FLOOD FREQUENCY ANALYSIS
NORTH SASKATCHEWAN RIVER
AT EDMONTON

Water Resources Management Services
Technical Services Division
Hydrology Branch

FLOOD FREQUENCY ANALYSIS
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AT EDMONTON

Submitted by: A. M. Mustapha, P. Eng.
Branch Head

Prepared by: A. DeBoer, P. Eng.
Hydrologist

NOVEMBER 1990

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1. INTRODUCTION

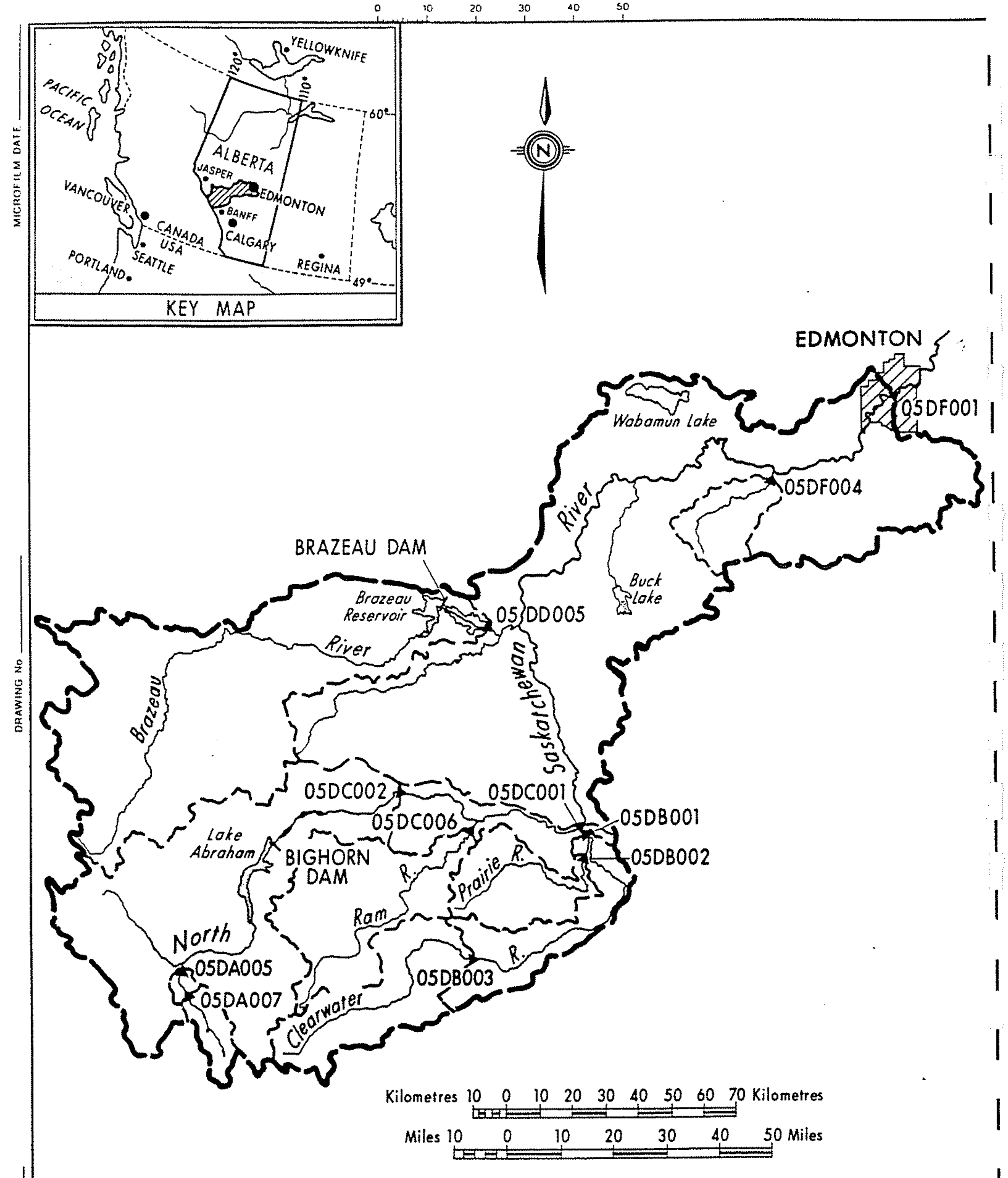
1.1 Study Scope

This study determines flood magnitudes for the North Saskatchewan River at Edmonton. Both natural and regulated annual maximum flood flows are examined in the assessment of the frequency of occurrence of future flood peak flow rates. Recorded flows and water levels within the North Saskatchewan River basin above Edmonton form the basis of the analyses. Several frequency distributions were applied to the annual flood discharge data and the most applicable distribution was selected. The results of the analyses reflect the most current information and methodologies available to determine flood frequency estimates.

1.2 Study Area

The North Saskatchewan River at Edmonton drains an area of 28,000 square kilometres. The drainage basin, depicted in Figure 1.1, traverses three major physiographic regions. These regions are the mountains, the foothills and the Great Plains. The following quotation from the Saskatchewan-Nelson Basin Study (SNBB, 1972) gives a detailed description of the basin.

> "The mountains occupy a narrow belt bounded on the west by the Continental Divide and on the east by the most easterly range of the Rocky Mountains. Local relief is extreme, with elevations varying between 1219 metres (4,000 feet) in the large river valleys to over 3048 metres (10,000 feet) at the mountain peaks. The mountain ranges are overthrusts of sedimentary rock. The lower slopes are covered by alpine forests up to about elevation 2133 metres (7,000 feet). In places, the mountains are capped by permanent snowfields and glaciers. The valleys



Alberta ENVIRONMENT

TECHNICAL SERVICES DIVISION
HYDROLOGY BRANCH

DRAINAGE BASIN FOR THE NORTH SASKATCHEWAN RIVER AT EDMONTON

SUBMITTED A. DE BOER, P. ENG.	DESIGNED A. DE BOER, P. ENG.		
DATE DEC., 1986	CHECKED		
APPROVED M. MUSTAPHA, P. ENG.	DRAWN V. DA SILVA	SCALE AS SHOWN	**FIGURE No. 1.1**
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contain glacial gravel deposits, sometimes in depths of hundreds of feet. Annual precipitation varies from about 50 centimetres in the valleys to 180 centimetres and higher in the mountains.

The foothills occupy a belt paralleling the mountains and extending eastward for about 160 kilometres from the easternmost limit of the Rockies. It is a transition zone between the mountains and the Canadian Plains, incorporating the eastern slopes of the Rocky Mountains, and characterized by ridges of hills paralleling the mountain ranges. The mountain-fed streams enter this belt at about 1280 metres (4,200 feet) elevation and emerge on to the plains at about 914 metres (3,000 feet). The transition zone characteristics are reflected in the vegetative cover. Rocky outcrop about the timber-line merges into alpine forest, as the elevation decreases, then into areas of deciduous trees and finally to rolling grassland. The average annual precipitation is similar to that in the mountain region. However, moist air from the southeast invades the foothills belt upon occasion, without penetrating beyond the first range of mountains. These storms release their moisture on the eastern slope of the Rockies, producing rainfall of intensities not experienced in the mountain region and causing the significant floods of the North Saskatchewan River Basin.

Most of the North Saskatchewan River Basin lies in the Great Plains region. This region extends from the foothills in Alberta to the eastern limits of the drainage basin. It is an area of low relief, sloping gently eastward at about two or three feet to the mile (0.4 to 0.6 metre per kilometre). Drainage patterns are poorly developed and there are many small undrained lakes, sloughs and marshes contained within the overall boundaries of the basin. The average annual precipitation is between 30 and 50 centimetres. Water yield from the plains is relatively low, making up only a small percentage of the North Saskatchewan River discharge, despite the fact that the plains comprise about 60 percent of the drainage area."

Flows on the North Saskatchewan River at Edmonton have been regulated by the Brazeau development since October 1, 1961. The Bighorn development further regulated flows since August 7, 1972. The influence of these reservoirs on flood peaks is investigated to determine the frequency of flood magnitudes at Edmonton.

1.3 Causes of Extreme Floods

The largest flood peaks on the North Saskatchewan River are generally produced when the runoff from mountain snowmelt combines with the runoff from heavy rainfall in the foothills region of the basin.

The storms which produce the major floods in the foothills are called "cold lows". The term "cold lows" refers to a certain type of low pressure air mass which originates off the west coast of North America. The low pressure system has counterclockwise circulation and travels generally from west to east across the continent. As the system crosses the continental divide, it often intensifies. The classic flood-producing situation occurs when the system draws warm, moist maritime air and mixes it with colder air from the polar regions at the ground surface. The circulation of the air mass is such that the moisture-laden air is directed towards the foothills and mountains. The air is forced to rise, as it rises it cools, as it cools it becomes saturated, and heavy rainfall in the foothills and along the most easterly range of mountains may result. The effect of the topography on intensification of the rainfall is referred to as the "orographic effect". Weather patterns for these storms are difficult to predict and thus offer limited warning for flood forecasting purposes.

1.4 Historical Floods at Edmonton

Research of the Hudson's Bay Company Archives, located at the Provincial Archives of Manitoba, indicated descriptions of flood events on the North Saskatchewan River at Fort Edmonton for the years 1812 to 1886. In particular, concerns with respect to river travel or overland travel impeded by high water were noted in the years 1820, 1825, 1827, 1832, 1833, 1850, 1857, 1862, 1863, 1864, 1866, and 1884.

The following description of September 19, 1825 (HBA, B 60/a23) indicates that a major flood event occurred in 1825.

