Overview of the Hydrology

in the Deh Cho Region - NWT

Derek A. Faria

August 2002

Water Resources Division
Indian and Northern Affairs Canada
Yellowknife, Northwest Territories
Canada

Table of Contents

List of Figures

List of Tables

Introduction

Surface hydrology is the most tangible aspect of all hydrological processes, and the measurement of stream flow is a traditional method for establishing the quantity of water moving through any region. The purpose of this report is to provide an overview of the stream flow data collected for the Deh Cho region, one of six Land Claim areas within the Northwest Territories (NWT). Many of the streams which flow through the Deh Cho region cross boundaries with neighbouring areas to the south, north and east, and carry water to or from these neighbouring areas. From 1938 up to the present time the Water Survey of Canada (WSC) has operated hydrometric stations on many of these streams, and the flow data up to December 2000 is published on a compact disk (Environment Canada, 2002). The data consists of daily averaged discharge (stream flow) given in cubic metres of water per second (m^3/s) which flows past each station. This report covers the flow data available from 41 hydrometric stations, 16 of which are currently operating. The data are presented using mean and extreme annual hydrographs, a summary of basin statistics, and frequency analyses of extreme annual events. All streams are characterised by hydrological regimes.

The Deh Cho Region Setting

Geographic Setting

The Deh Cho region is one of six land claim areas within the NWT and occupies the southwestern portion of the territory (Fig. 1). The Deh Cho land claim remains unsettled - the eastern boundary with the South Slave region and the northeastern boundary with the North Slave region are currently under negotiation and are tentative. The region is composed of two distinct physiographic areas - the high mountain cordillera to the west and the low interior plains to the east. The low plains are occupied by hundreds of lakes of various sizes, the largest of which is Great Slave Lake. Communities in the Deh Cho region rely heavily on its water resources, as all settlements reside on the shores of lakes and/or on the banks of navigable rivers.

Hydrological Regimes

Factors which combine to determine hydrological regimes include the size of the drainage area, topography, climate, landforms, bedrock, soil conditions and vegetative cover. Two distinct hydrological regimes can be defined in the Deh Cho region based on topography. They are the *alpine* regime in the western mountains and the *interior plains* regime in the eastern plains (Fig. 2). Each of the two largest streams, the Mackenzie and Liard rivers, drain tributary areas which lie within both the *alpine* and *interior plains* regimes. Therefore, these large rivers represent a more complex hydrological regime which we have defined as *major flows*, based on drainage size and complexity. The north-flowing reaches of the Mackenzie and Liard rivers roughly divide the region into the *alpine* and *interior plains* areas, with the *alpine* to the west and the *interior plains* to the east (Fig. 2). The climate cools as we go north through the region, and precipitation is generally higher in the western cordillera and to the south. The entire region is underlain by discontinuous

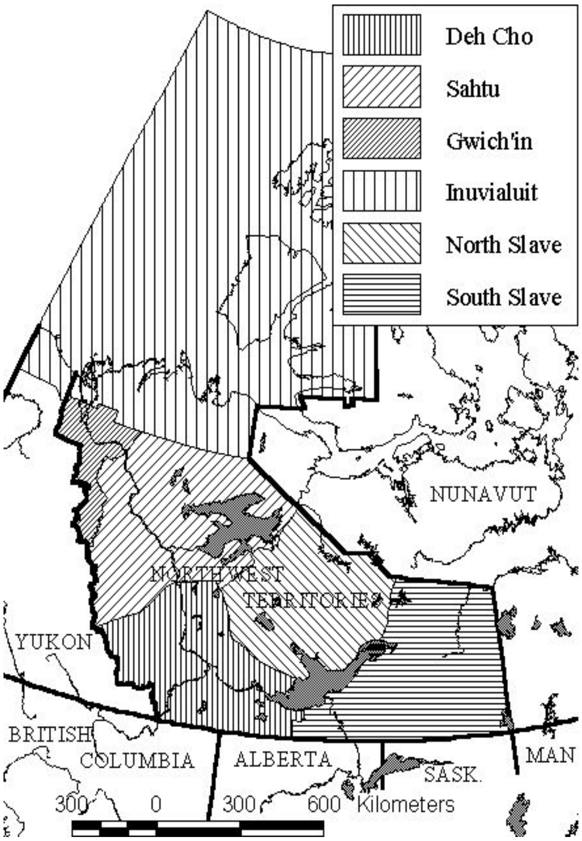


Figure 1. Land Claim areas of Northwest Territories.

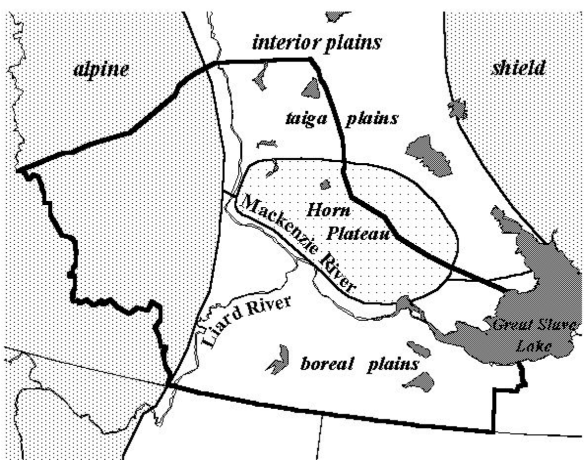


Figure 2. Hydrological Regimes in the Deh Cho region.

permafrost, which is generally more widespread towards the north (Mackenzie River Basin Committee, 1981). Northeast of the Deh Cho, eastwards and northwards of the *interior plains*, the hydrological regime is influenced by the open-tundra and taiga vegetation on the glacially-scoured Precambrian *shield*. Approximately 160,000 km² of this *shield* landscape drains into Great Slave Lake, contributing for the most part pristine sediment-free waters to the lake and henceforth to the Mackenzie River.

The Mackenzie River is the larger of the *major flows*, and is also known as the *'Big River'* or *'Deh Cho'*. It begins at the outflow of Great Slave Lake near Fort Providence where its drainage area is 980,000 km². The Mackenzie River flows westward from the outflow of Great Slave Lake past the confluence with the Liard River, then it turns northward towards the Beaufort Sea (Fig. 2). At Fort Simpson, just downstream from its confluence with the Liard River, the drainage area of the Mackenzie River is 1,270,000 km².

The Liard River is the largest tributary of the Mackenzie River downstream of Great Slave Lake. It drains an area of 275,000 km² and flows north to join the Mackenzie River near the centre of the Deh Cho region. At their confluence, the Liard drains about 20% of the combined drainage area while contributing about 40% of the flow and most of the sediment load (Carson *et al.*, 1998). The relatively large contributions of flow and sediment load from the Liard River are attributed to much of its drainage area being within the *alpine* regime, where higher precipitation and steeper gradients give higher and faster runoff with more erosion and transport of sediment.

The *interior plains* may be subdivided into three distinct areas, namely the *boreal plains*, *Horn Plateau* and *taiga plains* (Fig. 2). Lakes and muskeg areas dot the flat lands of the *interior plains*, in both the upland plateaus and the lowland areas, while the slopes and edges of the plateaus are well drained. Boreal forests in the south give way to more open taiga vegetation towards the north.

Tributary streams south of Great Slave Lake and south of the westward flowing reach of the Mackenzie River are within the *boreal plains* area. The boreal forests contribute to the formation of organic soils and peat bogs which can store water and buffer stream-flow response to precipitation run-off. Some streams in this area exhibit significant lake storage, which also buffers stream-flow response to run-off. Northwards from the westward flowing reach of the Mackenzie River, the *boreal plains* rise into the *Horn Plateau*. On the plateau, streams are influenced by the higher elevation and steeper gradients. Some lake storage exists in the headwater regions of the plateau with less storage in the lower reaches. A transition to the open forest of the *taiga plains* is evident as one moves northwards onto and over the plateau. The lakes and organic soils of the muskeg on the *taiga plains* provide significant storage, which attenuates stream-flow response to rainfall and snowmelt runoff.

In contrast, the *alpine* regime to the west exhibits less soil or lake storage, but some storage can exist within porous and fractured rock and within valley-bottom and terrace sediments. Cooler temperatures and higher snowfall in the mountains results in good snow storage (seasonal and perennial) and large differences between winter and summer flows. The *alpine* regime with its steep gradients exhibits a rapid stream-flow response to rainfall and contributes most of the sediment load transported by the Mackenzie River (DIAND, 1999).

All streams in the Deh Cho region exhibit a *subarctic nival* regime, in which the lowest production of runoff occurs in late winter, just before spring melt, the largest contribution to annual discharge comes from the melting of the winter snow pack during spring, and a transfer of in-stream water from discharge to ice storage occurs during freeze-up (Church, 1974). The discontinuous permafrost throughout the region tends to be more extensive towards the north and in the higher elevations of the western mountains (Mackenzie River Basin Committee, 1981). More extensive permafrost tends to quicken the hydrological response of streams to rain and snowmelt (Woo, 1986).

Hydrometric Data

Gauging of Streams

The hydrometric network in the Deh Cho currently consists of 16 operating stations with flow data published for years up to and including 2000 (Environment Canada, 2002). Also, historical stream-flow data is available from a total of 41 stations (Fig. 3). They are listed with WSC identification number, descriptive name, location and operating periods (Table 1). Gauges are generally located in areas of human activity and operating periods vary accordingly. Six stations provide 30 or more years of flow data, while 18 provide 20 or more years of data. The first gauges in the Deh Cho were established on the major flows, at Fort Simpson and Fort Liard. Most Deh Cho gauges are within the *interior plains* regime, generally in the boreal plains region where most of the communities are located. The largest communities are established on the banks of significant north-flowing streams in the southern lowlands. Ice jams often form during spring breakup on these streams, subjecting the towns of Hay River and Fort Simpson to periodical flooding (Wiens, 1983; Mackenzie River

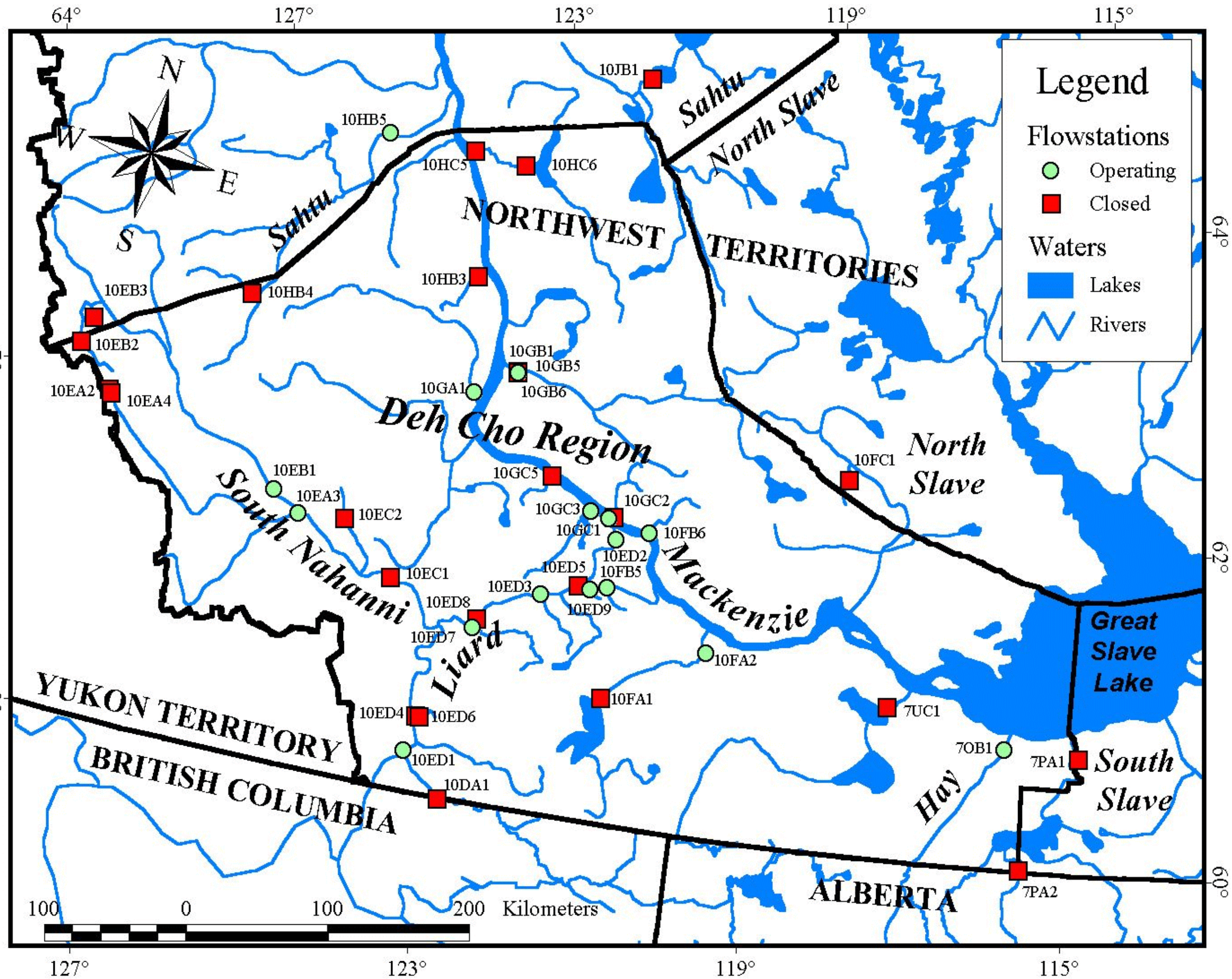


Figure 3. Hydrometric flow stations in the DehCho region (note: stations in close proximity to each other appear as one).

Table 1. Hydrometric Stations with geographic coordinates and operating periods.

Station ID	Station Description (operating stations in **bold**)	Latitude	Longitude	Operating Period
07OB001	**HAY RIVER NEAR HAY RIVER**	60.7431	-115.8578	**1963-2000**
07PA001	BUFFALO RIVER AT HIGHWAY NO. 5	60.7122	-114.9031	1969-1990
07PA002	WHITESAND RIVER NEAR ALTA/NWT BOUNDARY	60.0047	-115.5789	1986-1994
07UC001	KAKISA RIVER AT OUTLET OF KAKISA LAKE	60.9403	-117.4217	1962-1990
10DA001	PETITOT RIVER BELOW HIGHWAY #77	59.9889	-122.9564	1995-1996
10EA002	FLAT RIVER AT CANTUNG CAMP	61.9731	-128.2344	1973-1988
10EA003	**FLAT RIVER NEAR THE MOUTH**	61.5303	-125.4106	**1960-2000**
10EA004	FLAT RIVER AT TUNGSTEN AIRSTRIP	61.9525	-128.1978	1988-1992
10EB001	**SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS**	61.6358	-125.7953	**1962-2000**
10EB002	MAC CREEK NEAR THE MOUTH	62.2103	-128.7642	1978-1992
10EB003	LENED CREEK ABOVE LITTLE NAHANNI RIVER	62.3694	-128.6783	1982-1992
10EC001	SOUTH NAHANNI RIVER ABOVE CLAUSEN CREEK	61.2633	-124.0697	1969-1995
10EC002	PRAIRIE CREEK AT CADILLAC MINE	61.5583	-124.8125	1974-1990
10ED001	**LIARD RIVER AT FORT LIARD**	60.2431	-123.4792	**1942-1962, 1965-2000**
10ED002	**LIARD RIVER NEAR THE MOUTH**	61.7472	-121.2236	**1972-2000**
10ED003	**BIRCH RIVER AT HIGHWAY NO. 7**	61.3369	-122.0867	**1974-2000**
10ED004	RABBIT CREEK BELOW HIGHWAY NO. 7	60.4614	-123.4128	1978-1983
10ED005	MILE 14 CREEK AT HIGHWAY NO. 7	61.4250	-121.6250	1979-1981
10ED006	RABBIT CREEK AT HIGHWAY NO. 7	60.4639	-123.3650	1984-1990
10ED007	**BLACKSTONE RIVER AT HIGHWAY NO. 7**	61.0611	-122.8944	**1991-2000**
10ED008	LIARD RIVER AT LINDBERG LANDING	61.1181	-122.8597	1991-1996
10ED009	**SCOTTY CREEK AT HIGHWAY NO. 7**	61.4164	-121.4556	**1995-2000**
10FA001	TROUT RIVER NEAR OUTLET OF TROUT LAKE	60.7667	-121.1083	1965-1968
10FA002	**TROUT RIVER AT HIGHWAY NO. 1**	61.1397	-119.8358	**1969-2000**
10FB005	**JEAN-MARIE RIVER AT HIGHWAY NO. 1**	61.4458	-121.2411	**1972-2000**
10FB006	**MACKENZIE RIVER AT STRONG POINT**	61.8181	-120.7903	**1991-2000**
10FC001	PLATEAU CREEK NEAR WILLOW LAKE	62.3042	-118.2331	1976-1985
10GA001	**ROOT RIVER NEAR THE MOUTH**	62.4803	-123.4328	**1974-2000**
10GB001	WILLOWLAKE RIVER BELOW METAHDALI CREEK	62.6528	-122.9058	1963-1974
10GB005	METAHDALI CREEK ABOVE WILLOWLAKE RIVER	62.6497	-122.9064	1976-1987
10GB006	**WILLOWLAKE RIVER ABOVE METAHDALI CREEK**	62.6506	-122.9000	**1975-2000**
10GC001	**MACKENZIE RIVER AT FORT SIMPSON**	61.8686	-121.3569	**1938-2000**
10GC002	HARRIS RIVER NEAR THE MOUTH	61.8767	-121.2958	1972-1995
10GC003	**MARTIN RIVER AT HIGHWAY NO. 1**	61.8939	-121.6117	**1972-2000**
10GC005	SAHNDAA CREEK AT HIGHWAY NO. 1	62.0619	-122.2100	1982-1990
10HB003	WRIGLEY RIVER NEAR THE MOUTH	63.1761	-123.6903	1977-1988
10HB004	SILVERBERRY RIVER NEAR LITTLE DAL LAKE	62.7656	-126.6922	1980-1990
10HB005	**REDSTONE RIVER 63 KM ABOVE THE MOUTH**	63.9250	-125.2983	**1974-2000**
10HC005	BLACKWATER RIVER NEAR THE MOUTH	63.9281	-124.0656	1983-1985
10HC006	BLACKWATER RIVER AT OUTLET OF BLACKWATER LAKE	63.9003	-123.3228	1986-1994
10JB001	JOHNNY HOE RIVER ABOVE LAC STE. THERESE	64.5675	-121.7433	1969-1992

Basin Committee, 1981). Several gauges were established at highway stream crossings, where data are useful for design of culverts and bridges that can withstand flood events. Within the *alpine* regime the most gauged basin is the South Nahanni River basin, due to high level of activity in the basin. About 15% of this basin is occupied by the Nahanni National Park Reserve, and Parks Canada has conducted studies of the natural resources of the Park and solicited a report on flood hazard within the Park (Spence, 1998). The Wrigley River gauge was destroyed in 1988 by a flood which resulted from a regional summer rainstorm that extended over a wide area and affected many other streams in the Deh Cho region (Jasper and Kerr, 1992). Floods and droughts are extreme hydrological events which adversely affect human activities. Gauges provide valuable data for the analysis of flood and drought frequency, as presented later in this report, for the early warning of flood events, and for the planning developments.

