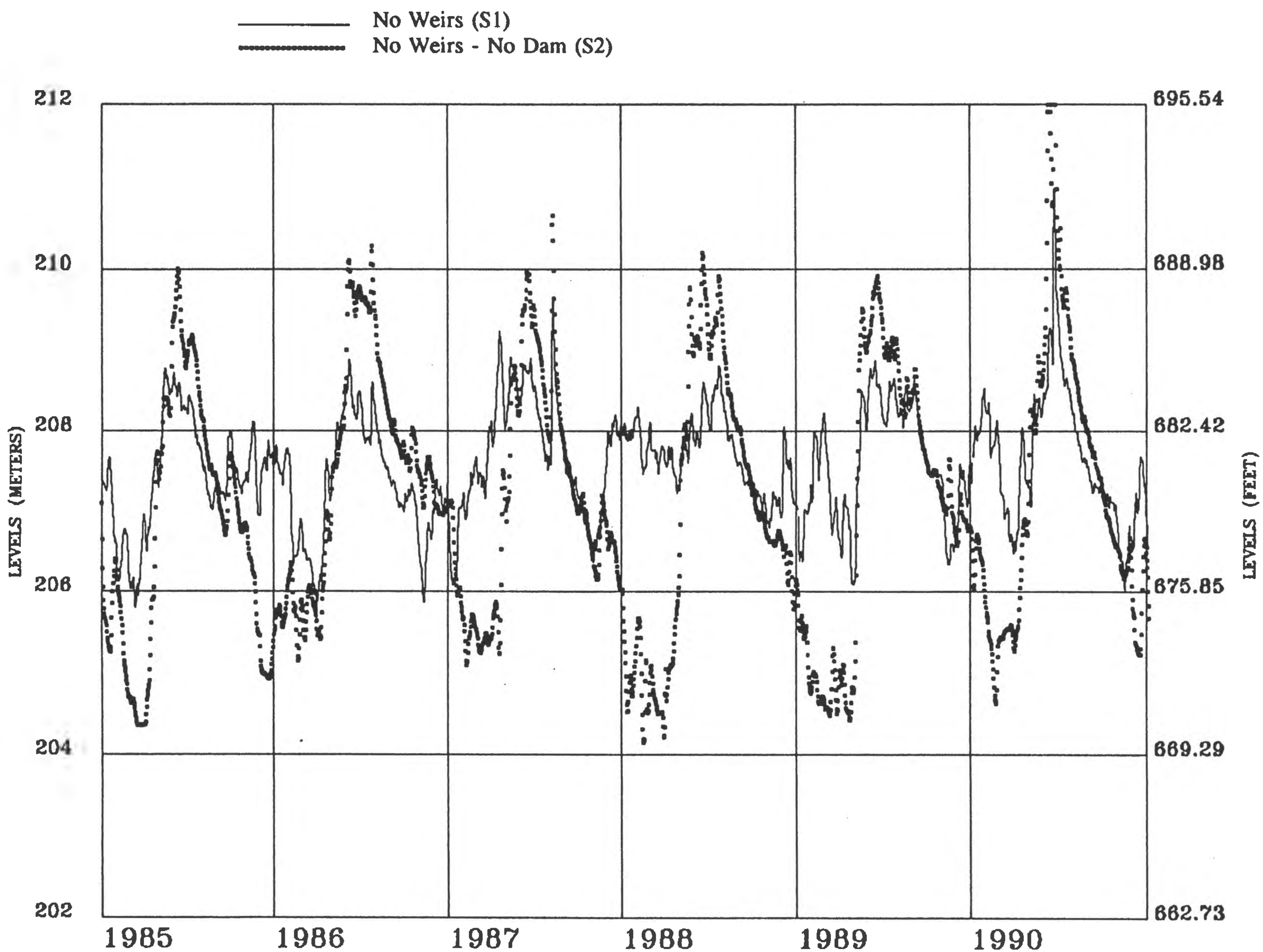


PEACE RIVER AT PEACE POINT

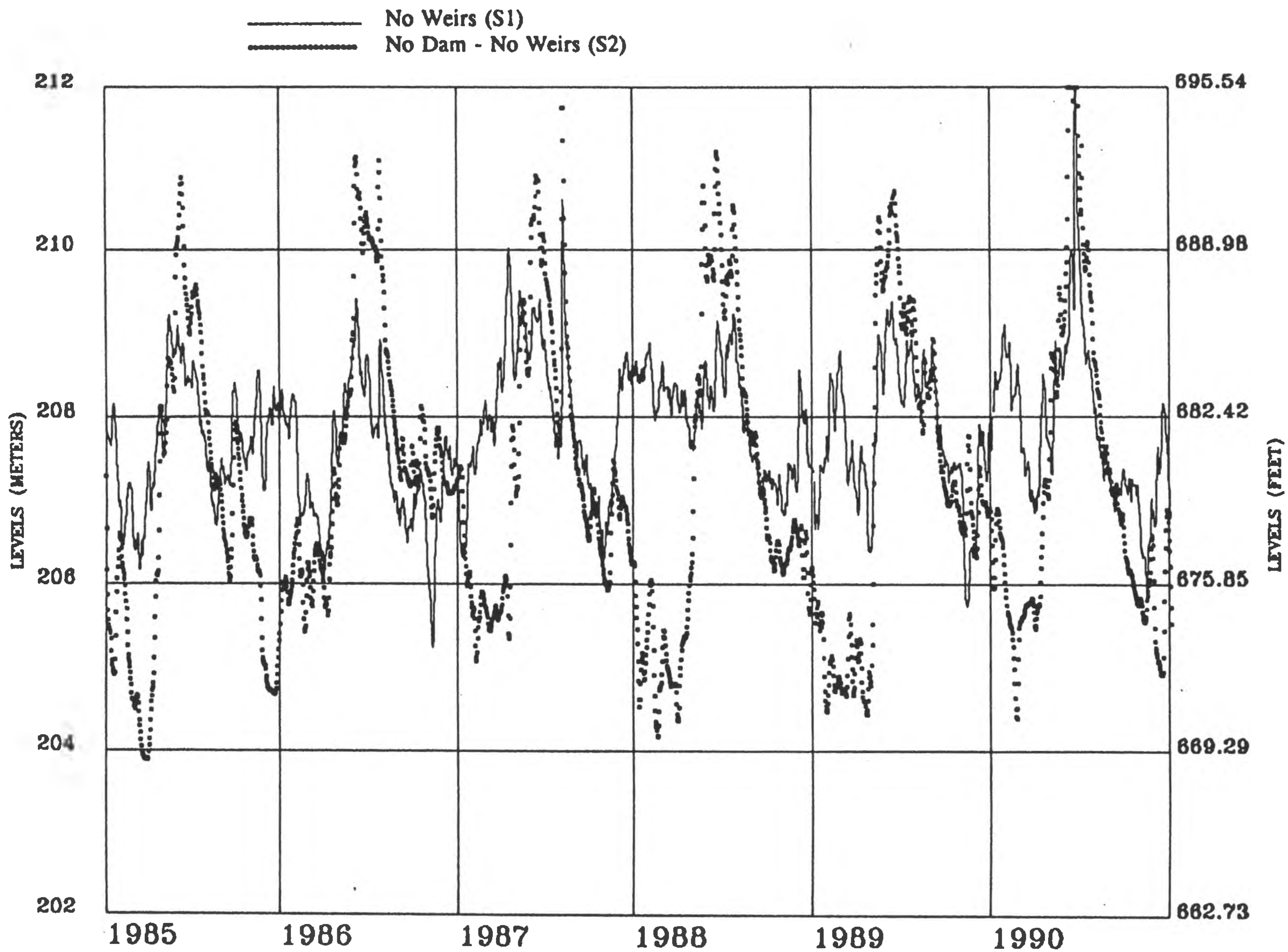



PEACE RIVER AT BARIL RIVER
No Weirs (S1)
No Dam - No Weirs (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

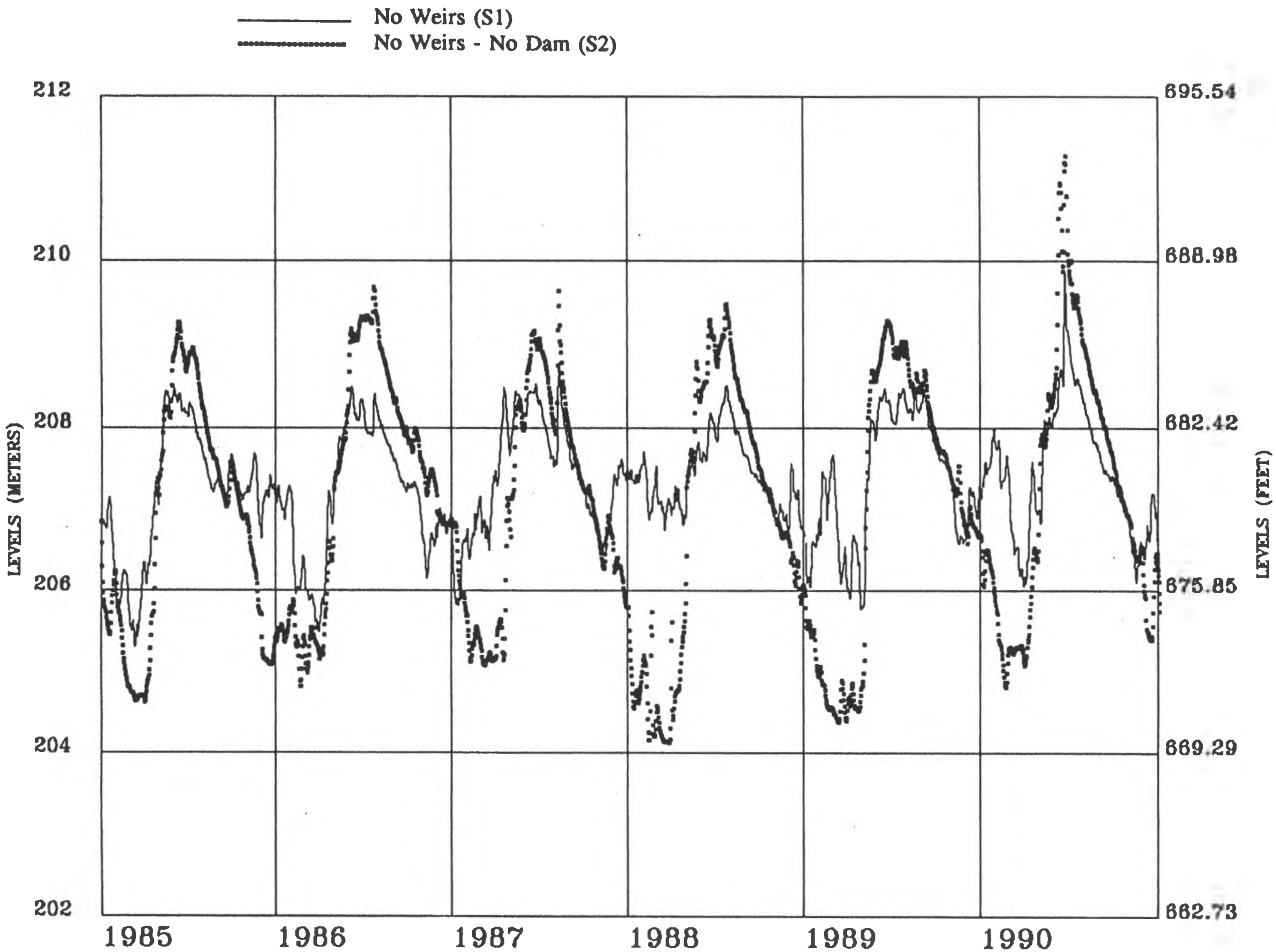
REVILLON COUPE ABOVE WEIR



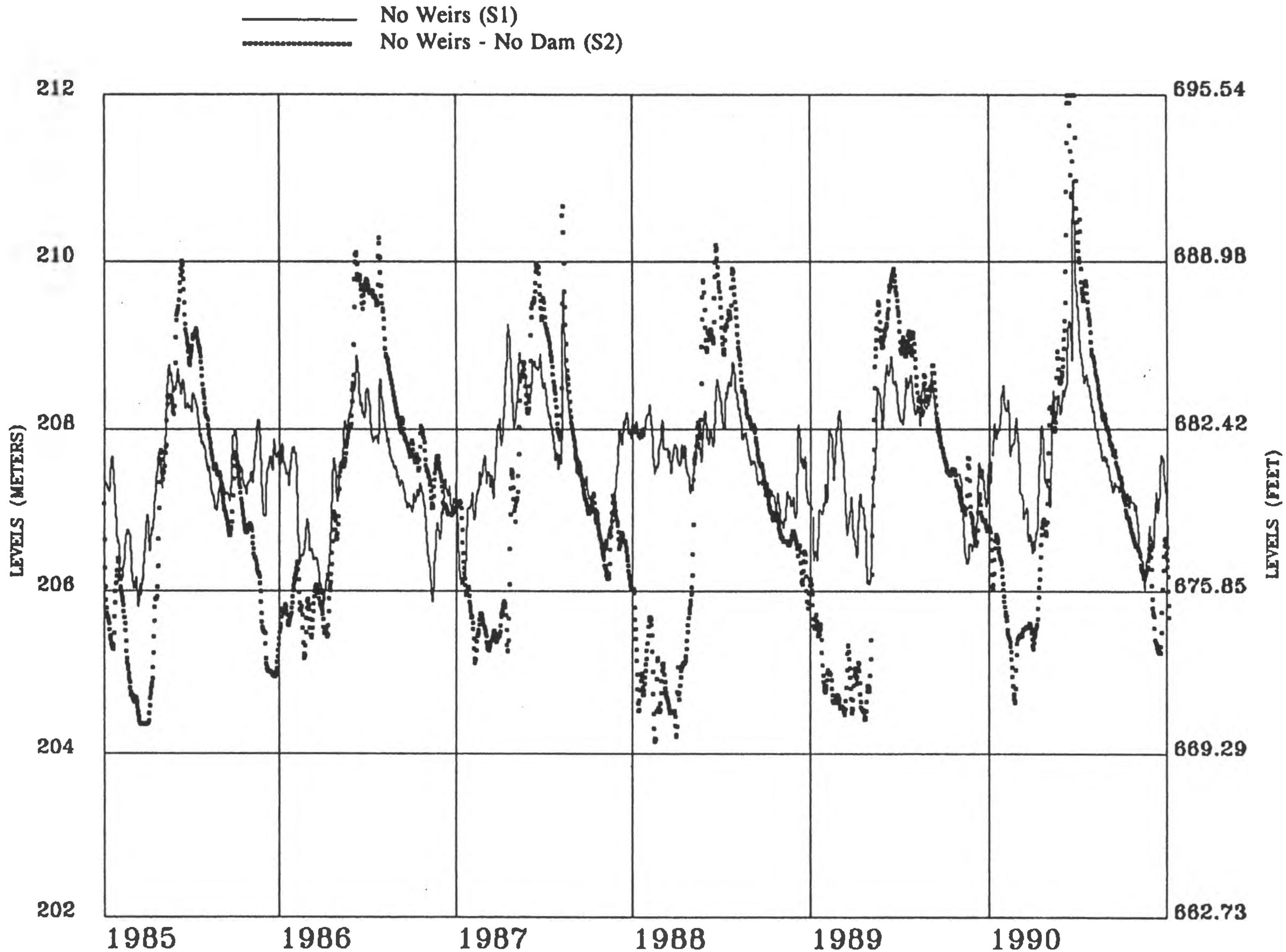
PEACE RIVER AT CHENAL DES QUATRE FOURCHES

