Project Millennium
Taking Suncor into the 21st Century

SUNCOR ENERGY



# HYDROLOGY BASELINE FOR PROJECT MILLENNIUM

## REPORT

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Klohn-Crippen

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# 1. INTRODUCTION

Suncor's Project Millennium comprises an extension of the Steepbank Mine presently being developed on the east side of the Athabasca River. The Steepbank Mine and Project Millennium collectively comprise the east bank mine. Both projects are located opposite Suncor's existing facilities, as shown on Figure 1. The area directly affected by Steepbank Mine and Project Millennium includes portions of Leases 19 and 25 as well as Fee Lots 3 and 4. Lease 97 and Fee Lot 1 will be affected by the approved Steepbank Mine but not by the proposed Project Millennium. Figure 2 shows the Leases and Fee Lots affected as well as an outline of east bank mine footprint.

The baseline presented in this report is that before the current development of the Steepbank Mine commenced.

# 2. STUDY BACKGROUND

## 2.1 Regional Study Area

The Regional Study Area (RSA) encompasses approximately 24 000 $km^2$ and is shown on Figure 3. This region encompasses the hydrologic basins in the oil sands region near Fort McMurray. These data provide a basis for establishing conditions and trends against which the proposed project impacts will be assessed.

## 2.2 Local Study Area

The Local Study Area (LSA) is approximately triangular in shape. It is bounded by the Athabasca River to the west and Steepbank River to the northeast. Watercourses within the LSA include those draining to Shipyard Lake (the largest of which are Unnamed Creek and Creek 2), Leggett Creek, Wood Creek, and McLean Creek. The McLean Creek watershed forms the south boundary of the LSA.

The topography of most of the LSA is flat to gently rolling. Relief across the LSA is about 190 m; ranging from elevation 235 to 240 mASL in the Athabasca River floodplain to about elevation 425 mASL in the east part of the site. The physiography of the LSA, shown on Figure 5, is divided into four main units: the Athabasca floodplain; Athabasca and Steepbank escarpments; Steepbank organic plain; and Steepbank uplands. The average slope of the Athabasca escarpment is approximately 8%: locally, the slopes are as high as 20% to 40%. In contrast, the Steepbank organic plain has an average gradient of approximately 0.7%. These physiographic areas are very evident on the longitudinal profiles of the smaller water courses in the LSA shown on Figure 6.

The Athabasca River has eroded through the surficial soils and bedrock (Crestaceous and Devonian) to form a valley that is approximately 80 m to 100 m deep. The escarpment slopes and floodplain are moderately forested. The river has an unstable thalweg and the channel has irregular meanders with occasional islands and bars.

Relatively steep slopes in the lower 35 km long reach of the Steepbank River that bounds the LSA have resulted in a moderately to well defined entrenched valley approximately 80 m deep. At the downstream end of Steepbank River, its valley cuts through the surficial deposits and, close to its confluence with the Athabasca River, the Cretaceous (McMurray Formation) and underlying Devonian bedrock are exposed. The Steepbank escarpment slopes are steep for a distance of approximately 6 km upstream of its confluence with the Athabasca River. Along this reach, gradients are locally in excess of 60%. Further upstream, the escarpment slopes become flatter and the average gradient is about 18%.

Within the LSA Unnamed Creek, Creek 2, Leggett Creek, Wood Creek and McLean Creek are deeply incised into the Athabasca escarpment and tend to flow year-round. The other creeks tend to be ephemeral and the entrenched channel systems are generally limited to the immediate vicinity of the Athabasca escarpment. On the organic plain and uplands, all watercourses are generally poorly drained and covered with muskeg fens and bogs. Here the creeks are not well defined and tend to comprise muskeg channels up to about 100 m to 150 m wide.

There is one large wetland complex on the Athabasca River floodplain within the study area known as: Shipyard Lake. It is located approximately 6 km upstream (south-east) of the confluence between the Athabasca and Steepbank Rivers as shown on Figure 4.

## 2.3 Drainage

The regional drainage is shown on Figure 7 while Figure 8 shows the drainage basins in the LSA. The principle drainage is via the Athabasca River, which forms the western boundary of the LSA. It flows northward past the proposed mine site and eventually discharges through a delta complex into Lake Athabasca. Secondary drainage is by the Steepbank River system which discharges into the Athabasca River opposite the existing Suncor mine, as shown on Figure 8. Within the LSA, a strip of land averaging less than a kilometre wide drains into the Steepbank River. The remainder of the LSA drains directly to the Athabasca River.

Of the Athabasca tributaries, Unnamed Creek, Creek 2 (both of which flow into Shipyard Lake), Leggett Creek and Wood Creek have most or all of their drainage basins entirely within the east bank mine footprint. McLean Creek, in contrast, has a substantial portion of its drainage outside the proposed mine limit. There are also several small drainage basins that drain to the Athabasca River that do not contain any well-defined watercourses or the creeks are ephemeral: these are named Athabasca A through 4 on Figure 9.

The drainage basin areas for watercourses in the LSA are presented on Table 1.

**Table 1 Drainage Basins in LSA**

| Basins | Leases and Lots Affected | Total Drainage Area ($km^2$) |
|---|---|---|
| Athabasca River | | 133 000 |
| Steepbank River | Leases 19, 25 and 97; Fee Lot 1 | 1 320 |
| Shipyard Creek | Leases 19, 25 and 97; Fee Lots 1 and 3 | 48.4 |
| Unnamed Creek | Leases 25 and 97; Fee Lot 3 | 8.7 |
| Creek 2 | Leases 19 and 25; Fee Lot 3 | 9.5 |
| Leggett Creek | Lease 19 | 23.0 |
| Wood Creek | Lease 19: Fee Lot 4 | 56.5 |
| McLean Creek | Lease 19: Fee Lot 4 | 43.4 |
| Athabasca A | Leases 25 and 97; Fee Lot 1 | 6.6 |
| Athabasca B | Leases 19, 25 and 97, Fee Lot 3 | 6.0 |
| Athabasca C | Lease 19 | 5.7 |
| Athabasca D | Lease 19 | 1.0 |

Muskeg fens and bogs with an average thickness of between 0.8 and 1.5 m cover approximately 60% of the LSA. These soils represent one of the most dominant features controlling surface runoff.

Muskeg is defined (Radforth and Brawner, 1977) as a soil substrate consisting largely of organic residues formed in a water-saturated condition as a result of an incomplete decomposition of plant constituents. The incomplete decomposition is a direct result of an anaerobic conditions. In muskeg, most of the moisture exchange takes place within an "active layer" at the surface. Literature (Radforth and Brawner, 1977) suggests that this layer is approximately 200 mm to 450 mm thick. Although, significant interflow can occur within the active layer, vertical permeability rapidly reduces with depth. At the lower boundary, decomposed and compressed organic material produces a relatively impervious zone. Ivanov (1953) and Boelter (1965, 1972) cite values of hydraulic conductivity of $1 \times 10^{-7}$ m/s, $0.75 \times 10^{-7}$ m/s and $2.2 \times 10^{-7}$ m/s for the highly decomposed peat typically found at the lower boundary of an active layer.

When the muskeg is saturated, lateral flow through the more permeable upper strata will predominate. This flow will be fed by precipitation and by the upward flows of groundwater from any underlying fluvial deposits. During dryer periods, vertical flow through the less permeable lower strata will predominate.

Hydrologically, the initial abstraction (absorption to satisfy soil moisture deficit) of rainfall during storm events to these soils will be significant and highly variable. Once saturated, infiltration to lower surficial materials will be low and a large proportion of the rainfall will run off.

## 2.4 Climate

The climate in the Athabasca Oil Sands area is characterized by long cold winters and short cool summers. Mean daily temperatures at Fort McMurray in January average about -20°C while July temperatures average 17°C. The mean annual temperature at this location is 0.2°C. There are usually less than 120 frost-free days per year (Atmospheric Environment Service, 1993).

The average annual precipitation at Fort McMurray Airport, approximately 30 km south of the LSA, is about 444 mm. Of this amount, 318 mm falls as rain during the summer and fall. The average total annual snowfall at both locations is 147 cm with the maximum typically occurring during November and December. The snow has an average water equivalent of 0.90 mm/cm and month-end snow cover typically increases to a maximum of 31 cm to 32 cm in January and February. The accumulated snow has usually melted by the end of April.

## 2.5 Surficial Geology

The surficial geology of the region has been mapped by L.A. Bayrock and T.H.F. Reimchem of the Research Council of Alberta in 1973 and by R.A. McPherson and C.P. Kathol in 1977. The surficial sediments are characterized by abrupt changes in lithology and grain size over short distances. For a more in-depth discussion of the geologic and groundwater regime in the study area, see the report titled "Hydrogeology Baseline for Project Millennium" (Klohn-Crippen, 1998).

### 2.5.1 Floodplains

The valley floor of the lower downcut reaches of the local tributaries consists of discontinuous alluvial gravel, sand, silt and clay. Where the McMurray oil sands are exposed the gravels are bitumen covered and bitumen rich sand bars and banks are common. Within the LSA the Athabasca floodplain is covered with an alluvial deposit of fine sand. Meltwater channel sediments, composed primarily of fine to coarse grained sand, are found below the alluvial deposits. The meltwater sediments are more or less continuous throughout the Athabasca River valley. The meltwater channel sediments are in contact with the Upper Devonian limestone.

### 2.5.2 Athabasca and Steepbank Escarpment

Colluvial slope wash material, discontinuously overlies McMurray formation bedrock along the escarpment valley slopes east of the Athabasca River and along the slopes of the Steepbank River and some of the smaller tributaries. At the downstream end (lower

15 km) of the Steepbank River and at locations along the Athabasca River (where some of the smaller creeks in the LSA have eroded deep channels through the escarpment and where the Athabasca River abuts the escarpment), surficial materials are completely eroded and the bedrock is exposed.

### 2.5.3 Organic Plain

As discussed in Section 2.3, the major portion of the LSA is an organic plain mainly comprising muskeg fens and bogs. Discontinuous deposits of sandy stratified sediments of glacial origin underlie the muskeg. For a more complete description of the deposits see Section 5.1.1 of the report titled "Hydrogeology Baseline for Project Millennium" (Klohn-Crippen, 1998).

### 2.5.4 Uplands

The uplands area occupies the eastern edge of the LSA. It is characterized by inorganic soils with pockets of muskeg fens and bogs. The uplands relief is higher and more hummocky than the organic plain.

# 3. PRECIPITATION AND EVAPORATION

## 3.1 Available Data

There are a number of long-term stations in the vicinity of the study area where precipitation is or has been monitored and recorded. The principal stations, which are operated by the Atmospheric Environment Service (AES) of Environment Canada or by the Alberta Forest Service, are listed on Table 2 and their locations are shown on Figure 9.

**Table 2 Long-Term Precipitation Monitoring Stations**

| Station | Location | Period of Record | Type of Record | Elevation (m) |
|---|---|---|---|---|
| Bitumount Lookout | 57°22'N 111°32'W | 1962-1995 | Seasonal | 349 |
| Ells Lookout | 57°11'N 112°20'W | 1961-1995 | Seasonal | 610 |
| Fort McMurray Airport | 56°39'N 111°13'W | 1908-1923<br>1924-1997 | Partial<br>Annual | 369 |
| Mildred Lake | 57°05'N 111°35'W | 1973-1982<br>1996-1997 | Annual | 310 |
| Muskeg Lookout | 57°08'N 110°54'W | 1959-1995 | Seasonal | 652 |
| Tar Island | 56° 59'N 111° 28'W | 1970-1984 | Annual | 346 |
| Thickwood Lookout | 56°53'N 111°39'W | 1957-1995 | Seasonal | 604 |

In addition, rainfall gauges have been set up in the past by Suncor Energy and others to gather project-specific data over a short period of time. One example of these project-specific sites is the gauge set up as part of a wetlands project being conducted by Suncor at its Lease 86/17 mine site where two years of seasonal rainfall data is available. While these data cannot be used for statistical analysis, they are useful in confirming relationships developed between precipitation in the project area and that measured at the long-term stations.

Of the long-term stations listed in Table 2, Mildred Lake and Tar Island are of most interest because of their close proximity to the LSA. Both precipitation monitoring stations are located on the left bank of the Athabasca River near the proposed mine. The Mildred Lake station is approximately 15 km northwest and the Tar Island station is approximately 5 km northwest of the centroid of Project Millennium. The station elevations of 310 m and 346 m, respectively, are within the range of elevation across the site from about 240 mASL adjacent to the Athabasca River to 425 mASL at the east perimeter of the mine. Precipitation was recorded at Mildred Lake from 1973 to 1982 and for 1996 and 1997. Data are available for Tar Island from 1970 to 1984. While the precipitation is considered to be representative of the study area, both record lengths are not long enough for a meaningful statistical analysis. In contrast, the climate station at Fort McMurray has been in operation for almost 90 years and provides an excellent basis for determining precipitation normal and extremes in the study area.

## 3.2 Precipitation in Local Study Area

A comparison of data using regression techniques demonstrates that there is a consistent relationship between the rainfall recorded at both Mildred Lake and Tar Island, and the rainfall recorded at Fort McMurray. Based on the common months of records (daily data is not available for Mildred Lake), the rainfall at Mildred Lake and Tar Island is approximately 84% and 86% of the rainfall at Fort McMurray, respectively, as shown on Figure 10. This relationship is confirmed by the daily rainfall data gathered for Suncor in 1992 and 1993 (EVS, 1993 and 1994) as part of a wetlands project. Using regression techniques, rainfall recorded in these two years is approximately 88% of the rainfall at Fort McMurray: see Figure 10. It is assumed, therefore, that the rainfall over the study area is 84% of that measured at the AES station at Fort McMurray airport. No adjustment is made for possible variations in precipitation across the study area due to differences in elevation. While there appears to be a relationship (AGRA, 1995) between precipitation and elevation in the geographic area, the trend is considered to be statistically weak.

The relationship between snowfall (snow-water equivalent) is not as consistent. Figure 11 shows, based on common months of record, that the snowfall recorded at Mildred Lake is the same as that recorded at Fort McMurray (the data recorded in 1996 and 1997 is considered to be unreliable and was not used for this analysis). The snowfall at Tar Island on the other hand is approximately 79% of the snowfall at Fort McMurray: see Figure 11. It should be noted, however, that the correlation (multiple R) between the snowfall data at Tar Island and Fort McMurray is only 0.50 compared with a value of 0.85 for the Mildred Lake and Fort McMurray data. No snow data was recorded as part of the Suncor wetland project. Since the data at Mildred Lake has a higher correlation, it was assumed that the snowfall (snow-water equivalent) recorded at Fort McMurray is typical of the study area.

Using these relationships between rainfall and snowfall at the project area and Fort McMurray (84% and 100% respectively), a long-term precipitation data set was developed. This data set is considered to be representative of the LSA. Other stations in the geographic area were not used as they are no closer to the project area than Mildred Lake and their periods of record are not as long as that at Fort McMurray. Figure 12 and Table 3 show the estimated mean monthly rainfall and snow-water equivalent for the LSA.

**Table 3 Mean Monthly Precipitation for the LSA**

| Precipitation (mm) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall | 0.4 | 1.1 | 1.1 | 7.6 | 27.8 | 55.1 | 65.9 | 52.4 | 40.6 | 14.9 | 1.9 | 0.3 |
| Snow Water Equivalent | 21.8 | 16.0 | 19.2 | 12.0 | 2.6 | 0.2 | 0.0 | 0.0 | 1.6 | 10.7 | 22.6 | 21.8 |
| Total Precipitation | 22.2 | 17.1 | 20.3 | 19.6 | 30.4 | 55.3 | 65.9 | 52.4 | 42.2 | 25.6 | 24.5 | 22.1 |

The results of a frequency analysis of annual precipitation using the Gumbel distribution are presented on Table 4. The estimates of annual precipitation, while lower than those used for the Aurora and Muskeg River Mines, are considered to be representative of Project Millennium. The reason for the differences is that no adjustment has been attempted for changes in elevation for the reasons cited above.

**Table 4 Annual Precipitation Frequency Analysis for the LSA**

| Conditions | Total Annual Precipitation (mm) |
|---|---|
| 1 in 100 dry year | 234 |
| 1 in 50 dry year | 245 |
| 1 in 10 dry year | 288 |
| 1 in 5 dry year | 319 |
| Average Year | 395 |
| 1 in 5 wet year | 466 |
| 1 in 10 wet year | 522 |
| 1 in 50 wet year | 644 |
| 1 in 100 wet year | 696 |

Precipitation extremes are only presented for Fort McMurray as daily data is not available from AES for Mildred Lake. The maximum recorded daily rainfall at Fort McMurray was 94.5 mm and occurred on August 26, 1976. The maximum daily snowfall at Fort McMurray of 29.7 cm occurred on March 16, 1951, and, because of the close correlation, can be considered to be typical of the study area. Monthly variations in extreme daily events at Fort McMurray are presented on Table 5.

**Table 5 Precipitation Extremes at Fort McMurray**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum daily rainfall (mm) | 6.4 | 4.8 | 8.0 | 15.4 | 38.4 | 46.0 | 51.6 | 94.5 | 60.5 | 29.4 | 15.2 | 84.4 |
| Maximum daily snowfall (cm) | 16.3 | 13.2 | 29.7 | 26.2 | 15.2 | 0.3 | 0.0 | 0.2 | 27.9 | 17.2 | 18.0 | 22.6 |

A rainfall intensity-duration-frequency analysis was performed by AES on data for the Fort McMurray Airport for the period 1966 through 1990. The results are presented on Figure 13. There is insufficient information available to support a regional analysis of rainfall intensity and the unadjusted curves for Fort McMurray are assumed to be representative of the LSA.

## 3.3 Evaporation and Evapotranspiration

Monthly data from Alberta Environmental Protection (Bothe and Abraham, 1987 and 1990, and Abraham, 1996) indicate that annual deep lake evaporation at Fort McMurray varies between 531 mm and 627 mm per year. Potential evapotranspiration varies between 684 mm and 891 mm while the areal evapotranspiration varies from 251 mm to 342 mm per year. The values for evaporation and evapotranspiration were computed by

Alberta Environmental Protection using Morton's Complementary Relationship Lake Evaporation (CRLE) and Complementary Relationship Areal Evapotranspiration (CRAE) models, respectively.

Average monthly potential evapotranspiration exceeds average monthly precipitation at Fort McMurray Airport from April through September. It also exceeds precipitation on a total annual basis. Average monthly aerial precipitation marginally exceeds precipitation in June and July.

Variations in mean monthly lake evaporation and aerial evapotranspiration are presented on Figure 14 and Tables 6 and 7. The values are those estimated by Alberta Environmental Protection for Fort McMurray for the period 1972 to 1994, and are considered to be representative of the LSA.

**Table 6 Lake Evaporation at Fort McMurray (in mm)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | -5 | -3 | 0 | 38 | 77 | 102 | 104 | 74 | 31 | 10 | -5 | -6 | 531 |
| Average | -2 | 0 | 17 | 60 | 104 | 120 | 128 | 99 | 42 | 15 | -2 | -3 | 572 |
| Maximum | -1 | 6 | 30 | 83 | 133 | 139 | 144 | 123 | 57 | 18 | 3 | -1 | 627 |

**Table 7 Aerial Evapotranspiration at Fort McMurray (in mm)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | -5 | -3 | 0 | 10 | 22 | 52 | 69 | 40 | 12 | 7 | -4 | -5 | 251 |
| Average | -2 | 0 | 12 | 19 | 39 | 65 | 79 | 54 | 16 | 10 | -1 | -2 | 288 |
| Maximum | 0 | 6 | 20 | 30 | 58 | 81 | 91 | 66 | 21 | 15 | 3 | -1 | 342 |

# 4. STREAMFLOW AND SEDIMENT

## 4.1 Hydrometric Records

Streamflow gauging stations in the vicinity of the study area are listed on Table 8 and their locations are shown on Figure 15. All of the stations are or were operated by the Water Survey of Canada (WSC). The WSC gauges on the Steepbank River, Beaver River, Muskeg River and Jackpine Creek (also known as Hartley Creek) are the only long-term flow records available in close proximity to the LSA.

**Table 8 Streamflow Monitoring Stations**

| Gauge | Station Number | Location | Streamflow Record | | Drainage Area ($km^2$) | Period of Sediment Records |
|---|---|---|---|---|---|---|
| | | | Period | Type | | |
| Athabasca River below Fort McMurray | 07DA001 | 56°47'N 111°24'W | 1957<br>1958-96 | Seasonal<br>Continuous | 133 000 | 1967-72 |
| Steepbank River near Fort McMurray | 07DA006 | 57°01'N 111°25'W | 1972-73<br>1974-86<br>1987-96 | Seasonal<br>Continuous<br>Seasonal | 1320 | 1975-83 |
| Poplar Creek near Fort McMurray | 07DA007 | 56°55'N 111°28'W | 1973-86 | Continuous | 151 | 1974-83 |
| Muskeg River near Fort MacKay | 07DA008 | 57°12'N 111°34'W | 1974-86<br>1987-96 | Continuous<br>Seasonal | 1 460 | 1976-83 |
| Jackpine (Hartley) Creek near Fort MacKay | 07DA009 | 57°16'N 111°28'W | 1975<br>1976-87<br>1988-93 | Seasonal<br>Continuous<br>Seasonal | 358 | 1976-83 |
| Unnamed Creek near Fort MacKay | 07DA011 | 57°40'N 111°31'W | 1975-80<br>1981-93 | Continuous<br>Seasonal | 274 | n/a |
| Joslyn Creek near Fort MacKay | 07DA016 | 57°16'N 111°45' | 1975-80<br>1981-93 | Continuous<br>Seasonal | 257 | 1976-83 |
| Ells River near the Mouth | 07DA017 | 57°16'N 111°43'W | 1975-86 | Continuous | 2450 | 1976-83 |
| Beaver River above Syncrude | 07DA018 | 56°56'N 111°34'W | 1975-87<br>1988-93 | Continuous<br>Seasonal | 165 | 1976-80 |
| MacKay River near Fort MacKay | 07DB001 | 57°13'N 111°42'W | 1972-86<br>1987-93 | Continuous<br>Seasonal | 5570 | 1975-83 |
| Firebag River near the Mouth | 07DC001 | 57°39'N 111°11'W | 1971<br>1972-86<br>1987-93 | Seasonal<br>Continuous<br>Seasonal | 5 990 | 1976-83 |

Instrumentation was installed by Suncor Energy in the vicinity of the study area to monitor discharges for the small creeks in the LSA, and water levels of the Athabasca

River and Shipyard Lake. These data are available for 1996 and 1997. The gauges, the locations of which are shown on Figure 16, were installed after spring snowmelt and removed in the fall of each year.

Flow gauging stations were originally installed in 1996 to monitor flows into and out of Shipyard Lake (Unnamed Creek, Creek 2 and Shipyard Creek). This program was expanded in 1997 to include creeks that might be affected by Project Millennium; namely Leggett Creek, Wood Creek and McLean Creek.

Water level recorders were installed on Shipyard Lake and the Athabasca River adjacent to Tar Island Dyke in 1996. The water level recorders were also installed on Shipyard Lake and the Athabasca River near Inglis Island (upstream of Shipyard Lake) in 1997. Unfortunately, the water level recorder on Shipyard Lake malfunctioned, and no data were recovered. These data were supplemented by weekly measurement of Athabasca River levels at Suncor's fresh water intake downstream of the LSA.

Data for the WSC gauges were used primarily for statistical and regional analyses. Data for the gauges installed by Suncor in the LSA, while too short in length to be included in the statistical or regional analyses, provide valuable insights into the hydrologic characteristics of the local drainage system.

## 4.2 Basin Characteristics

The results of soils classification adapted from satellite imagery by Golder Associates are presented on Table 9. The organic soil comprises the muskeg fens and bogs that dominate the organic plain. The inorganic soils comprise part of the uplands and all of the escarpment terrain units.

**Table 9 Soils Classification for Drainage Basins**

| Basin | Organic Soil | Inorganic Soil | Disturbed | Open Water |
|---|---|---|---|---|
| WSC Gauges | | | | |
| Steepbank River | 66% | 34% | 0% | 0% |
| Muskeg River | 68% | 26% | 6% | 0% |
| Jackpine Creek | 79% | 21% | 0% | 0% |
| Suncor Gauges | | | | |
| Unnamed Creek | 61% | 39% | 0% | 0% |
| Creek 2 | 77% | 23% | 0% | 0% |
| Shipyard Creek | 73% | 27% | 0% | 0% |
| Leggett Creek | 82% | 18% | 0% | 0% |
| Wood Creek 1 | 42% | 57% | 1% | 0% |
| Wood Creek 2 | 77% | 23% | 0% | 0% |
| McLean Creek | 70% | 30% | 0% | 0% |
| Other Basins | | | | |
| Athabasca A | 8% | 90% | 0% | 2% |
| Athabasca B | 35% | 53% | 0% | 12% |
| Athabasca C | 58% | 38% | 0% | 4% |
| Athabasca D | 0% | 96% | 0% | 4% |

Notes: Soils are measured as a percentage of catchment area to gauging station prior to Steepbank Mine construction activities Data from Golder Associates Ltd.

Comparing the GIS data and flow characteristics, the soils units shown on Table 9 appear to have a relatively close correlation to runoff at the WSC gauging stations. When considering the average annual runoff, the portion of inorganic soils in the drainage basin is the dominant factor. The organic soils appear to have a lower runoff due to the high soil-moisture holding characteristics of the muskeg described in Section 2.3. Similar relationships have been observed for the Beaver River on the west side of the Athabasca River (AGRA, 1995).

The relative proportions of organic and inorganic soils do not fully explain the differences in flow characteristics between the watercourses. The residual differences are considered a result of the different aspect (orientation to North) of the drainage basins. As discussed in Section 4.3.5, these differences are quite evident between the Steepbank River basin, and Muskeg River and Jackpine Creek basins. The significant impact that basin aspect can have on streamflow was also noted on a study of precipitation-runoff relationships for the existing Suncor mine on the west side of the Athabasca River (AGRA, 1995). This study concluded that runoff from upland areas is twice that from lowland areas. The upland and lowland areas used by AGRA are similar to the inorganic and organic soils adopted for this study.

As discussed in Section 4.3.5, differences in flow characteristics are more pronounced for data collected at the Suncor gauges in the LSA. The effect of localized variations in factors such as groundwater recharge and soil permeability can have a significant impact on runoff from these small basins.

## 4.3 Streamflow Characteristics

### 4.3.1 Athabasca River

The Athabasca River is largely unregulated apart from the outflows from Lesser Slave Lake and Paddle River Dam. Flows at Lesser Slave Lake and Paddle River Dam represent approximately 6% of the flow in the Athabasca River at the study area.

As stated in Section 4.1, flows have been recorded continuously upstream of the study area at Fort McMurray since 1957. There is only about a 0.5% difference in catchment area between the study area and the gauging station at Fort McMurray. Discharge data for Fort McMurray are, therefore, considered to be representative of flows at the proposed mine site.

The average flow at Fort McMurray is 655 $m^3/s$, while the maximum and minimum recorded mean daily flows are 4 700 $m^3/s$ and 89 $m^3/s$, respectively. The maximum recorded instantaneous flow is 4 790 $m^3/s$. Peak flows are typically experienced at Fort McMurray during the month of July.

Variations in mean monthly flows are shown on Figure 17, and flow duration curves are presented on Figure 18. Results of a flood and low flow frequency analysis of recorded annual maximum and minimum mean daily flows are presented on Figures 19 and 20 respectively, and the recommended values are shown on Table 10. Table 11 presents the results of a statistical analysis of annual runoff at this gauging station.

**Table 10 Athabasca River - Frequency Analyses**

| Return Interval | Maximum Mean Daily Flow ($m^3/s$) | Minimum Mean Daily Flow ($m^3/s$) |
|---|---|---|
| 1 in 5 years | 3 240 | 114 |
| 1 in 10 years | 3 780 | 102 |
| 1 in 50 years | 4 990 | 83.5 |
| 1 in 100 years | 5 510 | 76.6 |

Note: Maximum flow estimates are based on the Log Pearson Type III distribution.
Minimum flow estimates are based on the Pearson Type III distribution.

**Table 11 Athabasca River - Annual Runoff**

| Condition | Annual Runoff | |
|---|---|---|
| | Total ($dam^3$) | Depth (mm) |
| 1 in 100 dry year | 12 700 000 | 95 |
| 1 in 50 dry year | 13 500 000 | 102 |
| 1 in 10 dry year | 16 000 000 | 120 |
| 1 in 5 dry year | 17 500 000 | 132 |
| Average year | 20 700 000 | 156 |
| 1 in 5 wet year | 23 800 000 | 179 |
| 1 in 10 wet year | 25 600 000 | 192 |
| 1 in 50 wet year | 28 700 000 | 216 |
| 1 in 100 wet year | 29 800 000 | 224 |

Note: Based on the Log Pearson Type III distribution
The depth is a theoretical depth of water over the entire drainage basin.

### 4.3.2 Steepbank River

The average streamflow in the Steepbank River at the WSC gauging station near its confluence with the Athabasca River is approximately 6.0 $m^3/s$, or about 1% of the average flow in the Athabasca River. The maximum recorded mean daily flow is 81.0 $m^3/s$ and the maximum instantaneous flow was 92.0 $m^3/s$. The ratio of maximum instantaneous flow to daily peak flow of 1.06 is fairly typical of the flat hydrographs usually produced by snowmelt and is consistent with other watercourses in the area monitored by WSC as shown on Figure 21. Peak monthly flows are due to snowmelt and are usually experienced during the month of May. Secondary peak monthly flows, from rainfall, typically occur in September. Typical flood hydrographs for spring snowmelt and summer rainstorms are shown on Figure 22 for Steepbank River as well as for the Muskeg River and Jackpine Creek.

Variations in mean monthly flows are presented on Figure 23 and flow duration curves are shown on Figure 24. The results of a frequency analysis of annual maximum and minimum recorded peak mean daily flows are presented on Figure 25 and 26, respectively, and recommended values are shown on Table 12

**Table 12 Steepbank River - Frequency Analyses**

| Return Interval | Maximum Mean Daily Flow ($m^3/s$) | Minimum Mean Daily Flow ($m^3/s$) |
|---|---|---|
| 1 in 5 years | 55.4 | 0.188 |
| 1 in 10 years | 72.0 | 0.133 |
| 1 in 50 years | 112 | 0.031 |
| 1 in 100 years | 131 | 0 |

Note: Maximum flow estimates are based on the Log Pearson Type III distribution.
Minimum flow estimates are based on the Pearson Type III distribution.

Table 13 presents the results of a statistical analysis of annual runoff to the Steepbank River. Between 12% and 37% of the estimated annual precipitation for the LSA contributes to runoff with the percentage increasing in wetter years. The remainder will be lost to evapotranspiration, evaporation and temporary storage in muskeg and beaver ponds.

Streamflows occur throughout the winter months and are due to groundwater discharge from surficial and bedrock aquifers as well as drainage from muskeg fens and bogs. Typically, the lowest flows tend to occur in January, February or March. Winter flows were recorded on this watercourse at the WSC gauging station from 1975 through 1987 and, during this period, the average winter flow (January through March) was 0.40 $m^3/s$ while minimum mean monthly flow for these months was 0.081 $m^3/s$.

**Table 13 Steepbank River - Annual Runoff**

| Condition | Runoff | | |
|---|---|---|---|
| | **Total ($dam^3$)** | **Depth (mm)** | **% Precipitation** |
| 1 in 100 dry year | 37 900 | 28.7 | 12 |
| 1 in 50 dry year | 47 100 | 35.7 | 15 |
| 1 in 10 dry year | 77 300 | 58.6 | 20 |
| 1 in 5 dry year | 97 600 | 73.9 | 23 |
| Average year | 152 000 | 115 | 29 |
| 1 in 5 wet year | 201 000 | 152 | 33 |
| 1 in 10 wet year | 237 000 | 180 | 34 |
| 1 in 50 wet year | 312 000 | 236 | 37 |
| 1 in 100 wet year | 342 000 | 259 | 37 |

Note: Based on the Three Parameter Log-Normal distribution.

### 4.3.3 Muskeg River

Flows have been recorded since 1974 on Muskeg River at a gauging station approximately 10 km (measured along the valley) upstream of its confluence with the Athabasca River. The average streamflow at this location is 5.4 $m^3/s$ while maximum and minimum recorded mean daily flow is 66.1 $m^3/s$ and 0.095 $m^3/s$, respectively. The average winter flow from January through March is 0.35 $m^3/s$. The maximum recorded instantaneous peak and discharge was 66.4 $m^3/s$. Like the Steepbank River, peak monthly flows tend to occur in May from snowmelt with secondary peaks from rainfall in September (see Figure 22).

Variations in mean monthly flows are presented on Figure 27 and flow duration curves are shown on Figure 28 for monthly and daily discharges. The results of frequency analyses of annual maximum and minimum mean daily flows are presented on Figures 29 and 30 respectively, and the recommended values are shown on Table 14.

**Table 14 Muskeg River - Frequency Analyses**

| Return Interval | Maximum Mean Daily Flow ($m^3/s$) | Minimum Mean Daily Flow ($m^3/s$) |
|---|---|---|
| 1 in 5 years | 39.4 | 0.173 |
| 1 in 10 years | 49.3 | 0.131 |
| 1 in 50 years | 70.8 | 0.066 |
| 1 in 100 years | 79.8 | 0.045 |

Note: Maximum flow estimates are based on the Log Pearson Type III distribution.
Minimum flow estimates are based on the Pearson Type III distribution.

The results of an analysis of annual runoff volumes are presented on Table 15. Between about 4% and 29% of the estimated annual precipitation contributes to runoff.

**Table 15 Muskeg River - Annual Runoff**

| Condition | Runoff | | |
|---|---|---|---|
| | **Total (dam$^3$)** | **Depth (mm)** | **% Precipitation** |
| 1 in 100 dry year | 12 700 | 8.7 | 4 |
| 1 in 50 dry year | 22 800 | 15.6 | 6 |
| 1 in 10 dry year | 54 800 | 37.5 | 13 |
| 1 in 5 dry year | 75 500 | 51.7 | 16 |
| Average | 127 000 | 87.0 | 22 |
| 1 in 5 wet year | 176 000 | 121 | 26 |
| 1 in 10 wet year | 209 000 | 143 | 27 |
| 1 in 50 wet year | 274 000 | 188 | 29 |
| 1 in 100 wet year | 300 000 | 205 | 29 |

Note: Based on the Three Parameter Log-Normal distribution.

### 4.3.4 Jackpine Creek

Variations in mean monthly flows in Jackpine Creek (also known as Hartley Creek), a tributary of the Muskeg River, are presented on Figure 31 and flow-duration curves are shown on Figure 32. The results of a frequency analysis of annual maximum mean daily flows are presented on Figure 33 and the recommended values given on Table 16. A frequency analysis of low flows was not performed because a minimum daily flow of zero was observed in 6 out of the 16 years of records at this site. Based on these data, it is concluded that a minimum mean daily flow of zero can be expected about once every 3 years.

**Table 16 Jackpine Creek - Frequency Analyses**

| Return Interval | Maximum Mean Daily Flow ($m^3/s$) | Minimum Mean Daily Flow ($m^3/s$) |
|---|---|---|
| 1 in 5 years | 12.9 | 0 |
| 1 in 10 years | 16.6 | 0 |
| 1 in 50 years | 24.0 | 0 |
| 1 in 100 years | 26.7 | 0 |

Note: Maximum flow estimates are based on the Log Pearson Type III distribution.

The results of an analysis of annual runoff are presented on Table 17. Up to 32% of the annual precipitation contributes to runoff, again, with the percentage increasing in wetter years.

The relationship between annual runoff and precipitation for Jackpine Creek is very similar to that of Muskeg River which has over 4 times the drainage area. Unlike Muskeg River, however, minimum monthly flows of zero have been recorded over the winter months: The average flow from January through March is 0.013 $m^3/s$.

**Table 17 Jackpine Creek - Annual Runoff**

| Condition | Runoff | | |
|---|---|---|---|
| | Total ($dam^3$) | Depth (mm) | % Precipitation |
| 1 in 100 dry year | 0 | 0 | 0 |
| 1 in 50 dry year | 2 230 | 6.2 | 3 |
| 1 in 10 dry year | 11 300 | 31.6 | 11 |
| 1 in 5 dry year | 17 200 | 48.0 | 15 |
| Average year | 31 600 | 88.3 | 22 |
| 1 in 5 wet year | 45 200 | 126 | 27 |
| 1 in 10 wet year | 54 300 | 152 | 29 |
| 1 in 50 wet year | 72 300 | 202 | 31 |
| 1 in 100 wet year | 79 300 | 222 | 32 |

Note: Based on the Three Parameter Log-Normal distribution.

### 4.3.5 Smaller Creeks

Flows were recorded in Shipyard Creek (at the outlet to Shipyard Lake), Unnamed Creek, and Creek 2 in 1996 and 1997. In 1997, two gauging stations were installed on Wood Creek and one was installed towards the downstream end of both Leggett and McLean Creeks. The discharges are shown on Figures 34 through 38. The mean monthly flows at each site are presented on Table 18. Water levels recorded in the vicinity of the study area in 1996 are shown on Figure 39.