> "It is almost time to mention that on our arrival here we found all hands in good health and spirits. Mr. Small give us an account of the whole of the Summer Transactions. By the by it would not be improper to remark that the winter was near Carrying off the whole of the Establishment this last summer, the Oddest Flood in the River and the Indians themselves say the water was never so high before, the Plain about the Fort which is about a mile long was a Complete sheet of water and with fifty Freces in a Boat, they went out of the Fort with ease, all hand had to leave the Fort and were Encamp on the Top of the High Hills for several days with all the Property and it was from there they saw part of the Buildings and the Building of the Fort and Gardens falling down. The Gardens were mostly all destroyed and Timbers to make 15 Boats with a large quantity for House work, and all was lost.
>
> Also in short this Flood is a shocking state to what it was this last spring. But what is still worse than all that few Indians made their appearance in summer and of Course little or no Trade has been made here."

The following quotation from Hudson's Bay correspondence on "Saturday 24, 1841" (HBA, D3/2 fo 68) indicates the occurrence of a remarkable flood in 1829.

> (Fort Edmonton) "has a fine commanding situation, on an almost perpendicular part of the bank of about 200 feet in height; it formerly stood a little lower down the stream, about a furlong from its present position where the bank is not so much elevated, but a remarkable flood in the year 1829 destroyed the establishment which was then removed to its present site."

The following quotation from the Edmonton Bulletin, August 21, 1899, also alludes to a remarkable flood around the period 1825 to 1829.

> "There is a legend that at one time about 70 years ago a jam of ice caused the water to flow over Ross' flat. At that time the H. B. Co. Fort was on the flat, and it is said that this is the reason of the present site on higher ground having been selected. Mrs. Fraser, mother of John and Henry Fraser of this settlement, is said to remember the occasion. It will be noticed that the flood arose from a different cause, and was not a freshet in the proper sense of the word, as this was. Therefore as a matter of fact there has been no such flood so far as memory or even legend extends."

Since the Fort Edmonton journals for a three year period from 1829 to 1831 are missing, the flood which caused the relocation of Edmonton House from the flats to higher ground, near today's Legislative Building, is uncertain. The Archive search however indicates that the recorded floods of 1899 and 1915 at Edmonton were not likely exceeded during the period 1830 to 1899.

2. ANNUAL MAXIMUM NATURAL FLOODS AT EDMONTON

Two series of extremes are common to flood frequency analysis. The most widely used extreme value series is comprised of annual extremes. This series has a good theoretical basis for extrapolating the series beyond the range of observation. A criterion of the annual series is independence of events. The annual series of maximum instantaneous discharges can be considered independent. The low flow period during the winter excludes any possibility of one annual flood influencing another.

A second extreme value series is the partial duration series. This series is comprised of all events above a given base value. The lack of independence between associated events has limited the development of statistical theory for this series. The partial duration series tends to merge with the annual series at return periods greater than 1:10 years (Kite, 1976). As this study is concentrating on events greater than a 1:10 year return period, the annual series is used in the analysis. The 1989 data are preliminary data and are included in the analyses.

2.1 Recorded Natural Flood Flows

Station 05DF001 - North Saskatchewan River at Edmonton has recorded annual maximum discharges for the years 1911 to 1989. The recorded floods prior to 1962 are natural flood flows. Since October 1, 1961, flows at Edmonton are influenced by the operation of the Brazeau development and since August 7, 1972, the operation of the Bighorn development has further altered natural streamflow at Edmonton.

2.2 Estimated Natural Flood Flows

Flood levels at Edmonton were also recorded for the floods of 1899 and 1900 (Whyte, 1916). Maximum instantaneous discharges of 5100 m^3/s and 4250 m^3/s, respectively, were estimated for these flood events.

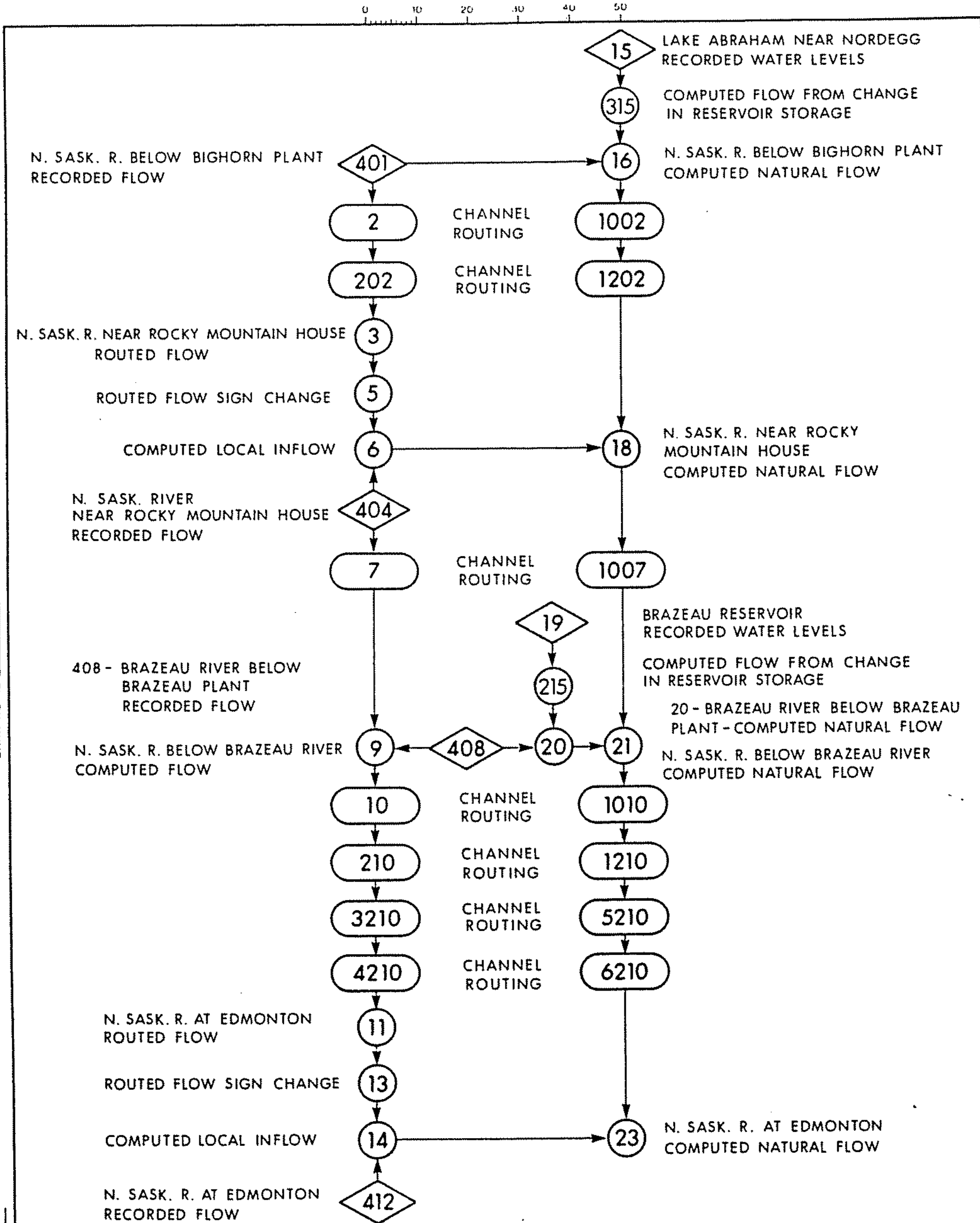
Since October 1, 1961, natural flows at Edmonton were reconstructed by computing natural flows at the reservoir sites and routing these natural flows to Edmonton. A reservoir routing model for the North Saskatchewan River, calibrated by the River Forecast Centre of Alberta Environment, was utilized to estimate natural flows at Edmonton. This Streamflow Synthesis and Reservoir Regulation Model (SSARR) was developed by the U.S. Army Corps of Engineers. Figure 2 shows the North Saskatchewan River System Flow Chart for Computing Natural Flows. Natural flows at the reservoir sites are computed by adding daily change in reservoir storage to recorded daily flows below the reservoirs. These natural flows are routed along the North Saskatchewan River in the computation of daily natural flows at Edmonton.

2.3 Natural Flood Flows at Edmonton

Annual maximum natural floods for the North Saskatchewan River at Edmonton are recorded or estimated for the years 1899 to 1900 and 1911 to 1989. For years where the maximum instantaneous discharge was not identified, estimates were obtained from a least squares curve fit between maximum daily (Q_D) and maximum instantaneous (Q_I) discharge. There are 22 years of natural flows where both parameters are available. The relationship, in m^3/s units, is given in Equation 1.

$$Q_I = 0.86404\ (Q_D)^{1.0303} \qquad \text{...(Equation 1)}$$

The index of determination (r^2) of Equation 1 is 0.994. This implies that 99.4 percent of the variation in the maximum instantaneous discharges is explained by the equation. The standard error of estimate for Equation 1 is about 5.1 percent. Table 2.1 lists the completed flood series of natural flows for the North Saskatchewan River at Edmonton. The peak flow estimate for the 1986 flood does not utilize Equation 1, as discussed in section 3.5 of this report.



