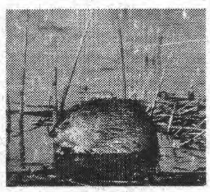
Canada Alberta Northwest Territories

Northern River Basins Study



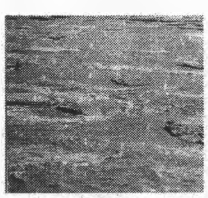


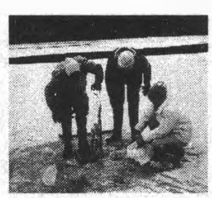




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 146

AN OVERVIEW OF STREAMFLOWS AND LAKE LEVELS FOR THE PEACE, ATHABASCA AND SLAVE RIVER BASINS



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by

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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.

NORTHERN RIVER BASINS STUDY
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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;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona — 14 May 96

(Dr. Fred J. Wrona, Science Director) — (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

P. A. Larkin — 24 May/96

(Dr. P. A. Larkin, Ph.D., Chair) — (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;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — May 29/96

(Lucille Partington, Co-chair) — (Date)

Robert McLeod — May 21/96

(Robert McLeod, Co-chair) — (Date)

AN OVERVIEW OF STREAMFLOWS AND LAKE LEVELS FOR THE PEACE, ATHABASCA AND SLAVE RIVER BASINS

STUDY PERSPECTIVE

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

The objectives of the Northern River Basins Study were directed at learning more about the affects of development on the aquatic ecosystem of the Peace, Athabasca and Slave rivers and their major tributaries. In particular, attention was focused on improving what was known about the rivers, how were they being affected by development and what could be done to improve the predictive capability for assessing the effects of further development. The Study Board was confronted with a large list of issues worthy of investigation but 16 questions were presented for resolution under the science program. One of the questions requested scientists to assess the effects of flow regulation on the aquatic/riparian ecosystem. To achieve some progress in the time and resources available to the Study, investigations were focused on the Peace-Slave rivers and the influence of the W.A.C. Bennett dam on flow. A need still existed to describe the present timing and size of flows for the Study area.

This report provides background information of the hydrology and processes affecting river flows and lake levels within the mainstem portions of the Peace, Athabasca and Slave rivers and some of their major tributaries. An annotated bibliography of existing hydrological information for the Study area is provided as an appendix to the report.

Besides providing an overview on the effects of flow regulation on Peace River, the report's authors concluded that the seasonal fluctuations in water levels on Lake Athabasca have been significantly reduced since flow regulation. Similarly, the mean monthly water levels of Great Slave Lake have also changed coincident with flow regulation on the Peace River and further work is recommended.

Information from this project will be used to support preparation of a synthesis report by the Hydrology component of the science program.

Report Summary

This report provides a summary of flow and lake level information for water bodies in the Peace, Athabasca and Slave river basins to provide a hydrologic background for many of the other reports published by the Northern River Basins Study. The trends in river flows for both the main stems and significant tributaries, and for lake levels, for both natural and regulated conditions were examined. Ice processes were discussed along with some of the environmental effects. Regulation on the Peace River has altered the hydrologic regime of both the Peace and Slave Rivers, as well as the ice regime on the Peace Riveras far downstream as Fort Vermilion. Lake Athabasca and Great Slave Lake levels have also been affected by the changes in the Peace River flow regime.

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1.0 INTRODUCTION

1.1 OBJECTIVES OF THE REPORT

Streamflows and lake levels are important parameters for many of the components of the Northern River Basins Study. They have a direct effect on the water quality, aquatic and riparian habitat, sediment transport, river/delta morphology, human uses of water bodies and the water body's ability to dilute effluent. The distribution, frequency of low and high flow events, and the synchronization of these flows and lake levels with the demands on rivers and lakes are also important factors in the hydrology of the basin. The purpose of this report is to provide an overview of the streamflows and lake levels of the study area and a review of some of the factors affecting them.

1.2 STUDY AREA

The study area is bounded by Canadian Shield on the east, the Cordillera on the west and the Interior Plains which runs through the centre. The Athabasca and Peace Rivers have their sources in the Cordillera physiographic region which includes the mountains and foothills at the western edge of the study area. They flow into the Boreal Plains which are fairly flat except for several rises such as the Swan Hills, the Caribou Mountains and the Birch Mountains. Lake Athabasca is almost completely surrounded by Canadian Shield, except for the very western tip which abuts against the boreal plains. The Slave River forms a boundary between the Boreal Plains on the west and the Taiga Shield on the east (Figure 1).

The Athabasca River originates in the Columbia ice fields approximately 100 km upstream of the town of Jasper. Initially, it flows slightly northwest until it reaches the town of Jasper. At Jasper, it turns northeast and flows through Jasper Lake and Brûle Lake where it passes out of the Rocky Mountains into the foothills. Approximately 50 km upstream of Whitecourt the river turns and flows east. At this point the river flows out of the foothills and into the Boreal Plains. It follows a general east/northeast direction until it reaches the town of Athabasca where the river turns north. From the town of Athabasca it flows almost due north until it reaches Lake Athabasca. Between the town of Athabasca and the city of Fort McMurray there are 12 sets of rapids identified on 1:50,000 National Topographic Survey (NTS) map sheets. Of these, the Grand Rapids are especially important as they do not usually freeze over in the winter and provide an opportunity for reoxygenation of the river in the winter. The Athabasca River is over 1400 km in total length and it drains over 159,000 km^2.

The Peace River begins at the confluence of the Parsnip and Finlay Rivers in the Rocky Mountains of northern British Columbia. It flows north into Williston Lake (Bennett Dam Reservoir) and then turns and flows almost due east. It flows out of the Rocky Mountains into the foothills near Hudson Hope, and from the foothills to the Boreal Plains near Fort St. John. At the town of Peace River the river turns and flows almost due north to the town of Fort Vermilion. From there it flows east-northeast until it joins the Peace-Athabasca Delta. Downstream of Fort Vermilion there are two sets of rapids, the Vermilion Chutes and the Boyer Rapids. Both of these rapids freeze over in the winter. The Peace River's total length is 1650 km and it drains over 300,000 km^2.

The Slave River has its source at the confluence of the Peace River and the Riviere des Rochers. From its source it flows almost due north into Great Slave Lake. In addition to the Athabasca and Peace Rivers, the Slave basin includes the Lake Athabasca drainage area, approximately 114,000 km^2, which includes much of northern Saskatchewan. The Slave River is 420 km long and it drains a total area of over 606,000 km^2.

In the Athabasca River basin there are 36 dams that are at least 7.6 m (25 ft.) high or impound at least 62 dam^3 (50 ac-ft) of water. Of these, 19 are licenced to Ducks Unlimited for wildlife habitat enhancement where the lake level is stabilized at an optimum level for waterfowl habitat. Most of the others provide water for industrial, municipal or agricultural uses. The largest reservoir is the Paddle River dam which is operated only during high flows as a flood control dam.

Its reservoir is at least half empty the majority of the time. The combined storage of these structures is equivalent to 0.81% of the mean annual flow volume for the Athabasca River at Athabasca. In the Peace River basin in Alberta there are 64 dams that meet the same criteria. The majority of them (54) are licensed to Ducks Unlimited for wildlife habitat enhancement. Most of the others provide water for industrial, municipal or agricultural uses. The combined storage of all the licensed structures in Alberta in equivalent to 0.34% of the total annual flow at Peace River. In both basins there are also numerous weirs for the purpose of lake stabilization. Lesser Slave Lake and Lake Athabasca are the largest lakes where weirs control the lake level. The Bennett Dam in British Columbia has by far the largest effect on the Peace River flows. The combined storage of the Bennett and Peace Canyon dams is 74.22 million dam^3. This represents approximately twice the mean annual flow volume at Hudson Hope. The location of some of the major structures are shown in Figure 2.

2.0 NATURAL STREAMFLOW

The array of hydrometric monitoring stations used by water resource management agencies in the study area is referred to as the 'hydrometric network'. The hydrometric network is operated through federal/provincial cost share agreements called a Memorandum of Understanding on Water Quantity Surveys. The water data is collected by Water Survey of Canada (WSC) and provincial staff. A short description of the hydrometric network and its development follows.

The hydrometric network has evolved over time in response to the needs of resource managers and users. In 1960, the network consisted of less than 50 stations that had been established for the purpose of determining the viability of power developments, water supplies and navigation routes. Since then, it has expanded to over 200 stations to meet the demands of the expanding oil and gas industry, pollution control, flood forecasting and environmental impact assessment such as impacts related to the WAC Bennett Dam. The need for hydrometric information has continued to grow and in 1995 there were approximately 190 river discharge stations and 37 water level stations in operation (Figure 3).

The expansion of the hydrometric network, which has grown more as an ad hoc response to specific needs rather than a strategic response, has tended to be inefficient, incomplete and uncoordinated (MRBC, 1981). In spite of this comment, the authors of the final report of the Mackenzie River Basin Study only recommended 8 additional hydrometric gauging stations be added to fill in the gaps in the network. The purpose of the recommended stations would be to provide data for bio-physically unique area of the basins where no data was available. Since these recommendations were submitted, three of the recommended stations have been built.

Table 1: Description of Selected Hydrometric Stations in the Athabasca, Peace and Slave River Basins

STATION NAME	STATION NUMBER	PERIOD OF RECORD	DRAINAGE AREA (km^2)
Athabasca River Basin			
Athabasca River near Jasper	07AA002	1913 - 31, 70 - 93	3880
Athabasca River at Entrance / Hinton	07AD001/	1915 - 39, 55 - 61	9530/
	07AD002	1961 - 93	9780
Athabasca River near Windfall	07AE001	1960 - 93	19600
Athabasca River at Athabasca	07BE001	1913 - 31, 38 - 93	74600
Athabasca River below McMurray	07DA001	1957 - 93	133000
Mcleod River near Whitecourt	07AG004	1968 - 93	9100
Pembina River at Jarvie	07BC002	1957 - 93	13100
Lesser Slave River at Hwy #2A	07BK006	1962 - 88	14400
Clearwater River at Draper	07CD001	1930 - 31, 53, 57 - 93	30800
Peace River Basin			
Peace River at Hudson Hope	07EF001	1917 - 22, 49 - 93	69900
Peace River at Peace River	07HA001	1915- 32, 57 - 93	186000
Peace River at Peace Point	07KC001	1959 - 93	293000
Pine River at East Pine	07FB001	1961 - 93	12100
Smoky River at Watino	07GJ001	1915 - 22, 55 - 93	50300
Wabasca River at Wadlin Lake Rd	07JD002	1970 - 93	35800
Slave River Basin			
Slave River at Fitzgerald	07NB001	1921- 22, 30,31,53-93	606000

Table 1 lists the hydrometric gauging stations that are used in the following analysis along with their period of record and drainage area. These stations were chosen from the more than 300 active and discontinued stations in the study area. The mainstem stations on the Peace, Athabasca and Slave Rivers were chosen to give the reader an understanding of the variability of flows between the headwaters and the mouth of each river system. The tributaries were selected to give an understanding of the relative importance of each of the tributaries and their effects on the mainstem flows. The stations selected are all stations with lengthy periods of record which allows added confidence to the analyses performed.

The analyses will include comparisons of runoff volumes and yields from the various parts of the basin and the monthly distribution of this runoff. As well peak flows and low flows are compared. The effect of lakes, deltas, and ice on the flow regime will also be discussed.

2.1 BASIN RUNOFF

2.1.1 ANNUAL RUNOFF VOLUMES

The rivers of the study area drain an area of over 606,000 square kilometres. The total annual volume of runoff is over 100 million cubic decametres. Figures 4 and 5 give a graphical representation of the annual runoff volume on the mainstem and the tributaries described in the previous section. From Figure 5 it can be seen that approximately 60% of the total annual runoff at Fitzerald comes from the Peace River and its tributaries. The remainder of the annual runoff is contributed by the Athabasca River (20%), Lake Athabasca and its tributaries, and a small amount from the tributaries of the Slave River.

The four major tributaries of the Athabasca River (McLeod River, 10%, Pembina River, 6%, Lesser Slave River, 8%, Clearwater River, 18%) together account for slightly less than half of the total Athabasca River flow as measured at Athabaca River below McMurray (Figure 4). The three major Peace River tributaries (Pine River, 10%, Smoky River 13%, Wabasca River 7%)

contribute approximately one third of the total Peace River flow at Peace Point (Figure 5).

2.1.2 RUNOFF DEPTH

Runoff depth or yield is a term used when comparing the water yielding properties of different watersheds. It is a summation of flows from a watershed over a given period of time, in this case, one year, divided by the area contributing to the flow. Using this, the yield of a basin can be calculated and compared to other basins of different sizes. From Figures 6 and 7 it can be seen that the watersheds (Pine River and the upper Athabasca River) in the western portion of the basin that have a major part of their flow coming from the mountain areas yield more than twice as much flow per unit area as the other tributaries (Table 2). Several phenomena combine to cause this effect. First, the slopes of the tributaries are usually much steeper than the mainstem which contributes to a quicker response. The soils in the mountain regions are generally less porous and consequently a greater fraction of the melt/rain water runs off. Additionally, the western portions of the basin receive greater amounts of precipitation (Figures 8 and 9).

2.1.3 MONTHLY STREAMFLOW VARIATION

The flow regime of the stations analyzed are quite similar to each other and typical of northern rivers. Although every river is different, by typical it is meant that the volume of the discharge increases rapidly in the spring, reaching its peak usually in June or early July and then recedes until February when the cycle begins again.

The majority of the annual flow volume occurs during the late spring/early summer months with 43 to 65% occurring in the May to July period. Up to 30% of the annual volume can occur in the month of June alone. The January to March period typically has the lowest volume with only 3 to 10% occurring during this period. The entire month of February can carry as little as 1% of the annual flow volume (Figures 10 and 11). Figure 12 illustrates the change in flow distribution on the Peace and Slave Rivers due to flow regulation. The change in flow distribution is most pronounced closest to the dam as the flow volume at Hudson Hope for the May - July period dropped from about 63% of the total annual flow for pre-regulation conditions to approximately 20% for post-regulation conditions. Similarly, the winter flows have increased with the change most evident at Hudson Hope with smaller differences at downstream stations. The decreasing differences in flow distribution in the downstream direction reflects the increased contribution from tributaries which diminishes the effect of the dam operation.

2.2 FLOODS

The cause of floods can be broken down to two mechanisms, meteorological and physical. The meteorological causes include snowmelt, major weather systems and local convective events or thunderstorms. The most common physical causes are ice jams or blockages by logs or debris. Prowse et al (1995) describes many of the flooding mechanisms in the basins in detail.

Much of the runoff in the basins comes from the melting of the winter snow pack in the spring. This melting is often accelerated by a rainfall on the snowpack. Table 2 shows that almost all of the historical recorded peak daily flows have occurred during the month of June. This is when the runoff from the mountain snowmelt goes through the basin. The tributary streams that do not have their headwaters in the mountains tend to have their peak flows earlier in the year because the snowpack usually melts earlier in the foothills and on the prairie.

Floods can also be caused by warm moist air moving into the basin. These air masses drop their moisture as they cool or as they are lifted when they move to higher elevations at the western side of the basins. These storms can produce large accumulations of precipitation over large areas. Thunderstorms may also cause floods in the basin. These storms can be extremely intense, but of relatively short duration and tend to affect a small area. The floods caused by thunderstorms tend to be seen on the tributaries rather than on the main stem of the rivers.

Table 2: Peak Discharge and Yield for Selected Stations in the Athabasca, Peace and Slave River Basins

STATION NAME	Station Number	Average Peak Discharge (m^3/s)	Peak Yield ($m^3/s/km^2$)	Highest Recorded Discharge (m^3/s)	Date
Athabasca River near Jasper	07AA002	445	11.47	642	June 1984
Athabasca River at Entrance, Hinton	07AD001/ 07AD002	830	8.49	1200	June 1972
Athabasca River near Windfall	07AE001	1226	6.26	2070	June 1960
Athabasca River at Athabasca	07BE001	2082	2.22	5440	June 1954
Athabasca River below McMurray	07DA001	2590	1.36	4700	July 1971
Mcleod River near Whitecourt	07AG004	574	2.79	1780	June 1980
Pembina River at Jarvie	07BC002	291	1.95	974	Apr 1974
Lesser Slave River at Hwy #2A	07BK006	90	6.31	146	July 1979
Clearwater River at Draper	07CD001	419	0.63	790	Apr 1974
Peace River at Hudson Hope	07EF001	3931	5.62	8810	June 1964
Peace River at Peace River	07HA001	7769	4.18	16500[1]	June 1990
Peace River at Peace Point	07KC001	7087	2.42	12600	June 1990
Pine River at East Pine	07FB001	1657	13.69	3960	July 1965
Smoky River at Watino	07GJ001	2756	5.48	8620	June 1990
Wabasca River at Wadlin Lake Rd	07JD002	618	1.73	1690	Apr 1974
Slave River at Fitzgerald	07NB001	6928	1.14	11200	Apr 1974

[1] the highest stage recorded at Peace River occurred in February 1992 due to an ice jam event

Floods caused by icejams or logjams are usually associated with one of the above events. The blockage elevates the water elevation above would have normally occurred under open water conditions. The floods caused by blockages do not necessarily coincide with peak flows but may cause extremely high local water levels. Many of the blockages occur at man made structures such as road or railway crossings (bridges, culverts), and also may occur at natural constrictions or tight bends in the river.