**Table 18 Smaller Creeks - Average Recorded Flows (L/s)**

| Month | Shipyard Creek | Unnamed Creek | Creek 2 | Leggett Creek | Wood Creek 1 | Wood Creek 2 | McLean Creek |
|---|---|---|---|---|---|---|---|
| July 1996 | 535 | 56 | 135 | n/a | n/a | n/a | n/a |
| August 1996 | 305 | 42 | 91 | n/a | n/a | n/a | n/a |
| September 1996 | 205 | 24 | 49 | n/a | n/a | n/a | n/a |
| October 1996 | 310 | 45 | 77 | n/a | n/a | n/a | n/a |
| June 1997 | n/a | 9 | 12 | 23 | 525 | 72 | 145 |
| July 1997 | n/a | 7 | 8 | 18 | 390 | 52 | n/a |
| August 1997 | 59 | 11 | 15 | 39 | 305 | 37 | 62 |
| September 1997 | 210 | 44 | 29 | 135 | 295 | 105 | 150 |
| October 1997 | 350 | 57 | 20 | 245 | 205 | 160 | 105 |

Due to difficult access, the gauges were not installed until after the snowmelt. While the data obtained did not capture the spring runoff, they do demonstrate the response of the creeks to rainfall events as well as changes in base flow throughout the year. When viewing the figures, it should be noted that both 1996 and 1997 were wetter than average. The total precipitation in both years were 104% and 108% of the average, respectively, while the rainfall was 143% and 122%, respectively.

All creeks exhibit decreasing base flow over the summer months until mid to late August when base flows increase in response to rainfall. All creeks also show a rapid response to rainfall events with relatively steep hydrograph recession limbs. With the exception of Wood Creek, discharges of less than 5 L/s were recorded at one or more times during the summer months. Wood Creek demonstrates a persistent baseflow in excess of 15 L/s at the upstream gauge site and greater than about 160 L/s at the downstream gauge site. It should be noted that the streamflow gauges on both Wood and McLean Creeks are located close to the top of the Athabasca escarpment and flow measurements may not reflect groundwater flow from the confined surficial aquifers (Klohn-Crippen, 1998).

Water levels in Shipyard Lake exhibit very little variation over the summer months. The average water level in 1996 was 237.18 mASL, while the maximum and minimum levels were 237.24 and 237.10 mASL, respectively.

While the data collected in 1996 and 1997 is useful, it is not adequate for determining streamflow characteristics of local watercourses in the LSA and a regional approach was adopted.

With a drainage area of 358 $km^2$, Hartley Creek is the smallest gauged basin in the vicinity of the Steepbank Mine which has a basin shape, soil type, topography and aspect that is similar to the smaller watercourses in the LSA. For these reasons, drainage data for this basin has been used as the basis for determining flows to Shipyard Lake, Leggett Creek, Wood Creek and McLean Creek. Based on a regional analysis of streamflow records, data was transposed using the following equations:

| | |
|---|---|
| Maximum Mean Daily Flows | - $Q_1 = (A_1 / A_2)^{0.77} Q_2$ |
| Mean Daily Flows | - $Q_1 = (A_1 / A_2)^{0.90} Q_2$ |
| Mean Annual Flows | - $Q_1 = (A_1 / A_2) Q_2$ |

where Q is the flow in $m^3/s$, A is the catchment area in $km^2$ and the subscripts 1 and 2 refer to the respective basins.

As discussed in Section 4.2, the proportion of different soil types in the drainage basin has an impact on streamflow characteristics. An earlier study undertaken by Suncor Energy (AGRA, 1996a) indicated that the "upland" portion of a drainage basin contributes approximately twice the annual runoff when compared with "lowland" areas.

Although AGRA's definition of "upland" is based on gradient rather than on soil type, a similar trend is exhibited when comparing runoff from organic soil (muskeg, fen and bog) with runoff from inorganic soil. Also, a comparison of typical gradients of upland areas indicates that this soils classification can be approximated to the "upland" concept adopted by AGRA.

Table 19 presents the annual unit runoff for inorganic soil based on data for Jackpine Creek. The unit runoff for organic soil (muskeg, fen and bogs), also shown on Table 19, is assumed to be 50% of that for inorganic soil. The values presented on Table 19 are similar to those estimated for Suncor's Lease 86/17 (AGRA, 1996a).

**Table 19 Estimated Annual Unit Runoff from Organic and Inorganic Soil (mm)**

| Condition | Organic Soil | Inorganic Soil |
|---|---|---|
| 1 in 100 dry year | 0 | 0 |
| 1 in 10 dry year | 26 | 52 |
| Average year | 73 | 145 |
| 1 in 10 wet year | 125 | 250 |
| 1 in 100 wet year | 183 | 366 |

For comparison, the equivalent annual unit runoffs for Steepbank and Muskeg Rivers are presented on Table 20. The differences between the watercourses are considered to be a function of basin aspect and drainage network patterns on annual runoff.

**Table 20 Comparison of Annual Unit Runoff (in mm)**

| Watercourse | Condition | | | Drainage Area ($km^2$) | Basin Aspect |
|---|---|---|---|---|---|
| | 1 in 100 Dry Year | Average Year | 1 in 100 Wet Year | | |
| Steepbank River | 28.7 | 115 | 259 | 1320 | S |
| Muskeg River | 8.7 | 87.0 | 205 | 1460 | NW |
| Jackpine Creek | 0 | 88.3 | 222 | 358 | W |

Using the unit runoff values presented on Table 19 and soils distribution on Table 9, the annual runoff was estimated for the drainage areas in the LSA. The results are presented on Table 21. Using the same methodology, the estimated mean, maximum and minimum monthly flows were estimated for the smaller creeks in the LSA based on the average distribution of monthly flows for Jackpine Creek. The results are presented on Figures 40 through 42.

**Table 21 Estimated Annual Runoff for Basins in LSA**

| Watercourse or Basin | Average Annual Discharge (L/s) | | |
|---|---|---|---|
| | 1 in 100 dry year | Average Year | 1 in 100 wet year |
| Shipyard Creek | 0 | 190 | 380 |
| Shipyard Lake | 0 | 142 | 355 |
| Unnamed Creek | 0 | 32 | 79 |
| Creek 2 | 0 | 30 | 76 |
| Leggett Creek | 0 | 66 | 163 |
| Wood Creek | 0 | 197 | 486 |
| McLean Creek | 0 | 130 | 321 |
| Athabasca A | 0 | 28 | 72 |
| Athabasca B | 0 | 16 | 62 |
| Athabasca C | 0 | 22 | 57 |
| Athabasca D | 0 | 5 | 12 |

Flood events were found to be more closely related to basin size and drainage patterns than to other characteristics such as aspect and soils. Table 22 shows the estimated peak mean daily discharges for gauging stations in the vicinity of the proposed mine. Note that they have been adjusted to a common basin area of 100 $km^2$ using the power function shown on Page 28.

**Table 22 Maximum Mean Daily Flows**

| Return Interval | Unit Discharge ($m^3/s$ per 100 $km^2$) | | |
|---|---|---|---|
| | Steepbank River | Muskeg River | Hartley Creek |
| 5 years | 7.60 | 5.00 | 4.83 |
| 10 years | 9.87 | 6.26 | 6.22 |
| 50 years | 15.4 | 8.98 | 8.99 |
| 100 years | 18.0 | 10.1 | 10.0 |

Note: Based on the Log Pearson Type III distribution.

The values for Jackpine Creek were used to estimate flood peaks for smaller watercourses and basins in the LSA with no adjustment to take account of differences in proportions of organic and inorganic soils as shown on Figure 43 and Table 23.

**Table 23 Estimated Flood Flows for Basins in LSA ($m^3/s$)**

| Watercourse or Basin | Return Interval | | | |
|---|---|---|---|---|
| | 5 Years | 10 Years | 50 Years | 100 Years |
| Shipyard Creek | 2.8 | 3.6 | 5.1 | 5.8 |
| Shipyard Lake | 2.6 | 3.3 | 4.7 | 5.2 |
| Unnamed Creek | 0.7 | 0.9 | 1.4 | 1.5 |
| Creek 2 | 0.8 | 1.0 | 1.5 | 1.6 |
| Leggett Creek | 1.6 | 2.0 | 2.9 | 3.2 |
| Wood Creek | 3.2 | 4.0 | 5.8 | 6.5 |
| McLean Creek | 2.6 | 3.3 | 4.7 | 5.3 |
| Athabasca A | 0.6 | 0.8 | 1.1 | 1.2 |
| Athabasca B | 0.6 | 0.7 | 1.0 | 1.2 |
| Athabasca C | 0.5 | 0.7 | 1.0 | 1.1 |
| Athabasca D | 0.1 | 0.2 | 0.3 | 0.3 |

Based on the analysis of low flows in Jackpine Creek, it is assumed that flows in creeks in the LSA will be zero for return intervals greater than 1 in 3 years.

### 4.3.6 Wetlands

As described earlier, there is one large wetlands complex within the study area known as Shipyard Lake.

The wetland is predominantly a shallow open water marsh wetland complex that is periodically flooded by the Athabasca River. The marshes are graminoid and shrubby marshes. While studies of water chemistry, sediments and plant species were performed, only limited measurements were taken of water level, inflow and outflow.

Surface water inflow is from numerous creeks. The two largest watercourses are Unnamed Creek, which discharges into the north end of the wetland, and Creek 2 to the south. Flows in both creeks were recorded in 1996 and 1997 as well as outflow from the north end Shipyard Lake (in Shipyard Creek). These flows are shown on Figures 34 through 36. Water levels on Shipyard Lake are controlled by a beaver dam at the north end.

Shipyard Lake receives its water from two sources; the Athabasca River and the creeks draining the local Shipyard Lake basin. Water can flow into Shipyard Lake from the Athabasca River across a low divide to the south. This typically occurs in June or July. For the balance of the year, inflow is from creeks draining the Athabasca escarpments and organic plain.

Based on observations by Klohn-Crippen personnel during a site visit on June 26, 1996 (Klohn-Crippen, 1997), water will flow into Shipyard Lake across the low divide to the south when discharges in the Athabasca River exceed approximately 2800 $m^3/s$. Using water level data available along the Athabasca River between Fort McMurray and Suncor Energy's Fresh Water Intake (see Figure 44), this overflow is estimated to take place when water levels immediately upstream of Shipyard Lake exceed about 237.7 m, (approximately 0.5 m above the average recorded water level of Shipyard Lake.). From available records, overflow from the Athabasca River to Shipyard Lake occurs about once every 3 years and lasts, on average, about 4 days. Figure 45 shows when this overflow would have taken place in 1996 and 1997.

The average annual discharge from Shipyard Lake is estimated to be approximately 150 L/s of which about 40% (or 60 L/s) is attributed to the Unnamed Creek and Creek 2 sub-basins. As shown below, this inflow far exceeds estimated losses due to evaporation and evaportranspiration, and is the main reason for the stable water levels recorded for Shipyard Lake in 1996 as shown on Figure 39.

The total area of the Shipyard Lake wetland complex based on available maps is approximately 169 ha, of which about 27 ha is open water. Assuming that loss from the open water will be equal to the lake evaporation and that the loss from the emergent vegetation will be equal to the aerial evapotranspiration, the annual loss from Shipyard Lake is estimated to vary between 14 L/s and 18 L/s with an average value of 15 L/s.

### 4.3.7 Runoff From Disturbed Areas

Annual runoff was estimated for different types of disturbed land surface based on the methodology adopted for Suncor's Lease 86/17 mine (AGRA 1996a). The values for annual losses and runoff are presented on Table 24 for the 1 in 100 year dry through 1 in

100 year wet conditions. These estimates are used when determining the effect of mine development on surface water flows.

With the exception of muskeg drainage, the basis for the values is provided in the report for Lease 86/17 (AGRA 1996a). For muskeg drainage, it was assumed that the annual runoff will vary from 0 during the 1 in 100 year dry conditions to 375 mm during average and wetter years. The maximum value was based on an average muskeg thickness of 1.5 m and assumes that a 0.75 m depth of water will be released over a 2 year period. It should be noted that the actual depth released and the period of time over which drainage will take place is dependent on factors such as the muskeg soil structure and spacing of drainage ditches and, as such, can be variable.

## 4.4 Water Balance

The water balance equation for a basin states that precipitation equals the sum of the runoff, evapotranspiration and change in storage. With the availability of reliable estimates of evapotranspiration, it is possible to assess the seasonal variations in these components at gauged basins.

**Table 24 Runoff From Disturbed Areas**

| | Annual Depth (mm) | | | | |
|---|---|---|---|---|---|
| | 1:100 Dry | 1:10 Dry | Mean | 1:10 Wet | 1:100 Wet |
| Uncleared Natural | | | | | |
| Inorganic Soil | 0 | 52 | 145 | 250 | 366 |
| Organic Soil | 0 | 26 | 73 | 125 | 183 |
| Cleared Natural | | | | | |
| Inorganic Soil | 0 | 62 | 174 | 300 | 439 |
| Organic Soil | 0 | 31 | 87 | 150 | 220 |
| Disturbed (Pre-Stripped) | | | | | |
| Uplands (10% slope) | 177 | 231 | 336 | 458 | 620 |
| Lowlands (1% Slope) | 144 | 197 | 301 | 420 | 577 |
| Muskeg Drainage | 0 | 200 | 375 | 375 | 375 |
| Sand Dykes | | | | | |
| Flat Vegetated | 0 | 9 | 25 | 44 | 64 |
| Steep Vegetated | 0 | 14 | 38 | 65 | 95 |
| Flat Unvegetated | 0 | 9 | 25 | 44 | 64 |
| Steep Unvegetated | 0 | 14 | 38 | 65 | 95 |
| Lakes (open water) | -404 | -321 | -184 | -29 | 174 |
| Overburden Dykes & Dumps (Reclaimed) | 23 | 76 | 170 | 277 | 399 |
| Mine and Plant | 222 | 274 | 376 | 496 | 399 |

Figure 46 shows the average annual water balances for Steepbank River, Muskeg River and Jackpine Creek. The charts are based on the correlated precipitation at Mildred Lake, flow records from Water Survey of Canada and estimates of evapotranspiration at Fort McMurray from Alberta Environmental Protection (Bothe and Abraham, 1987 and 1990). The top line is the average accumulated (or mass curve) of precipitation starting at the beginning of September. The difference between the top and middle lines is the evapotranspiration, while the difference between the middle and lower lines is the accumulated unit runoff. The area at the bottom represents basin storage and has been subdivided to show estimates of accumulated snow pack using measurements of snow on the ground at Fort McMurray airport.

The mass curves of precipitation and evapotranspiration are typical of a continental climate where the precipitation is high during the summer months when evapotranspiration is at its highest and low during the winter when evapotranspiration rates are negligible. All the curves are similar with decreasing flows in September and October and very low discharges over the winter. Storage in the Steepbank River basin has changed little over the period of simulation (1975-1988) while storage in the Muskeg River and Jackpine Creek basins appear to have increased over the period of simulation (1975-1988 and 1976-1988, respectively). It is believed that precipitation reaching surficial aquifers in the Muskeg River and Jackpine Creek basins may be draining to other watercourses or directly to the Athabasca River.

On an annual basis, the estimated average precipitation is 399 mm with about 288 mm (or about 70%) being lost to evapotranspiration. Total average unit runoff varies from a maximum of 115 mm for Steepbank River to 88 mm and 87 mm for Jackpine Creek and Muskeg River, respectively.

## 4.5 Water Quality

### 4.5.1 Sediment

Sediment samples have been obtained at a number of gauging stations operated in the area by Water Survey of Canada. At the gauging station on the Athabasca River below Fort McMurray, sediment samples were taken each day on a seasonal basis in 1969 and continuously from 1970 through 1972. In 1976 and 1977, only random sediment sampling was performed. At gauging stations on tributary watercourses samples were typically obtained once a month throughout the open water season. Data from these latter stations are considered to be representative of conditions within the study area. In general, the suspended sediment load in watercourses in the study area vary with flow. Concentrations are highest during spring snowmelt and summer floods and are lowest during the winter when flows are at a minimum. Variations in sediment concentration with mean daily discharge are presented on Figure 47 for the Athabasca River and Steepbank River, and Figure 48 for Muskeg River and Jackpine Creek.

The minimum, average and maximum recorded sediment concentrations are presented on Table 25.

**Table 25 Recorded Sediment Concentrations**

| Gauging Station | Sediment Concentration (mg/L) | | |
|---|---|---|---|
| | Minimum | Average [1] | Maximum |
| Athabasca River | 1 | 493 | 4820 |
| Steepbank River | 3 | 92 | 741 |
| Muskeg River | 3 | 9 | 41 |
| Jackpine Creek | 1 | 15 | 106 |

Note: [1]This is the average for all sediment samples.

The annual suspended sediment load on the Athabasca River below Fort McMurray is estimated to be about 1 million tonnes. Sediment concentration varied from a maximum of 4 820 mg/l on July 2, 1970 to a minimum of 1 mg/l on January 17, 1969. The corresponding mean daily flows were 3 650 $m^3/s$ and 151 $m^3/s$, respectively. The maximum and minimum sediment concentrations on the Steepbank River were 741 mg/l and 3 mg/l, respectively. As discussed above, only spot sampling of sediments was performed on the Athabasca River tributaries in the vicinity of the proposed mine: namely, Steepbank River, Muskeg River and Jackpine Creek. An analysis of daily sediment load data was performed for these three tributary watercourses. Based on the results, the daily sediment load can be estimated using the equation:

$$L = 12.3\,(A)^{-0.5}\,(Q)^{1.3}$$

where L is the daily load in tonnes, Q is the mean daily flow in $m^3/s$, and,
A is the catchment area in $km^2$.

The expected average annual sediment loads, based on this relationship are presented on Table 26 for the tributary watercourses.

**Table 26 Estimated Annual Sediment Loads**

| Watercourse | Sediment Load (Tonne) |
|---|---|
| Athabasca River | 1 000 000 |
| Steepbank River | 21 000 |
| Jackpine Creek | 490 |
| Shipyard Creek | 200 |
| Unnamed Creek | 90 |
| Creek 2 | 95 |
| Leggett Creek | 140 |
| Wood Creek | 210 |
| McLean Creek | 190 |

It can be seen that, on an annual basis, the sediment loads in the tributaries (except for the Steepbank River) are less than 1% percent of the load in the Athabasca River. The sediment load in the Steepbank River is approximately 2% of the load in the Athabasca River.

Surface water chemistry data are available for the Athabasca River, the Steepbank River, Shipyard Lake, Unnamed Creek, Wood Creek and other bodies in the region. These data are presented in detail in the aquatics impact assessment for Steepbank Mine (Suncor 1996a). A Piper Plot showing the major ion chemistry for the surface water points sampled as part of the 1995 Environmental Impact Sampling Program for Steepbank River is included as Figure 49.

# APPENDIX I

# GLOSSARY

# GLOSSARY

| | |
|---|---|
| Aquifer | A body of rock or soil which contains sufficient amounts of saturated permeable material to yield economic quantities of water to wells or springs. |
| Aquitard | A lithologic unit that impedes ground water movement and does not yield water freely to wells or springs but that may transmit appreciable water to or from adjacent aquifers. Where sufficiently thick, may act as a ground water storage zone. Synonymous with confining unit. |
| Available Drawdown | The vertical distance that the equipotential surface of an aquifer can be lowered; in confined aquifers, this is to the top of the aquifer; in unconfined aquifers, this is to the bottom of the aquifer. |
| Baseline | A surveyed condition which serves as a reference point to which later surveys are coordinated or correlated. |
| Bedrock | The body of rock which underlies the gravel, soil or other superficial material. |
| Borehole Log | The record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes and types of materials used, and other significant details regarding the drilling of an exploratory borehole or well. |
| Confined Aquifer | An aquifer in which the potentiometric surface is above the top of the aquifer. |
| Consolidated Tailings | The portion of ore that is deposited after washing and milling and which has undergone a reduction in volume and increase in density. (See also "Consolidation") |

| | |
|---|---|
| Consolidation | The gradual reduction in volume of a soil mass resulting from an increase in applied load.<br>a) Initial consolidation (initial compression): A comparatively sudden reduction in volume of a soil mass under an applied load due principally to release or the squeezing out and compression of gas in the soil voids preceding primary consolidation<br>b) Primary consolidation (primary compression) (primary time effect): The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to a squeezing out of water from the void spaces of the mass and accompanied by a transfer of the load from the soil water to the soil solids.<br>c) Secondary consolidation (secondary compression) (secondary time effect): The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to the adjustment of the internal structure of the soil mass after most of the load has been transferred from the soil water to the soil solids. |
| Darcy's Law | A law describing the rate of flow of water through porous media. (Named for Henry Darcy of Paris who formulated it in 1856 from extensive work on the flow of water through sand filter beds.) |
| Deposit | Material left in a new position by a natural transporting agent such as water, wind, ice or gravity, or by the activity of man. |
| De-pressurize | The process of reducing the pressure in an aquifer, by withdrawing water from it. |
| Deuterium | A stable isotope of hydrogen, which has two neutrons. |
| Energy Dissipation | A structure designed to dissipate the excessive structure energy of a high velocity fluid (i.e. water), to establish a safe flow condition and prevent scour or minimize erosion. (See also "Hydraulic structure") |

| | |
|---|---|
| Ephemeral | A phenomena, feature, marriage which only lasts for a short time (ie., an ephemeral stream is only present for short periods during the year. |
| Equipotential Level | The level on which the potential everywhere is constant; the level at surface which the pressure head of a body of groundwater is the same. |
| Floodplain | Land near rivers and lakes that may be flooded during seasonally high water levels. |
| Fluvial | Relating to a stream or river. |
| Glacial Till | Unsorted and unstratified glacial drift, generally unconsolidated, deposited directly by a glacier without subsequent reworking by water from the glacier, and consisting of a heterogeneous mixture of clay, silt, sand, gravel and boulders varying widely in size and shape. |
| Glacio-Lacustrine | Relating to the lakes that formed of the edge of glaciers as the glaciers receded. Glacio-lacustrine sediments are commonly laminar deposits of fine sand, silt and clay. |
| Ground Penetrating | Method of mapping subsurface layer geometry using radar. |
| Groundwater | Water that is found below the ground surface, in soil and rock. |
| Groundwater Level | The level below which the rock and subsoil, to unknown depths, are saturated. |
| Groundwater Regime | Water below the land surface in a zone of saturation. |
| Groundwater Velocity | The speed at which groundwater advances through the ground. The way that the term is used in this document, it technically refers to the average linear velocity of the groundwater. |

| | |
|---|---|
| Head | The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. It is used in various compound terms such as pressure head, velocity head, and loss of head. |
| Hydraulic Conductivity | The permeability of soil or rock to water. |
| Hydraulic Gradient | A measure of the force moving groundwater through soil or rock. It is measured as the rate of change in total head per unit distance of flow in a given direction. Hydraulic gradient is commonly shown as being dimensionless, since its units are m/m, ft/ft. |
| Hydraulic Head | The elevation with respect to a specified reference level at which water stands in a piezometer connected to the point in question in the soil. Its definition can be extended to soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head in systems under atmospheric pressure may be identified with a potential expressed in terms of the height of a water column. More specifically, it can be identified with the sum of gravitational and capillary potentials, and may be termed the hydraulic potential. |
| Hydraulic Structure | Any structure which is designed to handle water in any way. This includes the retention, conveyance, control, regulation, and dissipation of the energy of water. |
| Hydrogeology | The study of the factors that deal with subsurface water, and the related geologic aspects of surface water. |
| Inorganics | Pertaining or relating to a compound that contains no carbon. (See also "Organic compounds") |
| Landform | Any physical, recognizable form or feature of the Earth's surface, having a characteristic shape, and produced by natural causes. |

| | |
|---|---|
| Lean Oil Sands | Oil bearing sands, which do not have a high enough saturation of oil to make mining of them economically feasible. |
| Microtox | A measure of toxicity in a sample. (See also "Toxicity") |
| Organic Compounds | Chemicals (naturally occurring or otherwise) which contain carbon, with the exception of carbon dioxide ($CO^2$) and carbonates (e.g., CACO3) |
| Overburden | The soil, sand, silt, or clay that overlies bedrock. In mining terms, this includes all material which has to be removed to expose the ore. |
| Oxygen-18 | A stable isotope of oxygen which has two more neutrons than the more common oxygen-16. |
| Piezometer | An instrument for measuring pressure. In groundwater and geotechnical investigations, piezometers are commonly Poly Vinyl Chloride pipe that has been sealed in a drill hole. The height to which groundwater rises in the pipe is a measure of the water pressure at the bottom of the piezometer. |
| Piezometric Surface | If water level elevations in wells completed in an aquifer are plotted on a map and contoured, the resulting surface described by the contours is known as a potentiometric or piezometric surface. |
| Pneumatic Piezometer | A type of piezometer in which the hydraulic head is measured using a compressed gas. |
| Pore Water | Water that is present between the grains of a soil or rock. |
| Potentiometric Surface | An imaginary surface representing the static head of groundwater. The water table is a particular potentiometric surface. |
| Quality | Refers to the concentration of dissolved and suspended compounds found naturally or otherwise in the water |

| | |
|---|---|
| Sediment Sampling | A field procedure relating to a methodology for determining the configuration of sediment deposits. |
| Sedimentation | The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. |
| Snow Water Equivalent | Snow water equivalent is the water content of snow. |
| Stable Isotopes | Isotopes of a particular element have the same number of protons; but different numbers of neutrons. Isotopes are stable if they do not naturally undergo radioactive decay. |
| Static Water Level | The elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping. |
| Stratigraphy | The succession and age of strata of rock and unconsolidated material. Also concerns the form, distribution, lithologic composition, fossil content and other properties of the strata. |
| Surficial Aquifer | A surficial deposit containing water to be considered an aquifer. |
| Surficial Deposit | A geologic deposit (like clay, silt or sand) that has been placed above bedrock. (See also "Overburden") |
| Tailings | The portion of ore, after washing and milling, which is too low grade to warrant further processing. |
| Total Dissolved Solids (TDS) | The total concentration of all dissolved compounds solids found in a water sample. |
| Toxicity | The tendency of a chemical or condition to cause harm to the life process. |
| Twenty Year Safe Yield ($Q_{20}$) | An estimation of the long term rate at which a water well will produce water. The Q20 is the rate at which a well can be pumped continuously for 20 years, without the water level |

| | |
|---|---|
| | dropping below the top of the aquifer. (See also "Available drawdown") |
| Unconfined Aquifer | An aquifer in the which the water level is below the top of the aquifer. |
| Water Equivalent | As relating to snow; the depth of water that would result from melting. |
| Water Table | The shallowest saturated ground below ground level - technically, that surface of a body of unconfined groundwater in which the pressure is equal to atmospheric pressure. |
| Wetlands | Area of surface water ponding which forms the habitat for a variety of wildlife including water fowl. |

# APPENDIX II
# REFERENCES

# REFERENCES

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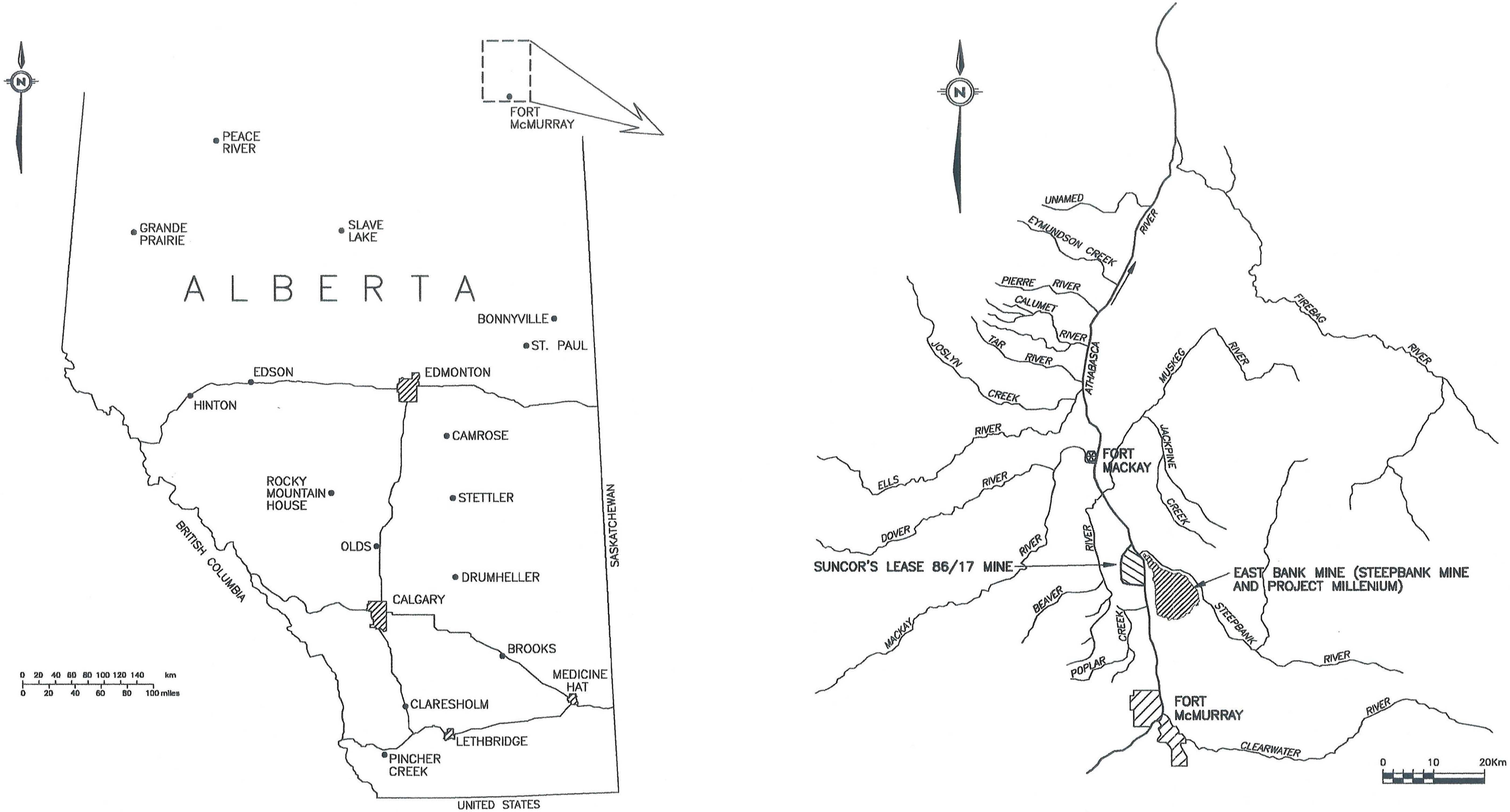
# FIGURES




SUNCOR ENERGY

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LOCATION PLAN

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 1 | DRAWN BY: C.L.F. |

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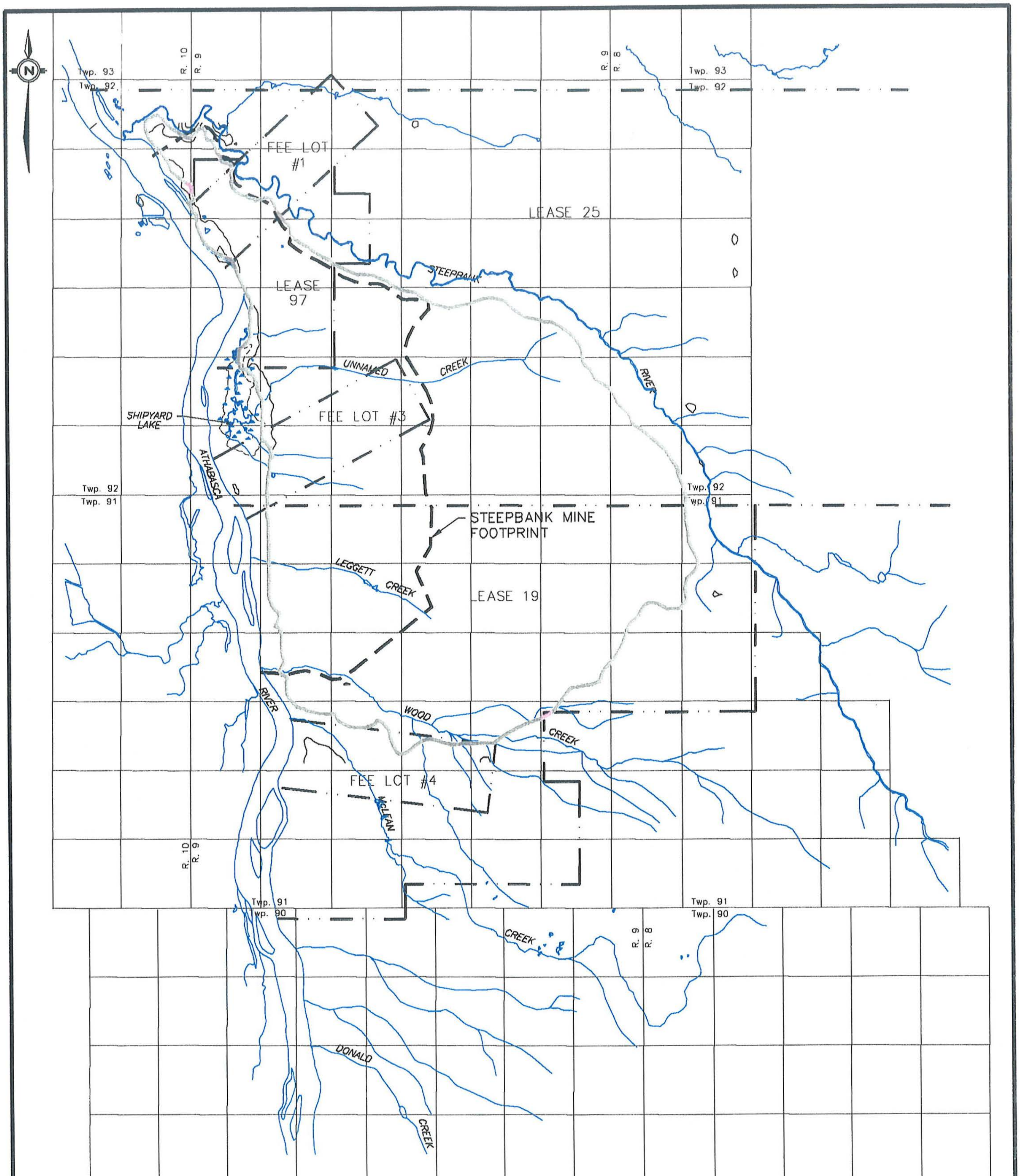


**LEGEND:**

MINE DEVELOPMENT AREA
LEASE AND FEE LOT BOUNDARY
WATER COURSE

1:120,000 0 1 2Km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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SITE MAP

| APRIL 1998 | FIGURE 2 | DRAWN BY: C.P.B. |
|---|---|---|

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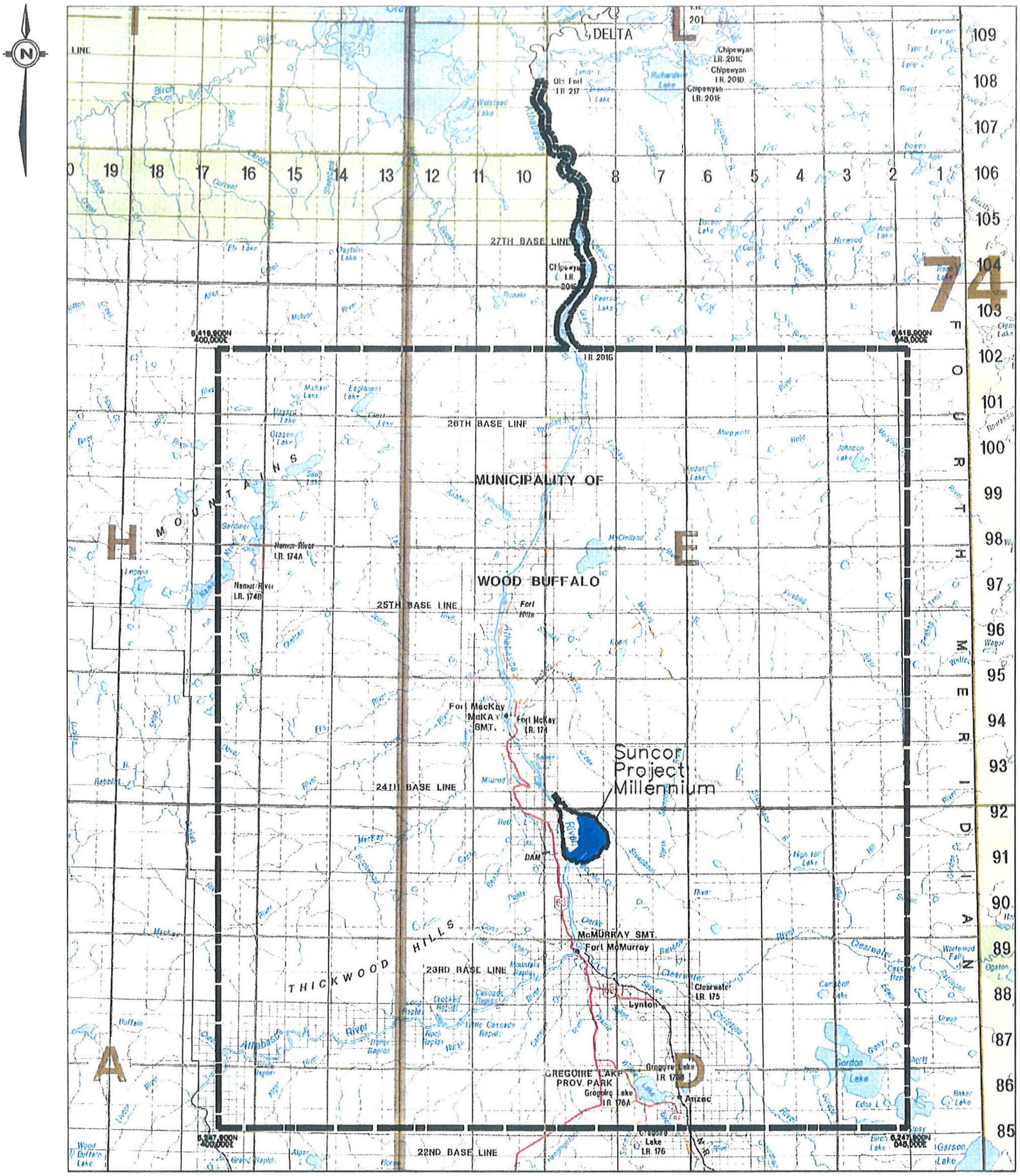