Alberta ENVIRONMENT	TECHNICAL SERVICES DIVISION **HYDROLOGY BRANCH**	NORTH SASKATCHEWAN RIVER SYSTEM FLOW CHART FOR COMPUTING NATURAL FLOWS
SUBMITTED A. DE BOER, P. ENG. DATE DEC., 1986	DESIGNED A. DE BOER, P. ENG. CHECKED	
APPROVED M. MUSTAPHA, P. ENG. DATE DEC., 1986	DRAWN V. DA SILVA CHECKED A. DE BOER, P. ENG.	SCALE AS SHOWN DATE DEC., 1986 — **FIGURE No. 2.1**

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Table 2.1: Annual Natural Floods of North Saskatchewan River at Edmonton

Year	Annual Maximum Daily Discharge (m³/s)	Date	Annual Maximum Instantaneous Discharge (m³/s)	Date
1899	4570 e	--	5100	--
1900	3830 e	--	4250	--
1911	1460	Jul 03	1570 e	Jul 03 e
1912	2100	Jul 10	2290 e	Jul 10 e
1913	923	Aug 15	981 e	Aug 15 e
1914	1750	Jun 09	1900 e	Jun 09 e
1915	4640	Jun29	5800	Jun 28
1916	1670	Jun 22	1740	Jun 22
1917	1860	May 18	2020 e	May 18 e
1918	1000	Jun 16	1070 e	Jun 16 e
1919	564	Jun 24	590 e	Jun 24 e
1920	1620	May 10	1750 e	May 10 e
1921	705	May 23	776	May 23
1922	731	Aug 18	810	Aug 18
1923	2380	Jun 25	2820	Jun 25
1924	779	Jul 05	782	Jul 05
1925	2150	Aug 18	2180	Aug 18
1926	1660	Sep 04	1800 e	Sep 04 e
1927	1140	Jun 29	1280	Jun 28
1928	1730	Jul 07	1870 e	Jul 07 e
1929	1080	Jun 05	1150 e	Jun 05 e
1930	671	Jul 17	677	Jun 13
1931	1110	Jul 02	1190 e	Jul 02 e
1932	1870	Jun 04	2030 e	Jun 04 e
1933	974	Jun 19	1040 e	Jun 19 e
1934	796	Jun 01	842 e	Jun 01 e
1935	1310	Jul 11	1410 e	Jul 11 e
1936	1140	Apr 19	1220 e	Apr 19 e
1937	892	Jul 17	947 e	Jul 17 e
1938	1130	Jul 04	1210 e	Jul 04 e
1939	855	Jun 28	906 e	Jun 28 e
1940	1010	Apr 18	1080 e	Apr 18 e
1941	756	Jun 28	798 e	Jun 28 e
1942	1200	Jul 14	1290 e	Jul 14 e
1943	1250	Apr 12	1340 e	Apr 12 e
1944	3450	Jun 16	3570	Jun 16
1945	688	Jun 01	725 e	Jun 01 e
1946	1270	Jun 24	1360 e	Jun 24 e
1947	810	Jun 13	857 e	Jun 13 e
1948	1850	May 25	2010 e	May 25 e
1949	926	Jul 22	984 e	Jul 22 e

...Table 2.1 continued...

...Table 2.1 concluded...

Year	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date
1950	1420	Jun 17	1520	Jun 17
1951	1100	May 03	1160	May 03
1952	3540	Jun 25	3740	Jun 25
1953	1270	Jun 05	1300	Jun 05
1954	3030	Jun 08	3340	Jun 08
1955	861	Jun 15	906	Jun 15
1956	722	Jun 07	753	Jun 07
1957	617	Jun 11	663	May 22
1958	1410	Jun 30	1480	Jun 30
1959	1310	Jun 29	1460	Jun 28
1960	1040	Jul 03	1100	Jul 03
1961	770	Jul 31	852	Jul 31
1962	795 e	Aug 06 e	841 e	Aug 06 e
1963	1050 e	Jul 18 e	1130 e	Jul 17 e
1964	1340 e	Jun 21 e	1440 e	Jun 21 e
1965	2580 e	Jun 29 e	2830 e	Jun 29 e
1966	2030 e	Jul 06 e	2210 e	Jul 06 e
1967	1100 e	Jun 19 e	1180 e	Jun 19 e
1968	736 e	Jul 24 e	777 e	Jul 24 e
1969	2120 e	Jul 07 e	2310 e	Jul 07 e
1970	1920 e	Jun 18 e	2090 e	Jun 18 e
1971	1440 e	Jun 11 e	1550 e	Jun 11 e
1972	3290 e	Jun 27 e	3630 e	Jun 27 e
1973	1150 e	Jun 26 e	1230 e	Jun 26 e
1974	1040 e	Jul 13 e	1110 e	Jul 13 e
1975	634 e	Jul 16 e	566 e	Jul 16 e
1976	716 e	Aug 18 e	755 e	Aug 18 e
1977	1030 e	May 31 e	1100 e	May 31 e
1978	1320 e	Jul 13 e	1420 e	Jul 13 e
1979	473 e	Jun 07 e	493 e	Jun 07 e
1980	2280 e	Jun 06 e	2490 e	Jun 06 e
1981	1570 e	Jul 17 e	1700 e	Jul 17 e
1982	2380 e	Jul 06 e	2600 e	Jul 06 e
1983	709 e	Jul 05 e	747 e	Jul 05 e
1984	660 e	Jun 17 e	694 e	Jun 17 e
1985	748 e	Sep 15 e	790 e	Sep 15 e
1986	3710 e	Jul 20 e	4570 e	Jul 19 e
1987	555 e	Aug 05 e	581 e	Aug 05 e
1988	739 e	Jun 11 e	780 e	Jun 11 e
1989	1090 e	Aug 05 e	1160 e	Aug 05 e

e - estimated

3. ANNUAL MAXIMUM REGULATED FLOOD FLOWS

3.1 Historical Flow Regulation

Flow regulation at the Brazeau Plant commenced in October 1961. The development created 438,000 cubic decametres of live storage at a reservoir full supply level of 964.63 metres. The development altered natural streamflows from a 5660 square kilometre drainage basin. From 1961 to 1969, conduits, initially designed for water diversion during construction, were used to discharge water from the reservoir.

A permanent spillway at the Brazeau Dam was completed in October of 1969. At this time the full supply level of the reservoir was increased to elevation 966.22 metres. The structure has a spillway capacity of 1840 m^3/s at the reservoir full supply level. The capability of also passing 311 m^3/s through the plant gives a total discharge capacity of 2150 m^3/s from the development prior to breaching of the canal dyke.

Flow regulation at the Bighorn Plant commenced in August 1972. The development altered natural streamflows from a 3890 square kilometre drainage basin. The reservoir has a storage capacity of 1,436,000 cubic decametres. The spillway capacity at the development is 1420 m^3/s and the capacity through the two turbines is 164 m^3/s. Due to the large storage capability of the reservoir, flows through the spillway are expected to occur infrequently.

3.2 Computation of Regulated Flood Flows

Regulation of streamflows at the two hydro-power reservoirs is dependent on reservoir inflow, hydro-power demand and protection against failure of the developments. Even though planned operation of the developments may be generalized, real-time operation may dictate deviation from the typical operational plans.

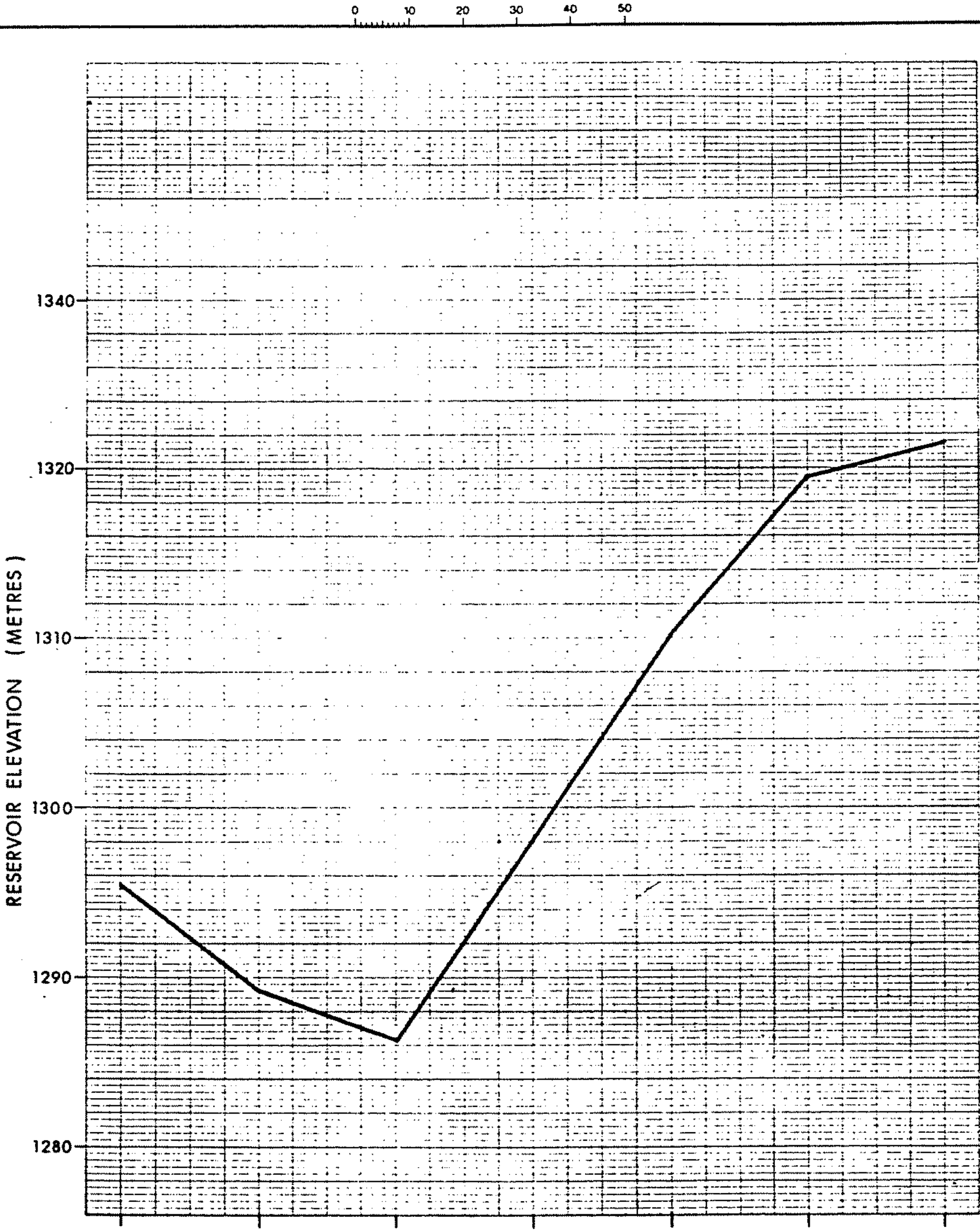
Typical operational procedures, including flood action plans, for both the Bighorn and Brazeau developments are currently utilized (note reference) by TransAlta Utilities. Target reservoir levels throughout the year typify the preferred method of operation. Figure 3.1 shows the Bighorn Reservoir Typical Operational Rule Curve and Figure 3.2 shows the Brazeau Reservoir Typical Operational Rule Curve. During a flood event each development is operated with consideration to a Flood Action Plan which always allocates sufficient reservoir storage to ensure the safety of the dam in the event of the Probable Maximum Flood occurring. Inflow forecasts, available reservoir storage, and outflow capability are utilized to minimize the downstream impact of any flood event. Table 3.1 summarizes the Bighorn Development Flood Action Plan and Table 3.2 summarizes the Brazeau Development Flood Action Plan.