Annual Hydrographs

Annual hydrographs are an effective means of illustrating the hydrology of a river basin. A complete annual hydrograph is derived from daily flow data gauged at a given location on a stream for each day of a given year. The area under a complete annual hydrograph gives the total annual flow or discharge volume of the stream, which is divided by the drainage area of the basin upstream of the gauge location to obtain the depth of annual basin yield at the gauged outflow. The annual yield of a stream basin is its contribution to annual stream flow expressed as depth of water per unit area of the basin (mm). This is a useful yardstick for comparing the hydrological performance of neighbouring and/or regional basins, but consideration of time periods is important in such comparisons. Basin areas as well as annual discharge and yield, as derived from annual hydrographs and basin area, are useful summary statistics for comparison and classification of basins (Table 2). With just a few years of data, mean annual hydrographs will illustrate the seasonal patterns of high and low flows. With more than 20 or 30 years of data the annual high and low flow values can be extracted from annual hydrographs and used in the frequency analysis of flood and drought events.

Annual hydrographs are presented for each of the 41 hydrometric stations listed in Table 2. Annual hydrographs for selected stations are depicted in this section below, and the others are shown in Appendix A. Wherever possible, a mean annual hydrograph and two or three selected annual hydrographs are also presented for each station. Hydrographs are selected on the basis of annual peak discharge (the highest daily discharge for a given year), by selecting from the record a year in which the recorded peak was the lowest (Min) and a year when the recorded peak was the highest (Max). The annual peak discharge can occur any time from late April to early September, depending on the hydrological regime and annual variability in precipitation (snow and rain). A complete six-month record of daily averaged flows from mid April to mid September is therefore required to extract the annual peak discharge. Hydrographs for extremely wet years are sometimes included, with rainfall-runoff peaks evident on the graphs.

Table 2. Summary Flow Statistics from 40 hydrometric stations on Deh Cho streams.

Station Description (operating stations *italicised* below, with **bolded** number of complete years at right)	Number of Complete Annual Hydrographs	Mean Flow (m³/s)	Mean Total Annual Flow (10^6 m³/y)	Basin Area (km²)	Basin Yield (mm/y)
***major flow* regime**					
Mackenzie River at Fort Simpson	**36**	6,808	214,684	1,270,000	169
Mackenzie River at Strong Point	**5**	4,826	152,193	N/A	N/A
Liard River at Fort Liard	**34**	1,930	60,871	222,000	274
Liard River at Lindberg Landing	5	2,372	74,803	N/A	N/A
Liard River near the mouth	**27**	2,447	77,153	275,000	281
***alpine* regime**					
South Nahanni River above Clausen Creek	23	404	12,741	31,100	410
South Nahanni River above Virginia Falls	**29**	226	7,111	14,600	487
Prairie Creek at Cadillac Mine	16	5.44	172	495	347
Flat River near the mouth	**26**	94.1	2,968	8,560	347
Mac Creek near the mouth	15	3.33	105	216	486
Flat River at Cantung Camp	14	2.47	78	155	503
Flat River at Tungsten Airstrip	4	3.72	117	171	686
Lened Creek above Little Nahanni River	10	0.77	24	34	708
Wrigley River near the mouth	10	7.26	229	1,230	186
Silverberry River near Little Dal Lake	10	20.4	643	1,420	453
Redstone River 63 km above the mouth	**15**	175	5,525	15,406	359
Root River near the mouth	**21**	93.0	2,933	9,820	299
***interior plains* regime**					
boreal plains region					
Hay River near Hay River	**36**	114	3,579	47,900	74.7
Petitot River below Highway 77	2	53.1	1,675	22,400	74.8
Buffalo River at Highway 5	22	49.5	1,561	18,500	84.4
Kakisa River at outlet of Kakisa Lake	27	41.1	1,296	15,600	83.1
Trout River at Highway 1	**29**	34.4	1,085	9,270	117
Trout River near outlet of Trout Lake	0	23.4	738	N/A	N/A
Whitesand River near Alberta/NWT boundary	6	20.9	661	3,410	194
Martin River at Highway 1	**27**	6.89	217	2,050	106
Blackstone River at Highway 7	**8**	7.16	226	1,390	162
Jean-Marie River at Highway 1	**27**	4.00	126	1,310	96
Harris River near the mouth	23	1.47	46.4	701	66
Birch River at Highway 7	**25**	2.25	71.0	542	131
Sahndaa Creek at Highway 1	9	1.83	57.7	251	230
Scotty Creek at Highway 7	**5**	0.35	11.0	202	54.6
Rabbit Creek below Highway 7	6	0.42	13.2	105	126
Rabbit Creek at Highway 7	7	0.47	14.8	92.7	160
Mile 14 Creek at Highway 7	3	0.07	2.21	N/A	N/A
Horn Plateau region					
Willowlake River below Metahdali Creek	11	62.7	1,977	20,500	96
Willowlake River above Metahdali Creek	**21**	66.7	2,103	20,200	104
Metahdali Creek above Willowlake River	11	1.12	35.3	344	103
Plateau Creek near Willow Lake	6	0.24	7.57	69.9	108
taiga plains region					
Blackwater River at outlet of Blackwater Lake	7	46.3	1,460	7,850	186
Blackwater River near the mouth	2	54.0	1,703	10,400	164
Johnny Hoe River above Lac Ste. Therese	20	40.8	1,287	17,300	74

Major Flow Hydrographs

Mackenzie River at Fort Simpson

The Fort Simpson station on the Mackenzie River boasts the longest stream-flow record in the NWT. The Mackenzie River is presently and historically a major transportation route, with a major hub in the Fort Simpson area at the heart of the Deh Cho, just downstream from the confluence of the two *major flow* streams. Averaging the daily values over the 62 years of data results in smoothing out of the annual variations (Fig. 4). The resulting mean annual hydrograph is characterised by a steep rising limb in May with a peak in mid June, then a gradual summer-fall recession to late October, a steeper recession in November as water is moved into ice storage during freeze-up, and a very gradual winter recession is evident from late November to late April, with the lowest flow occurring before spring melt. These features of the mean annual hydrograph are characteristic of northern rivers: the lowest production of runoff occurs in late winter before spring melt; the largest contribution to annual discharge comes from melting snow in spring; and a transfer of in-stream water from discharge into ice storage occurs during freeze-up (Church, 1974).

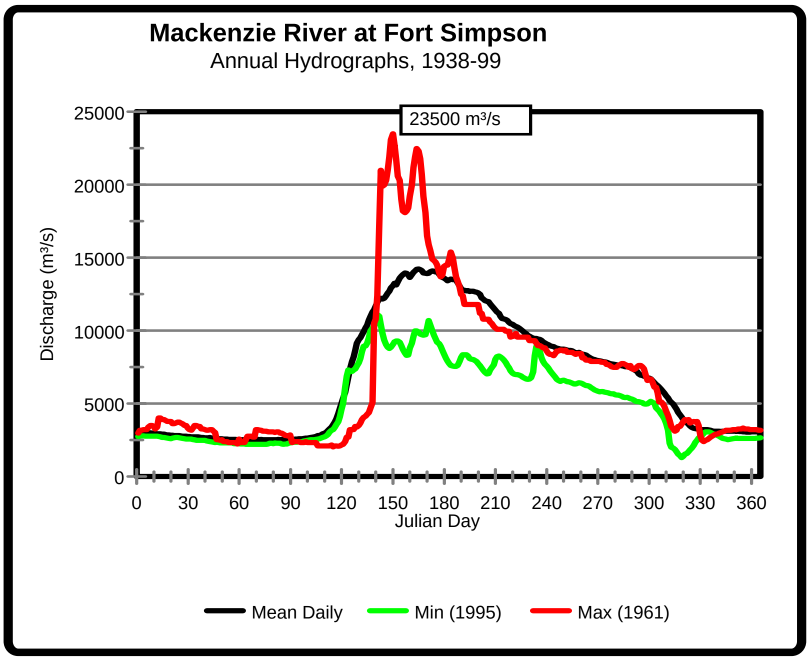


Figure 4. Mackenzie River at Fort Simpson annual hydrographs, mean and selected years.

The individual annual hydrographs in Figure 4 illustrate the annual variability and also show more details of flow response to spring melt, summer rains and fall freeze-up. The freshet from spring melt can be very dramatic (Fig. 4, 1961) and contributes to the annual breakup of ice cover on lower reaches of the river. The earlier melting of winter snow cover in more southerly headwater regions of the river basin often contributes to the formation of ice jams on the Mackenzie River just downstream from Fort Simpson. Breakup on the Mackenzie River below Fort Simpson is generally triggered by the earlier breakup on the Liard River, and Great Slave Lake remains ice covered six to eight weeks afterwards (Mackenzie River Basin Committee, 1981). The spring freshet usually results in the annual peak discharge, and the storage potential of the Great Slave Lake sub-basin attenuates the summer-fall recession. However, summer rains in the Liard River sub-basin can contribute to secondary discharge peaks at Fort Simpson (Fig. 4, 1995).

Mackenzie River at Strong Point

The nine year record at Strong Point illustrates the dominant effect of the spring freshet on the discharge of the Mackenzie River (Fig. 5). Comparing the mean annual hydrograph at Strong Point with that at Fort Simpson defines the influence of the Liard River at Fort Simpson. The spring freshet is less pronounced at Strong Point, but the summer, fall and winter recessions are still evident. The selected annual hydrographs show an absence of secondary peaks during summer recession (Figs. 5 and 6), which is attributed to the storage effect of Great Slave Lake and the lack of significant tributaries between the lake outflow and the Strong Point gauge. The decrease in discharge during the fall is not caused by a decrease in basin production, but rather by the transfer of water into ice-induced storage (Gerard, 1990; Prowse and Carter, 2002). The discharge recovers after ice and snow cover thickens enough to retard the rate of further freezing, and the gradual winter recession continues until spring melt.

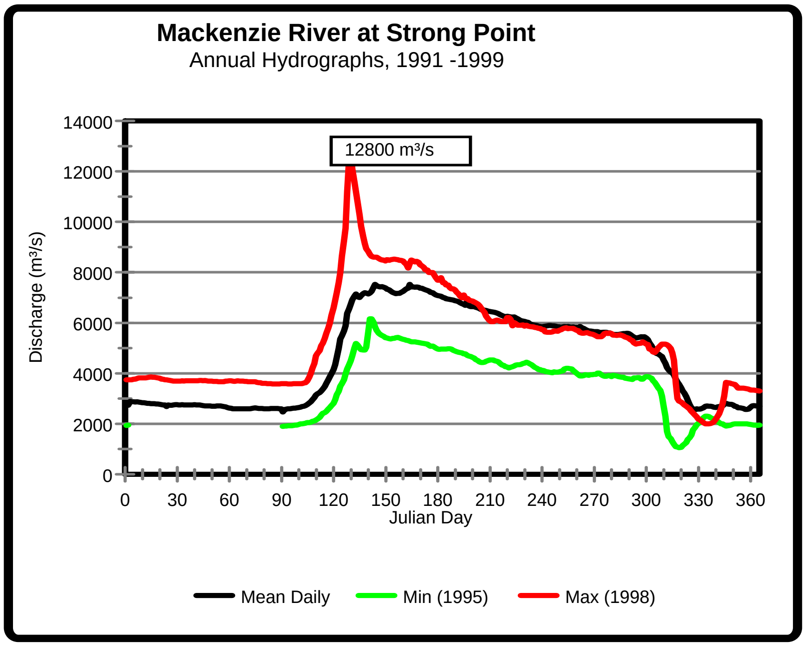


Figure 5. Mackenzie River at Strong Point annual hydrographs, mean and selected years.

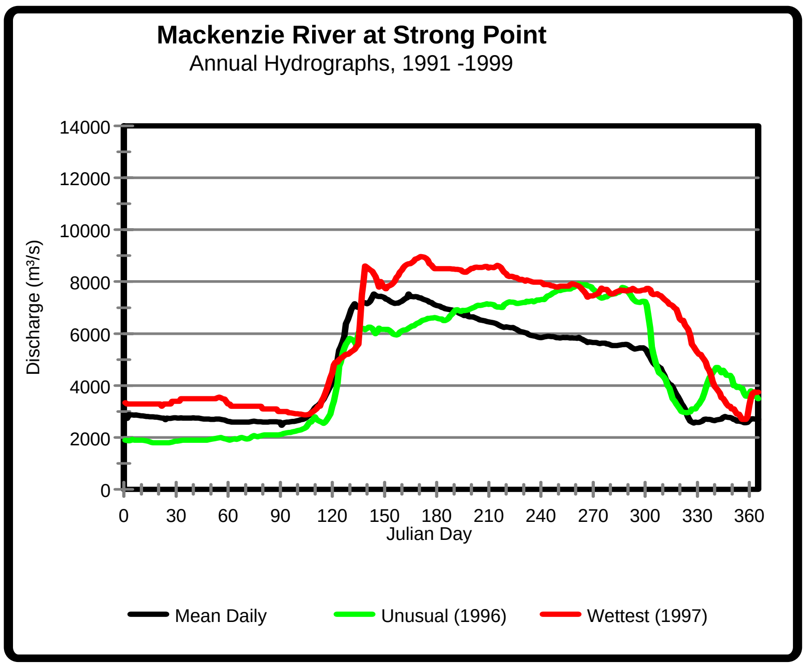


Figure 6. Mackenzie River at Strong Point annual hydrographs, unusual year and wettest.

The drought of 1995 (Fig. 5) was followed by a spring freshet in 1996 which was below average (Fig. 6). The 1996 spring freshet was still the dominant hydrological event of the year, tripling the flow volume from around 2,000 m^3/s before melt to over 6,000 m^3/s after melt, but an unusual increase in discharge volume during the summer and early fall was evident. The discharge increased to almost 8,000 m^3/s by late September, as the release of water at Bennett

Dam from June to August affected the hydrograph. The following year (1997) was the wettest on record, with the highest mean annual discharge recorded at both the Strong Point and Fort Simpson stations. High flows from rainfall runoff persisted well into November 1997 (Fig. 6). Wet conditions preceding a late freeze-up in December 1997 and winter snowfall contributed to the maximum annual peak recorded in the spring of 1998 (Fig. 5).

Liard River, at Fort Liard and near the mouth

The mean annual hydrograph at Fort Liard has a steep rising limb and spring freshet peak of about 6,000 m³/s followed by a steep summer recession (Fig. 7). The recession becomes increasingly subdued through fall and winter. Low storage and a rapid runoff response is characteristic of the *alpine* regime. The Fort Liard station provides a 56-year flow record with 34 complete annual hydrographs. The maximum recorded annual peak discharge occurred in 1988 (Fig. 7), which was also the wettest year of the 34 years with a complete record. Most of the drainage area above Fort Liard falls within the *alpine* regime, which explains the rapid response of the Liard River to summer rains as illustrated in the sharp mid-summer peak on the 1988 hydrograph. This summer peak resulted from a regional rainstorm (Jasper and Kerr, 1992). Although the drainage area at this gauge is about 20% that of the Strong Point gauge, rapid rainfall runoff from the upper *alpine* reaches can result in flow on the Liard River at Fort Liard exceeding concurrent flow on the Mackenzie River at Strong Point.