Human activity in the basin has caused flood levels to increase in some instances and to decrease in others. The town of Peace River experienced a major flood during the winter of 1992 which may have been aggravated by the higher than natural winter flows from the Bennett Dam coupled with unusually warm weather which caused the Peace River to breakup and form an ice jam at the town of Peace River. This raised the water levels high enough to overtop dykes designed to protect against the 1:100 year open water flood and flooded many areas of town. The 1:100 year flood is defined as the flood that has a 1% chance of occurring in any one year. This was the historic high water elevation for the Peace River at the town of Peace River. On the other hand, it is postulated that the lack of flooding in the Peace - Athabasca Delta is caused by a reduction in the number of major ice jams on the Peace River near the delta (Prowse et al, 1995). This reduction in ice jams may be the result of the changed flow regime attributed to the operation of the Bennett Dam.

The flood event characteristics listed in Table 2 show some interesting spatial characteristics of large rivers systems. It would be expected that the stations with larger drainage areas would have the largest peak discharges. This assumption is correct for the Athabasca River (Figure 13), but on the Peace River the magnitude of the peak discharge increases only as far downstream as the town of Peace River (Figure 14). The mean annual peak at Peace Point is 10% less than Peace River but the drainage area is more than 50% larger. This is an example of how a very long channel can attenuate a peak by temporally storing water in the channel. The next downstream station at Fitzgerald has a drainage area more than double that of Peace Point, but the peak discharge is slightly smaller. This shows the large dampening capacity of the Lake Athabasca Peace - Athabasca Delta system. The data for the Lesser Slave Lake station gives us some indication of the dampening effect that a lake can have on the magnitude of the peak flow. The stations on the Pembina and Pine rivers have slightly smaller drainage areas but the mean annual peaks are 3 and 18 times larger than the mean annual peak on the Lesser Slave River (Figures 6 and 7).

3.0 LAKE AND DELTA EFFECTS

Lakes and deltas have a significant effect on the flow regime of a river system. Lakes and deltas have the ability to reduce the peak flows and vary the distribution of flows. As well, they can stabilize the temperature, remove sediment, and change water quality. This is demonstrated by the lake or delta's ability to receive large volumes of inflow, store it and then release it over a period of days to months. The time over which the stored water is released depends on the size of the lake and the type of outlet. In the NRB study area, there are three major lake systems that significantly modify the flow. Lesser Slave Lake on the Athabasca River system, Williston Lake on the Peace and the Lake Athabasca - Peace-Athabasca Delta system which modifies both the Peace and Athabasca River flows as they flow downstream to the Slave River. Great Slave Lake forms the downstream boundary of the study area.

Lesser Slave Lake affects the flows in the Athabasca River by reducing the magnitude of the peaks into the Lesser Slave River by dampening the outflow (Figure 13). As mentioned previously, the Lesser Slave River has a daily peak discharge much lower than other basins of similar size. The peak monthly flow occurs in July. This has the effect of supplementing the Athabasca River flows after the flows from other tributaries has started to recede.

The other major lake in the study area is Williston Lake. The outflow from Williston Lake is controlled by the Bennett Dam and therefore its effect can be more complex. The mean monthly lake level for the Williston Reservoir can vary by 10 metres or more for a given month (Table 3, Figure 15). This is because the outflow from the dam is dictated by electrical generation concerns rather than hydrologic conditions upstream. The effect of regulation on the mean monthly lake levels for Lake Athabasca and Great Slave Lake can be seen by regulation can be seen in Table 3 and Figures 16 and 17.

Table 3: Mean Monthly Lake Levels for Large Lakes in the Slave River Basin

LAKE NAME	STATION No.	DRAINAGE AREA (km^2)	PERIOD OF RECORD		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Williston Lake at Lost Cabin Creek (assumed datum)	07EF002	69900	1976-93	Maximum	39.313	37.661	37.134	36.749	36.541	37.427	40.499	42.170	42.188	42.028	41.841	40.952	39.218
				Mean	34.656	33.866	32.114	30.438	28.953	30.063	34.977	38.137	39.036	38.850	38.124	37.177	35.565
				Minimum	30.653	30.207	28.224	26.485	24.719	25.813	30.884	33.933	33.654	33.120	32.618	32.425	31.574
Lesser Slave Lake at Faust	07BJ002	13600	1923-31, 33-49, 51-1993	Maximum				576.338	576.360	577.832	578.080	578.220	578.255	578.051	577.803		
				Mean				576.151	576.124	576.628	576.836	576.863	576.973	576.891	576.732		
				Minimum				576.023	575.855	575.840	575.910	576.040	575.953	575.980	576.017		
Lake Claire-Prairie River	07KF002		1970-93	Maximum	210.352	209.189	209.145	209.169	209.276	209.404	209.832	209.829	210.509	210.352	210.148	209.337	209.220
				Mean	208.987	208.883	208.889	208.916	209.004	209.078	209.283	209.267	209.361	209.262	209.192	208.994	209.041
				Minimum	208.342	208.553	208.506	208.483	208.528	208.823	208.774	208.794	208.633	208.521	208.495	208.342	208.682
Lake Athabasca at Crackingstone Point*	07MC003	271000	1956-66 pre-reg	Maximum	209.285	208.982	208.718	208.459	208.365	209.243	210.009	210.445	210.437	210.100	209.774	209.410	209.152
				Mean	209.094	208.649	208.460	208.188	208.184	208.737	209.506	209.886	209.731	209.386	209.011	208.721	208.724
				Minimum	208.836	208.168	208.141	207.951	208.021	208.297	208.937	209.308	209.109	208.697	208.400	208.163	208.289
			1972-93 post-reg	Maximum	209.252	209.049	208.913	208.768	208.739	209.483	210.100	210.081	209.981	209.653	209.507	209.295	209.126
				Mean	208.831	208.586	208.496	208.427	208.403	208.837	209.135	209.301	209.302	209.124	208.944	208.746	208.681
				Minimum	208.341	207.988	207.975	207.971	207.959	208.303	208.485	208.726	208.706	208.481	208.227	208.061	208.000
Great Slave Lake at Yellowknife Bay*	07SB001		1934-66 pre-reg	Maximum	156.87	156.785	156.801	156.802	156.803	156.86	156.96	157.106	157.164	157.134	156.993	156.886	156.788
				Mean	156.632	156.511	156.508	156.492	156.461	156.535	156.738	156.853	156.872	156.791	156.664	156.563	156.518
				Minimum	156.301	156.195	156.172	156.158	156.139	156.175	156.379	156.536	156.517	156.426	156.311	156.229	156.181
			1972-93 post-reg	Maximum	156.777	156.761	156.782	156.857	156.914	157.014	157.018	156.994	156.985	156.885	156.782	156.725	156.728
				Mean	156.683	156.581	156.626	156.675	156.695	156.731	156.794	156.809	156.771	156.666	156.576	156.507	156.508
				Minimum	156.442	156.242	156.31	156.385	156.393	156.44	156.441	156.425	156.38	156.276	156.249	156.198	156.225

Note: Blank values mean insufficient data was available to determine the value

* the period 1967-71 was not included since the Williston Reservoir was being filled at that time

4.0 EFFECTS OF REGULATION ON STREAMFLOW

4.1 HISTORICAL PERSPECTIVE

In 1967, the British Columbia government initiated construction of the Bennett Dam on the Peace River, creating the Williston Reservoir. By the end of 1971, the reservoir was full. The dam was constructed to support the generation of power. Flows on the Peace River are stored in Williston Lake during the spring and early summer months to support the higher than natural flow releases required for power generation throughout the winter months during years of high demand for power. River regulation has flattened the Peace and Slave River hydrographs compared to the natural hydrographs (Figures 18 to 21).

4.2 EFFECTS

Between 1968 and 1971, when Williston Lake was being filled, the reduced flows on the Peace River significantly reduced water levels in the Peace-Athabasca Delta. The governments of Canada, Alberta and Saskatchewan established the Peace-Athabasca Delta Project (PADP) Group in 1971 to determine immediate means for raising the water levels of Lake Athabasca and the delta lakes. In the fall of 1971, a temporary dam was constructed at the outlet of Mamawi Lake. This interim measure raised water levels throughout 60 percent of the delta.

The PADP Group also undertook an intensive research program to find a longer term solution to restoring water levels in the delta to approximately what would have occurred under natural conditions. A permanent rock weir, ancillary fish bypass channel and boat tramway were completed on the major outflow channel from Lake Athabasca in September 1975. By March of

1976, a rock weir was completed on a minor Lake Athabasca outlet channel and the temporary dam at the outlet of Mamawi Lake was removed (Figure 3).

The effect of regulation on streamflow is only a re-distribution of the natural streamflow hydrograph. However, because the water flow is the engine that drives the other processes in the riparian environment, a change in the flow regime can in turn, affect every other component in that environment. To provide an indication of the effects of regulation on streamflow, the recorded flow data from 1972 to 1993 are compared to natural streamflow estimates. Natural flows for the Peace River at Hudson Hope, at Peace River at Peace Point were recorded or computed for the years 1960 to 1991 (Aitken and Sapach, 1994). Computed natural flows were a co-operative effort between B.C. Hydro, Alberta Environmental Protection and Environment Canada. Natural flows for the Slave River at Fitzgerald were recorded or computed by Environment Canada for the years 1960 to 1984, for studies related to the Peace-Athabasca Delta (Table 4; Figure 22).

4.3 COMPARISON OF NATURAL AND REGULATED FLOWS

In general, regulated streamflows exceed natural streamflows for the months October to April and regulated streamflows are less than natural streamflows for the months May to September. Table 4 compares the mean monthly and mean annual regulated flows to natural flows at various sites along the Peace and Slave Rivers. River regulation tends to flatten the annual hydrograph along the rivers, but the effect diminishes further downstream (Table 4, Figures 18 to 22).

4.4 REGULATED FLOOD FLOWS

The influence of regulation on flood flows is greatest immediately below the Bennett Dam and decreases in the downstream direction. Table 5 gives recorded flood flow characteristics for several stations along the Peace and Slave Rivers.

Table 4: Comparison of Natural and Regulated Mean Monthly Streamflows (m^3/s)

Month	Peace River at Hudson Hope 07EF001		Peace River at Peace River 07HA001		Peace River at Peace Point 07KC001		Slave River at Fitzgerald 07NB001	
	Nat[1]	Reg[2]	Nat	Reg	Nat	Reg	Nat	Reg
January	288	1350	446	1520	529	1570	1400	2300
February	254	1280	409	1470	474	1530	1190	2280
March	246	1200	401	1410	1455	1460	1010	2130
April	493	1170	1280	1990	1030	2030	1500	2510
May	2360	930	4250	2820	4280	3460	5290	4670
June	3900	875	6350	3100	6560	3660	7470	5230
July	2100	966	3730	2370	4500	2930	6920	4920
August	1040	953	1950	1800	2390	2130	5220	4260
September	817	1070	1390	1580	1650	1780	4340	3800
October	832	1240	1330	1690	1520	1860	3920	3630
November	562	1380	861	1640	1070	1670	2560	2680
December	345	1440	514	1610	607	1640	1490	2280
Annual	1110	1150	1910	1920	2090	2150	3550	3390

[1] Nat - natural

[2] Reg - regulated

Based on the mean maximum daily discharges, flood peaks are generally reduced along the Peace, downstream of the town of Peace River, and Slave Rivers due to regulation (Tables 2, 5). However, based on the maximum annual daily discharges recorded, major floods can occur under regulation. The largest flood peaks on the Peace River are generally produced when the runoff from mountain snowmelt combines with runoff from heavy rainfall in the foothills region of the basin. The foothills region, which is located below the Bennett Dam, produces significantly higher peak flow yields than the mountain region. Therefore, even though water is being stored in the Williston Reservoir from the mountain region during this type of flood event, the reduction in the flood peak becomes less significant as the runoff yields in the downstream area increase.

Table 5: Comparison of Regulated and Natural Maximum Daily Flows (Aitken and Sapach, 1994)

Station Name	Station Number	Mean Maximum Recorded Daily Discharge (m^3/s)		Maximum Recorded Daily Discharge (m^3/s)	
		Natural	Regulated	Natural	Regulated
Peace River at Hudson Hope	07EF001	6160	2050	8810	5130
Peace River at Peace River	07HA001	9160	6460	13300	16500
Slave River at Fitzgerald	07NB001	7720	6560	8950	8830

The weirs built on the outflows channels of Lake Athabasca have an insignificant effect on Slave River regulated flows (Table 6). The simulated regulated Slave River mean monthly flows for the years 1960 to 1984, shown in Table 6, were derived for studies related to the Peace-Athabasca Delta.

The Slave River is further influenced, for both the natural and regulated condition, by the Peace-Athabasca Delta. The predominant direction of streamflow from the delta is northward, towards the Peace River. However, during spring or summer flooding, the elevation of the Peace River may exceed that of Lake Athabasca and result in peak flows from the Peace River being stored in the delta. Consequently, peak flood flows on the Slave River are significantly less than those of the Peace River, even though the Slave River drains an area of about double the area draining to the mouth of the Peace River.

4.5 NATURAL AND REGULATED LOW FLOW RUNOFF EVENTS

A hydrologic parameter that has become synonymous with water quality evaluations of rivers is the term "7Q10". This term represents annual minimum 7-day average discharge at a particular location along a river. Flows less than the 7Q10 would be expected to occur in only 10% of the years, or the 7Q10 discharge would be equalled or exceeded in 90% of the years. Table 7 describes the 7Q10 and Minimum Daily flows for selected unregulated streams in the study area, and Table 8 gives regulated 7Q10 estimates for the Peace and Slave Rivers predicated on the assumption that regulation in the future will be similar to what has occurred from 1972 to 1993. The table also provides minimum daily flows that have been recorded during this period.

Table 6: Effect of Lake Athabasca Regulation on Slave River Mean Monthly Flows (simulated for the period 1960 to 1984)

Month	Slave River Regulated Mean Flow (m^3/s)	
	Without Weirs	**With Weirs**
January	2050	2200
February	1960	2150
March	1900	2090
April	2410	2580
May	5190	5140
June	5690	5700
July	5470	5340
August	4690	4360
September	4120	3850
October	3870	3680
November	2720	2800
December	2030	2190

Regulated flows, such as those on the Peace River, do not meet the criteria for natural flow analyses where the variable of interest is generally a random independent event. This is because a hydro-electric power development such as the Bennett Dam is operated in accordance to the demand for electricity and other management considerations, and not in response to hydrologic conditions. For example, extreme short duration low flows may be possible due to emergency turbine shut-downs. Such extremes in operation cannot be associated with a probability distribution.

Table 7 : Natural Low Flow Estimates

Station Number	Station Number	7Q10 (m^3/s)	Minimum Daily (m^3/s)
Peace River Basin			
Wapiti River near Grande Prairie	07GE001	6.86	4.02
Smoky River at Watino	07GJ001	22.9	14
Athabasca River Basin			
Athabasca River at Hinton	07AD001	16.7	7.08
Athabasca River near Windfall	07AE001	28.6	19.3
Athabasca River at Athabasca	07BE001	51.1	42.2
Athabasca River below McMurray	07DA001	109	88.6

4.6 REGULATED PEACE-ATHABASCA DELTA WATER LEVELS

In 1985, comparative water level simulations for Lakes Athabasca, Claire and Mamawi for the natural regime, the Bennett Dam without weirs and the Bennett Dam regime with weirs were completed for the Peace-Athabasca Delta. The results indicated that Lake Athabasca's average water levels during the summer growing season (May 15 to August 15) with the weirs in place are about 0.1 metres above the natural average (Figure 23). Peak summer levels are less than 0.1 metres below the natural average. The mean variation of summer levels is reduced from 0.5 to 0.3 metres for both the regulated condition with weirs and without. When compared to the long-term

Table 8: Regulated Low Flow Estimates (m^3/s)

Station Name	Station Number	7Q10 (m^3/s)	Minimum Daily (m^3/s)
Peace River at Hudson Hope	07EF001	238	175
Peace River at Peace River	07HA001	624	500
Peace River at Peace Point	07KC001	734	480
Slave River at Fitzgerald	07NB001	1340	1090

summer average Lake Athabasca level, the simulated natural levels are slightly lower and the simulated levels with the weirs are slightly higher.