Regulated flows below each development are computed by routing the natural flow, as determined in Figure 2.1, through each reservoir based on the typical operational rule curve and the flood action plan. The procedure is based on continuity of flow where outflow is a function of inflow, reservoir change in storage and development outlet capacities.

The computed regulated flows below the Bighorn and Brazeau developments are input into the North Saskatchewan River routing model (SSARR) to estimate regulated flows at Edmonton. Figure 3.3 shows the North Saskatchewan River System Flow Chart for Computing Regulated Flows.

3.3 Regulated Flood Flows Below Bighorn Plant

Table 3.3 shows annual maximum mean daily flows for the North Saskatchewan River below Bighorn Plant. Both natural and regulated flow estimates are provided along with flows which were recorded. For the years 1969 to 1972, daily natural flows below Bighorn Plant were determined by subtracting local inflow estimates between the plant and Saunders from the recorded flows on the North Saskatchewan River at Saunders. The local inflow estimates are represented by 67.74 percent of the recorded flows on the Ram River near the mouth.



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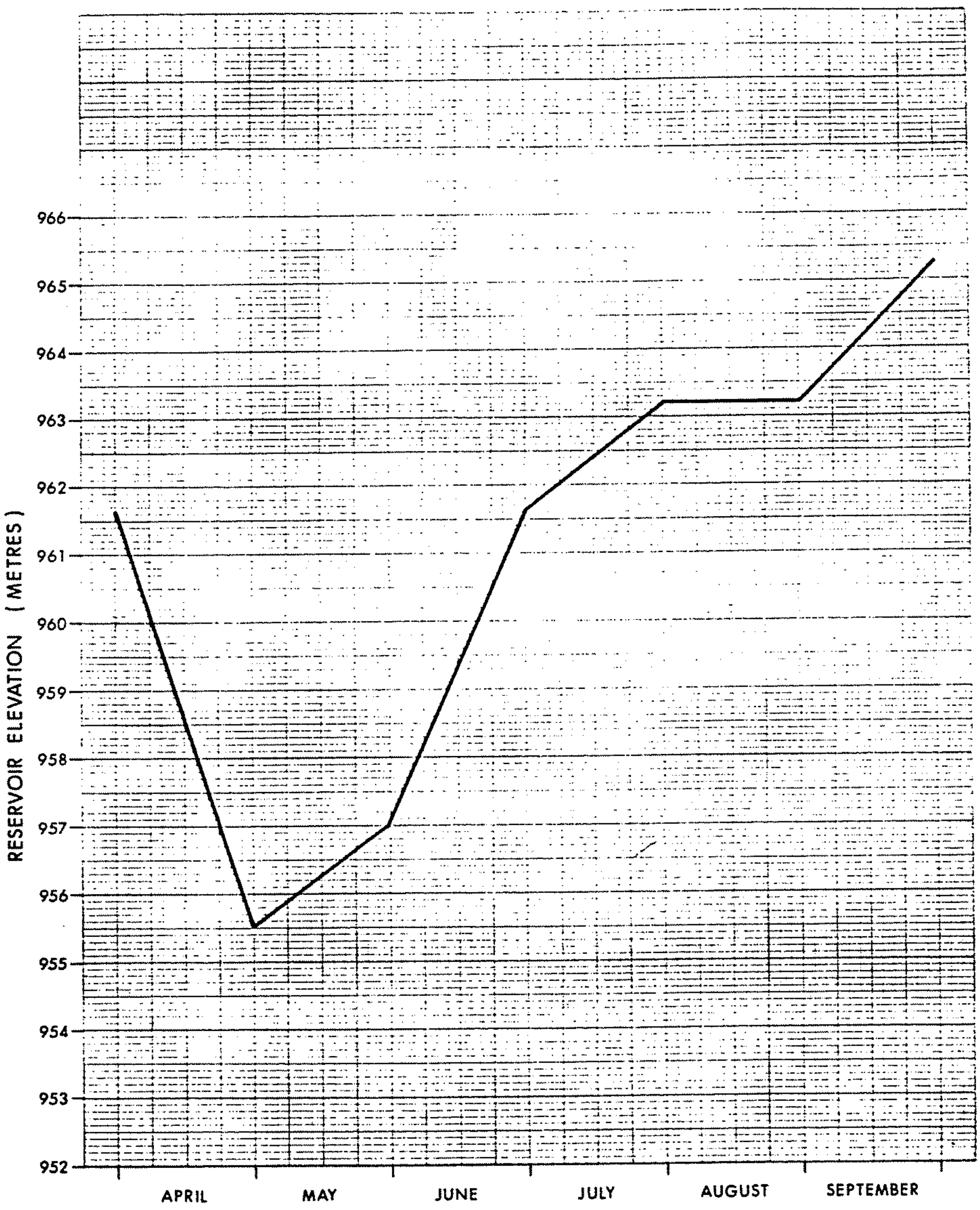
Alberta ENVIRONMENT	TECHNICAL SERVICES DIVISION **HYDROLOGY BRANCH**	**BIGHORN RESERVOIR TYPICAL OPERATIONAL RULE CURVE**
SUBMITTED A. DE BOER, P. ENG. DATE DEC., 1986	DESIGNED A. DE BOER, P. ENG. CHECKED	
APPROVED M. MUSTAPHA, P. ENG. DATE DEC., 1986	DRAWN V. DA SILVA CHECKED A. DE BOER, P. ENG.	SCALE AS SHOWN DATE DEC. 1986 — **FIGURE No. 3.1**



Alberta ENVIRONMENT

TECHNICAL SERVICES DIVISION
HYDROLOGY BRANCH

BRAZEAU RESERVOIR TYPICAL OPERATIONAL RULE CURVE

SUBMITTED A. DE BOER, P. ENG.
DATE DEC., 1986

APPROVED M. MUSTAPHA, P. ENG.
DATE DEC., 1986

DESIGNED A. DE BOER, P. ENG.
CHECKED

DRAWN V. DA SILVA
CHECKED A. DE BOER, P. ENG.

SCALE AS SHOWN
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FIGURE No. 3.2

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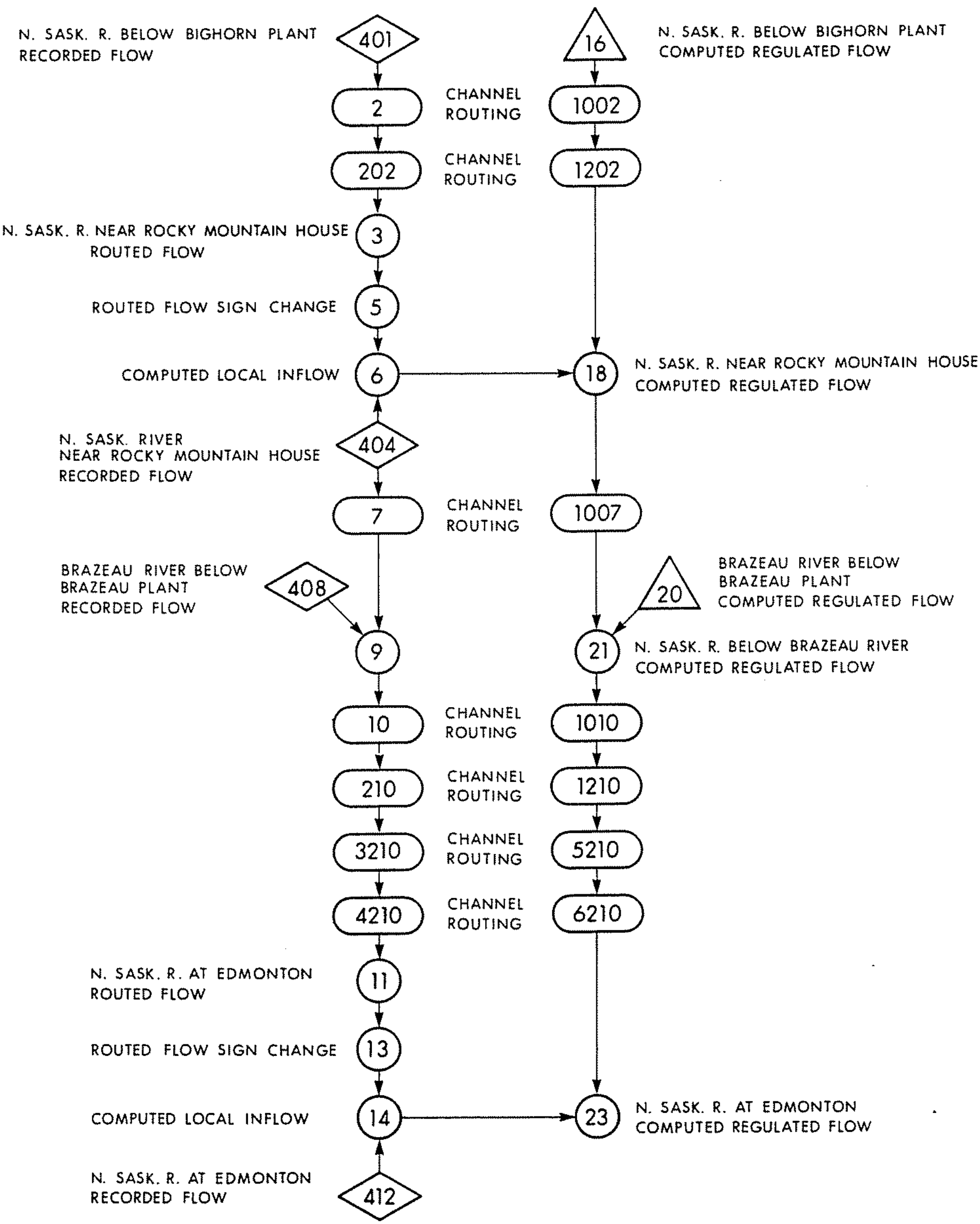
Table 3.1: Bighorn Development Flood Action Plan