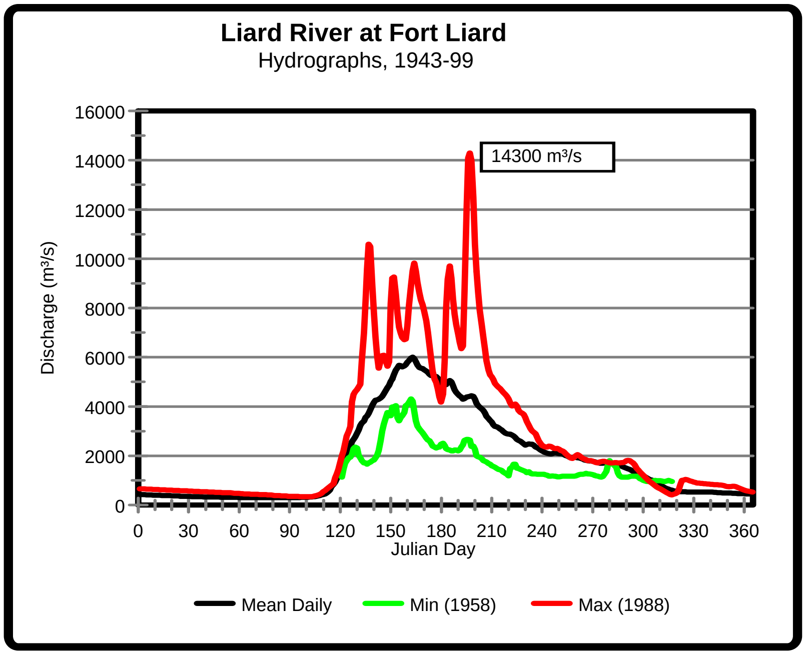


Figure 7. Liard River at Fort Liard annual hydrographs, mean and selected years.

The gauge on the Liard River at Lindberg Landing is downstream of the confluence with the *alpine* South Nahanni River, which is a very significant tributary. At this gauge the peak of the mean annual hydrograph is about 7,860 m³/s, 30% higher than at Fort Liard (Appendix A). Farther downstream near the mouth of the Liard River, where the drainage area of the hydrometric station is about 24% greater than at Fort Liard, the peak of the mean annual hydrograph is no higher than at Lindberg Landing (Appendix A). This is because flow peaks at Lindberg Landing dissipate as they move downstream, due to channel friction and temporary storage, and tributary inputs between Lindberg Landing and the mouth are much less significant than the *alpine* South Nahanni River.

Alpine Hydrographs

South Nahanni River Basin hydrographs

Whereas the Liard River is largely an *alpine* river with some eastern tributaries that fall within the *interior plains* regime, the South Nahanni drainage is entirely within the *alpine* regime. The South Nahanni River is also the largest and most extensively gauged of the *alpine* streams within the Deh Cho region. The influence of the *alpine* regime generally increases upstream and towards the mountain divide, with increase in altitude and gradient, and corresponding increases in basin yield are evident. Figure 8 illustrates a comparison of annual basin yields for the eight gauges in the South Nahanni River basin from 1983 to 1990, during which annual yields for six or more gauges

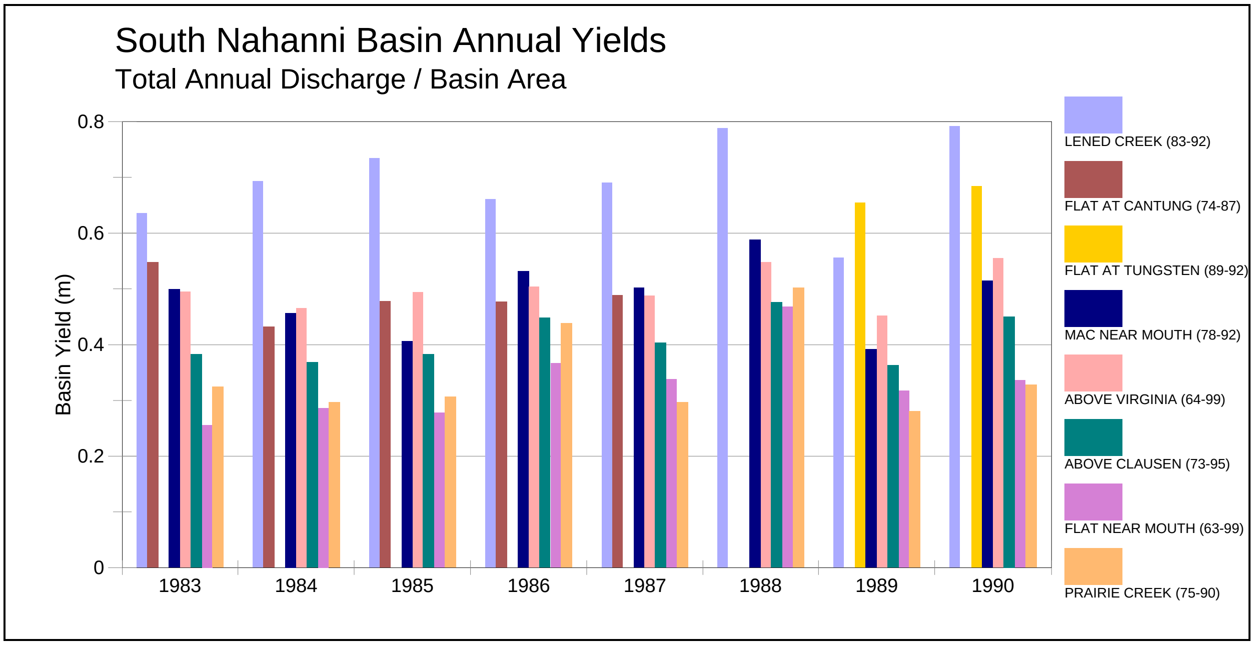


Figure 8. Comparison of annual yields from hydrographs of the South Nahanni River basin gauges.

are available. The gauges are ranked according to average annual yield from Table 2. Runoff varies dramatically with the seasons and a complete annual hydrograph is required to calculate annual yield, so the Figure 8 legend indicates the time periods for which annual yields are available for each gauge.

The mean annual hydrograph for the South Nahanni River above Clausen Creek is characteristic of the *alpine* regime (Fig. 9). The spring-melt event occurs later than on the *interior plains* due to cooler temperature and deep snow pack at high elevation. Sharp rainfall-runoff peaks of individual annual hydrographs are also characteristic of the *alpine* regime, where high gradients and low storage capacity result in rapid runoff. The smallest gauged basin in the Deh Cho is the Lened Creek

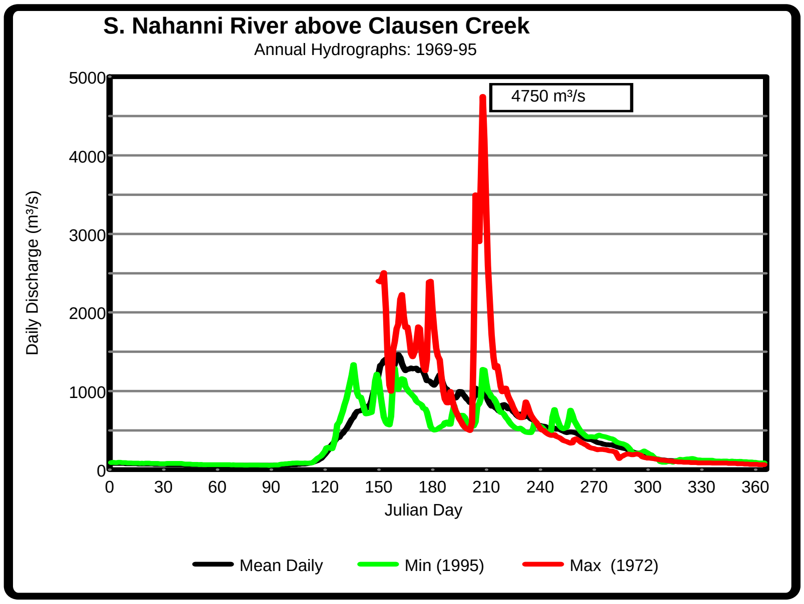


Figure 9. South Nahanni River above Clausen Creek annual hydrographs, mean and selected years.

basin in the headwaters of the South Nahanni River. The deep snow pack and summer rains of this high *alpine* basin yielded an average annual runoff of 708 mm/year over the 11 year record, which is the highest yield recorded for gauged streams in the Deh Cho region (Table 2). For the small sub-basins at high elevations, peak discharge on the mean annual hydrograph occurs later in the year and annual hydrograph peaks are subdued. This effect of cool temperatures and the storage capacity of the perennial snow pack is evident at the upper Flat River gauges, at Cantung Camp and Tungsten Airstrip (Appendix A).

Other Alpine hydrographs

Hydrographs are presented (Appendix A) for the four gauges operated on three *west-bank* tributaries to the Mackenzie River. Waters from these tributary basins flow out of the Mackenzie Mountains and eastward through the Deh Cho region to join the Mackenzie River at its west bank. The annual hydrographs from all four of these gauges share some common features: they all exhibit sharp peaks with rapid recessions for spring melt and summer rainfall events; and of those years with complete annual hydrographs, 1982 was the wettest year recorded at all four gauges. The Wrigley River represents the smallest drainage area, mean annual discharge and basin yield of the four gauges (Table 2). Its relatively low yield is attributed to its drainage area being the most easterly and having the lowest average elevation of the four gauged west-bank tributaries. Its lower reaches even lie outside the *alpine* regime, within the *taiga plains* region. In contrast, the gauge record from the Silverberry River shows over double the yield, from a drainage area of comparable size and for a similar time period (Tables 1 and 2). This is because the highest elevations in the Redstone River basin are to be found within its Silverberry River sub-basin.

Boreal Plains Hydrographs

Streams in the *boreal plains* region exhibit a less dramatic response to snowmelt and rainfall runoff than do the *alpine* streams. The rising limbs of these hydrographs are less steep, and recessions are more prolonged. Lake storage varies between basins, and can have a dramatic effect on the annual hydrographs.

Hay River and Petitot River

The mean annual hydrograph for the Hay River has a pronounced peak which clearly defines the dominance of the spring freshet (Fig. 10). This peak occurs about a month sooner on this river than on the *alpine* rivers. The regional rainfall event of July 1988 resulted in the highest annual yield recorded at this gauge. This had little effect on the shape of the mean annual hydrograph over the 38 years of record.

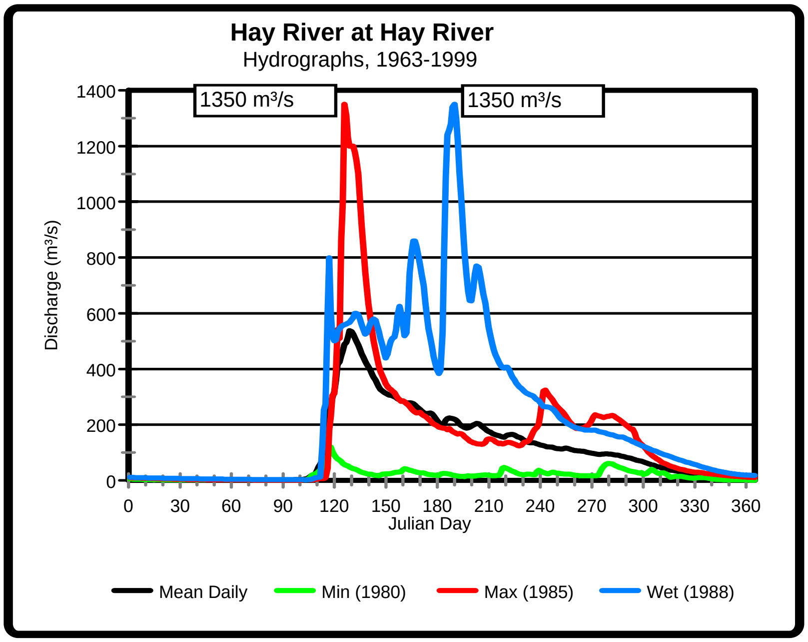


Figure 10. Hay River at Hay River annual hydrographs, mean and selected years.

The short hydrological record for the Petitot River demonstrates the similarity in the hydrological responses of the Petitot and Hay Rivers. The drainage area of the Petitot River gauge is about half that of the Hay River gauge. However, these two basins adjoin each other and exhibit similar characteristics of elevation and lake storage. Similarity in hydrological response is illustrated with the 1996 hydrographs for the two gauges (Fig. 11). The pattern of spring freshet response for both basins is virtually identical, with small differences that are easily explained. The smaller Petitot River basin exhibits a lower peak discharge because of its smaller catchment area, while it exhibits an earlier occurrence of peak freshet discharge because of the shorter distance and time for runoff to reach the gauge. Differences in hydrological response to summer rains are explained by rainfall duration and extent. Small convective rainfall events are short-lived and limited in their areal extent of influence, and they therefore elicit

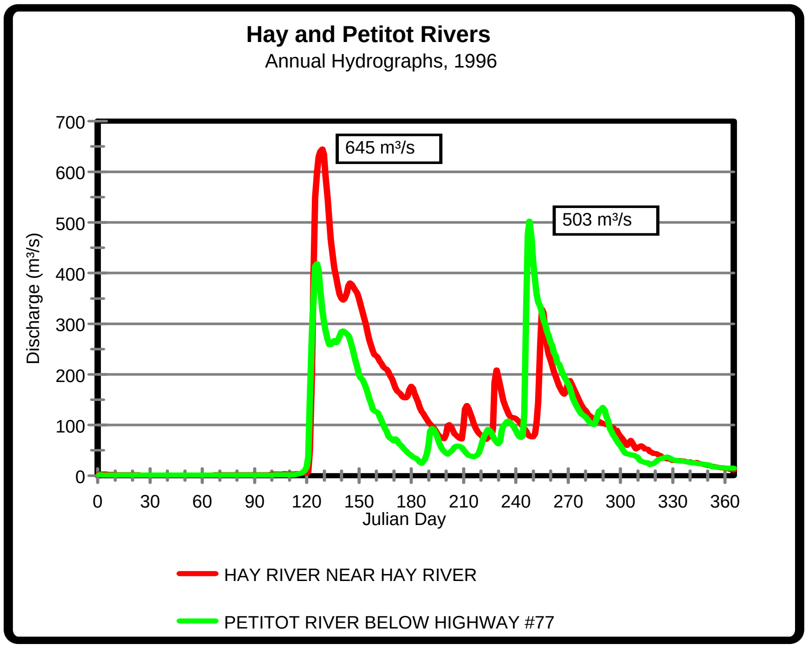


Figure 11. Comparison of Hay River and Petitot River annual hydrographs for 1996.

independent responses from each basin. Larger frontal rainfall events affect wider areas, such as the September 1996 storm which affected both basins. However, while frontal storms affect wider areas than convective storms, they usually follow a defined path along the frontal convergence zone. This September 1996 storm obviously affected the Petitot River more than the Hay River, as evidenced by the higher discharge from the smaller basin (Fig. 11).

Lake Storage effect - Buffalo, Kakisa and Trout Rivers

These river basins in the *boreal plains* regime exhibit substantial lake storage but to differing degrees. Figure 12 shows some hydrographs for the Buffalo River. Lakes store water temporarily, dampening hydrograph response to runoff. Hydrograph peaks are subdued and delayed, and recessions are sustained over longer periods. This effect is explained by lake size, but also by the distribution of the lake area within a drainage basin. The gauges on each of these three rivers were established downstream of relatively large lakes, so the annual hydrographs illustrate the storage effect dramatically, when compared to hydrographs for the Hay (Fig.10) and Petitot (Appendix A) Rivers.

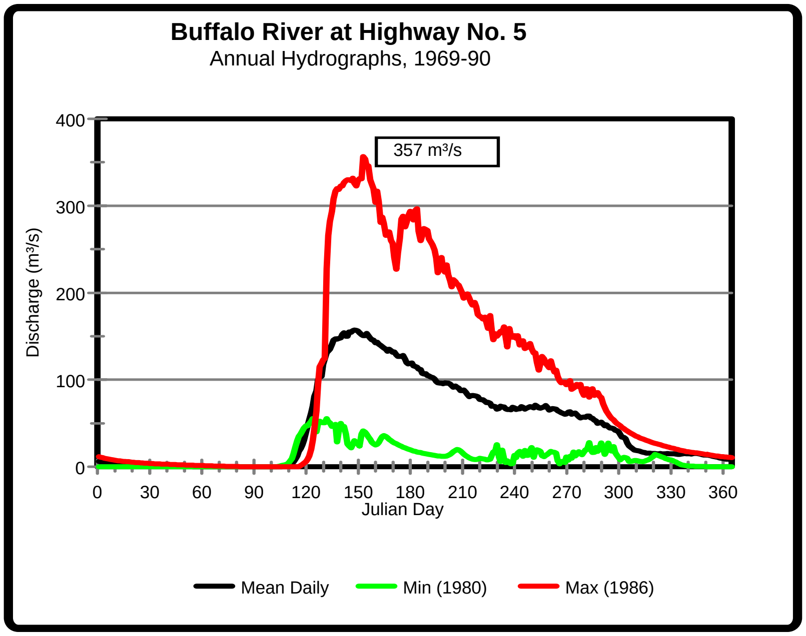


Figure 12. Buffalo River at Highway No. 5 annual hydrographs, mean and selected years.

Lake inflow volume gets distributed over the lake area, so the time taken for water to travel through a lake between its inflow and outflow is directly proportional to lake size. Any increase in the rate of inflow to a lake, such as spring freshet or rainstorm runoff, results in a temporary rise in lake level equal to the increase in inflow volume divided by the lake area. Therefore, a larger lake area results in a smaller change in water level for a given change in inflow volume. Just as lake level is sensitive to changes in the rate of inflow, the rate of outflow is also sensitive to changes in lake water level. A small increase in lake level results in a small increase in outflow rate. Hence, a larger lake will retain water and sustain its outflow for a longer period than a smaller lake.