LEGEND

REGIONAL STUDY AREA

0 10 20 30 40 50km

SCALE 1:1,250,000

REFERENCE

SCANNED IMAGE OF ALBERTA ENVIRONMENTAL PROTECTION PROVINCIAL BASE MAP 1997, ORIGINAL SCALE 1:1,000,000

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**REGIONAL STUDY AREA**

| APRIL 1998 | FIGURE 3 | DRAWN BY: C.L.F. |
|---|---|---|

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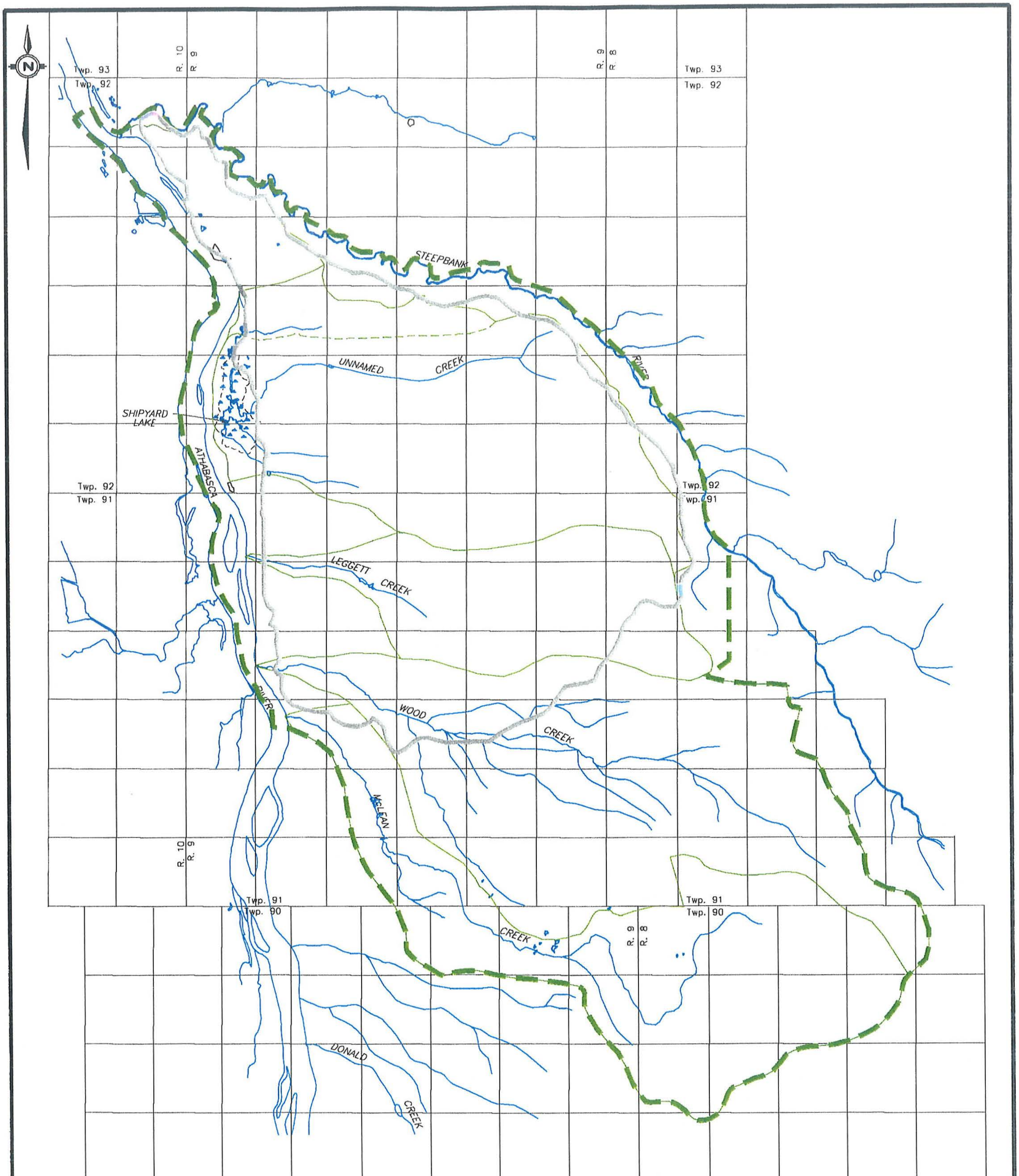


**LEGEND:**

- DRAINAGE BASIN BOUNDARY
- EAST BANK MINE FOOTPRINT
- WATERCOURSES
- LSA BOUNDARY

1:120,000 0 1 2Km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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**LOCAL STUDY AREA**

| APRIL 1998 | FIGURE 4 | DRAWN BY: C.P.B. |
|---|---|---|

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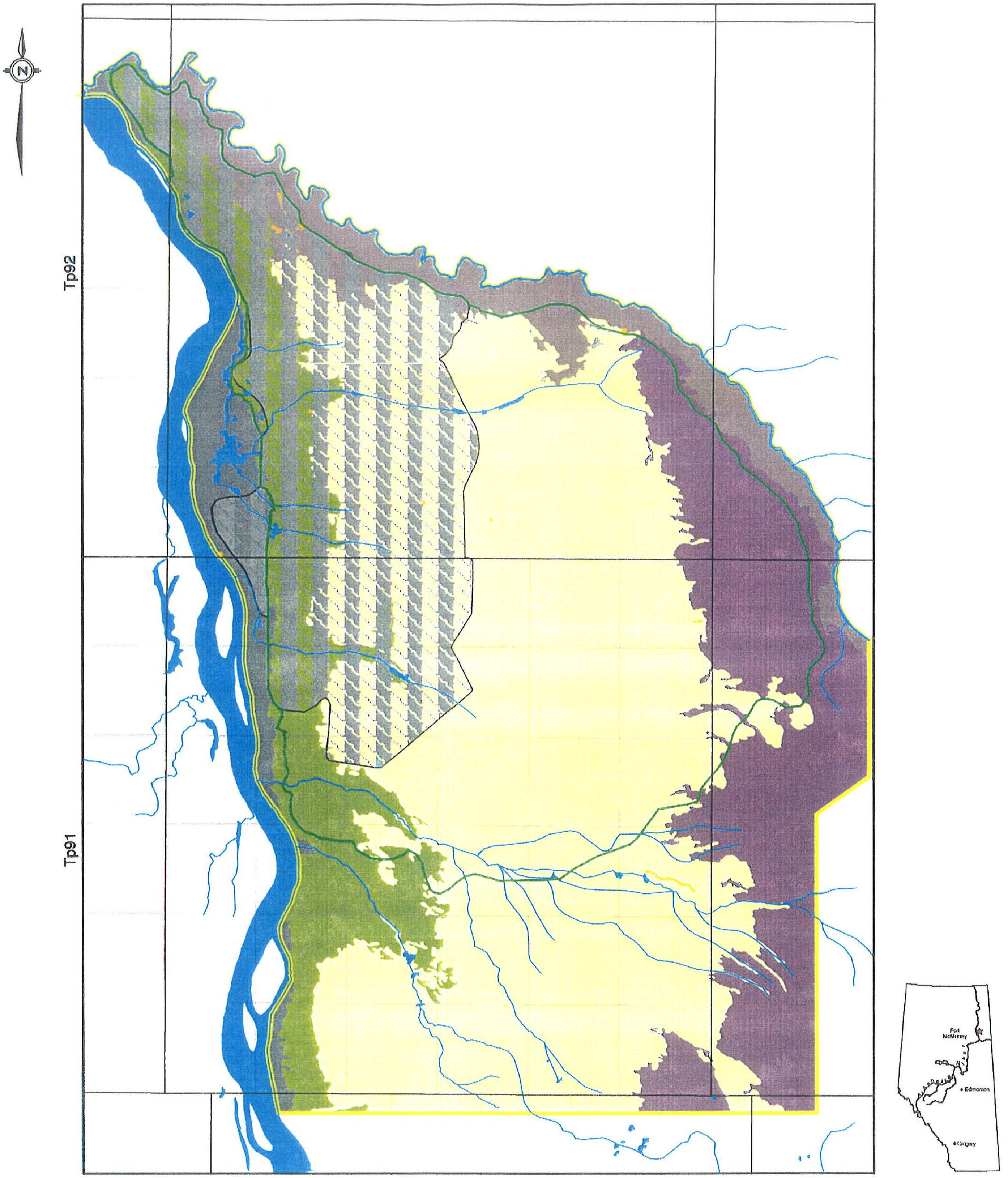


LEGEND
- Terrestrial Local Study Area
- Steepbank Mine
- East Bank Mining Area
- Open Water
- Cultural Features and Disturbed Lands

Macroterrain Units
- Athabasca Escarpment
- Athabasca Floodplain
- Steepbank Escarpment
- Steepbank Organic Plain
- Steepbank Upland

SOURCES: Suncor
Golder
Klohn-Crippen
CAN-AG
The Forestry Corp

Map Projection: UTM 12
Datum: NAD 83

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MACROTERRAIN IN LSA

| | | | |
|---|---|---|---|
| APRIL 1998 | FIGURE 5 | DRAWN BY: | C.L.F. |

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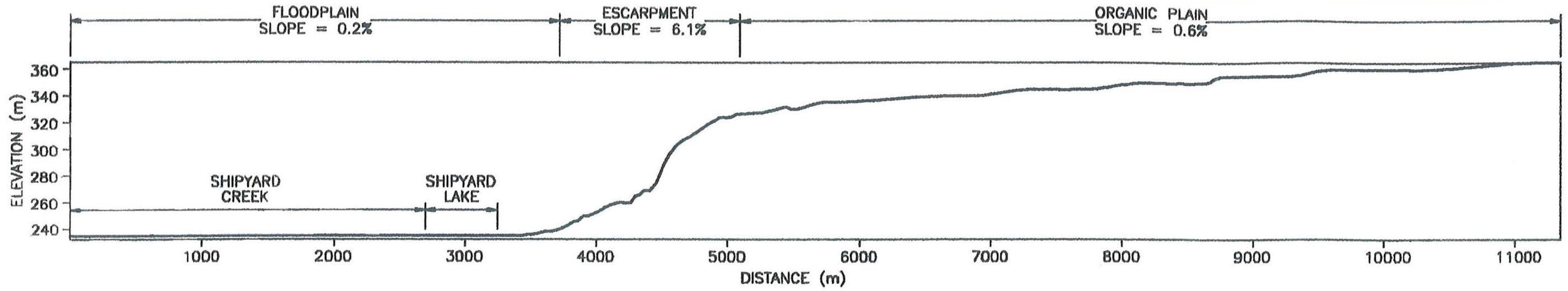
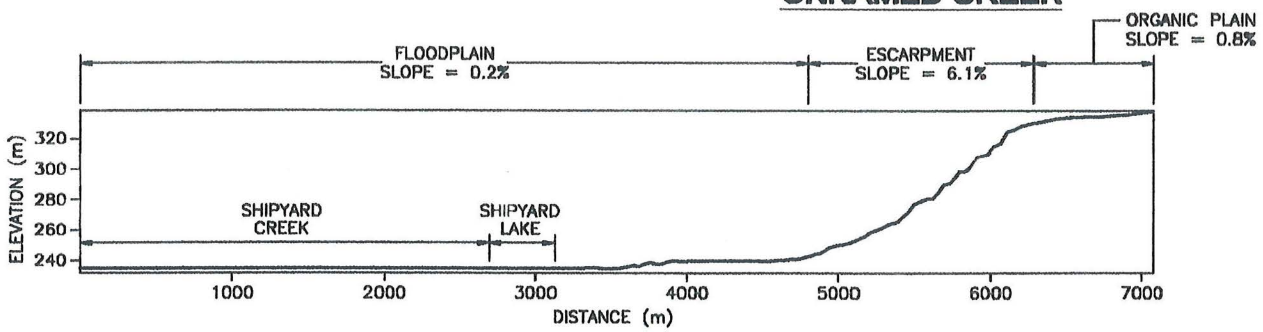
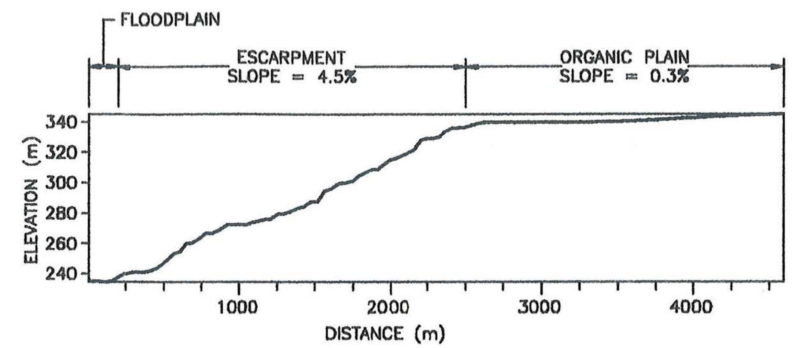


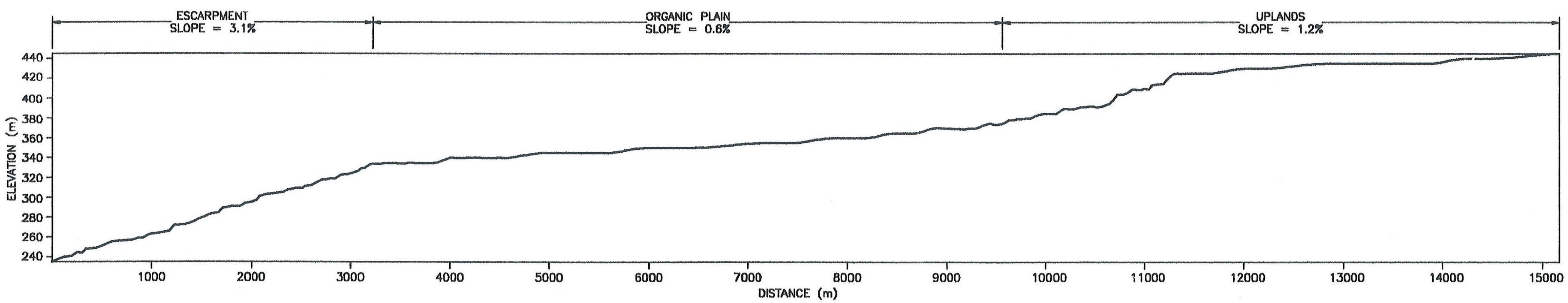

## UNNAMED CREEK



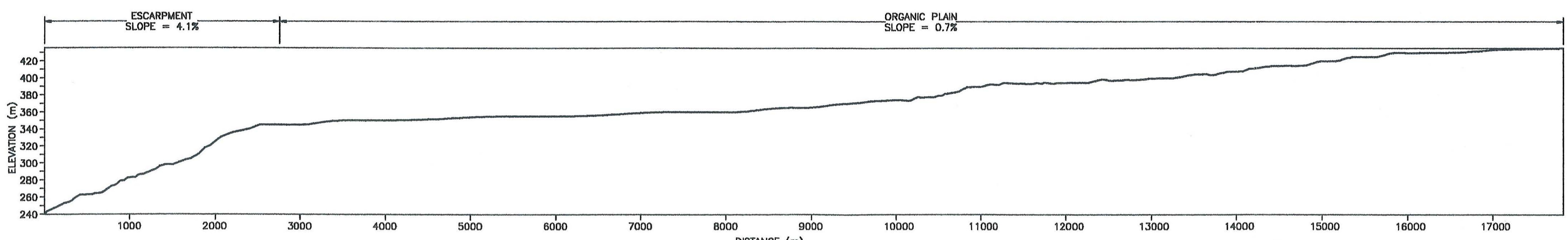

## CREEK 2



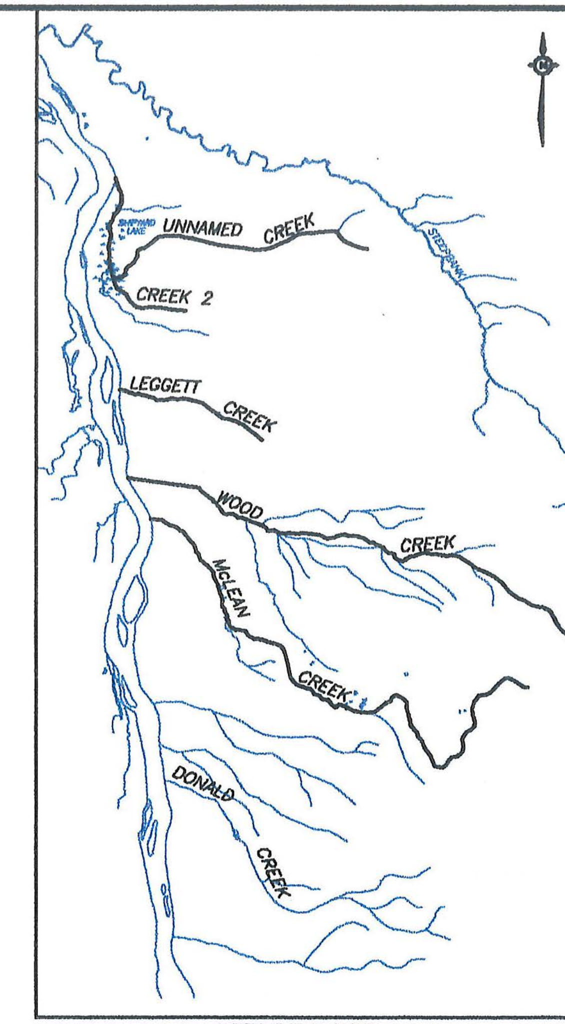

## LEGGETT CREEK




## WOOD CREEK




## MCLEAN CREEK




## KEY PLAN

N.T.S.

VERT. 1:5,000 0 50 100m
HOR. 1:50,000 0 500 1000m

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Project Millennium

PROFILE OF CREEKS IN LSA

APRIL 1998 | FIGURE 6 | DRAWN BY: C.P.B.

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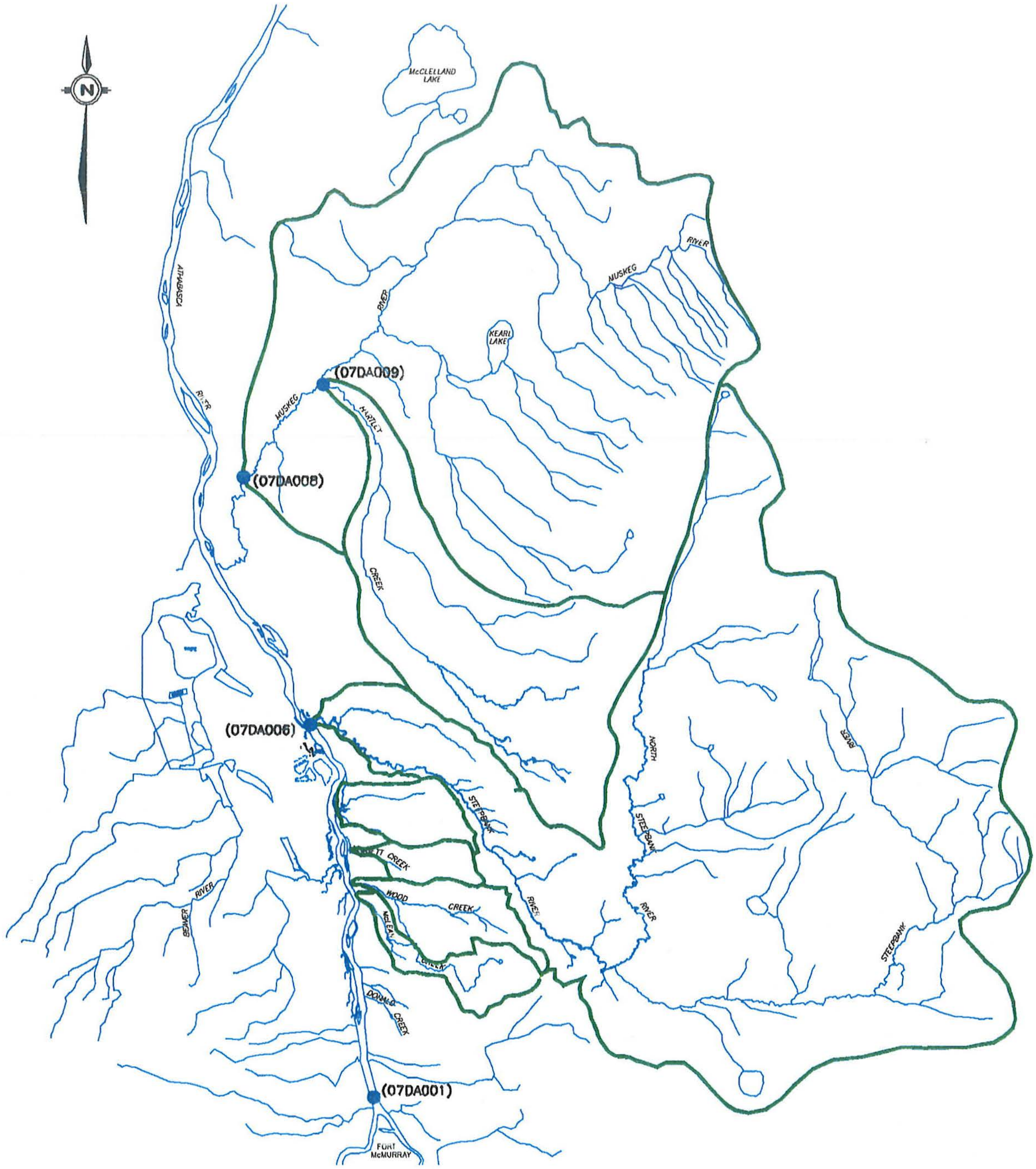


**LEGEND**

DRAINAGE BASIN BOUNDARY

WATER SURVEY OF CANADA GAUGING STATION (WITH WSC DESIGNATION)

1:500,000 0 5 10Km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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DRAINAGE BASINS IN VICINITY OF STUDY AREA

| APRIL 1998 | FIGURE 7 | DRAWN BY: C.P.B. |
|---|---|---|

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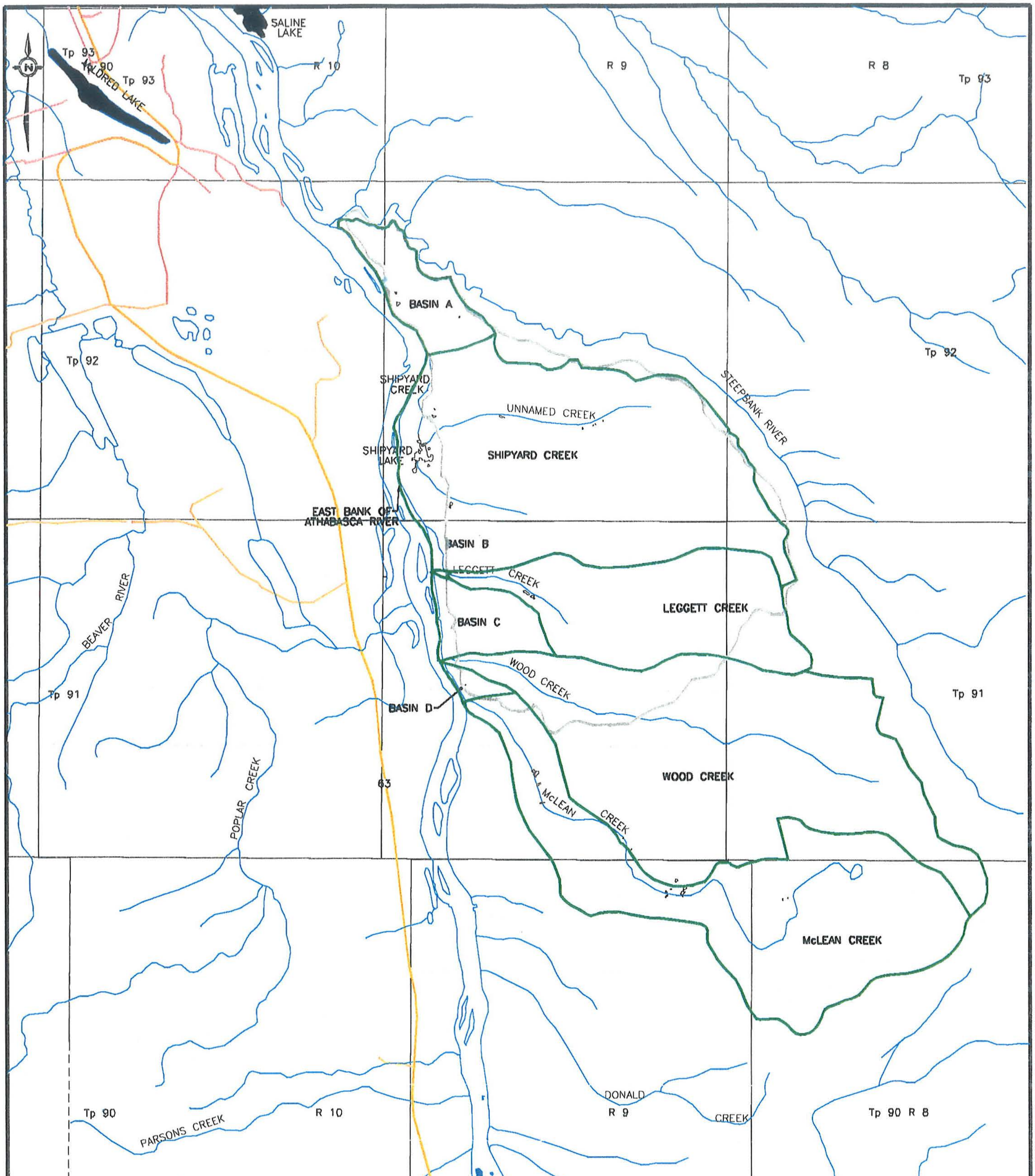


**LEGEND:**

DRAINAGE BASIN BOUNDARY

WATERCOURSES

1:150,000 0 1.5 3km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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**DRAINAGE BASINS IN LSA**

| APRIL 1998 | FIGURE 8 | DRAWN BY: C.L.F. |
|---|---|---|

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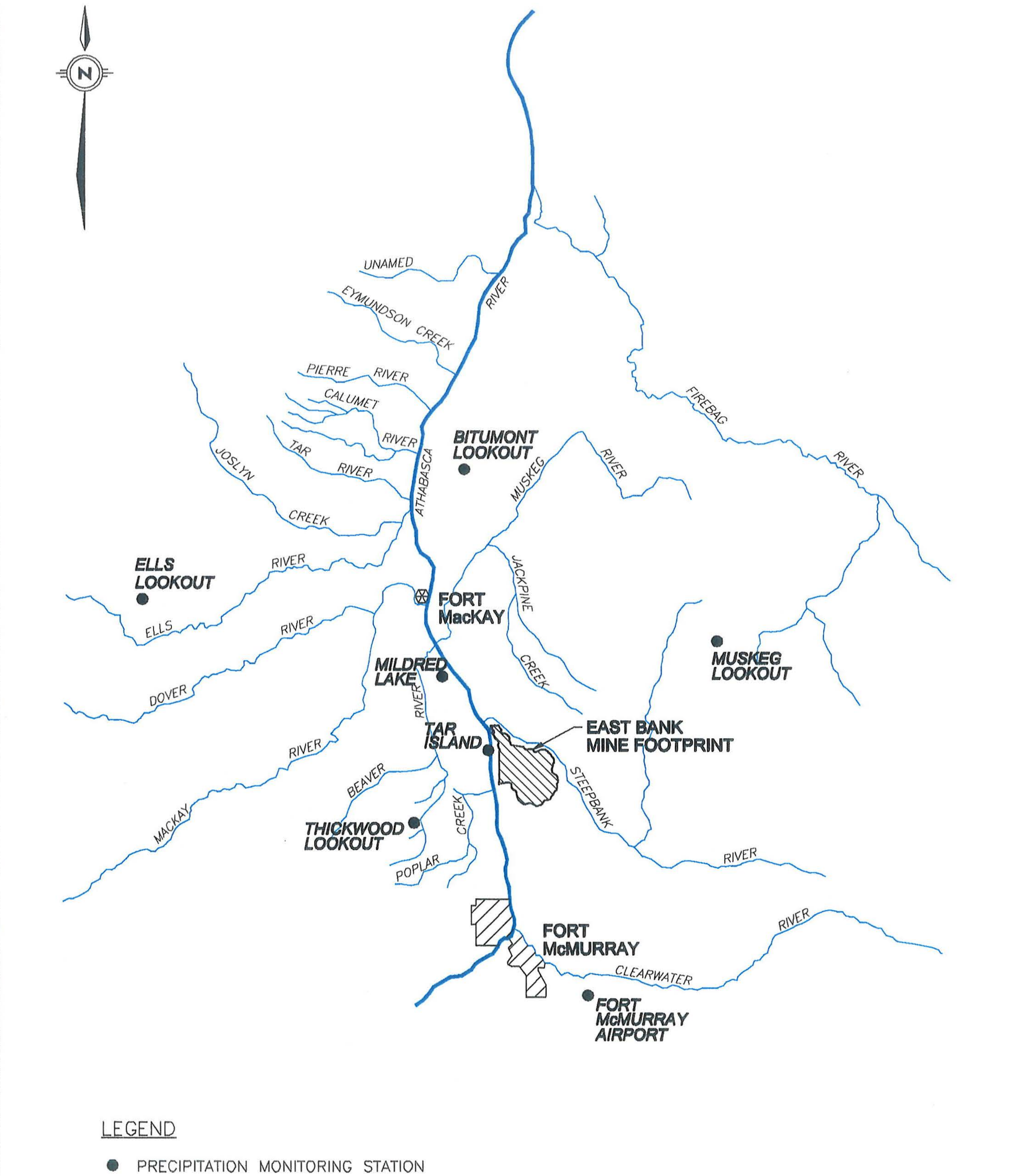


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PRECIPITATION MONITORING STATIONS

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 9 | DRAWN BY: C.L.F. |

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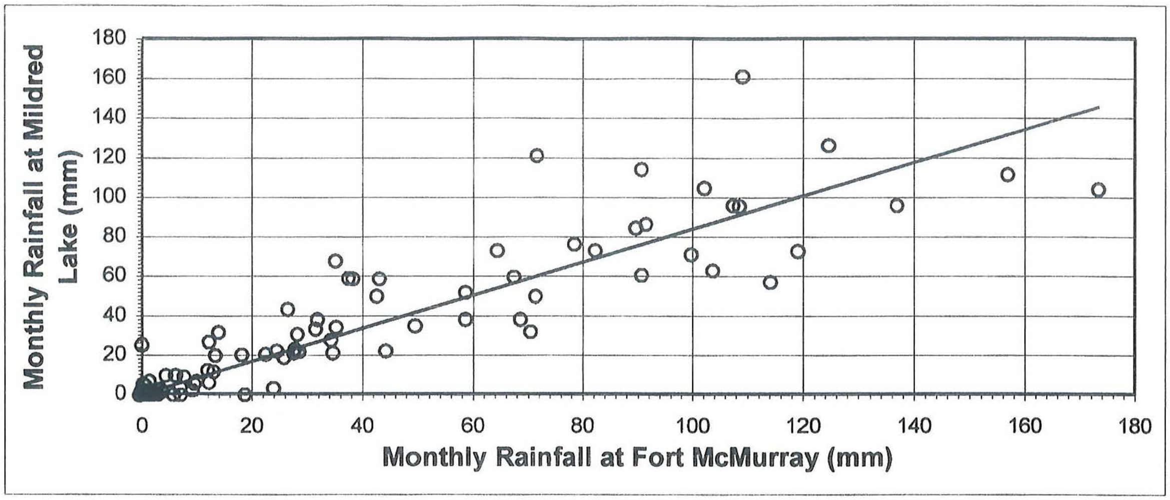


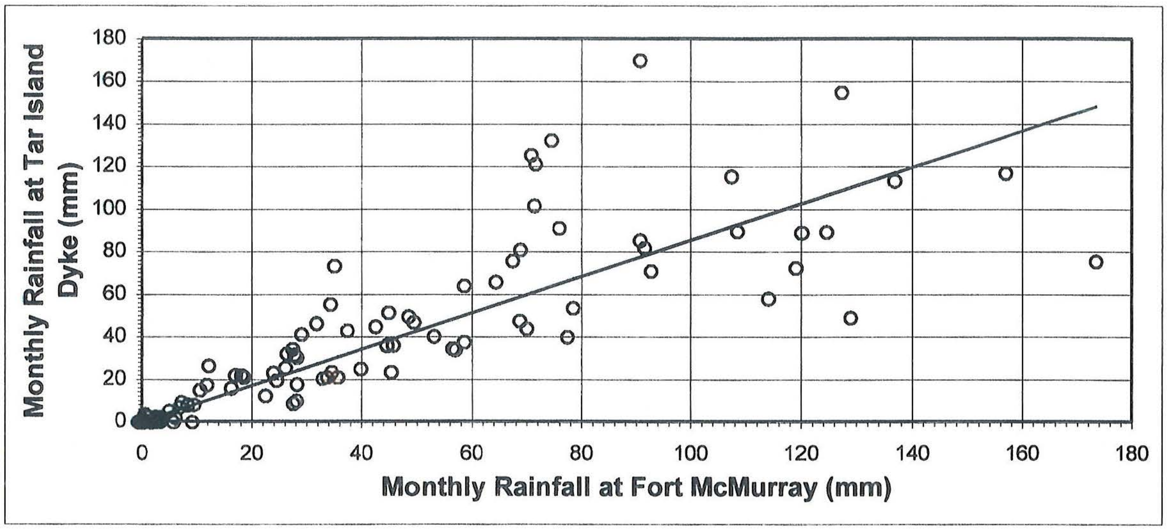


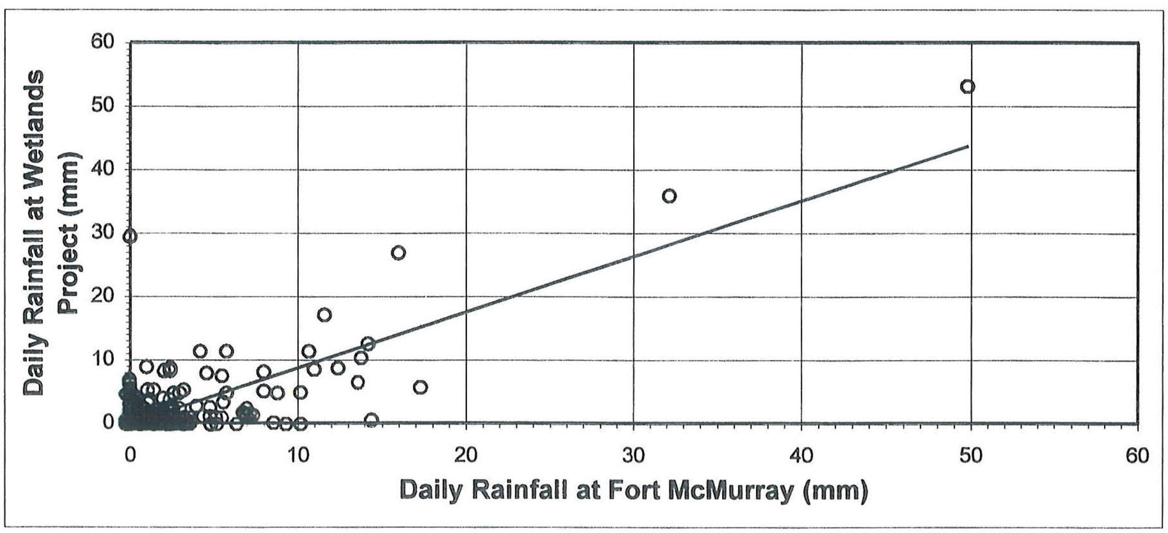


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REGRESSION ANALYSIS FOR RAINFALL