Alarm Phase	Flood Condition	Operation Requirement
Phase I Alarm	Reservoir above normal filling curve. High inflows, reservoir begins to rise.	Maintain full load on units.
		Alert spillway operating crews.
Phase II Alarm	Inflows increasing, reservoir approaches 1316.74 m (1318.26 m after mid-September).	Operate spillway to hold reservoir at 1316.74 m (1318.26 m after mid-September) up to full discharge capacity if required.
Phase III Alarm	Inflows increasing reservoir rising above 1321.31 m.	Inspect retaining structures for stability.
Phase IV Alarm	Dam overtops at elevation 1324.97 m.	

Table 3.2: Brazeau Development Flood Action Plan

Alarm Phase	Flood Condition	Operation Requirement
Phase I Alarm	Reservoir near key elevation. High inflows cause reservoir to rise.	Maintain full load on unit. Alert operating crews.
Phase II Alarm	Reservoir approaching or at key elevation and rising.	Open spillway gates as required to hold reservoir at key elevation. If canal dyke has breached and reservoir level at key elevation with spillway fully open, increase flows through venturi gates.
Phase III Alarm	Discharge capacity utilized, reservoir rising above key elevations.	Inspect reservoir structures for stability.
Phase IV Alarm	Earth fill dam overtops at elevation 968.35 m.	



Alberta ENVIRONMENT	TECHNICAL SERVICES DIVISION **HYDROLOGY BRANCH**	NORTH SASKATCHEWAN RIVER SYSTEM FLOW CHART FOR COMPUTING REGULATED FLOWS	
SUBMITTED A. DE BOER, P. ENG. DATE DEC., 1986	DESIGNED A. DE BOER, P. ENG. CHECKED		
APPROVED M. MUSTAPHA, P. ENG. DATE DEC., 1986	DRAWN V. DA SILVA CHECKED A. DE BOER, P. ENG.	SCALE AS SHOWN DATE DEC., 1986	**FIGURE No. 3.3**

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Table 3.3: North Saskatchewan River Below Bighorn Plant
Annual Maximum Mean Daily Flows (m^3/s)

Year	Natural	Date	Regulated	Date	Recorded	Date
1964	447	Jul 09	164 e	*		
1965	538	Jul 08	164 e	*		
1966	379	Jul 04	164 e	*		
1967	408	Jun 17	164 e	*		
1968	464	Jun 27	164 e	*		
1969	357 e	Jun 06	164 e	*		
1970	289 e	Jul 09	151 e	*		
1971	346 e	Aug 09	164 e	*		
1972	541 e	Jun 11	164 e	*		
1973	490 e	Jun 23	164 e	*	118	Jul 05
1974	515 e	Jun 24	164 e	*	161	Jul 04
1975	391 e	Jul 14	164 e	*	132	Jan 07
1976	379 e	Aug 07	164 e	*	131	Sep 13
1977	317 e	Jun 08	155 e	Jun 09	149	Jun 23
1978	408 e	Jun 06	164 e	*	163	Jul 06
1979	331 e	Jul 20	164 e	*	130	Apr 21
1980	402 e	Jun 17	164 e	*	171	Jun 28
1981	428 e	Jul 14	164 e	*	155	May 02
1982	399 e	Jun 22	164 e	*	165	Jun 26
1983	310 e	Jul 13	164 e	*	162	Apr 25
1984	402 e	Jun 29	164 e	*	145	Aug 18
1985	278 e	Jul 05	164 e	*	149	May 28
1986	497 e	Jun 01	164 e	*	167	Jul 14
1987	299 e	Jul 05	164 e	*	140	Jun 17
1988	442 e	Jun 08	164 e	*	162	Jun 10
1989	354 e	Jun 15	164 e	*	160	Jun 19

e - estimated
* - various dates

The recorded flows below Bighorn Plant show close agreement with the regulated flows estimated for development operation. The recorded flows also show that outflow from the development has always been through the turbines during the period of operation from 1973 to 1989.

The Bighorn development does significantly reduce flood peak flow rates. The amount of reduction is equal to the natural peak flow rate less the flow being discharged through the turbines. For example, on June 24, 1974, the daily natural flood peak of 515 m^3/s less turbine outflow of 158 m^3/s recorded on that date resulted in a daily peak flow reduction of 357 m^3/s.

3.4 Regulated Flood Flows Below Brazeau Plant

Table 3.4 shows annual maximum mean daily flows for the Brazeau River below Brazeau Plant. Both natural and regulated flow estimates are provided along with flows which were recorded.

The close agreement between the recorded flows and the regulated flows indicates that the development generally operates along the typical procedures outlined in Section 3.2. Flow regulation at the Brazeau development is largely dependent on the reservoir level at the time of the flood event. As shown in Figure 3.2, major filling of the reservoir occurs in June and the amount of flow reduction is greatest during this month. From the end of June to the end of August, only a limited amount of inflow is stored in the reservoir because the reservoir is approaching its full supply level and any remaining live storage must be conserved to protect the development in the event of a maximum probable flood. In September, the reservoir is permitted to approach its full supply level because the threat of major rainfall storms has subsided. As indicated by the flood of July 18, 1986, flow reduction due to the Brazeau development is limited for major floods which occur after July 1.

Table 3.4: Brazeau River Below Brazeau Plant
Annual Maximum Mean Daily Flows (m^3/s)

Year	Natural	Date	Regulated	Date	Recorded	Date
1964	422 e	Jun 19	340 e	*	411	Jun 20
1965	569 e	Jun 01	340 e	*	496	Jun 29
1966	1060 e	Jul 05	340 e	*	575	Jul 05
1967	280 e	Jun 19	230 e	Jun 19	198	Jun 26
1968	220 e	Jul 31	209 e	Aug 08	199	Sep 10
1969	932 e	Aug 07	640 e	Aug 07	270	Jul 06
1970	725 e	Jun 16	340 e	*	234	Dec 04
1971	544 e	Jun 10	340 e	*	257	Jun 10
1972	1100 e	Jun 25	663 e	Jun 26	513	Jun 27
1973	323 e	Jun 25	272 e	Jun 25	209	May 08
1974	297 e	Jun 17	249 e	Jun 17	194	Jul 22
1975	147 e	Jul 14	127 e	Jul 14	130	Dec 12
1976	242 e	Aug 10	242 e	Aug 10	147	Jan 08
1977	244 e	May 30	231 e	May 30	226	Jun 03
1978	439 e	Jul 12	340 e	*	309	Jul 12
1979	165 e	May 26	151 e	May 26	131	May 26
1980	909 e	Jun 04	340 e	*	464	Jun 06
1981	462 e	Jul 15	340 e	*	376	Jul 26
1982	578 e	Jul 05	340 e	*	527	Jul 08
1983	233 e	Jun 25	183 e	Jun 25	140	Jul 07
1984	206 e	Jun 15	151 e	Jun 16	137	Jun 19
1985	252 e	Sep 14	221 e	Sep 14	152	Sep 15
1986	1100 e	Jul 18	801 e	Jul 19	1090	Jul 18
1987	207 e	Aug 03	207 e	Aug 03	110	Mar 11
1988	259 e	Jun 09	209 e	Jun 09	92	Jul 22
1989	485 e	Aug 18	340 e	*	334	Aug 18

e - estimated
* - various dates

3.5 Regulated Flood Flows at Edmonton

Table 3.5 shows annual maximum daily flows for the North Saskatchewan River at Edmonton. Both natural and regulated flow estimates are provided along with flows which were recorded. In general, the table shows that regulation at the Bighorn and Brazeau reservoirs may marginally reduce natuaral flood peaks at Edmonton. The amount of flow reduction, however, appears to be dependent on both the magnitude of the flood event and the time of the season when the flood occurs.