The effect of distribution of lake area is illustrated by the Buffalo and Kakisa basins. These basins are similar in size and annual yield (Table 2), and in geographic location (Fig. 3). The Kakisa River basin has a slightly greater proportion of lake area than the Buffalo River basin, but the Kakisa River exhibits much greater storage effect. Hydrograph peaks at the Kakisa River gauge are more delayed and subdued while fall and winter recession flows are more sustained (Fig. 13). This is because

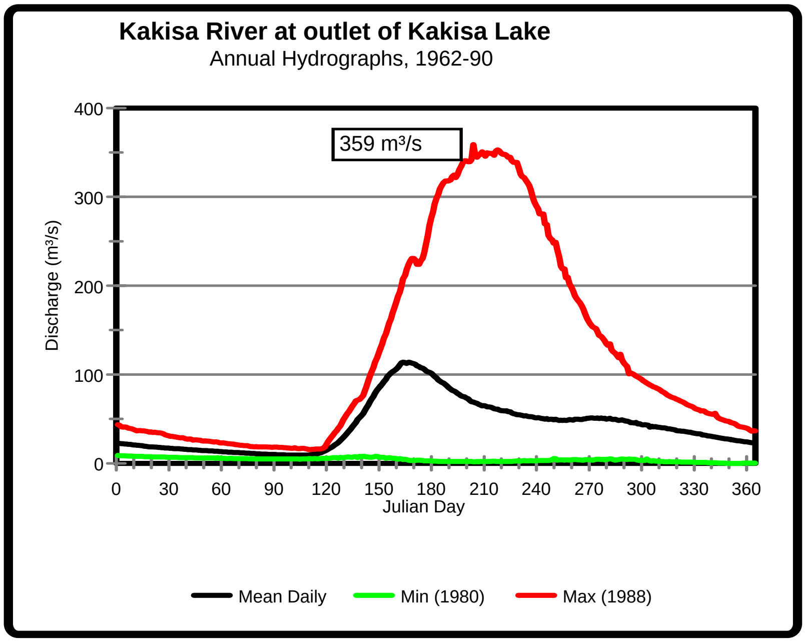


Figure 13. Kakisa River at outlet of Kakisa Lake annual hydrographs, mean and selected years.

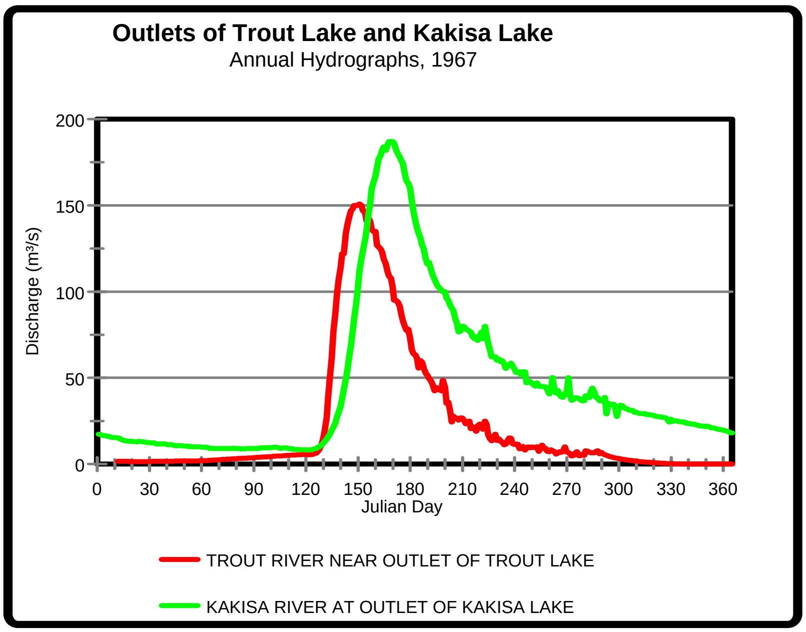


Figure 14. Comparison of 1967 hydrographs, outlets of Trout and Kakisa Lakes.

most of the Kakisa River flow passes through two large lakes before reaching the gauge. This compounds the storage time in the Kakisa basin to some degree, as the inflows to the second lake are already delayed and subdued. Recorded flow for the Buffalo River actually dropped to zero during winter (below the measurable levels for the gauge) for two thirds of the years on record (compare Figs. 12 and 13).

The effect of lake location on lake storage is illustrated by data from the gauge at the outlet of Trout Lake. No concurrent hydrographs exist for the Trout River gauge at Highway 1 and the gauge at the Trout Lake outlet, but comparison of the 1967 hydrographs for the outlets of Trout and Kakisa Lakes illustrates a difference in runoff response (Fig. 14). Trout Lake is closer to its basin headwaters, and less than half the drainage area of the Trout River is upstream of the lake. Hence, Trout Lake inflows and outflows are relatively small and rapid compared to those of Kakisa Lake (Fig. 14). Trout Lake also has no storage effect on the basin area downstream of the lake outflow. Consequently, runoff from the lower portion of the basin can result in sharp hydrograph peaks at the Highway 1 gauge (Appendix A).

The other 10 gauged streams within the *boreal plains* region are relatively small, with drainage areas ranging from one tenth to one thousandth the size of the Hay River drainage. Storage capacity decreases with the basin size, because shorter distances require less travel time, so hydrograph response is more rapid for these streams (Appendix A). Record length also varies considerably, with generally shorter-term records for the smaller streams. The mean annual hydrographs can also be misleading. They are smoother for gauges with longer records where the annual variability is hidden, and more jagged for short-term gauges where the long-term average is not clearly defined.

Horn Plateau Hydrographs

Willowlake River and Plateau Creek

Horn Plateau hydrographs resemble the *alpine* hydrographs (Appendix A). Limited lake storage in the upper Willowlake basin has little effect on runoff in the lower basin. The small lake area with negligible inflows is ineffectual, more so than for Trout Lake as discussed above. The peaks of the mean annual hydrographs occur in this regime later than in the *boreal plains* but earlier than in the *alpine* regime. This is attributed to the climatic effects of latitude and elevation. Metahdali Creek is an insignificant tributary to Willowlake River with one sixtieth its drainage area (Table 2). The Plateau Creek basin is much smaller, and lies off the eastern edge of the plateau. This basin is only one fifth the area of Metahdali Creek basin, with a comparatively steep gradient, so runoff response to rain and snow melt is more rapid.

Taiga Plains Hydrographs

Blackwater River and Johnny Hoe River

These two streams are of comparable size. Both their basins have substantial lake area but with differing degrees of lake storage effects. Most of the drainage area of the Blackwater River (75%) is upstream of Blackwater Lake. In contrast, most of the lake area in the Johnny Hoe basin is near its tributary headwaters, as in the Willowlake basin. Consequently, the lake storage effect is more pronounced in the Blackwater basin. Spring freshet arrives at the stream gauges later than in the *Horn Plateau* regime (Appendix A), which is likely due to both the cooler climate and the subdued gradients.

Frequency Analyses of Extremes

Extremes of high-flow (flood) or low-flow (drought) events can have significant impact on stream ecology and human activities. Historical magnitudes of annual extremes can be used to predict the likelihood or probability of similar events by the statistical technique of *frequency analysis*. The probability of an event of a given magnitude is expressed as a *return period*, which is the number of years that can be expected between events of that magnitude. As noted earlier, the accuracy of the *return period* estimate increases with the length of the data record. Though estimates of *return period* can be useful in planning activities and developments near streams, one limitation on the application of the technique is worth noting — the magnitudes of the annual extremes and their corresponding return periods generally follow a characteristic distribution for each stream, but two events of equal magnitude with a given return period can and do occur within less time than expected. This is because a 100 year flood is expected once every 100 years, but an event of such magnitude has a one % probability of occurring every year. The distribution of extremes is modelled using the *Pearson* theoretical distribution, a widely used statistical model for describing extreme hydrological events.

Annual extremes are used in the analyses to allow their *return period* to be estimated in years. Frequency analyses of extreme annual events generally require 30 or more years of data to effectively describe the distribution of extremes. However, few of the 41 stations covered fit this requirement. Data from 18 of the 41 stations include 20 or more years of recorded annual maximum flows. The frequency analyses therefore focus on these 18 stations, for annual flood and low-flow events.

Flood Events

The frequency analysis of flood events is accomplished for each stream by ranking the observed annual maxima by magnitude and fitting the ranked observations to the *Pearson* distribution. The flow record from the gauge at Fort Simpson is 63 years long (Table 1). Only 36 complete annual hydrographs exist (Table 2). However, the annual flood, or high-flow event, never occurs during winter, so a complete annual hydrograph is not required to establish the annual maximum. The Fort Simpson gauge provides 51 years of recorded annual maximum flows. The annual maxima are assigned a *return period*, T, where

$$T = \frac{n+1}{m} \qquad (1)$$

defines the plotting position of the observations (Chow, 1964) based on the number of years of record, n, and their rank, m, with the highest value having the first rank, m = 1. In Figure 15, the

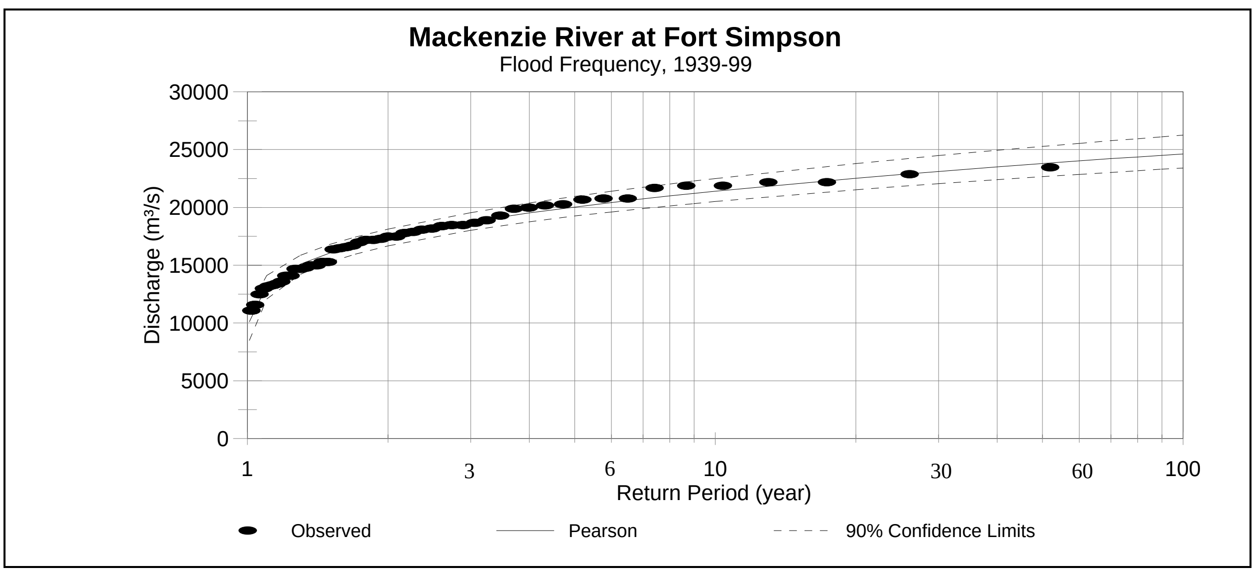


Figure 15. Flood frequency distribution for Mackenzie River at Fort Simpson, 1939-99.

return period estimate, T, for the first ranked observation (m = 1) is therefore 52 years, for the second it is 26 years, for the third it is 17 **a** years, and for the fourth it is 13 years (Eq. 1). The fitted *Pearson* distribution and its 90% confidence limits are also shown on the graph (Fig. 15). The *return period* is two years for both medians, of the ranked observations (where m = 26) and of the *Pearson* distribution, denoting that the magnitude of the median event is expected to be exceeded every other year (ie. 50% of the time). One limitation of estimating *return period* by this method is illustrated by the Hay River data, where n = 36 years. The two highest recorded annual peak events are of equal magnitude (1350 m^3/s) and occurred within four years of each other (Fig. 10), while the fitted *Pearson* distribution estimates the *return period* for events of this magnitude as 45

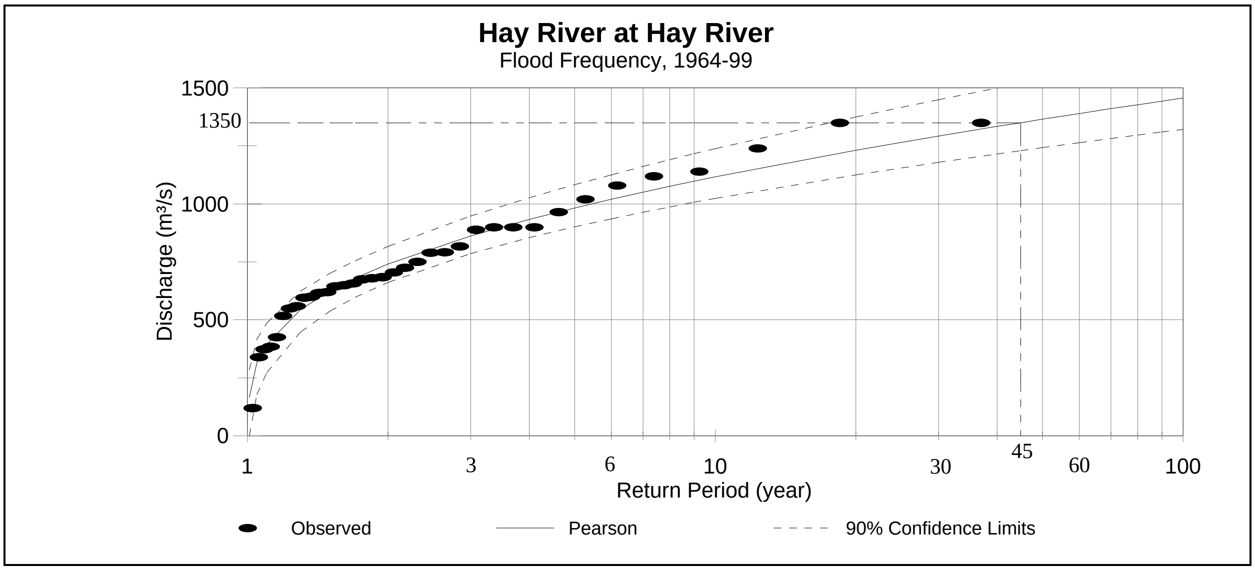


Figure 16. Flood frequency distribution for Hay River at Hay River, 1964-99.

years (Fig. 16). This is because the *Pearson* distribution does not account for the short-term auto-correlation of extreme hydrological events, which is due to natural cycles and trends. The analysis results for 18 stations are summarised in Table 3, and their plotted distributions are shown in Appendix B.

Low-flow Events

The frequency analysis of annual low-flow events is accomplished in a similar fashion to the flood frequency analysis. However, the ranking is reversed in that the first rank (m = 1) is assigned to the lowest value, and the formula for the *Pearson* frequency parameter is adjusted to account for this (Janowicz, 1991). Zero values are also included where winter flows were below the measurement threshold for the gauge (Stedinger et al., 1993). Complete annual hydrographs are not strictly required, because the annual minima occur either during fall freeze-up or just prior to spring melt.

In the data from the Mackenzie River gauge at Fort Simpson, 36 annual minima were observed. The plotting position, T, for the lowest observation (1300 m^3/s; m = 1) is therefore 37 years (Eq. 1). The

Table 3. Results of Flood Frequency Analysis (18 Deh Cho stations - 20+ years of data).

Station Description	Number of High-Flow Data Years	Pearson 10-Year High Flow (m³/s)	Pearson 25-Year High Flow (m³/s)	Pearson 100-Year High Flow (m³/s)	Maximum Daily Flow Recorded (m³/s)	Date of Maximum Daily Flow Recorded	Pearson T of Record Maximum (yrs)
Hay River near Hay River	36	1117	1266	1457	1350	1985, 1988	44.8
Buffalo River at Highway 5	22	288	334	393	357	1986/06/02	42.1
Kakisa River at outlet of Kakisa Lake	27	217	270	347	359	1988/07/22	125
Flat River near the mouth	35	958	1121	1348	1250	1972/07/26	54.2
South Nahanni River above Virginia Falls	36	1902	2103	2371	2250	1972/07/26	52.4
South Nahanni River above Clausen Creek	27	3115	3730	4699	4750	1972/07/26	107
Liard River at Fort Liard	52	11824	13225	15074	14300	1988/07/15	54.7
Liard River near the mouth	28	14781	16006	17462	16100	1977/06/06	27.1
Birch River at Highway 7	25	95	161	284	304	1988/07/02	122
Trout River at Highway 1	30	374	476	626	614	1988/07/04	89.8
Jean-Marie River at Highway 1	27	91	133	203	211	1988/07/04	117
Root River near the mouth	25	2939	4011	5693	5730	1988/07/01	103
Willowlake River above Metahdali Creek	25	1242	1561	2043	1910	1988/07/02	68.3
Mackenzie River at Fort Simpson	51	21405	22862	24647	23500	1961/05/30	39.7
Harris River near the mouth	23	43	53	68	62.3	1988/07/03	59.8
Martin River at Highway 1	27	269	456	813	895	1988/07/03	133
Redstone River 63 km above the mouth	21	2738	3321	4142	3750	1991/07/28	51
Johnny Hoe River above Lac Ste. Therese	20	523	596	688	650	1975/05/13	54.7

Pearson fit estimates the *return period* of the 1300 m^3/s observation as 69 years, and estimates the magnitude of the 100-year low-flow at 1260 m^3/s (Fig. 17). In the case of smaller streams which approach or periodically attain zero flow over winter, estimates of low-flow *return periods* are valuable for the management of fisheries. The results of the low-flow analyses for 18 stations are summarised in Table 4, and the plotted distributions are shown in Appendix C.