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 10 | DRAWN BY: C.P.B. |

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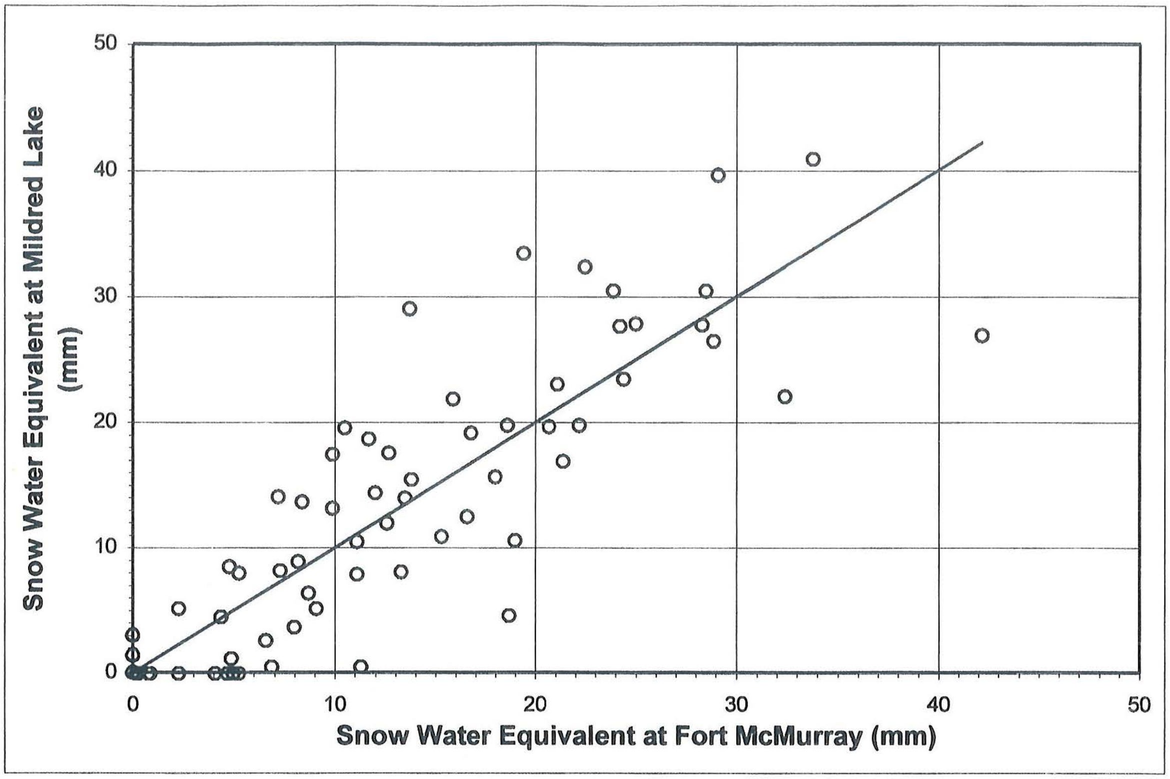


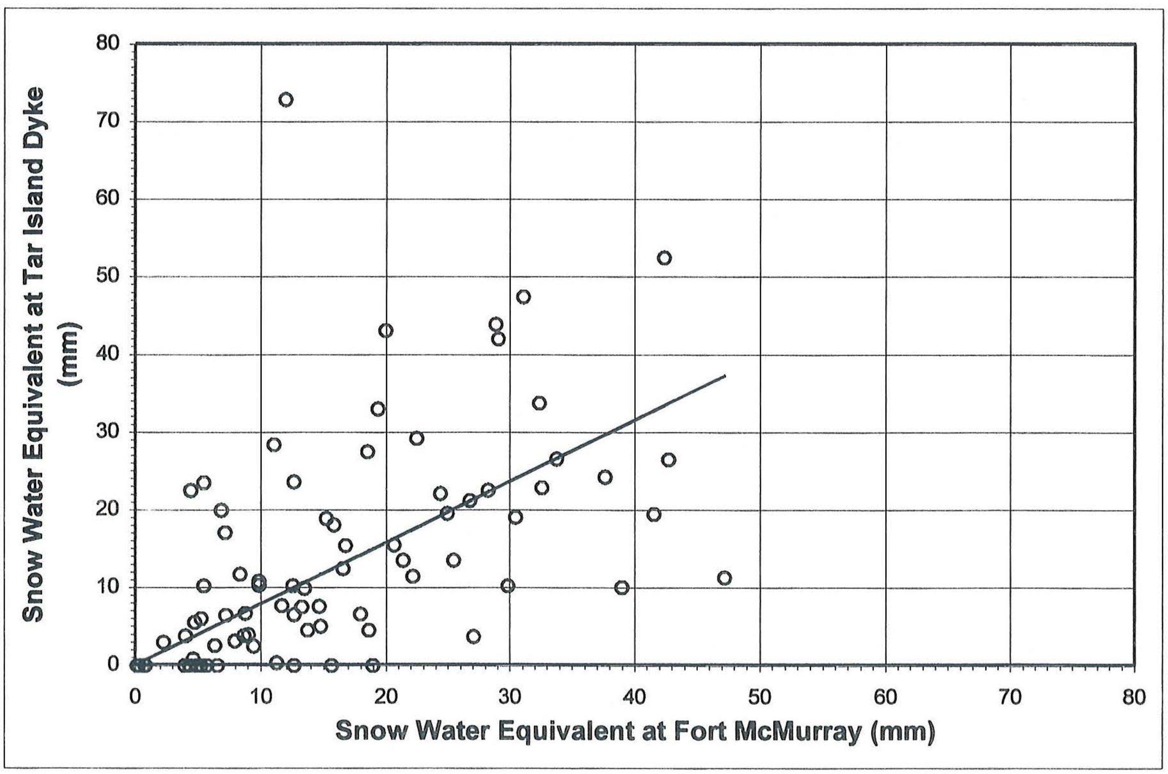


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**REGRESSION ANALYSIS FOR SNOWFALL**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 11 | DRAWN BY: C.P.B. |

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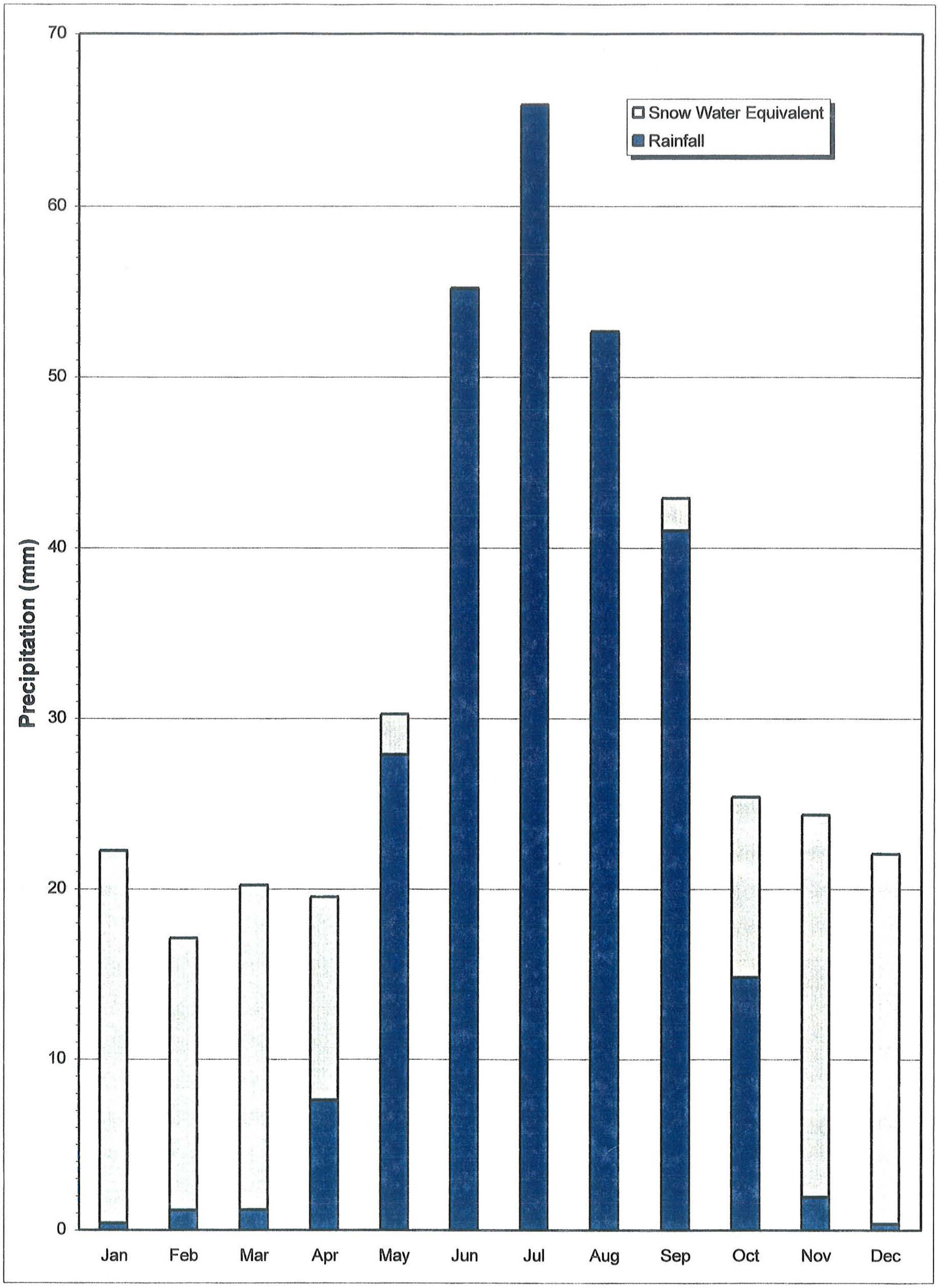


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ESTIMATED PRECIPITATION FOR LSA

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 12 | DRAWN BY: C.P.B. |

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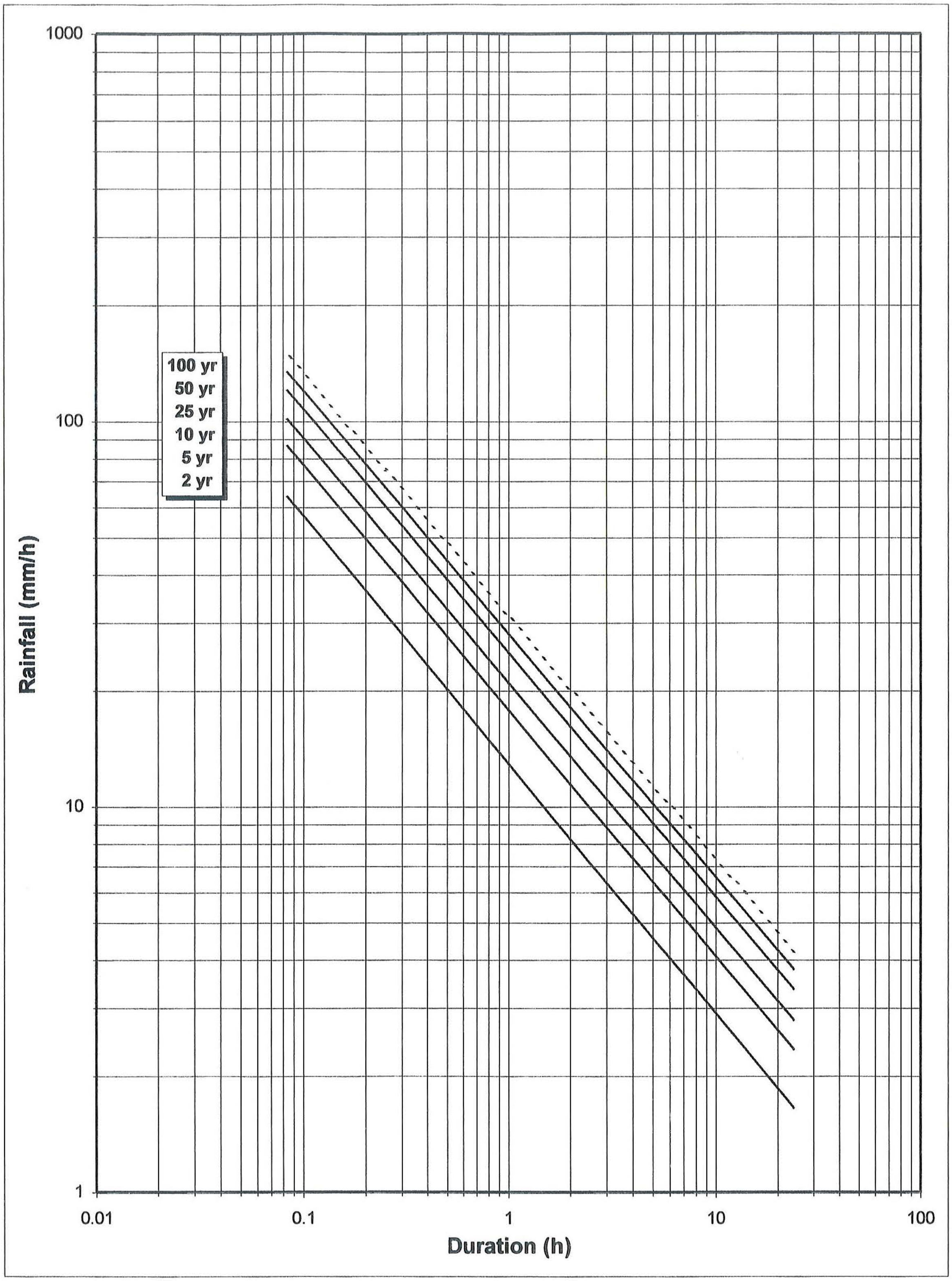


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INTENSITY - DURATION - FREQUENCY CURVES FOR LSA

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 13 | DRAWN BY: C.P.B. |

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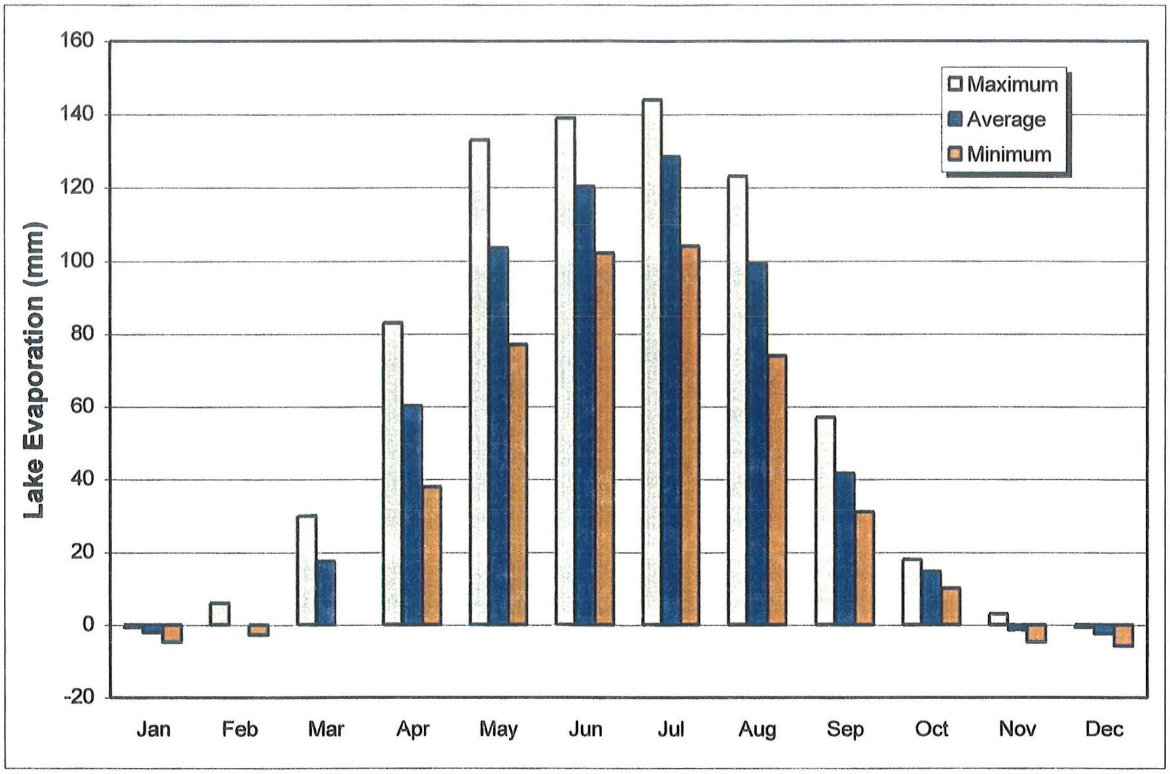


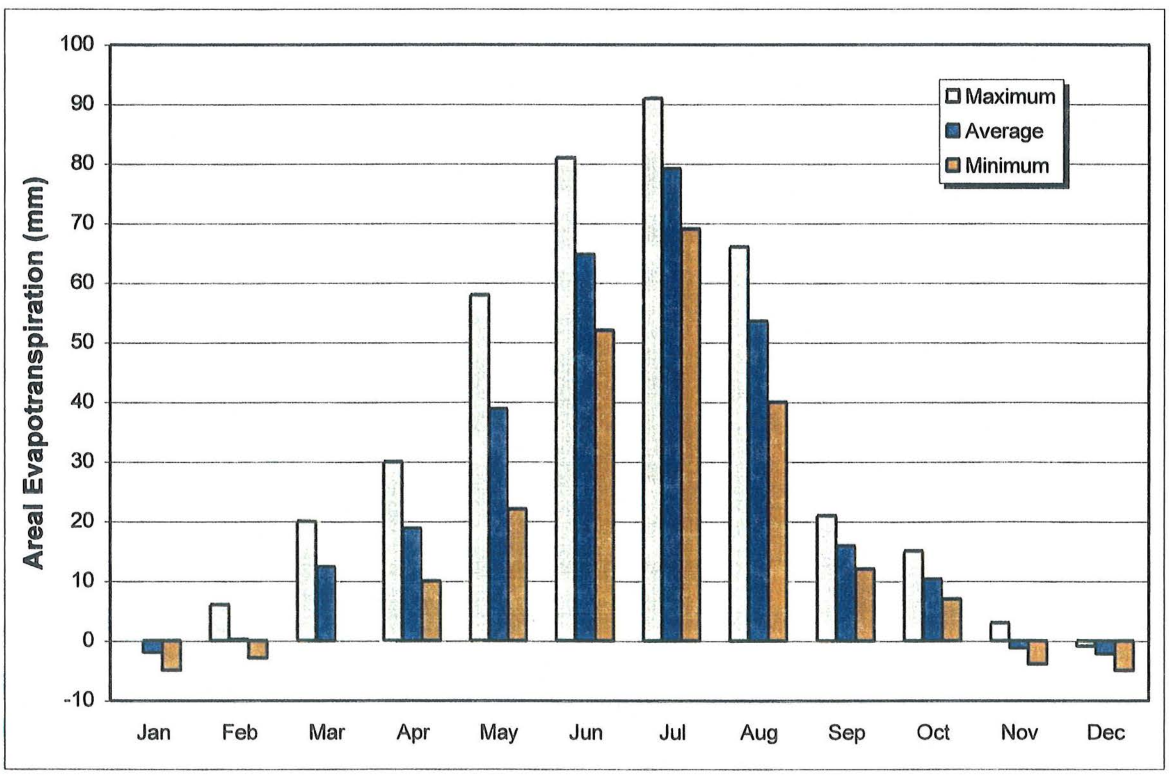


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Taking Suncor into the 21st Century

EVAPORATION AND EVAPOTRANSPIRATION FOR LSA

| APRIL 1998 | FIGURE 14 | DRAWN BY: C.P.B. |
|---|---|---|

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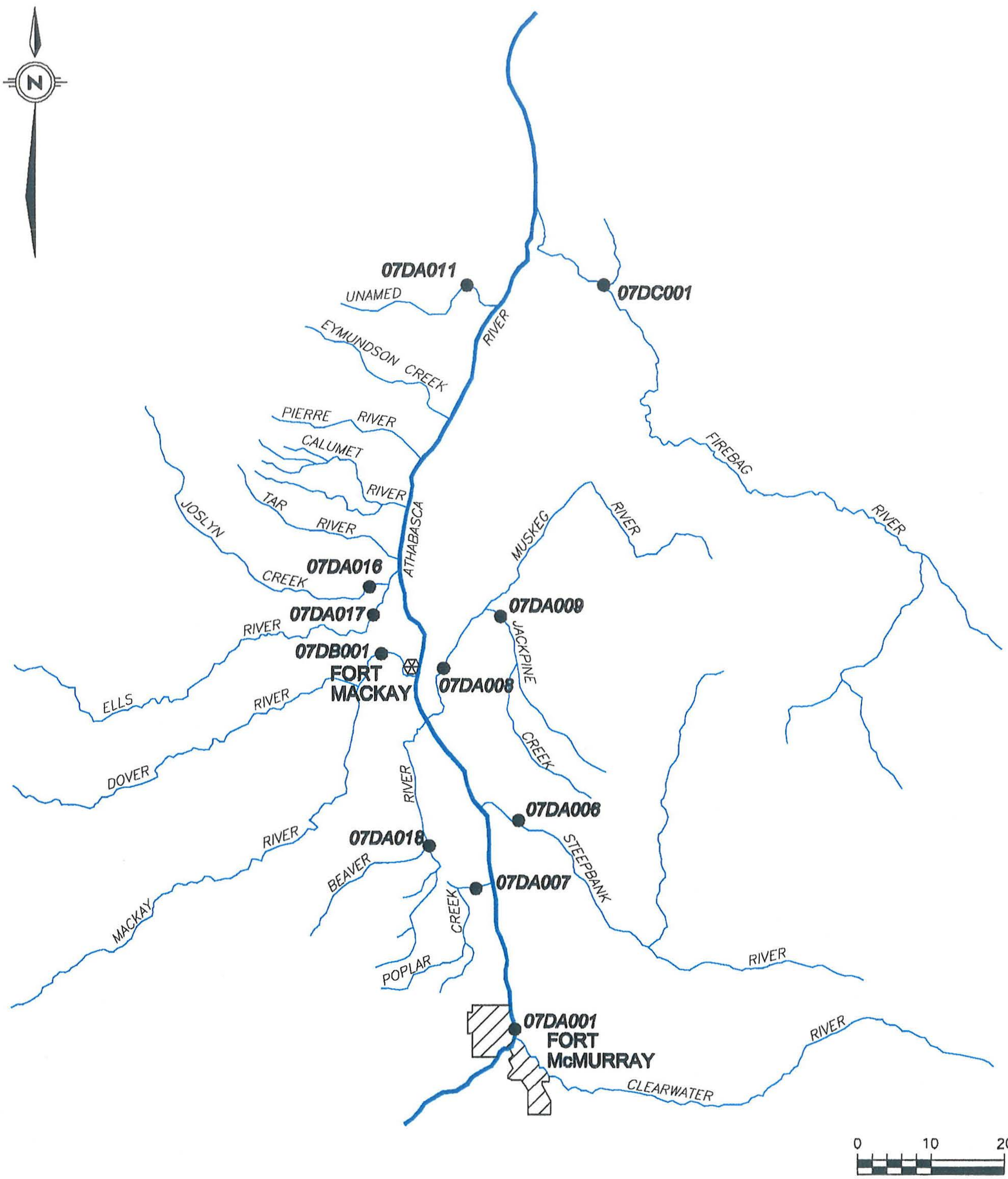


LEGEND

● STREAMFLOW GAUGING STATION SHOWING THE WSC STATION NUMBER

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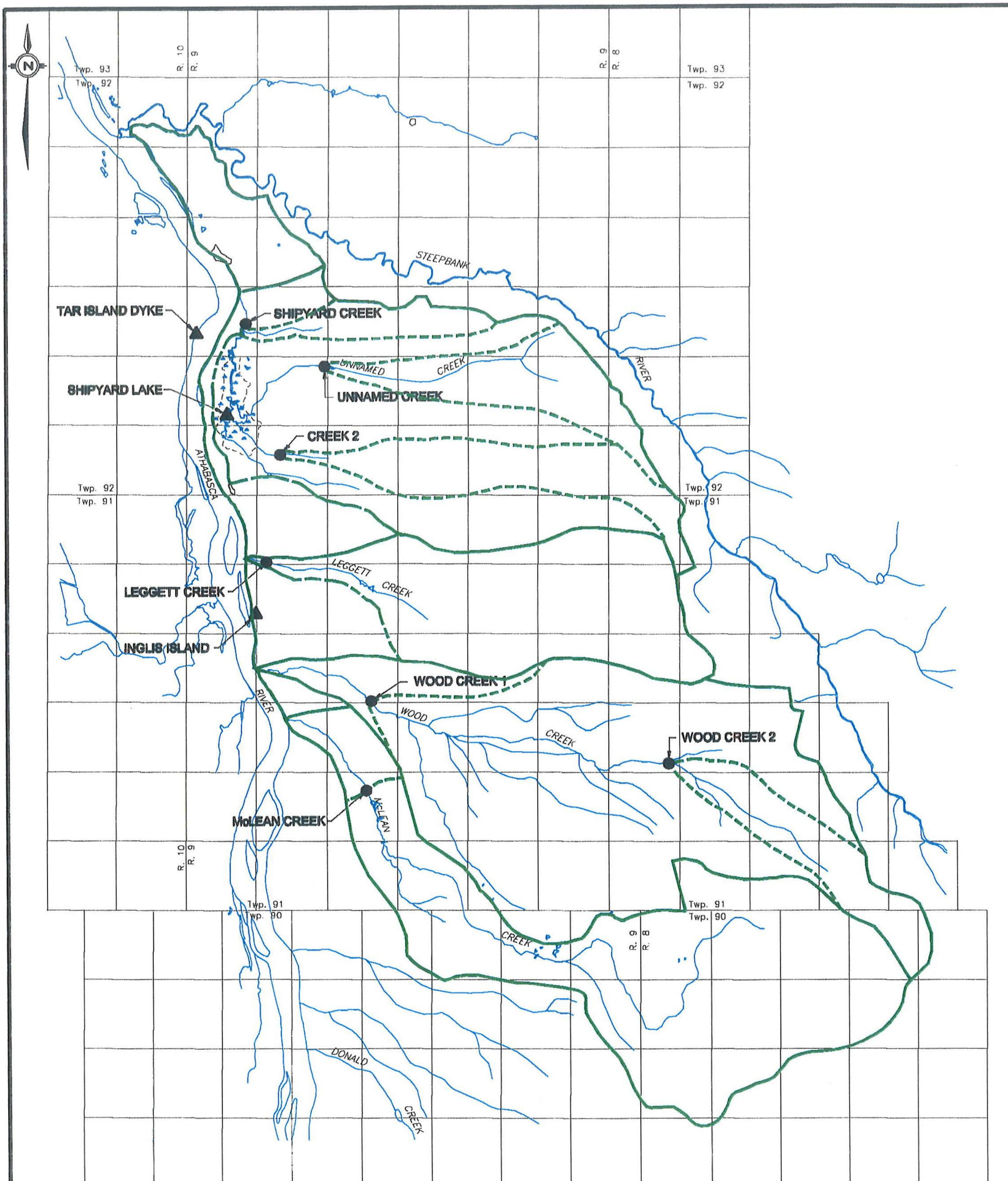
STREAMFLOW GAUGING STATIONS IN RSA

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 15 | DRAWN BY: R.F.K./C.L.F. |

2839w022.dwg




**LEGEND:**

| | |
|---|---|
| | DRAINAGE BASIN BOUNDARY |
| | WATERCOURSES |
| ● | STREAMFLOW GAUGE |
| ▲ | WATER LEVEL RECORDER |

1:120,000 0 1 2Km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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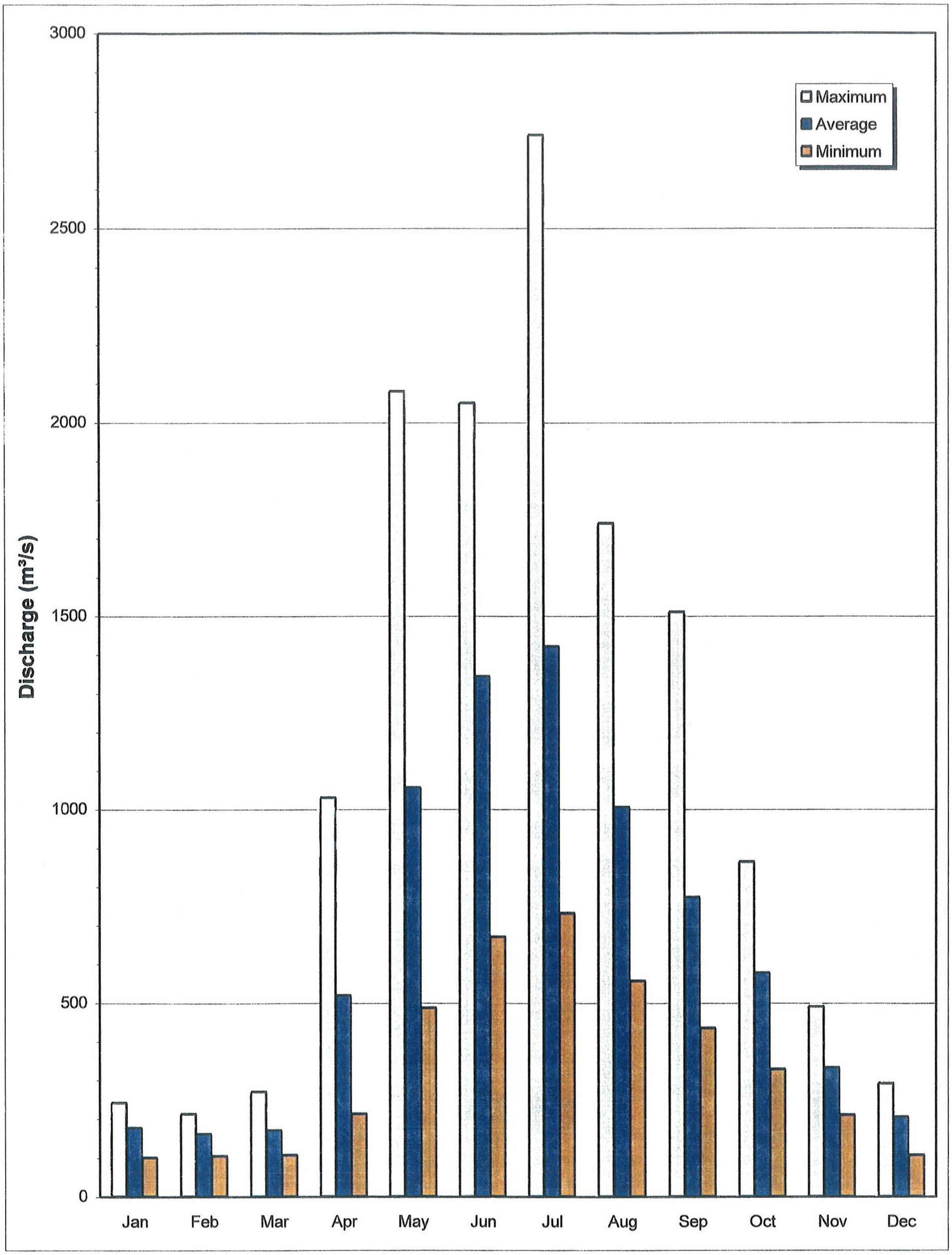
**STREAMFLOW AND WATER LEVEL GAUGES IN LSA**

| APRIL 1998 | FIGURE 16 | DRAWN BY: C.P.B. |
|---|---|---|

2839w178.dwg

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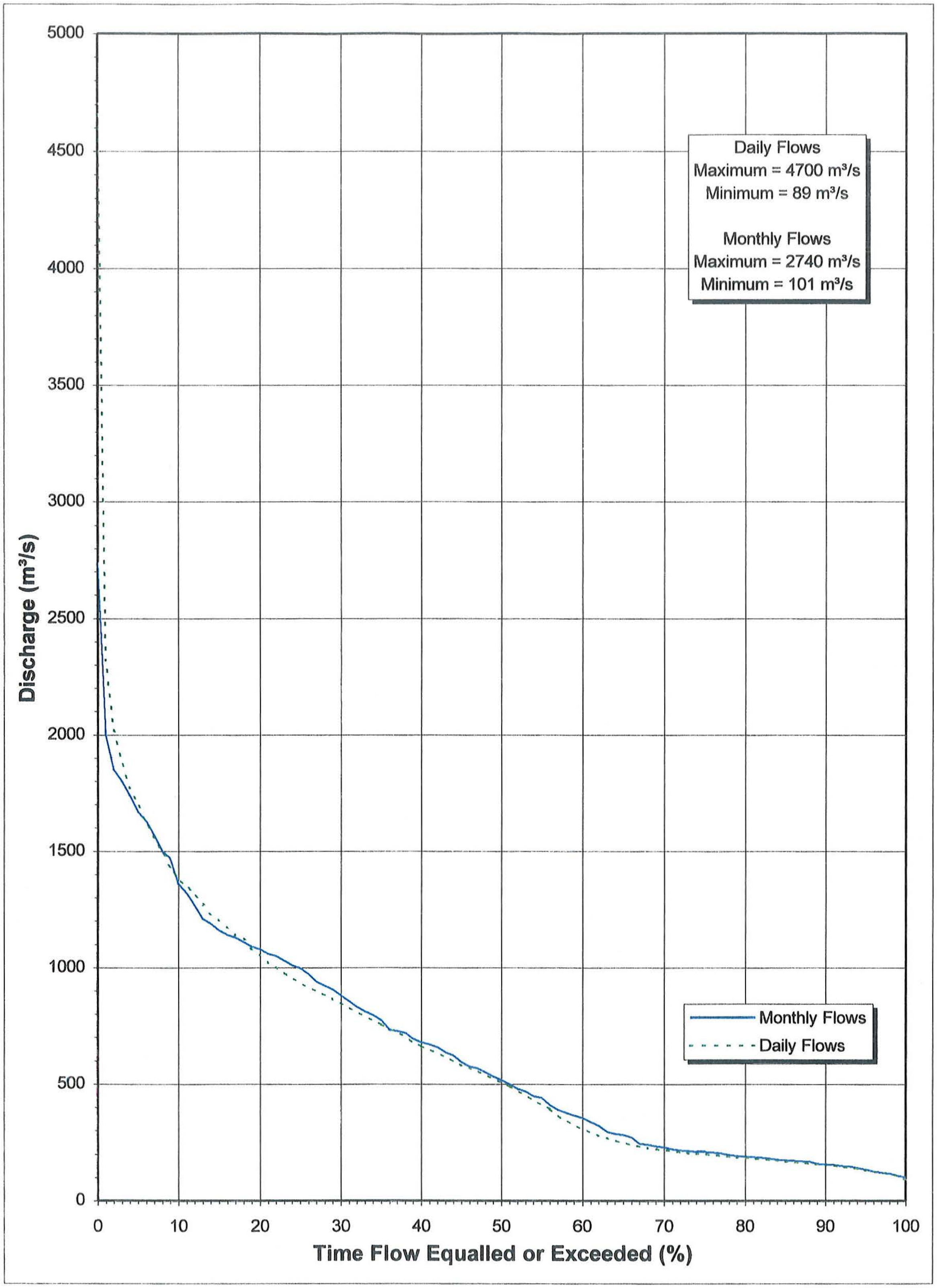
ATHABASCA RIVER: AVERAGE ANNUAL RUNOFF