Curves illustrating the duration of daily water levels for Lakes Athabasca, Claire and Mamawi are provided in Figure 24. The curves show the percentage of time that specific levels are equalled or exceeded. The duration curves, like the hydrographs, illustrate that the amplitude of annual water levels has been significantly reduced by regulation. The duration curves also show that the peak Lake Athabasca levels are virtually restored under the existing regime. The lake levels above elevation 209.9 metres are exceeded only 1-2% less frequently than under the natural regime.

5.0 ICE EFFECTS

5.1 LAKES

Typically in mid to late summer, deep lakes, such as Lake Athabasca, will have a temperature gradient with the coldest water at the bottom of the lake and the warmest at the surface. This condition is referred to as temperature stratification or thermal density stratification. It is caused by the surface layer being heated by solar radiation and the higher air temperatures throughout the summer. The density of water is at a maximum at 4°C. Consequently, water that is warmer or colder than 4°C will float above this water. In a deep lake at the end of the summer, the warmest water will be at the surface and the coolest water will be at the bottom. In the fall, as the surface water cools, it becomes denser and sinks to the bottom of the lake, displacing the warmer, lighter water. This circulation is called fall turnover. There is also a similar spring turnover when the surface water warms up to 4°C and sinks displacing the colder (2-3°C), lighter water at the lake bottom. The fall turnover is an important contributor to re-oxygenation of the deeper water. The surface water will continue to cool and its temperature will drop below 4°C. Since water is lighter at this temperature, it will float on top of warmer heavier water. Consequently, in a deep lake there will usually be a layer of water at the bottom of the lake where the temperature is about 4°C which has had an infusion of water with a relatively high dissolved oxygen concentration where fish and other aquatic organisms can over winter. The completeness of the turnover is dependent on slow cooling in the fall or heating in the spring occurring along with sufficient wind to stimulate mixing between the thermal layers. Fast cooling or warming with little wind does not allow enough time for complete mixing of the lake.

As the lake cools further, ice formation usually begins in calm areas where a thin supercooled layer forms. The term supercooled refers to a situation where the water temperature is less than 0°C. A thin film of ice forms on the lake surface. The density of ice is less than that of water and so it floats. The ice sheet grows downward from the surface in response to the climatic conditions. In this way, the lake has an insulating layer that thickens in response to colder weather and allows the water beneath it to remain in its liquid state over the winter. Snowfall on the ice will also add insulation value. The water immediately under the ice will have a temperature of about 0°C.

5.2 RIVERS

In rivers, the water temperature is usually fairly constant throughout the flow due to mixing caused by the river turbulence. When the water becomes supercooled, frazil ice crystals appear throughout the flow. The frazil crystals would typically be ice discs that have a diameter of 1 mm or less. In super cooled water frazil particles will adhere to each other to form flocs, to rocks in the bed to form anchor ice, to water intakes, blocking them partially or completely, and to other structures. The flocs float to the water surface where they are referred to as floes. Initially the floe is basically floating slush, but once on the water surface the floe begins to freeze. The floating floes eventually lodge at some point in the river and floes start to accumulate. The ice sheet grows upstream as more floes accumulate. The floes freeze together to form the ice cover. This is often referred to as a freeze up ice jam. Once the ice cover has established itself, the ice sheet thickens by heat loss. The ice sheet also insulates the water keeping the water temperature at 0°C or higher and frazil production drops to zero except where there is open water.

The lodgements tend to occur at the same locations year after year. Tight bends, changes in river slope (confluences with other river and lakes) and where islands and bars present are prime locations for ice lodging.

Initially the river ice cover is fairly rough on the bottom and it can be a significant impedance to the flow. This results in lower river velocities and increased depth of flow. Over a few days, the flow can be significantly reduced. Over time, the bottom of the ice cover will be smoothed by the flow. On a river, the ice cover types formed are referred to as either juxtaposed or consolidated. A juxtaposed ice cover is formed when the accumulating ice floes remain flat on the water surface and an ice sheet one floe thick is formed. A consolidated ice cover is formed when the upstream forces on an ice cover do not allow the floes to remain flat and the floes under turn and submerge to form a thicker ice cover to resist these forces. Increased winter flows, such as those resulting from flow regulation, can increase these forces and create a consolidated ice cover where a juxtaposed one existed naturally. On the Peace River, the increase in water elevation from a juxtaposed ice cover is typically less than 2 m while a consolidated ice cover can increase it by up to 5 m. Increased river levels can also lead to increased ground water levels along the margins of the river (Andres, 1994).

The ice sheet can seal the river or lake off from the atmosphere. This prevents re-oxygenation of the water and can result in dissolved oxygen concentrations dropping to levels where fish and other aquatic organisms have reduced survival rates. Open water areas where ice does not form will allow local re-oxygenation of the water. Sites where this can occur are at rapid sections, effluent outfalls, concentrated ground water inflow points and river reaches downstream of lakes and reservoirs. In very cold winters some of these sites could freeze over or have reduced open water surface area and thus reduce the amount of re-oxygenation possible. Under clear ice with no snow cover, photosynthesis may take place. In the early spring this can make a significant contribution to the dissolved oxygen concentrations if there is sufficient light penetration (Noton and Allan, 1994). The most critical time for dissolved oxygen levels tends to be in late February, just before breakup and the initiation of photosynthetic activity.

The two critical times for ice in a river are at freeze up and break up. Freeze up has already been discussed and break up will be described here. There are two different modes of break up, thermal and mechanical. In a thermal break up the ice basically melts in place with few problems. There is little or no increase in water level caused by this type of break up. Any increase in water level would be due to increased inflow from runoff.

Normally, the floating ice cover can accommodate minor changes in discharge. However, should a dramatic increase in discharge occur, then a mechanical break up can be initiated. In a mechanical breakup the ice is still relatively strong and an increase in flow causes the ice to break into chunks. Because the ice is fairly strong it will jam if conditions are right. The locations of jams tends to be the same ones where lodgement of the ice floes occurs at freeze up. Although the discharge is relatively low compared to open water values, because of the roughness and the thickness of the ice accumulation and the actual obstruction of the channel by the ice, water levels can be dramatically higher. Also, the ice jam can form, dam up water and then break and send a surge of water down the river. Ice jams can be important for flooding perched water bodies that depend on this type of mechanism for recharge. Normally, break up jams only last a few days to a week and then either melt out or break up.

The average freeze up and breakup dates for WSC gauges along the Peace and Athabasca Rivers are shown in Tables 9 and 10. It can be seen that generally speaking the ice cover arrives earliest and remains the longest at the downstream gauges.

The freeze up and breakup dates for the Peace River were determined by examining the water level charts from the WSC stations along the river. A sudden increase in water level during freeze up or a sudden drop in the water level during breakup would identify the exact date for freeze up and breakup respectively. The freeze up and breakup dates on the Athabasca River were determined from the records where the WSC operator first noticed a significant backwater increase or decrease due to ice action (Table 10). This method is not as accurate as examining the charts but should only be out by a few days for any particular site.

Table 9: **Pre and Post-regulation Ice Statistics for the Peace River** (α=0.05; Prowse et al, 1995)

	Pre-regulation			Post-regulation			
Station Name	**Average Freeze up Date**	**Average Breakup Date**	**Average Duration of Ice Cover (days)**	**Average Freeze up Date**	**Average Breakup Date**	**Average Duration of Ice Cover (days)**	**Comments**
Peace River at Hudson Hope 07EF001	N/A	N/A	141	N/A	N/A	no ice	significant change
Peace River at Taylor 07FD003	N/A	N/A	158	N/A	N/A	no ice	significant change
Peace River at Dunvegan 07FD003	N/A	Apr. 27	N/A	N/A	N/A	N/A	insufficient data
Peace River at Peace River 07HA001	Dec. 11	*May 2*	*126*	Jan. 1	*Apr. 10*	*98*	significant change in freeze-up dates
Peace River at Fort Vermillion 07HF001	Nov. 15	Apr 29	172	N/A	Apr 24	N/A	significant change in break-up dates
Peace River at Peace Point 07KC001	Nov. 15	May 2	169	Nov. 20	Apr. 28	160	no significant change from pre-regulation values

Regulation of the Peace River has significantly affected the freeze up and breakup dates and the ice duration for sites at Fort Vermilion and upstream (Table 9). The effect of the Bennett Dam on the ice regime is most pronounced closest to the dam. The Peace River at Hudson Hope and at Taylor has not had an ice cover in winter since the dam went into operation. Typically , the furthest upstream the ice front grows now (post-regulation) is between Dunvegan and the Alberta/B.C. border in an average year. The ice front may extend upstream of the B.C. border once every five years on average. Peace River at Peace River has had a significant change in freeze up and breakup dates, while the dates for the Peace River at Peace Point have not changed significantly (Table 9).

Table 10: Ice Statistics for the Athabasca River

Station Name	Station Number	Average Freeze up Date	Average Breakup date	Average Duration of Ice Cover (days)
Athabasca River near Jasper	07AA002	Nov 12	Mar 21	128
Athabasca River at Hinton	07AD002	Nov 10	Apr 7	149
Athabasca River near Windfall	07AE001	Nov 6	Apr 21	169
Athabasca River at Athabaca	07BE001	Nov 8	Apr 20	164
Athabasca River below MacMurray	07AD001	Nov 3	Apr 24	173

One consequence of river regulation is that there is open water downstream of the dam all winter long. This means that there will be continuous frazil ice production all winter long also. Once frazil flows under the ice, it is not so sticky, but it will deposit in slower moving areas of the flow, somewhat similar to sediment deposition. These locations can be important overwintering sites. Thus, the frazil deposition can result in reduced over wintering habitat for aquatic organisms (Prowse et al, 1995).

6.0 SUMMARY

1. River regulation on the Peace River has significantly altered the annual hydrologic regime of both the Peace and Slave Rivers. The hydrographs have been significantly flattened by river regulation. The effect is most pronounced closest to the dam, but is still discernable on the Slave River.

2. The ice regime of the Peace River has been significantly altered by river regulation at least as far downstream as the town of Fort Vermilion. At Fort Vermilion there has been a significant change in the breakup dates, but not in the freeze up dates, although this may be mainly due to lack of data. There was no significant change in the freeze up or breakup dates at Peace Point.

3. While the mean water elevation of Lake Athabasca has not changed significantly from the post-regulation condition compared to pre regulation, the fluctuations in water elevation have been significantly reduced.

4. The mean monthly water levels of Great Slave Lake show a change from the pre-regulated condition compared to the post-regulation condition. The differences should be investigated in greater detail to determine the effect that flow regulation on the Peace has had on Great Slave Lake.