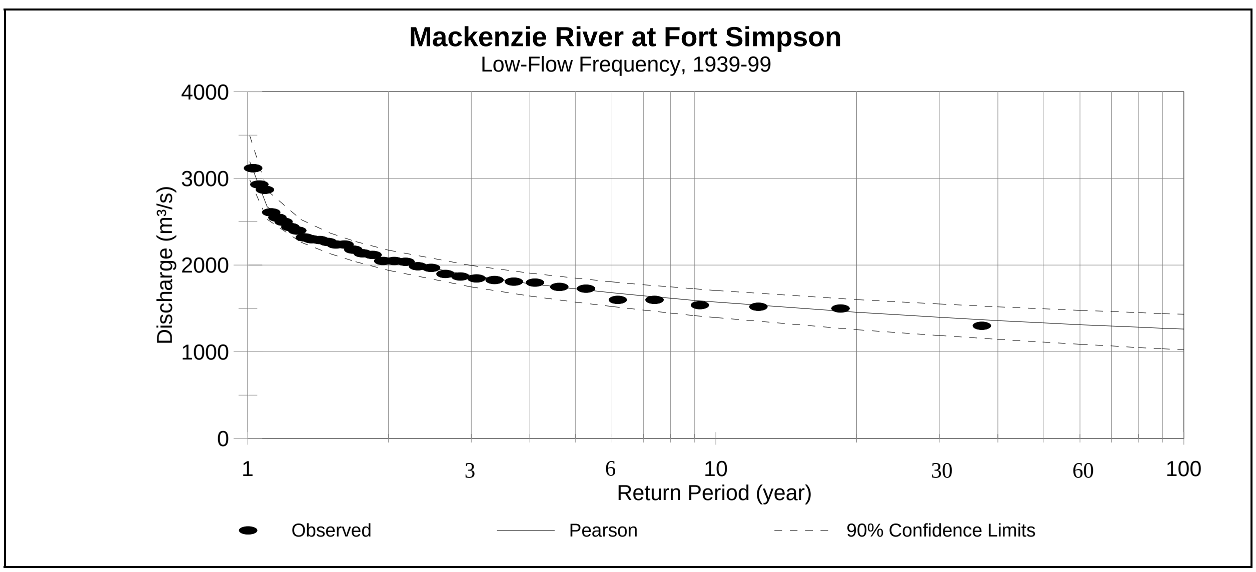


Figure 17. Low-flow frequency distribution for Mackenzie River at Fort Simpson, 1939-99.

Table 4. Results of Low-Flow Frequency Analysis (18 Deh Cho stations - 18+ years of data).

Station Description	Number of Low-Flow Data Years	Pearson 10-Year Low Flow (m^3/s)	Pearson 25-Year Low Flow (m^3/s)	Pearson 100-Year Low Flow (m^3/s)	Minimum Daily Flow Recorded (m^3/s)	Date of Minimum Daily Flow Recorded	Pearson T of Record Minimum (yrs)
Hay River near Hay River	36	0.26	0	0	0.283	1971/02/11	9.62
Buffalo River at Highway 5	22	0	0	0	0	14of22years	2.1
Kakisa River at outlet of Kakisa Lake	27	2.9	0.90	0	0.275	1980/12/17	34.7
Flat River near the mouth	27	10.2	9.5	8.8	4	1986/03/21	N/A
South Nahanni River above Virginia Falls	34	20	18	16	15.5	1984/01/31	200
South Nahanni River above Clausen Creek	23	46	42	37	44	1973/02/26	17
Liard River at Fort Liard	34	208	187	162	172	1972/02/18	56
Liard River near the mouth	27	255	214	160	227	1995/11/11	18.3
Birch River at Highway 7	26	0	0	0	0	'84, '93, '96	4.2
Trout River at Highway 1	31	0	0	0	0	1972/03/06	4.9
Jean-Marie River at Highway 1	28	0.049	0.013	0	0.003	1985/03/27	33
Root River near the mouth	21	4.5	2.9	0.83	2.3	1979/04/03	36
Willowlake River above Metahdali Creek	21	1.3	0.84	0.35	0.941	1995/11/29	19.8
Mackenzie River at Fort Simpson	36	1573	1424	1262	1300	1995/11/15	68.7
Harris River near the mouth	23	0	0	0	0	16of23years	2.1
Martin River at Highway 1	27	0	0	0	0.001	'76, '77, '85	7.3
Redstone River 63 km above the mouth	18	11	8.4	5.6	9.4	1979/02/22	16
Johnny Hoe River above Lac Ste. Therese	20	1.2	0.82	0.47	0.87	1972/04/19	22

The Hay River data again illustrates a limitation of the analysis method, with particular respect to low-flow analysis. During 36 years of year-round daily observations, no flow of zero was ever measured. However, the *Pearson* distribution fitted to the 36 observed annual minima estimates the *return period* for zero-flow as 17.5 years (Fig. 18). Also, the minimum recorded flow (0.283 m^3/s) observed in 1971 (Table 4) was almost repeated 3 years later (in 1974) when a flow of 0.29 m^3/s was measured (Fig. 18), but the *return period* as estimated by the *Pearson* fit is 9.6 years.

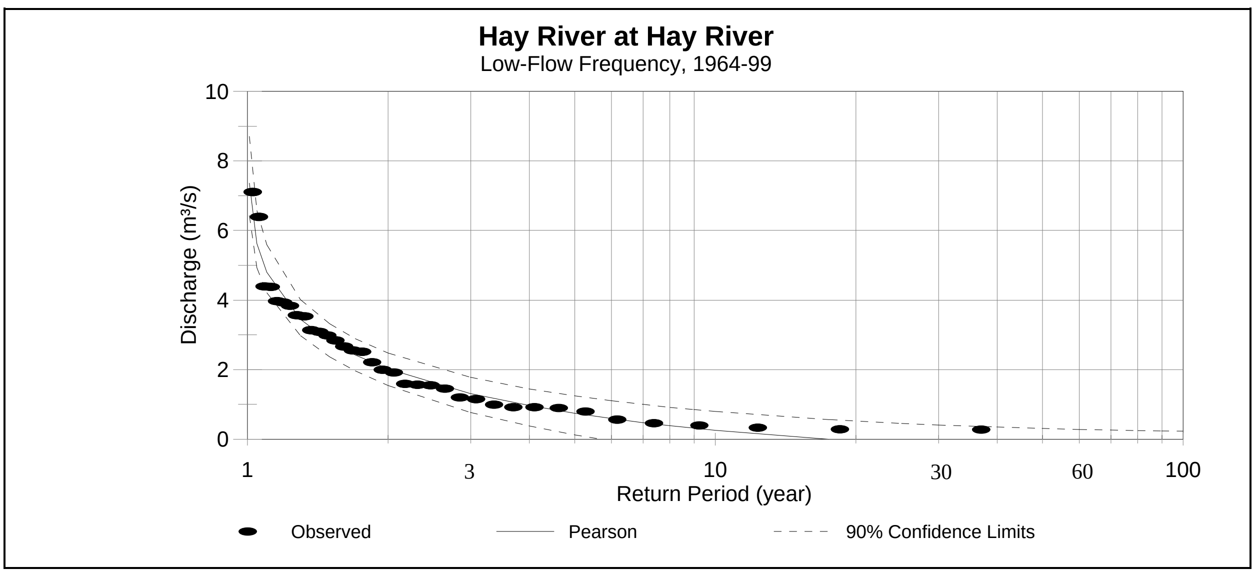


Figure 18. Low-flow frequency distribution for Hay River at Hay River, 1964-99.

Conclusions

This report is based on stream-flow data from 41 hydrometric stations on Deh Cho streams. The time periods of gauge operations vary considerably, from two to 63 years. Hydrometric gauges are generally located on streams that affect areas of human activity. Consequently, gauges have operated near settlements, highways and mining camps. Data are more readily comparable between gauges operated over similar periods. Gauge data provide valuable information for development planning and design, and for early flood warning.

Within a diversity of Deh Cho landscapes two distinct hydrological regimes are identified. They are the *alpine* and the *interior plains* regimes. The two largest Deh Cho streams encompass elements of both these regimes, and are therefore classified in a third regime called *major flows*. The *interior plains* regime is also sub-divided into three sub-regions. From south to north they are the *boreal plains*, *Horn Plateau* and the *taiga plains* sub-regions. Most hydrometric gauges in the Deh Cho are situated in the *boreal plains* sub-region, as the majority of the population has settled in the southern part of the Deh Cho lowlands.

A *subarctic nival* regime is evident throughout the Deh Cho, where the spring snowmelt is the primary source of water for the region and annual peak flows usually occur in springtime. The timing of the spring melt varies with latitude and elevation, and generally occurs later at higher latitude and at higher elevation due to a climatic influence. Basin runoff is directly related to basin area, but basin yields also increase with elevation. The elevation effect on yield is clearly demonstrated in the gauged basins of the western cordillera.

Frequency analyses were performed on gauges that provide a minimum of 20 annual extremes. Although the Pearson Theoretical Distribution curve calculated for each stream generally fits the observed data quite well, it is not as good at determining the return period of the highest or lowest of extreme annual events. This would improve as the period of record increases.

Acknowledgements

The author acknowledges the flood-frequency analysis of hydrological data for selected NWT streams, which was previously undertaken by Moise Coulombe-Pontbriand (1998). Cover photos are provided by Denise Bicknell, who also assisted in creating the digital maps. Assistance received from persons at the Water Survey Division of Environment Canada (Yellowknife) in obtaining updated information and data is also gratefully acknowledged. Discussions with Bob Reid and Shawne Kokelj were essential to completion of the report.

References

Carson, M.A., J.N. Jasper and F.M. Conly, 1998, *Magnitude and sources of sediment input to the Mackenzie Delta, Northwest Territories*, in *Arctic 51* (2), p.116 - 124.

Chow, V.T., 1964, *Handbook of Applied Hydrology*, McGraw-Hill Book Company, New York.

Church, M., 1974, *Hydrology and permafrost with reference to northern North America*, in *Permafrost Hydrology, Proceedings of Workshop Seminar, Canadian National Committee for International Hydrological Decade*, Ottawa, p.7 - 20.

Coulombe-Pontbriand, M., 1998, *Main Rivers of Northwest Territories: Maximum discharge frequency analyses and annual hydrographs*, Indian and Northern Affairs Canada, Yellowknife, NT, internal report.

Department of Indian Affairs and Northern Development - DIAND, 1999, *Report on Map 95H*, in *Mackenzie River Hydrologic Information Map Series (HIMS)*, Water Resources Division, Yellowknife, p.95H1 - 95H43.

Environment Canada, 2002, *HYDAT*: *surface water and sediment data* (Compact Disc), Water Survey of Canada /Meteorological Service of Canada, version 2000 - 2.01.

Gerard, R., 1990, *Hydrology of floating ice*, in *T.D. Prowse and C.S.L. Ommanney (eds.) Northern Hydrology: Canadian Perspectives*, NHRI Science Report No. 1, Environment Canada.

Janowicz, J.R., 1991, *Regionalization of Low Flows in Yukon Territory*, in *T.D. Prowse and C.S.L. Ommanney (eds.) Northern Hydrology: Selected Perspectives - Proceedings of the Northern Hydrology Symposium* - 10 - 12 July, 1990, Saskatoon, Saskatchewan, p.140 - 150.

Jasper, J.N. and J.A. Kerr, 1992, *An Historic N.W.T. Flood: 1988 flooding in the Liard and Mackenzie River basins*, Environment Canada.

Mackenzie River Basin Committee, 1981, *Mackenzie River Basin Study report*, A report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin, Canada - Alberta - British Columbia - Saskatchewan - Northwest Territories - Yukon Territory.

Prowse, T.D. and T. Carter, 2002, *Significance of Ice-Induced Storage to Spring Runoff: a case study of the Mackenzie River*, in *M. Ferrick and T. Prowse (eds.) Hydrological Processes 16* (4), John Wiley and Sons, p.779 - 788.

Spence, C., 1998, *An Overview of River Conditions for South Nahanni River Basin, NWT*, Environment Canada.

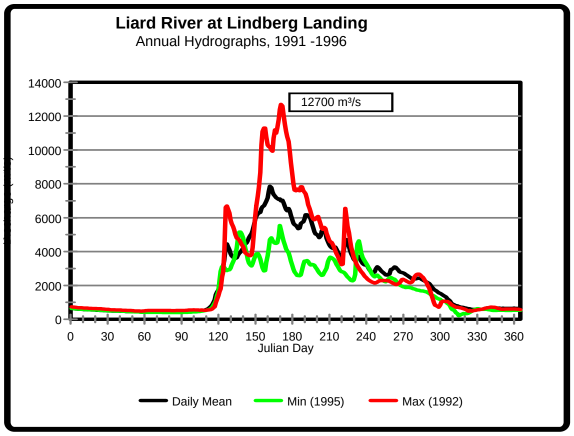
Stedinger, Jery R., Richard M. Vogel and Efi Foufoula-Georgiou, 1993, *Frequency Analysis of Extreme Events*, in *David R. Maidment (ed.) Handbook of Hydrology*, McGraw-Hill.

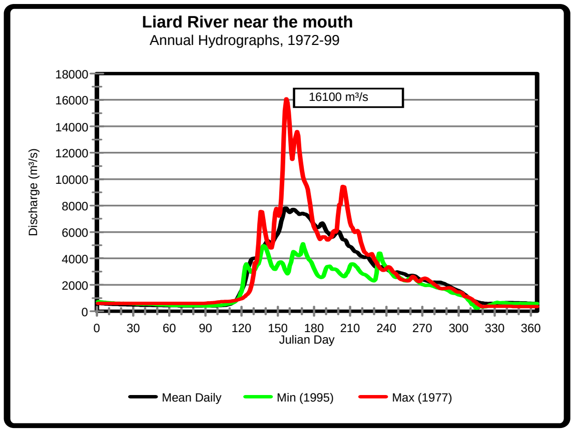
Wiens, L.H., 1983, *Hay River flood risk study*, Inland Waters Directorate, Western and Northern Region, Environment Canada.

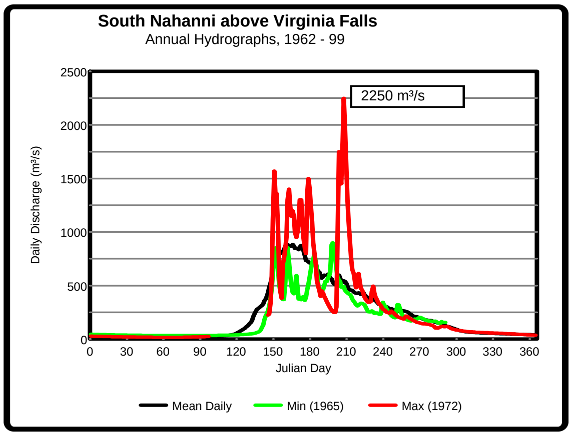
Woo, Ming-ko, 1986, *Permafrost hydrology in North America*, in *Atmosphere-Ocean 24* (3), Canadian Meteorological and Oceanographic Society, p.201 - 234.