Table 3.5: North Saskatchewan River at Edmonton
Annual Maximum Mean Daily Flows (m^3/s)

Year	Natural	Date	Regulated	Date	Recorded	Date
1964	1340 e	Jun 21	1330 e	May 08	1350	Jun 21
1965	2580 e	Jun 29	2310 e	Jun 29	2590	Jun 29
1966	2030 e	Jul 06	1290 e	Jul 06	1630	Jul 06
1967	1100 e	Jun 19	827 e	Jun 19	1000	Jun 19
1968	736 e	Jul 24	527 e	Jul 24	597	Aug 09
1969	2120 e	Jul 07	1610 e	Jul 08	1740	Jul 07
1970	1920 e	Jun 18	1570 e	Jun 18	1520	Jun 18
1971	1440 e	Jun 11	1120 e	Jun 11	1180	Jun 11
1972	3290 e	Jun 27	2890 e	Jun 27	2970	Jun 27
1973	1150 e	Jun 26	796 e	Jun 26	589	Jun 26
1974	1040 e	Jul 13	915 e	Jul 13	1060	Apr 20
1975	634 e	Jul 16	405 e	Jul 16	419	May 07
1976	716 e	Aug 18	552 e	Aug 19	430	Aug 19
1977	1030 e	May 31	1040 e	May 31	920	May 31
1978	1320 e	Jul 13	1050 e	Jul 13	949	Jul 13
1979	473 e	Jun 07	416 e	May 29	385	Apr 26
1980	2280 e	Jun 06	1710 e	Jun 06	1740	Jun 07
1981	1570 e	Jul 17	1350 e	Jul 26	1160	Jul 26
1982	2380 e	Jul 06	2050 e	Jul 06	1920	Jul 06
1983	709 e	Jul 05	507 e	Jul 06	493	Apr 27
1984	660 e	Jun 17	439 e	Jun 11	373	Jun 11
1985	748 e	Sep 15	608 e	Sep 15	661	Sep 15
1986	3710 e	Jul 20	3050 e	Jul 19	3990	Jul 19
1987	555 e	Aug 05	386 e	Aug 05	378	Aug 05
1988	739 e	Jun 11	439 e	Jun 12	451	Jul 07
1989	1090 e	Aug 05	913 e	Aug 05	853	Aug 05

e - estimated

The 1986 flood can readily illustrate the influence of regulation on floods at Edmonton. For this flood event, natural flows for the system, as described in Figure 2.1, were computed based on hourly data at the input locations. An evaluation of the results showed that the maximum computed hourly local inflow of 2540 m^3/s at Edmonton represented about 56 percent of the recorded peak flow of 4520 m^3/s at Edmonton. This computed local inflow is not included in the channel routing of the model between Rocky Mountian House and Edmonton, which influences the timing of the computed natural flows. The computed natural flows at Edmonton gave two high mean daily flow estimates and a small under-estimation of the peak flow which occurred between the two days. Due to this routing limitation of the model, a more accurate estimate of the natural peak flow at Edmonton for the 1986 flood may be determined by assessing the data at the reservoir sites.

The peak flood wave at the Brazeau development occurred on July 18, 1986. The computed daily natural flow of 1100 m^3/s exceeded the recorded outflow of 1090 m^3/s. Thus a reduction of 10 m^3/s to the flood at Edmonton may be attributed to the Brazeau development. Prior to July 17, natural flows at the Bighorn development exceeded recorded outflows by about 40 m^3/s. Thus, a reduction of 50 m^3/s to the flood at Edmonton may be attributed to flow regulation at the reservoirs for the 1986 flood.

The Bighorn development controls 13.9 percent of the area draining to Edmonton. This portion of the drainage basin generally does not experience the major rainfall events which produce the large floods at Edmonton. Therefore, peak flows at the development generally do not coincide with peak flows at Edmonton. Negligible flow reduction for major floods at Edmonton due to the Bighorn development should be assumed.

The Brazeau development controls 20.2 percent of the area draining to Edmonton. This portion of the drainage basin generally does experience the major rainfall events which produce the large floods at Edmonton. Peak flows therefore often do coincide at these two locations. However, live storage at the Brazeau development is often limited for peak flow reduction during these flood events and therefore negligible flow reduction due to the Brazeau development should be assumed during the occurrence of major floods at Edmonton.

In summary, the Bighorn and Brazeau developments cannot be relied upon to reduce the magnitude of the major floods that occur at Edmonton. Therefore, it is recommended that the natural flood series at Edmonton be used to estimate the 1:100 year return period flood flow.

4. ANALYSES OF FLOODS AT EDMONTON

Maximum annual instantaneous discharges are a series of random events for which the probability distribution is unknown. However, to facilitate assigning flood probabilities, it is necessary to associate a frequency distribution with these events. Several statistical distributions are applied to the annual flood discharge data to identify an appropriate distribution.

4.1 Distribution Selection

A criterion to select a statistical distribution can only be applied to a period of years with a continuous record of flood events. The analysis is therefore limited to the unbroken period of record, 1911 to 1989. The assumption is made that a distribution representative of the series of 79 recorded events will also be representative for a historically adjusted period.

For a sample of observed data, sample probabilities can be calculated (Lin, 1984) for various continuous probability distributions. The probability distribution which has the highest sample probability can be considered the one which best fits the data.

The procedure involves the calculation of the continuous probability distribution from the annual flood discharge data. The exceedance probabilities of the high recorded floods are then estimated from the probability distribution. The flood exceedance probabilities are evaluated by modified equations of Multinomial Distribution to determine the sample probability of the recorded flood(s) from the flood population.

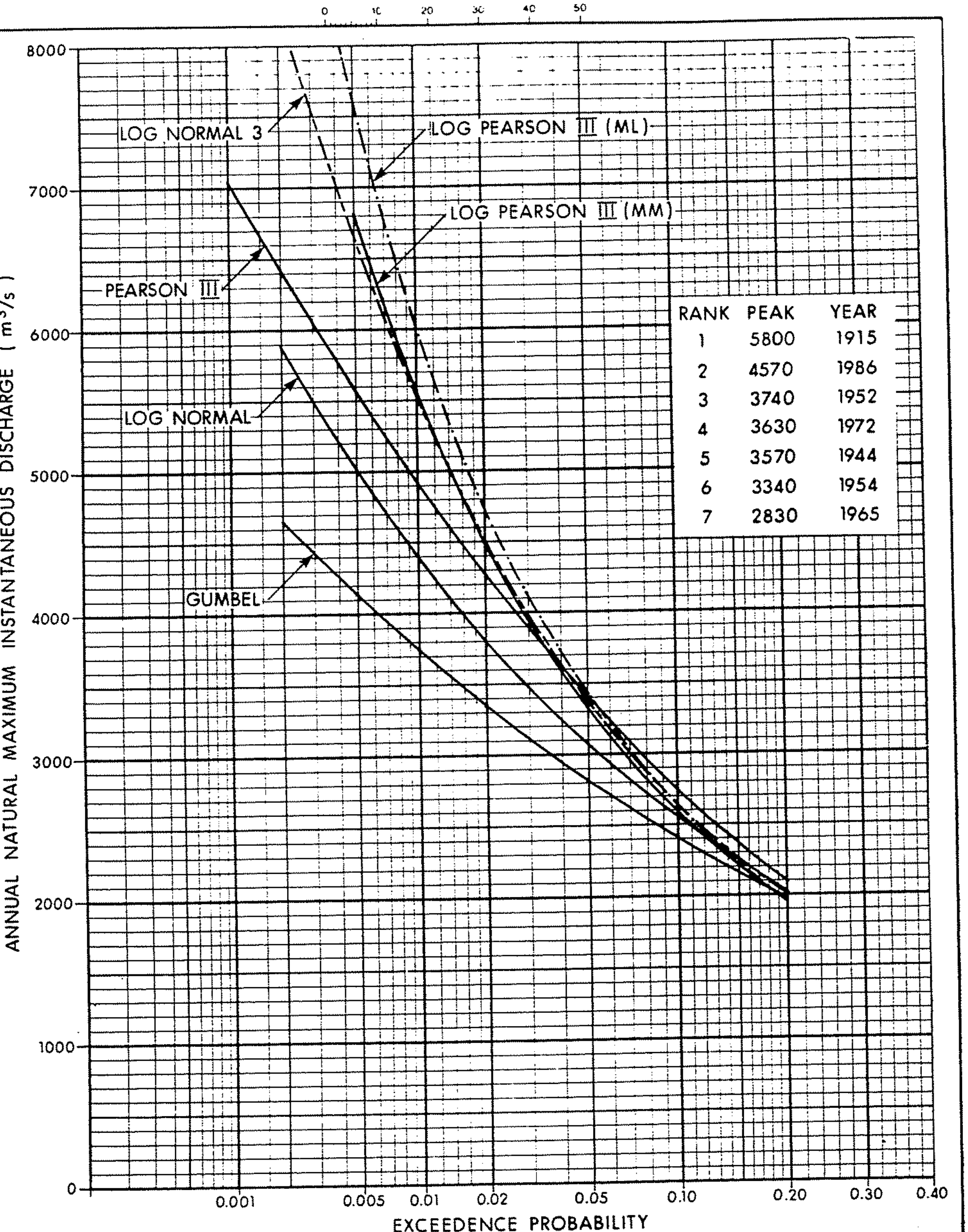
Five commonly used statistical probability distributions, where the distribution parameters are computed by both maximum likelihood theory and by the method of moments, are applied to the annual flood discharge data to select the distributions which best fit the data. The theories of these distributions (Pearson Type III, log-Pearson Type III, log-Normal, 3 parameter log-Normal, and Gumbel Type I) are outlined in various publications on statistics. Other known distributions (Gamma (3), and log-Gamma(3)) are not presented because the Pearson or log-Pearson distribution will take the form of these distributions if the flood data is distributed by their theories.

Flood frequency curves of the five distribution types are presented in Figure 4.1 for the North Saskatchewan River at Edmonton. The figure also shows the seven highest natural flood events. The exceedance probabilities for these flood events, for each of the distributions, are summarized in Table 4.1. Each of the continuous probability distributions gives different exceedance probabilities for each high flow event, clearly indicating the need for a selection criterion.