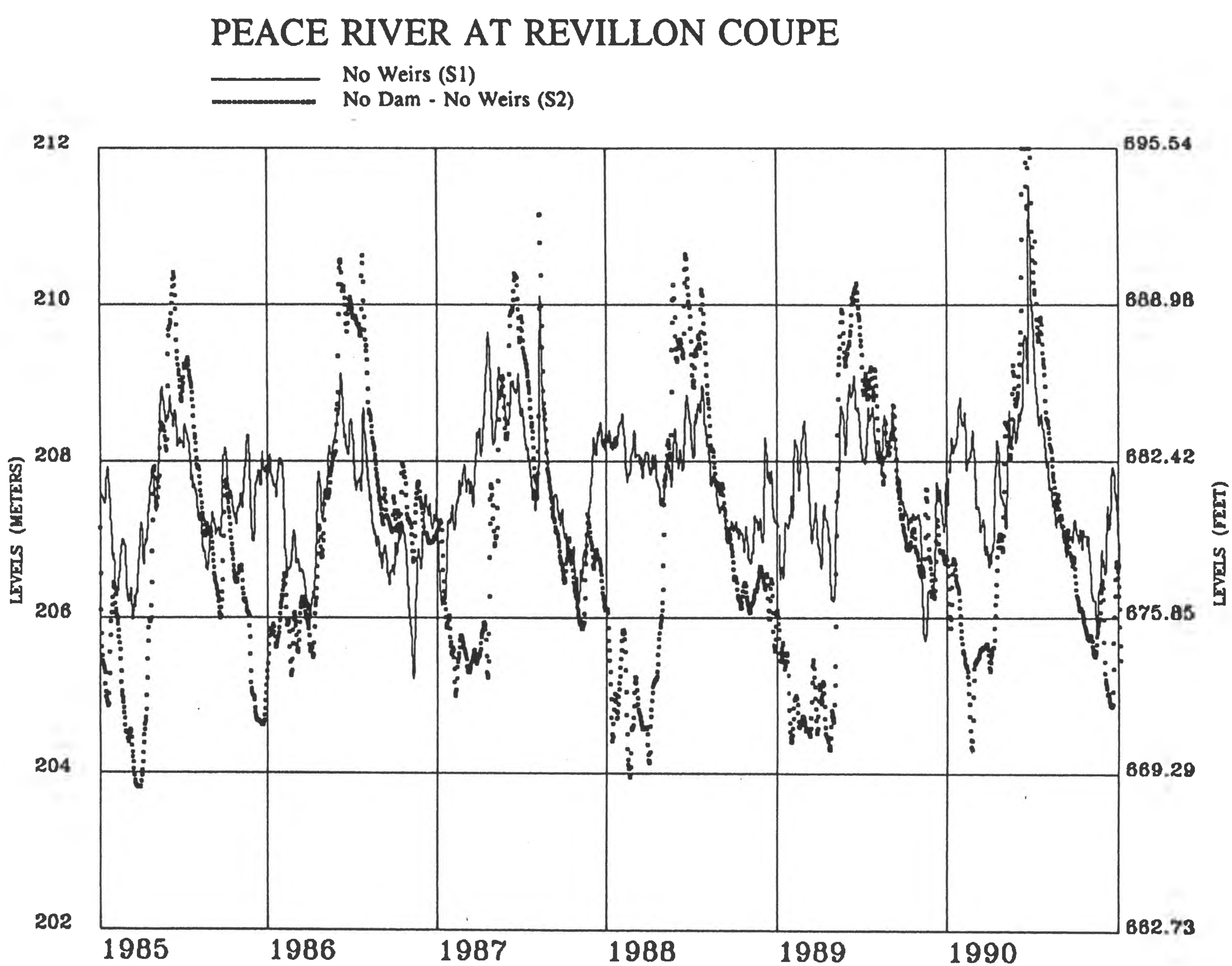


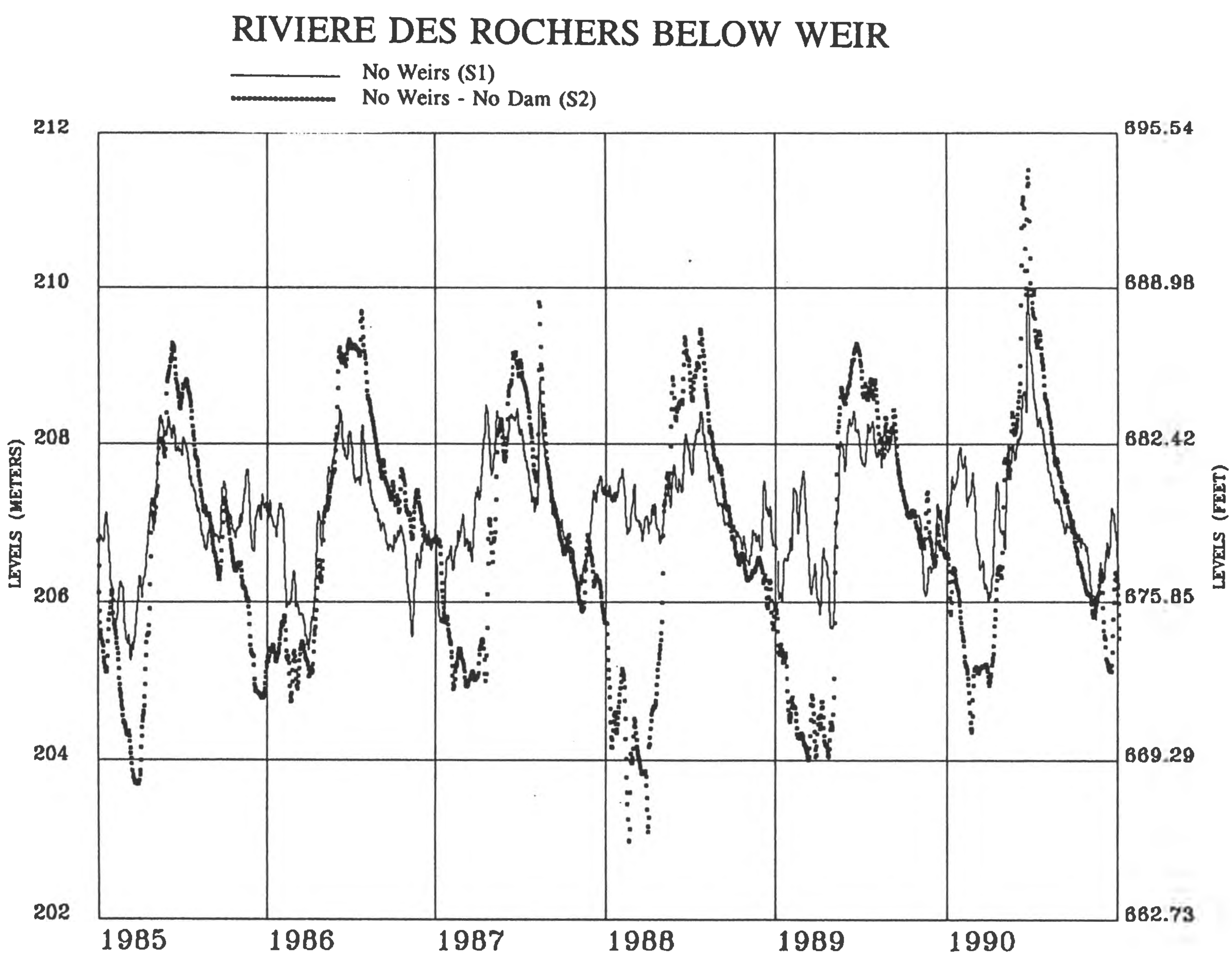
RIVIERE DES ROCHERS ABOVE WEIR



REVILLON COUPE BELOW WEIR

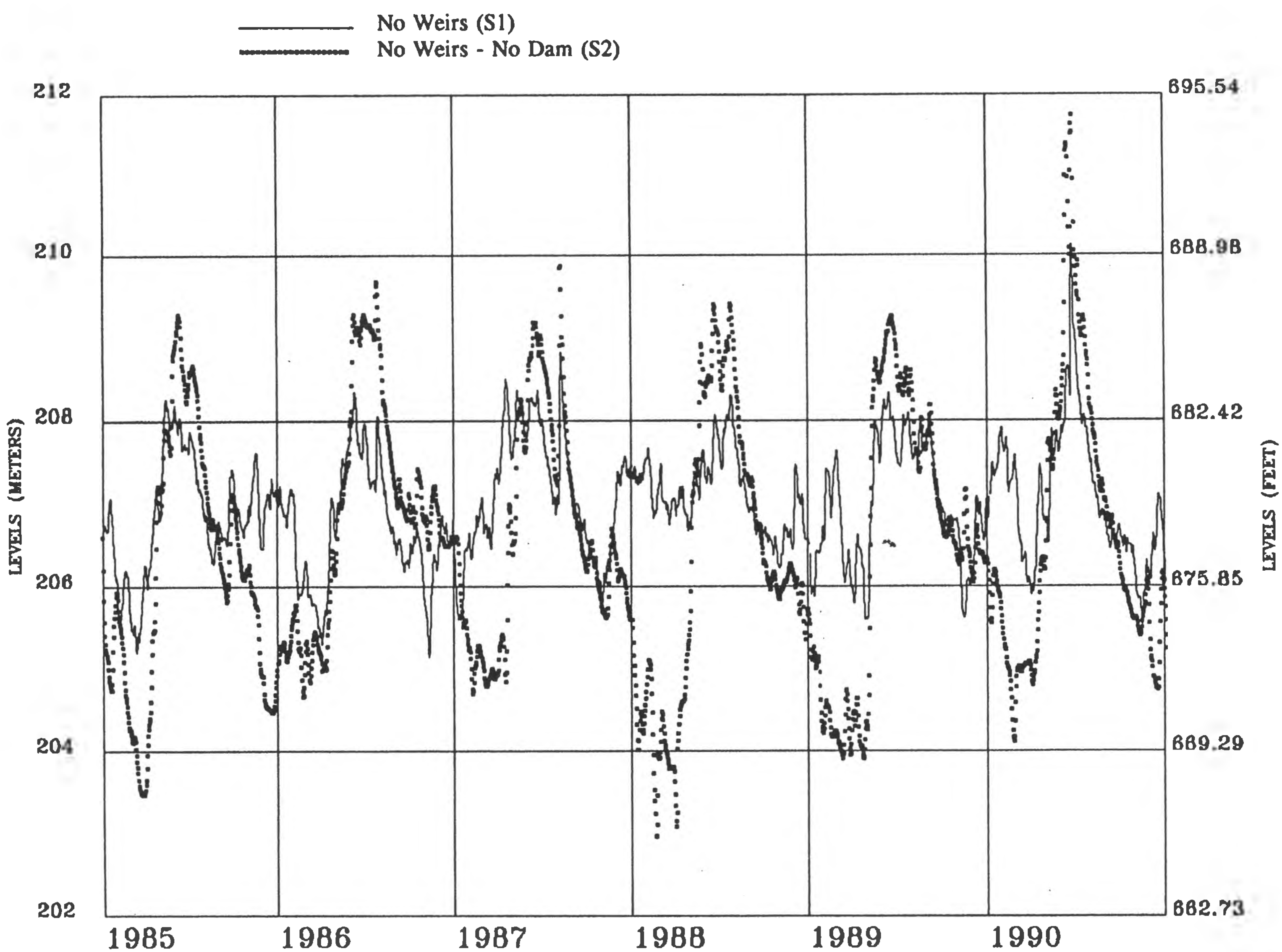


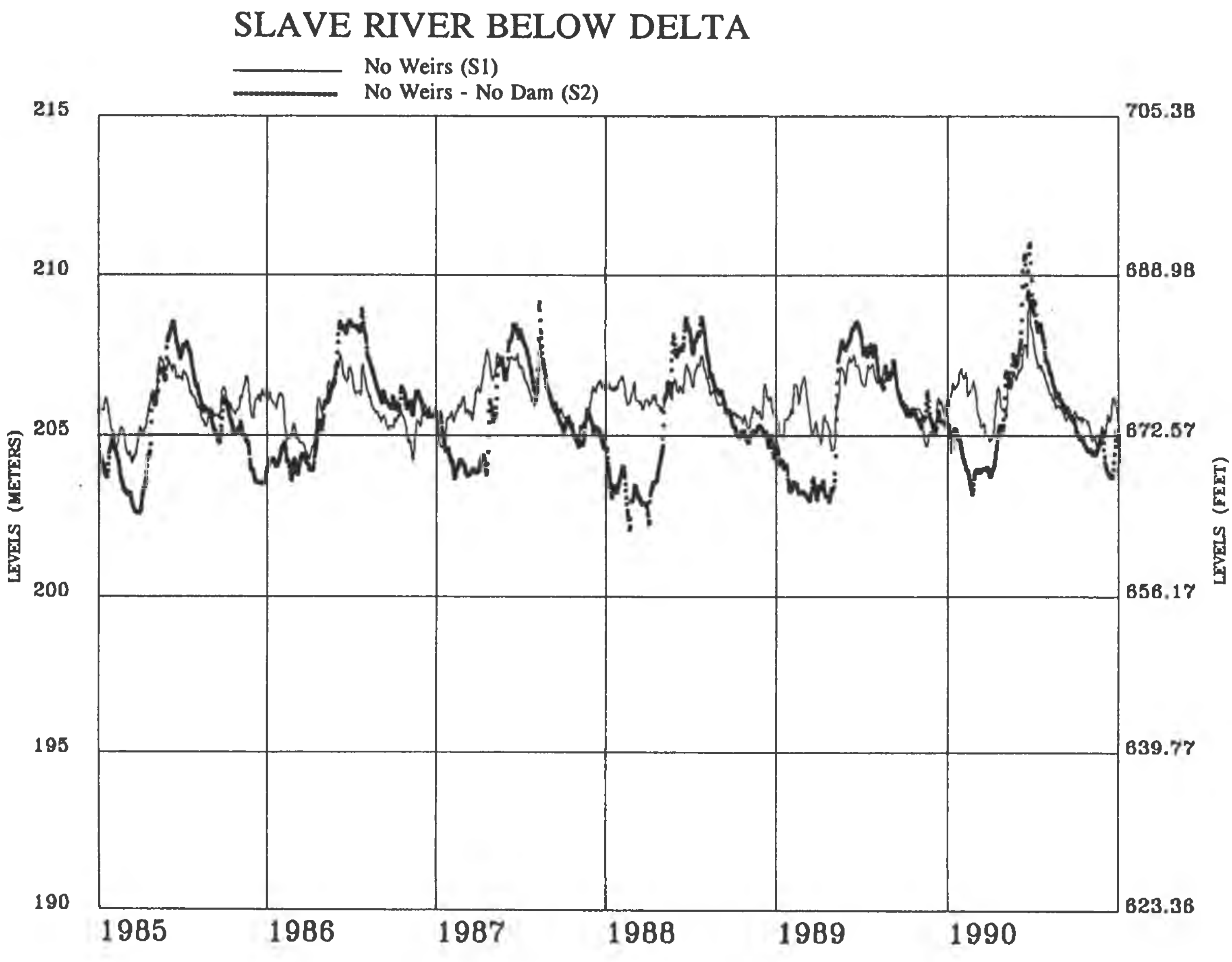

PEACE RIVER AT REVILLON COUPE
No Weirs (S1)
No Dam - No Weirs (S2)
212
210
208
206
204
202
LEVELS (METERS)
695.54
688.98
682.42
675.85
669.29
662.73
LEVELS (FEET)
1985
1986
1987
1988
1989
1990



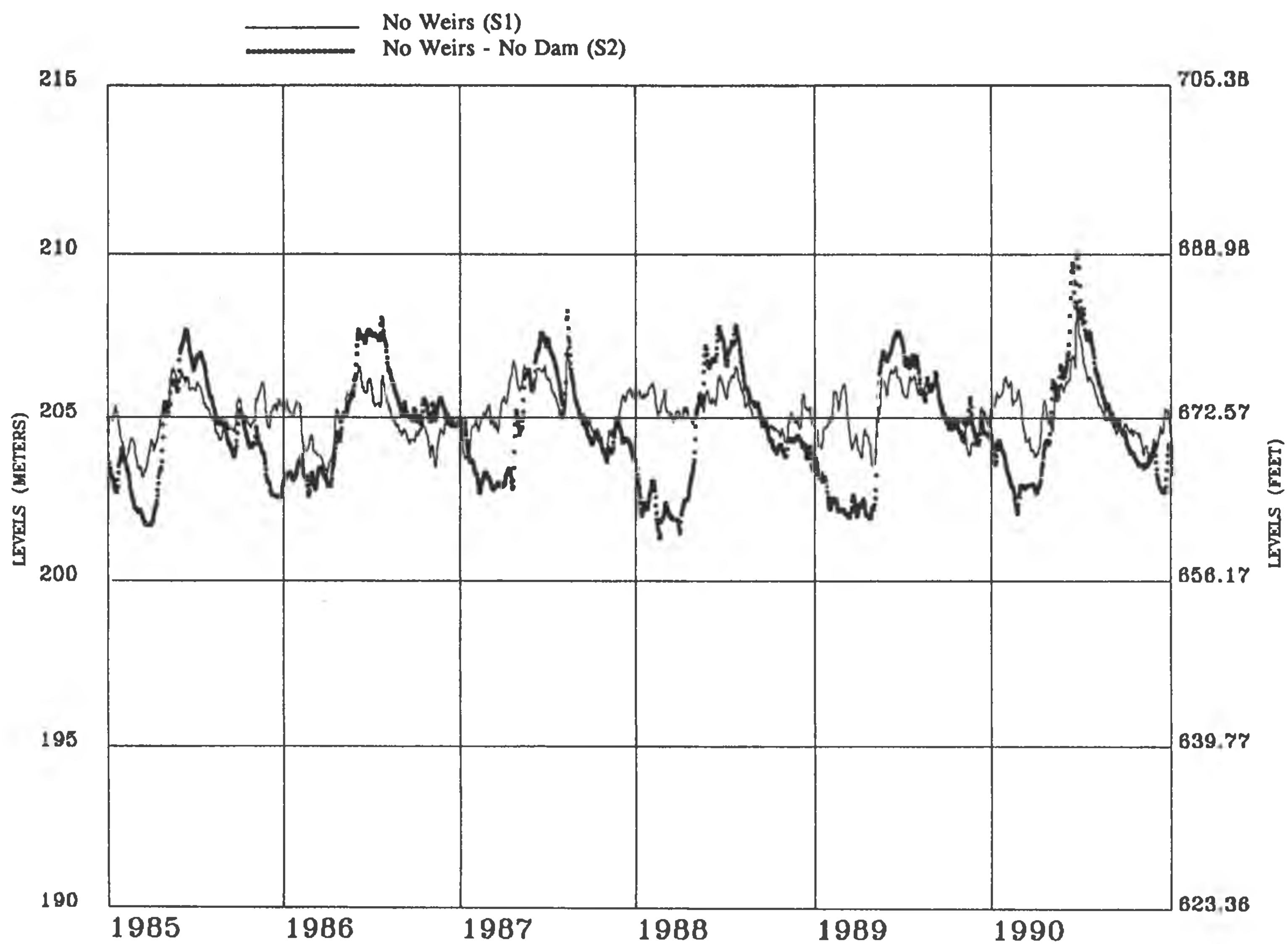
RIVIERE DES ROCHERS BELOW WEIR
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
LEVELS (FEET)
212
210
208
206
204
202
695.54
688.98
682.42
675.85
669.29
662.73
1985
1986
1987
1988
1989
1990

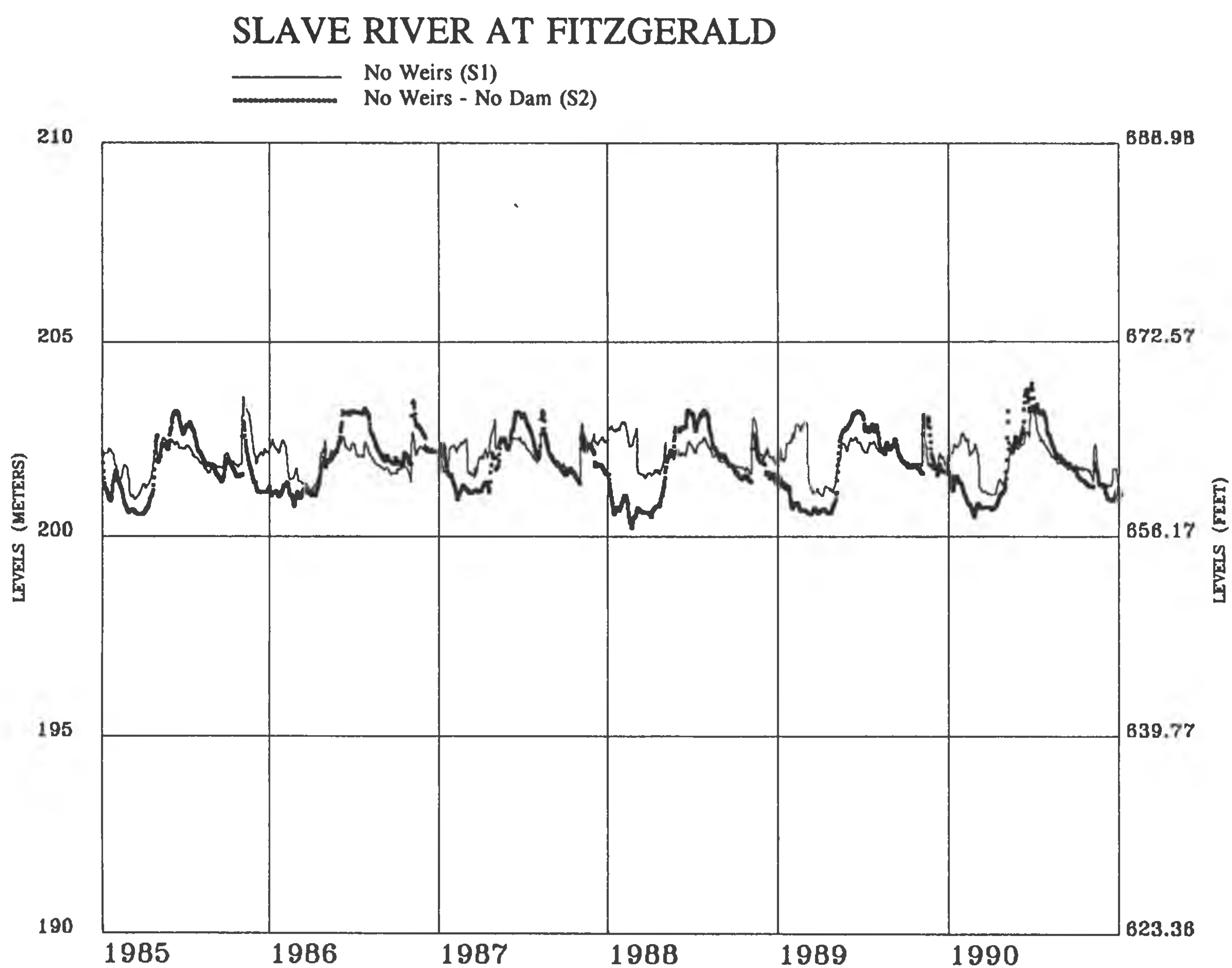
SLAVE RIVER AT DELTA




SLAVE RIVER BELOW DELTA
No Weirs (S1)
No Weirs - No Dam (S2)
LEVELS (METERS)
LEVELS (FEET)
215
210
205
200
195
190
705.38
688.98
672.57
656.17
639.77
623.36
1985
1986
1987
1988
1989
1990

SLAVE RIVER ABOVE FITZGERALD

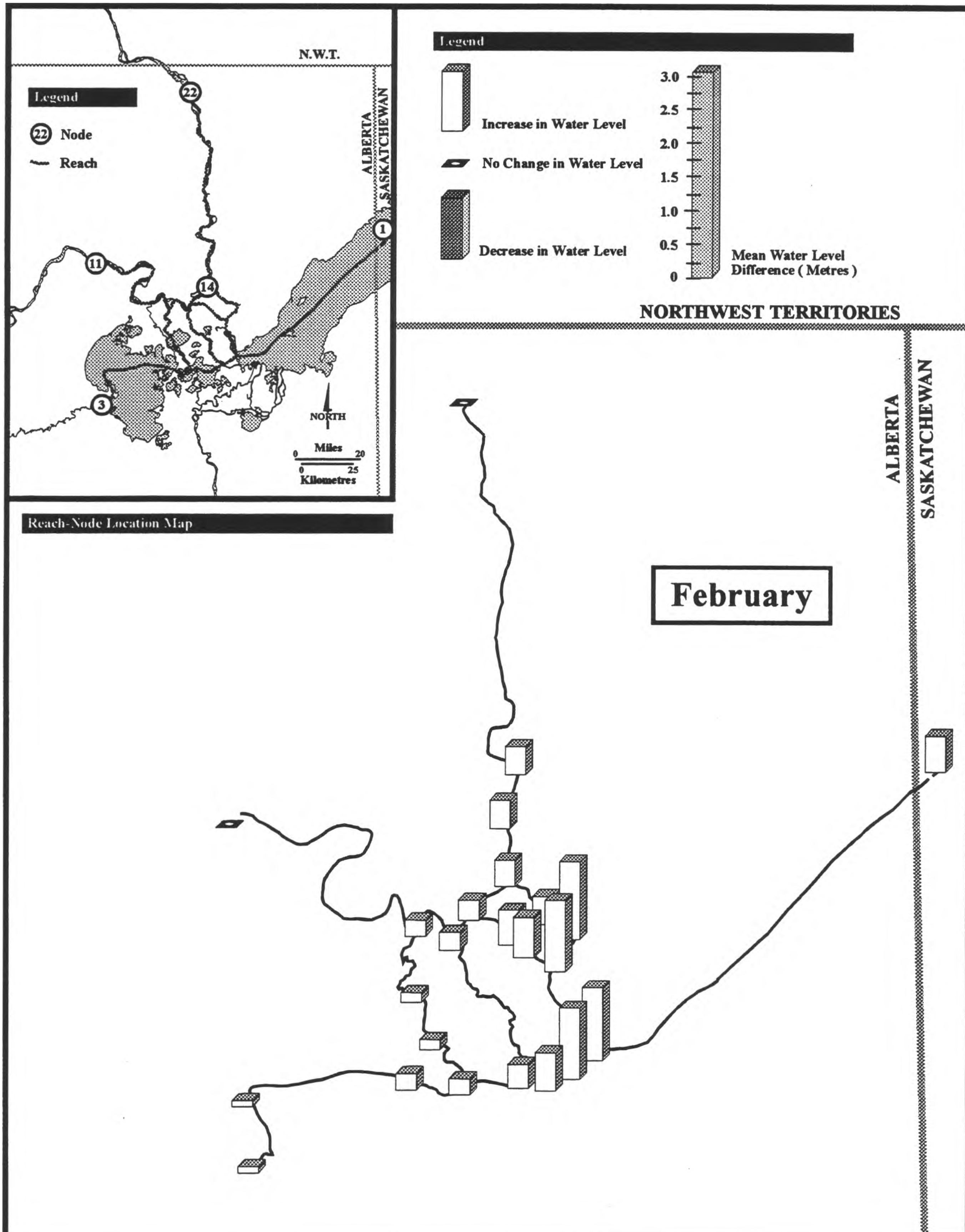




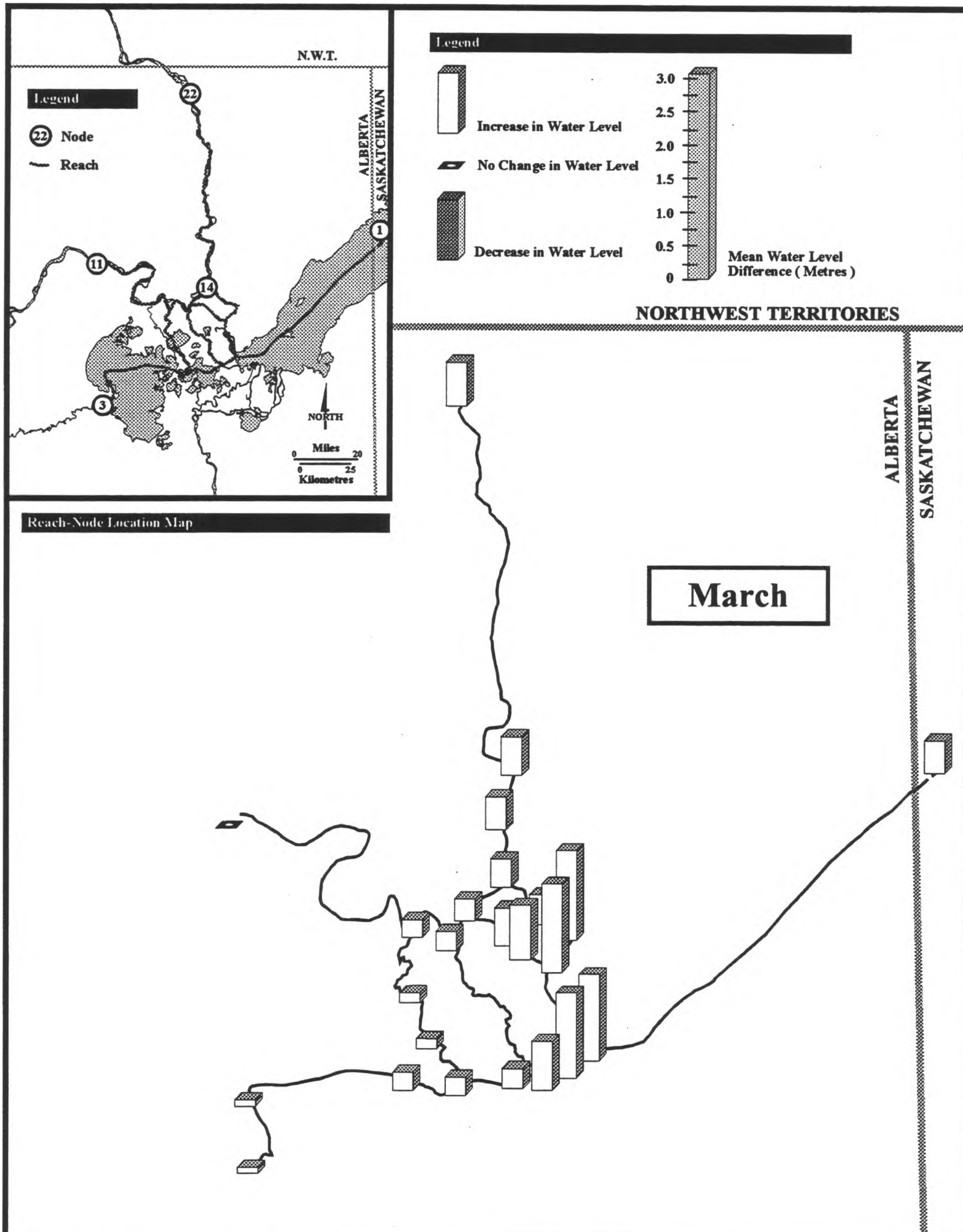
SLAVE RIVER AT FITZGERALD
No Weirs (S1)
No Weirs - No Dam (S2)
210
205
200
195
190
LEVELS (METERS)
688.98
672.57
656.17
639.77
623.36
LEVELS (FEET)
1985
1986
1987
1988
1989
1990