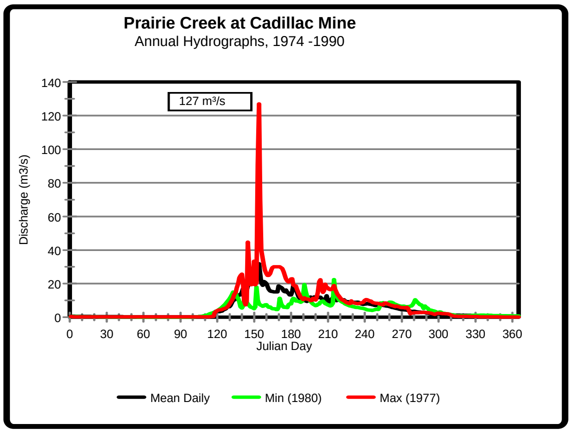
APPENDICES

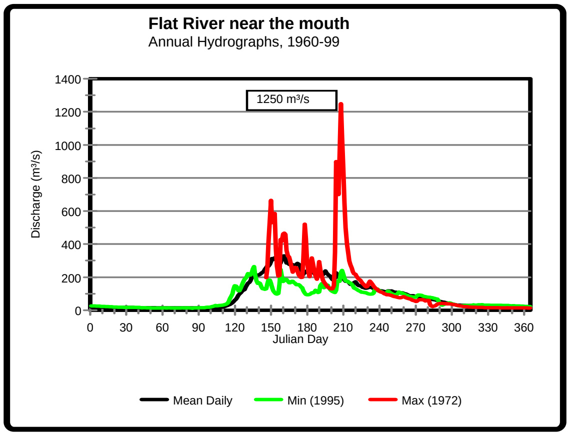
Appendix A: Annual Hydrographs

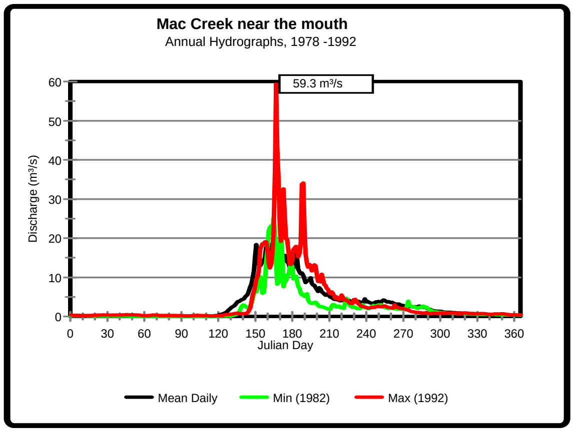


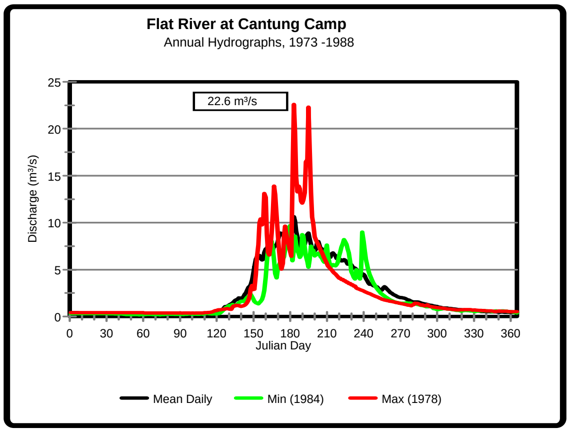


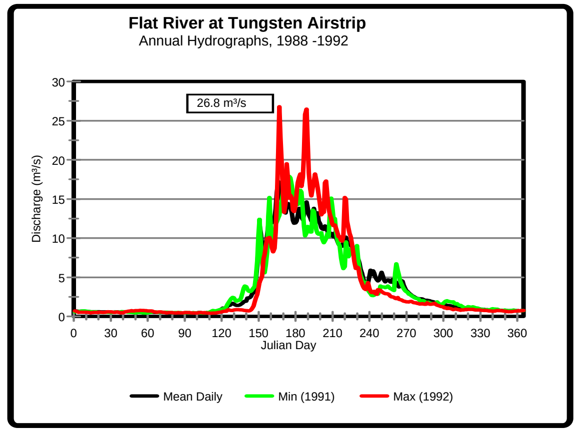


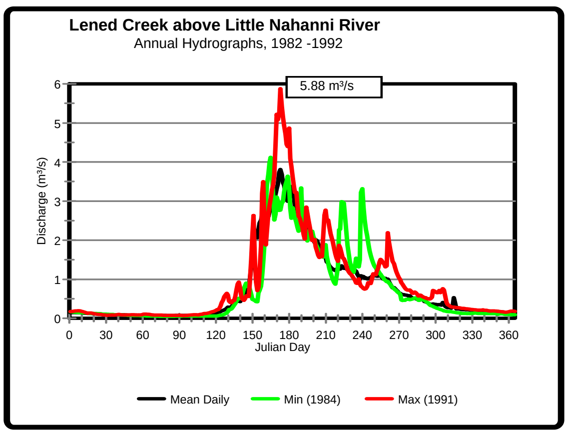


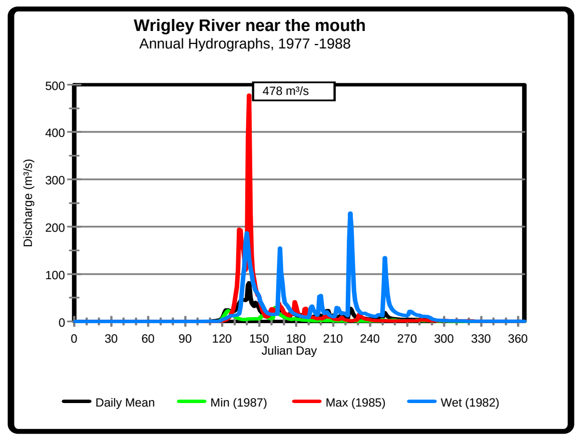


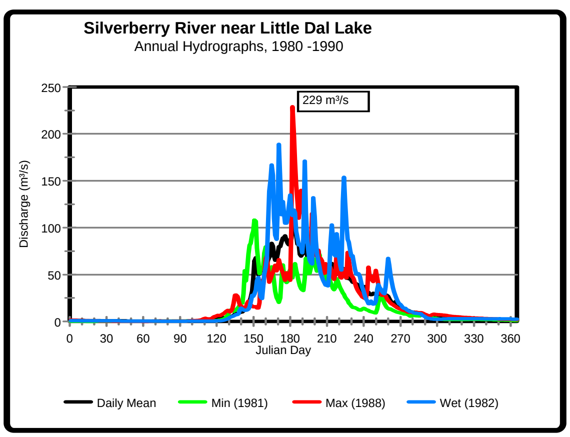


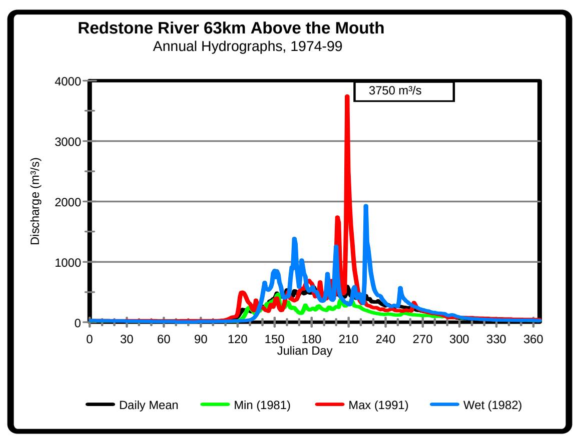

Flat River at Cantung Camp
Annual Hydrographs, 1973 -1988
22.6 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1984)
Max (1978)

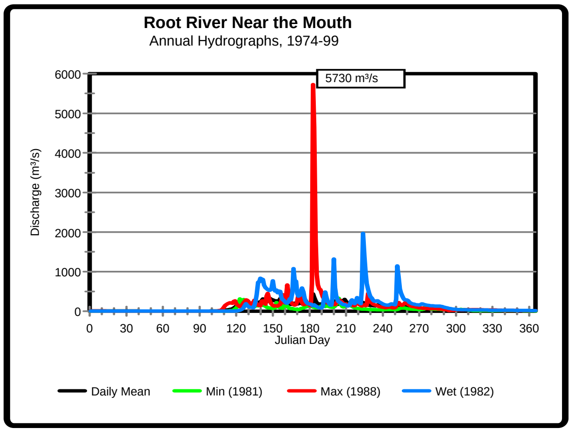

Flat River at Tungsten Airstrip
Annual Hydrographs, 1988 -1992
26.8 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1991)
Max (1992)

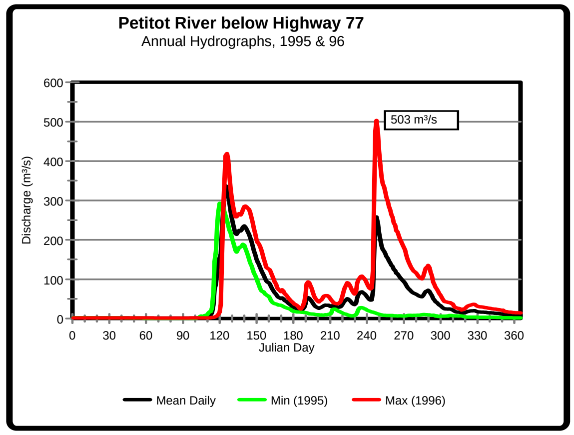

Lened Creek above Little Nahanni River
Annual Hydrographs, 1982 -1992
5.88 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1984)
Max (1991)

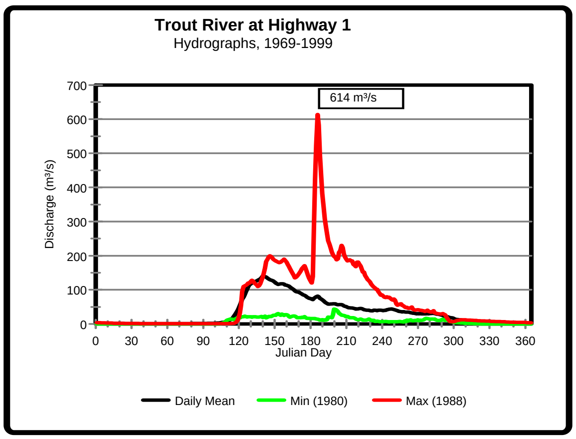

Wrigley River near the mouth
Annual Hydrographs, 1977 -1988
478 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1987)
Max (1985)
Wet (1982)

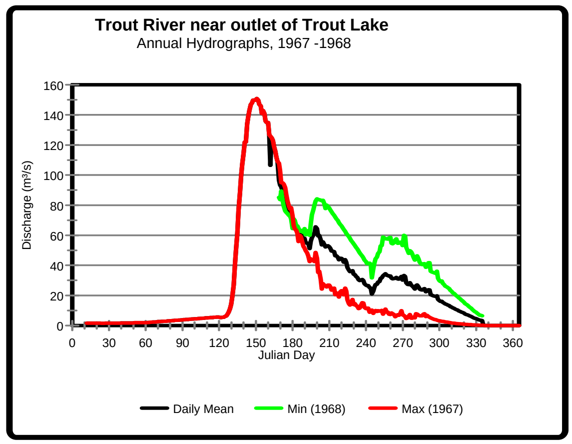

Silverberry River near Little Dal Lake
Annual Hydrographs, 1980 -1990
229 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1981)
Max (1988)
Wet (1982)

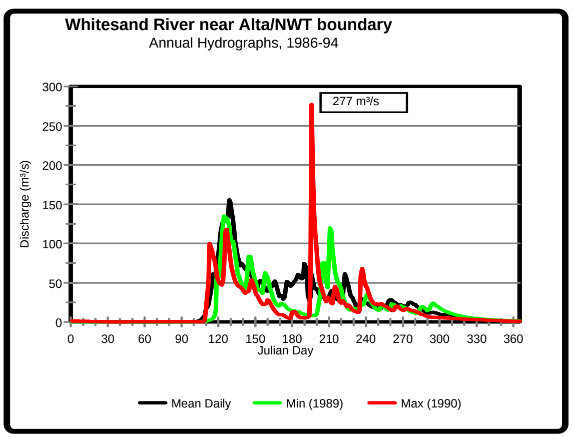

Redstone River 63km Above the Mouth
Annual Hydrographs, 1974-99
3750 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1981)
Max (1991)
Wet (1982)

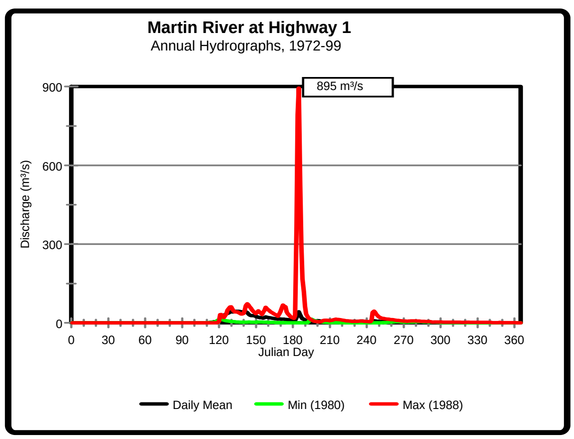

Root River Near the Mouth
Annual Hydrographs, 1974-99
5730 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1981)
Max (1988)
Wet (1982)

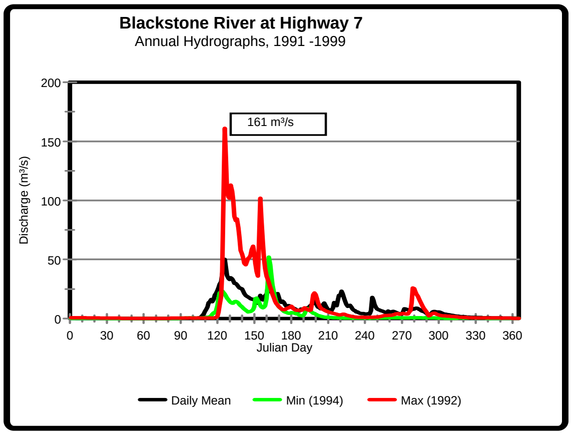

Petitot River below Highway 77
Annual Hydrographs, 1995 & 96
503 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1995)
Max (1996)

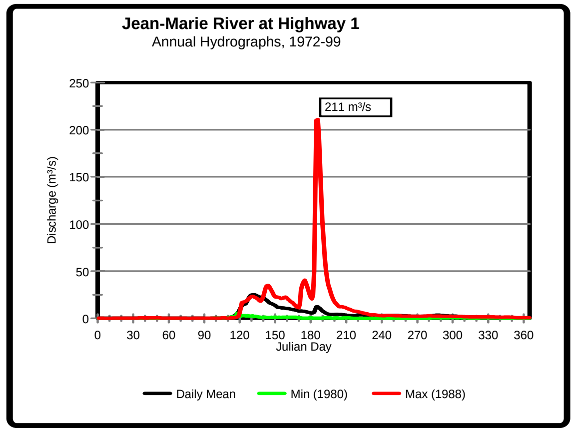

Trout River at Highway 1
Hydrographs, 1969-1999
614 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1988)

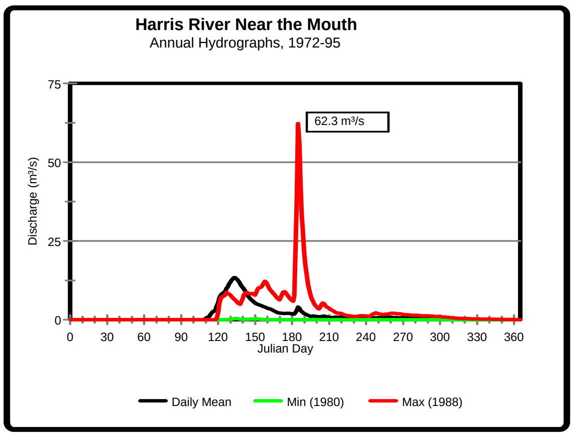

Trout River near outlet of Trout Lake
Annual Hydrographs, 1967 -1968
Discharge (m³/s)
Julian Day
Daily Mean
Min (1968)
Max (1967)

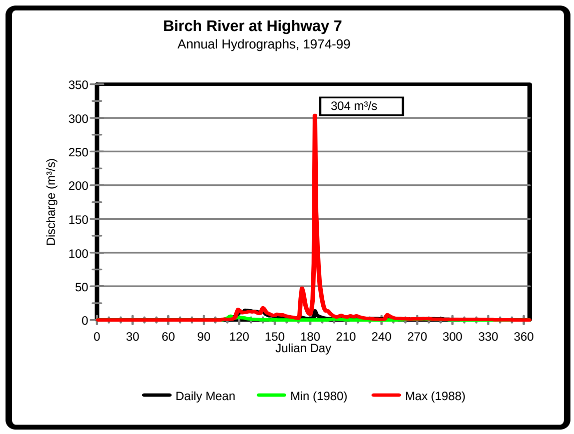

Whitesand River near Alta/NWT boundary
Annual Hydrographs, 1986-94
277 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1989)
Max (1990)

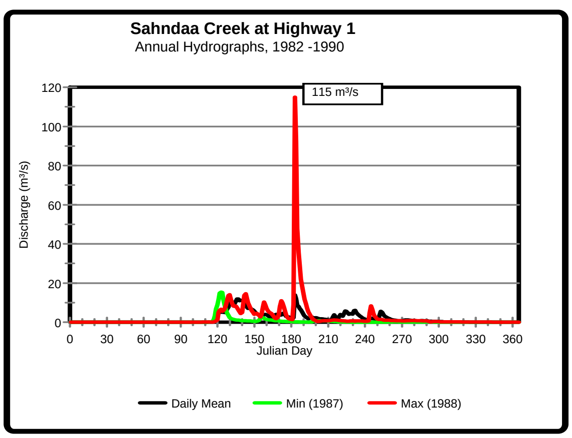

Martin River at Highway 1
Annual Hydrographs, 1972-99
895 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1988)

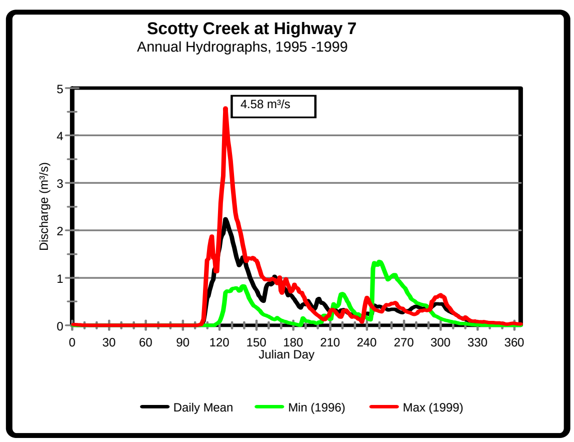

Blackstone River at Highway 7
Annual Hydrographs, 1991 -1999
161 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1994)
Max (1992)