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 17 | DRAWN BY: C.P.B. |

2839w172.dwg

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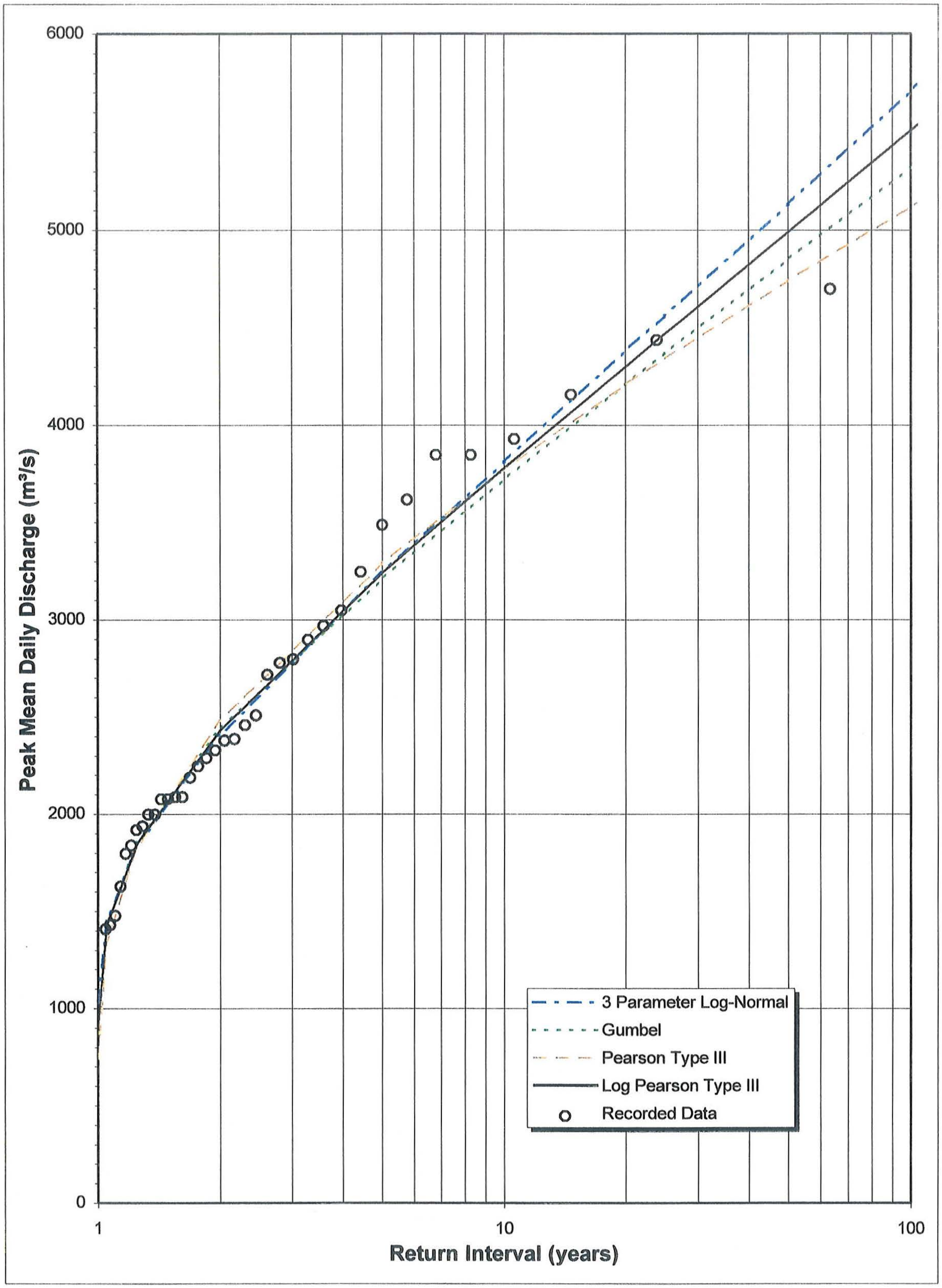
ATHABASCA RIVER: FLOW DURATION CURVES

| APRIL 1998 | FIGURE 18 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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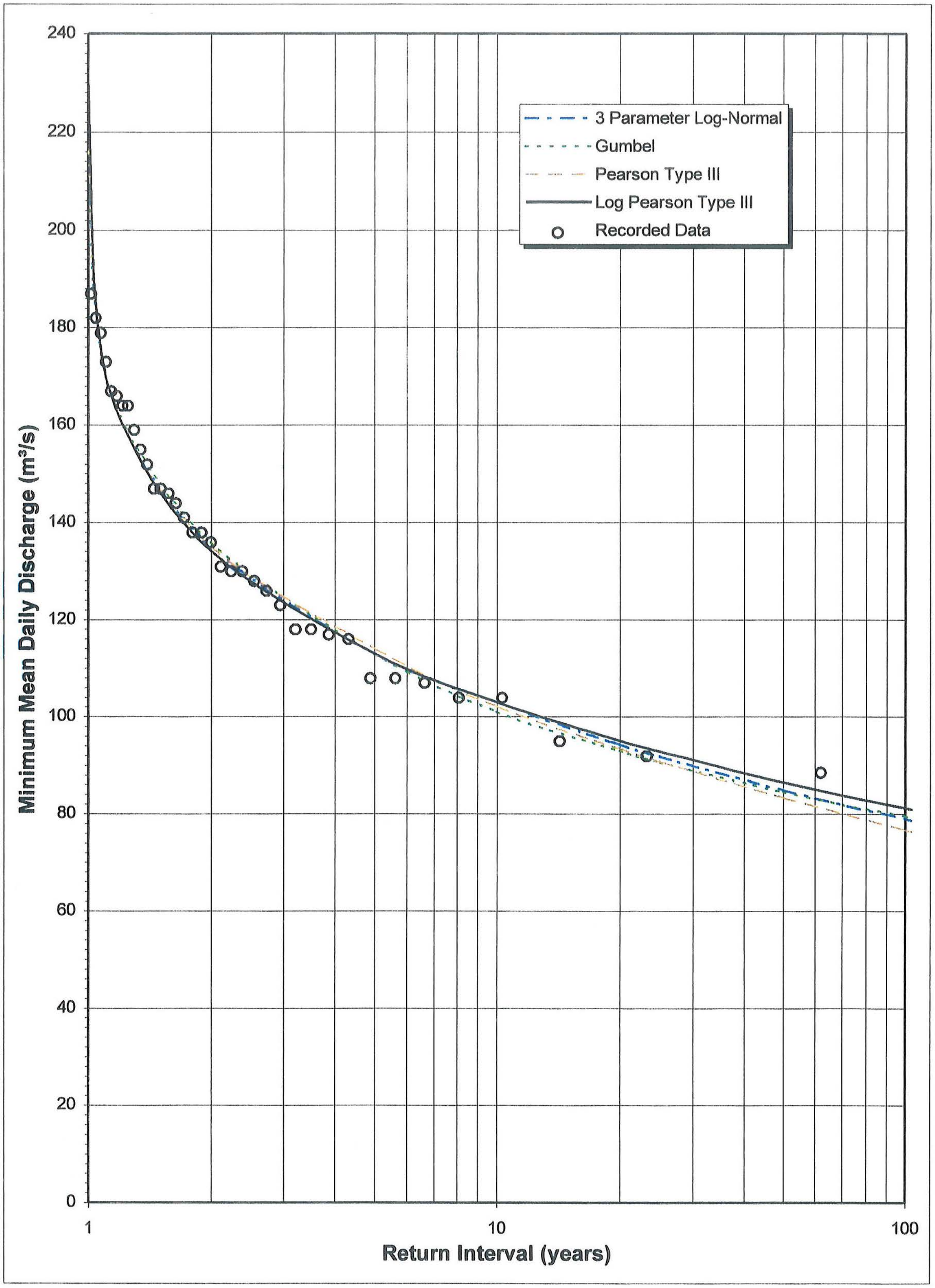
**ATHABASCA RIVER: FLOOD FLOW FREQUENCY ANALYSIS**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 19 | DRAWN BY: C.P.B. |

2839w172.dwg

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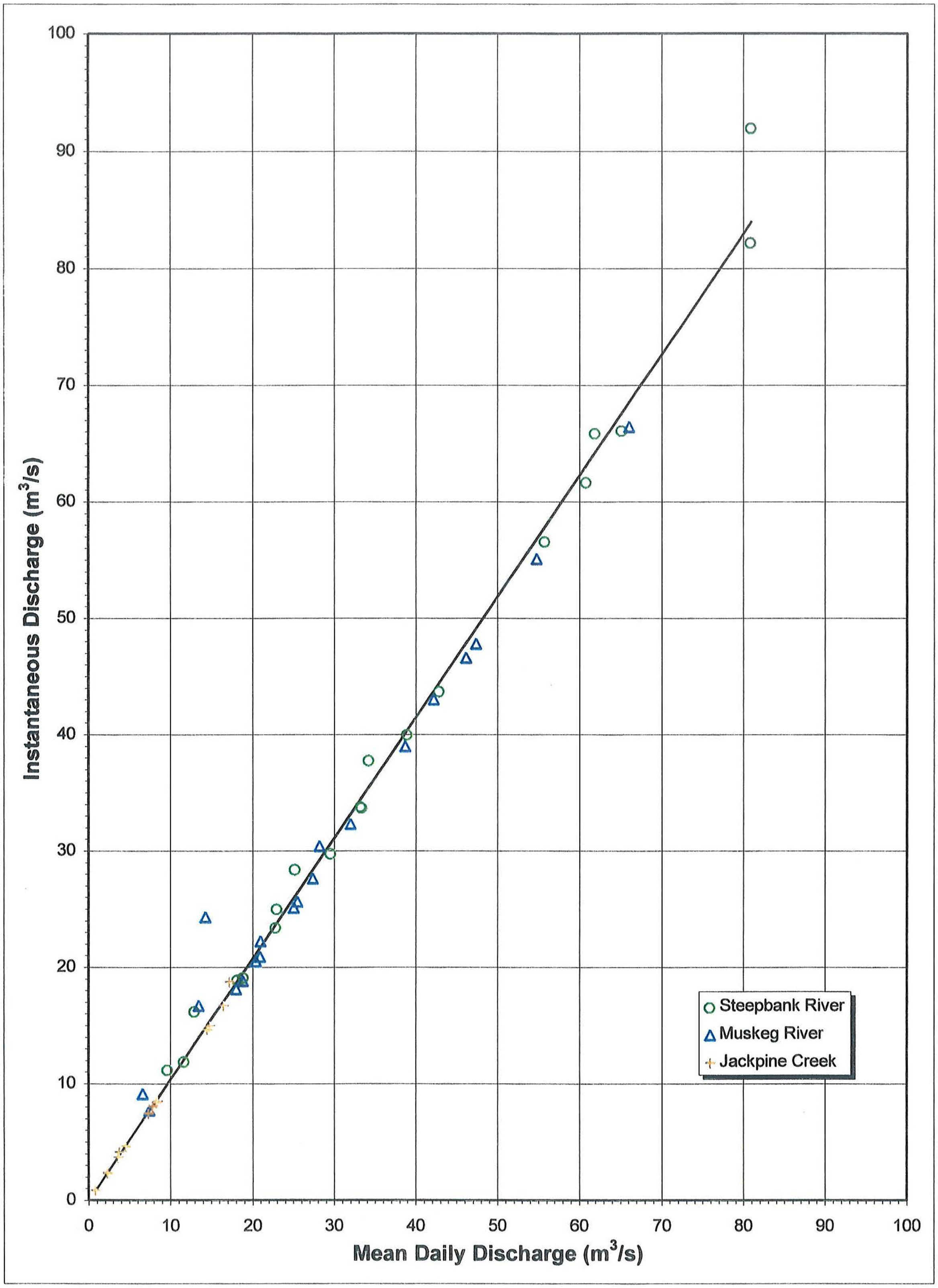
ATHABASCA RIVER: LOW FLOW FREQUENCY ANALYSIS

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 20 | DRAWN BY: C.P.B. |

2839w172.dwg

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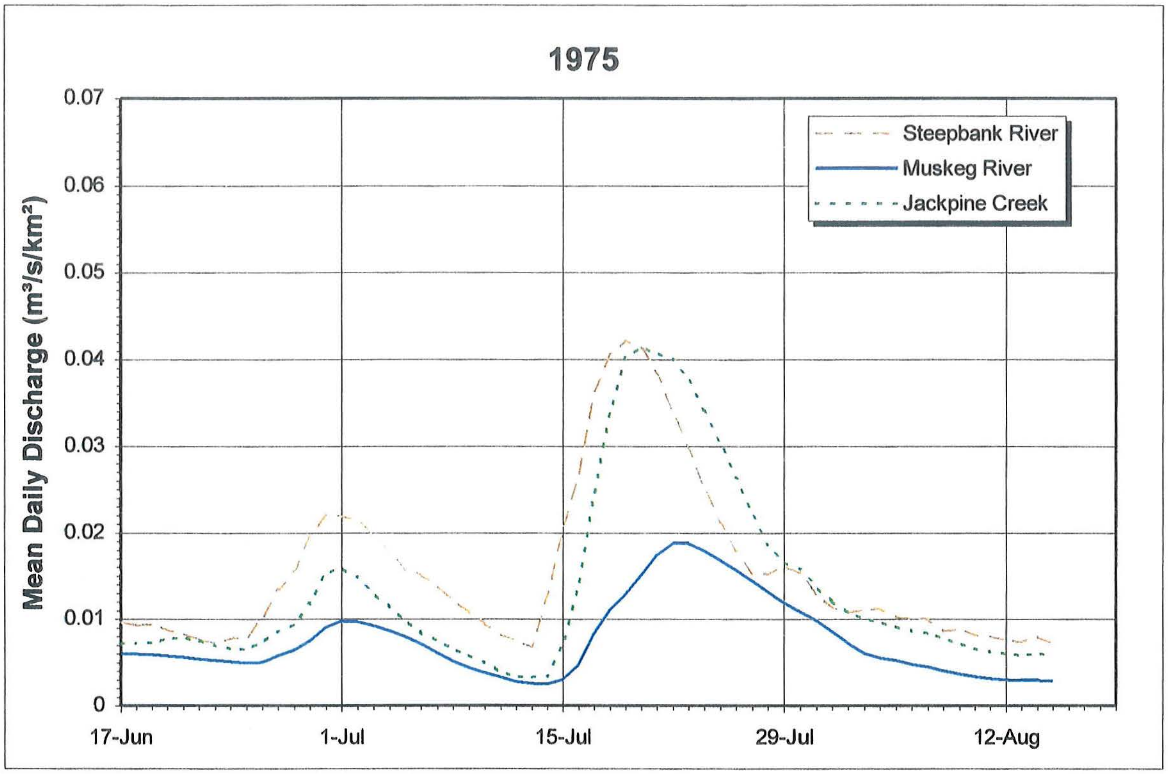
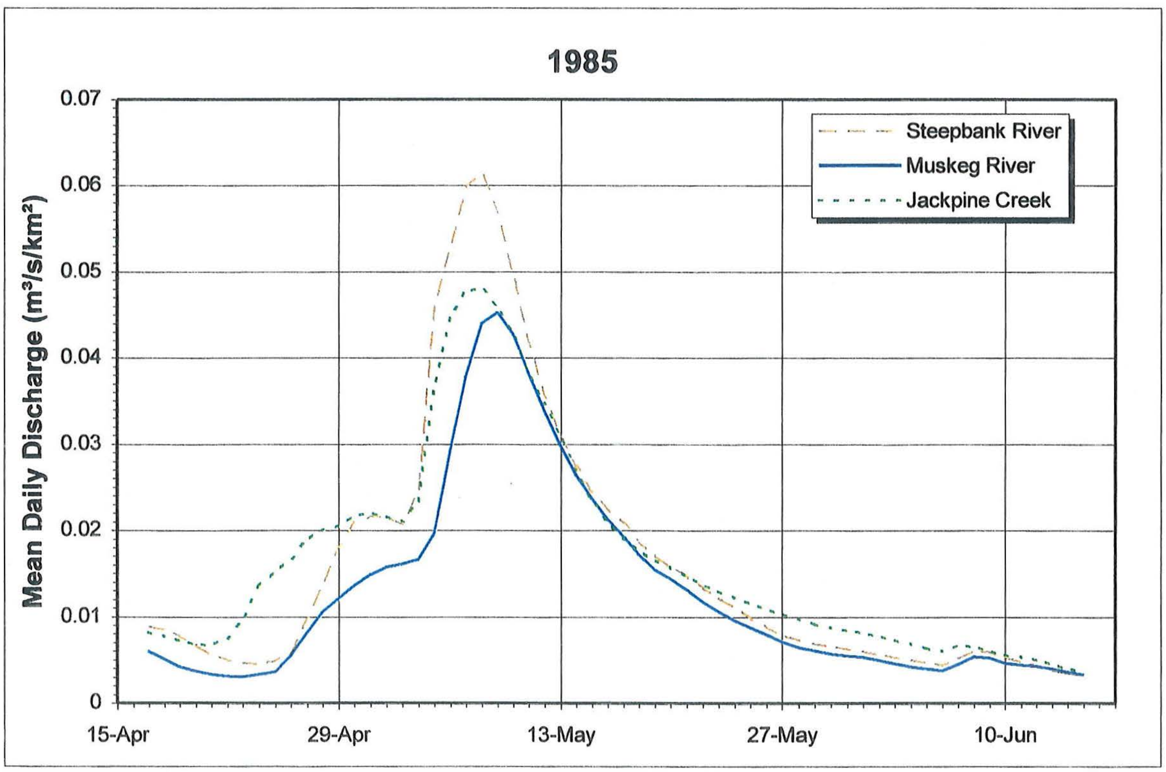
INSTANTANEOUS VS MEAN DAILY PEAK FLOWS

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 21 | DRAWN BY: C.P.B. |

2B39w172.dwg

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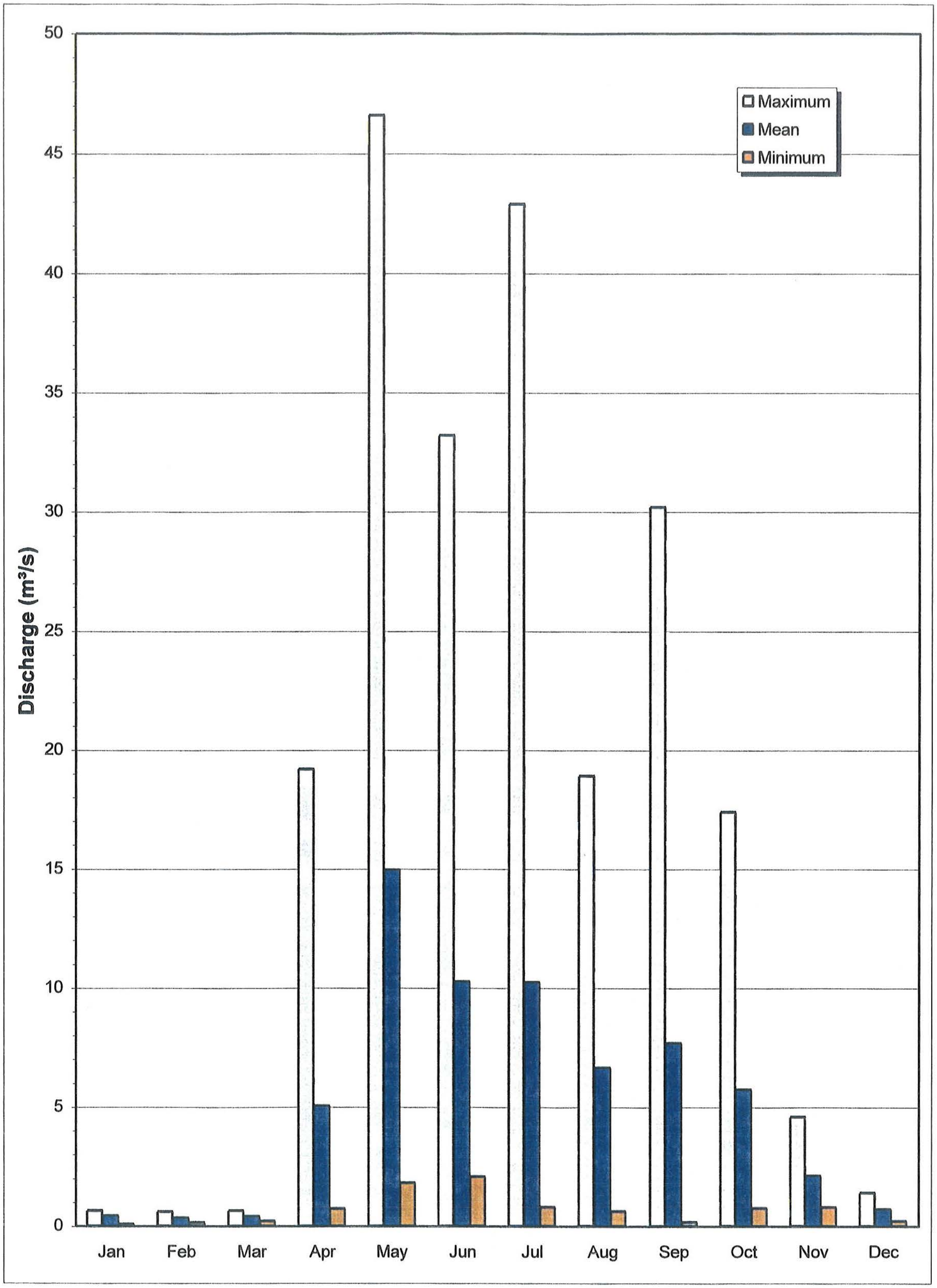
SAMPLE HYDROGRAPHS FOR WATERCOURSES

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 22 | DRAWN BY: C.P.B. |

2839w172.dwg

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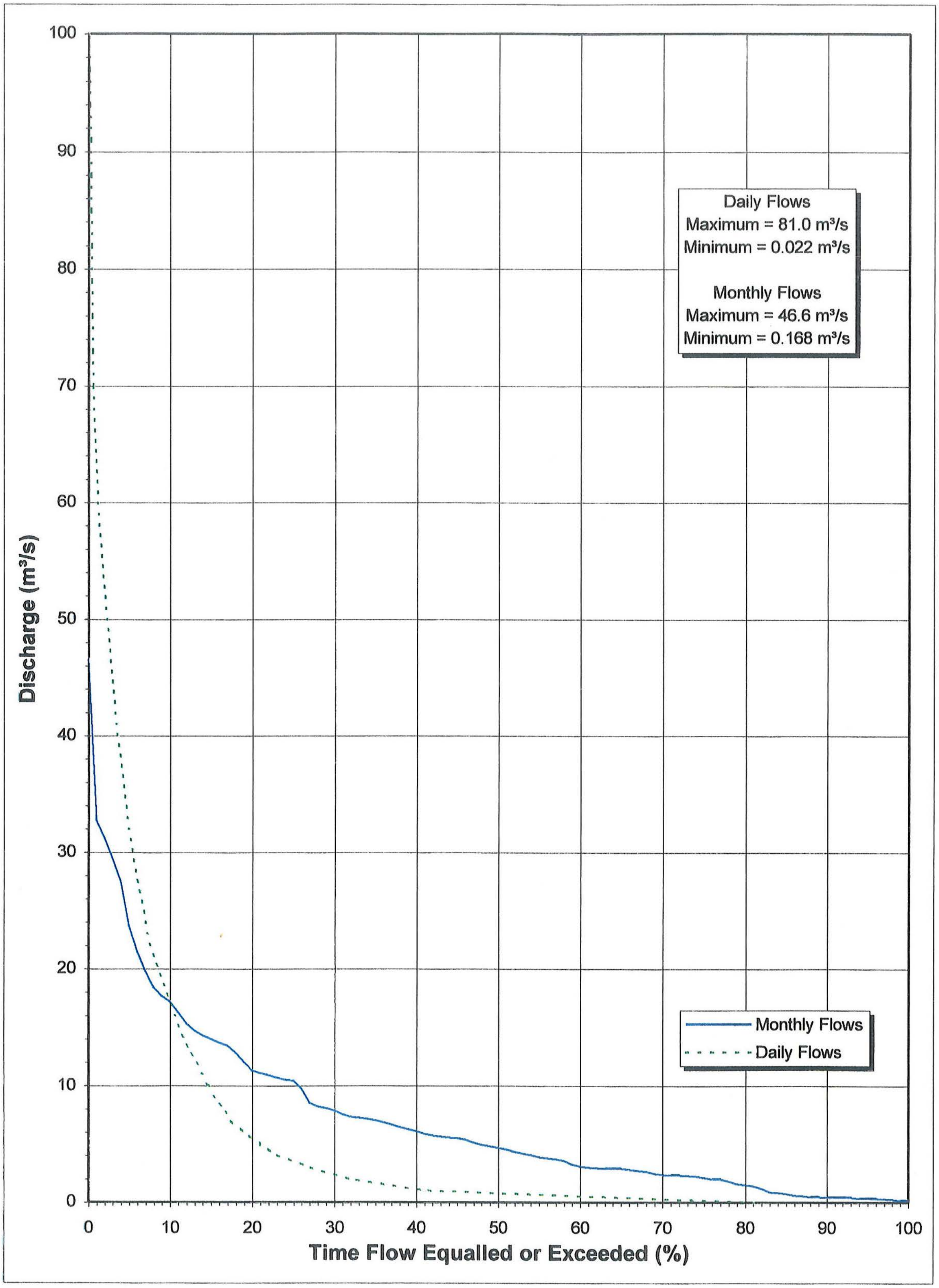
STEEPBANK RIVER: AVERAGE ANNUAL RUNOFF

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 23 | DRAWN BY: C.P.B. |

2B39w172.dwg

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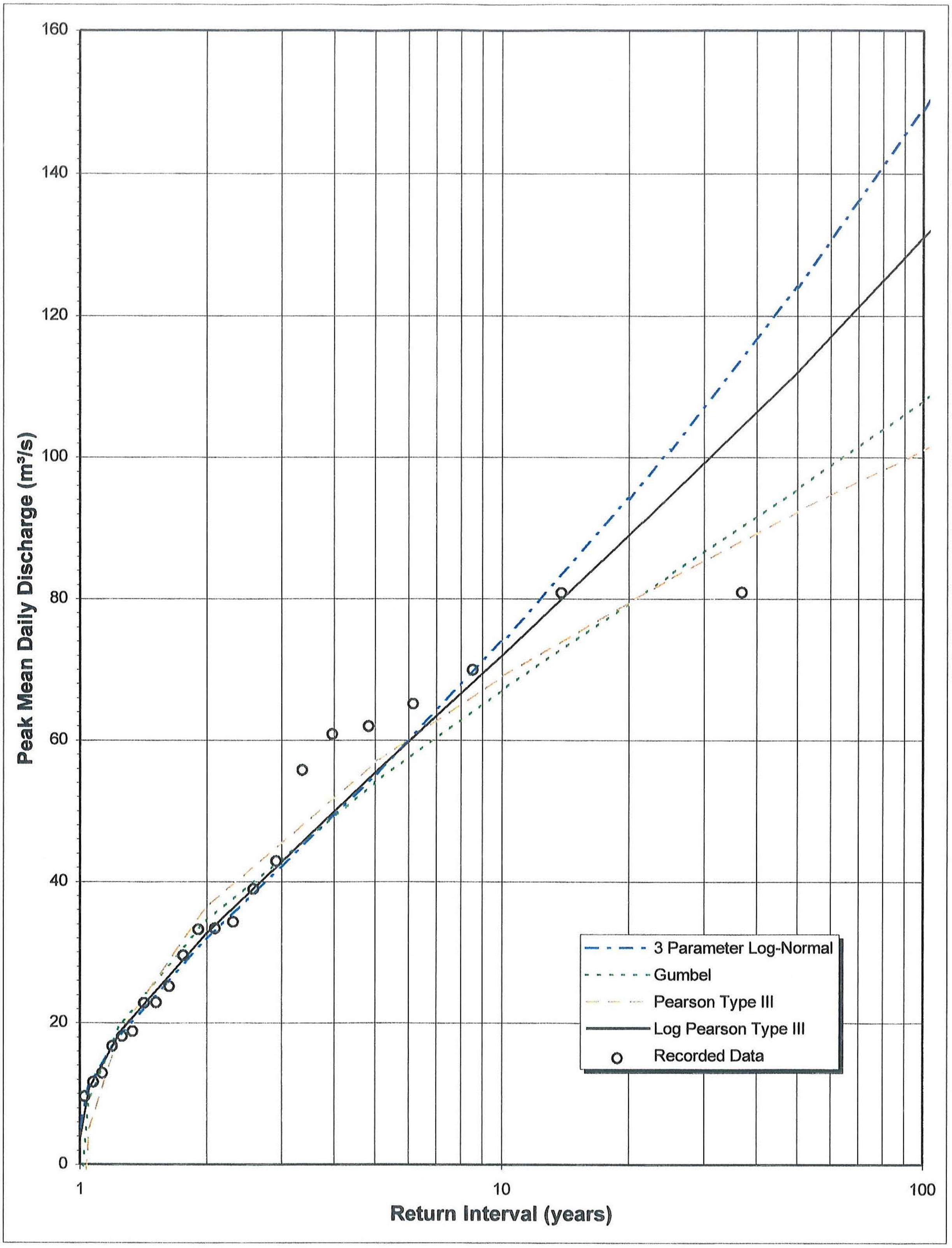
STEEPBANK RIVER: FLOW DURATION CURVES

| APRIL 1998 | FIGURE 24 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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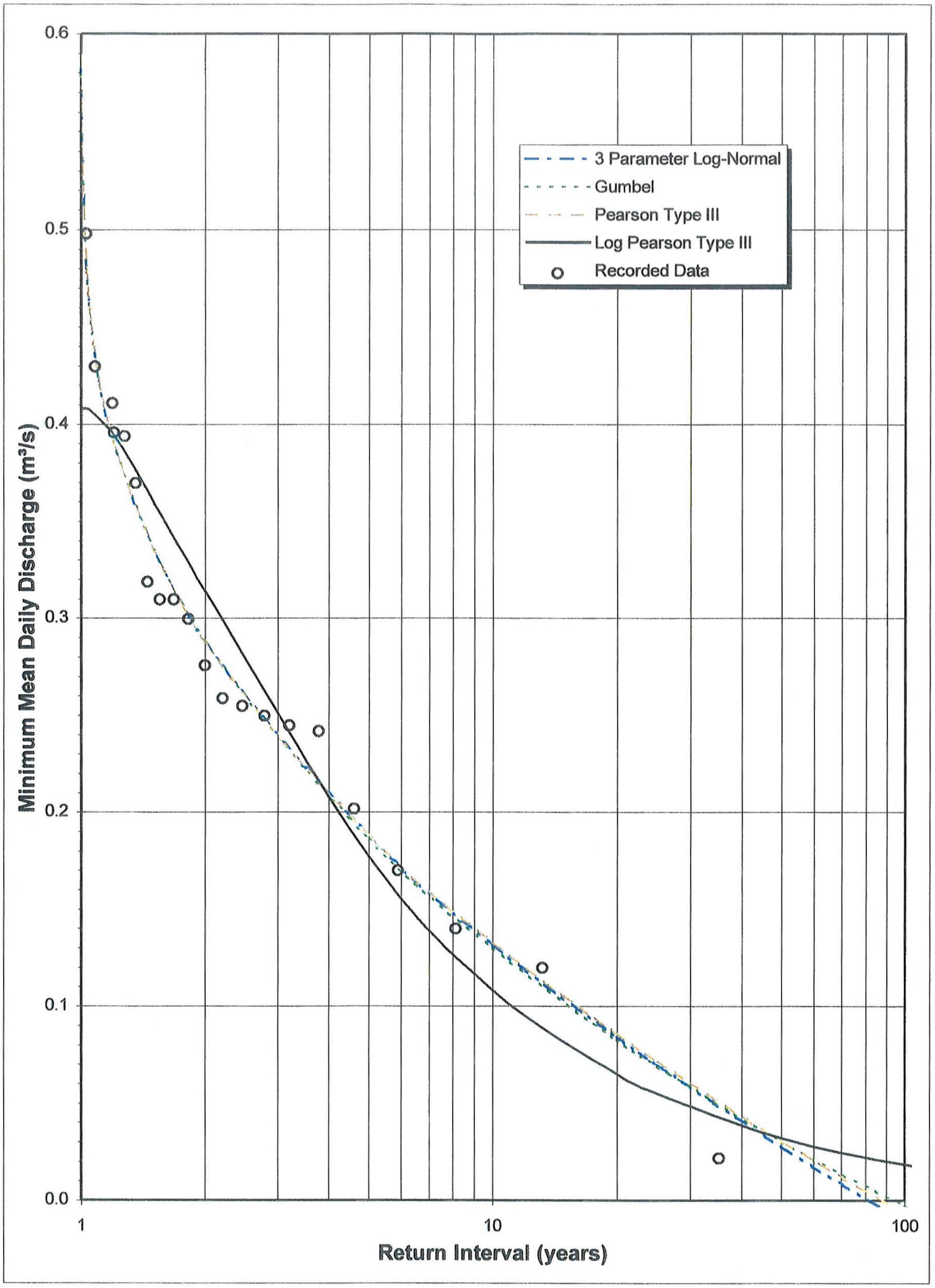
**STEEPBANK RIVER: FLOOD FLOW FREQUENCY ANALYSIS**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 25 | DRAWN BY: C.P.B. |

2839w172.dwg

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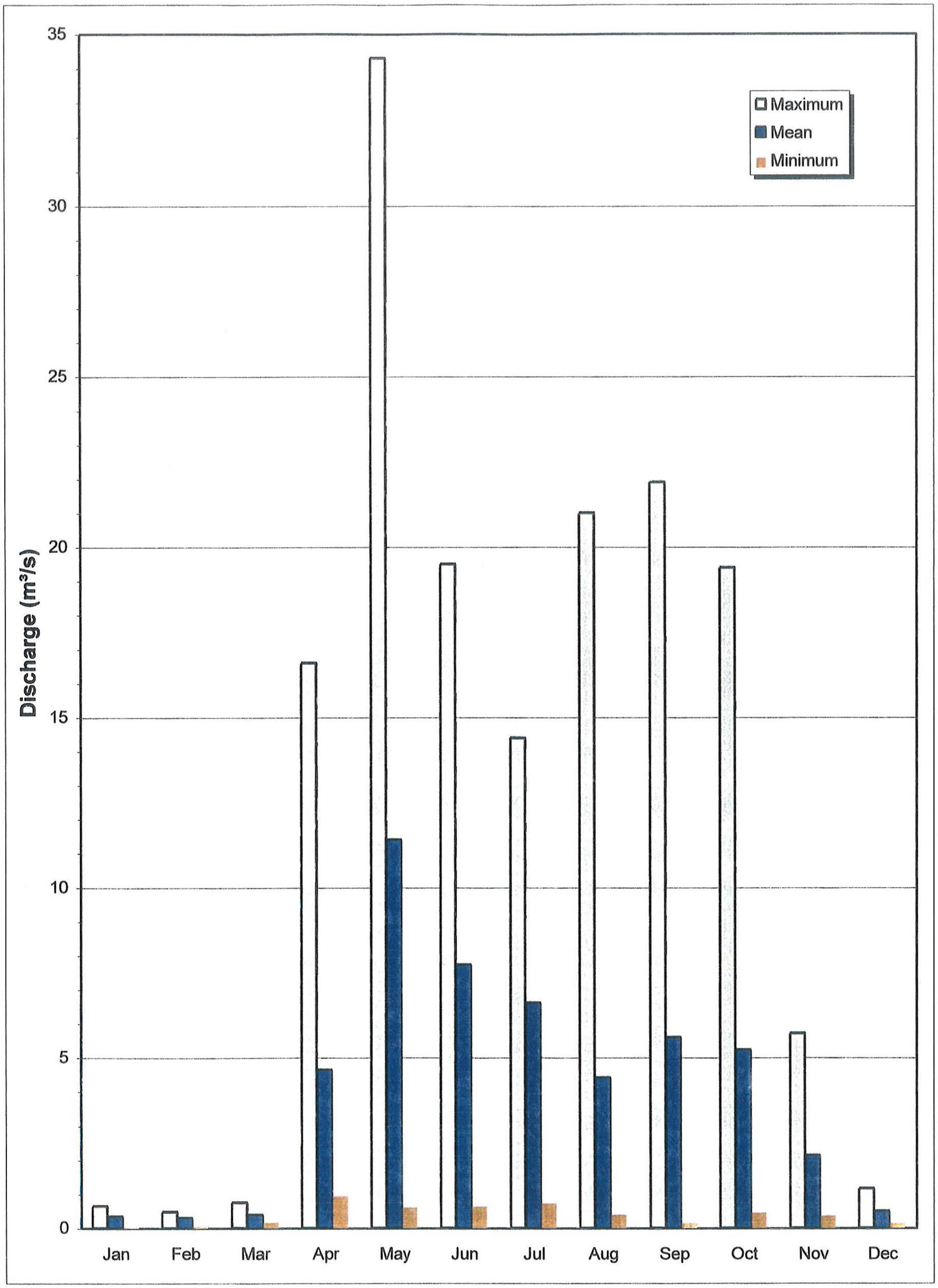
**STEEPBANK RIVER: LOW FLOW FREQUENCY ANALYSIS**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 26 | DRAWN BY: C.P.B. |