APPENDIX F.
Water Level Mean Difference

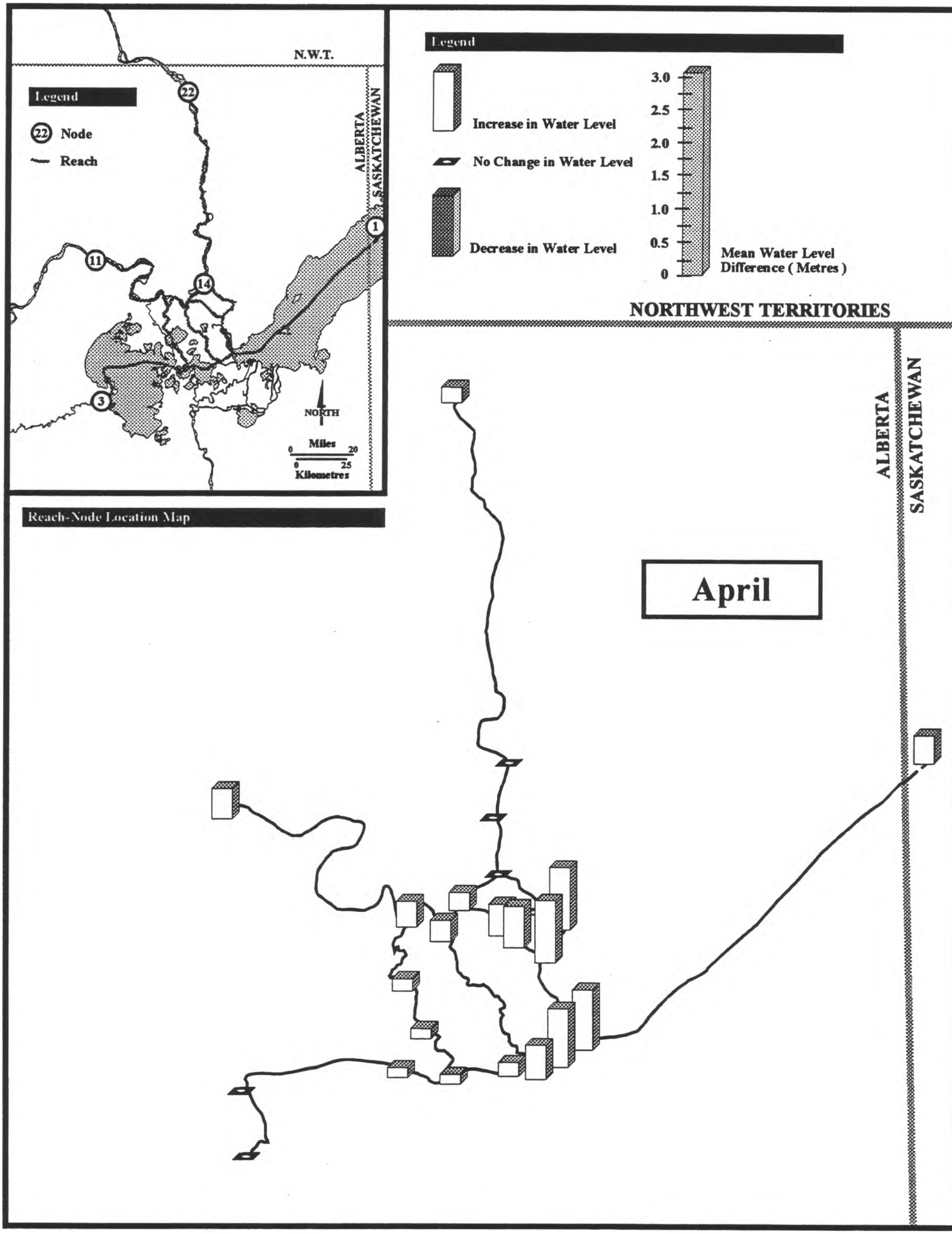
Effect of Weirs on
Present Conditions



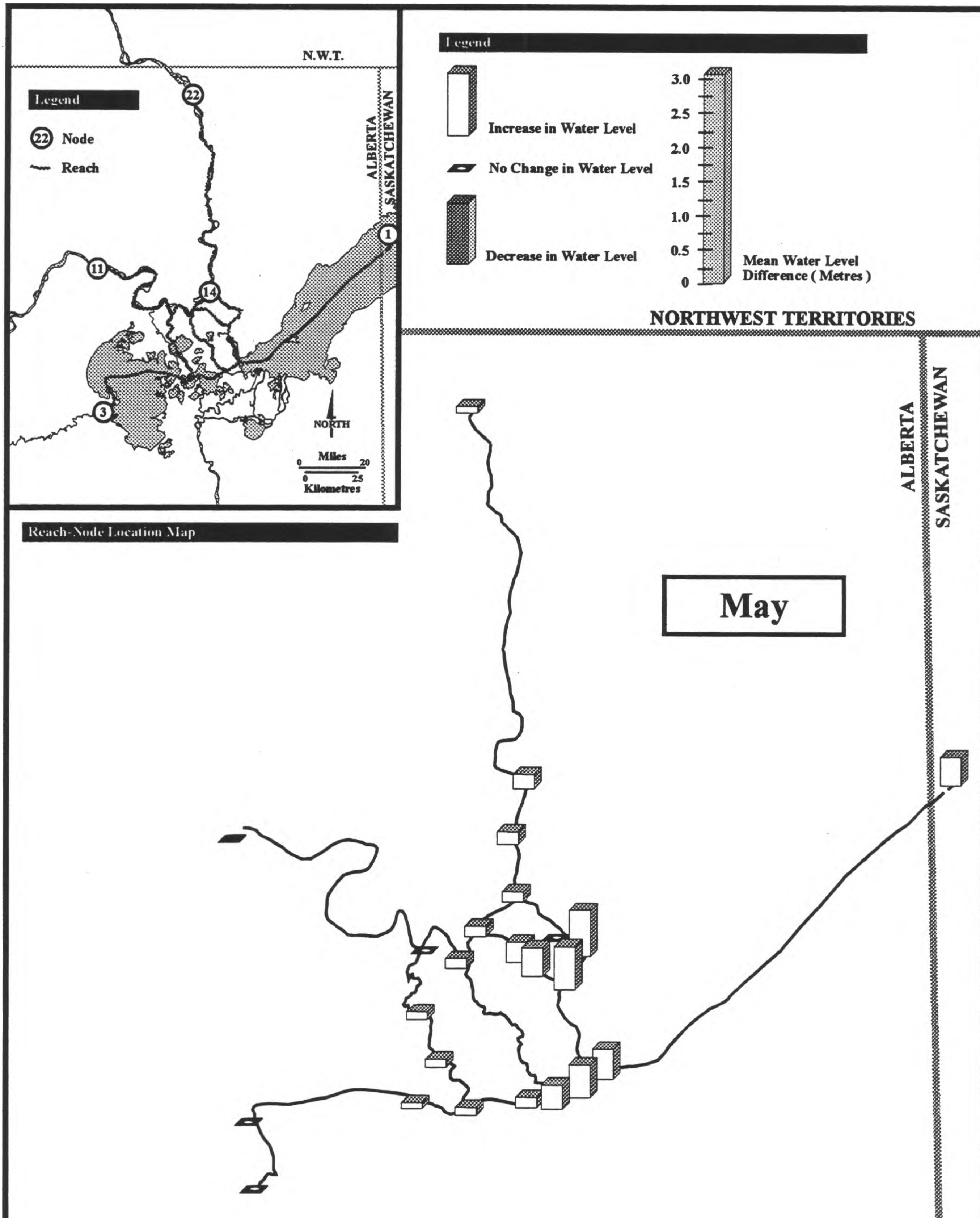
Effect of Weirs on Present Conditions - February



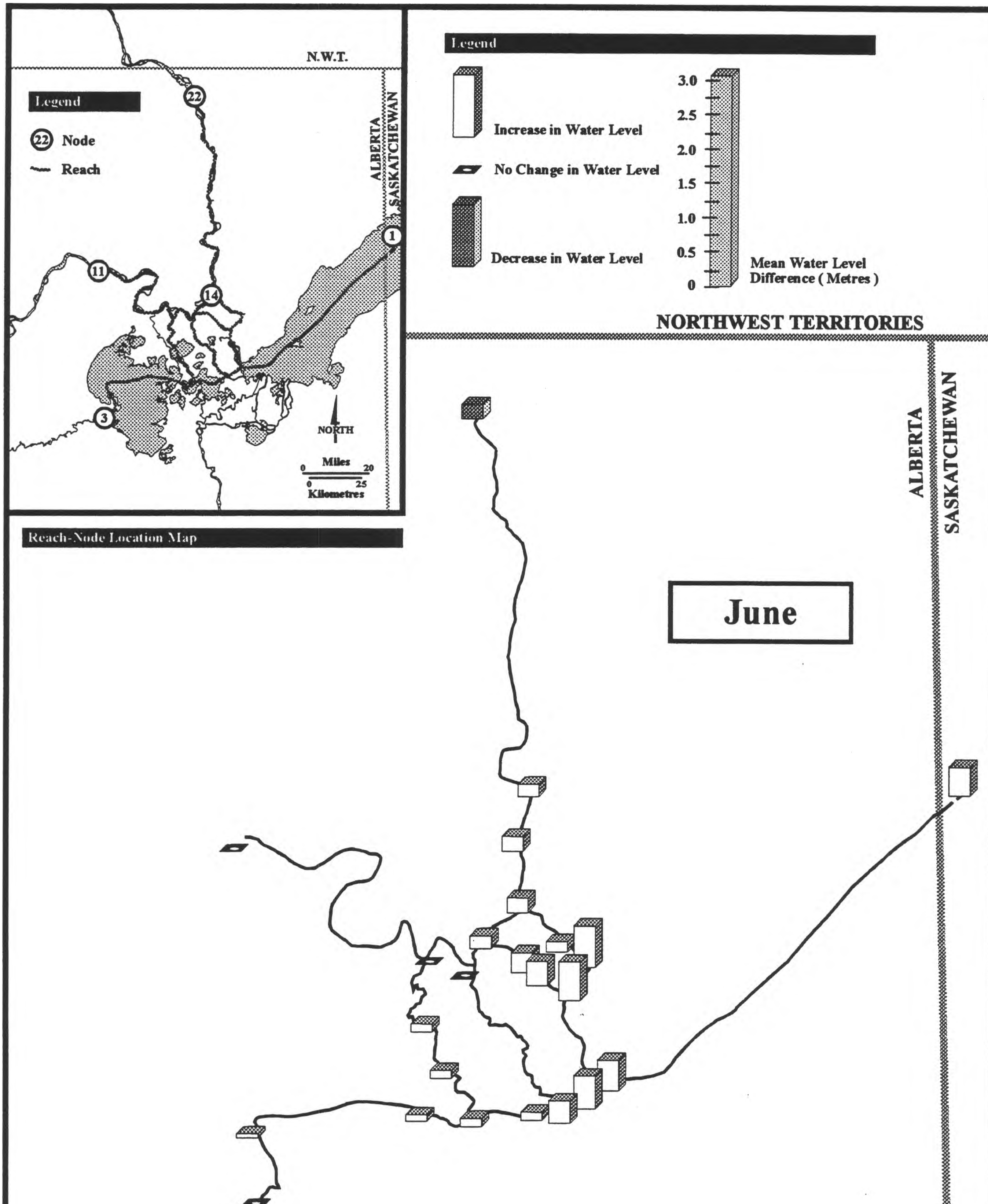
Effect of Weirs on Present Conditions - March



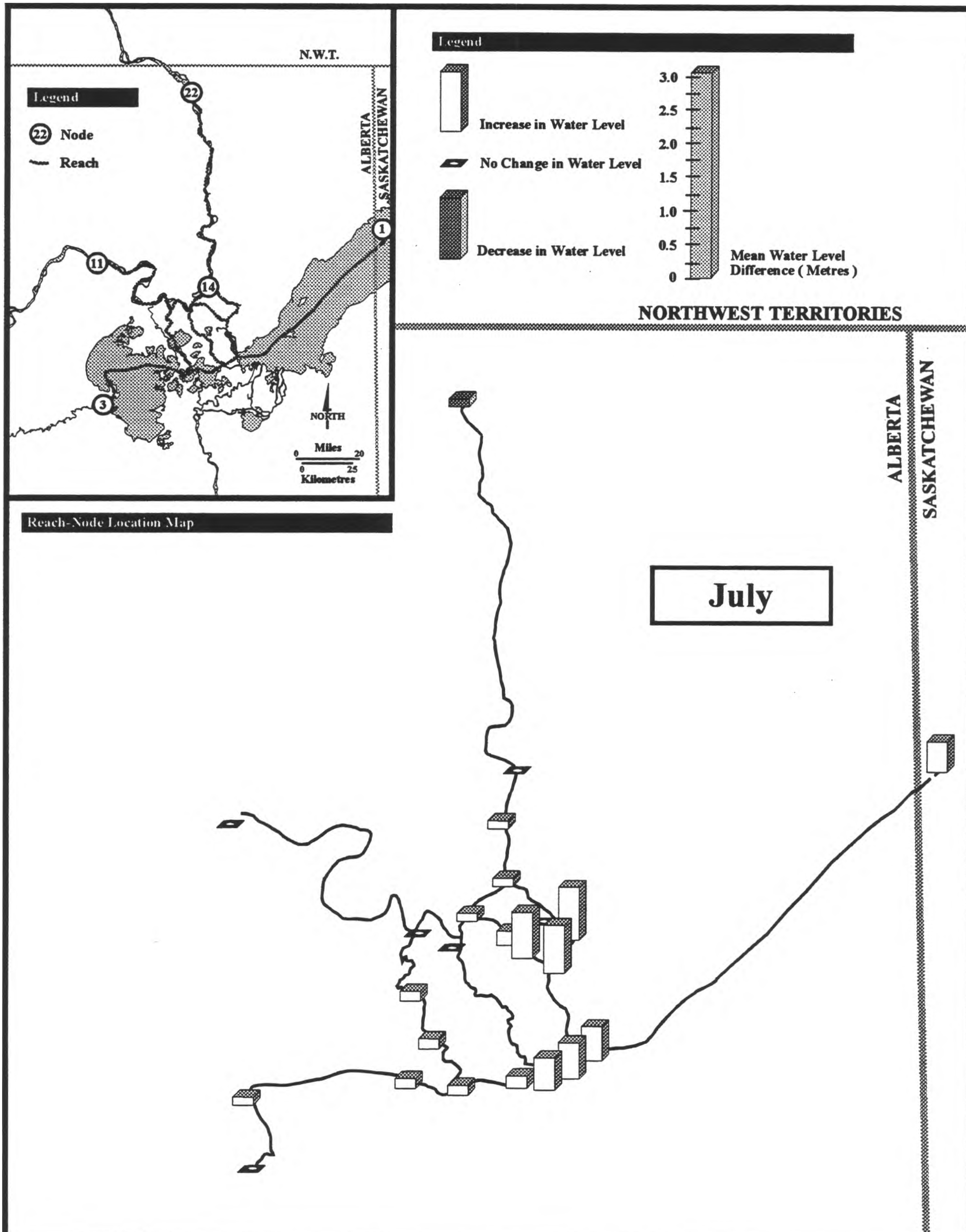
Effect of Weirs on Present Conditions - April



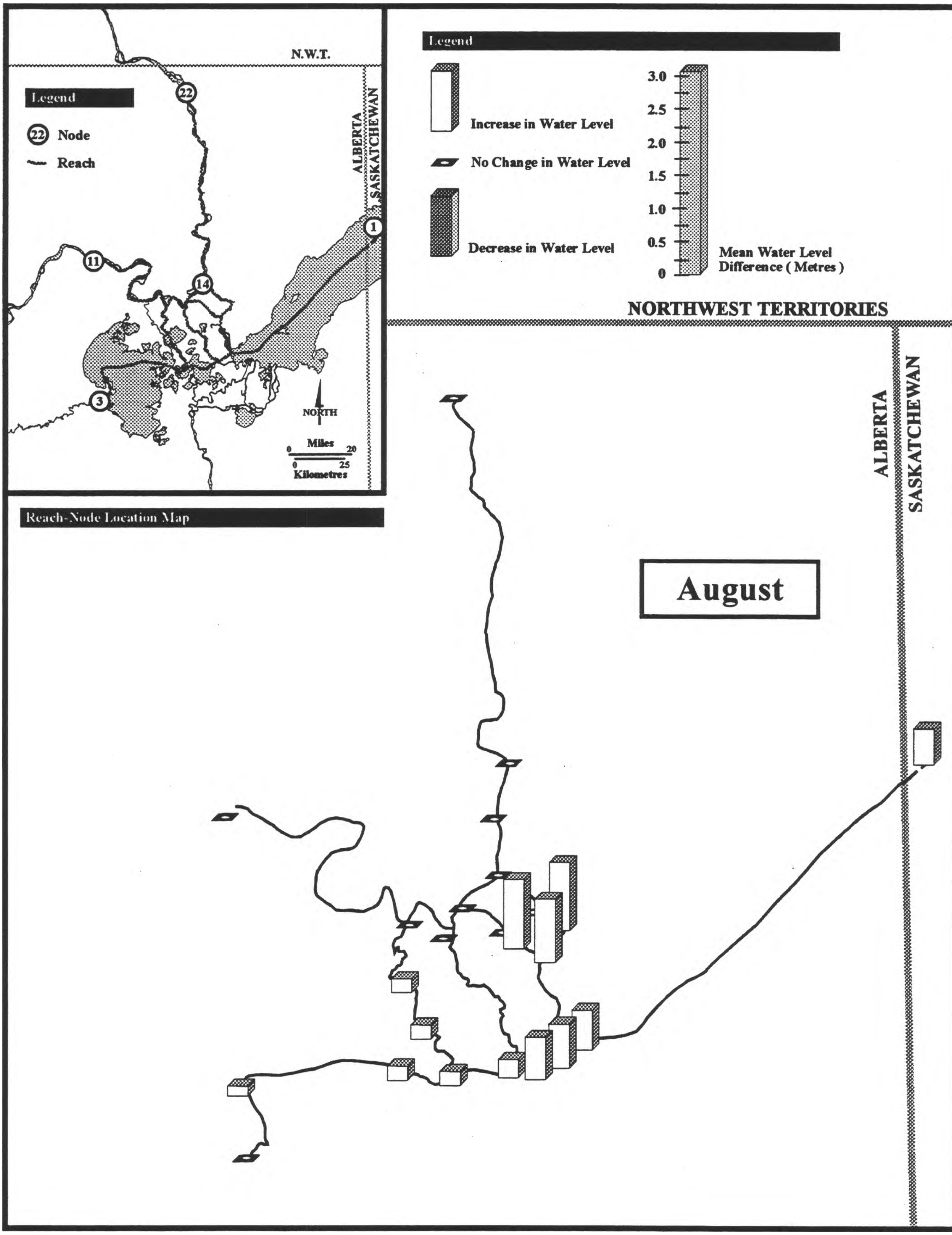
Effect of Weirs on Present Conditions - May



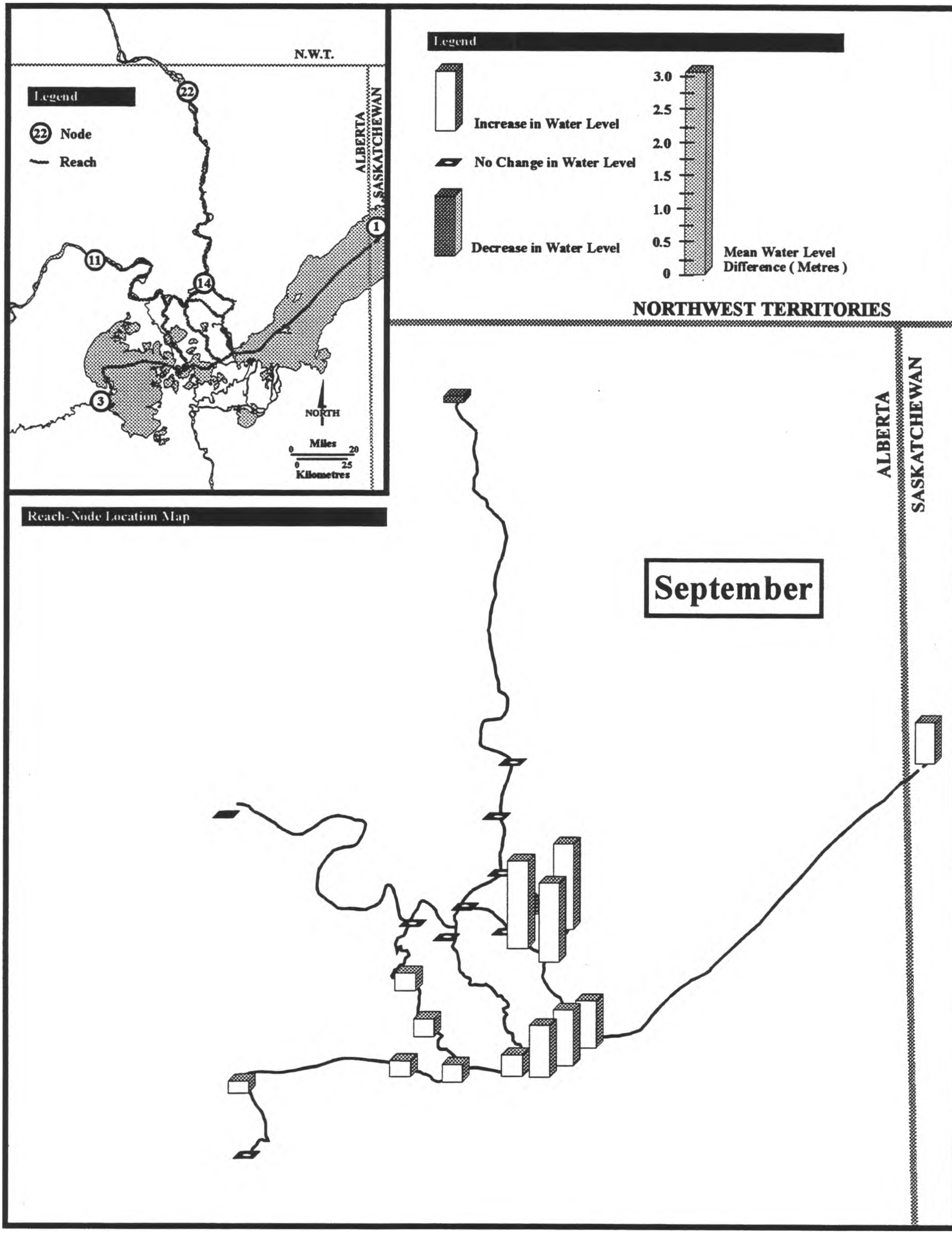
Effect of Weirs on Present Conditions - June