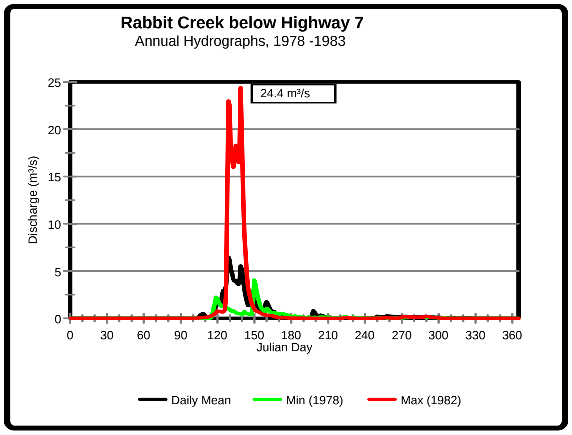

Jean-Marie River at Highway 1
Annual Hydrographs, 1972-99
211 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1988)

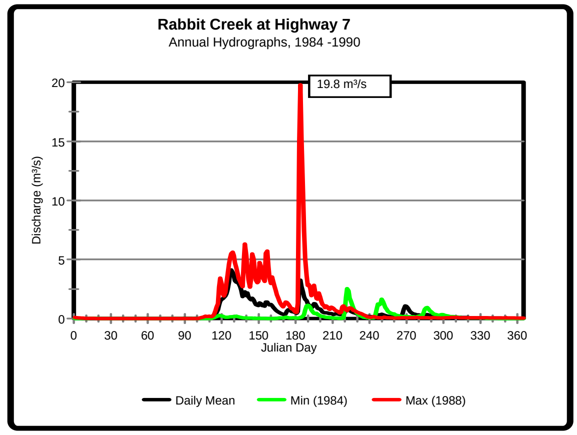

Harris River Near the Mouth
Annual Hydrographs, 1972-95
62.3 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1988)

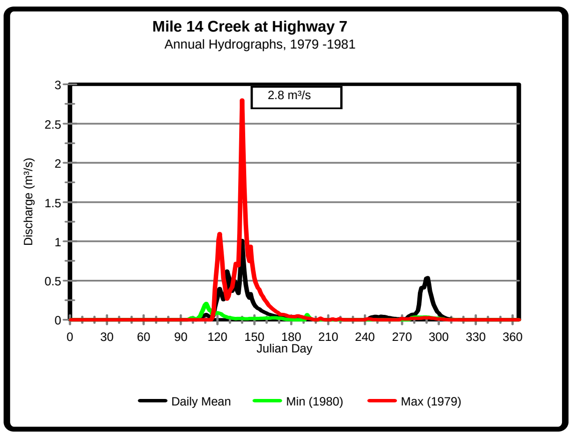

Birch River at Highway 7
Annual Hydrographs, 1974-99
304 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1988)

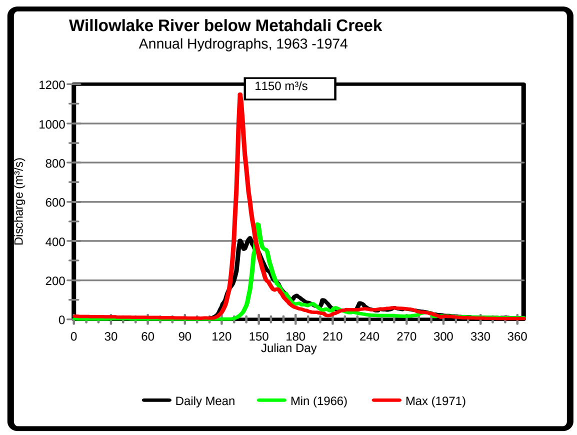

Sahndaa Creek at Highway 1
Annual Hydrographs, 1982 -1990
115 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1987)
Max (1988)

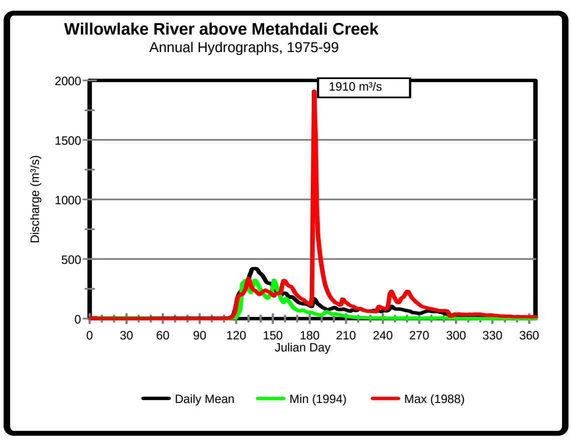

Scotty Creek at Highway 7
Annual Hydrographs, 1995 -1999
4.58 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1996)
Max (1999)

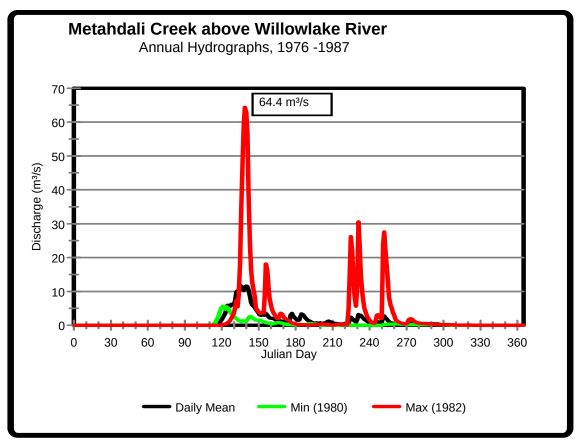

Rabbit Creek below Highway 7
Annual Hydrographs, 1978 -1983
24.4 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1978)
Max (1982)

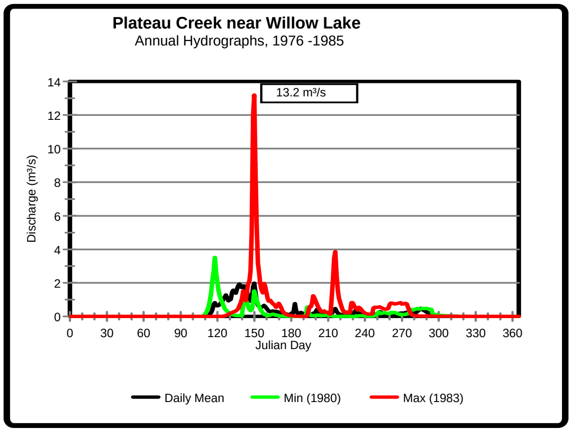

Rabbit Creek at Highway 7
Annual Hydrographs, 1984 -1990
19.8 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1984)
Max (1988)


Mile 14 Creek at Highway 7
Annual Hydrographs, 1979 -1981
2.8 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1979)

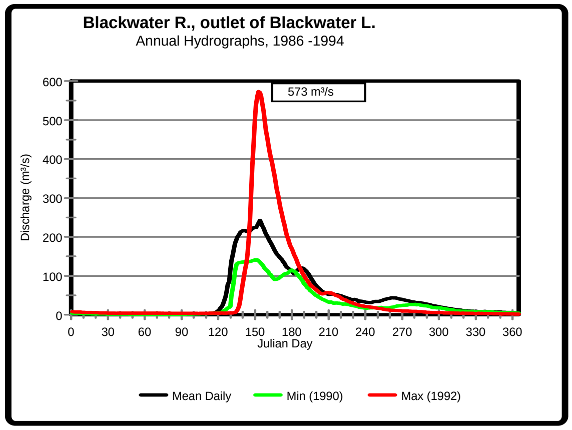

Willowlake River below Metahdali Creek
Annual Hydrographs, 1963 -1974
1150 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1966)
Max (1971)


Willowlake River above Metahdali Creek
Annual Hydrographs, 1975-99
1910 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1994)
Max (1988)

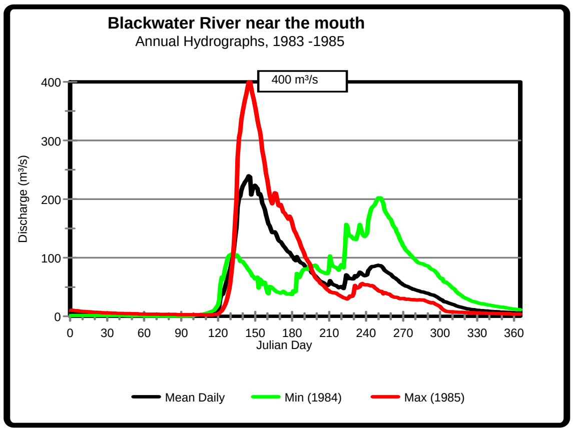

Metahdali Creek above Willowlake River
Annual Hydrographs, 1976 -1987
64.4 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1982)



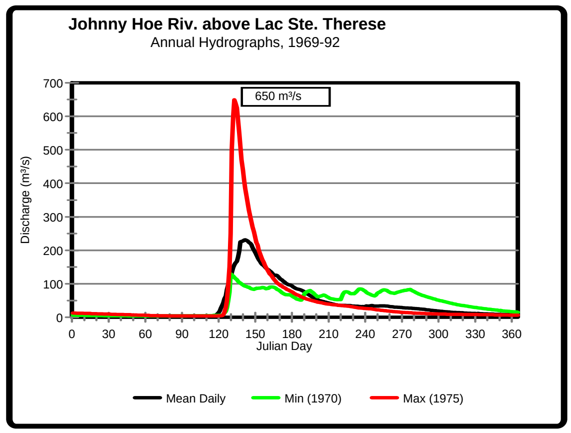
Plateau Creek near Willow Lake
Annual Hydrographs, 1976 -1985
13.2 m³/s
Discharge (m³/s)
Julian Day
Daily Mean
Min (1980)
Max (1983)



Blackwater R., outlet of Blackwater L.
Annual Hydrographs, 1986 -1994
573 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1990)
Max (1992)

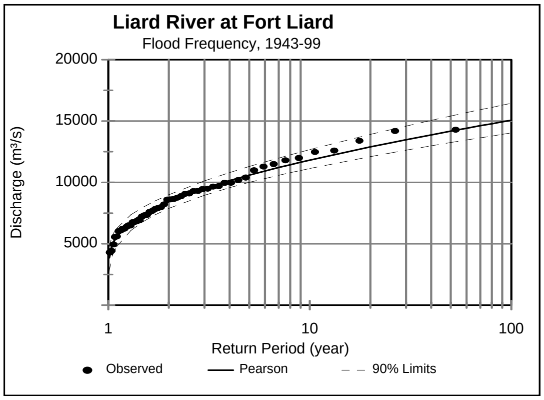


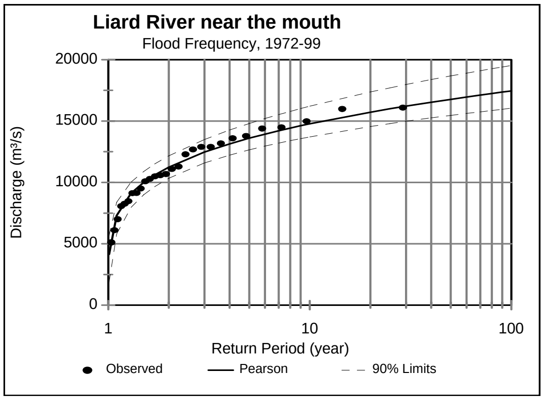
Blackwater River near the mouth
Annual Hydrographs, 1983 -1985
400 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1984)
Max (1985)

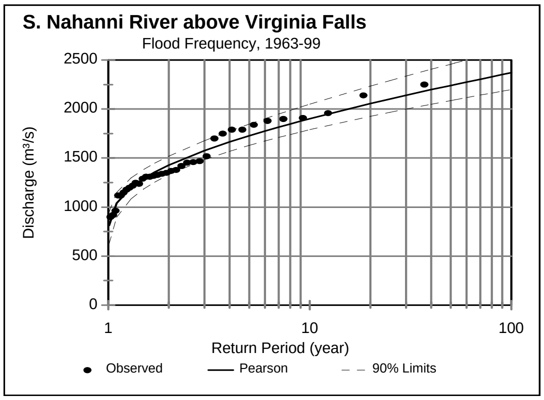


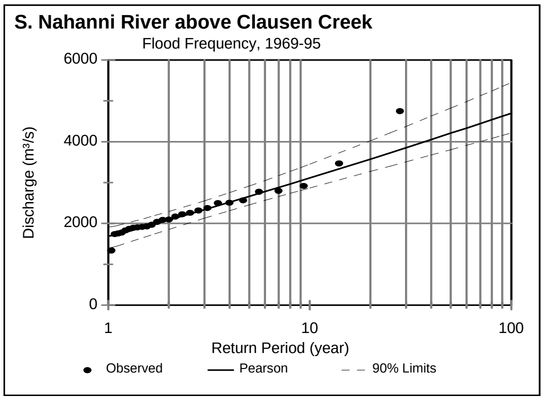
Johnny Hoe Riv. above Lac Ste. Therese
Annual Hydrographs, 1969-92
650 m³/s
Discharge (m³/s)
Julian Day
Mean Daily
Min (1970)
Max (1975)

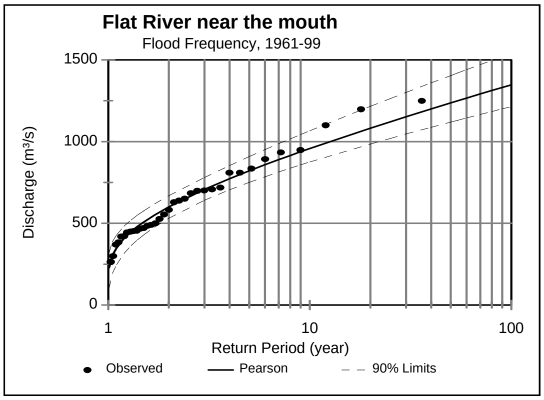
Appendix B: Flood Frequency Graphs

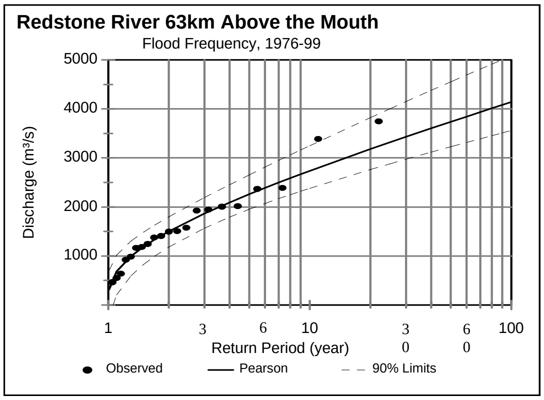


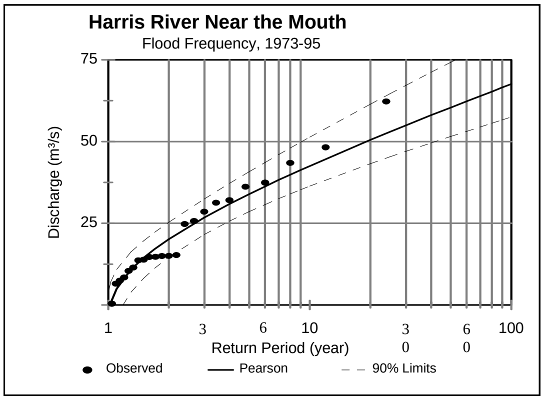


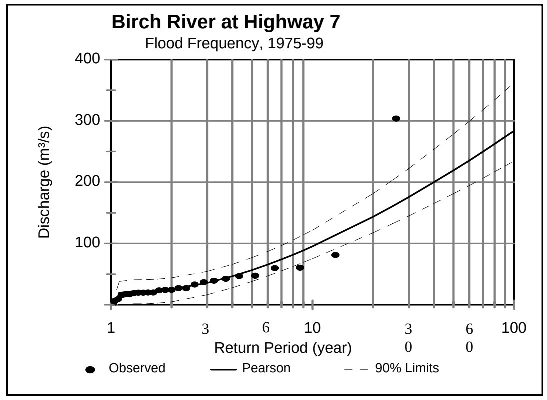


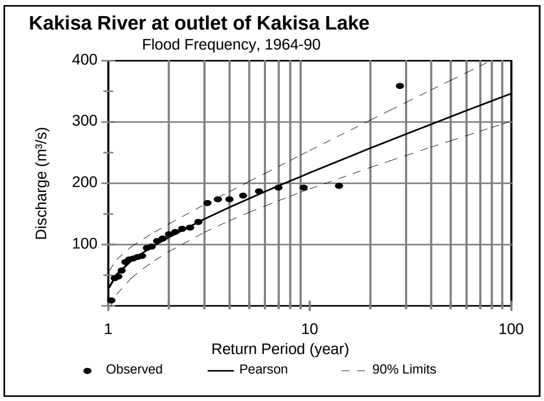


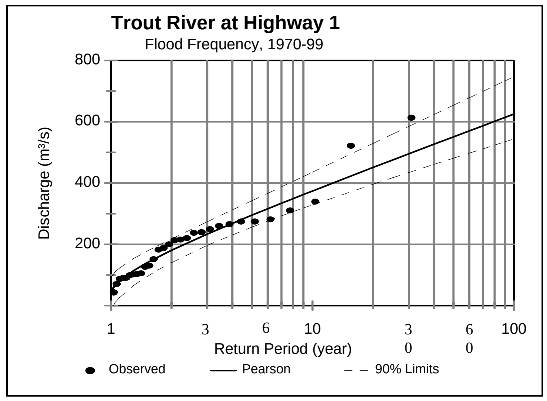


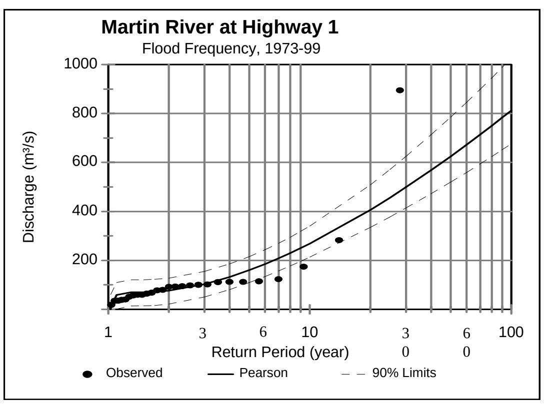


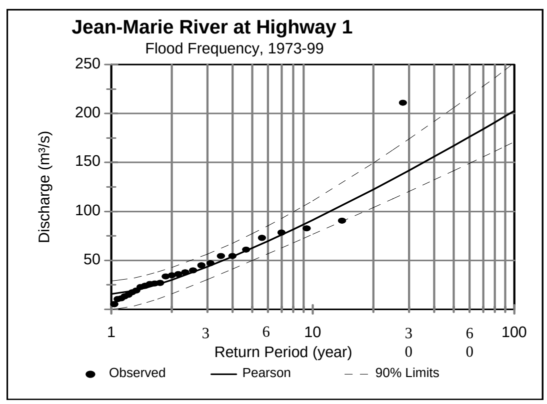

Harris River Near the Mouth
Flood Frequency, 1973-95
Discharge (m³/s)
75
50
25
1
3
6
10
30
60
100
Return Period (year)
Observed
Pearson
90% Limits