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FIGURES

Figure 1

Northern River Basins Study

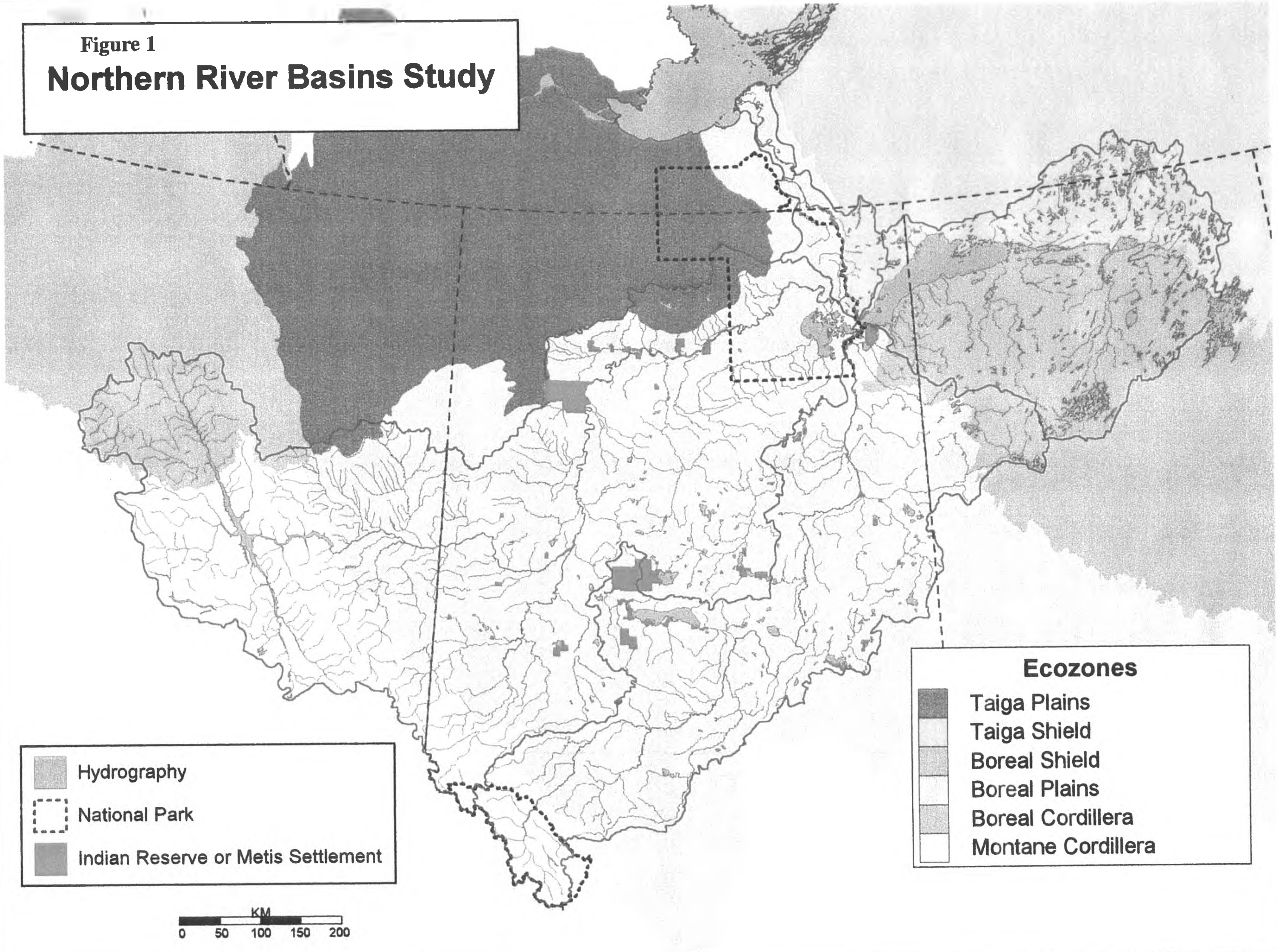


Figure 2

Water Control Structures

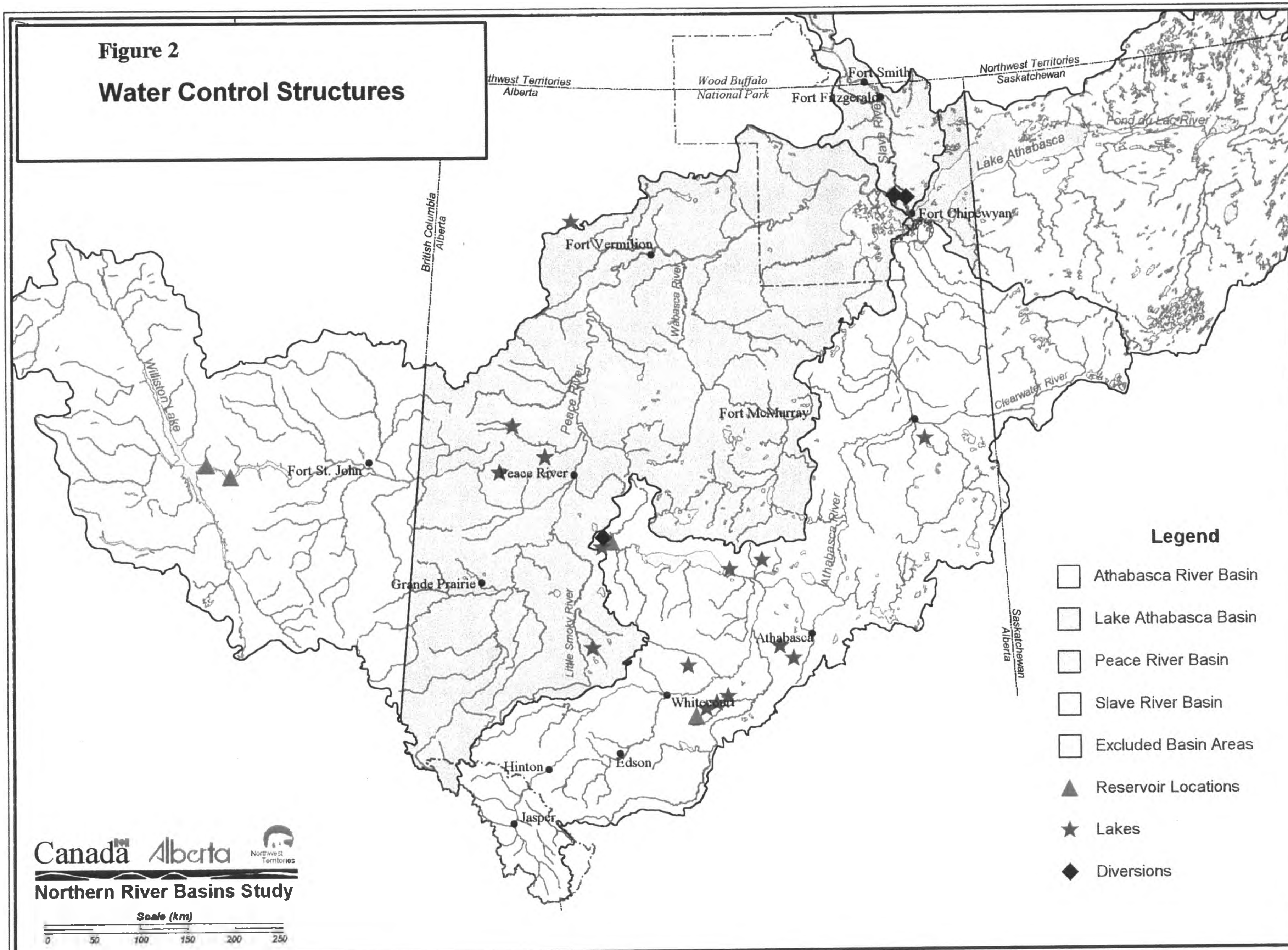
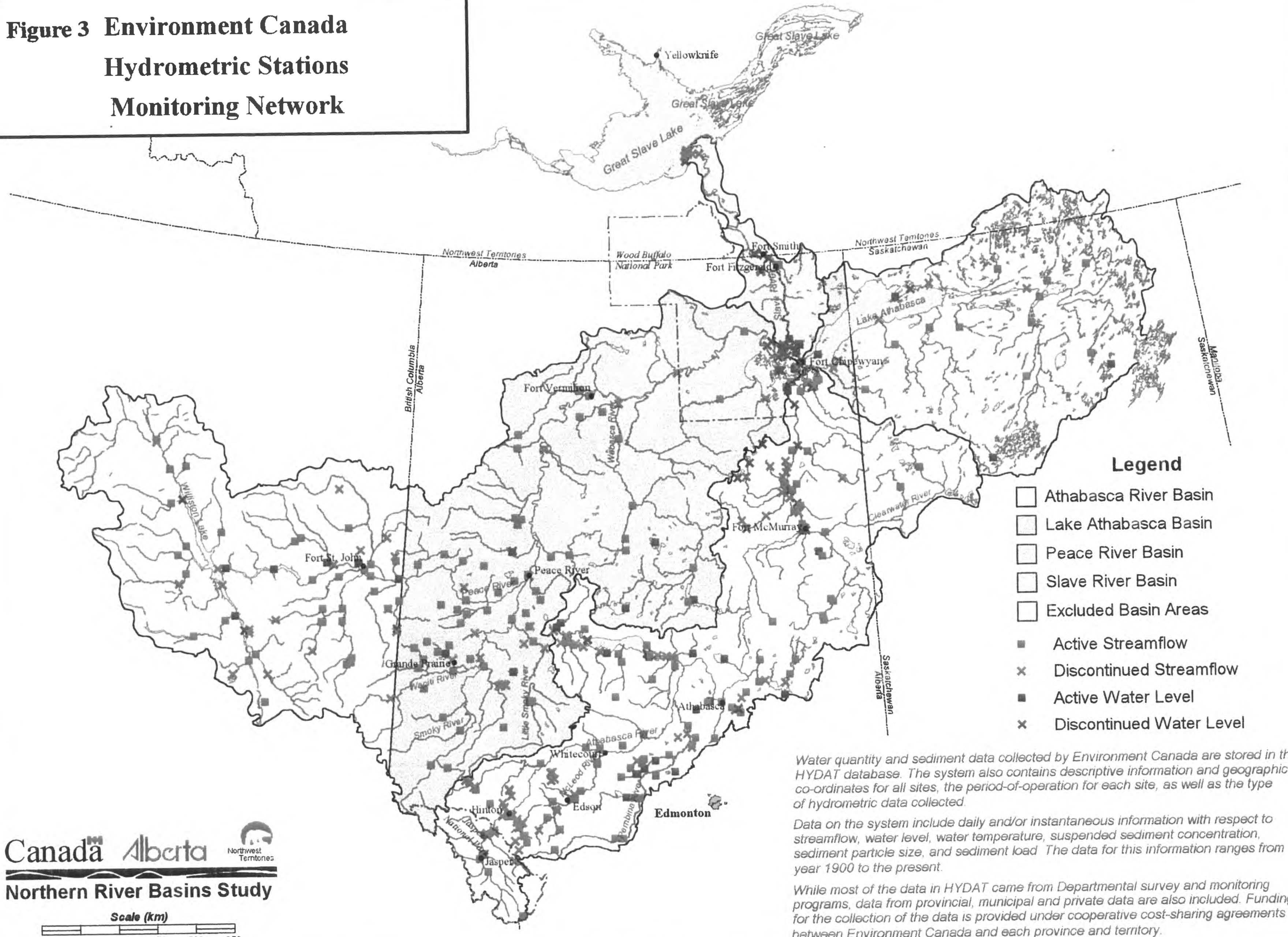


Figure 3 Environment Canada Hydrometric Stations Monitoring Network



Water quantity and sediment data collected by Environment Canada are stored in the HYDAT database. The system also contains descriptive information and geographical co-ordinates for all sites, the period-of-operation for each site, as well as the type of hydrometric data collected.

Data on the system include daily and/or instantaneous information with respect to streamflow, water level, water temperature, suspended sediment concentration, sediment particle size, and sediment load. The data for this information ranges from year 1900 to the present.

While most of the data in HYDAT came from Departmental survey and monitoring programs, data from provincial, municipal and private data are also included. Funding for the collection of the data is provided under cooperative cost-sharing agreements between Environment Canada and each province and territory.

Figure 4: Mean Annual Volume for Runoff for Selected Streams in the Athabasca Basin

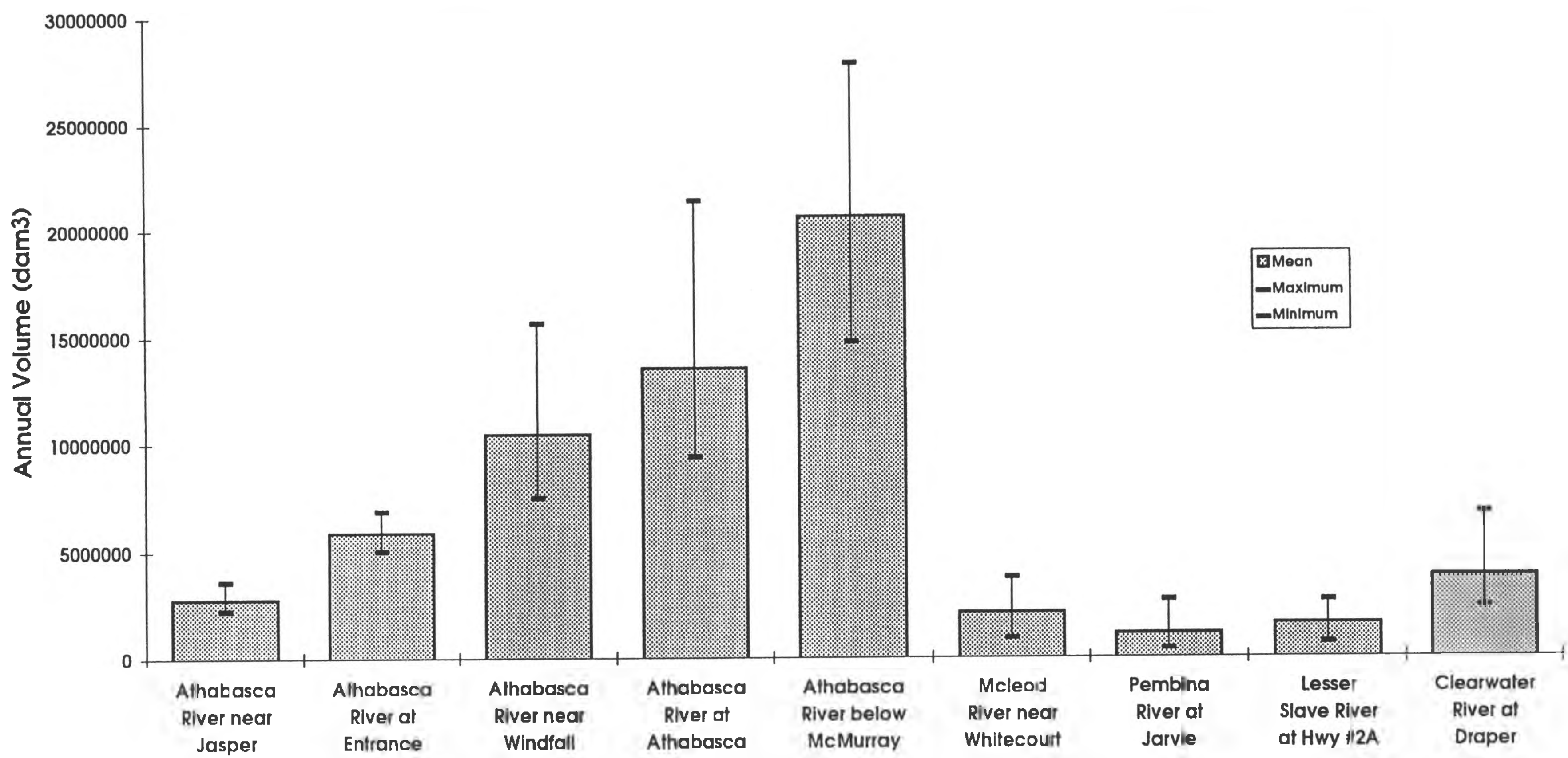


Figure 5: Mean Annual Volume of Flow for Selected Streams in Peace/Slave River Basin

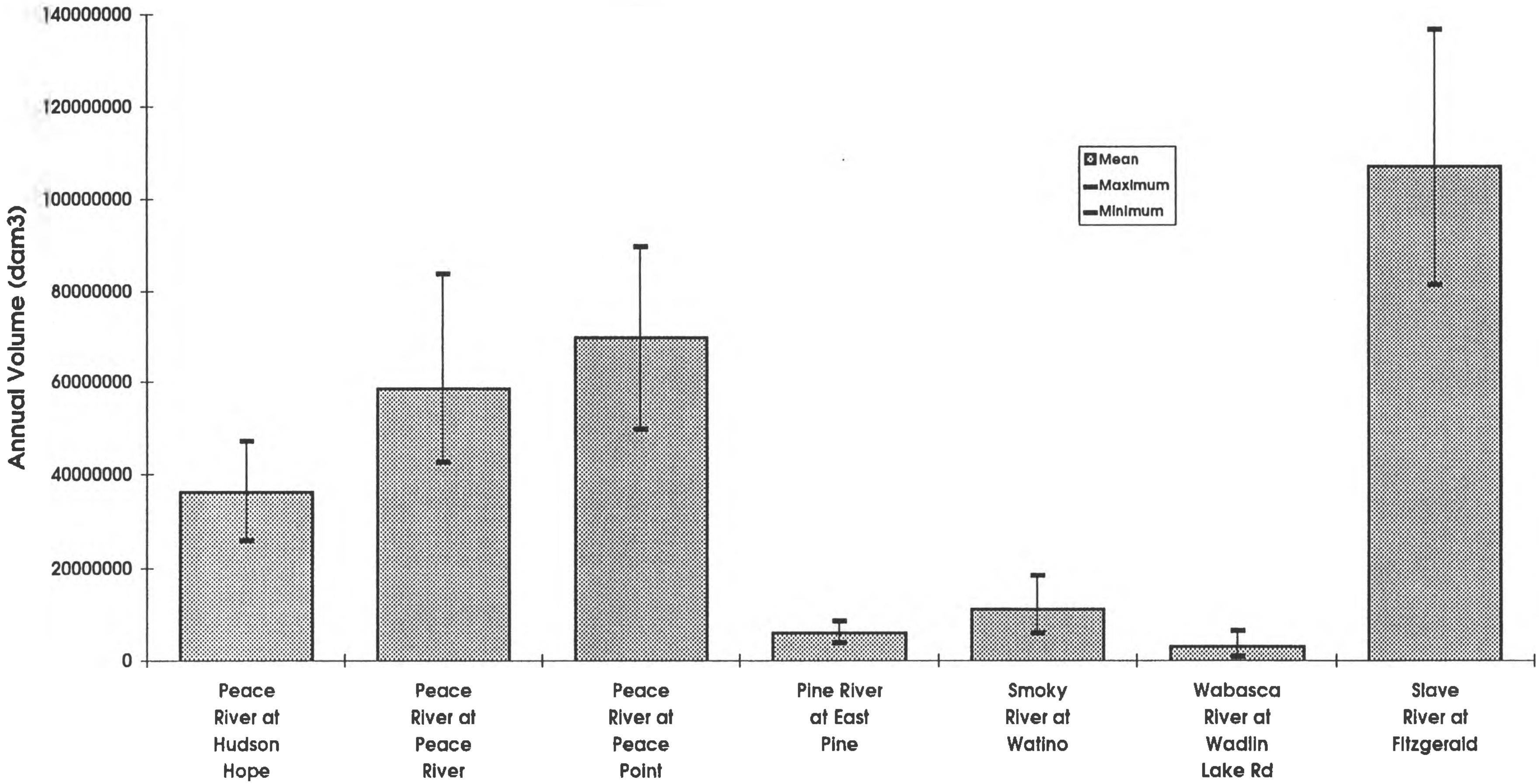


Figure 6: Mean Annual Runoff Depth for Selected Streams in the Athabasca River Basin

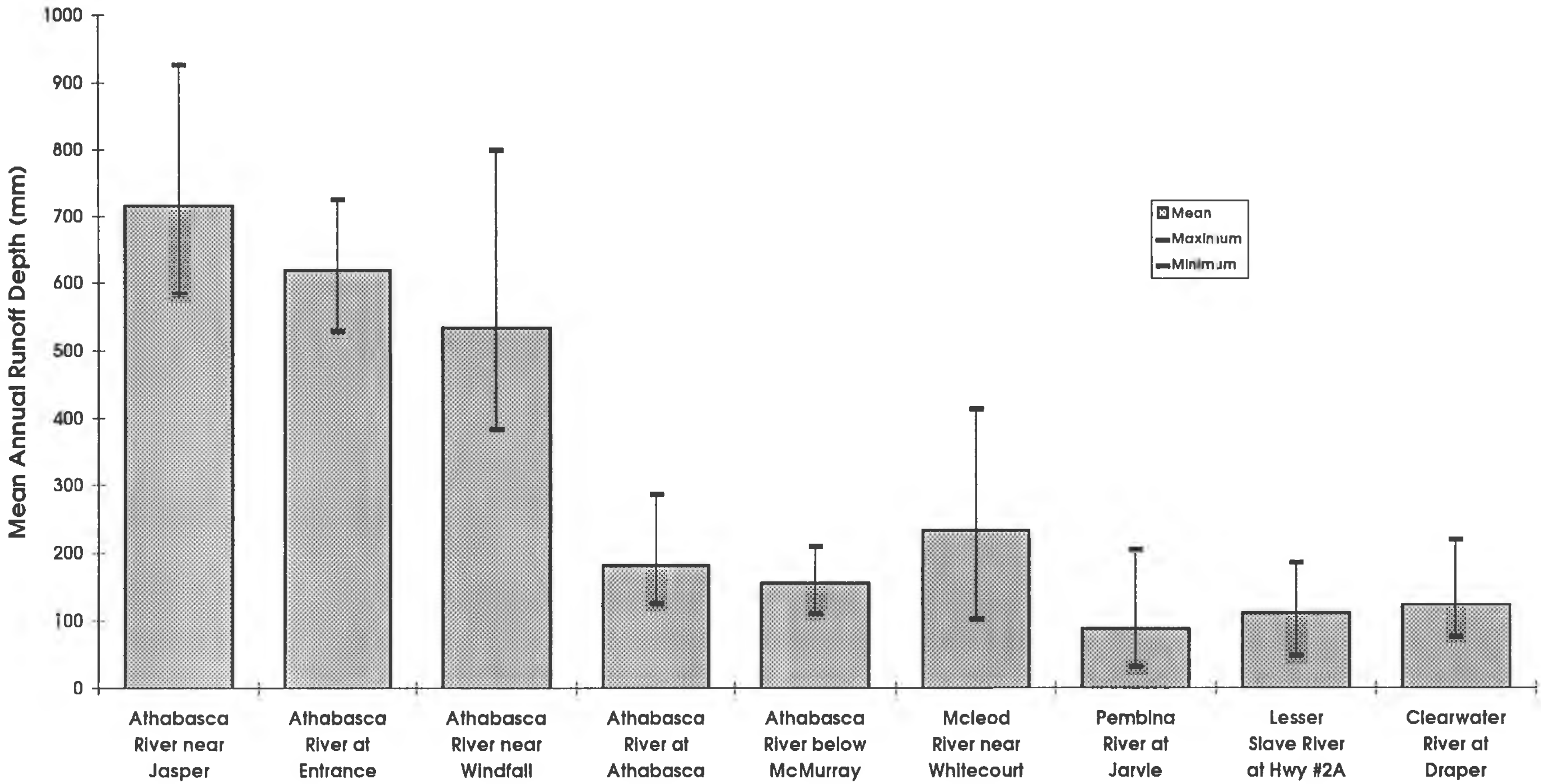


Figure 7: Mean Annual Volume of Flow for Selected Streams in Peace/Slave River Basin