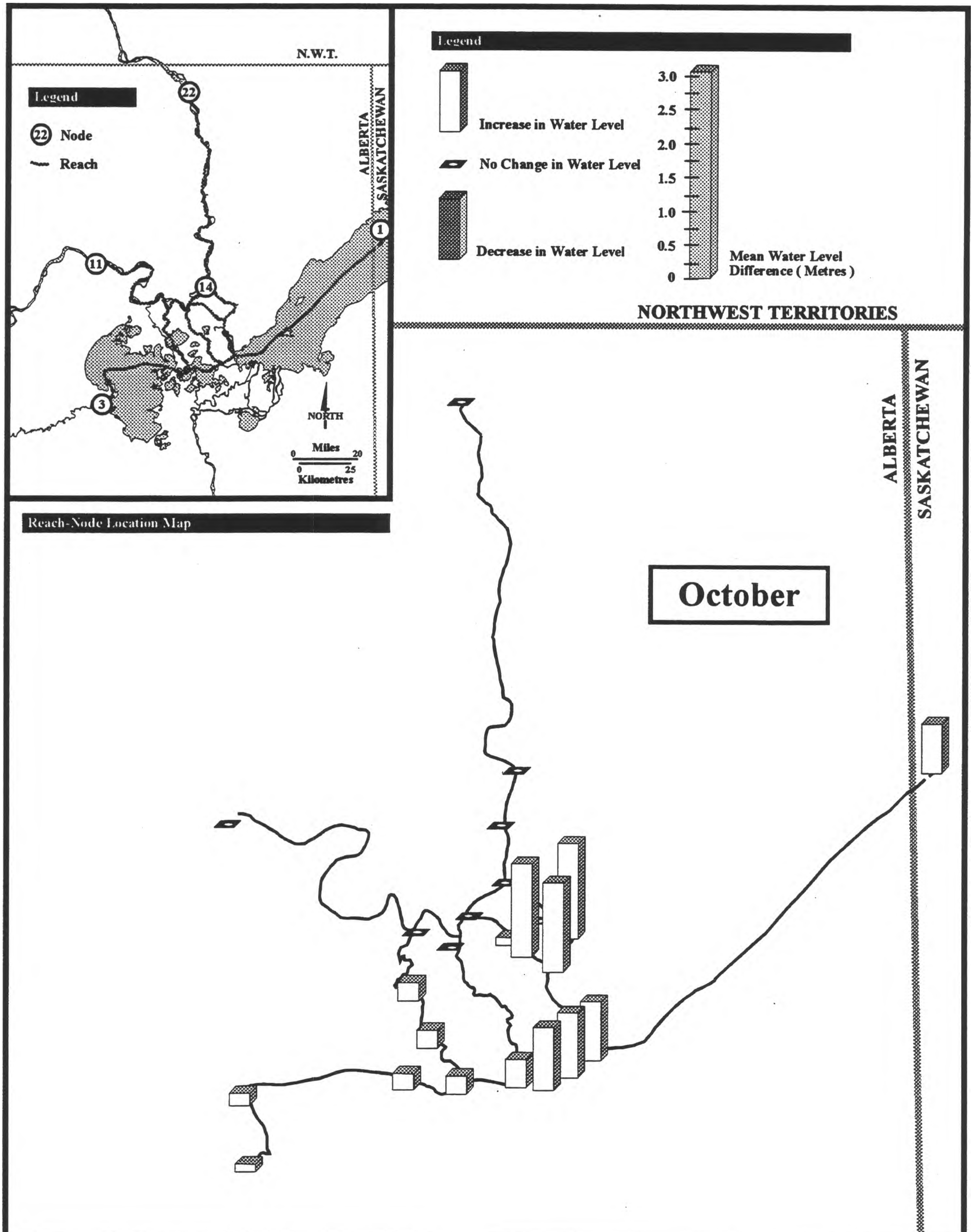
Effect of Weirs on Present Conditions - July



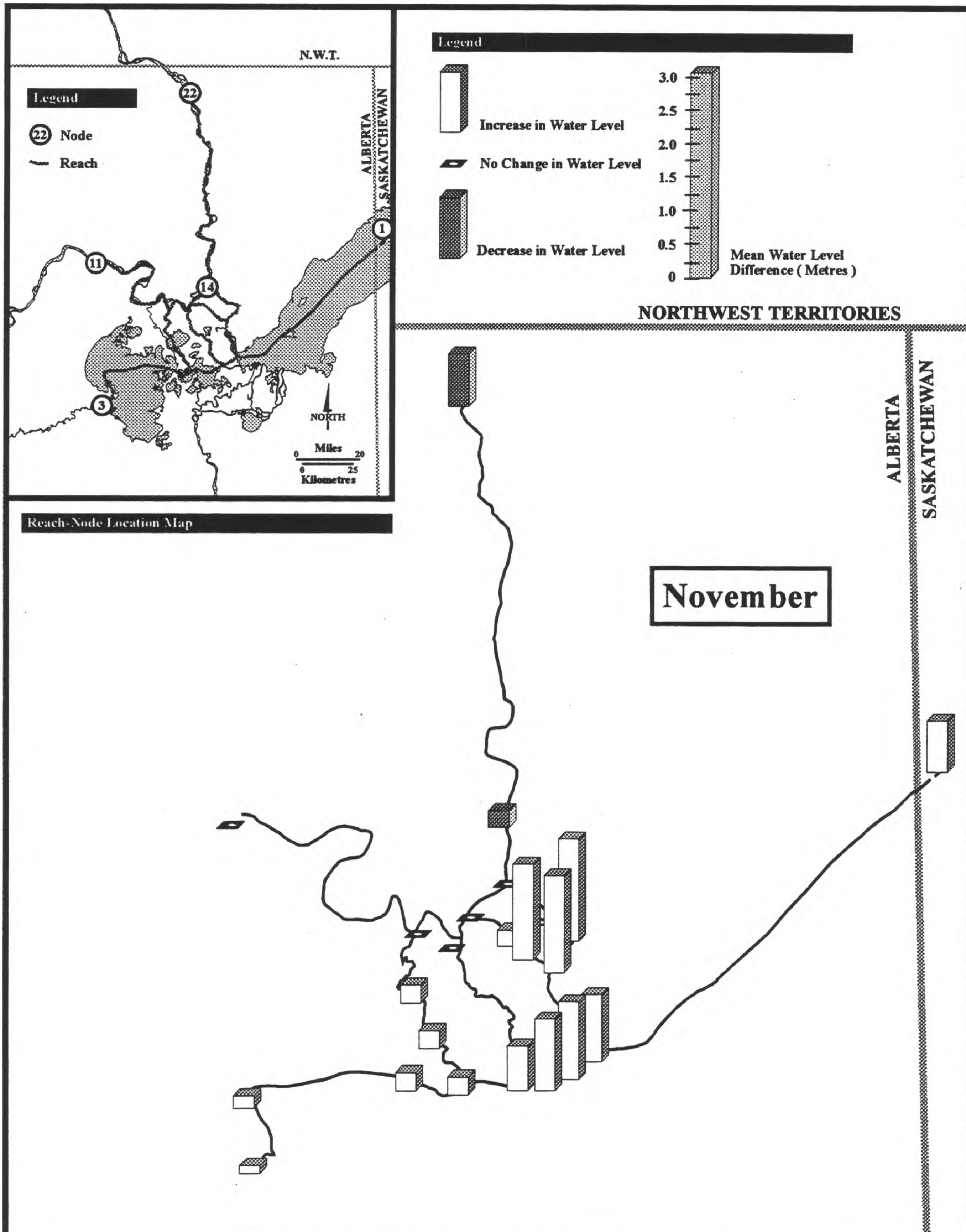
Effect of Weirs on Present Conditions - August



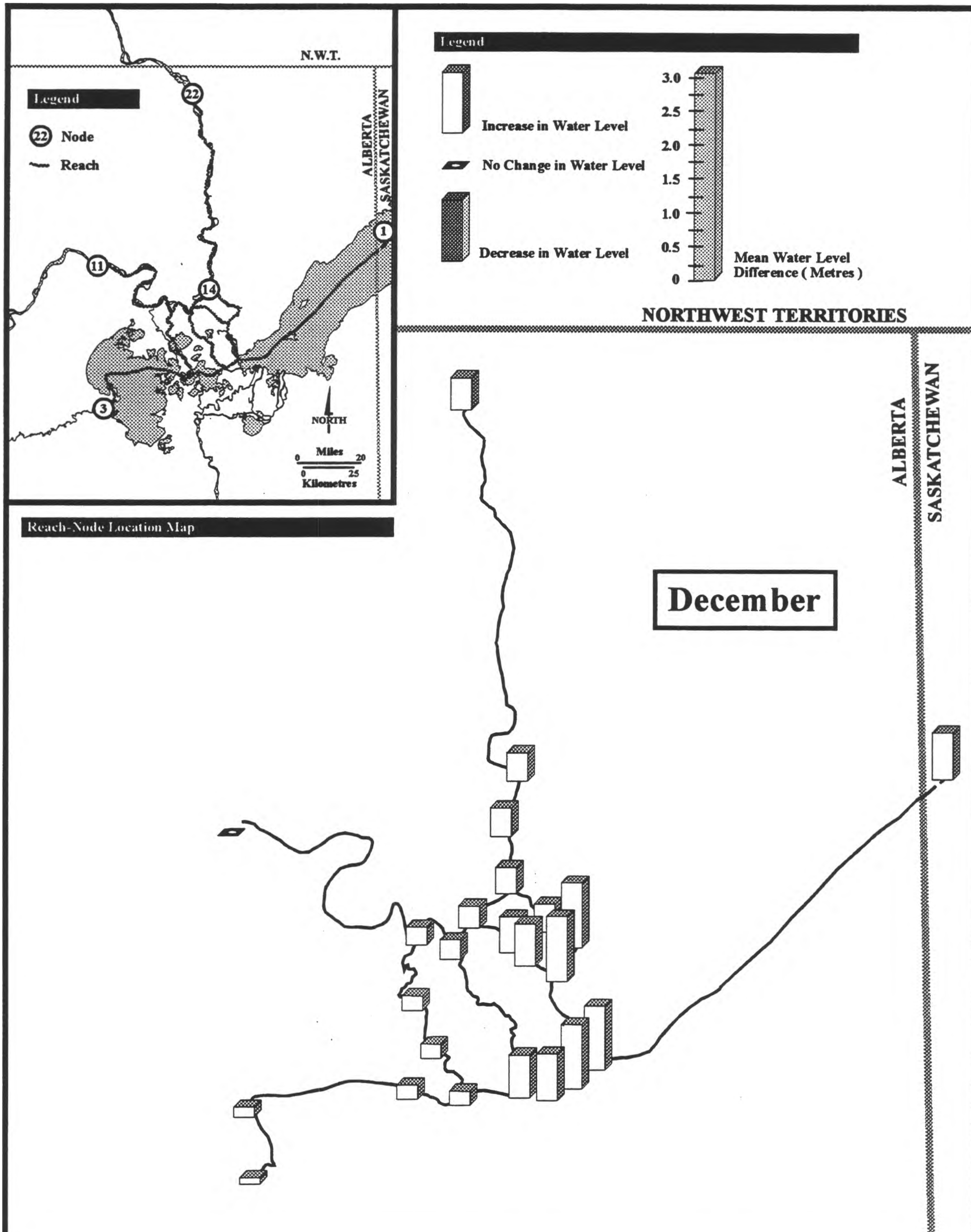
Effect of Weirs on Present Conditions - September



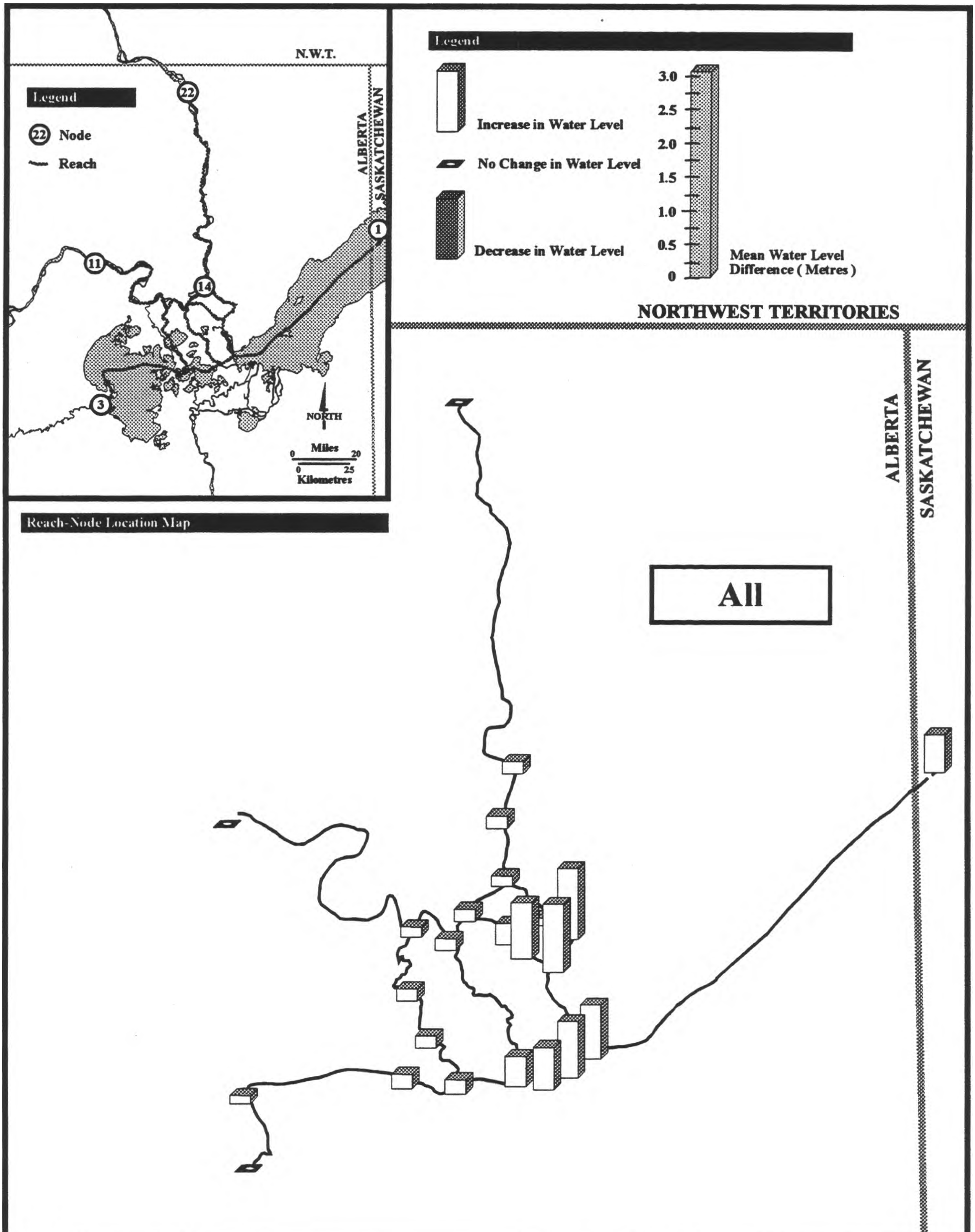
Effect of Weirs on Present Conditions - October



Effect of Weirs on Present Conditions - November



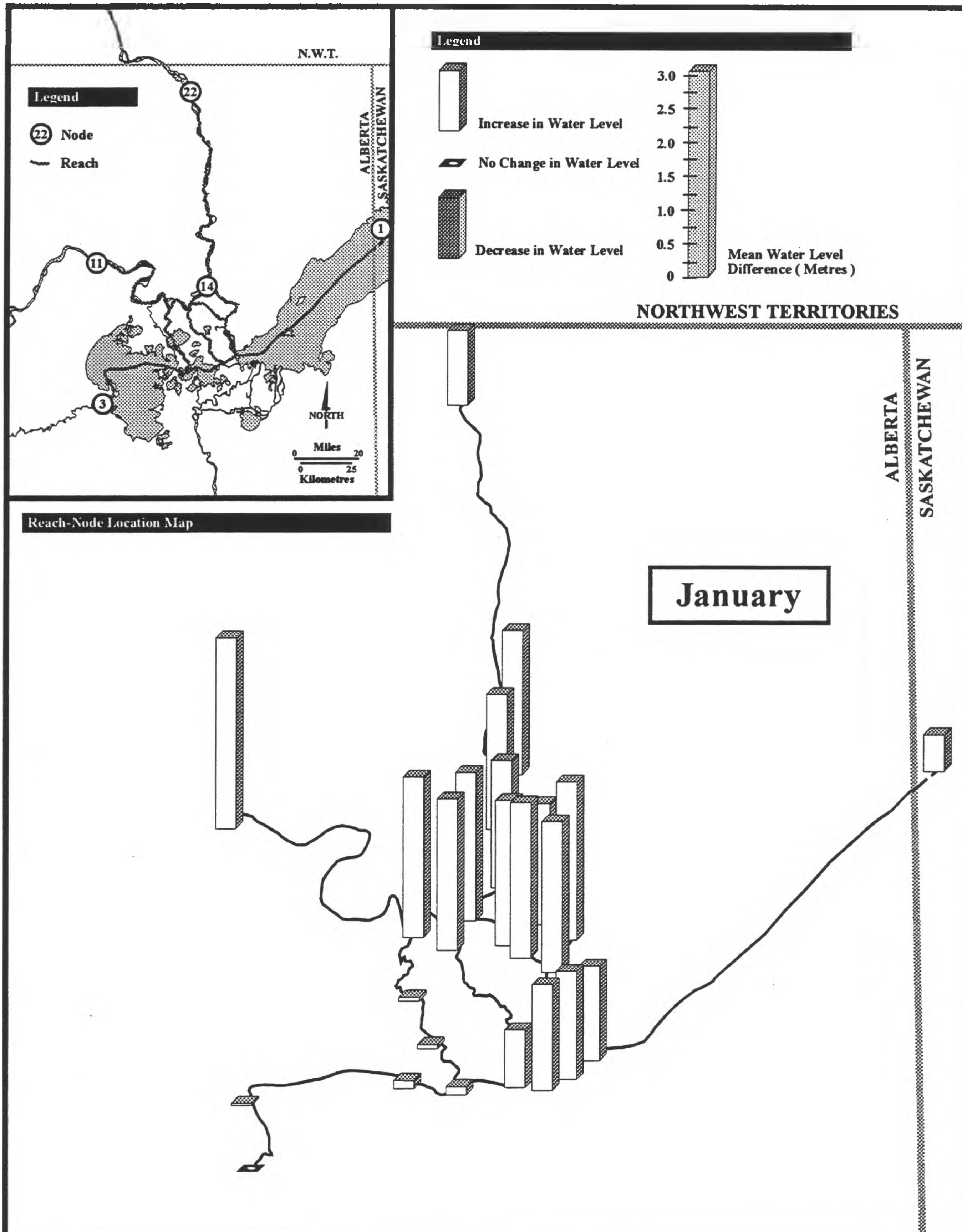
Effect of Weirs on Present Conditions - December



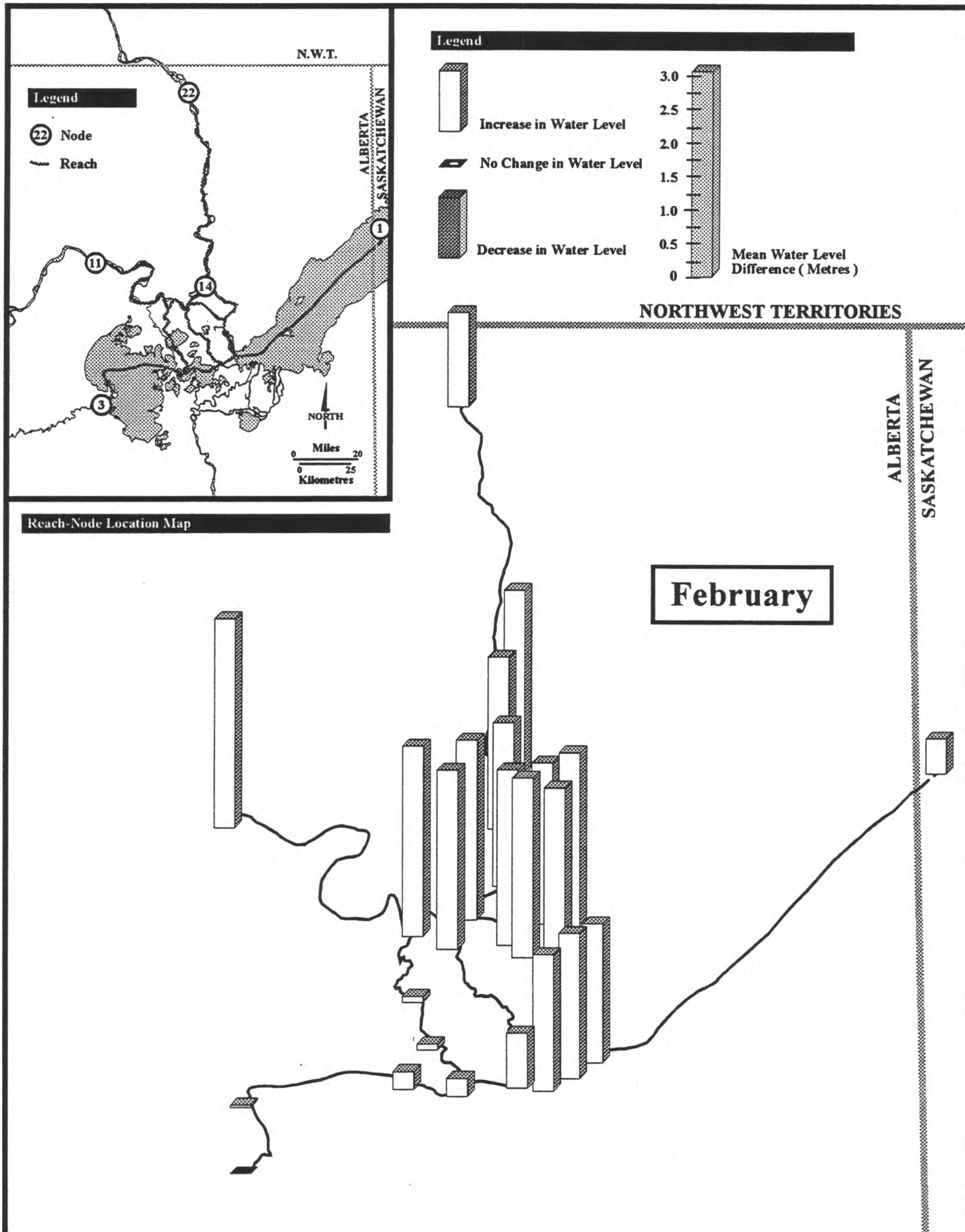
Effect of Weirs on Present Conditions - All