Table 4.1: Exceedance Proabilities for the Natural High Flow Events on the North Saskatchewan River at Edmonton

Probability Distribution	$F(Q_1)$	$F(Q_2)$	$F(Q_3)$	$F(Q_4)$	$F(Q_5)$	$F(Q_6)$	$F(Q_7)$
Gumbel I	0.0005	0.0026	0.0103	0.0130	0.0145	0.0206	0.0494
log-Normal	0.0023	0.0087	0.0233	0.0278	0.0303	0.0397	0.0741
log-Normal-3	0.0088	0.0198	0.0413	0.0442	0.0458	0.0547	0.0887
Pearson III*	0.0041	0.0154	0.0365	0.0399	0.0428	0.0562	0.0955
log-Pearson III*	0.0090	0.0194	0.0399	0.0428	0.0443	0.0507	0.0856
log-Pearson III	0.0120	0.0247	0.0433	0.0457	0.0471	0.0563	0.0881

* based on method of moments



Alberta ENVIRONMENT

TECHNICAL SERVICES DIVISION
HYDROLOGY BRANCH

FLOOD FREQUENCY CURVES
NORTH SASKATCHEWAN RIVER AT EDMONTON

SUBMITTED A. DE BOER, P. ENG.	DESIGNED A. DE BOER, P. ENG.	SCALE AS SHOWN	**FIGURE No. 4.1**
DATE APRIL, 1990	CHECKED	DATE APRIL, 1990	
APPROVED M. MUSTAPHA, P. ENG.	DRAWN V. DA SILVA		
DATE APRIL, 1990	CHECKED		

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The probabilities of each distribution fitting the largest one, two, three,... six floods (called the sample probabilities) were calculated by modified equations of Multinomial Distribution to determine the distributions which best fit the annual flood discharge data. The sample probabilities and the ranks of the sample probabilities are presented in Table 4.2. The results show, as indicated by the sample probabilities, that the Gumbel, log-Pearson III and log-Normal distributions give the least probable fit to the high flood events. The 3 parameter log-Normal, Pearson III* and log-Pearson III* distributions give the most probable fit to these flood events. Table 4.2 indicates that the log-Pearson III* distribution has the highest probability of fitting only the three highest floods. All three acceptable distributions have a similar high probability of fitting the three largest floods. When the six largest floods are evaluated, the Pearson III* distribution gives the most probable fit to the flood data.

Table 4.2: Sample Probabilities and Ranks for the Natural High Flow Events on the North Saskatchewan River at Edmonton

Probability Distribution	P_1	P_{21}	P_{321}	P_{4321}	P_{54321}	P_{654321}
Sample Probabilities						
Gumbel I	0.10850	0.02844	0.00769	0.00106	0.00023	0.00008
log-Normal	0.28259	0.10278	0.03660	0.00763	0.00222	0.00070
log-Normal-3	0.36733	0.13133	0.04861	0.00728	0.00200	0.00063
Pearson III*	0.35870	0.12853	0.04757	0.00926	0.00314	0.00083
log-Pearson III*	0.36766	0.13318	0.04918	0.00722	0.00165	0.00053
log-Pearson III	0.34189	0.12334	0.04499	0.00586	0.00162	0.00052
Ranks of Sample Probabilities						
Gumbel I	6	6	6	6	6	6
log-Normal	5	5	5	2	2	2
log-Normal-3	2	2	2	3	3	3
Pearson III*	3	3	3	1	1	1
log-Pearson III*	1	1	1	4	4	4
log-Pearson III	4	4	4	5	5	5

* based on method of moments

Acceptance of a certain distribution for analysis of flood peaks must also be based on the goals and conditions that are to be fulfilled and satisfied by the distribution. The most important criteria in the selection of a distribution are that there be a sound theory describing the phenomenon and that the distribution abstract the required information from the data using proper estimation techniques.

A group of frequency distributions can be derived from a generalized differential equation proposed by Karl Pearson. This generalized equation has four constants and by equating some to zero or to each other and solving the differential equation a series of symmetrical or skewed distributions are found. One solution leads to a two parameter distribution and by combinations of these parameters a variety of U and J-shaped distributions are attainable. The Pearson Type III frequency distribution offers considerable flexibility because most common frequency distributions can be found in a solution for the Pearson distribution.

The Pearson Type III distribution becomes bounded at the upper end, a condition not suitable for analysis of maximum events, when the sample coefficient of skew is negative. When the sample coefficient of skew is positive, as is common for almost all hydrologic events, the distribution is bounded at the lower end by a value of zero. This is extremely advantageous for flood frequency analysis because negative floods at shorter return periods, a condition which is physically unrealistic, are not permitted. Sample skewness, which is sensitive to extreme events, should be carefully evaluated when using the Pearson distribution. As the length of station record increases, the skew computed from individual station data is usually more reliable. The United States Water Resources Council (1977) recommends that the station skew should be used exclusively if records of 100 years or more are available. For a record length of 25 to 100 years, a weighted skew should be calculated in which the station skew is given a weight of (N-25)/75, where N is the length of record, and a generalized skew is given a weight of 1.0 minus (N-25)/75. The sample skewness for the 79 years of systematic data would be given a weight of 72 percent in determining the population skewness of floods on the North Saskatchewan River at Edmonton. Since generalized skew coefficients are unavailable for Alberta (because several stations having 100 or more years of record are required for development), it is assumed that the sample skewness, determined from the annual flood series, is representative of the population skewness.

The solution of the Pearson Type III distribution parameters are determined by the method of moments because it is not always possible to guarantee finding the minimum variance solution using maximum likelihood methods.

The Pearson Type III distribution, using the method of moments, provides sound theory for flood frequency analysis of the recorded streamflow data. This 3 parameter distribution fits the skewness of the data sample and has a lower boundary which ensures that negative floods for lower return periods are not computed. Flood frequency estimates for the North Saskatchewan River at Edmonton can best be described by this continuous probability distribution.

4.2 Historically Adjusted Flood Frequency Estimates

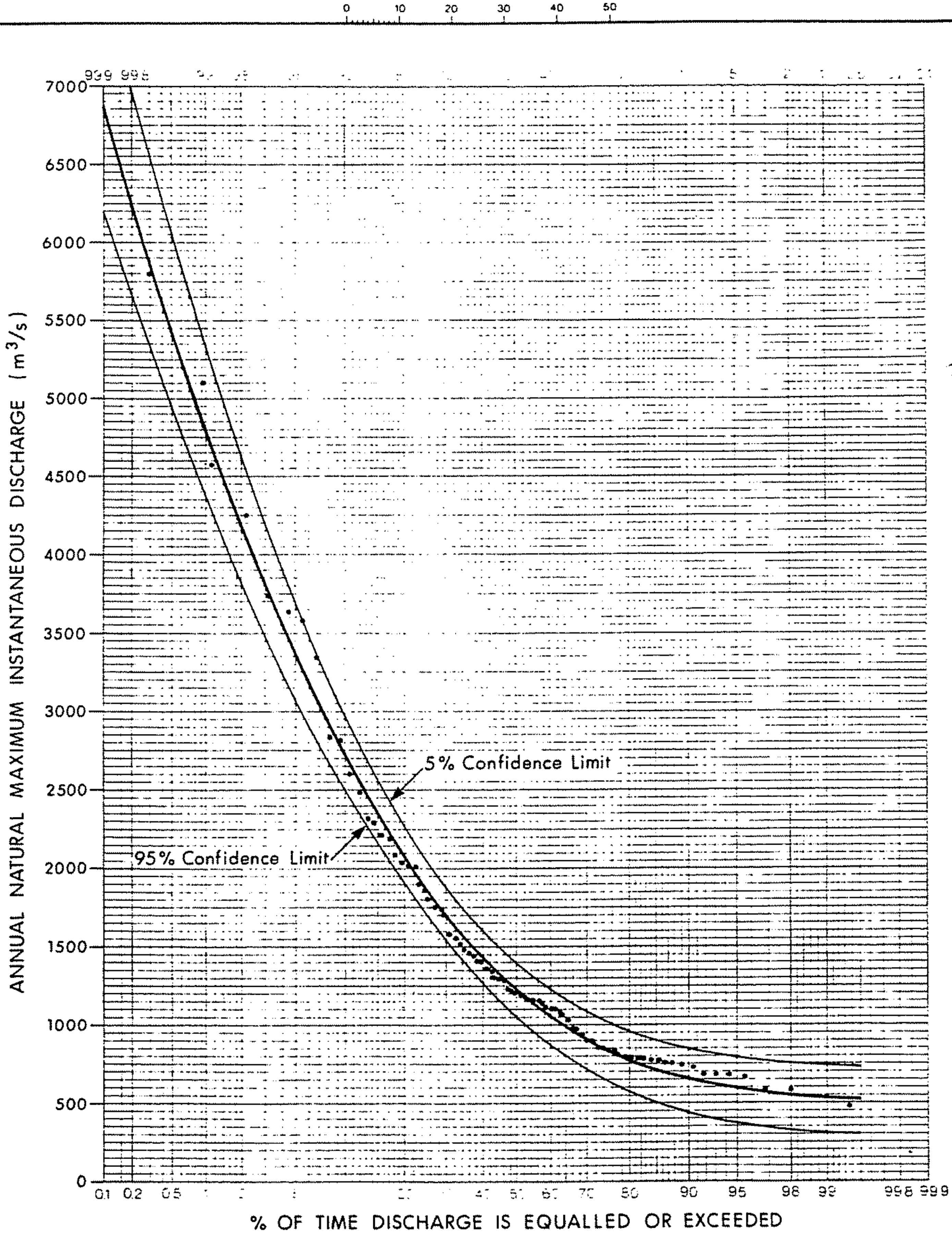
Analysis of the flood data has shown that the natural flood series should be used in the determination of flood frequency estimates for the North Saskatchewan River at Edmonton. The Pearson Type III probability distribution was selected for the analysis because this distribution provides a good fit to the flood data and exhibits sound theory in defining the objectives of a flood frequency analysis. The inclusion of historical floods in the analysis will extract the maximum information from the flood data. Appendix A shows the procedures used to compute a historically weighted Pearson III frequency curve.