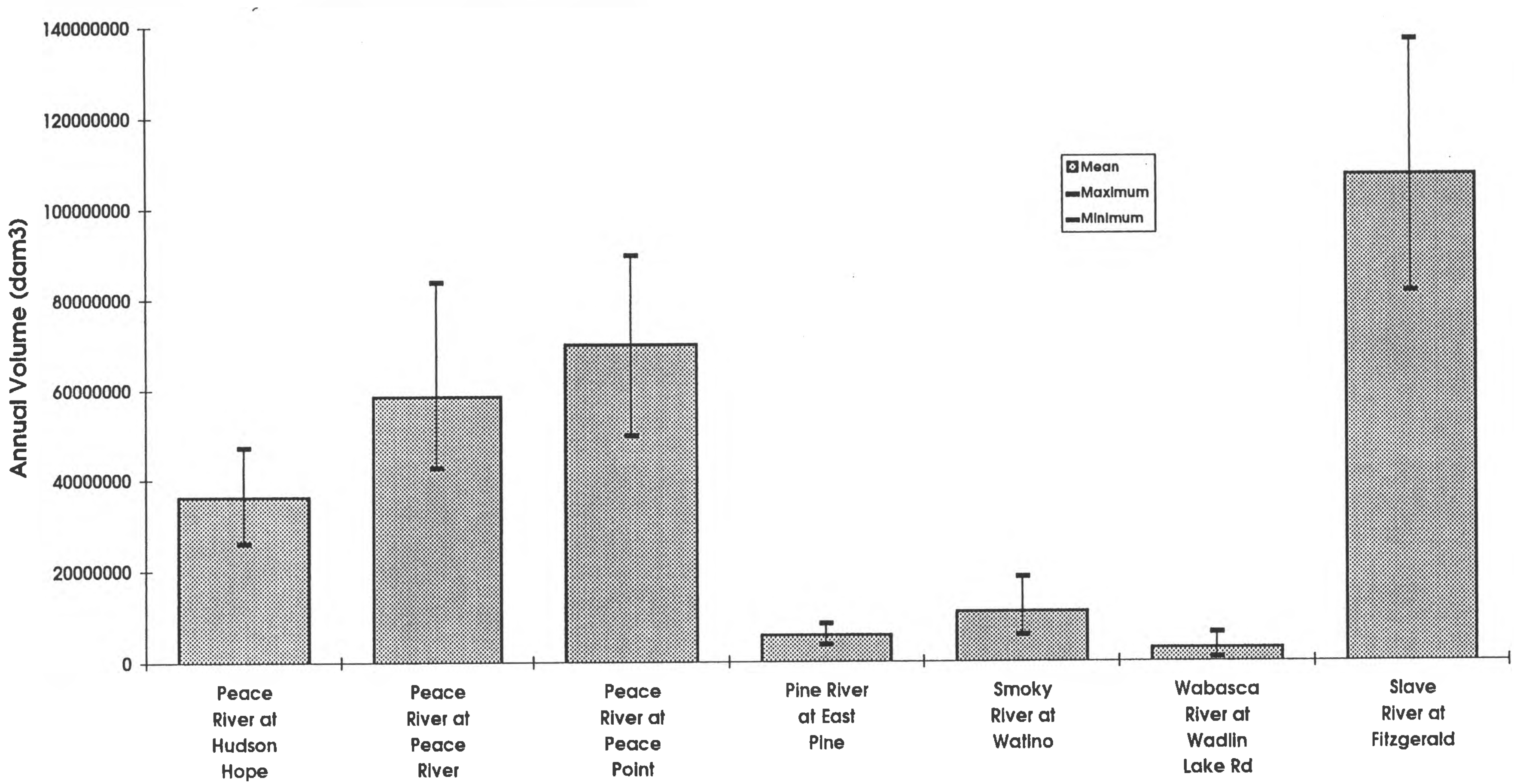


Figure 8: Mean Annual Precipitation for Selected Stations in the Athabasca River Basin

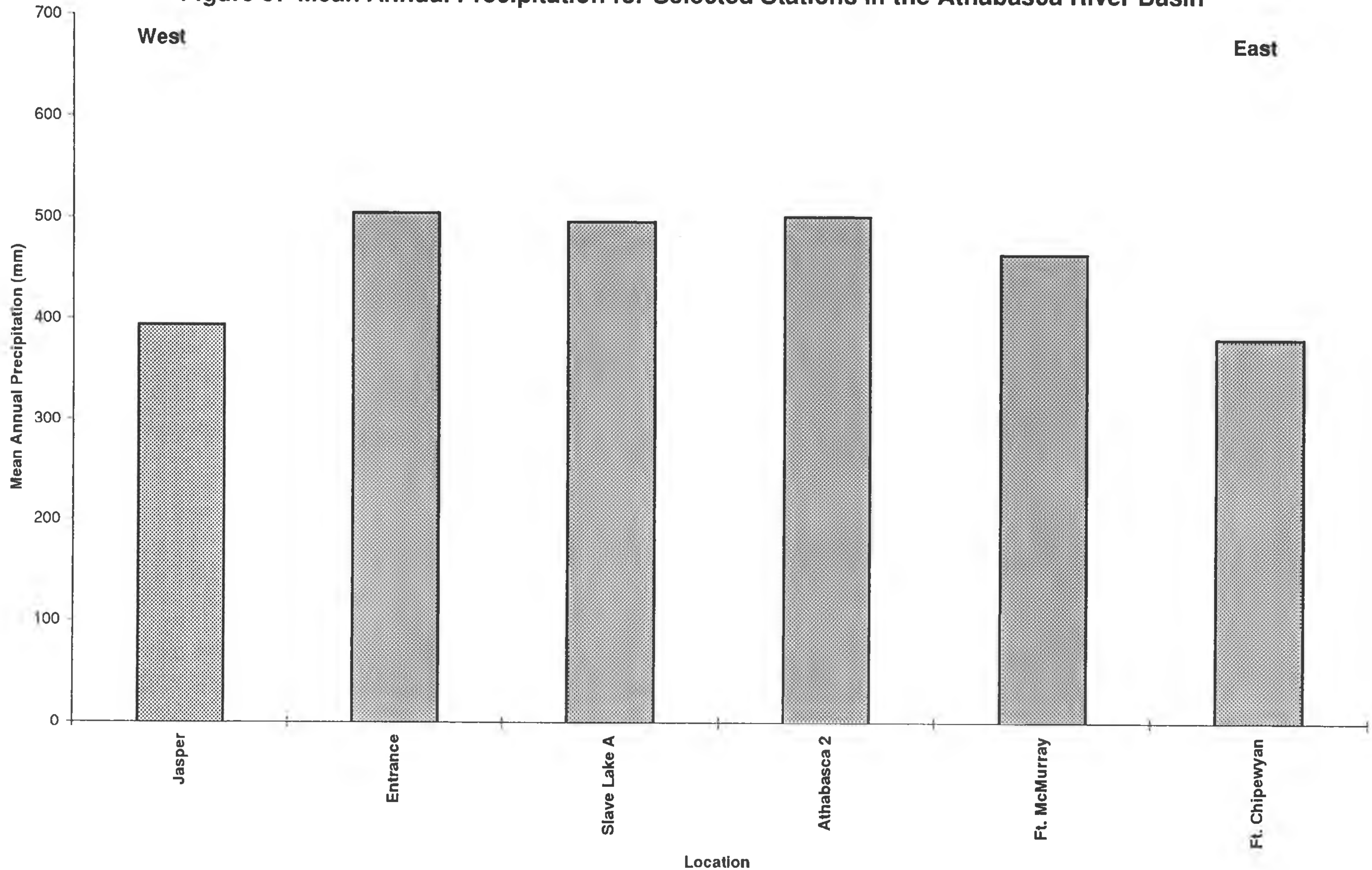


Figure 9: Mean Annual Precipitation for Selected Stations in the Peace River Basin

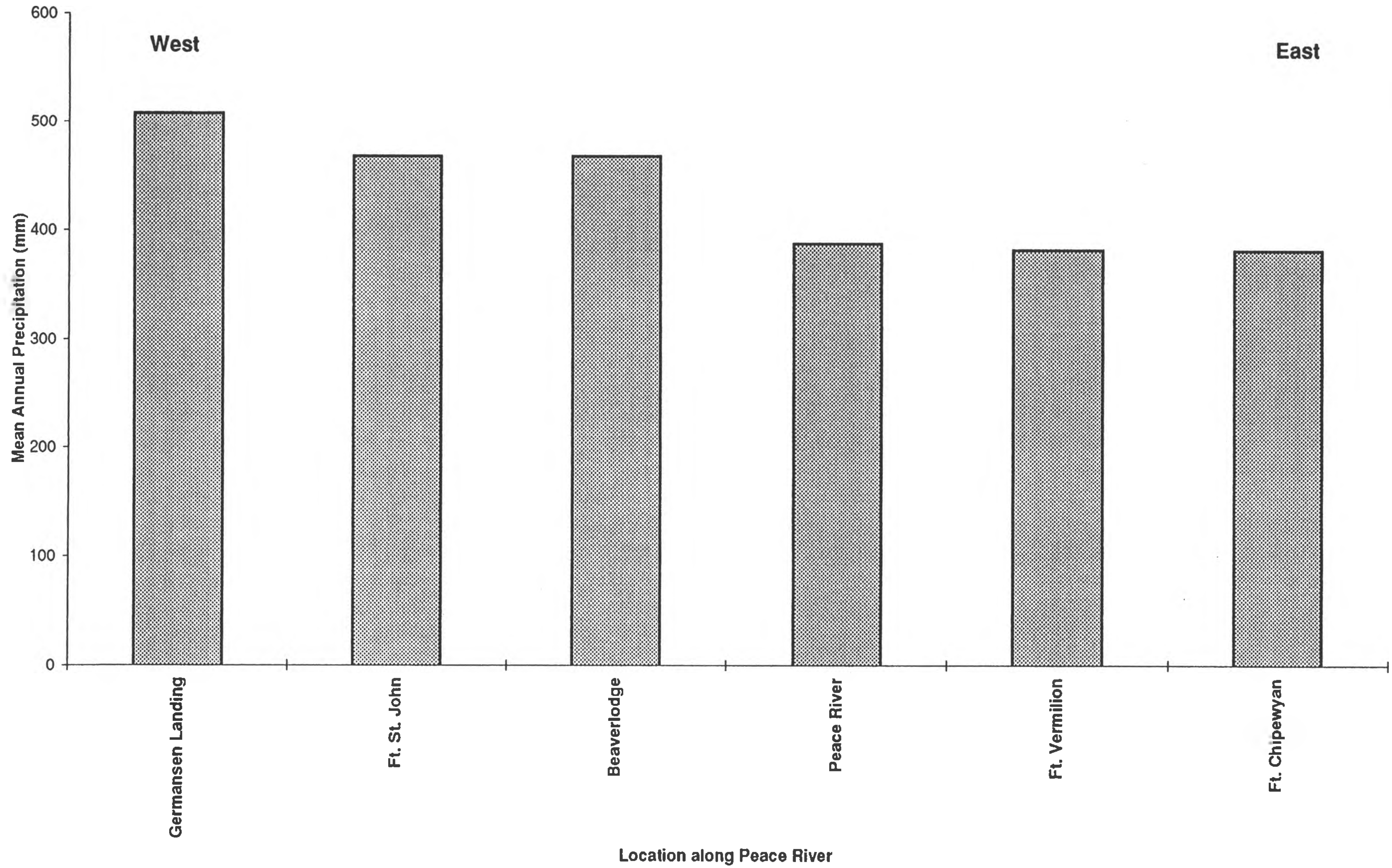


Figure 10: Variation in Streamflow Throughout the Year for Selected Streams in the Athabasca Basin

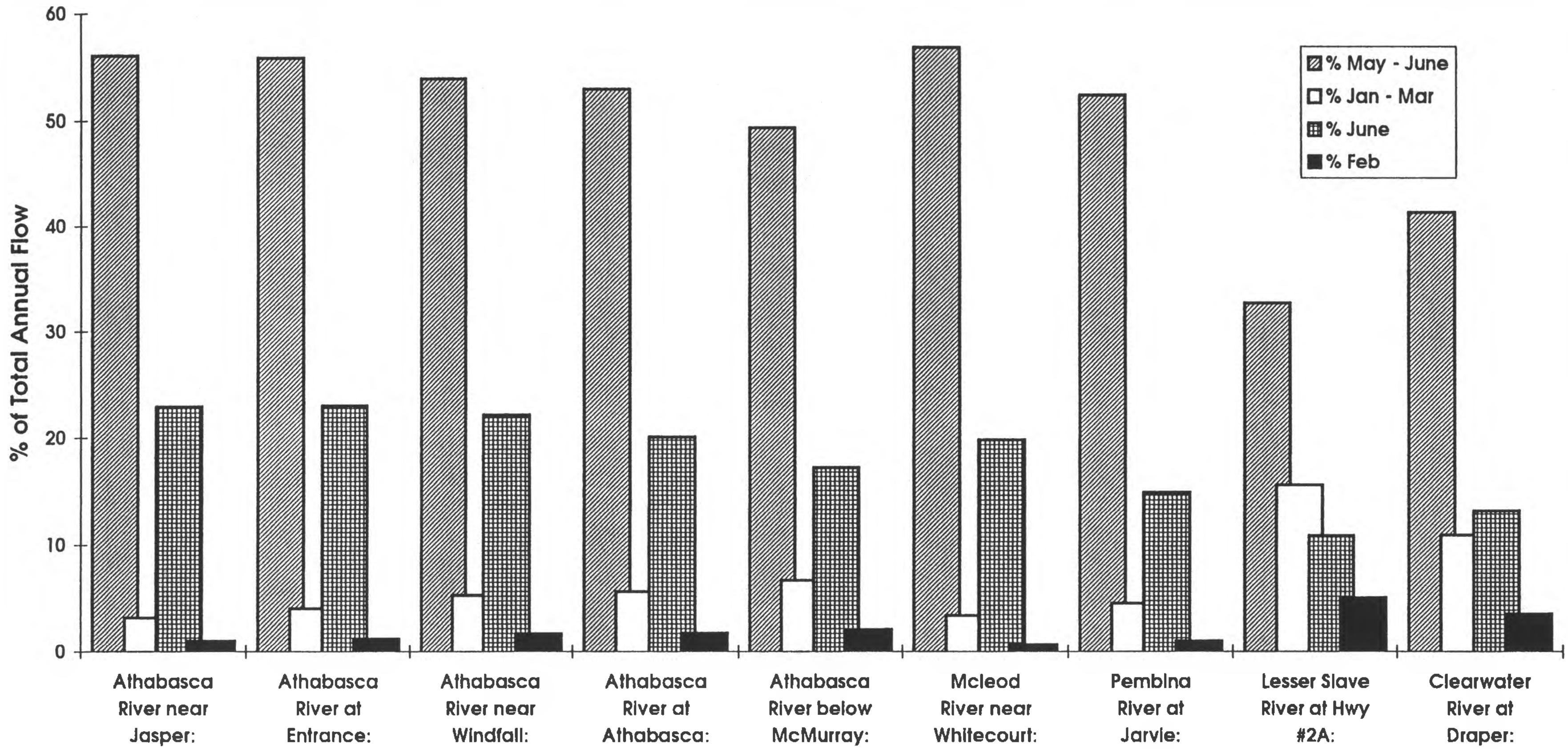


Figure 11: Variation in Streamflow Throughout the Year for Selected Streams in the Peace/Slave Rivers Basin (Pre-regulation)