APPENDIX G
Water Level Mean Difference

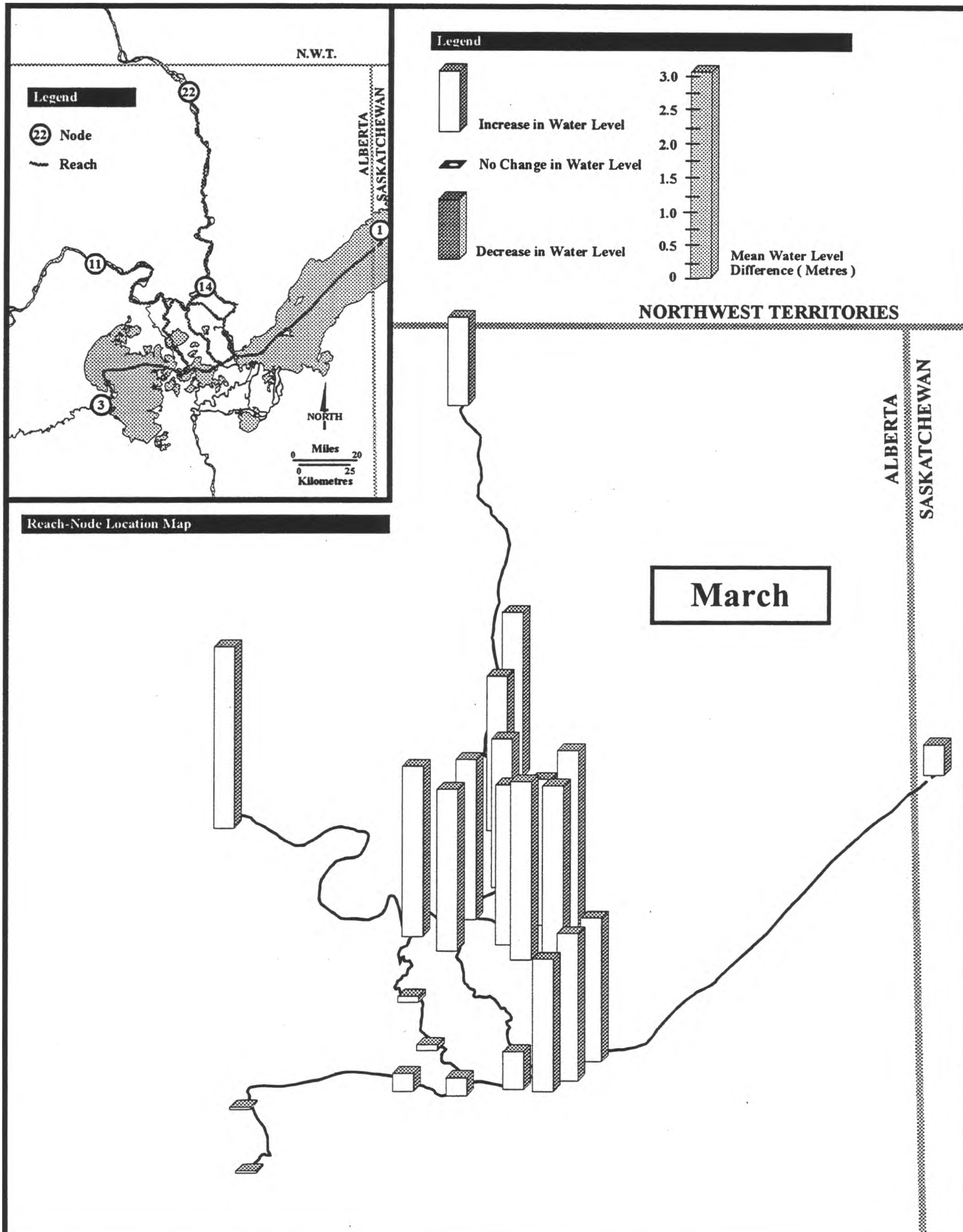
Effect of Weirs and Bennett Dam on Natural Conditions



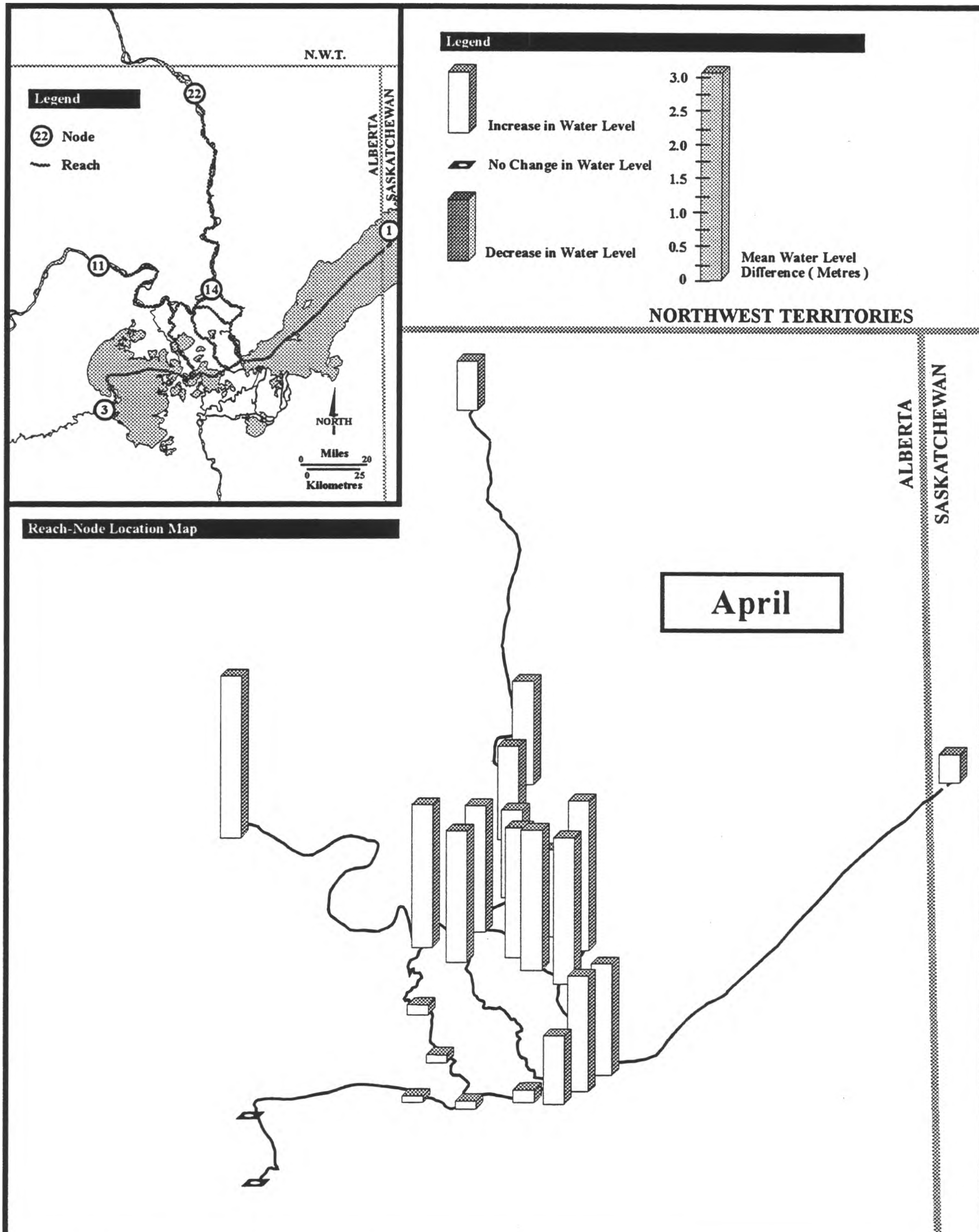
Effect of Weirs and Bennet Dam on Natural Conditions - January



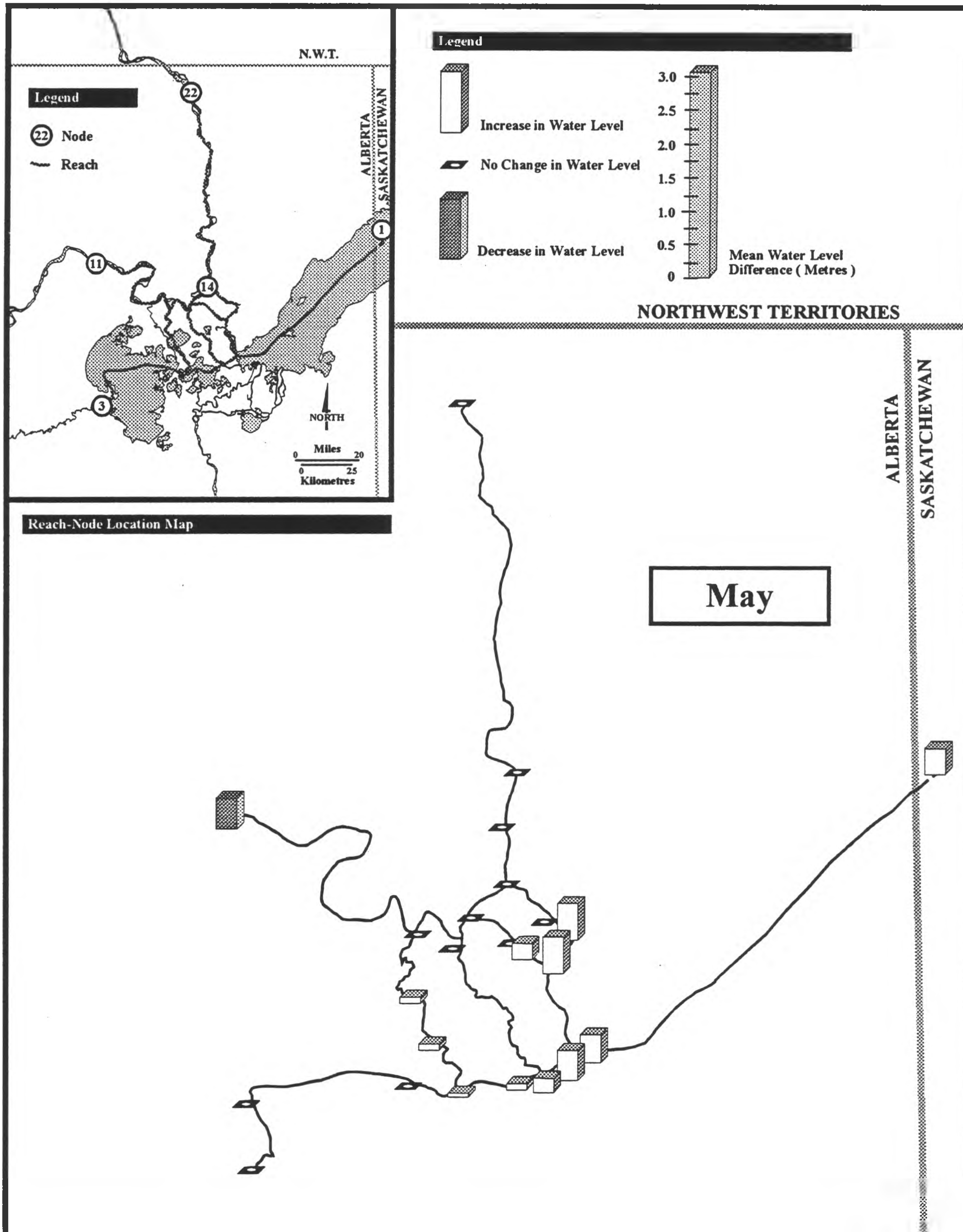
Effect of Weirs and Bennet Dam on Natural Conditions - February



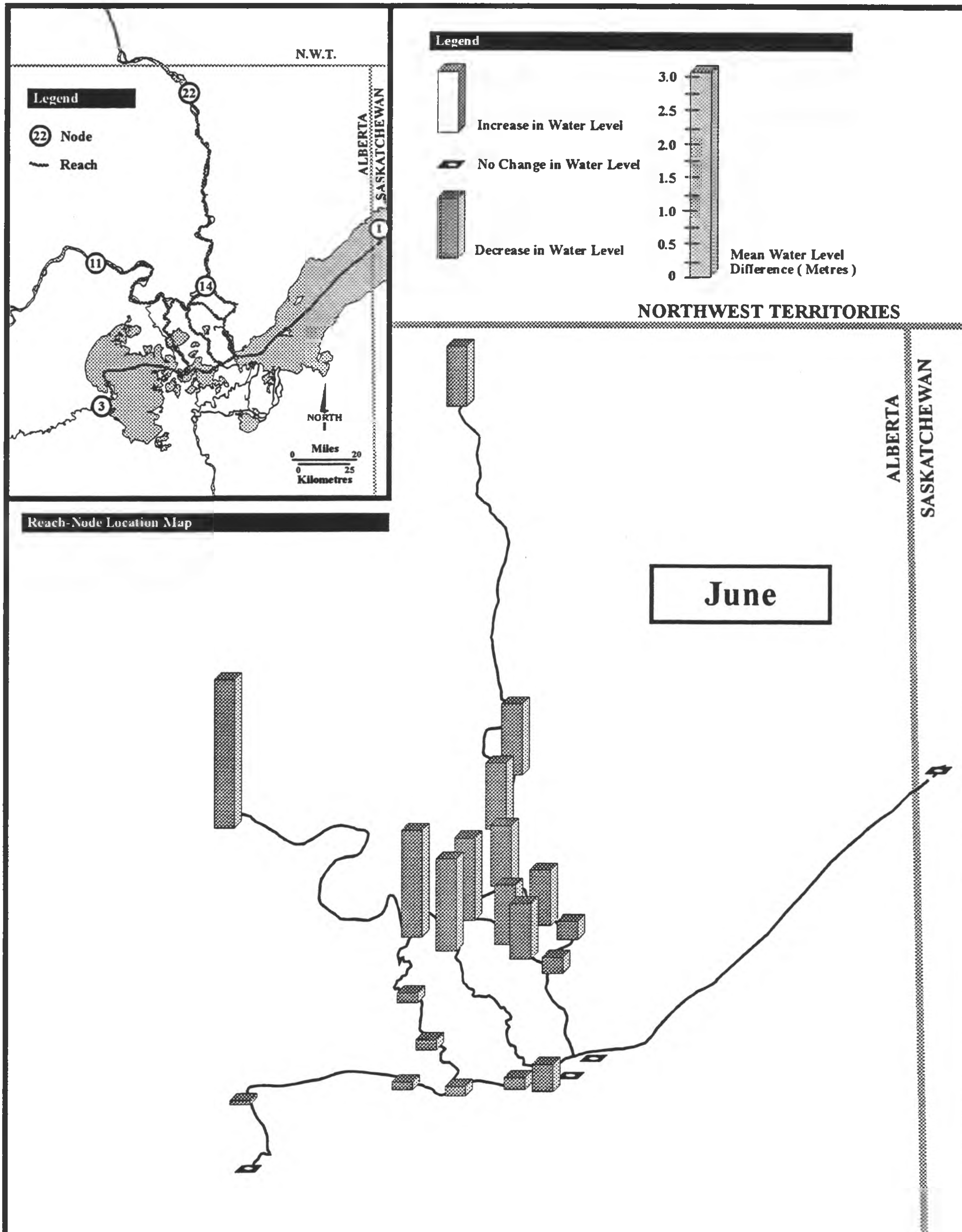
Effect of Weirs and Bennet Dam on Natural Conditions - March



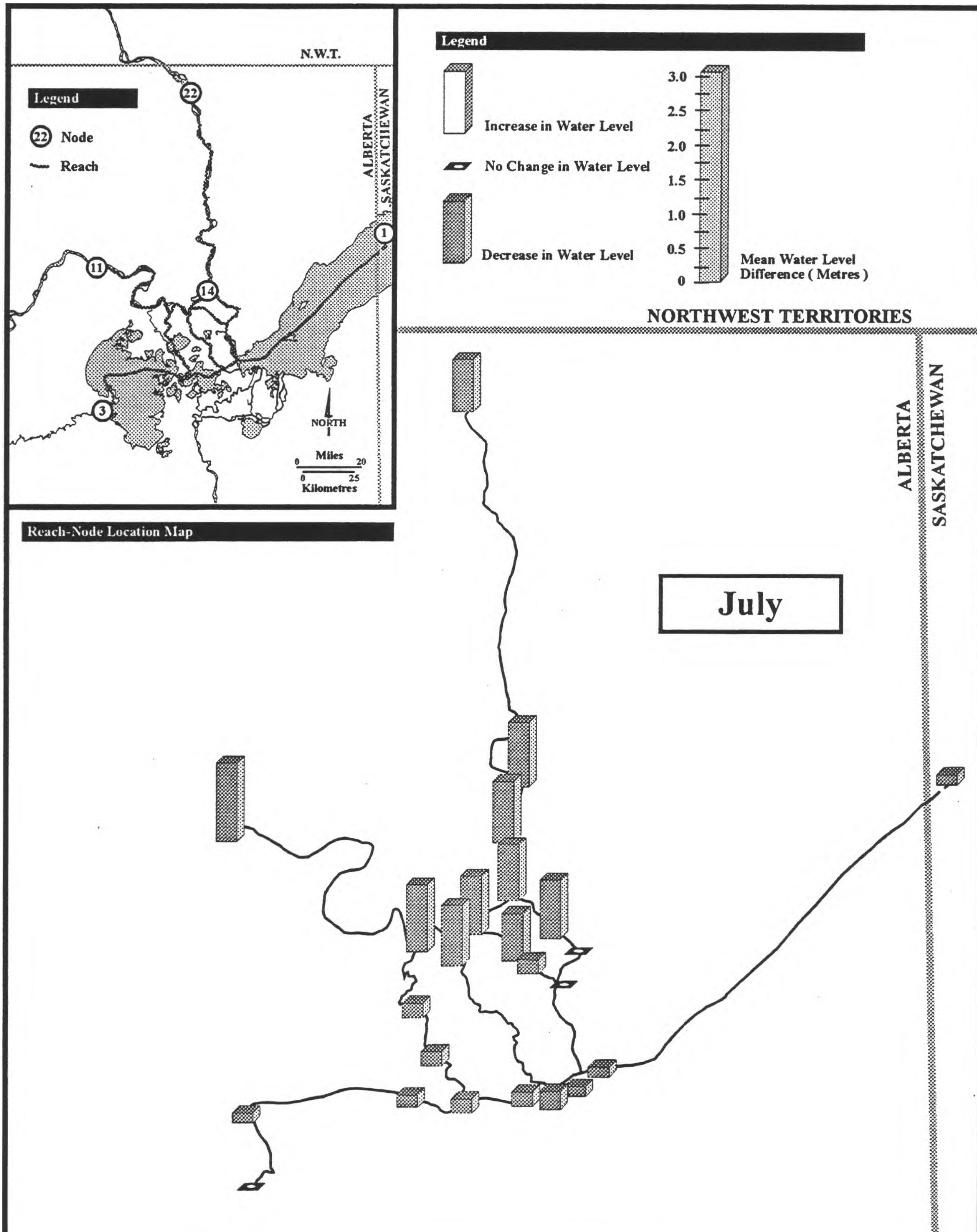
Effect of Weirs and Bennet Dam on Natural Conditions - April



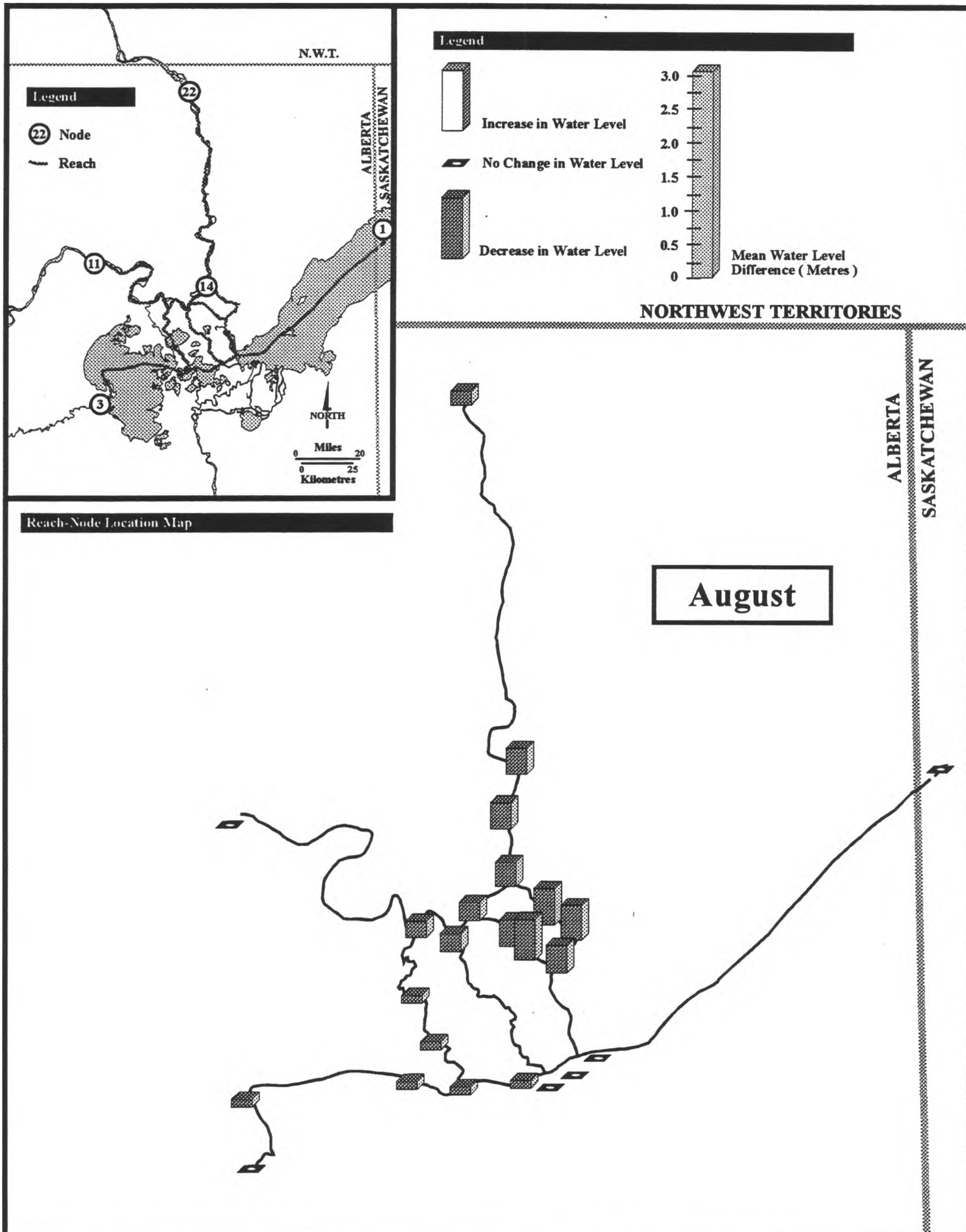
Effect of Weirs and Bennet Dam on Natural Conditions - May