2839w172.dwg

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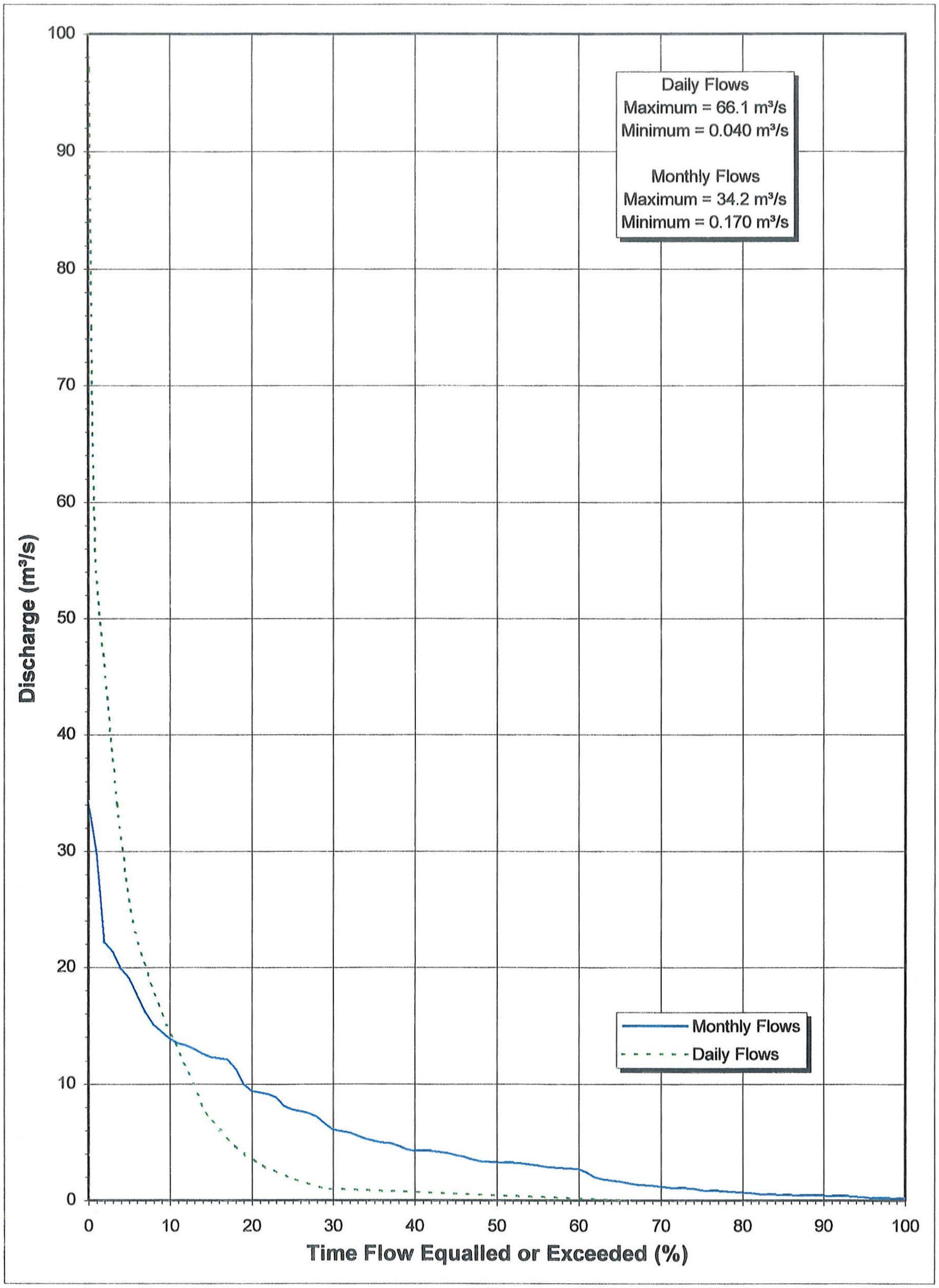
MUSKEG RIVER: AVERAGE ANNUAL RUNOFF

| APRIL 1998 | FIGURE 27 | DRAWN BY: C.P.B. |
| --- | --- | --- |

2839w172.dwg

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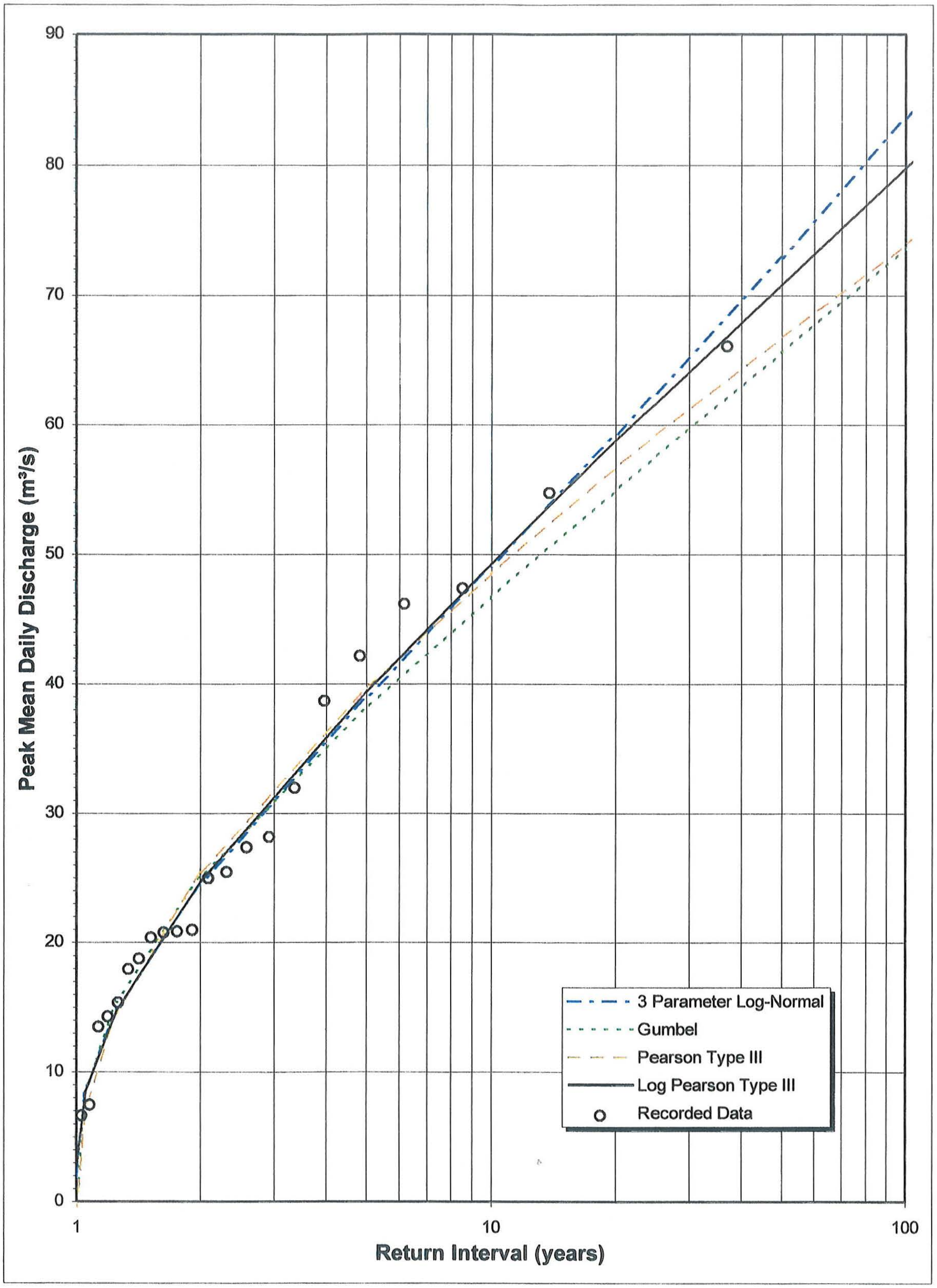
MUSKEG RIVER: FLOW DURATION CURVES

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 28 | DRAWN BY: C.P.B. |

2839w172.dwg

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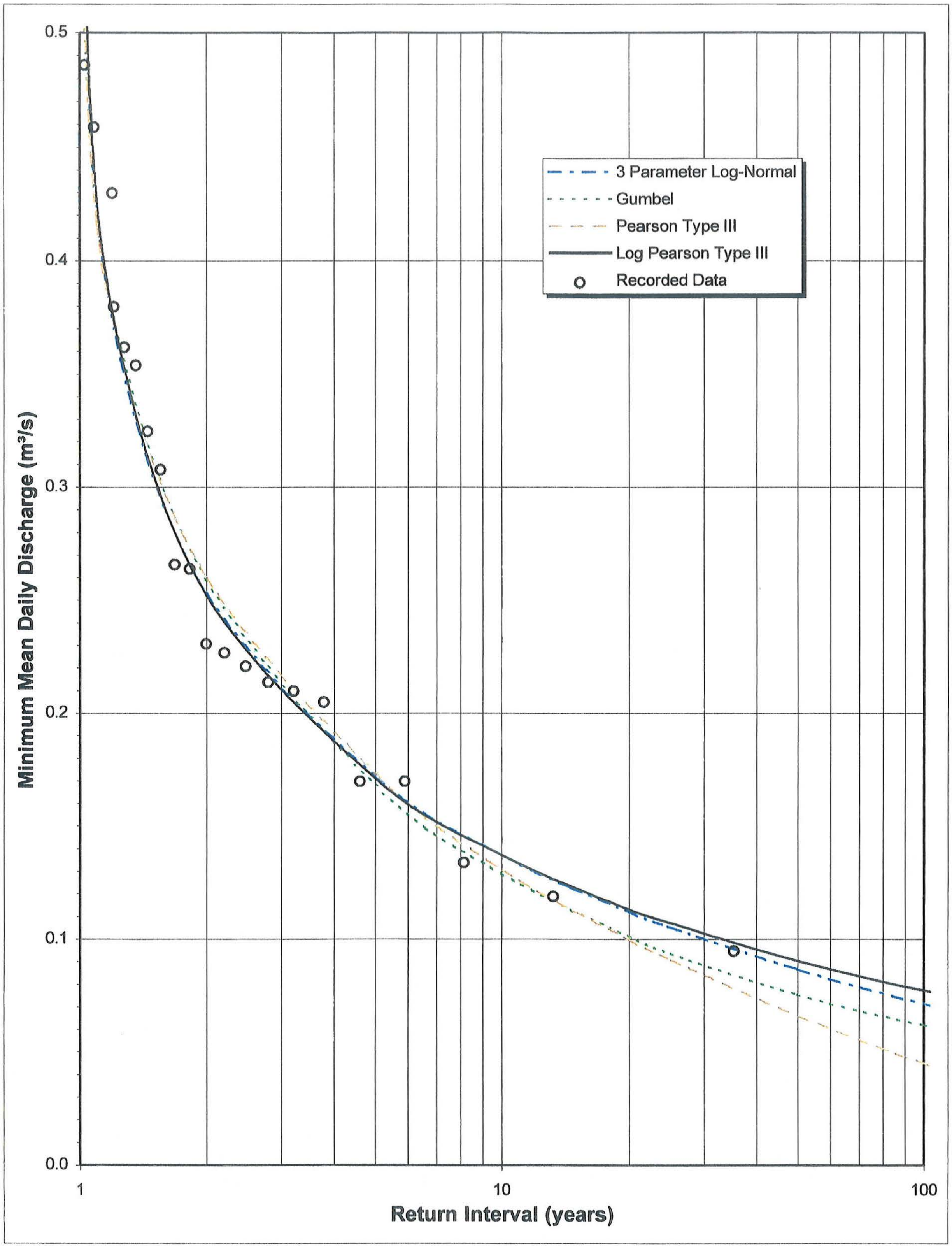
**MUSKEG RIVER: FLOOD FLOW FREQUENCY ANALYSIS**

| APRIL 1998 | FIGURE 29 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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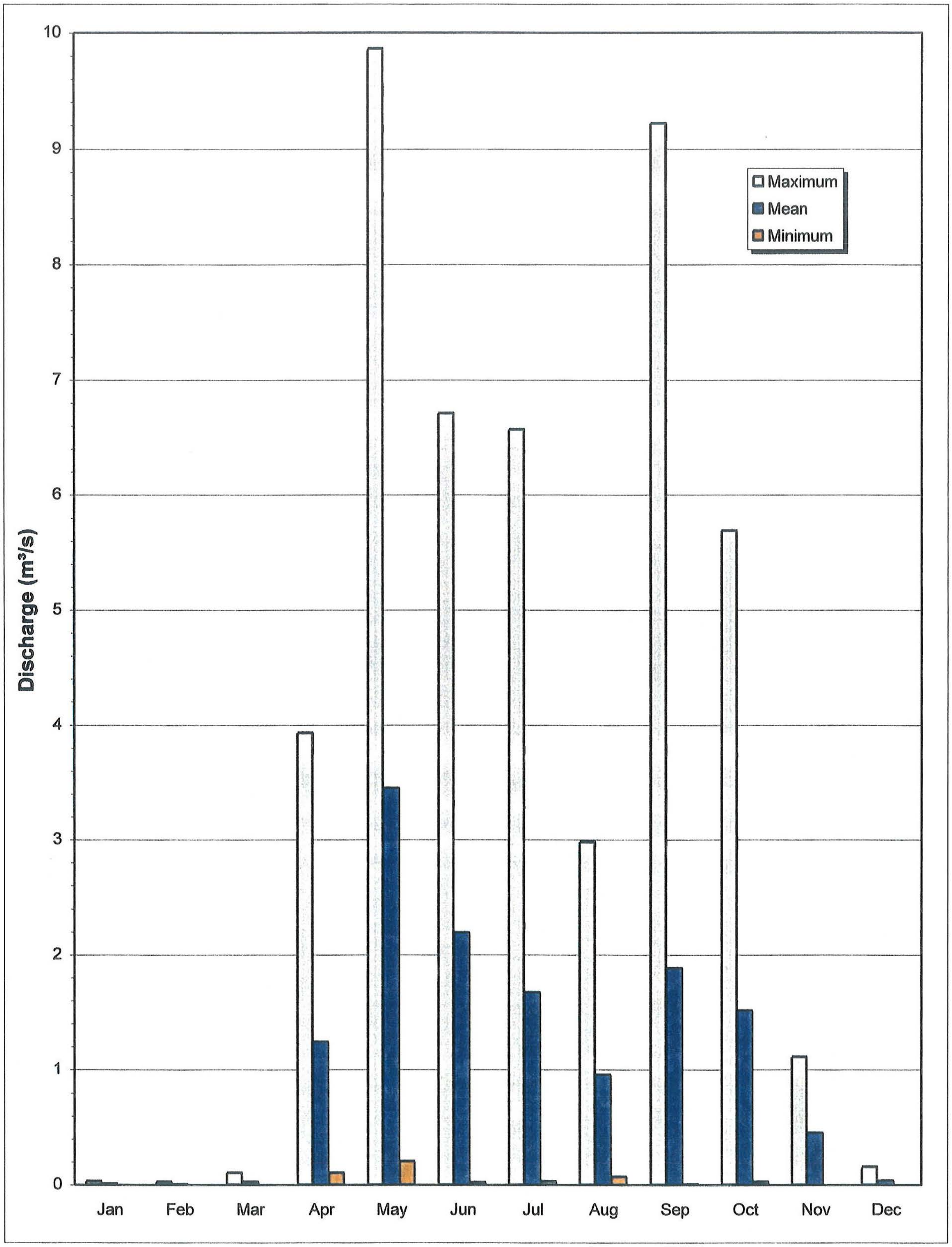
**MUSKEG RIVER: LOW FLOW FREQUENCY ANALYSIS**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 30 | DRAWN BY: C.P.B. |

2839w172.dwg

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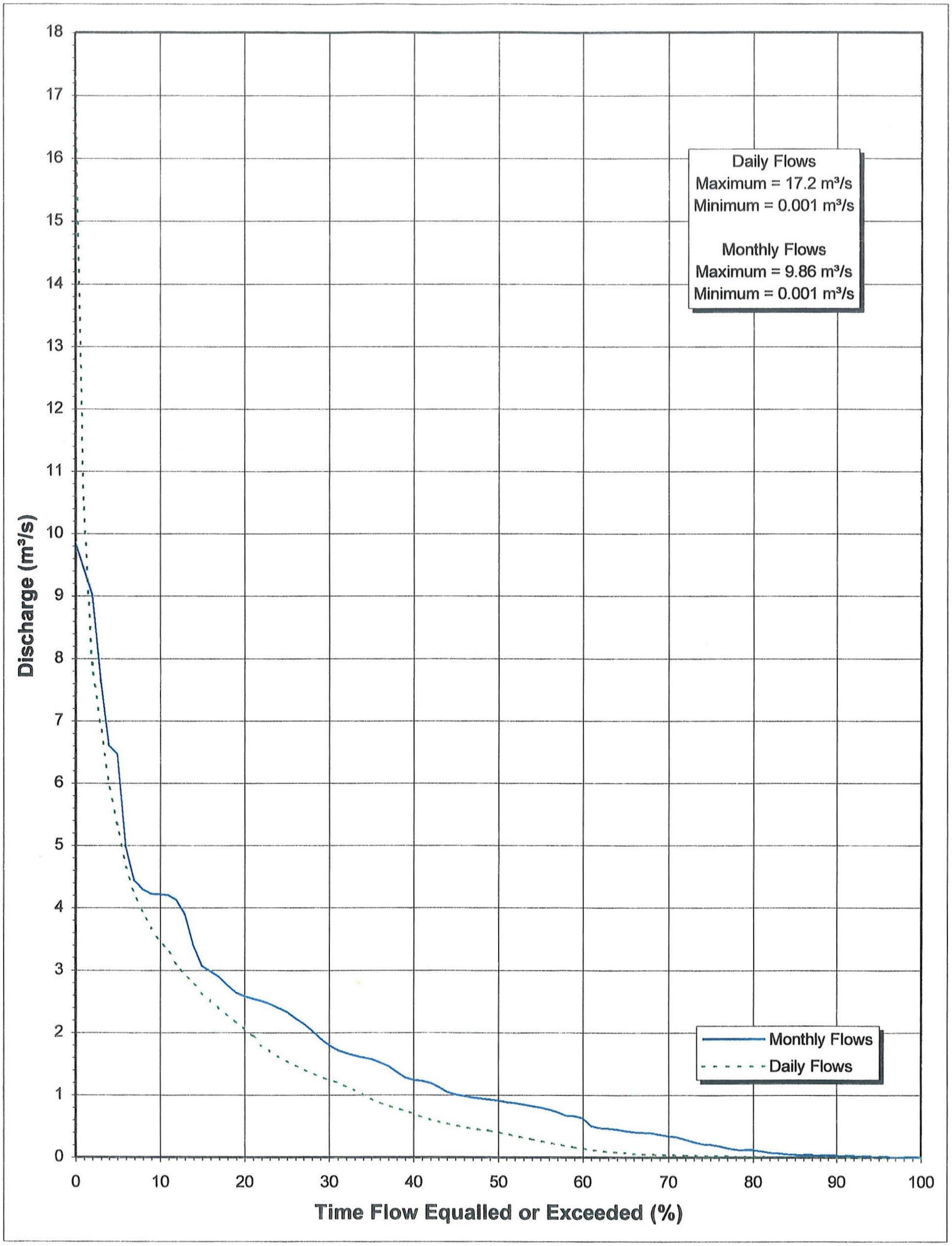
JACKPINE CREEK: AVERAGE ANNUAL RUNOFF

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 31 | DRAWN BY: C.P.B. |

2839w172.dwg

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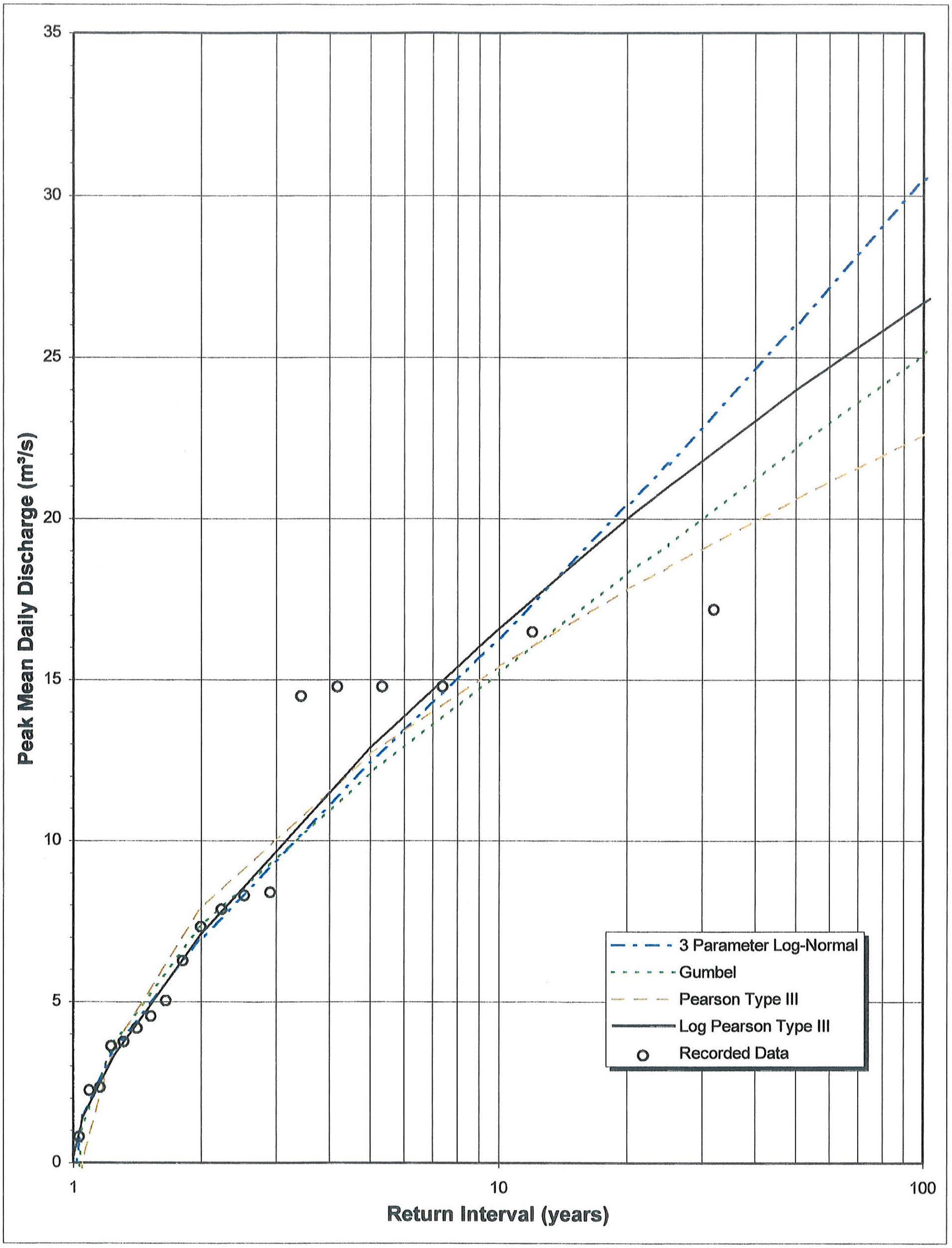
**JACKPINE CREEK: FLOW DURATION CURVES**

| APRIL 1998 | FIGURE 32 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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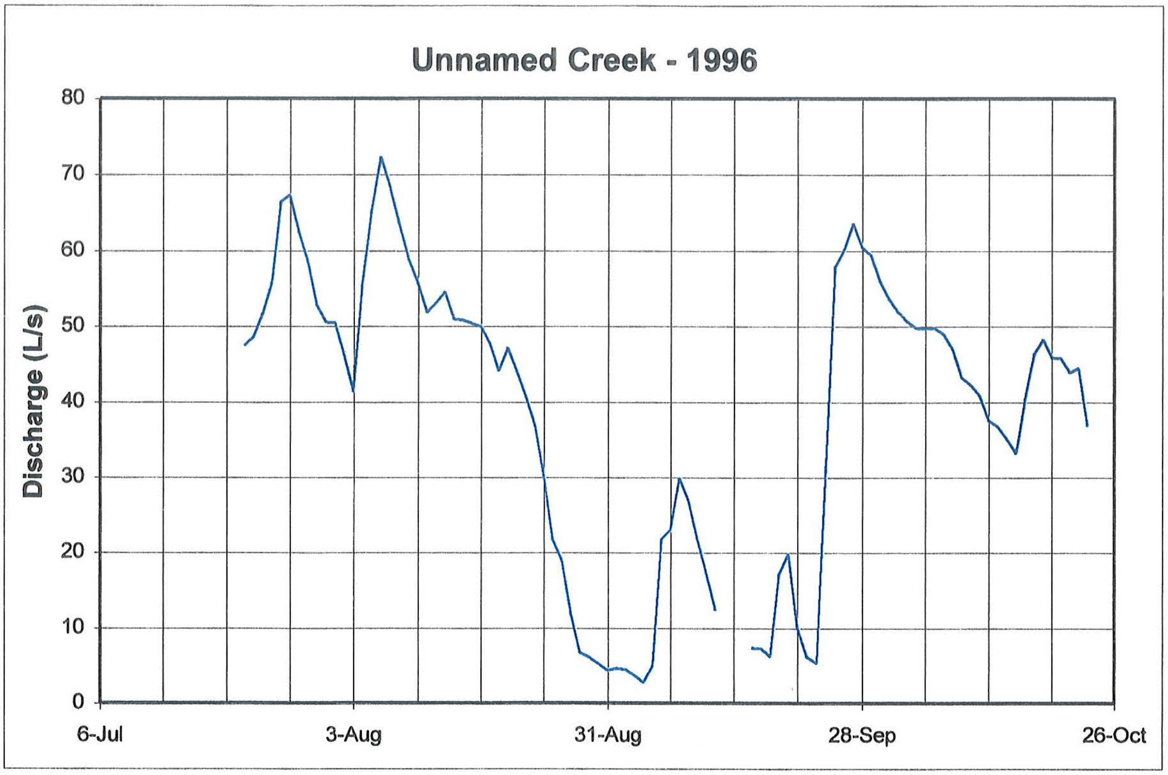
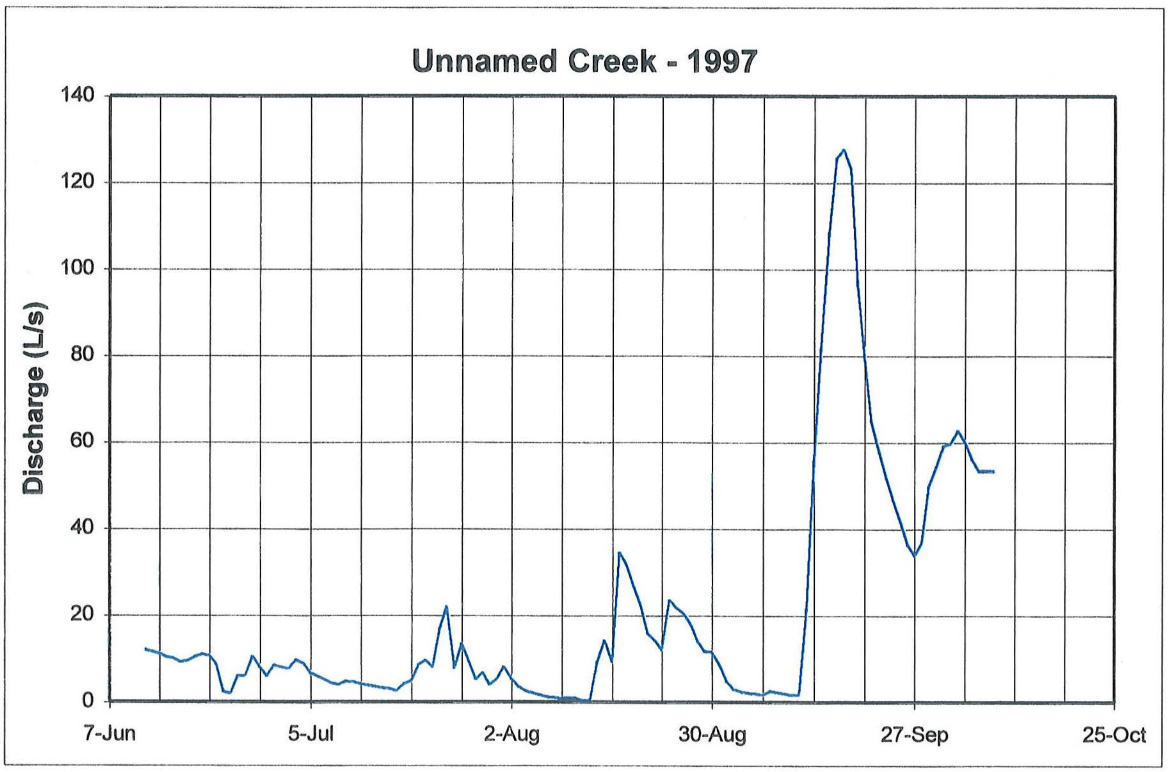
JACKPINE CREEK: FLOOD FLOW FREQUENCY ANALYSIS

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 33 | DRAWN BY: C.P.B. |

2839w172.dwg

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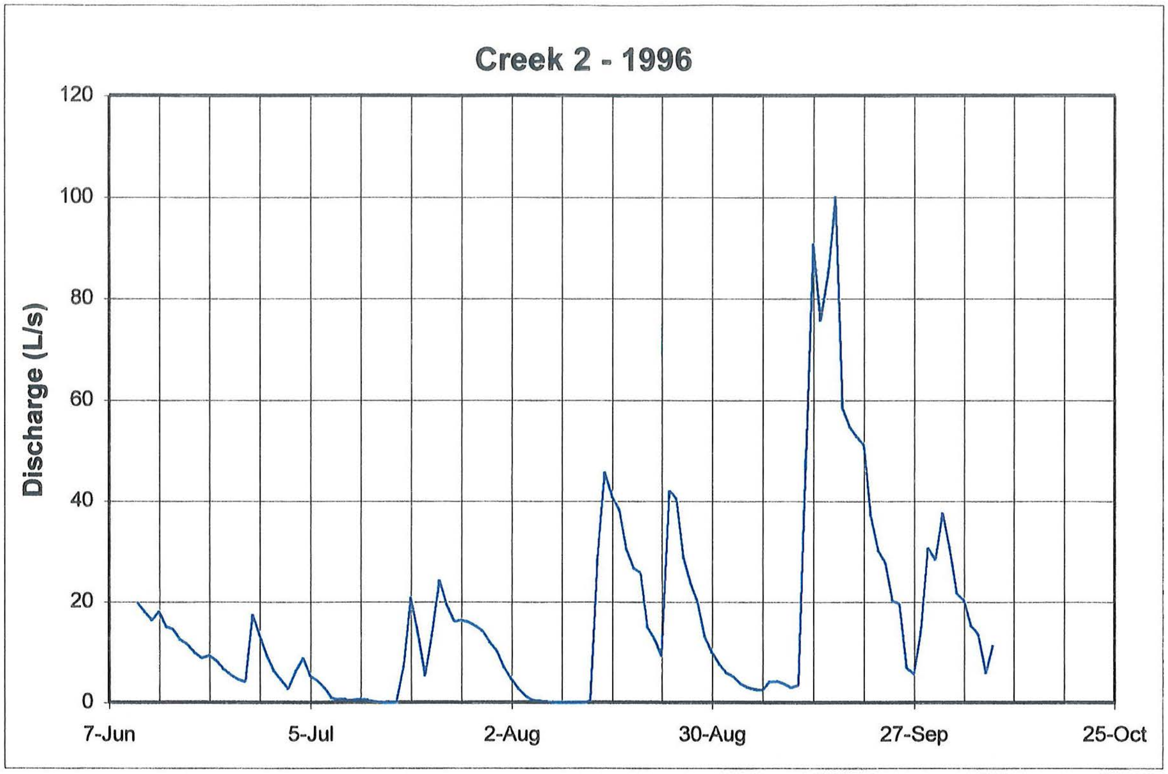
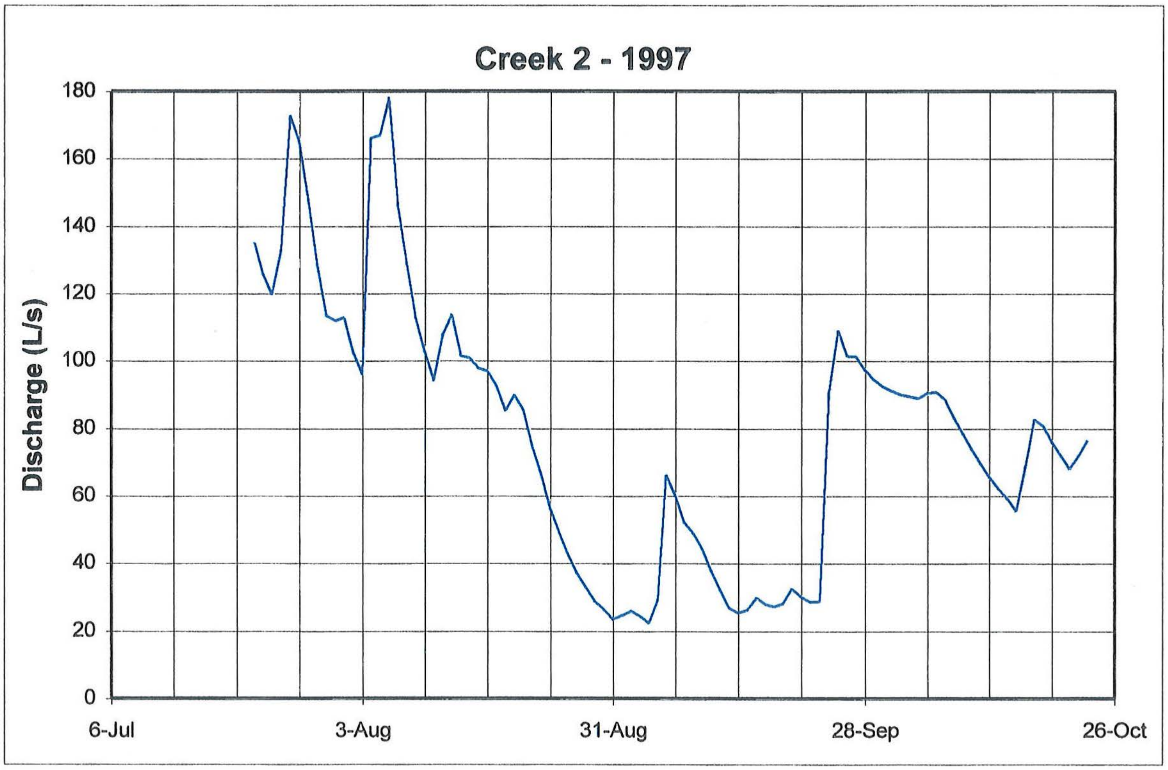
**FLOW DATA FOR SMALLER WATERCOURSES: SHEET 1**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 34 | DRAWN BY: C.P.B. |