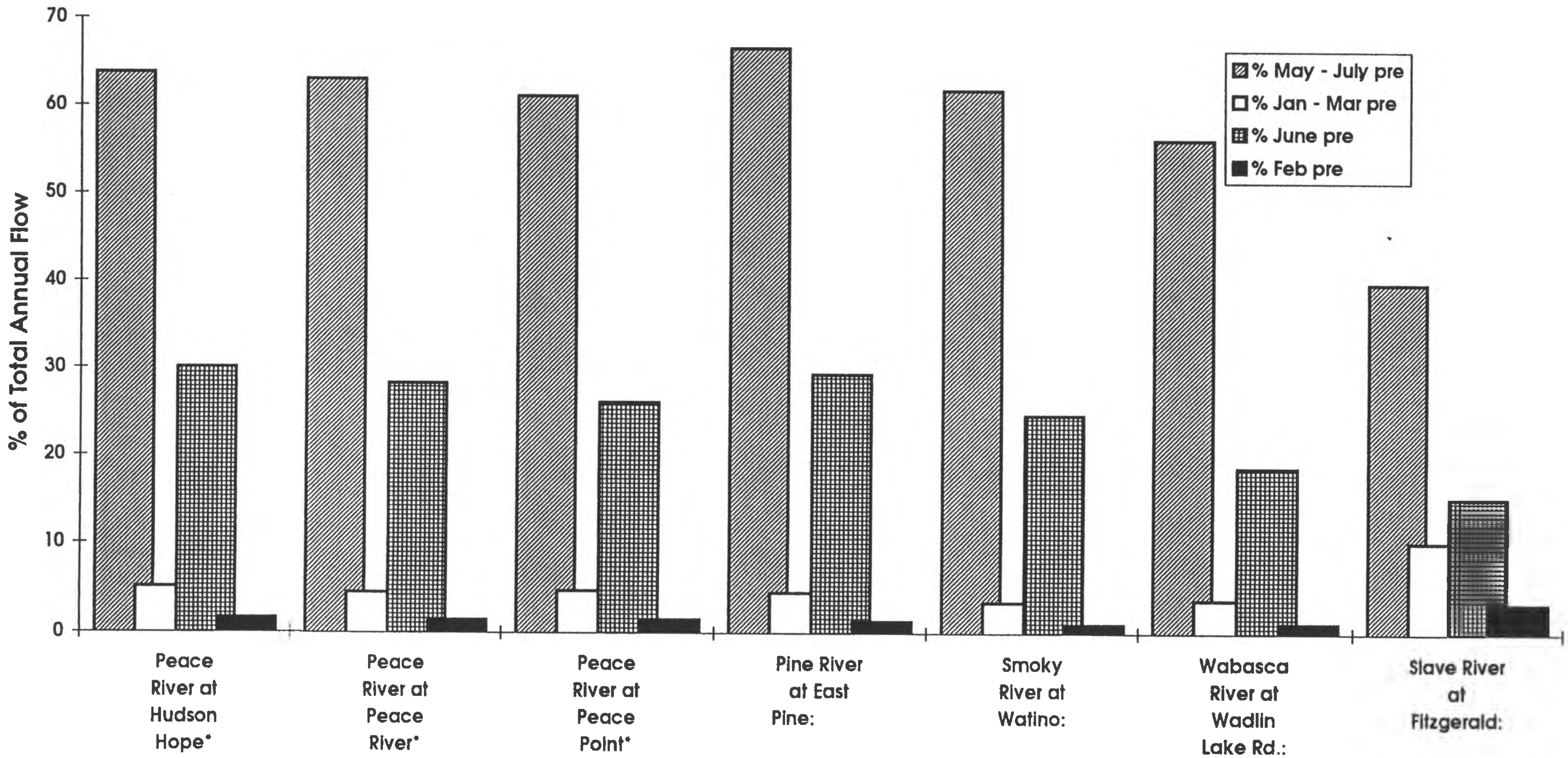


Figure 12: Variation in Streamflow Throughout the Year for Selected Streams in the Peace/Slave Rivers Basin (Post Regulation)

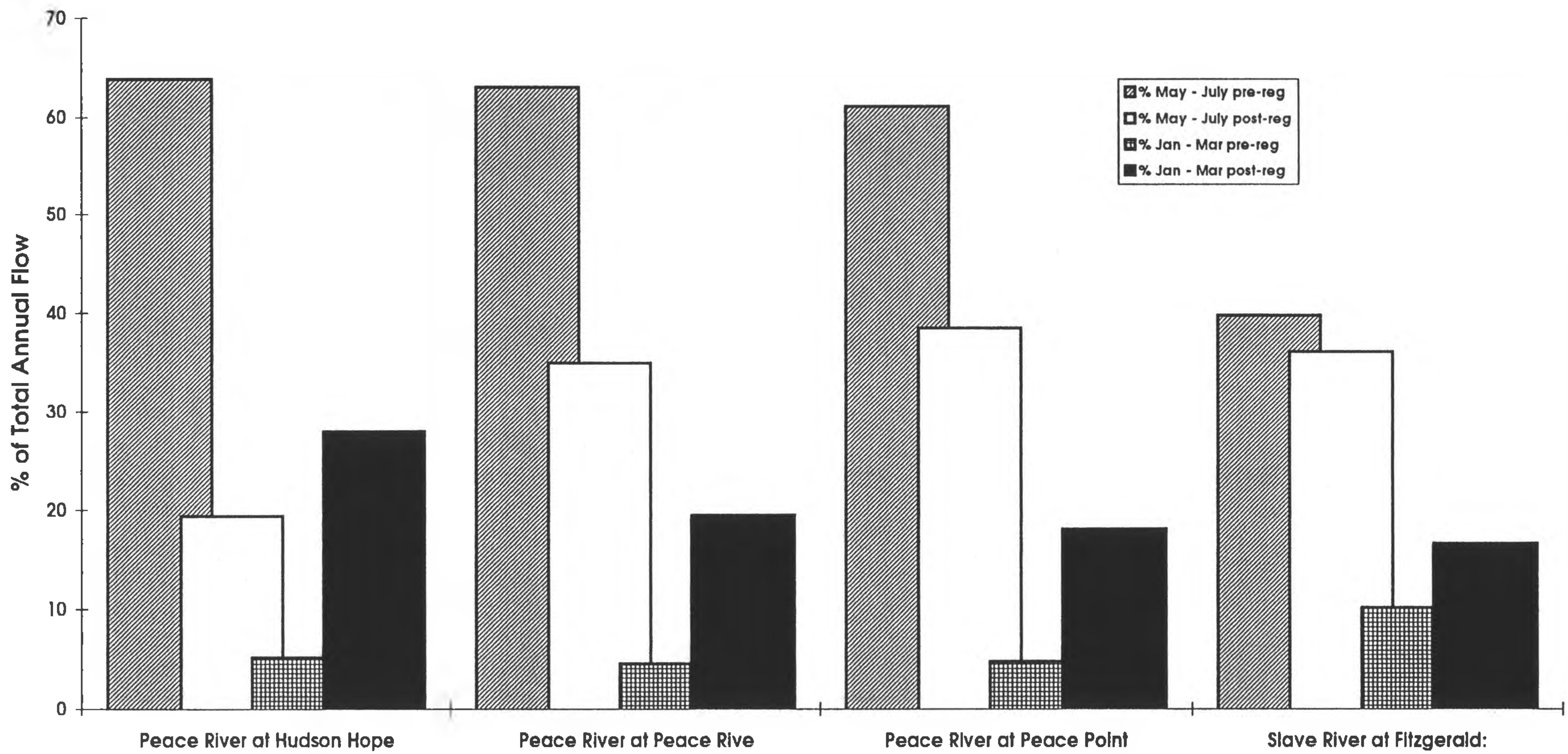


Figure 13: Comparison of Maximum, Average and Minimum Flows for Selected Stations in the Athabasca Basin

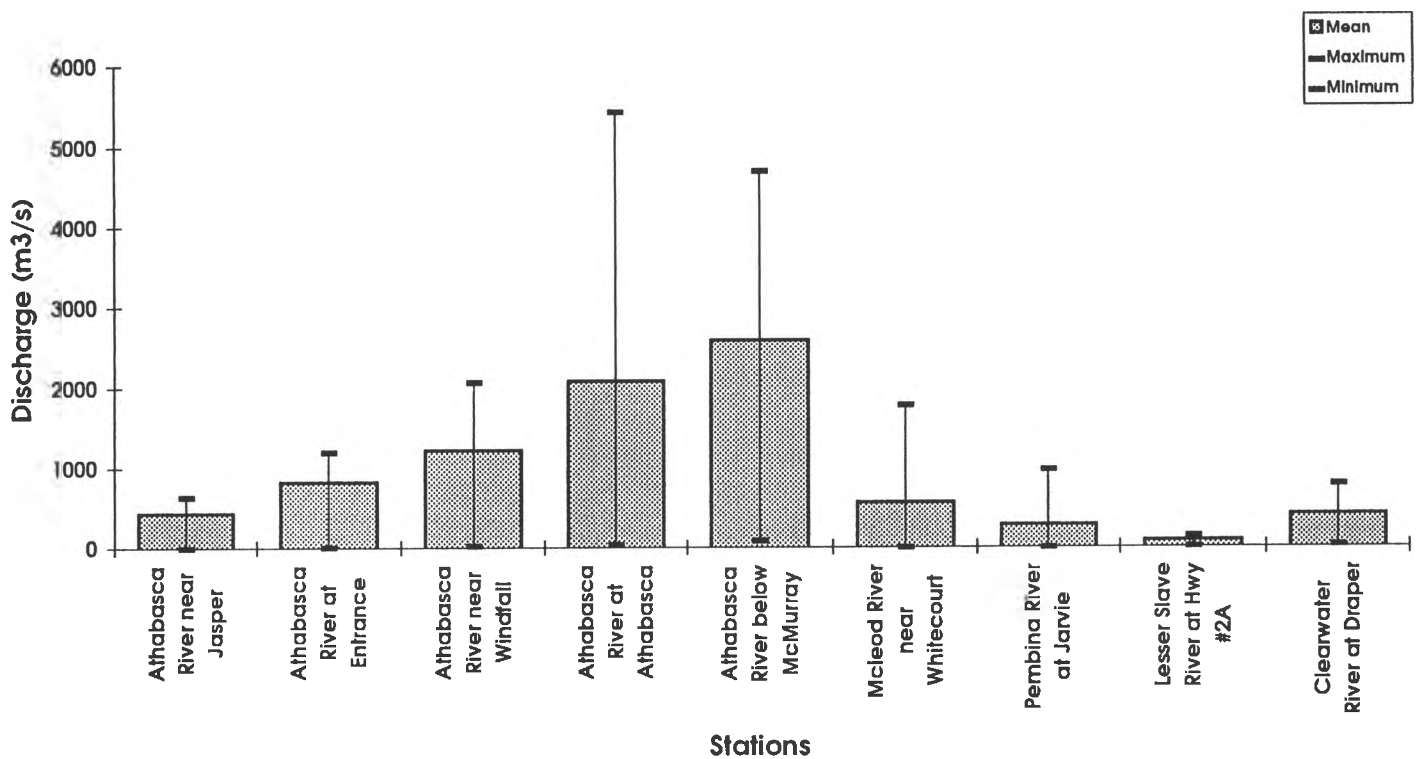


Figure 14: Comparison of Maximum, Average and Minimum Flows for Selected Stations in the Peace/Slave System (1967-71 period not included)

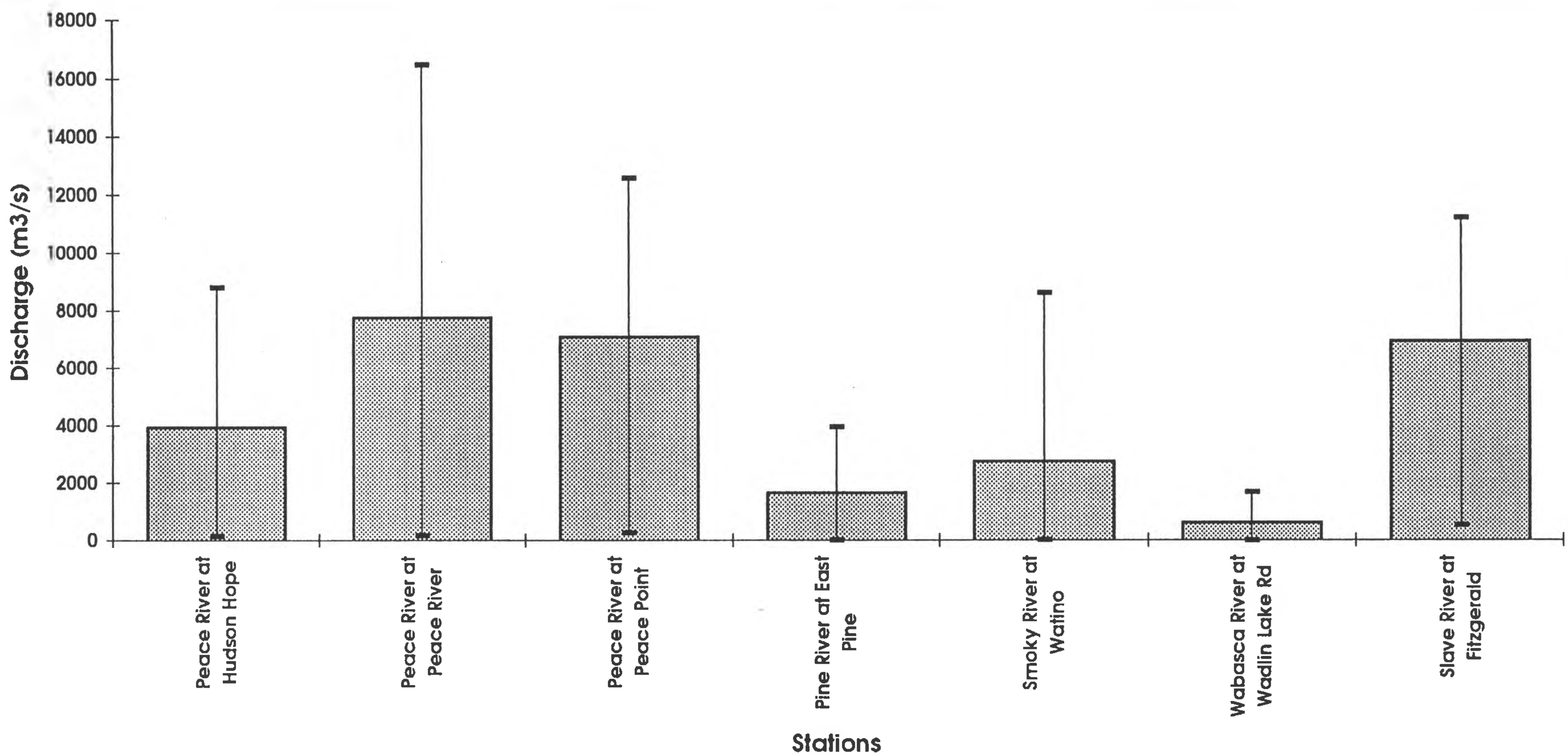


Figure 15: Monthly Lake Levels for Williston Lake (Williston Lake at Lost Cabin Creek; Bennett Dam Reservoir)