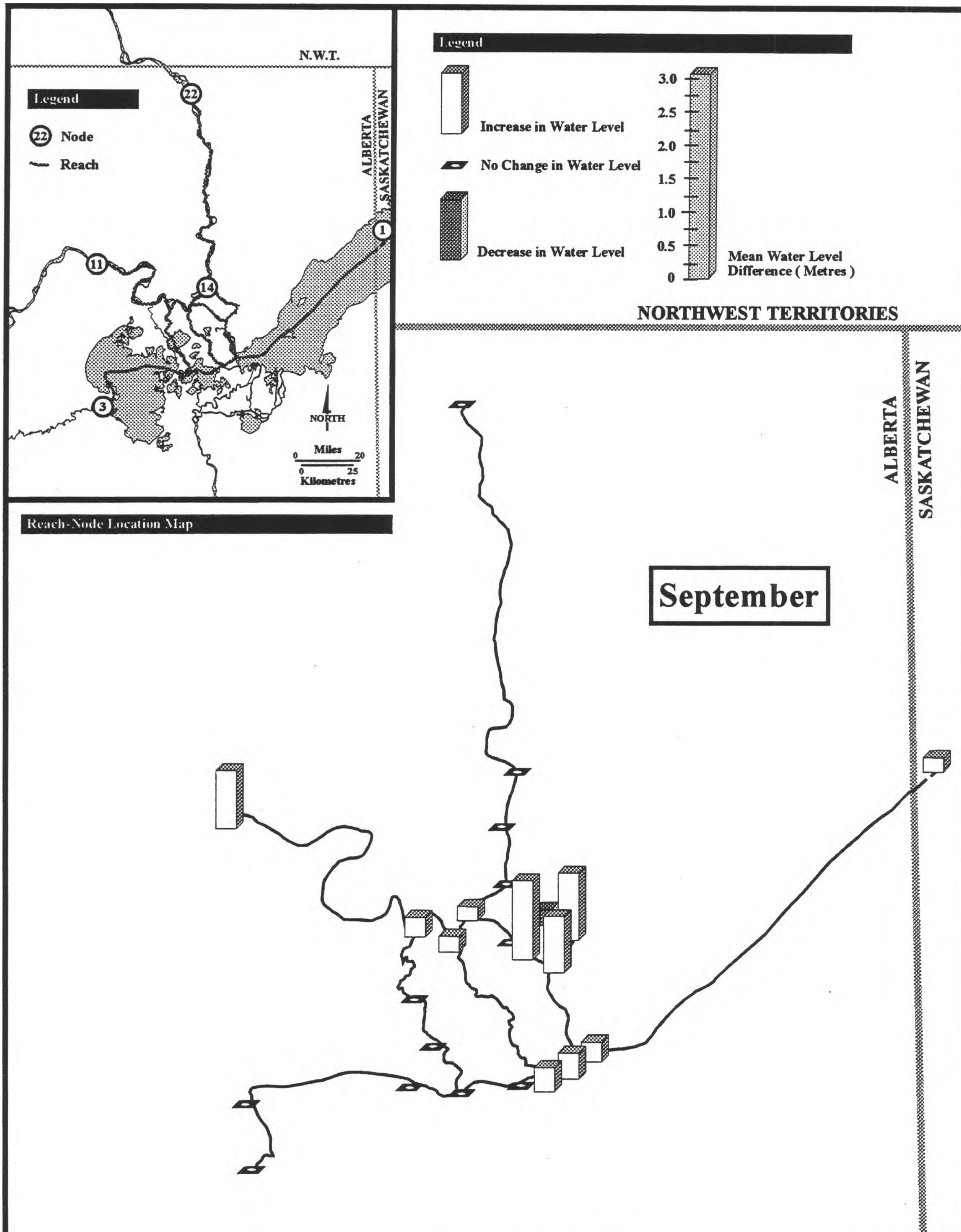
Effect of Weirs and Bennet Dam on Natural Conditions - June



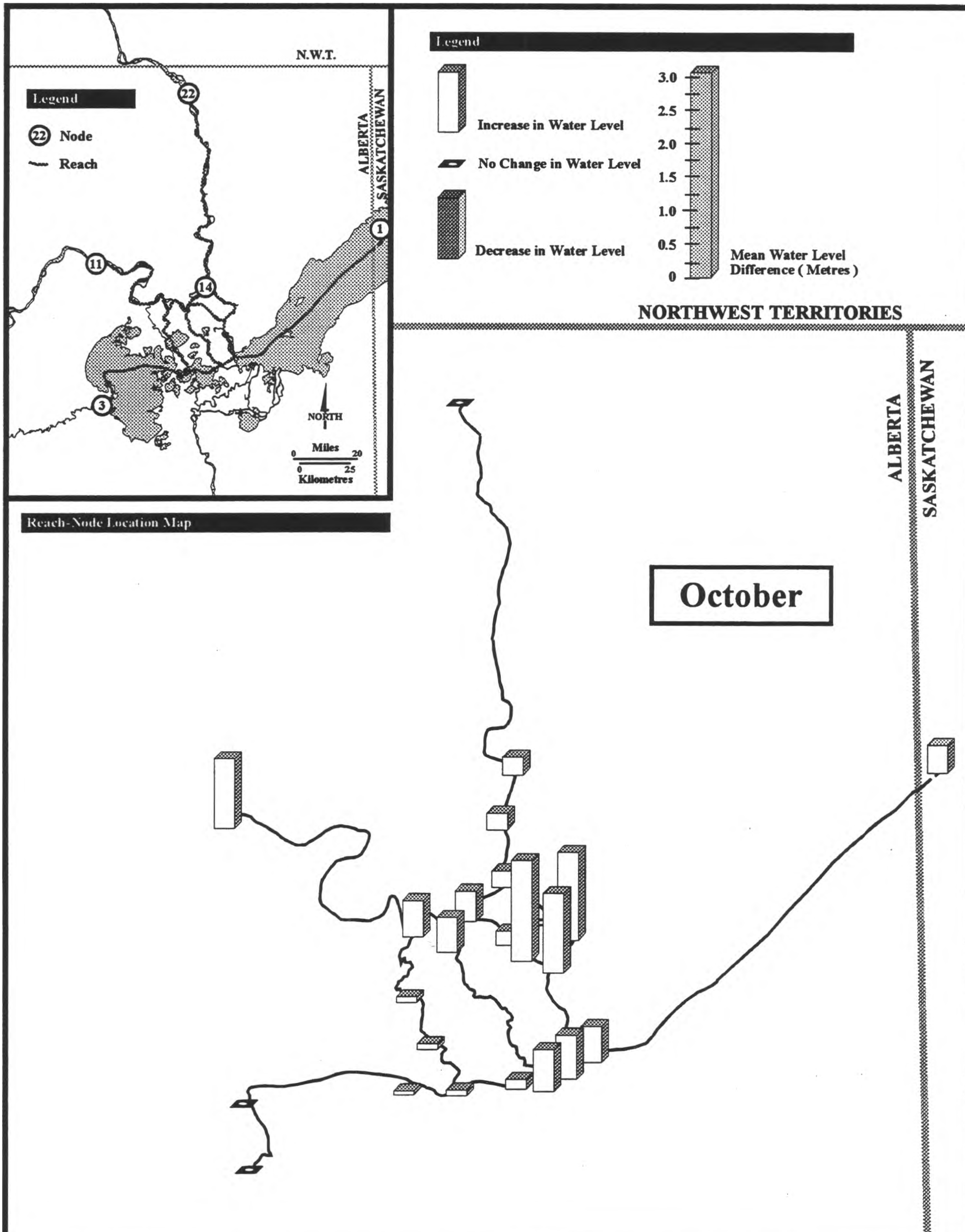
Effect of Weirs and Bennet Dam on Natural Conditions - July



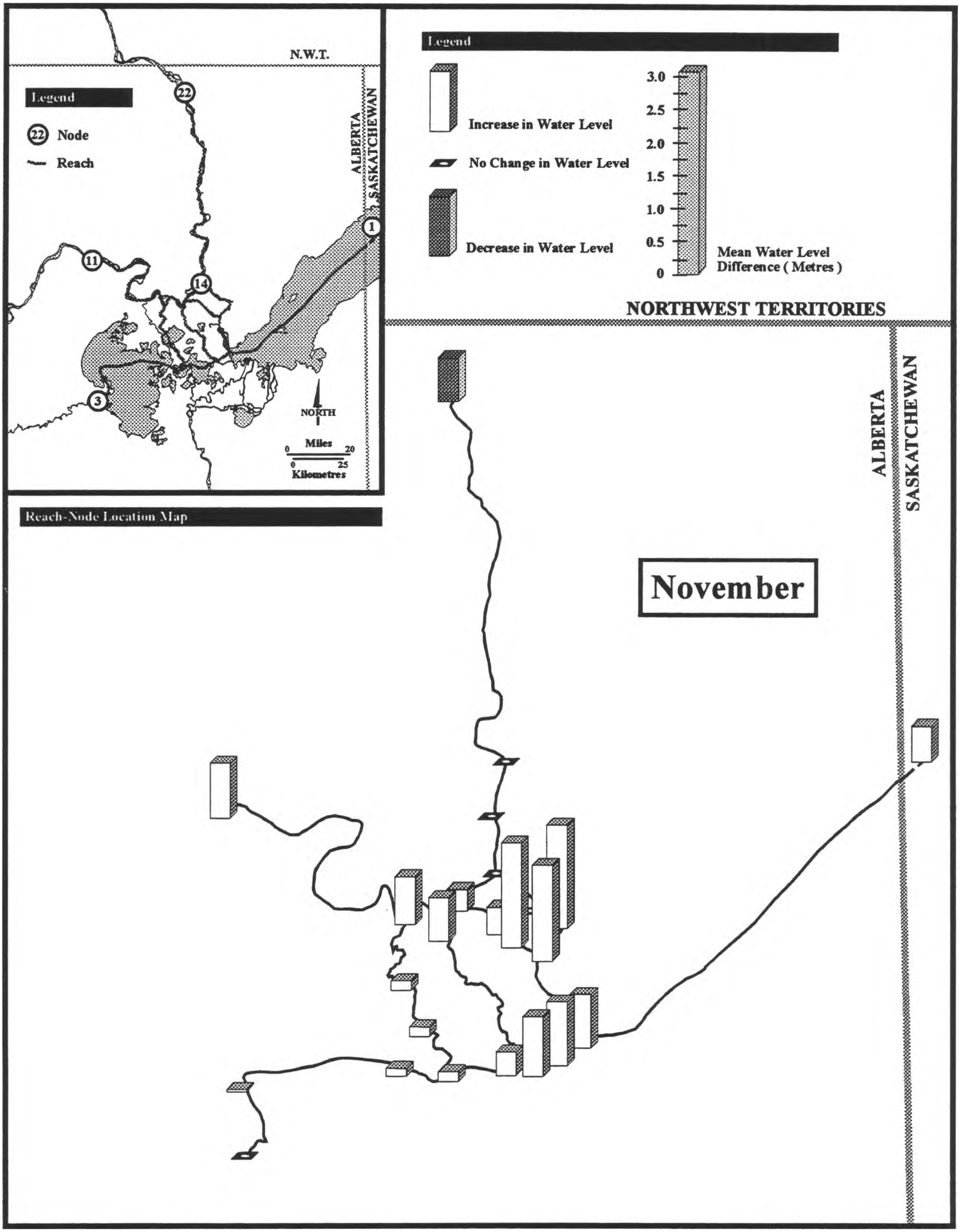
Effect of Weirs and Bennet Dam on Natural Conditions - August



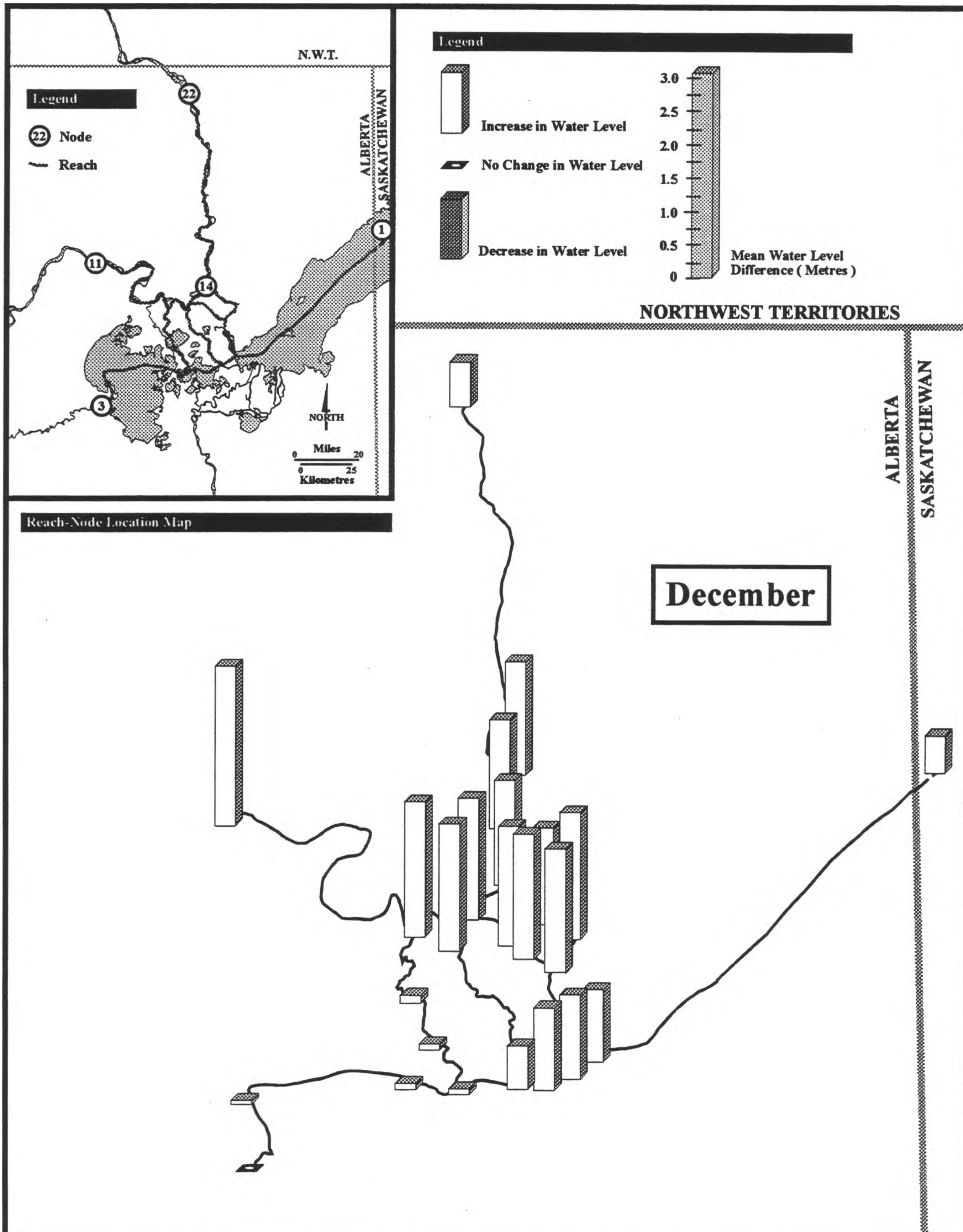
Effect of Weirs and Bennet Dam on Natural Conditions - September



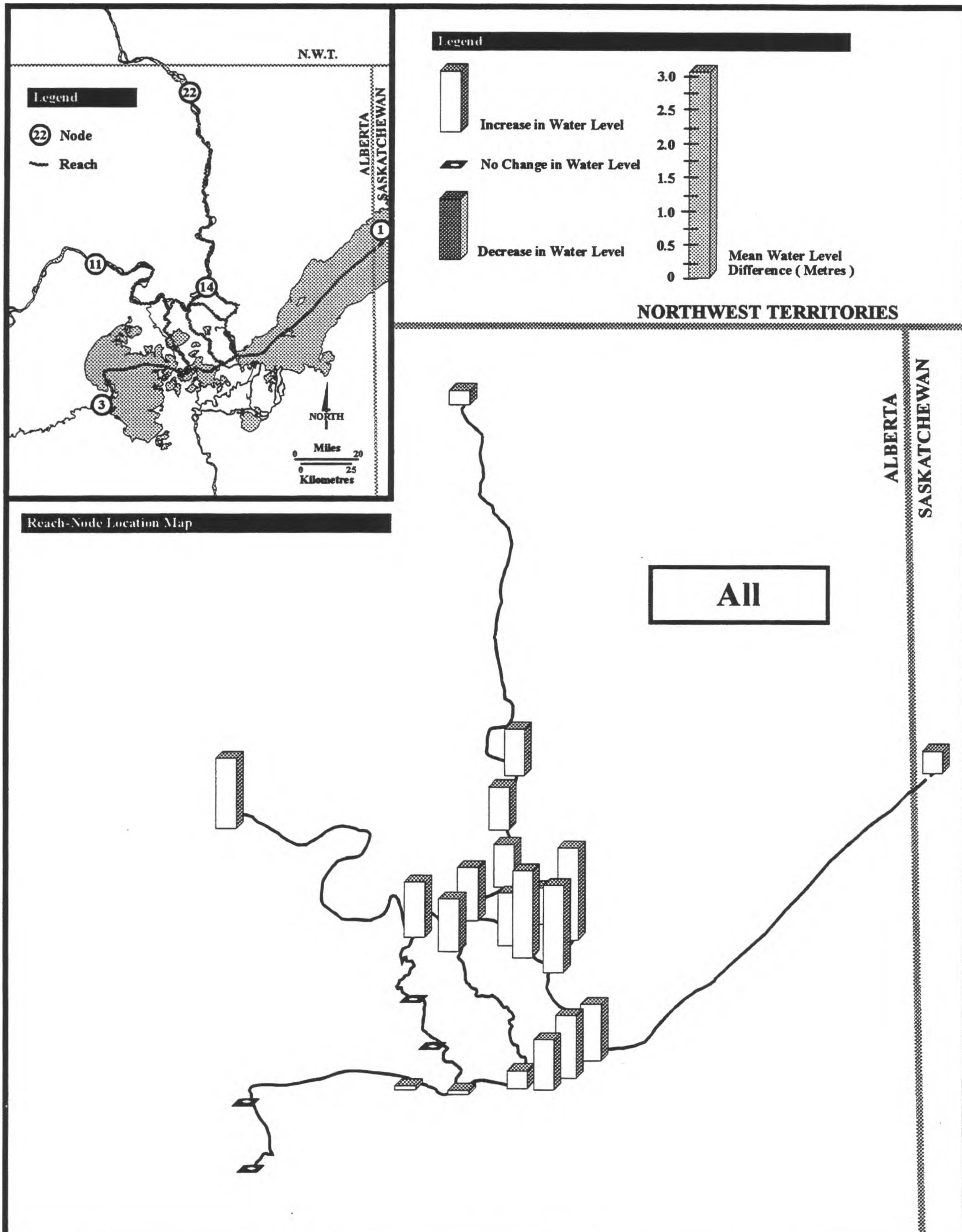
Effect of Weirs and Bennet Dam on Natural Conditions - October



Effect of Weirs and Bennet Dam on Natural Conditions - November



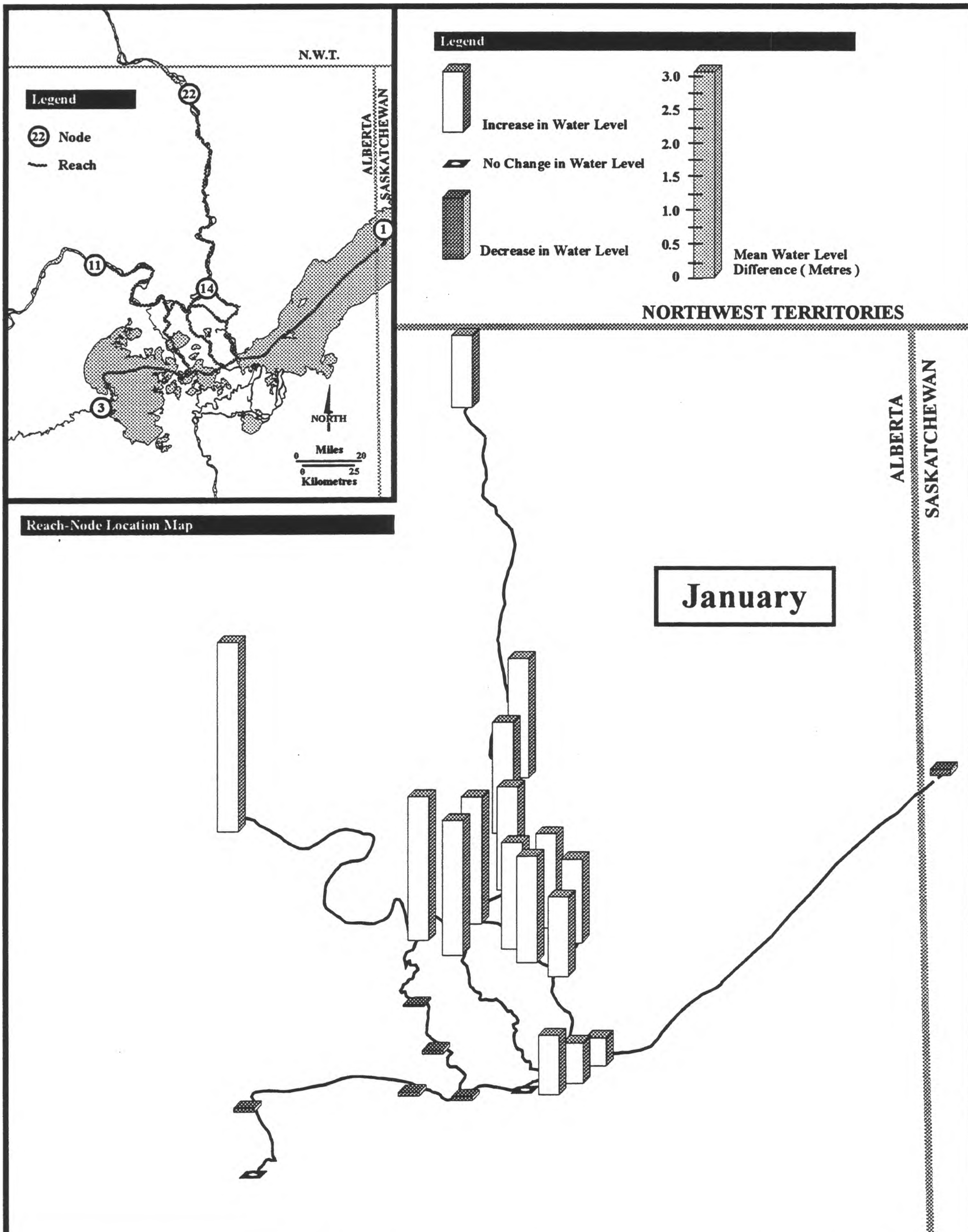
Effect of Weirs and Bennet Dam on Natural Conditions - December