2839w172.dwg

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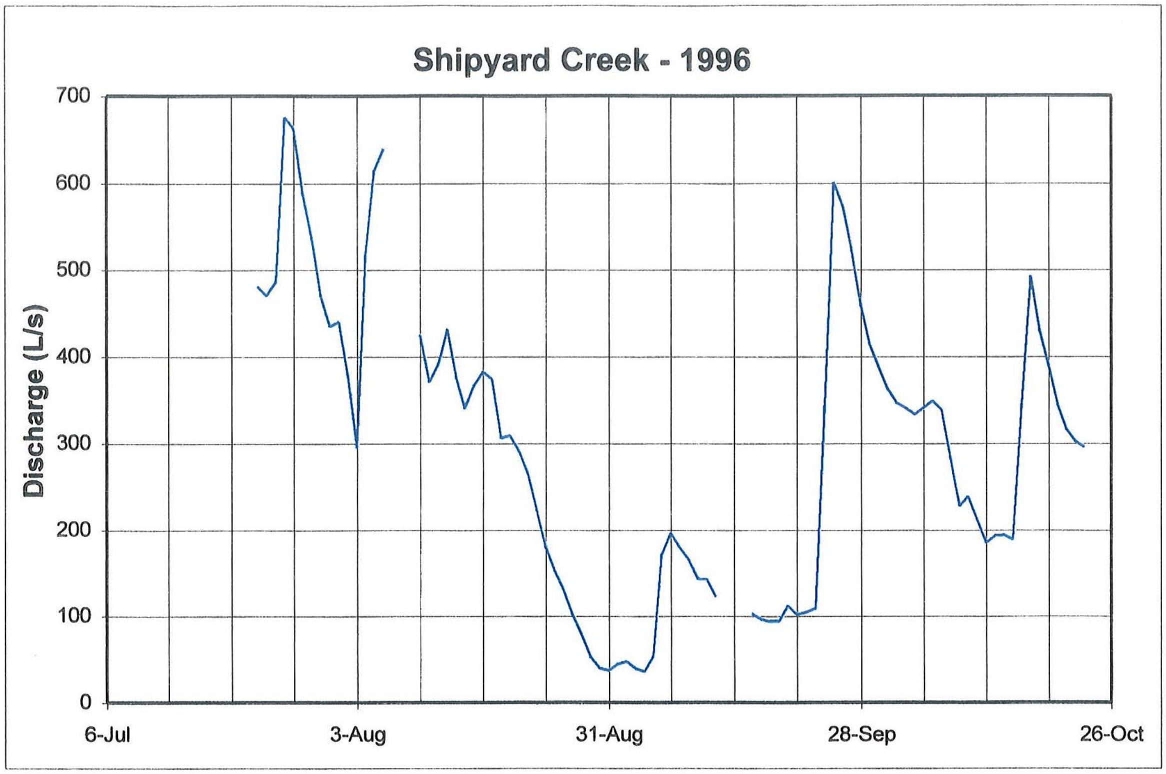
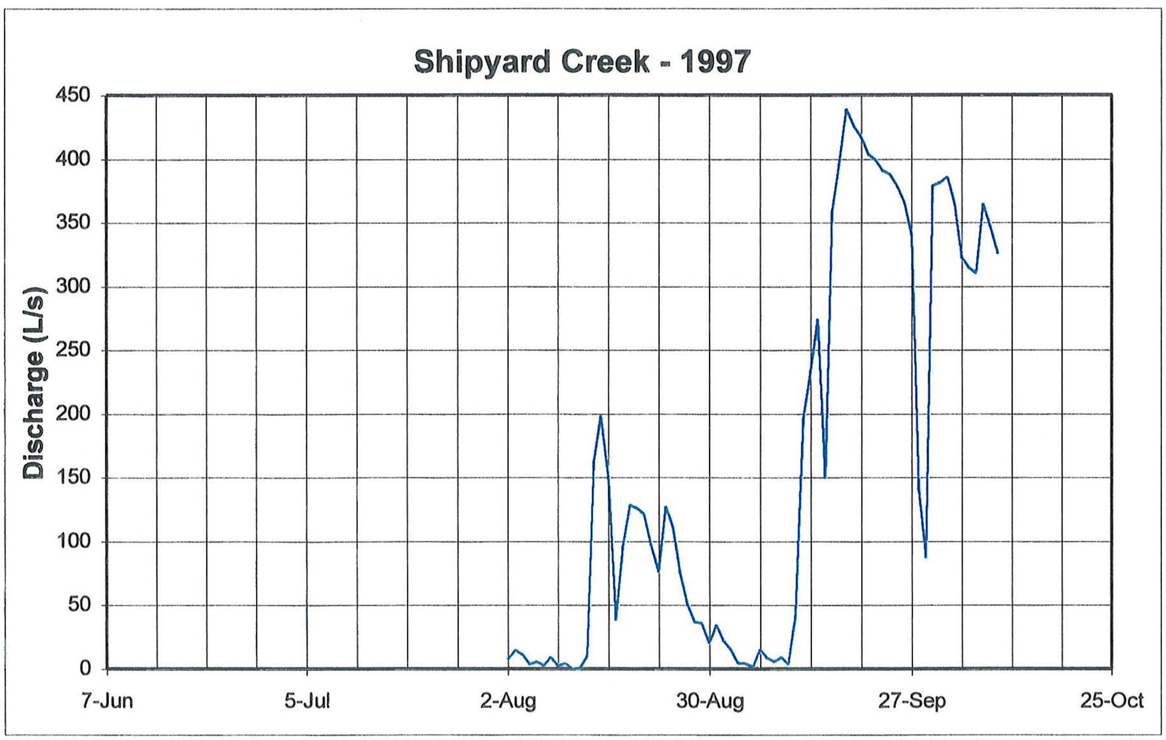
FLOW DATA FOR SMALLER WATERCOURSES: SHEET 2

| APRIL 1998 | FIGURE 35 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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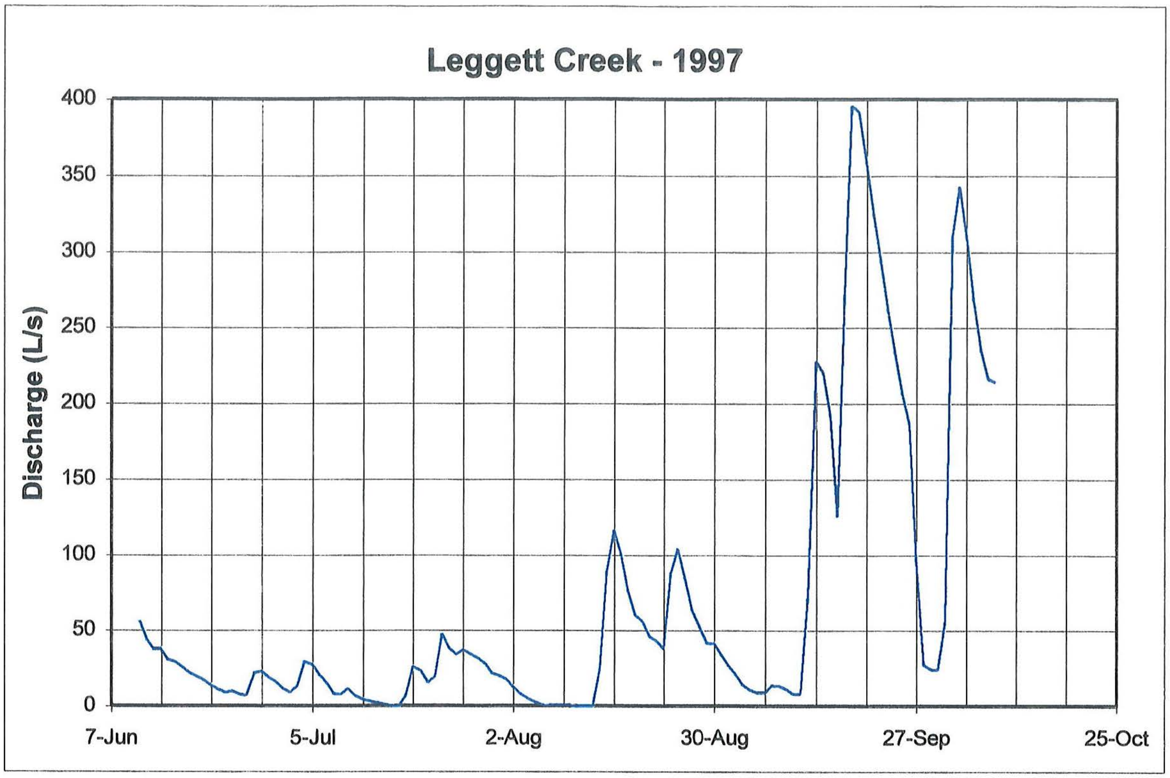
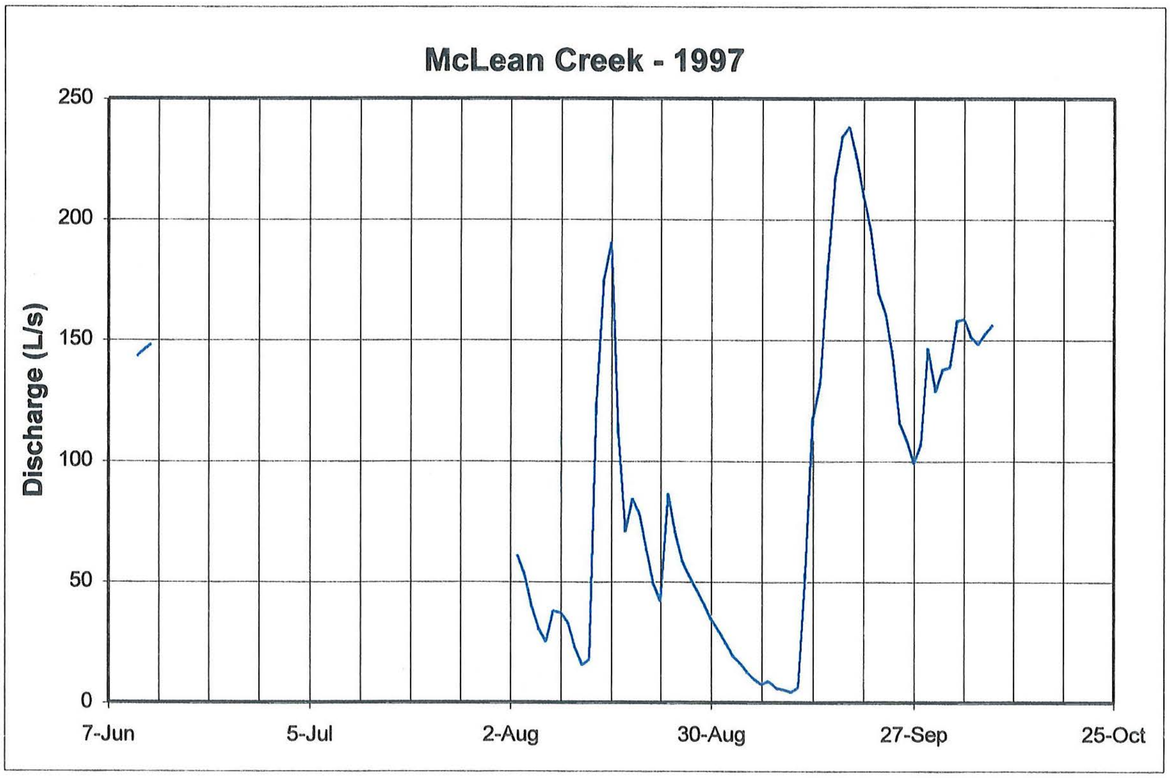
**FLOW DATA FOR SMALLER WATERCOURSES: SHEET 3**

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 36 | DRAWN BY: C.P.B. |

2839w172.dwg

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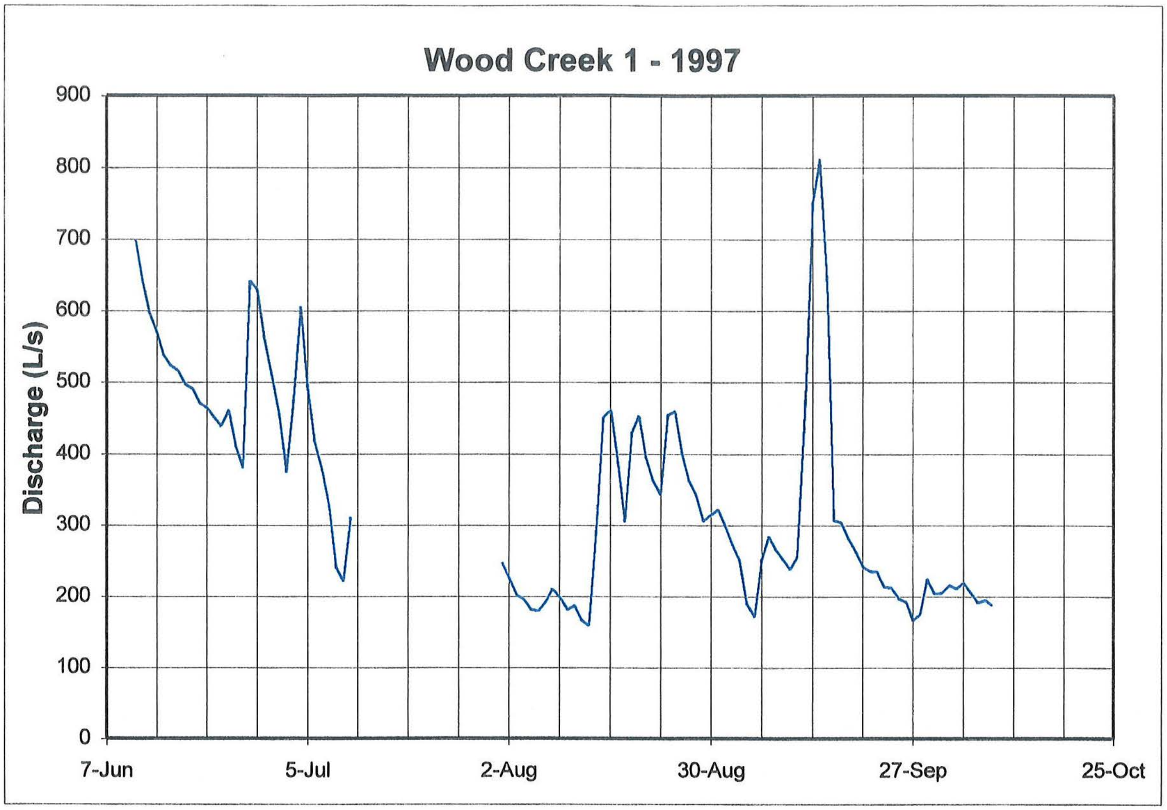
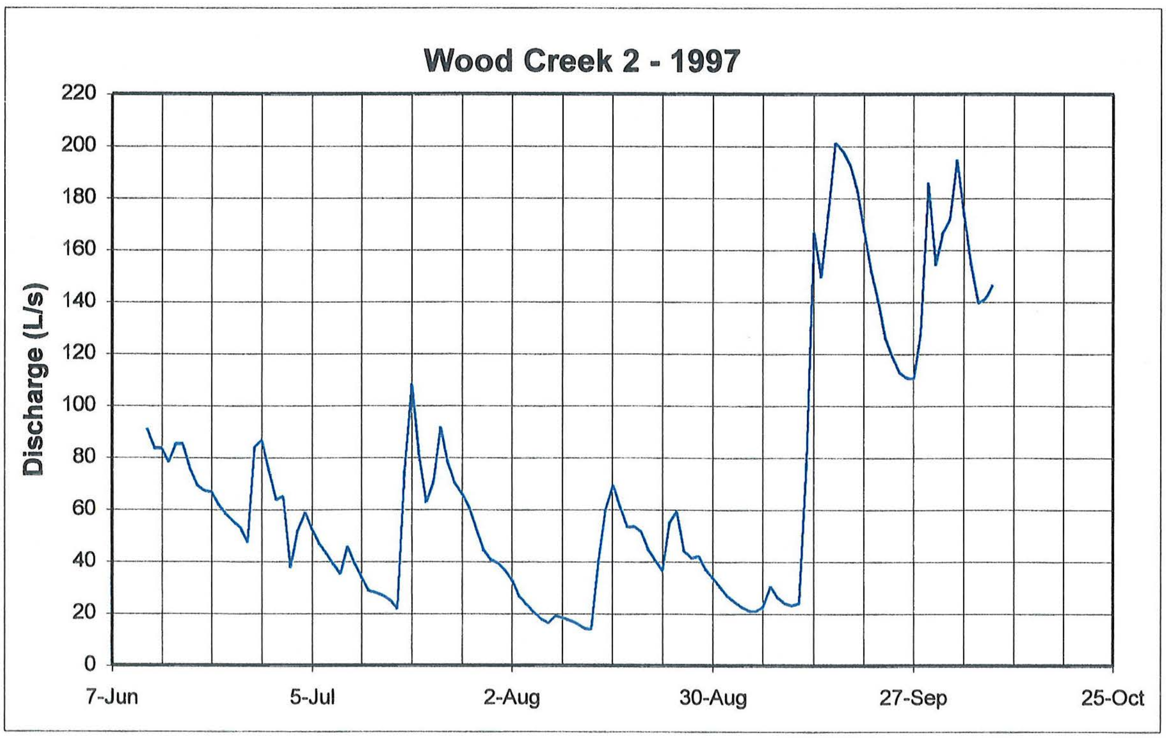
**FLOW DATA FOR SMALLER WATERCOURSES: SHEET 4**

| APRIL 1998 | FIGURE 37 | DRAWN BY: C.P.B. |
|---|---|---|

2B39w172.dwg

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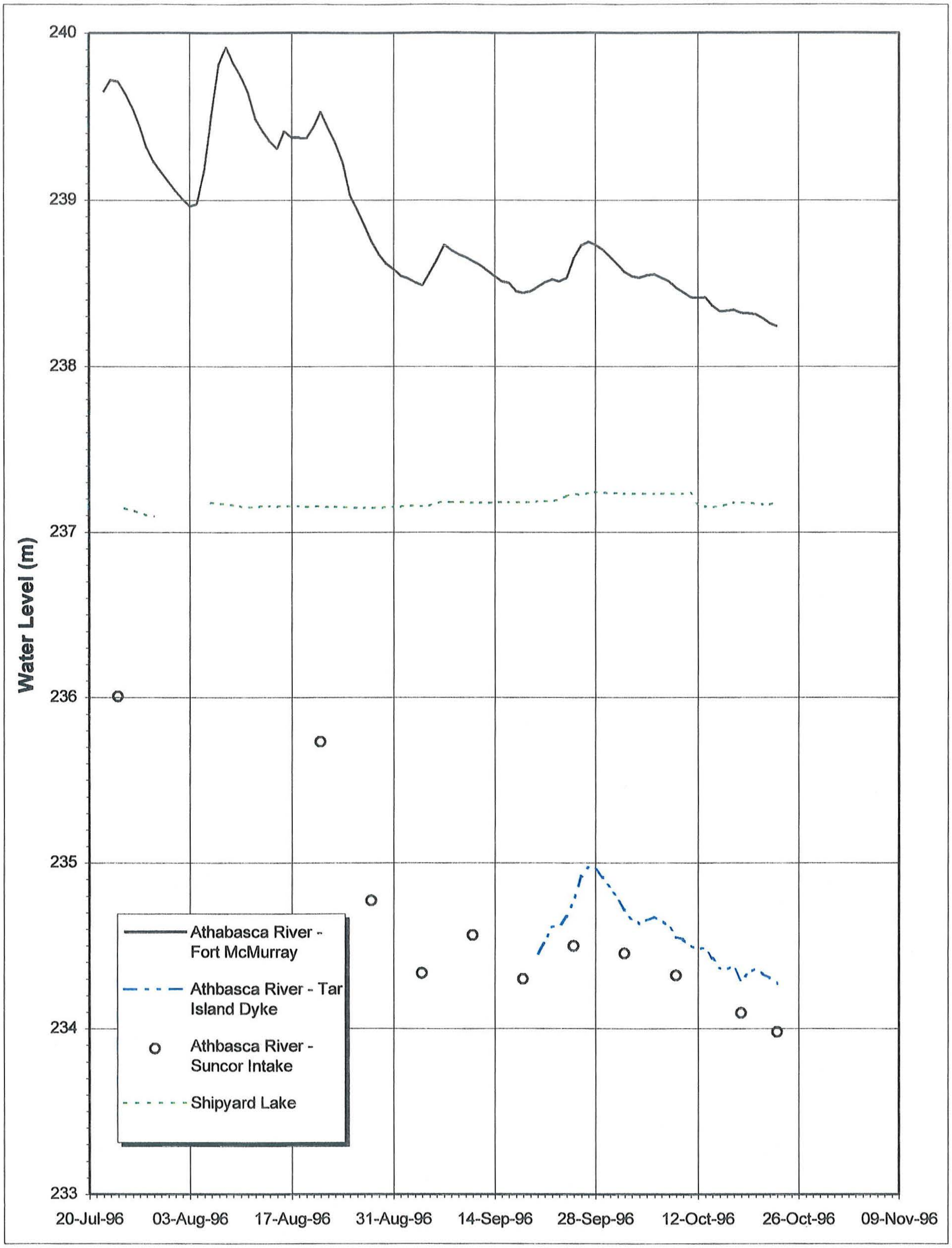
**FLOW DATA FOR SMALLER WATERCOURSES: SHEET 5**

| APRIL 1998 | FIGURE 38 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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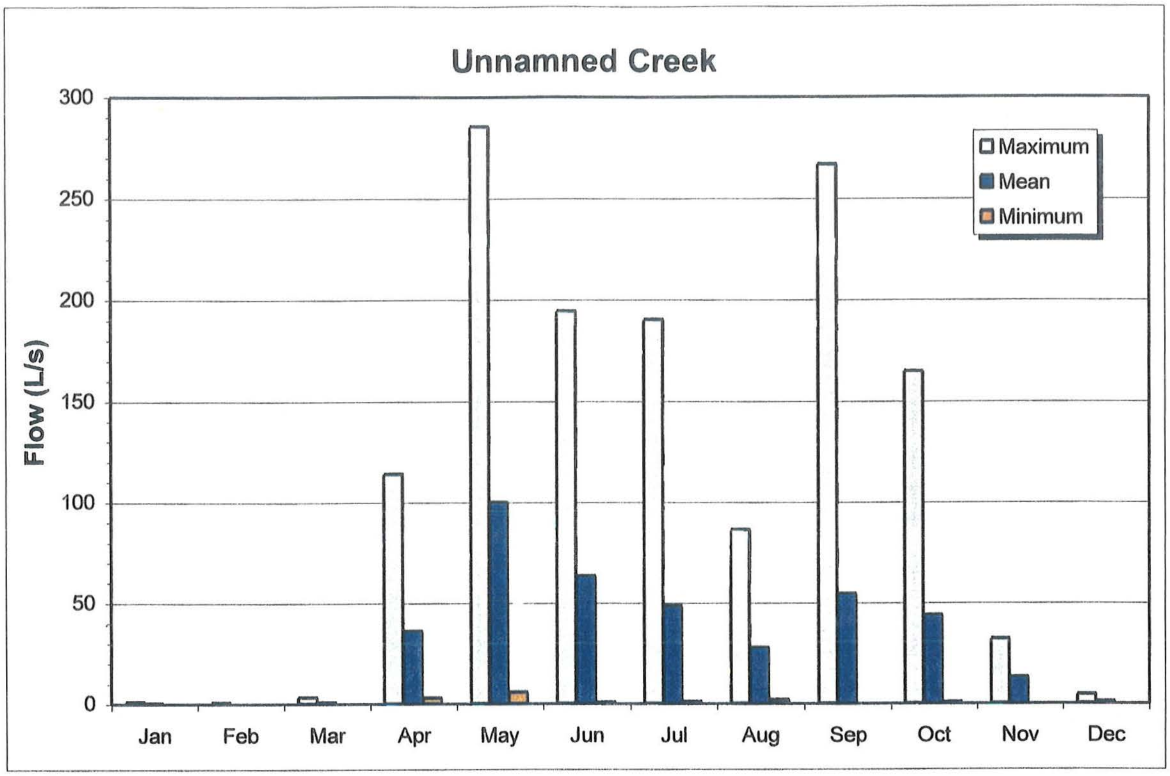
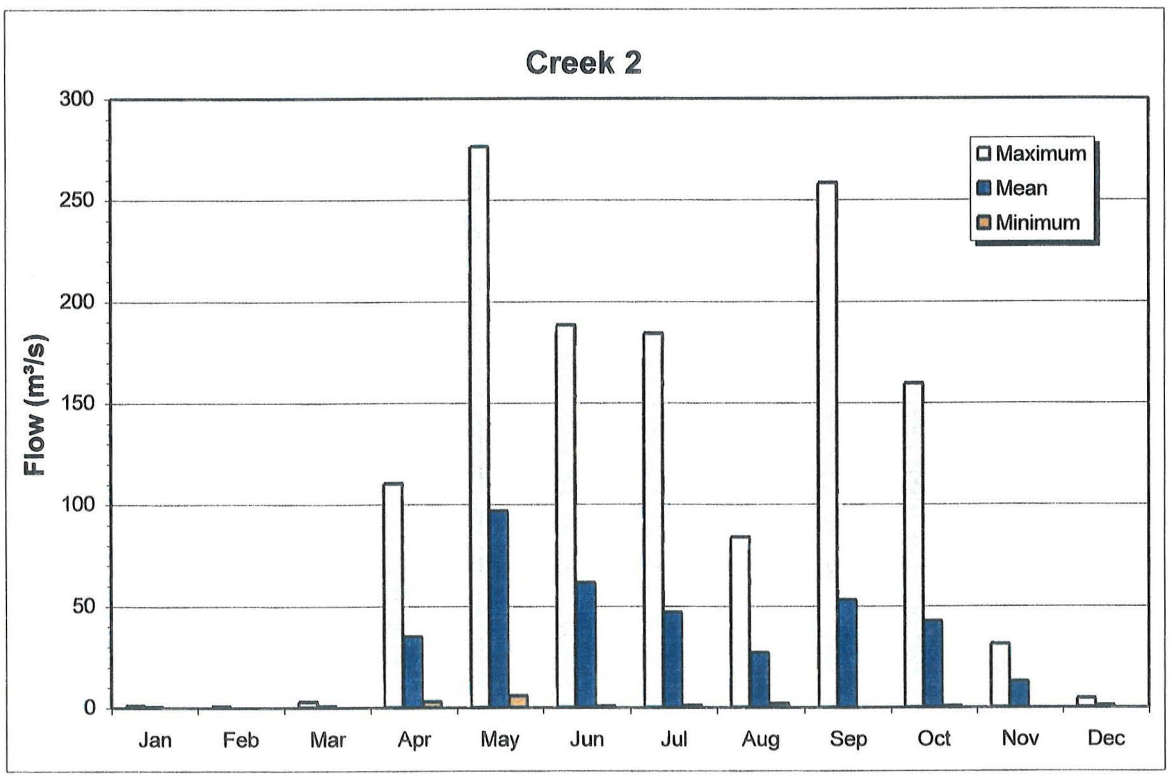
WATER LEVELS ON ATHABASCA RIVER AND SHIPYARD LAKE

| APRIL 1998 | FIGURE 39 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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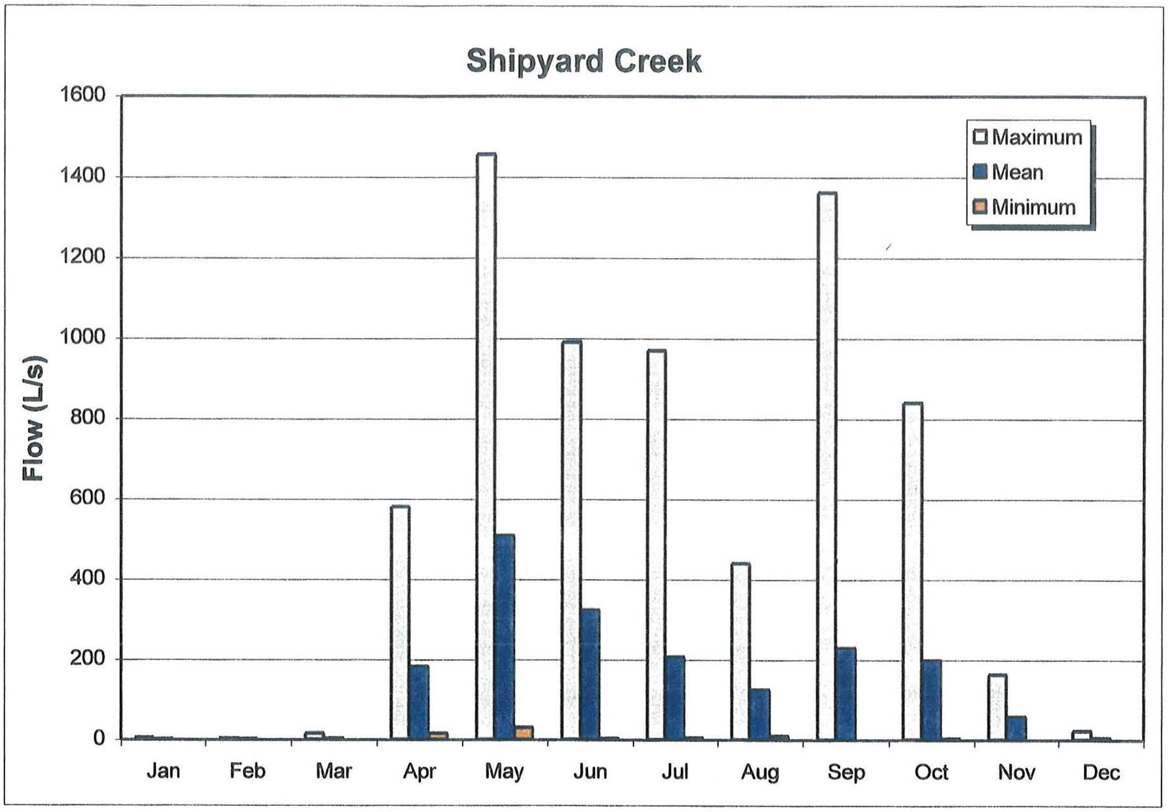
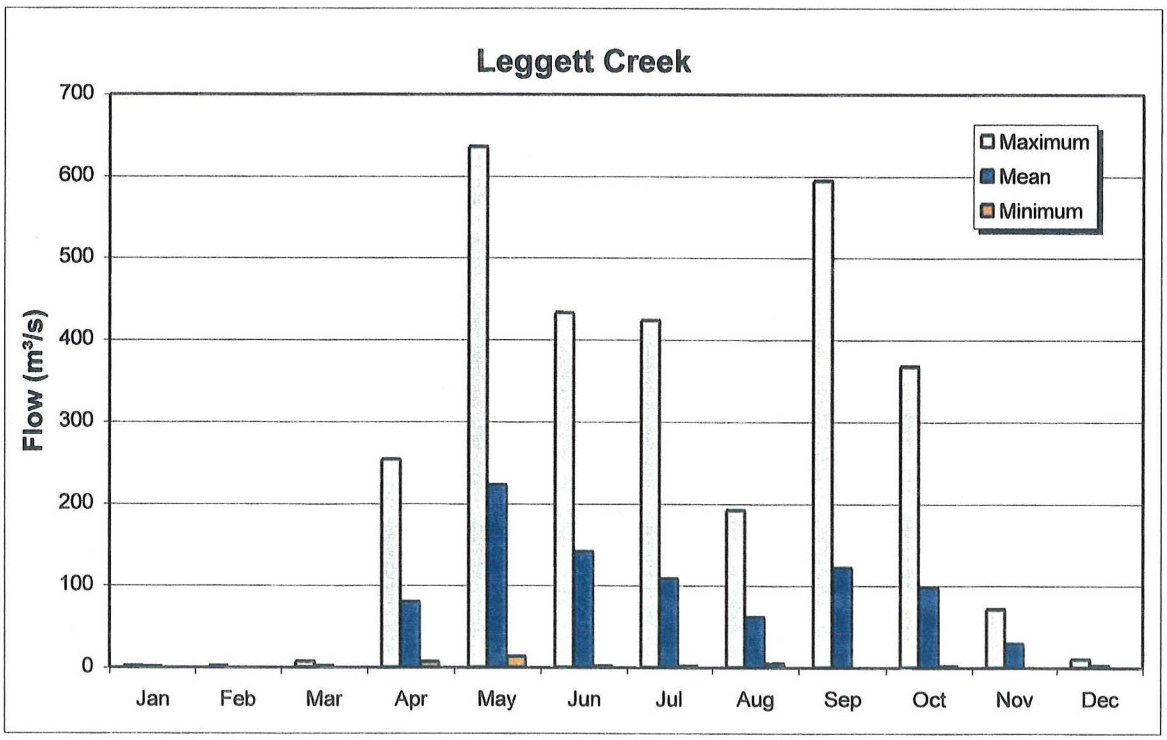
ESTIMATED MONTHLY FLOWS IN SMALLER WATERCOURSES: SHEET 1

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 40 | DRAWN BY: C.P.B. |

2839w172.dwg

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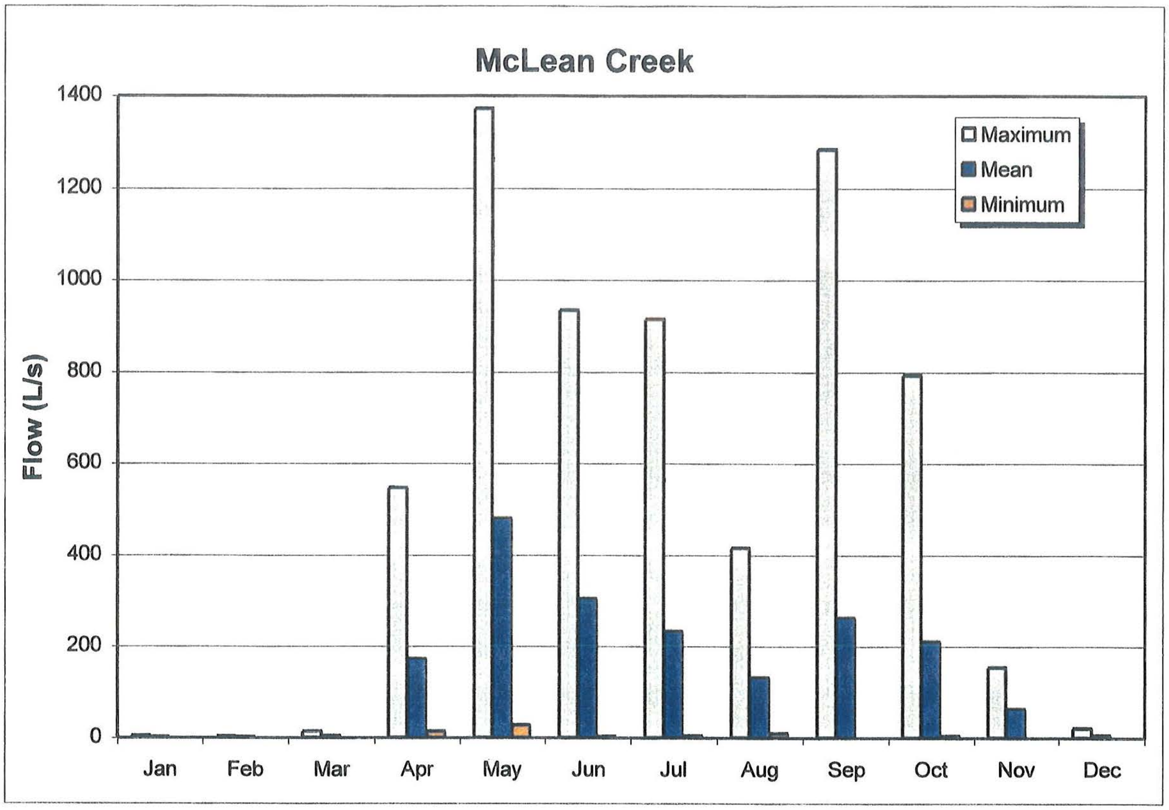
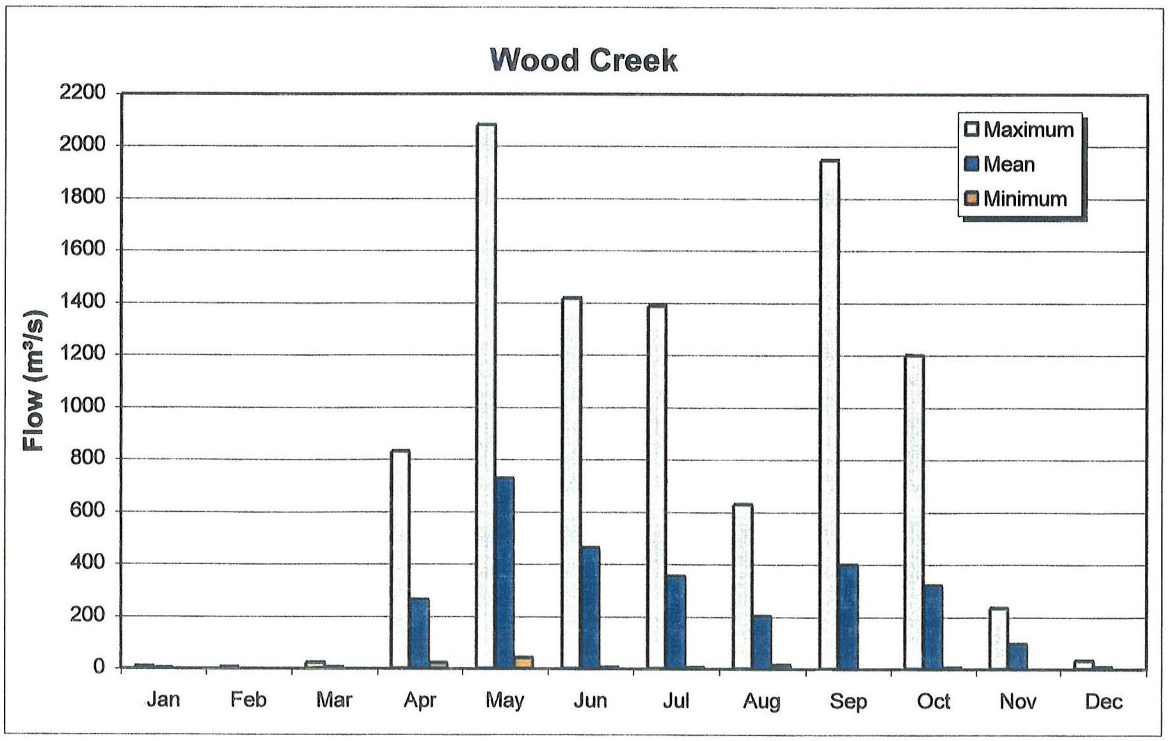
**ESTIMATED MONTHLY FLOWS IN SMALLER WATERCOURSES: SHEET 2**

| APRIL 1998 | FIGURE 41 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg

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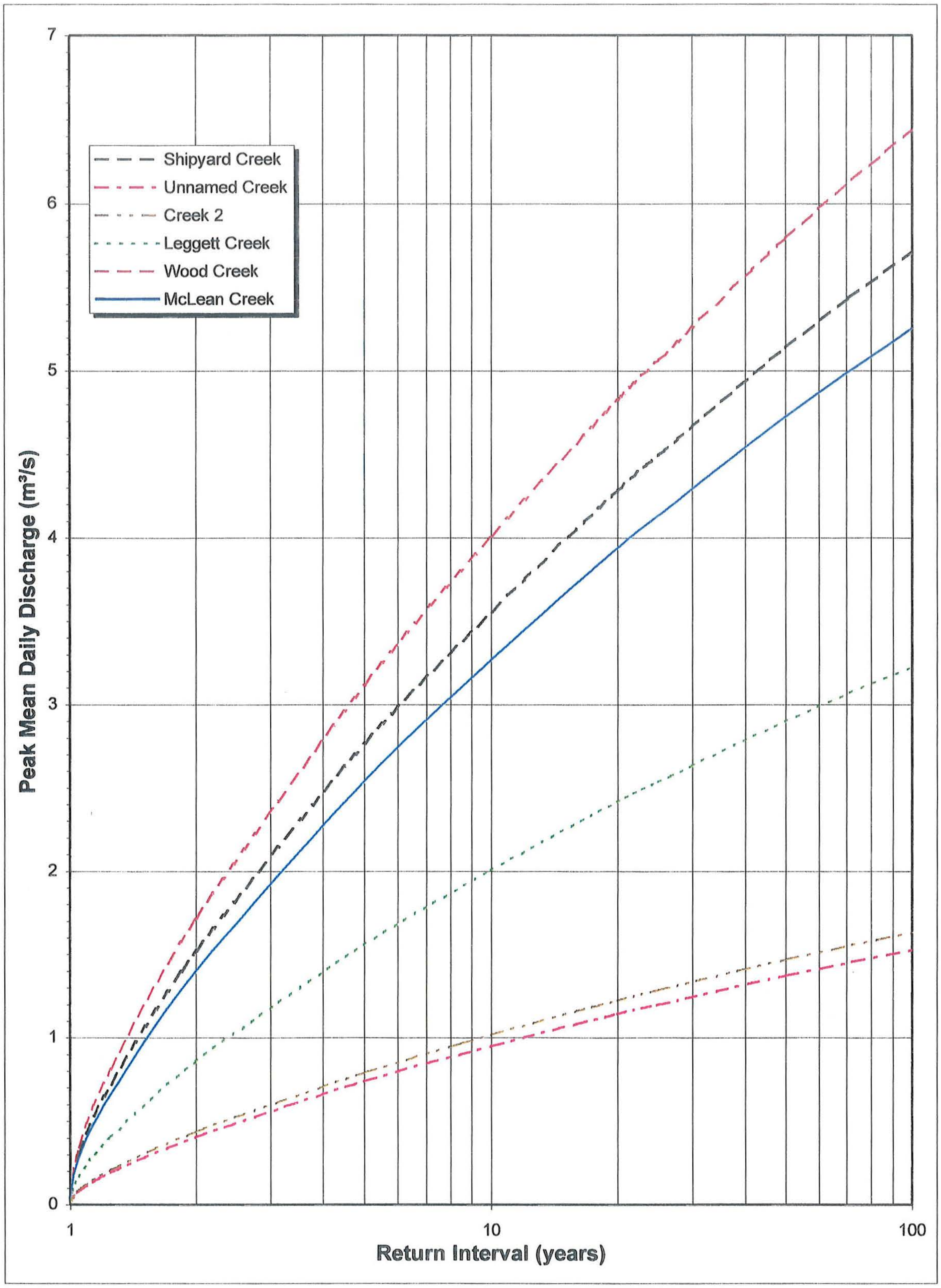
ESTIMATED MONTHLY FLOWS IN SMALLER WATERCOURSES: SHEET 3