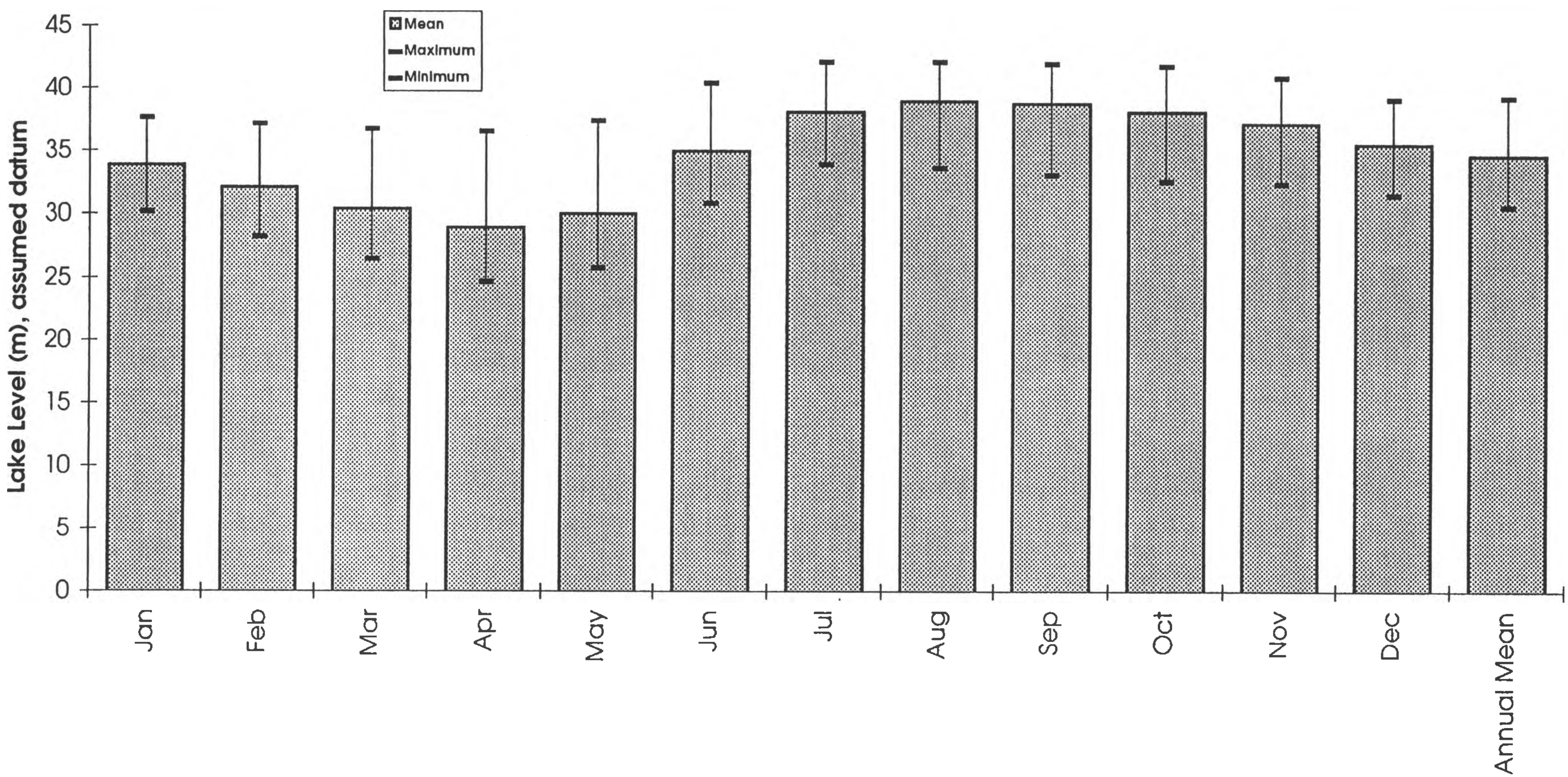


Figure 16: Mean Monthly Lake Levels for Lake Athabasca (Lake Athabasca at Crackingstone Point)

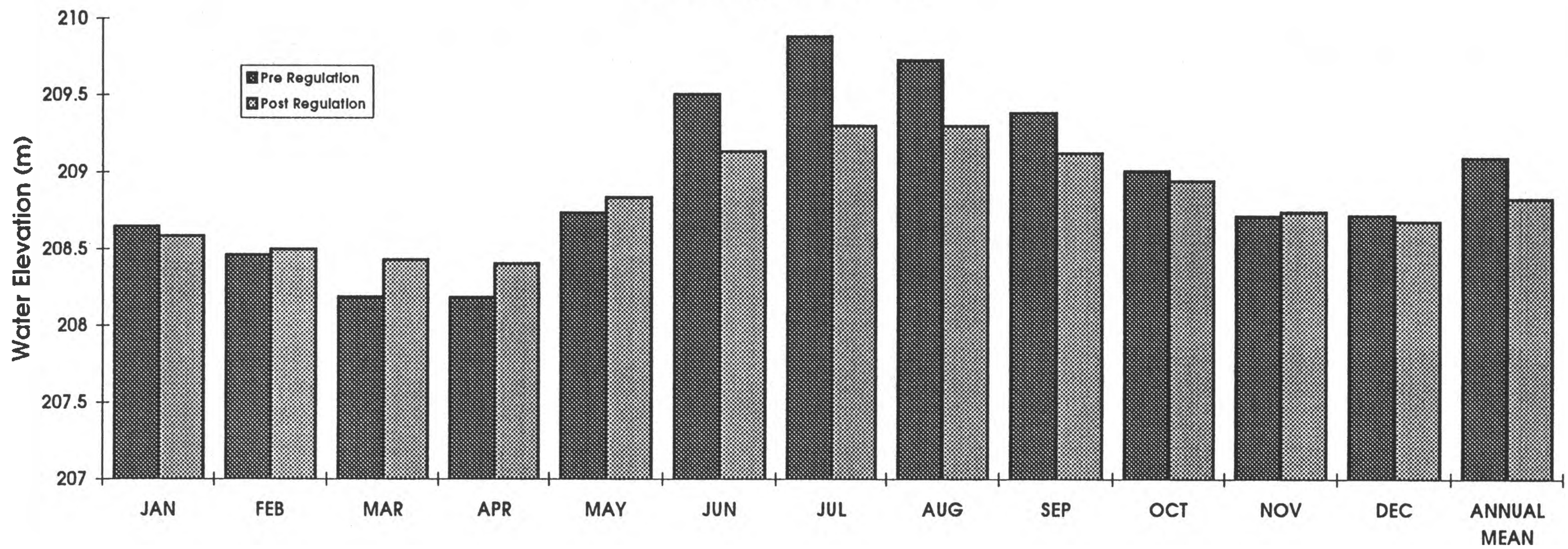


Figure 17: Mean Monthly Lake Levels for Great Slave Lake (Great Slave Lake at Yellowknife Bay)

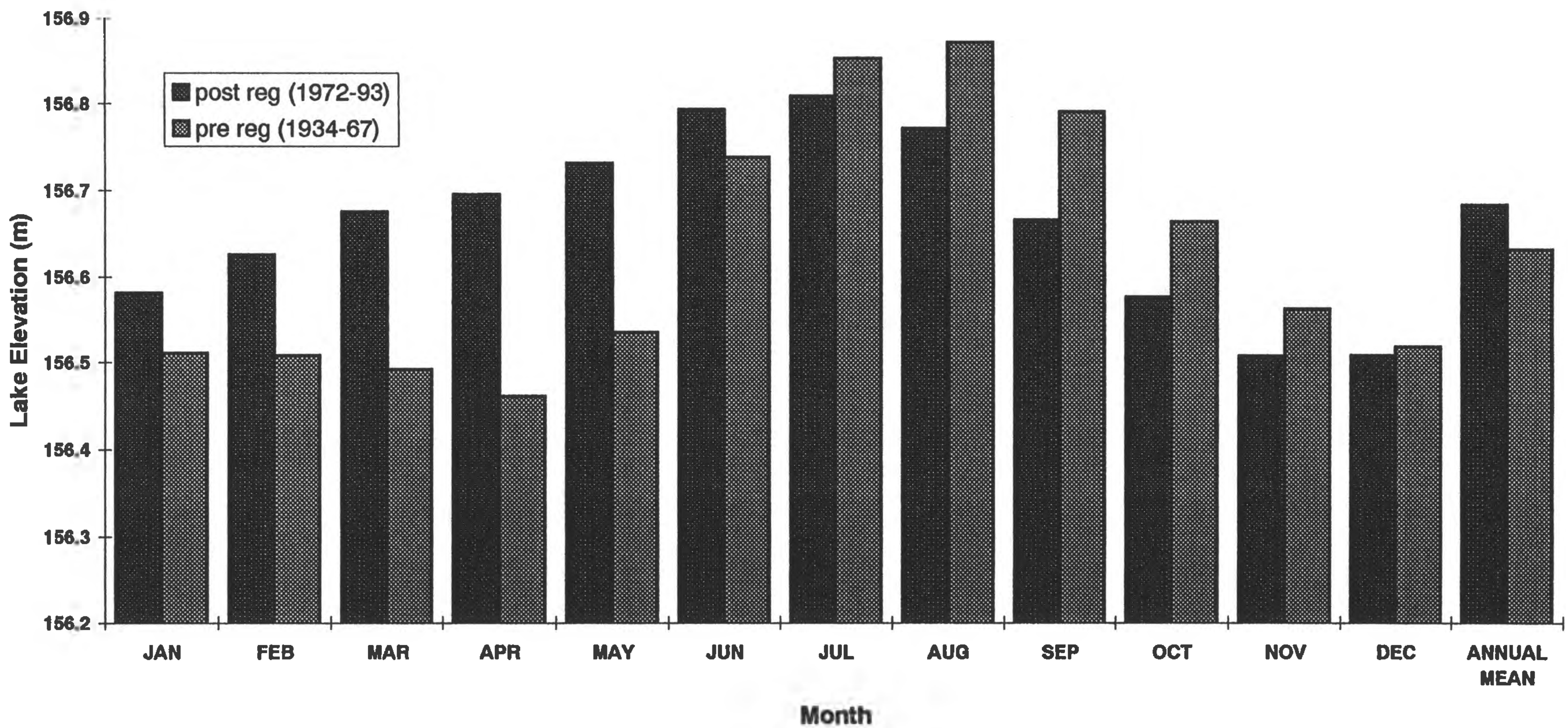


Figure 18: Comparison of Natural and Regulated Mean Monthly Flows for the Peace River at Hudson Hope (07EF001)

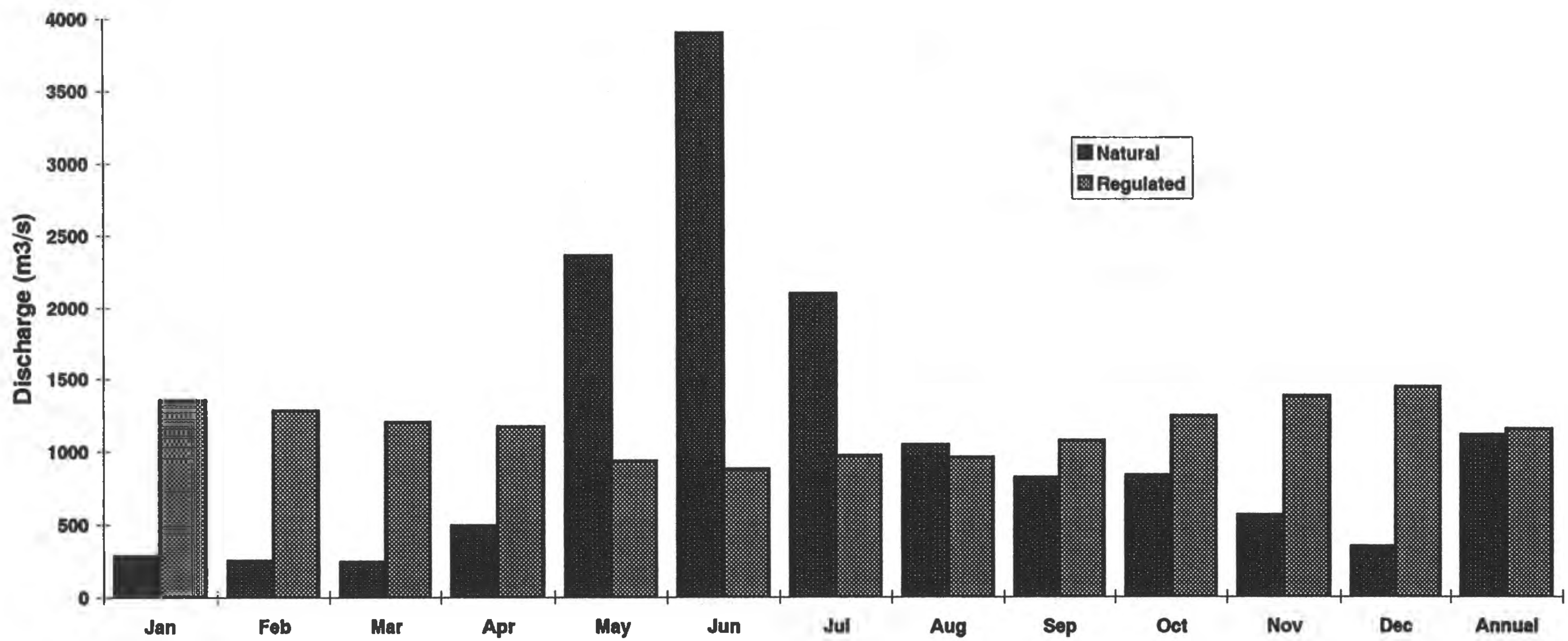


Figure 19: Comparison of Natural and Regulated Mean Monthly Flows for the Peace River at Peace River (07HA001)

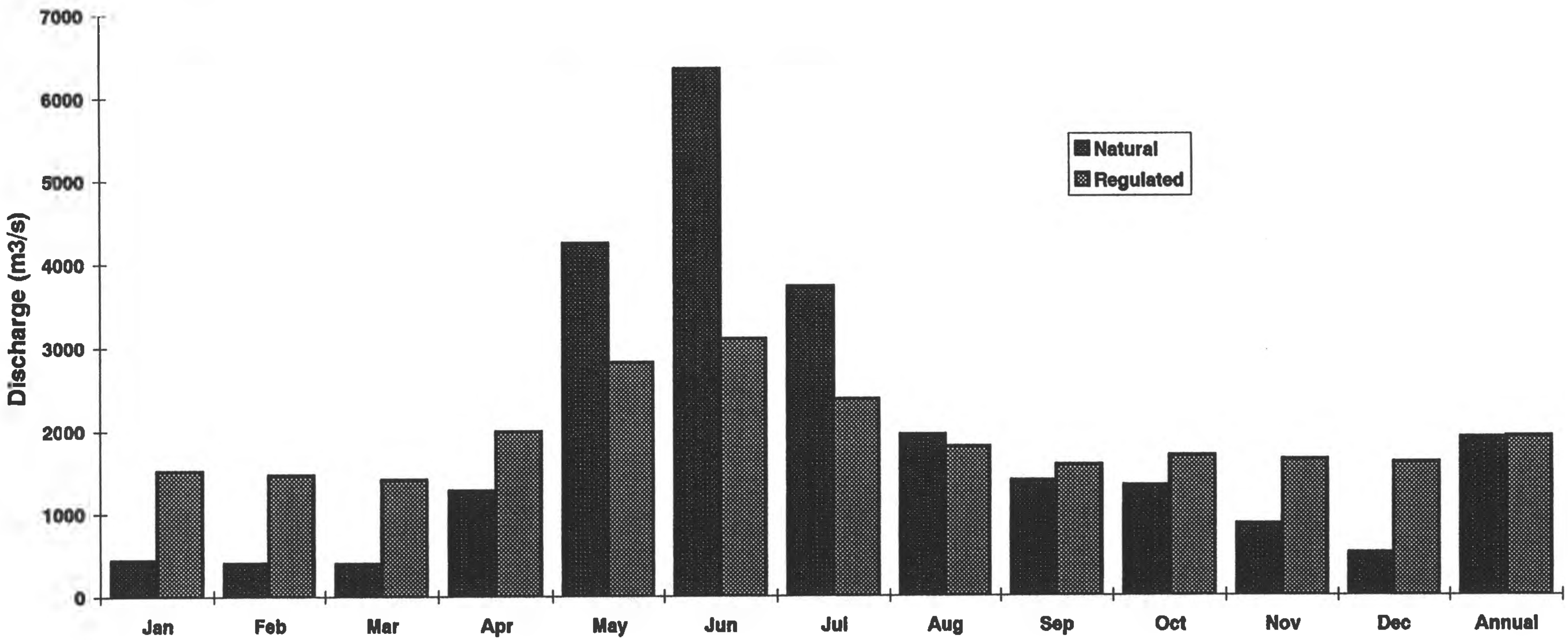


Figure 20: Comparison of Natural and Regulated Mean Monthly Flows for the Peace River at Peace Point (07KC001)