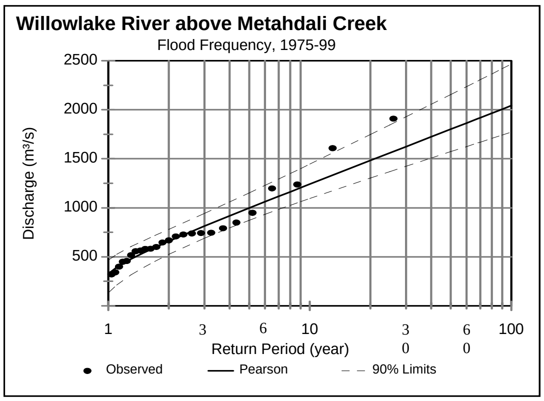

Birch River at Highway 7
Flood Frequency, 1975-99
Discharge (m³/s)
400
300
200
100
1
3
6
10
30
60
100
Return Period (year)
Observed
Pearson
90% Limits

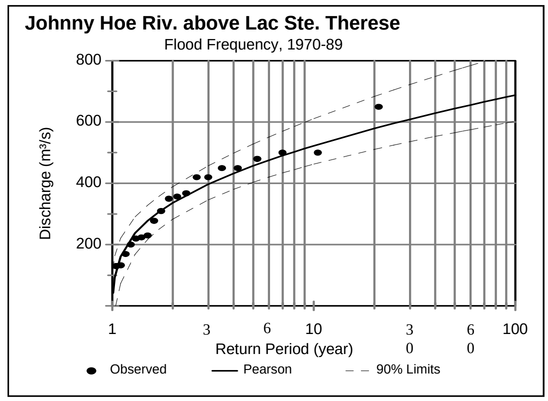

Kakisa River at outlet of Kakisa Lake
Flood Frequency, 1964-90
Discharge (m³/s)
400
300
200
100
1
10
100
Return Period (year)
Observed
Pearson
90% Limits


Trout River at Highway 1
Flood Frequency, 1970-99
Discharge (m³/s)
800
600
400
200
1
3
6
10
30
60
100
Return Period (year)
Observed
Pearson
90% Limits

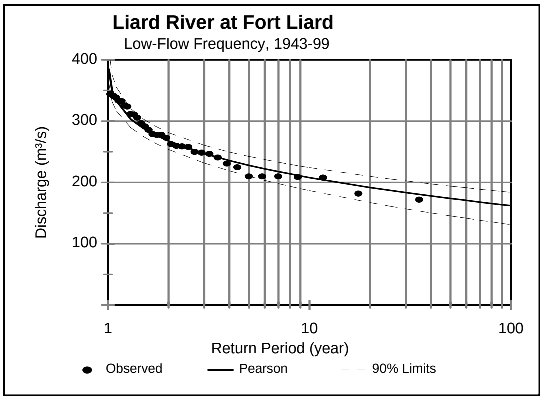

Martin River at Highway 1
Flood Frequency, 1973-99
Discharge (m³/s)
1000
800
600
400
200
1
3
6
10
30
60
100
Return Period (year)
Observed
Pearson
90% Limits

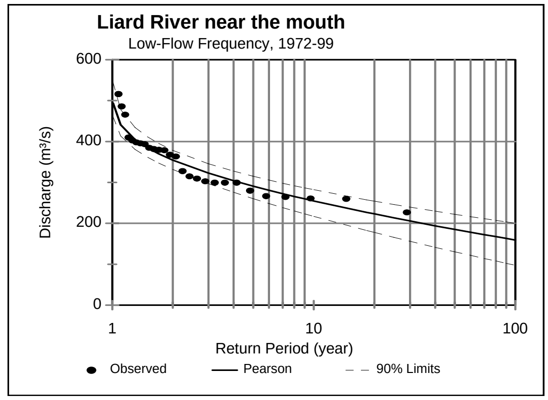

Jean-Marie River at Highway 1
Flood Frequency, 1973-99
Discharge (m³/s)
250
200
150
100
50
1
3
6
10
30
60
100
Return Period (year)
Observed
Pearson
90% Limits

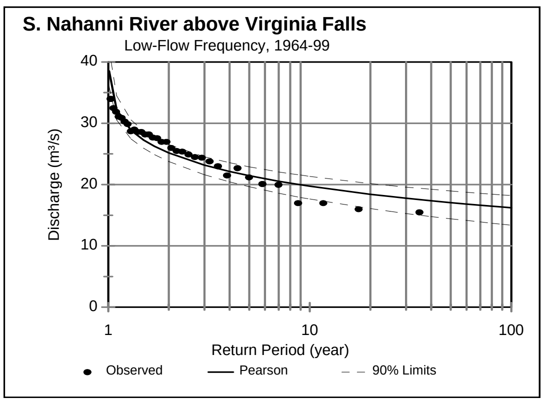

Willowlake River above Metahdali Creek
Flood Frequency, 1975-99
Discharge (m³/s)
2500
2000
1500
1000
500
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits

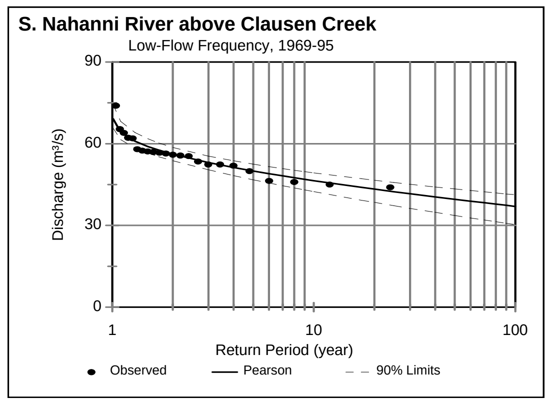

Johnny Hoe Riv. above Lac Ste. Therese
Flood Frequency, 1970-89
Discharge (m³/s)
800
600
400
200
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits

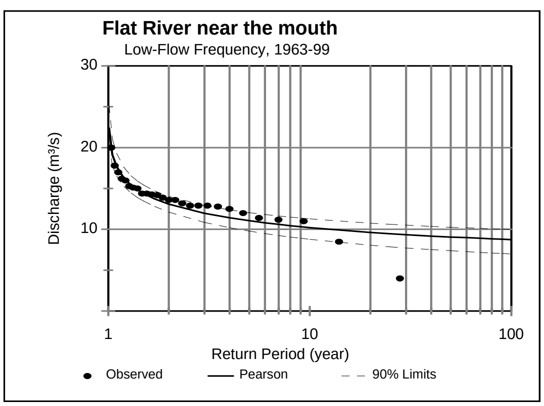
Appendix C: Low-Flow Frequency Graphs

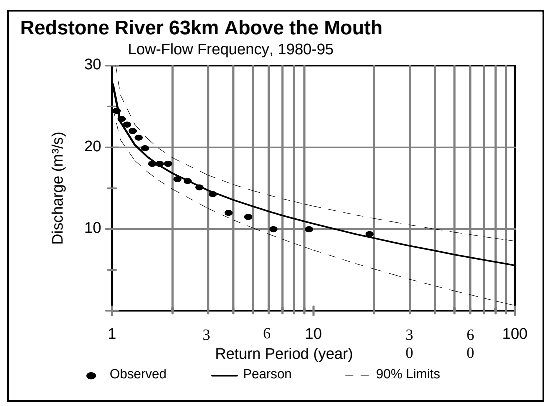


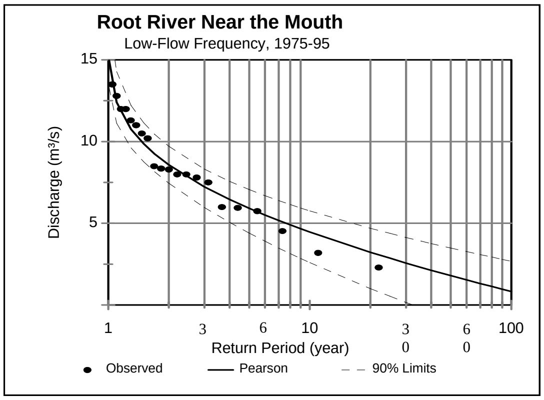


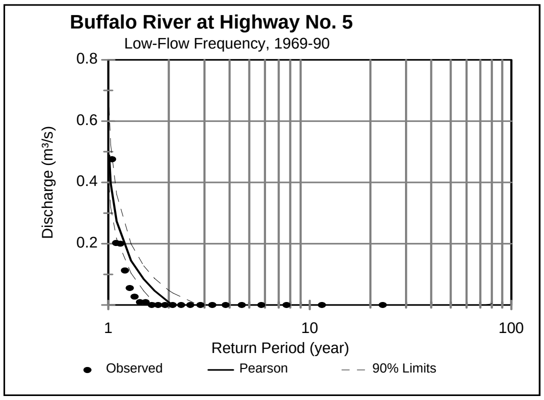


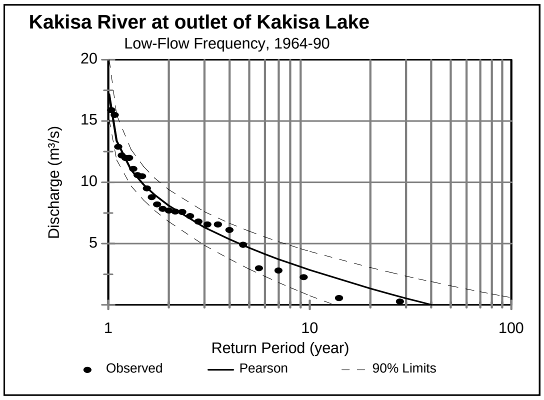


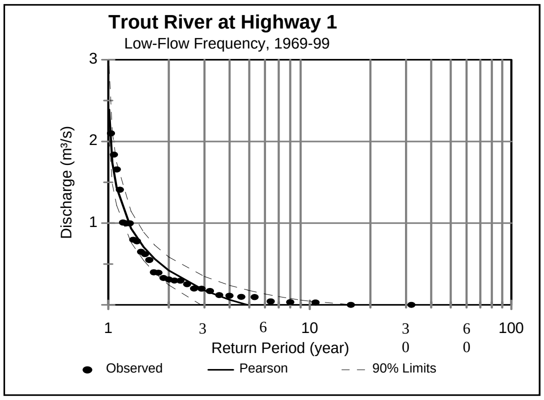


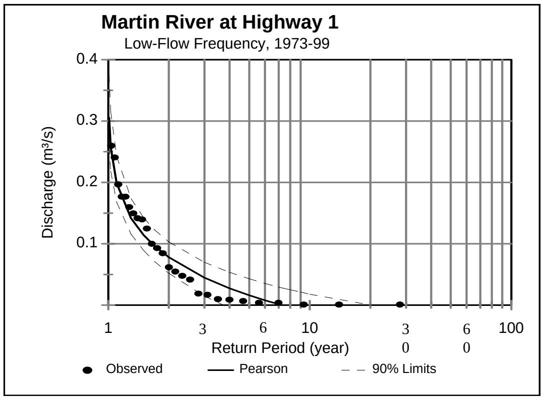


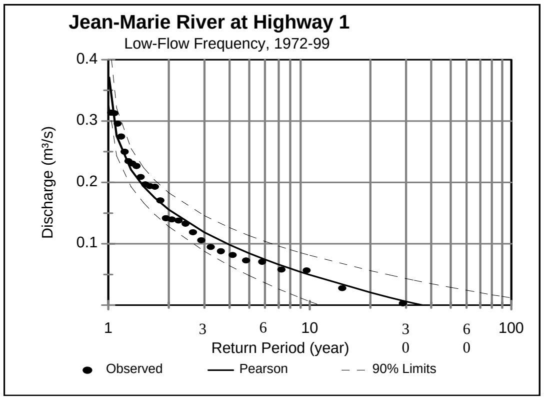

Root River Near the Mouth
Low-Flow Frequency, 1975-95
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits

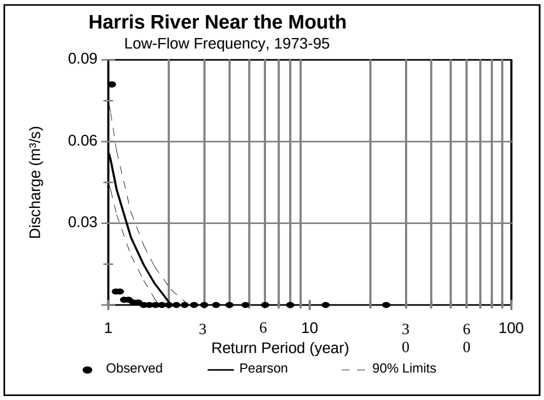

Buffalo River at Highway No. 5
Low-Flow Frequency, 1969-90
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits

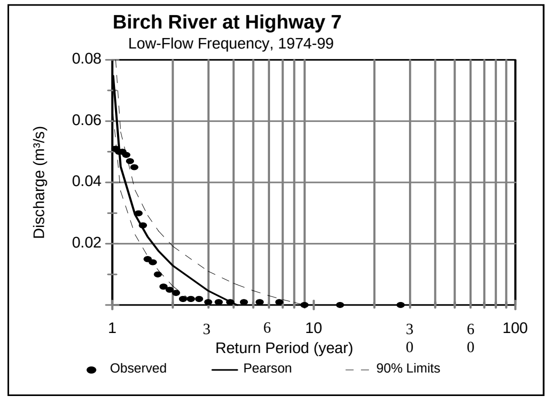

Kakisa River at outlet of Kakisa Lake
Low-Flow Frequency, 1964-90
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits

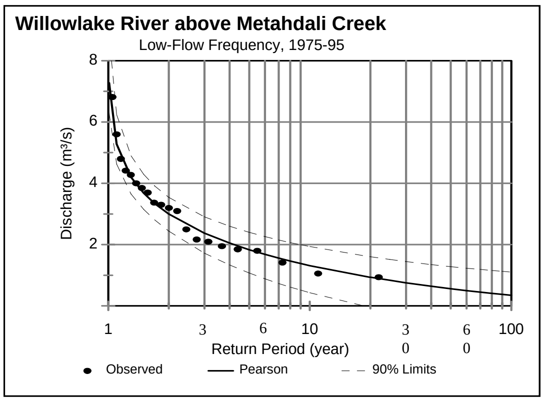

Trout River at Highway 1
Low-Flow Frequency, 1969-99
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits

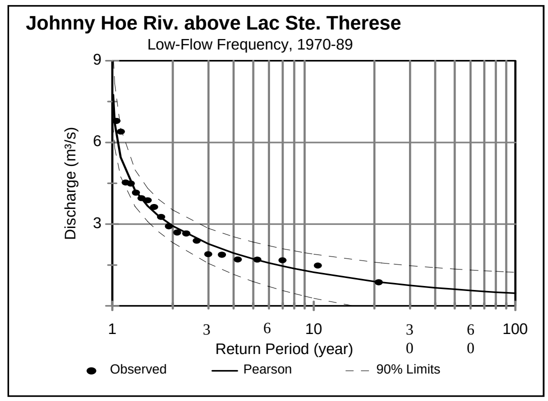

Martin River at Highway 1
Low-Flow Frequency, 1973-99
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits


Jean-Marie River at Highway 1
Low-Flow Frequency, 1972-99
Discharge (m³/s)
Return Period (year)
Observed
Pearson
90% Limits


Harris River Near the Mouth
Low-Flow Frequency, 1973-95
Discharge (m³/s)
0.09
0.06
0.03
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits


Birch River at Highway 7
Low-Flow Frequency, 1974-99
Discharge (m³/s)
0.08
0.06
0.04
0.02
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits


Willowlake River above Metahdali Creek
Low-Flow Frequency, 1975-95
Discharge (m³/s)
8
6
4
2
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits


Johnny Hoe Riv. above Lac Ste. Therese
Low-Flow Frequency, 1970-89
Discharge (m³/s)
9
6
3
1
3
6
10
3
0
6
0
100
Return Period (year)
Observed
Pearson
90% Limits