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 42 | DRAWN BY: C.P.B. |

2839w172.dwg

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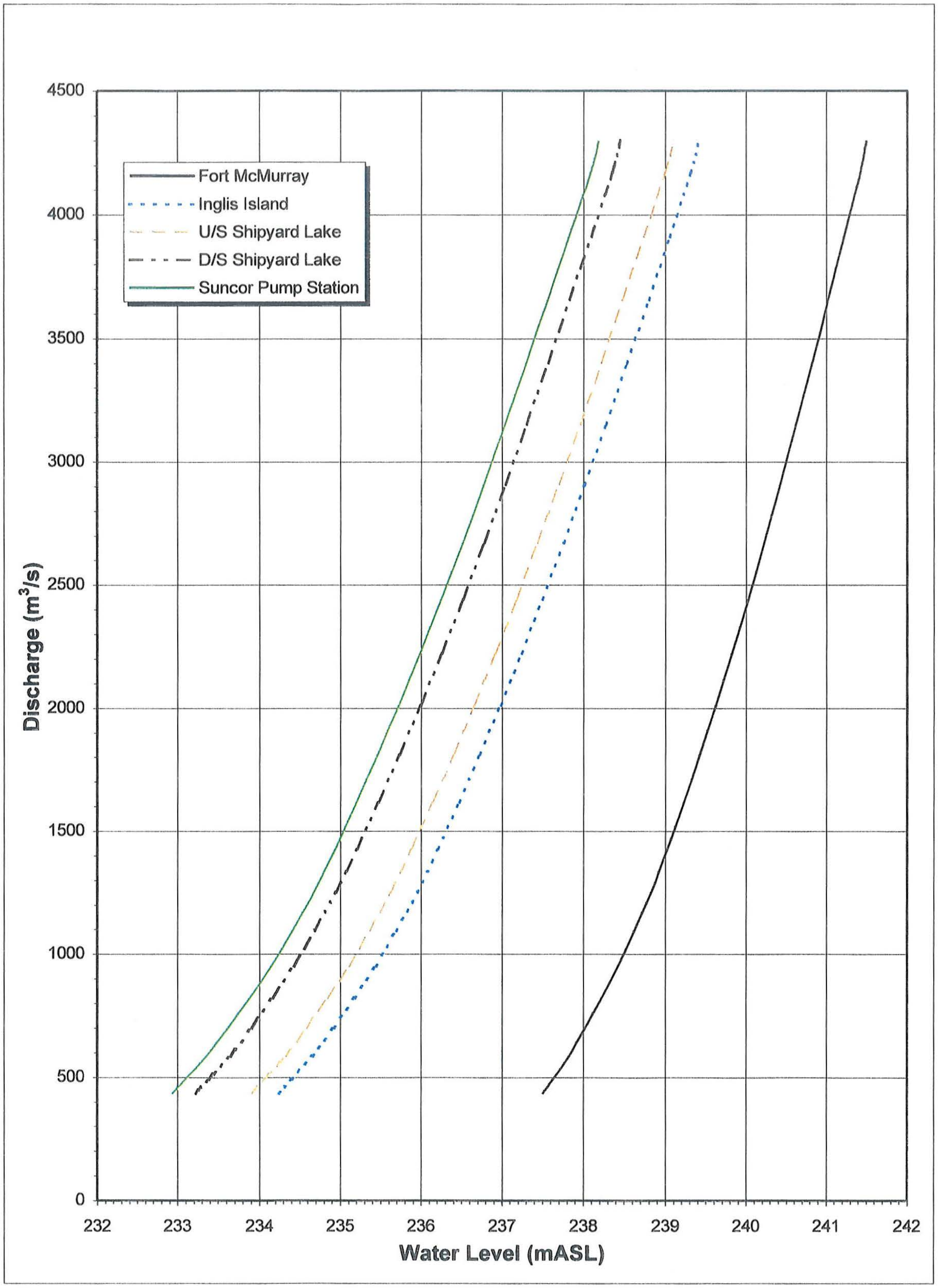
ESTIMATED FLOOD FLOWS FOR SMALLER WATERCOURSES

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 43 | DRAWN BY: C.P.B. |

2839w172.dwg

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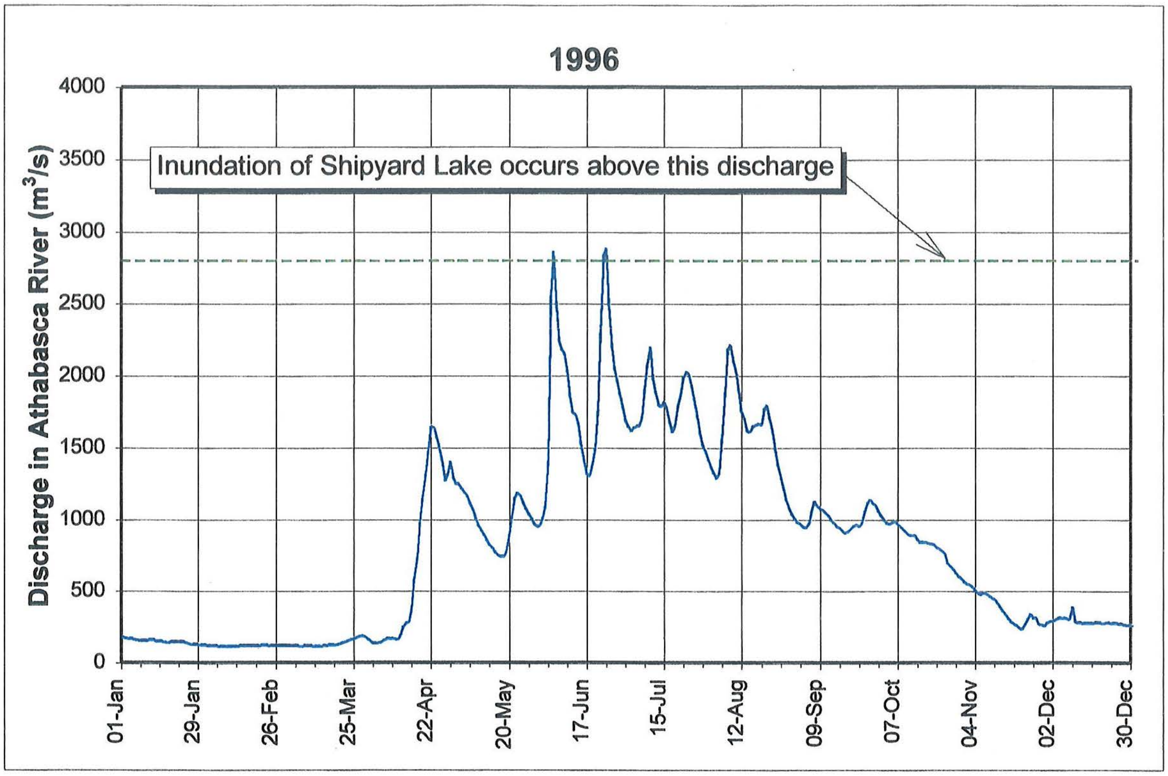
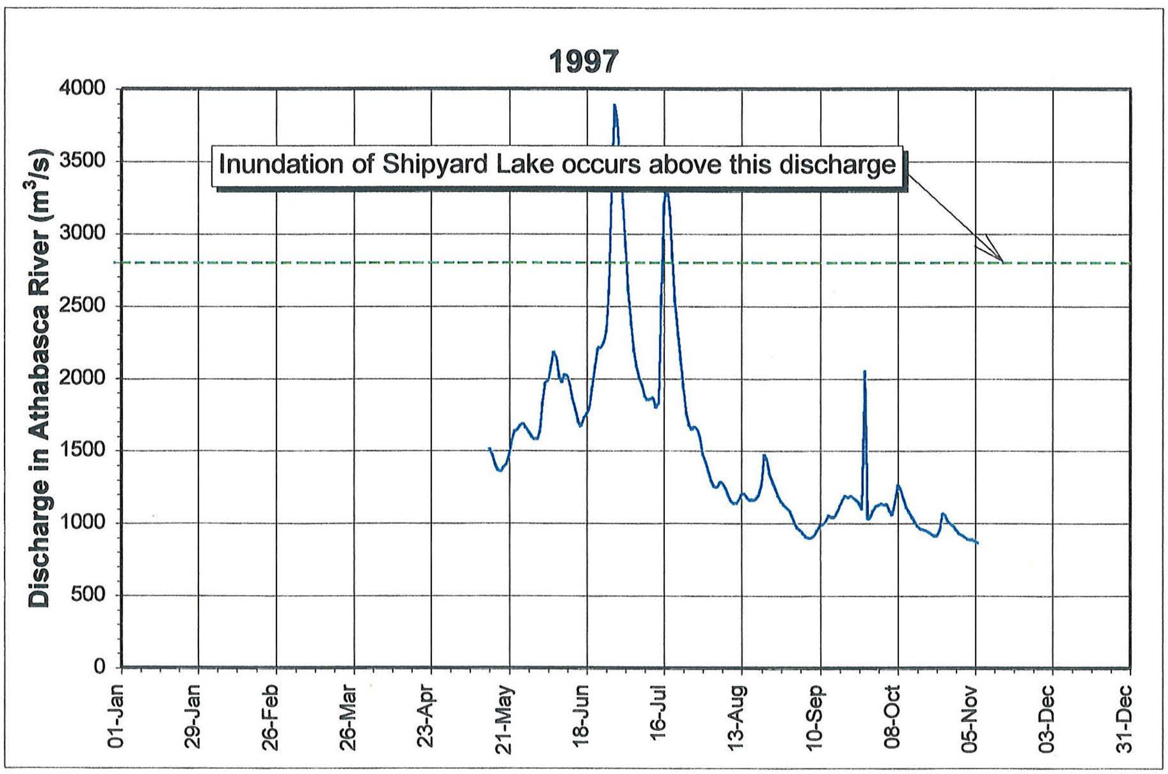
ATHABASCA RIVER: ESTIMATED STAGE-DISCHARGE CURVES

| | | | |
|---|---|---|---|
| APRIL 1998 | FIGURE 44 | DRAWN BY: | C.P.B. |

2839w172.dwg

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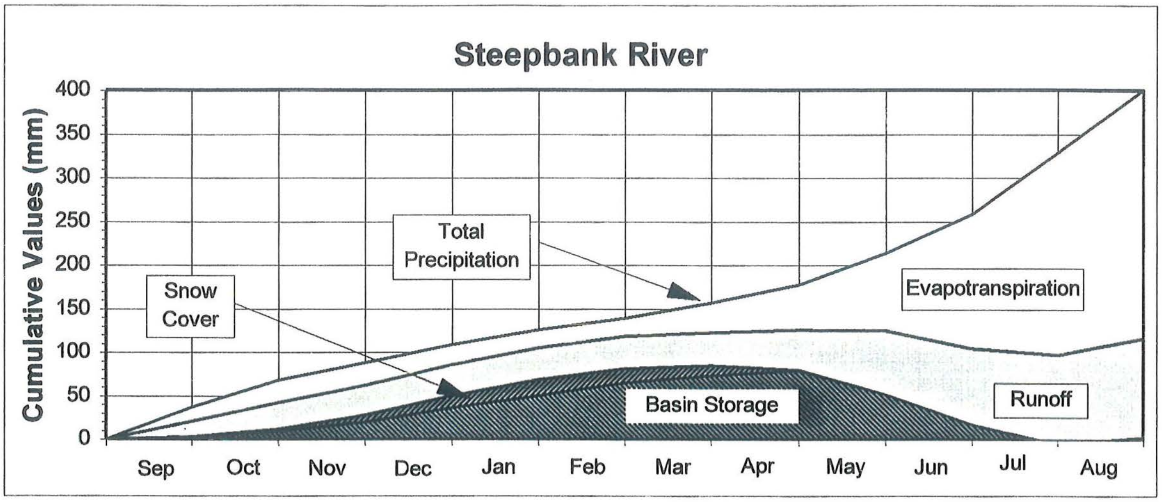
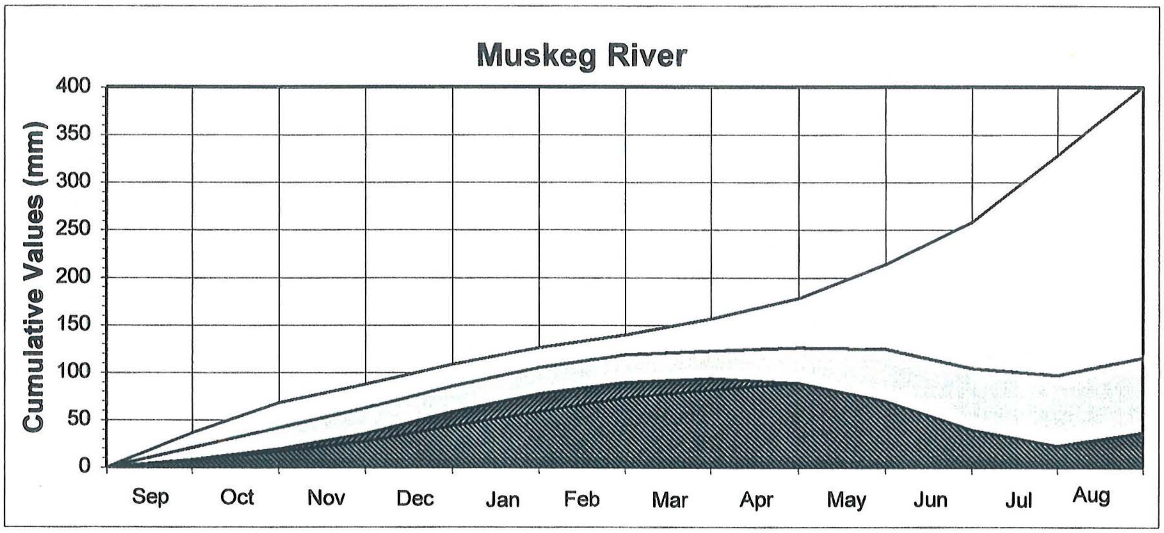
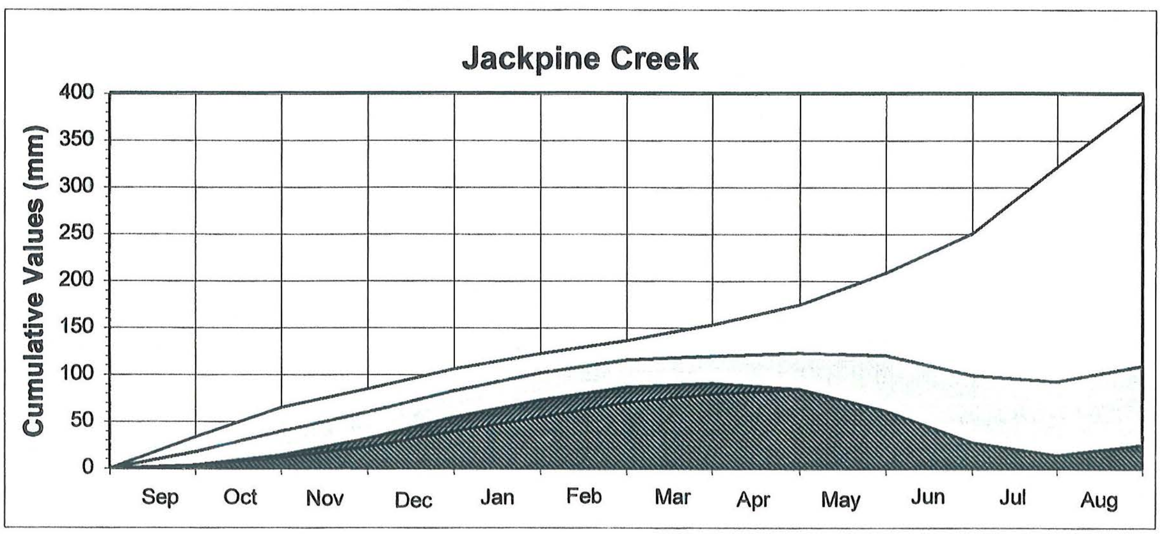
INNUNDATION OF SHIPYARD CREEK

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 45 | DRAWN BY: C.P.B. |

2839w172.dwg

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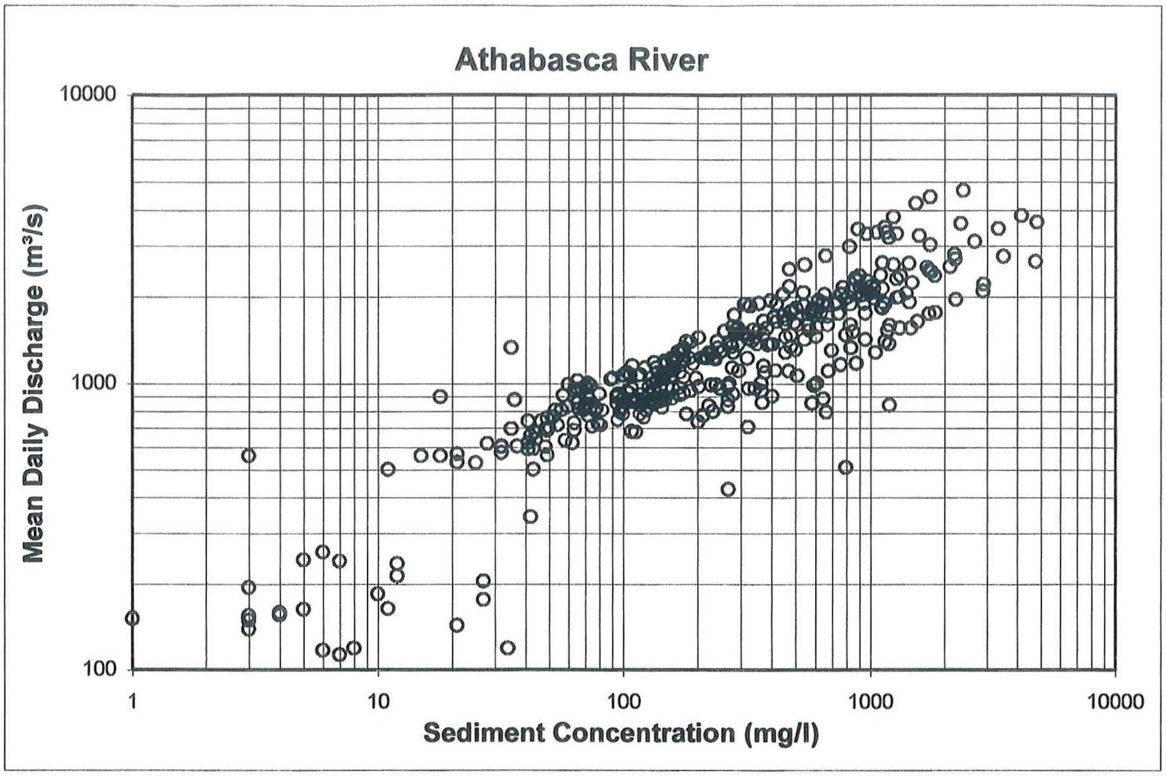
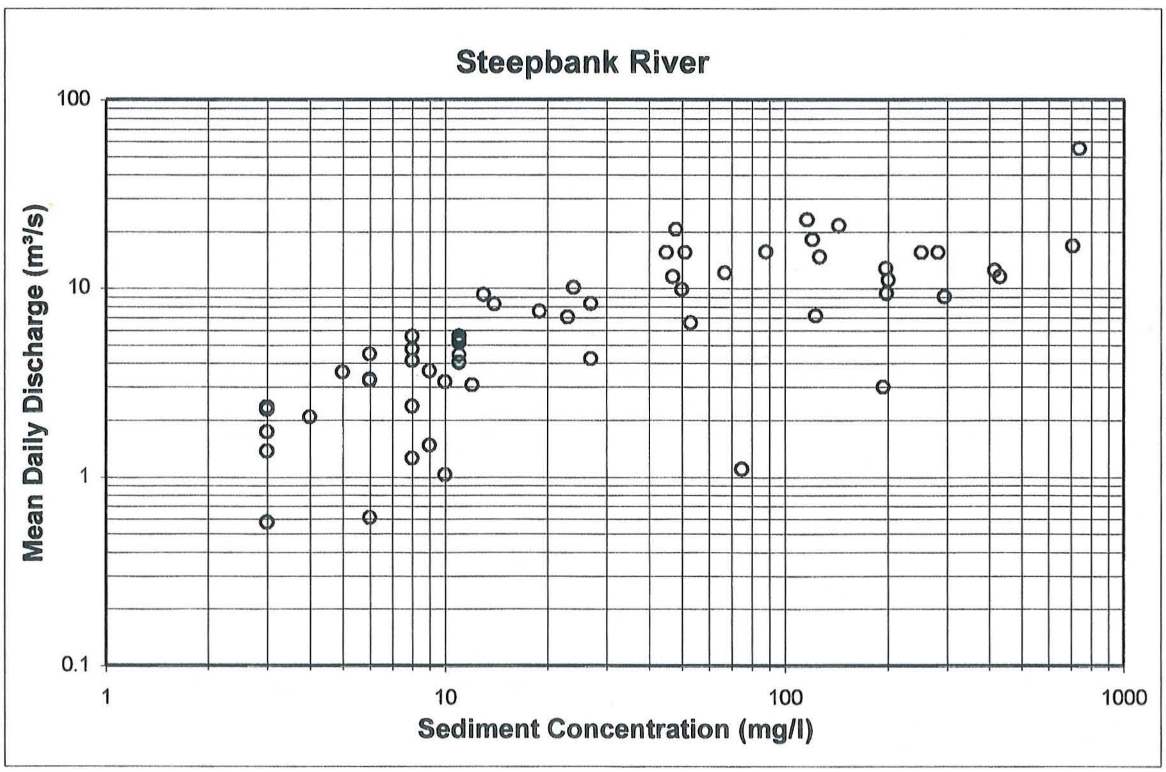
WATER BALANCE FOR LARGER WATERCOURSES

| APRIL 1998 | FIGURE 46 | DRAWN BY: C.P.B. |
|---|---|---|

2839w172.dwg




| | | |
|---|---|---|
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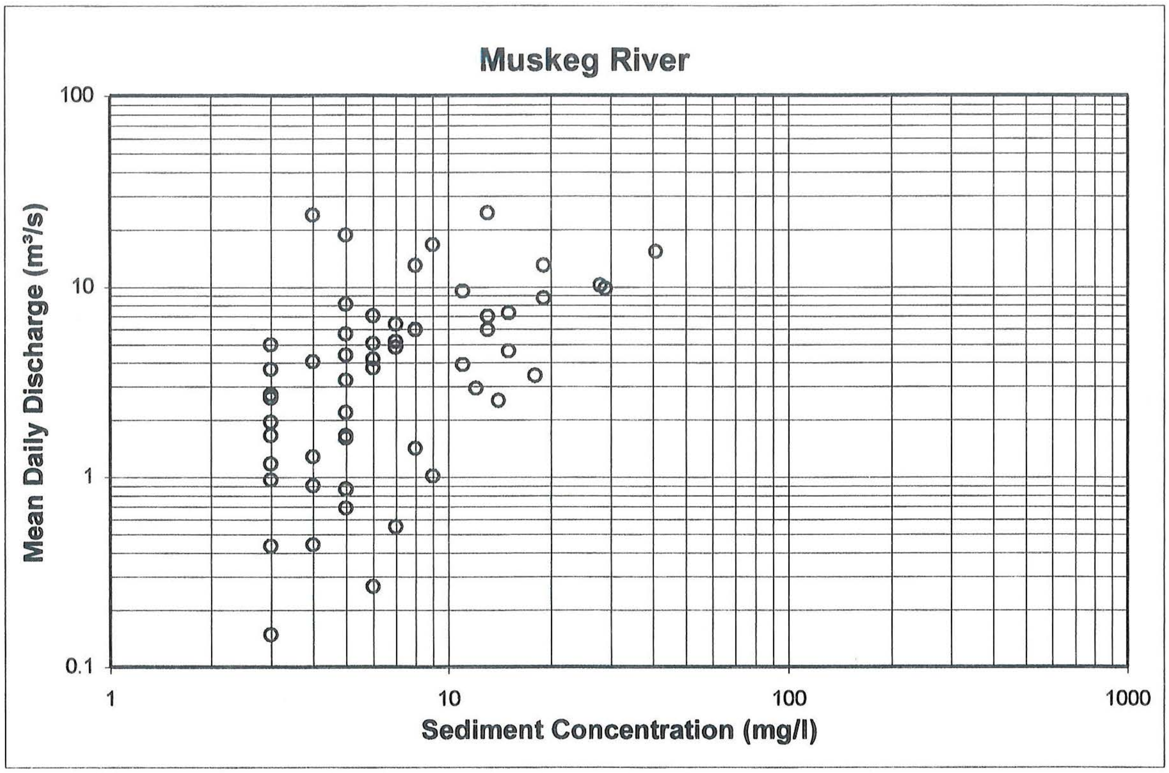
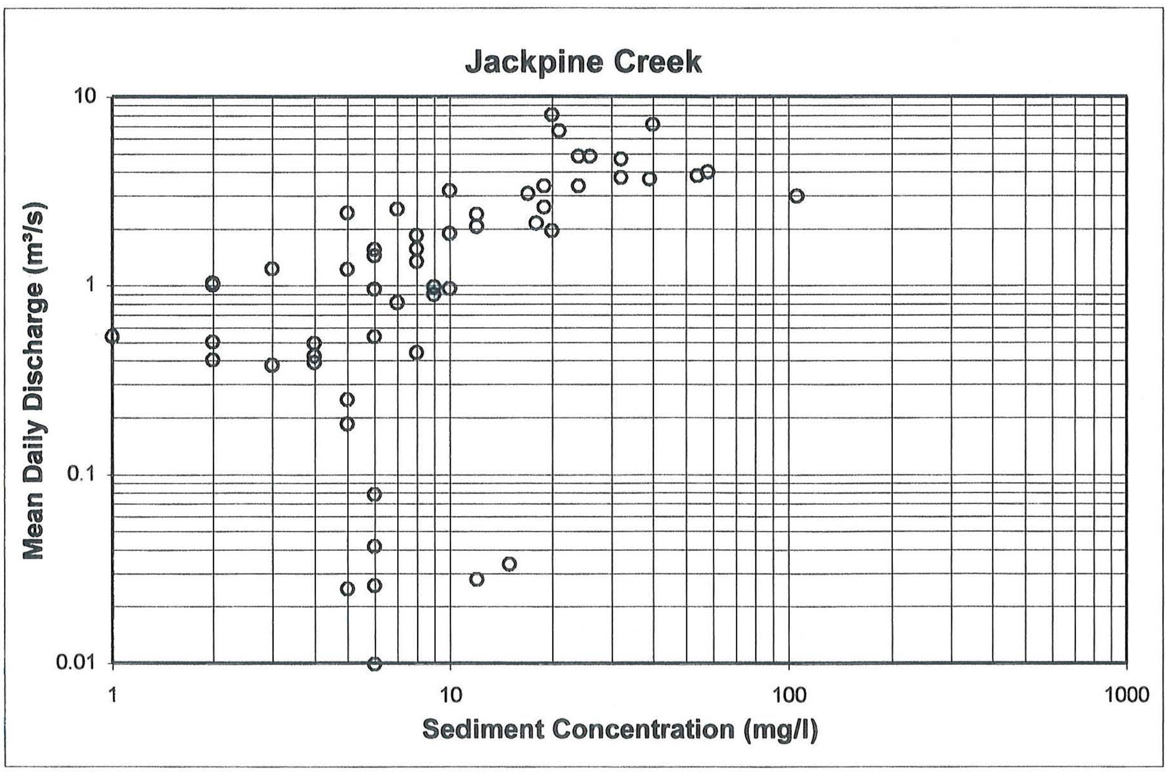
| SEDIMENT CONCENTRATION: SHEET 1 | | |
| APRIL 1998 | FIGURE 47 | DRAWN BY: C.P.B. |

2839w172.dwg

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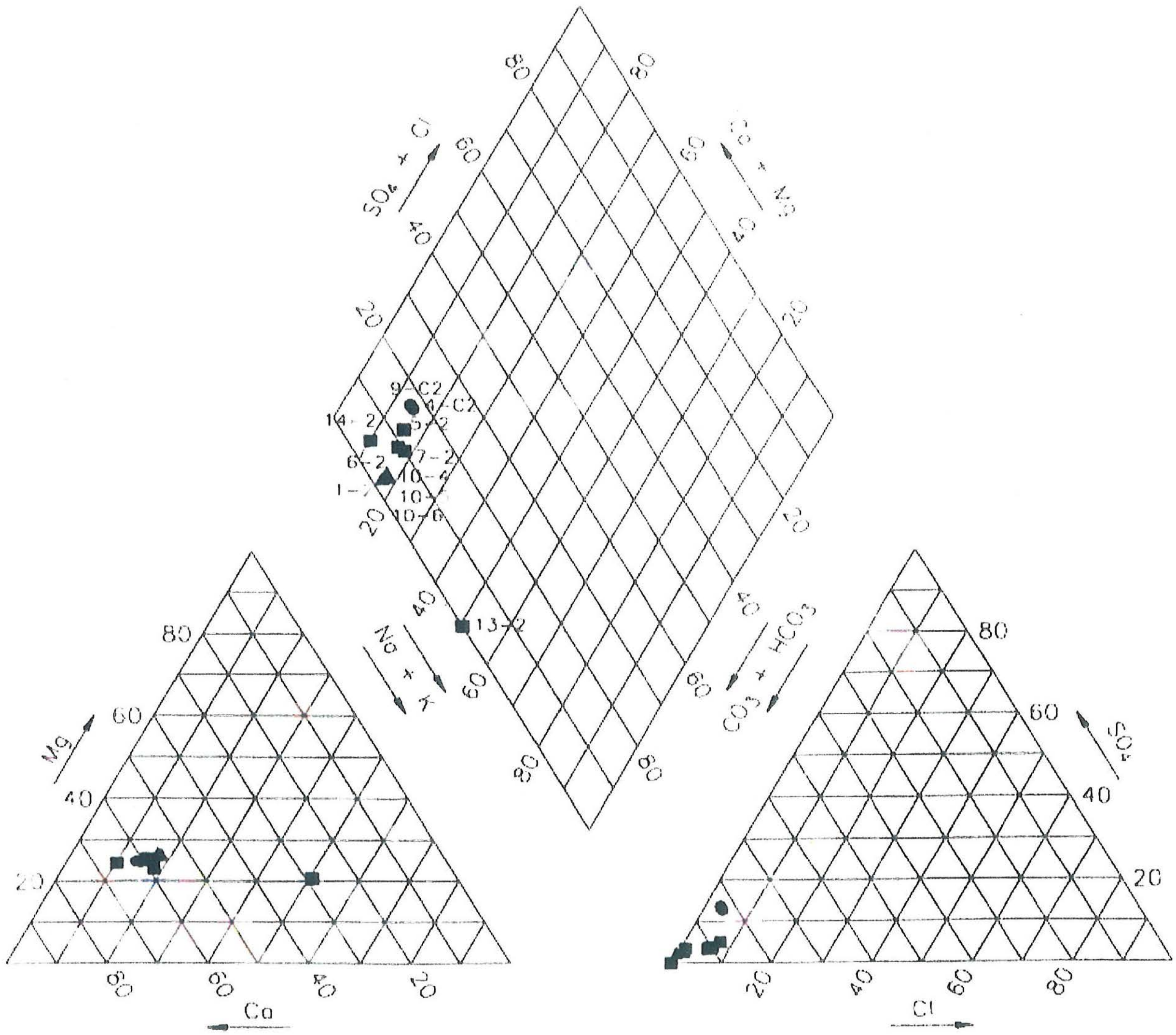
SEDIMENT CONCENTRATION: SHEET 2

| | | |
|---|---|---|
| APRIL 1998 | FIGURE 48 | DRAWN BY: C.P.B. |

2B39w172.dwg

| Site | Plot No | Location | Matrix | Ca | Mg | Na | K | Cl | SO4 | Alkalinity |
|---|---|---|---|---|---|---|---|---|---|---|
| AW001-S002 | 1-2 | Steepbank-L19 border | surface | 22.5 | 6.4 | 7.5 | 0.63 | 0 | 1.6 | 79.7 |
| AW005-S002 | 5-2 | McLean creek-mouth | surface | 38.5 | 10.1 | 11 | 0.92 | 8 | 7.3 | 132 |
| AW006-S002 | 6-2 | Wood creek-mouth | surface | 51.7 | 13.6 | 16.3 | 0.6 | 7 | 5.8 | 157 |
| AW007-S002 | 7-2 | Reference wetland outlet | surface | 48.2 | 11.4 | 16.2 | 1.47 | 8 | 6.6 | 161 |
| AW010-S004 | 10-4 | Steepbank-mouth | surface | 26.3 | 7.2 | 9 | 0.41 | 0.8 | 2.2 | 89.3 |
| AW010-S005 | 10-5 | Steepbank-mouth | surface | 25.4 | 7.1 | 9 | 0.48 | 0.9 | 2.1 | 89.6 |
| AW010-S006 | 10-6 | Steepbank-mouth | surface | 25 | 7.1 | 9.1 | 0.5 | 0.8 | 2.1 | 90.1 |
| AW013-S002 | 13-2 | Unnamed creek field blank | surface | 0.3 | 0.13 | 0.57 | 0.06 | 0 | 0 | 3.2 |
| AW014-S002 | 14-2 | Legget creek-mouth | surface | 50.1 | 11.3 | 8.6 | 0.68 | 1.2 | 5.3 | 148 |
| AW004-C002 | 4-C2 | Athabasca-u/s L19 | composite | 32.5 | 8 | 8.6 | 0.9 | 3.1 | 13.1 | 88.2 |
| AW009-C002 | 9-C2 | Athabasca-u/s L25 | composite | 33.5 | 8.2 | 8.3 | 0.7 | 2.6 | 14.2 | 90.3 |




CATIONS

ANIONS

PERCENTAGE

SUNCOR ENERGY

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SURFACE WATER CHEMISTRY

| APRIL 1998 | FIGURE 49 | DRAWN BY: C.S.F. |
|---|---|---|

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