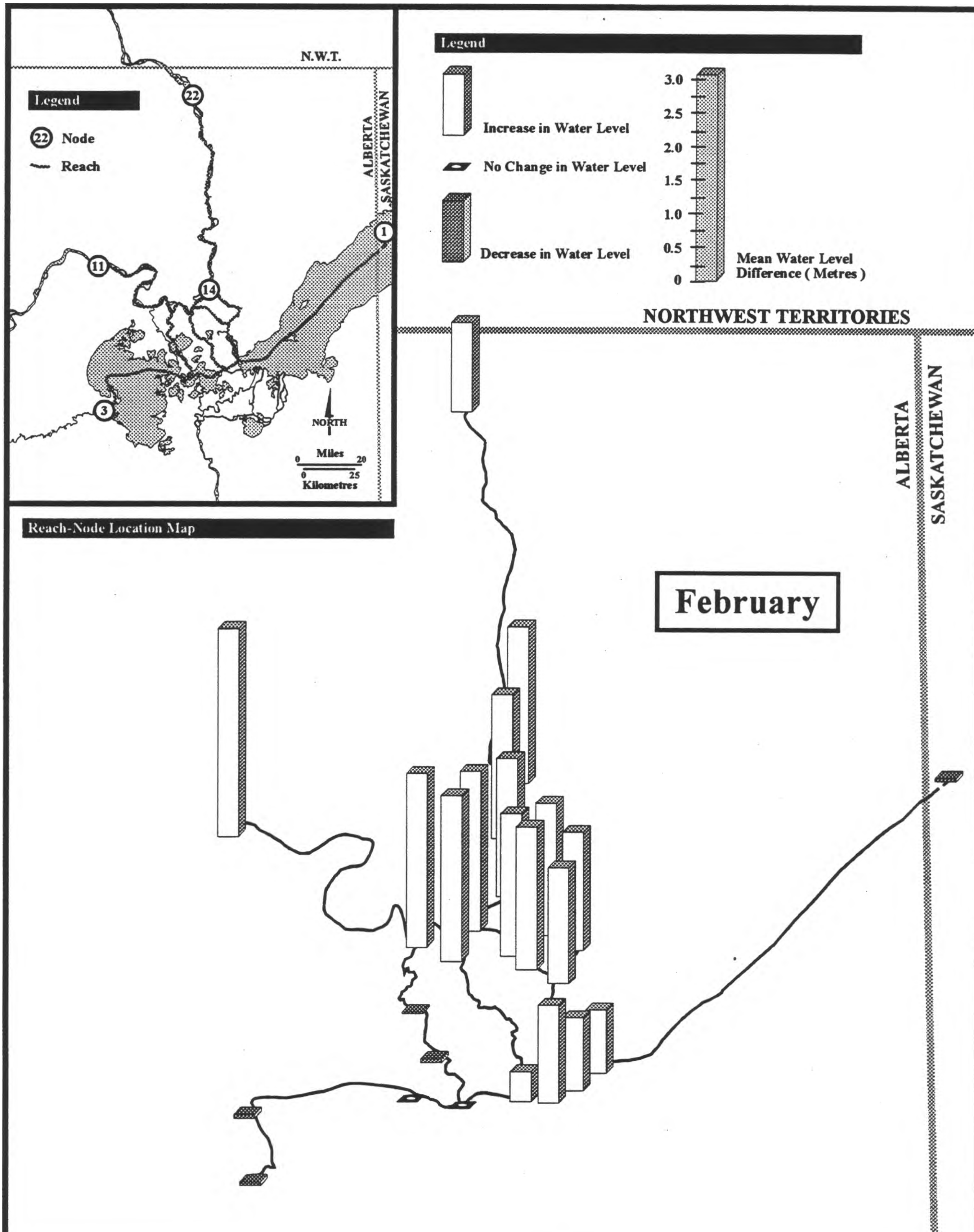
Effect of Weirs and Bennet Dam on Natural Conditions - All

APPENDIX H
Water Level Mean Difference

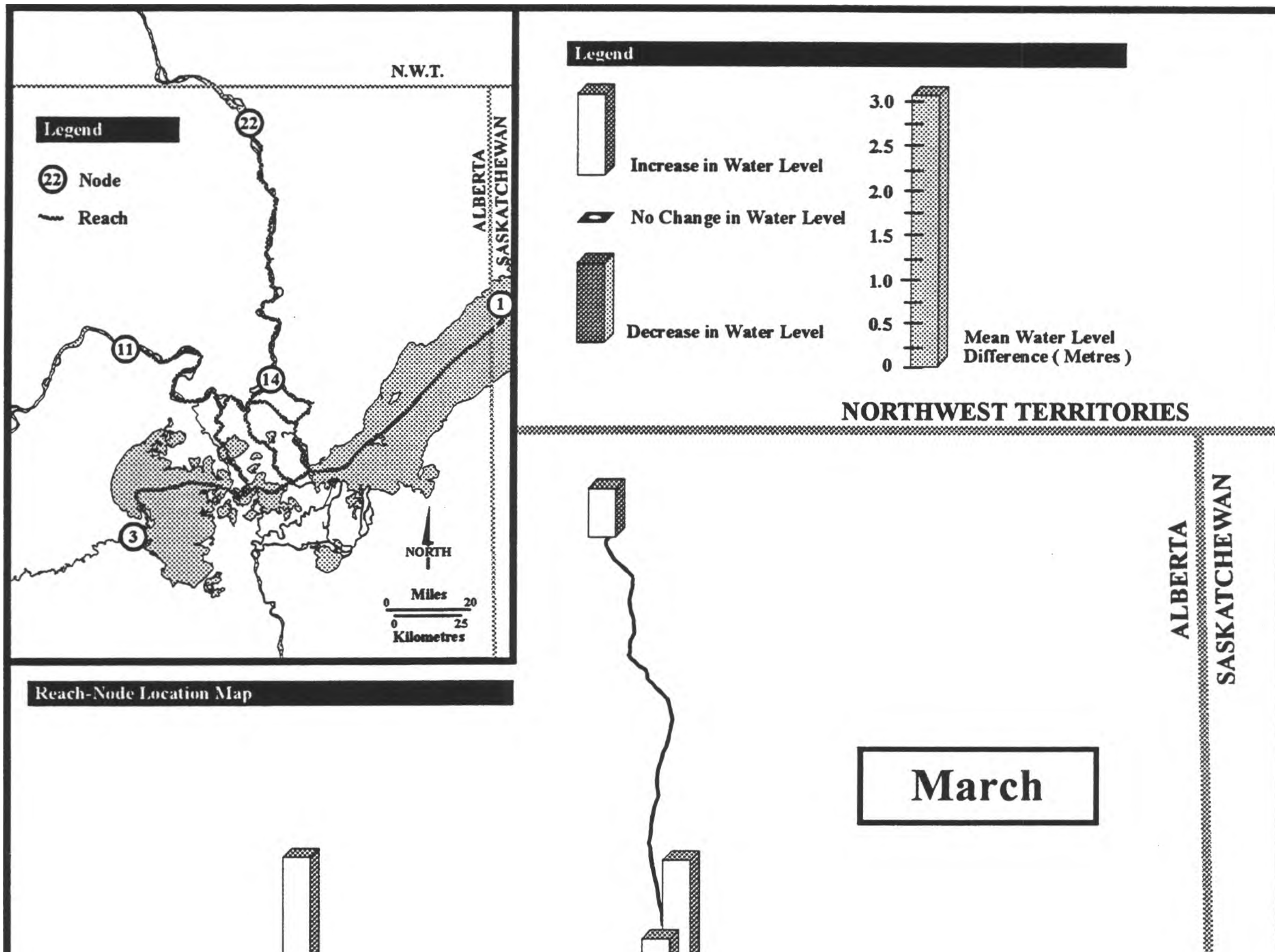
Effect of Bennett Dam on Natural Conditions



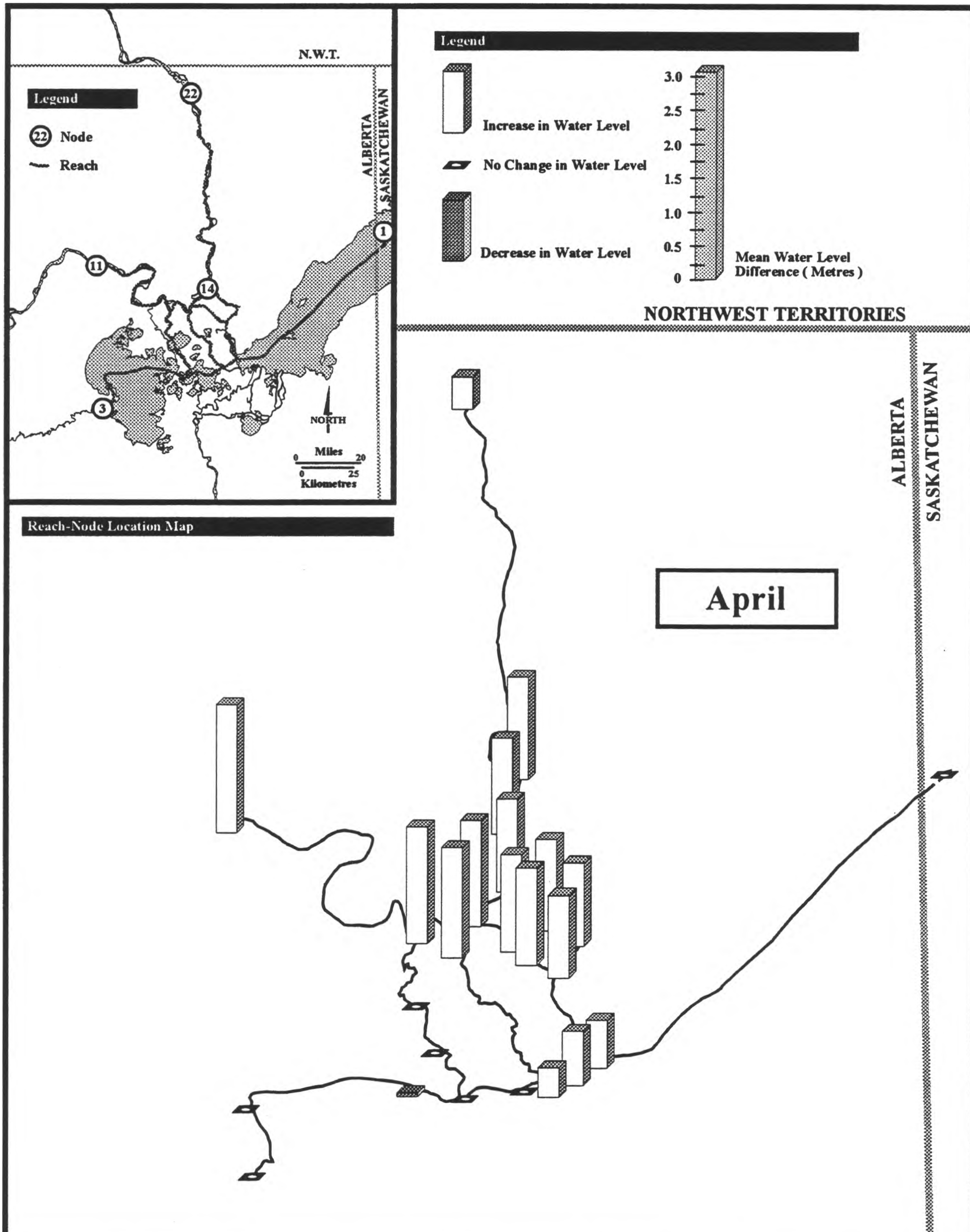
Effect of Bennet Dam on Natural Conditions - January



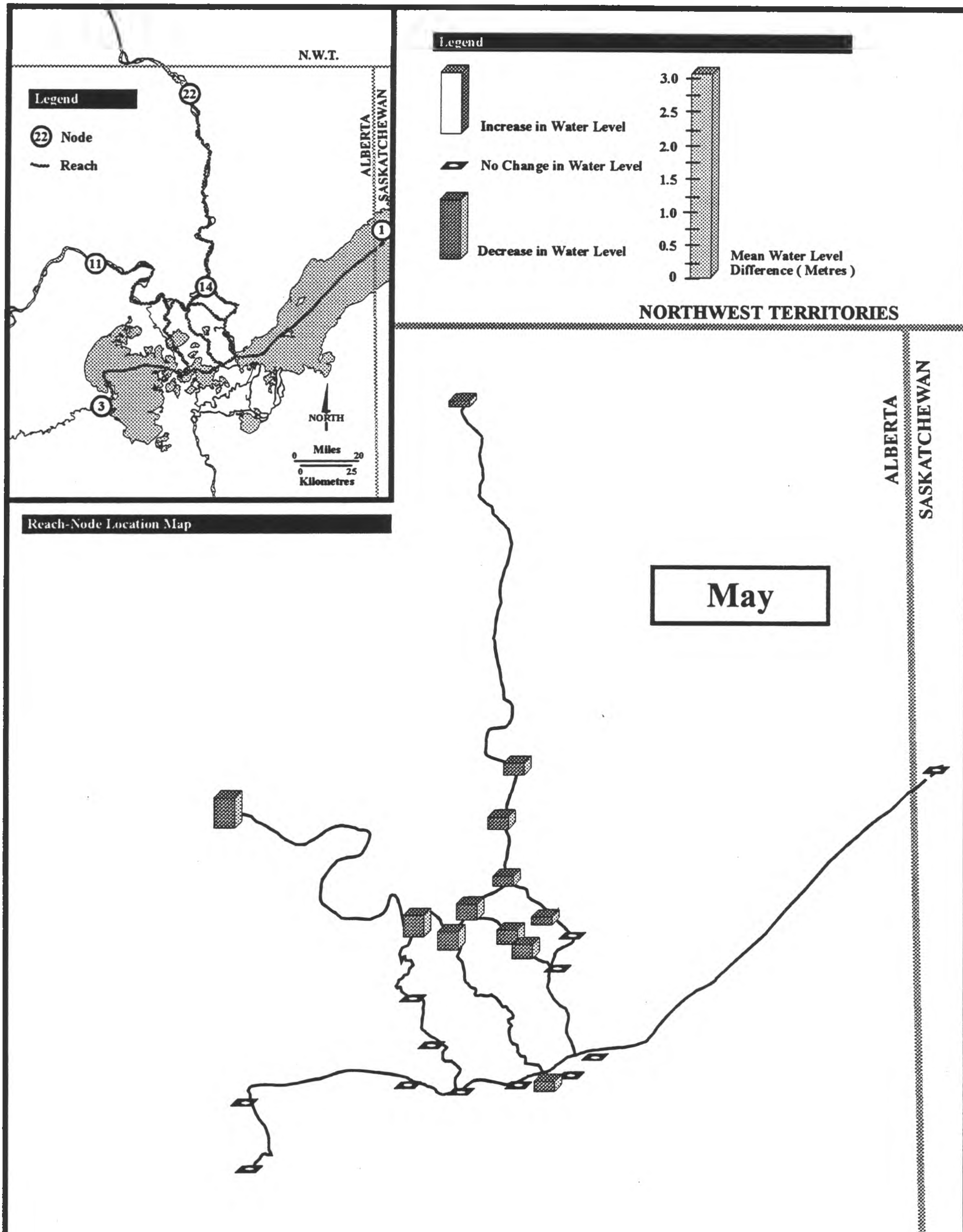
Effect of Bennet Dam on Natural Conditions - February



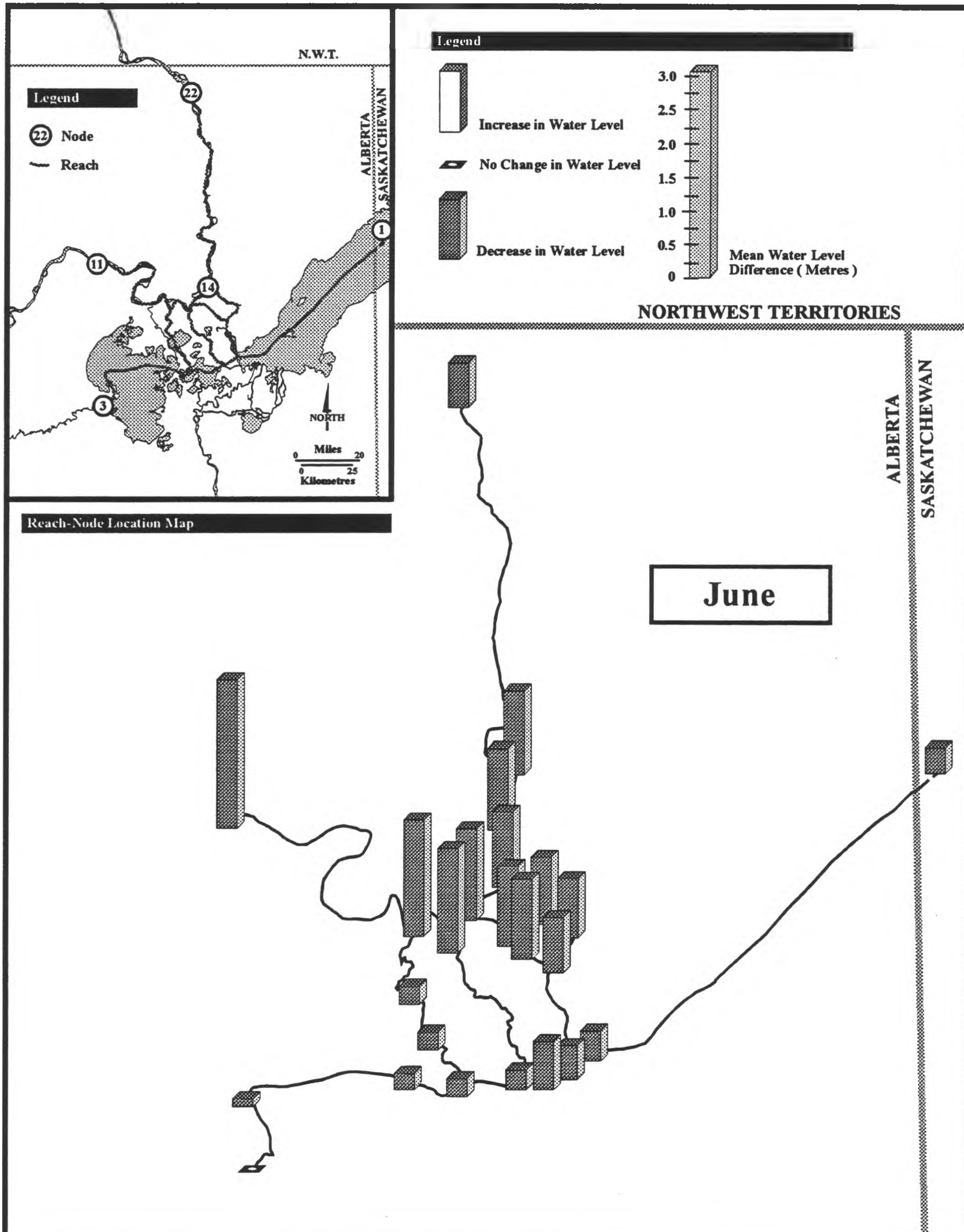
Effect of Bennet Dam on Natural Conditions - March



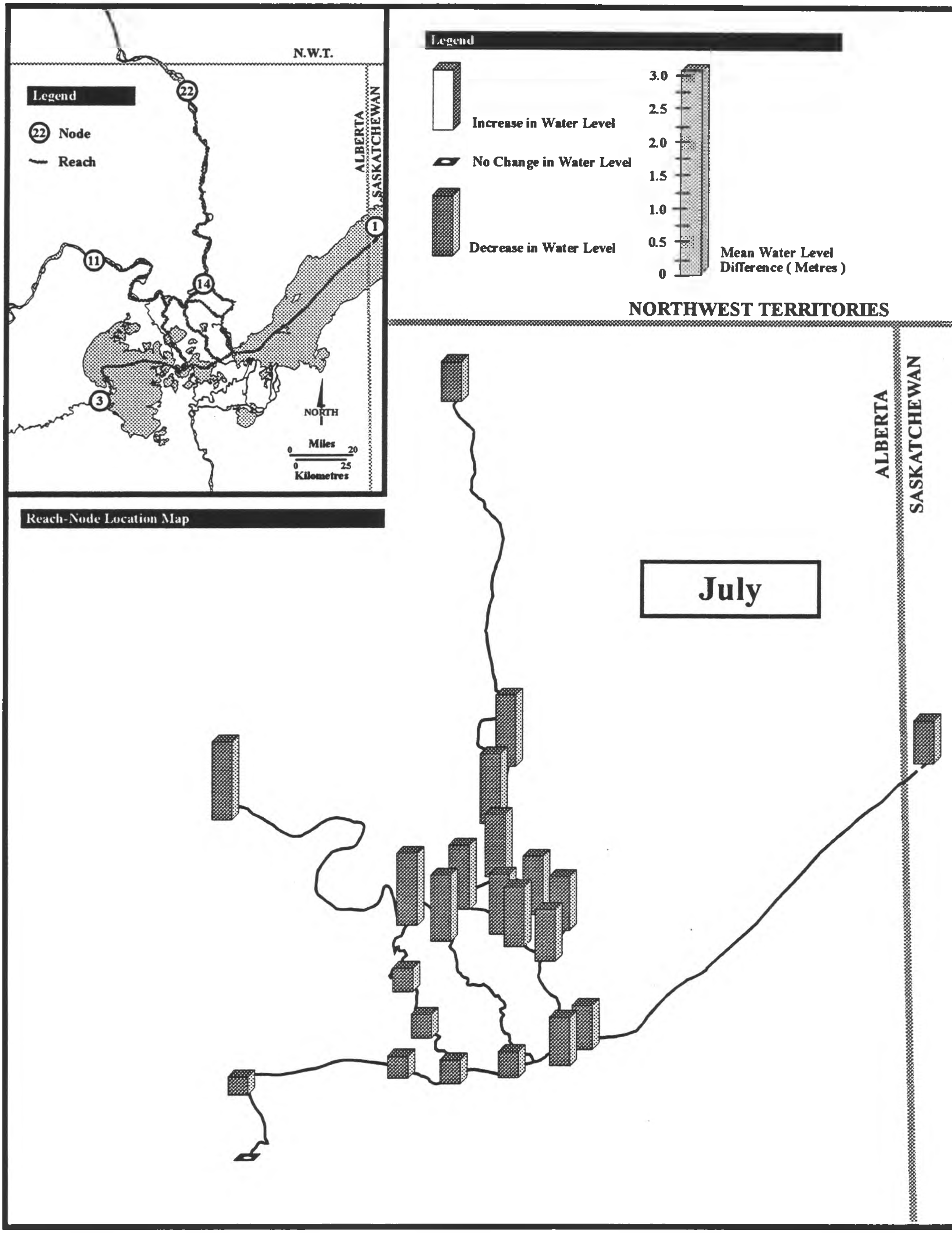
Effect of Bennet Dam on Natural Conditions - April