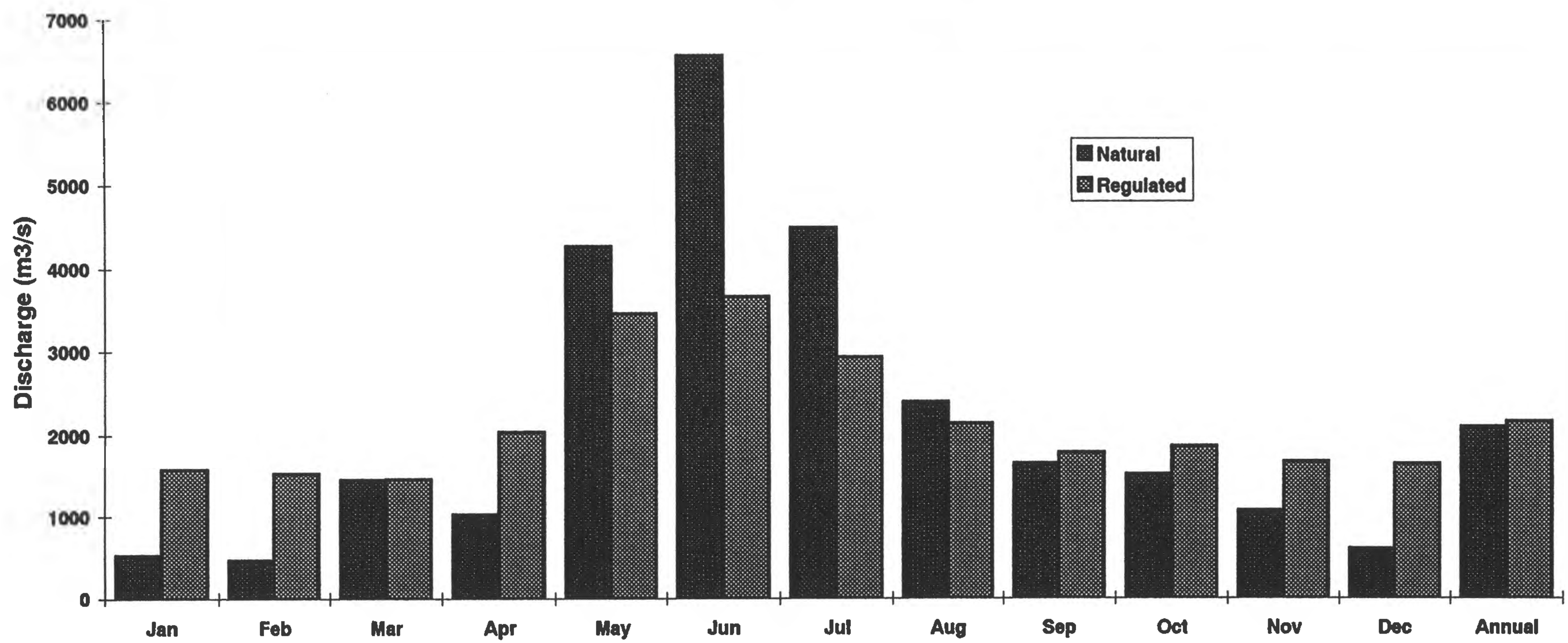


Figure 21: Comparison of Natural and Regulated Mean Monthly Flows for theSlave River at Fitzgerald (07NB001)

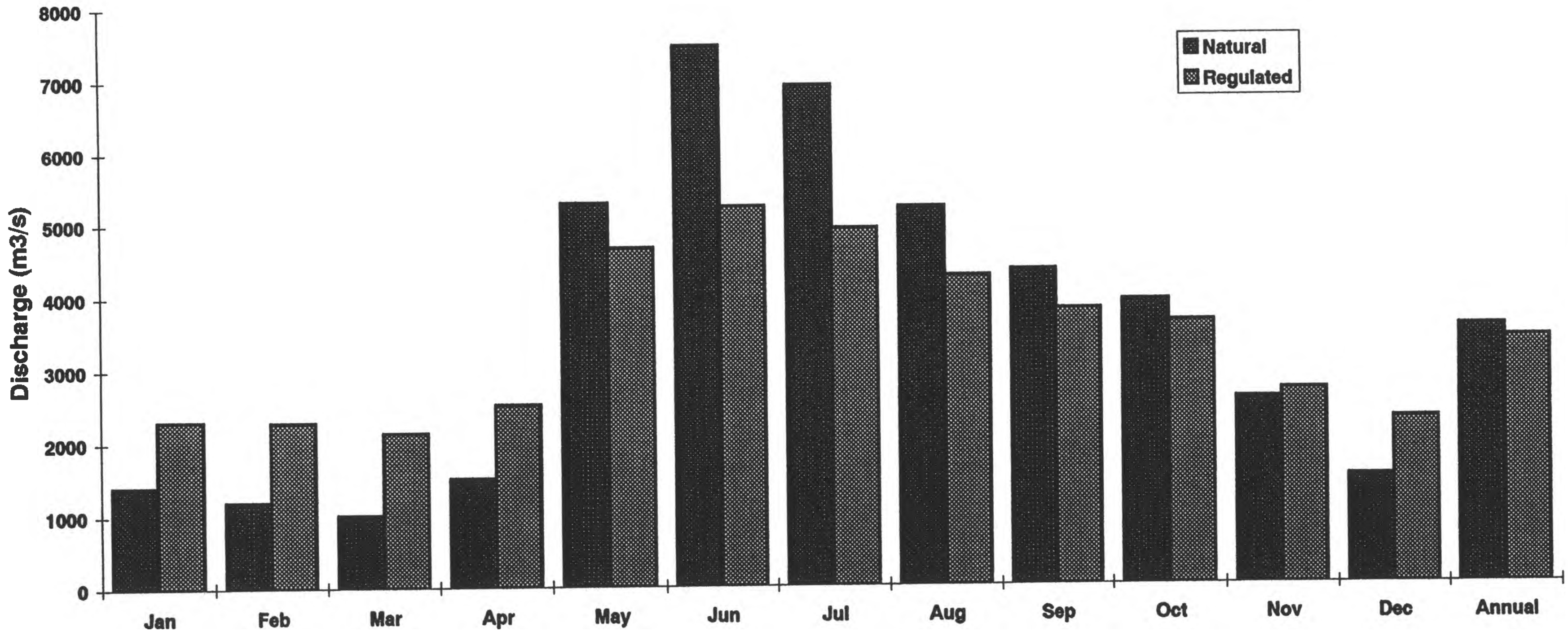
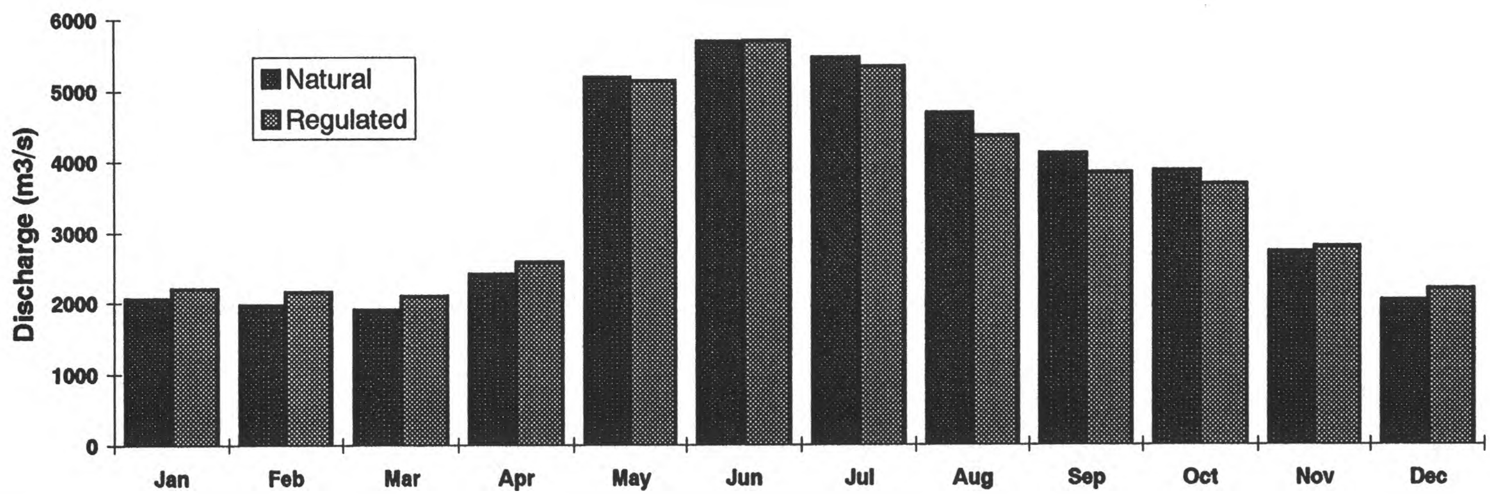
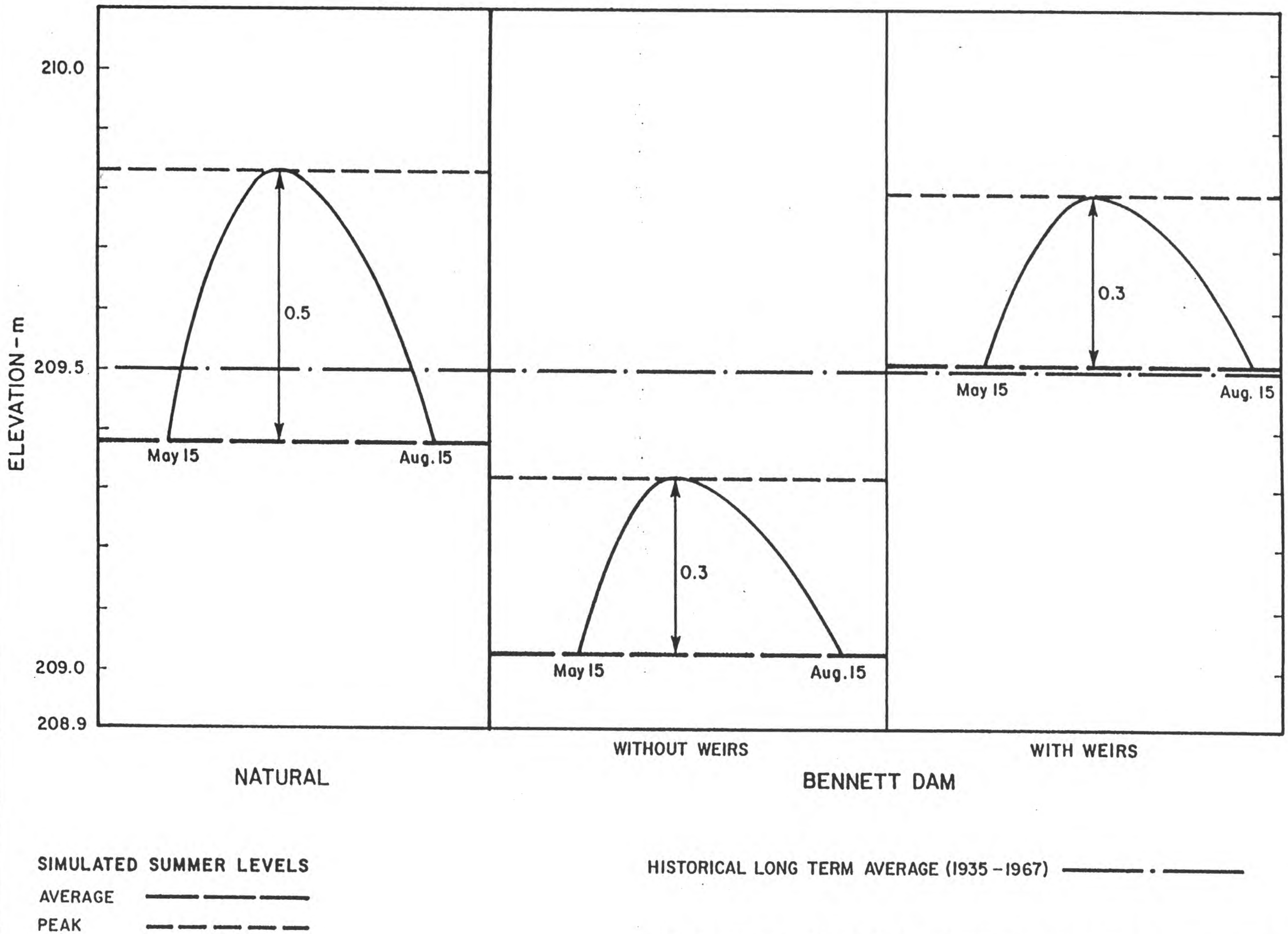


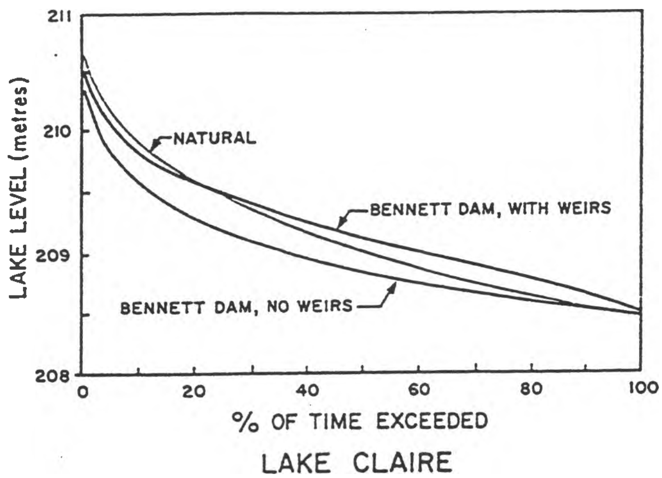
Figure 22: Effect of Lake Athabasca Regulation on Slave River Mean Monthly Flows
(simulated for the period 1960 to 1984)

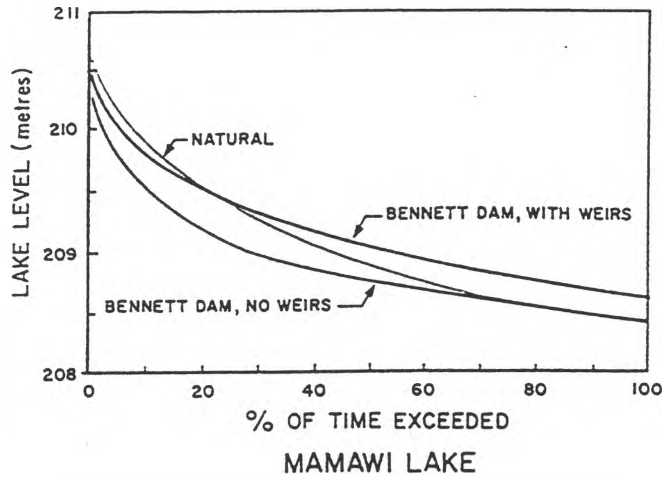


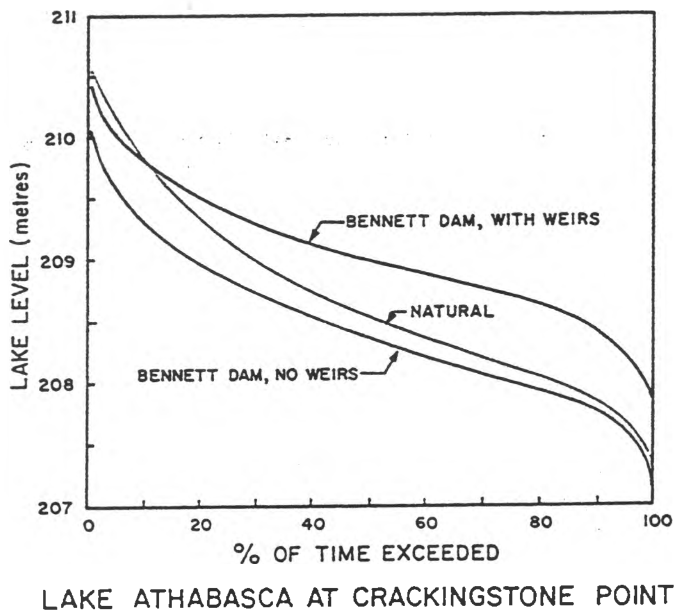


SIMULATED AVERAGE SUMMER LEVELS AND PEAKS OF LAKE ATHABASCA

Figure 23







WATER LEVEL DURATION CURVES
FOR LAKES ATHABASCA, CLAIRE AND MAMAWI

Figure 24

APPENDIX A: TERMS OF REFERENCE

No contractual Terms of Reference were prepared for the work documented in this report. The work was undertaken by the authors as a contribution in kind from their employing agencies and represents a part of their responsibilities to the working committee of the Hydrology/Hydraulics Component of the Northern River Basins Study.

APPENDIX B: ANNOTATED BIBLIOGRAPHY

This Appendix is provided on the disk bound as the last page of this report; it contains a bibliography of hydrology/hydraulics information for the study area assembled by Dr. Leah Watson, National Hydrology Research Institute.

The disk comprising this Appendix contains three files, using 601,007 bytes.

1. INSTALL.BAT; being 74 bytes in size.
2. PR146.EXE; being 109,431 bytes in size.
3. DISCLAIM.TXT; being 486 bytes in size.

To install the bibliographic database copy the three files on this disk to a directory on your hard drive and type install.bat. The result will be 11 files totalling 306,774 bytes. DAMNOTES.WP5 uses Word Perfect 5.1 and is the more extensive bibliography with annotations for certain reference. README.DOC explains the remaining files; all remaining files except DAM.DOC uses Pro Cite.