Reliable flood magnitudes were determined for the historical floods of 1899 and 1900 at Edmonton. These floods must be included in the analysis. The analysis may be extended if it is certain that the highest recorded floods have not been exceeded within a known time period. The Archive search of journals and letters at Fort Edmonton indicates that the largest recorded floods of 1915, 1899, 1986 and 1900 were likely not exceeded during the period 1830 to 1989. Based on this premise, flood frequency estimates for the North Saskatchewan River at Edmonton are summarized in Table 4.3 and shown on Figure 4.2.

Table 4.3: Flood Frequency Estimates - North Saskatchewan River at Edmonton (1830 to 1989) [not recommended]

Return Period (Years)	Annual Natural Maximum Instantaneous Discharge (m^3/s)
200	5420
100	4800
50	4180
25	3560
20	3350
10	2720
5	2090
2	1240

Extension of the frequency analysis to include the period 1830 to 1989 incorporates several uncertainties. Firstly, the reason for the reporting of "too much water" was primarily based on "inconvenience". Thus, the river at Edmonton was likely more prominent when the fort was near the river than after the fort was moved to higher ground. Secondly, the reporting of events took place when a writer was at the fort. The description of events was often based on memory after months or even years had passed. Thirdly, flood events were generally described rather than quantified. The relative magnitude of the 1825 flood to quantified floods at Edmonton is therefore speculative and the relationship of the historical period with the systematic period is uncertain. For these reasons, extension of the frequency analysis to include the historical period 1830 to 1989 is not recommended.



Alberta ENVIRONMENT	TECHNICAL SERVICES DIVISION **HYDROLOGY BRANCH**	PEARSON TYPE III FLOOD FREQUENCY ESTIMATES NORTH SASKATCHEWAN RIVER AT EDMONTON (1830 - 1989)	
SUBMITTED A. DE BOER, P. ENG. DATE APRIL, 1990	DESIGNED A. DE BOER, P. ENG. CHECKED		
APPROVED M. MUSTAPHA, P. ENG. DATE APRIL, 1990	DRAWN V. DA SILVA CHECKED	SCALE AS SHOWN DATE APRIL, 1990	**FIGURE No. 4.2**

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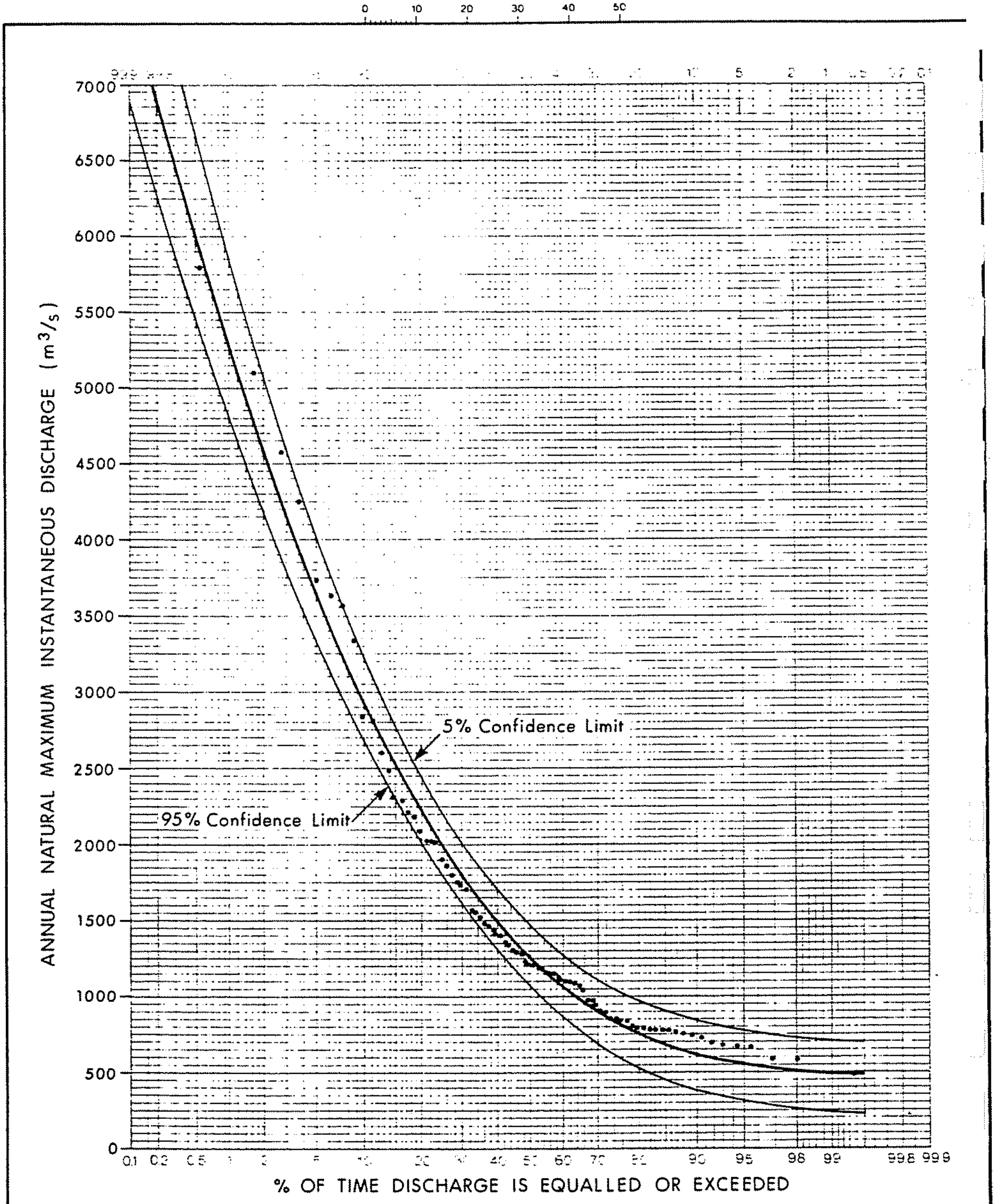
The historical period 1899 to 1989 is reliable in the determination of flood frequency estimates for the North Saskatchewan River at Edmonton. Figure 4.3 shows the Pearson Type III flood frequency curve of the annual flood discharge data. The annual maximum instantaneous discharge estimates for various return period flood events are summarized in Table 4.4.

Table 4.4: Flood Frequency Estimates - North Saskatchewan River at Edmonton (1899 to 1989) [recommended]

Return Period (Years)	Annual Natural Maximum Instantaneous Discharge (m^3/s)
200	5960
100	5270
50	4570
25	3870
20	3640
10	2940
5	2230
2	1270



Alberta ENVIRONMENT	TECHNICAL SERVICES DIVISION **HYDROLOGY BRANCH**	PEARSON TYPE III FLOOD FREQUENCY ESTIMATES NORTH SASKATCHEWAN RIVER AT EDMONTON (1899 - 1989)
SUBMITTED A. DE BOER, P. ENG. DATE APRIL, 1990	DESIGNED A. DE BOER, P. ENG. CHECKED	
APPROVED M. MUSTAPHA, P. ENG. DATE APRIL, 1990	DRAWN V. DA SILVA CHECKED	SCALE AS SHOWN DATE APRIL, 1990 — **FIGURE No. 4.3**

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5. SUMMARY

Analyses of recorded water level and flow data within the North Saskatchewan River drainage basin lead to the conclusion that the influence of flow regulation at the Bighorn and Brazeau developments is negligible in the reduction of peak flows at Edmonton, especially for higher return period flood events. Annual natural maximum instantaneous discharges were therefore recommended to estimate the magnitude and frequency of expected future flood flows.

Historical extension of the flood data beyond the period 1899 to 1989 is not recommended because flood magnitudes outside of this period are not quantified and the reporting of "too much water" was primarily based on "inconvenience". The Pearson Type III frequency distribution provides a good probable fit to the natural flood data and is best suited to include the historical floods of 1899 and 1900.

The predicted 1:100 year return period flood magnitude for the North Saskatchewan River at Edmonton is 5270 m^3/s, as provided in Table 4.4. The study results reflect the most current data and assessment available.

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APPENDIX A

HISTORICAL FREQUENCY ANALYSIS

HISTORICAL FREQUENCY ANALYSIS

Information on major floods that occurred prior to the start of a systematic record can often be used to improve frequency estimates. In such a situation, the following procedures are used to compute a historically weighted Pearson III frequency curve.

Historic knowledge is used to define the historically longer period of "H" years. The number "Z" of events that are known to be the largest in the period "H" are given a weight of 1.0. The remaining "N" events from the systematic record are given a weight of (H-Z)/N on the assumption that their distribution represents the (H-Z) remaining years of the historically longer period.

The computations are done by applying the weights to each individual year's data using the following equations.

$$W = \frac{H - Z}{N}$$

$$M = \frac{W \Sigma X + \Sigma X_Z}{H}$$

$$S^2 = \frac{W \Sigma (X - M)^2 + \Sigma (X_Z - M)^2}{(H - 1)}$$

$$G = \frac{H}{(H - 1) \quad (H - 2)} \quad \frac{W \Sigma (X - M)^3 + \Sigma (X_Z - M)^3}{S^3}$$

$$Q = M + KS$$

Where X = annual peak flow.

N = number of events in systematic record being used.

M = historically weighted mean.

S = historically weighted standard deviation.

G = historically weighted skew coefficient.

K = Pearson III coordinate expressed in number of standard deviations from the mean for a specified recurrence interval.

The plotting positions for the individual flood events are computed as follows:

$$m = E \text{ when } 1 \leq E \leq Z$$

$$m = WE - (W-1)(Z+0.5) \text{ when } (Z+1) \leq E \leq (Z+N)$$

$$pp = \frac{m - a}{H+1-2a} 100$$

Where m = weighted order number of each event for use in formulas to compute plotting position.

E = event number when events are ranked in order from greatest magnitude to smallest magnitude.

a = constant that is characteristic of a given plotting position formula. For Hazen; a = 0.5; for Weibull, a = 0.