Effect of Bennet Dam on Natural Conditions - May



Effect of Bennet Dam on Natural Conditions - June



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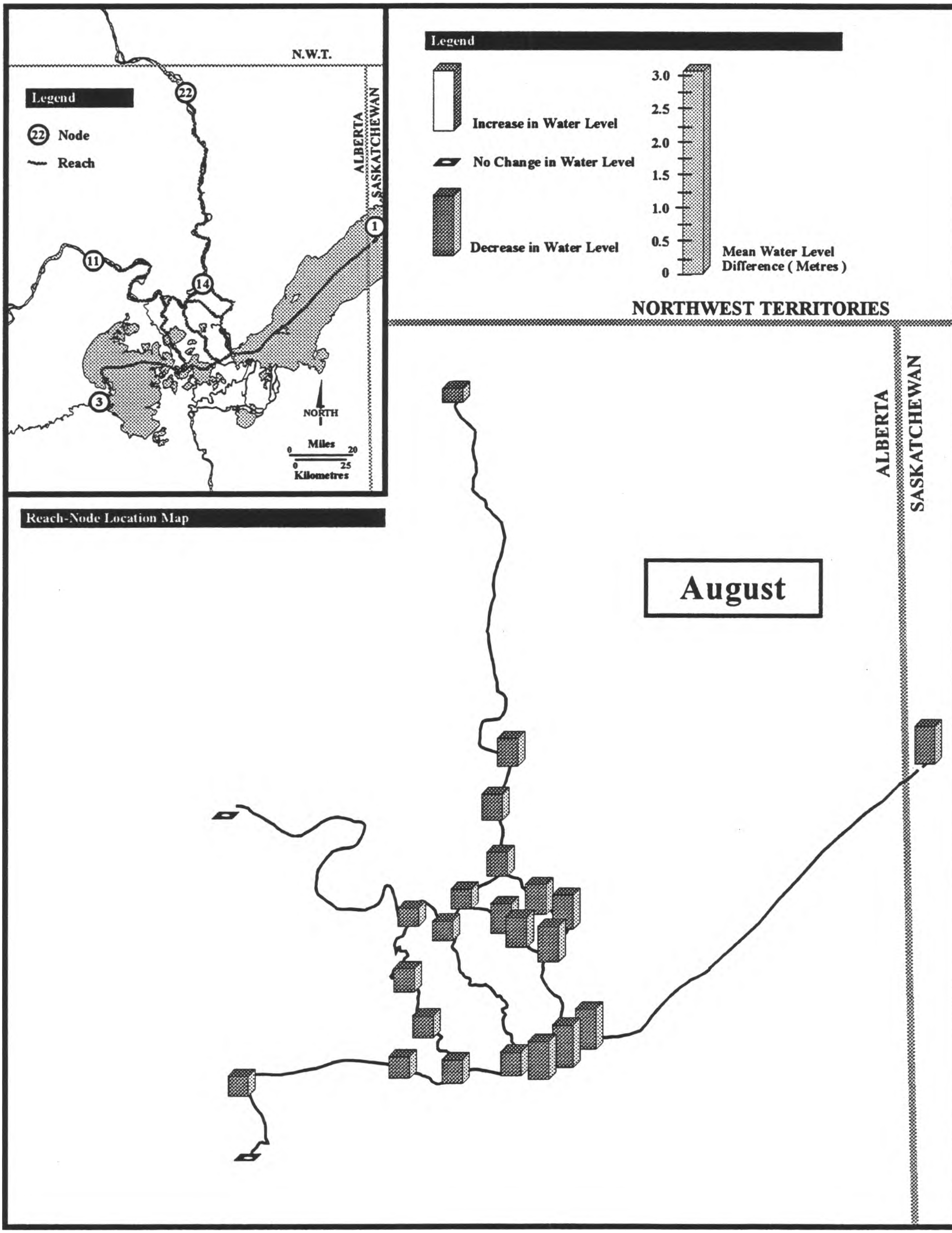
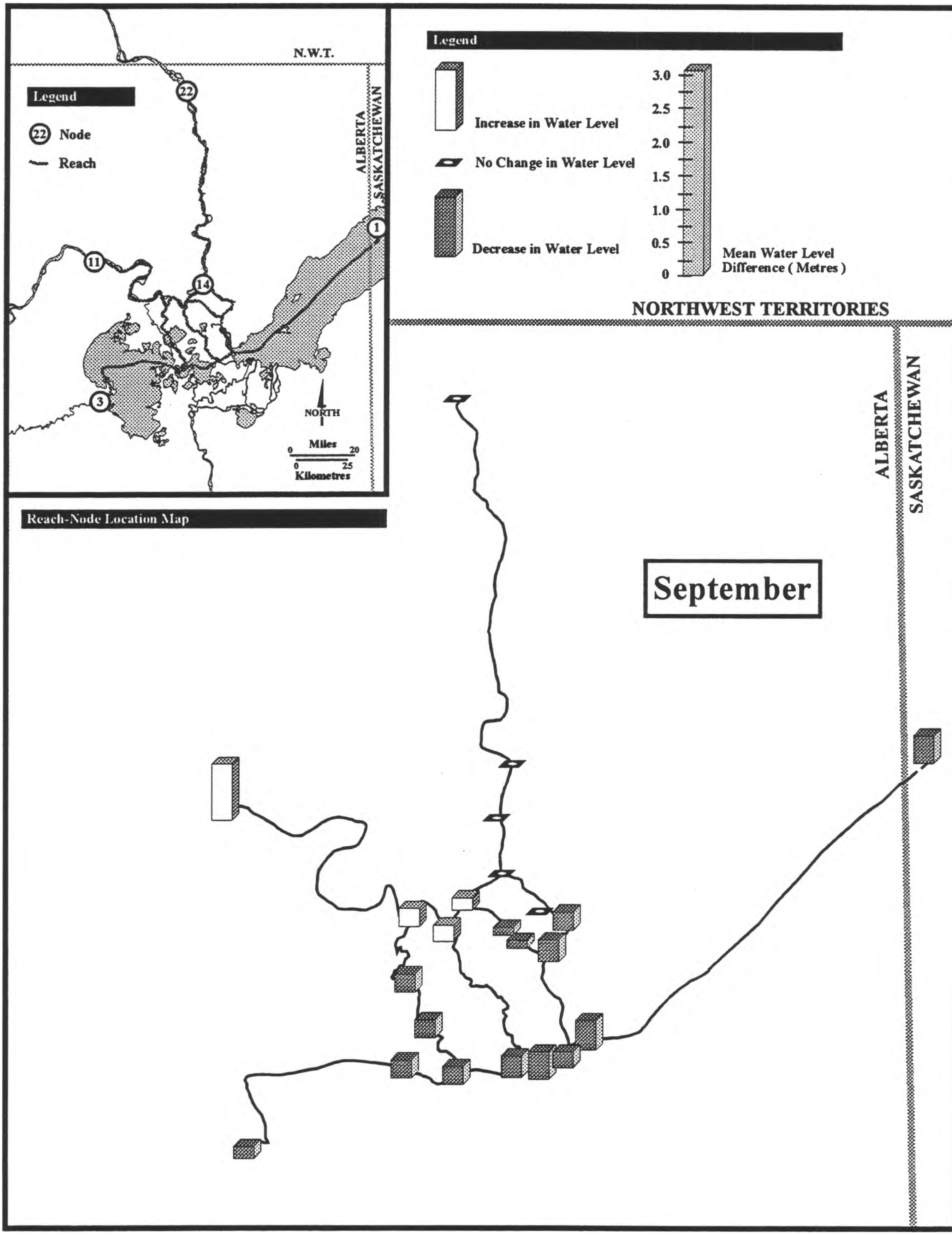
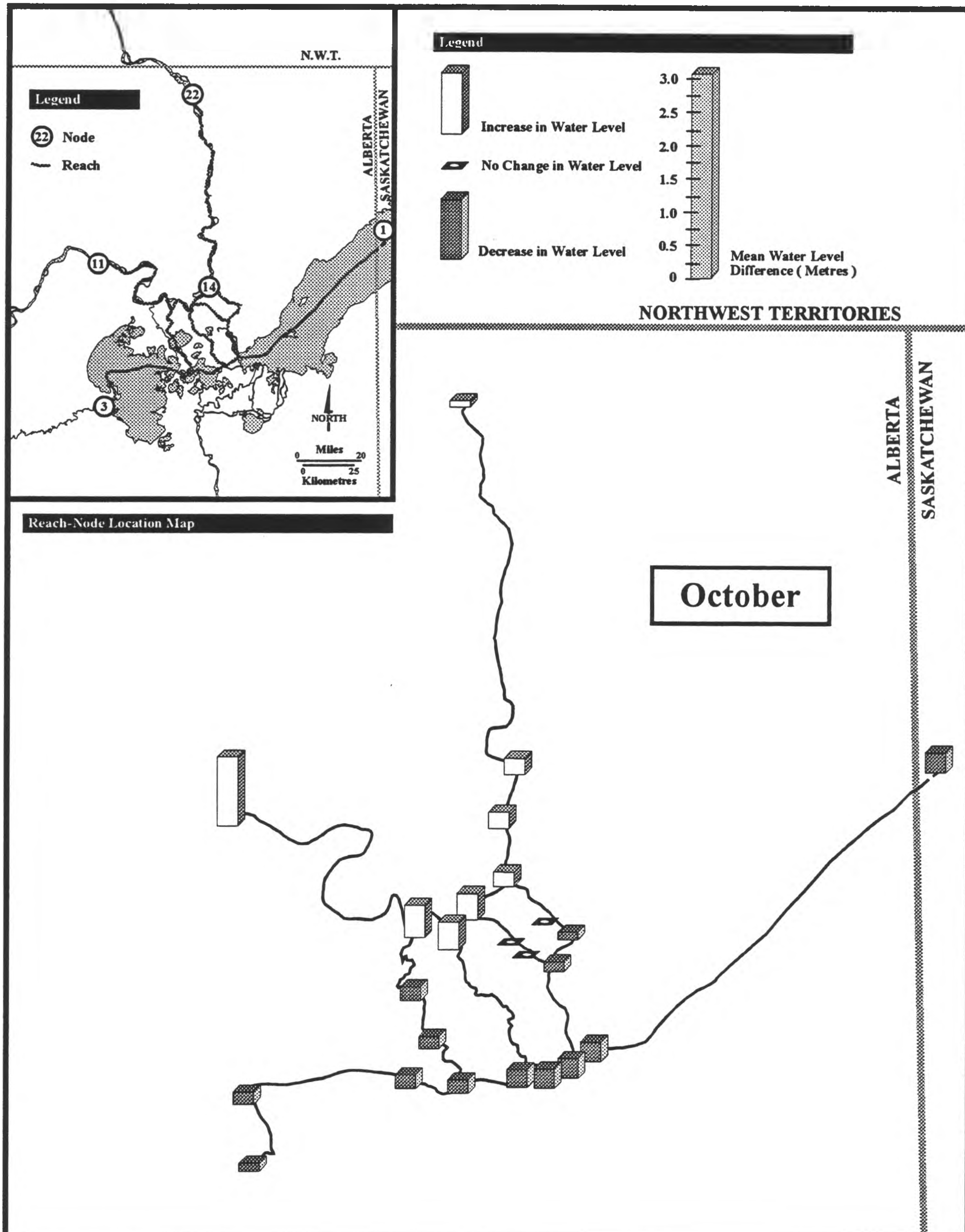


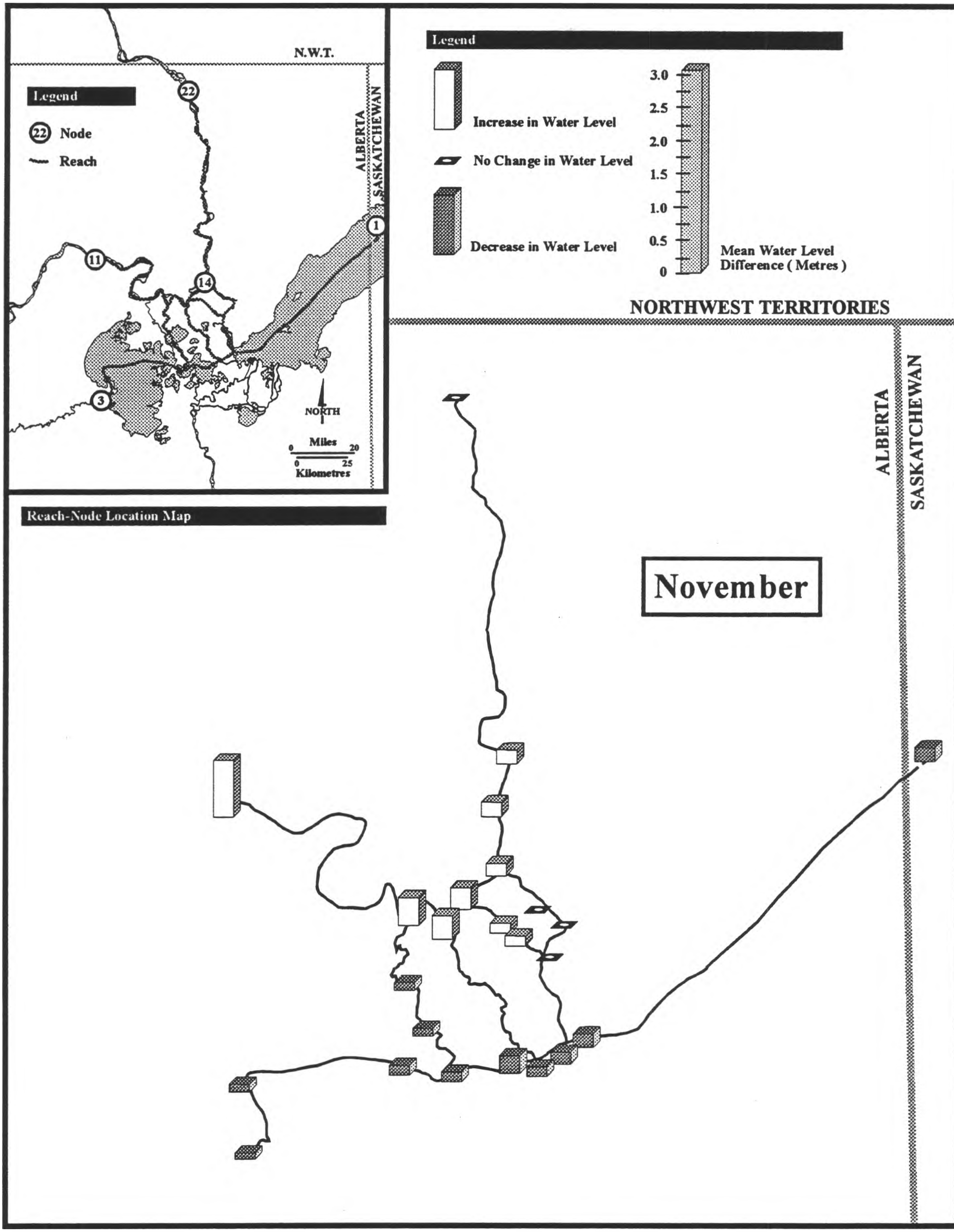
Effect of Bennet Dam on Natural Conditions - August



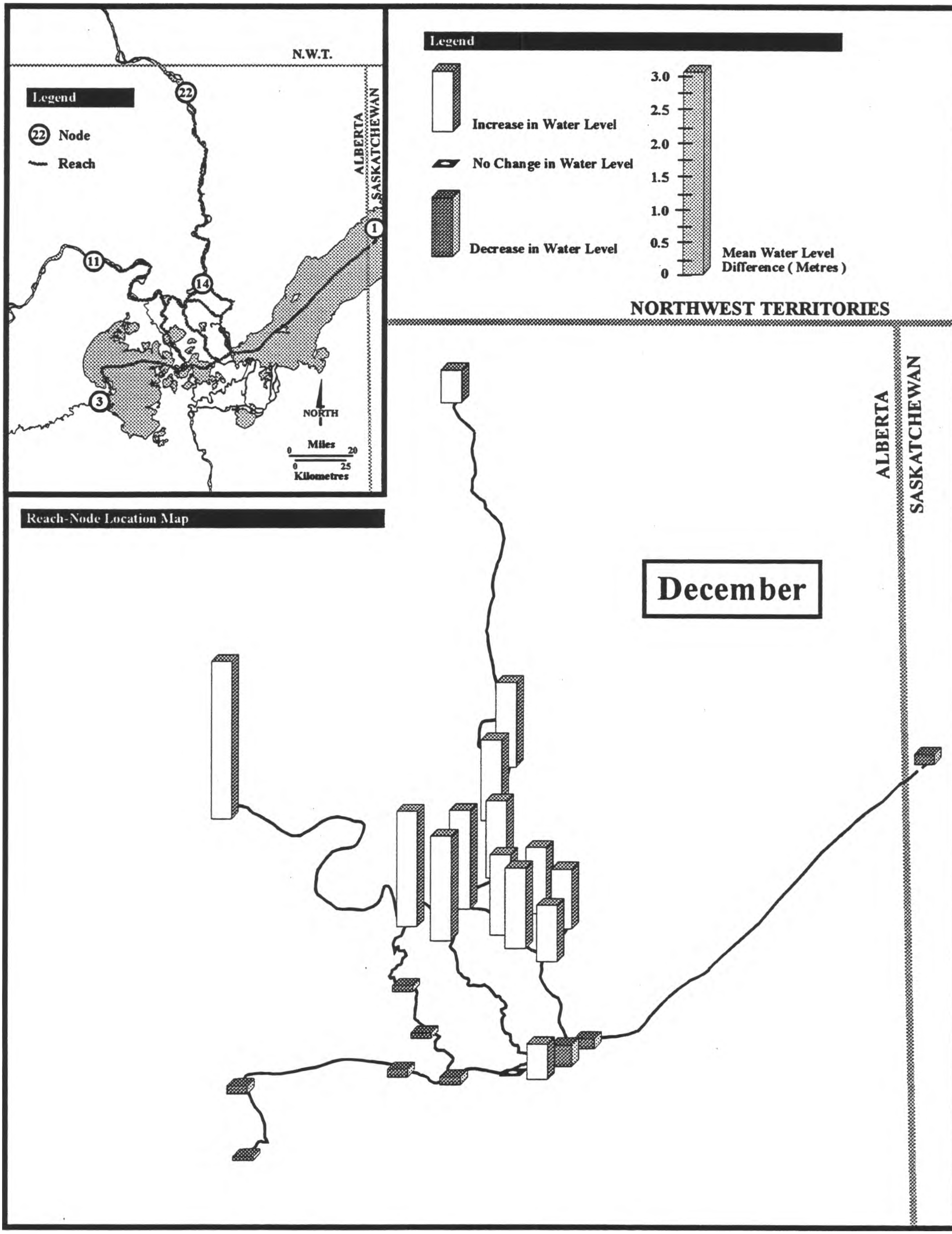
Effect of Bennet Dam on Natural Conditions - September



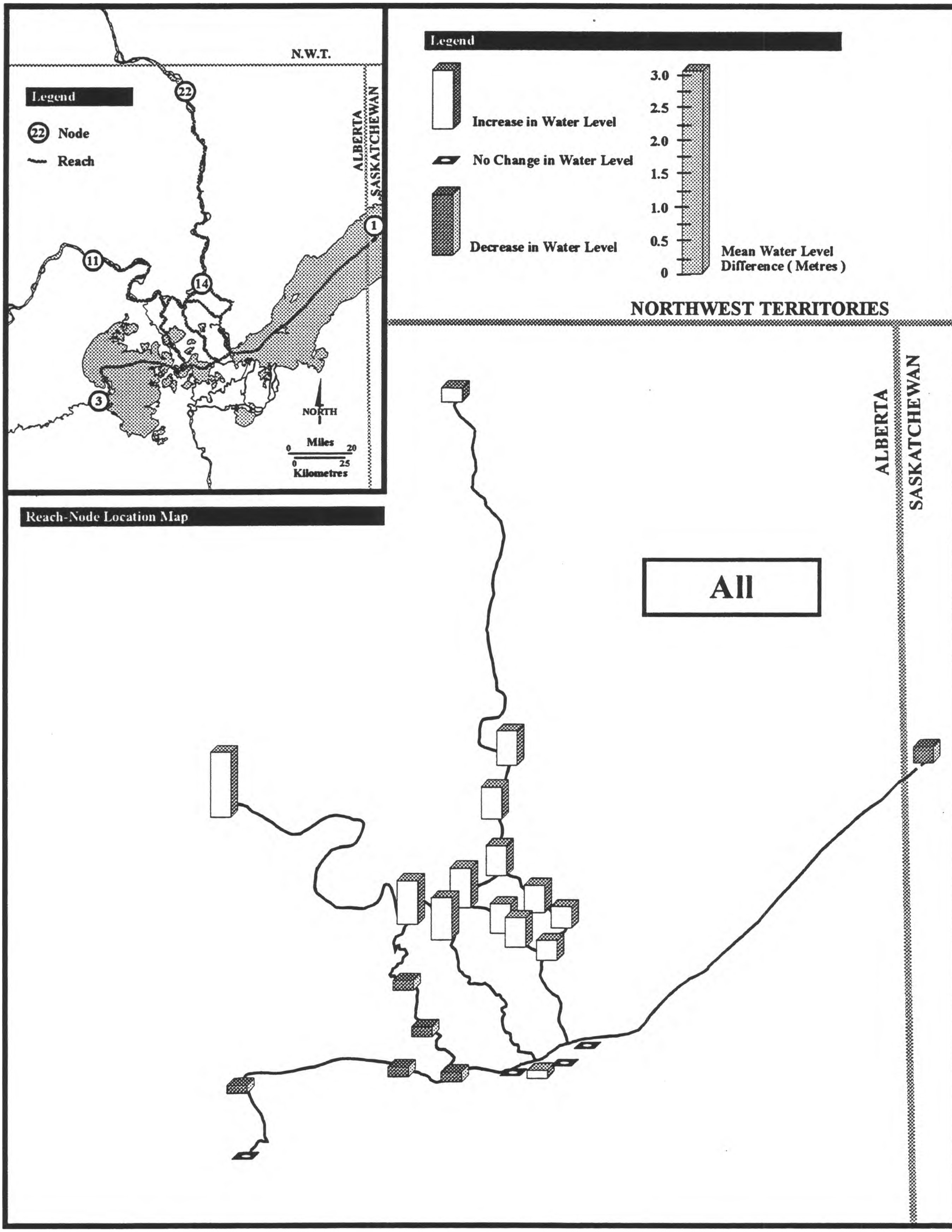
Effect of Bennet Dam on Natural Conditions - October



Effect of Bennet Dam on Natural Conditions - November



Effect of Bennet Dam on Natural Conditions - December



Effect of Bennet Dam on Natural Conditions - All

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