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May 5, 2006

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Faro Mine Closure Planning Office
206, Hanson St.,
Whitehorse,
Yukon
Y1A 1Y4

Attention: Roger Payne
Director

Re: PMF determination- Faro Mine Yukon

Dear Sir:

Water Management Consultants is pleased to present the attached report on the Probable Maximum Flood (PMF) for Faro Mine Yukon.

Thank you for this opportunity to provide consulting services to the Faro Mine Closure Planning Office.

Yours truly,

CDN WATER MANAGEMENT CONSULTANTS

C. David Sellars, P. Eng.
Principal

FARO MINE

ROSE CREEK
PROBABLE MAXIMUM FLOOD

May 2006

7113

Prepared for:

Deloitte and Touche
on behalf of the

Faro Mine Closure Project Office
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CONTENTS

EXECUTIVE SUMMARY

ROSE CREEK PROBABLE MAXIMUM FLOOD

WATER MANAGEMENT CONSULTANTS

The objectives of the study were to:

- Determine catchment characteristics for the sub-catchments contributing to Rose Creek
- Calculate basin-wide Probable Maximum Precipitation (PMP)
- Carry out hydrologic modelling of the PMP and antecedent conditions to estimate the Probable Maximum Flood (PMF) at three locations:
    - At the Haul Road crossing
    - At the upstream end of the Rose Creek Diversion
    - At the downstream end of the Rose Creek Diversion
- Complete sensitivity analysis of modelling parameters
- Compare the results with significant recorded flood events

The hydrologic analysis determined the PMF resulting from the PMP. It was concluded that a rain-on-snow event would be an appropriate PMF scenario. The recommended PMF values for Rose Creek are as follows:

North Fork	384 m^3/s
Upper end of Rose Creek Diversion	674 m^3/s
Lower end of Rose Creek Diversion	692 m^3/s

The results were compared with significant recorded events in the region and it was concluded that the results were reasonable when compared with peak flows recorded in southeast Yukon.

No further work has been recommended on the PMF and the results have been approved by the Faro Mine Closure Project Office.

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1. INTRODUCTION

This report on the Probable Maximum Flood (PMF) for Rose Creek at the Faro Mine, Yukon, was prepared by Water Management Consultants of Richmond BC under contract to Deloitte and Touche. The letter of authorization from Deloitte and Touche to proceed with the study was dated August 23, 2005

Rose Creek is currently diverted around the tailings deposition area at the Faro Mine. A PMF estimate for Rose Creek is required to determine the design flow for the diversion channel.

An estimate of the Probable Maximum Precipitation (PMP) for the Faro Mine has been provided in a report by George Taylor dated October 2005. This PMF study used the PMP characteristics defined in the Taylor report and subsequent communications.

The scope of work for this study included the following:

- Determination of catchment characteristics for the sub-catchments contributing to Rose Creek

- Calculation of basin-wide PMP

- Hydrologic modelling of the PMP and antecedent conditions to estimate the PMF at three locations:

    - At the Haul Road crossing
    - At the upstream end of the Rose Creek Diversion
    - At the downstream end of the Rose Creek Diversion

- Sensitivity analysis of modelling parameters

- Comparison with significant recorded flood events

2. ROSE CREEK CATCHMENT

The catchment of Rose Creek is located east of the Faro Mine in the Anvil Range and has an elevation range of 3400 feet (1040 m) to 6600 feet (2010 m). Figure 1 is a general plan of the Rose Creek catchment area.

The North Fork of Rose Creek is defined for this report at the Haul Road Crossing. The catchment area of the North Fork above this point is 122.5 km^2. This includes the catchment of Faro Creek which is currently diverted around the pit into the North Fork. During a PMF event this diversion may fail and the overflow would enter the pit and water eventually discharge to the North Fork.

The South Fork originates just west of the headwaters of Vangorda Creek and has a total catchment area of 83.5 km^2 including a small portion downstream of the Haul Road Crossing. A water supply dam had been located on this creek but it has since been removed.

A third catchment area of 11.3 km^2 was defined for the south slope above the Rose Creek diversion.

The Rose Creek watershed is characterized by moderately steep slopes in the lower portions and very steep slopes in the headwaters. The watershed area was inspected from the air on September 13 2005. The upper slopes have exposed bedrock outcrops and the lower slopes are characterized by shallow muskeg overlying bedrock and glacial deposits with likely areas of discontinuous permafrost. While there will be the potential for water storage in the muskeg in dry periods, once saturated, the runoff potential from these areas will be high. During the inspection the catchment boundaries defined from the 1:50,000 topographic mapping (Sheet 105K/6) were confirmed including the uncertain catchment boundary at the east end of the North Fork watershed.

3. PROBABLE MAXIMUM PRECIPITATION

3.1. Point PMP estimates

A PMP study for the Faro area was carried out by George Taylor of the Oregon Climate Service. The report (Taylor, 2005a) concluded that the largest storm transferable to the Faro Mine area was the Quiet Lake event of July, 1972 which produced a maximum one-day precipitation total of 66 mm. Maximizing moisture and transposing the observed data to the Faro Mine area produced a point PMP estimate of 175 mm in 24 hours. This value corresponds to the highest elevations in the Rose Creek watershed area. Detailed point PMP estimates were provided by George Taylor to Water Management Consultants and the variation in PMP values across the watershed is considerable. At low elevations in the Rose Creek valley, point 24-hour PMP values were estimated by Taylor to be 86 mm.

3.2. Basin wide PMP values

Figure 2 is the 24-hour point PMP distribution across the Rose Creek catchment area. To determine the hydrologic model input requirements a basin average PMP is required. The point PMP values in Figure 2 were used to calculate the average point PMP in each catchment area. The depth-area reduction relationships provided by Taylor (2005b) were then used to calculate the area-wide PMP values. For the derivation of the PMF for the diversion, the appropriate area reduction for the PMP is 0.78 for the entire basin as shown in Table 1.

Table 1: Subcatchment 24-hour PMP values in mm

Subcatchment	Average point PMP	Area Reduction	Area wide PMP
North Fork	118	0.78	92
South Fork	121	0.78	94
South Slope	96	0.78	75

3.3. Time distribution of PMP

The Taylor (2005a) report provides a time distribution of PMP as shown in Table 2 based on data from eastern Washington State derived from US Department of Commerce (1994). This time distribution is similar to the SCS Type 1 distribution, which is recommended for Alaska in Haan et al (1994). This provides additional justification for application in Yukon.

Table 2: Time distribution of PMP

Averaging period (hours)	Ratio
1	0.20
2	0.36
3	0.46
6	0.59
8	0.70
12	0.80
18	0.91
24	1.00

For the hydrologic modelling a time step of 30 minutes was required and the values in Table 2 were extrapolated to give a ratio of 0.12 for a 30 minute period. As shown in Table 2, about 80% of the PMP occurs in 12 hours.

To develop a hyetograph for hydrologic modelling, the time distribution was developed in 15 minute increments using the alternating block method recommended by the WMO (1986). The highest intensities are placed in the centre of the storm as shown in Figure 3.

The Taylor report indicates that the month of June has the highest extreme one-day precipitation values. Therefore the PMP is most likely to occur in the month of June. Antecedent conditions for the PMP are discussed in the next section.

4. HYDROLOGIC MODELLING

4.1. HEC-HMS Model

A hydrologic model of the Rose Creek watershed was set up using HEC-HMS. HEC-HMS is the Hydrologic Modelling System developed by the US Army Corps of Engineers and was the modelling software used for this study. HEC-HMS is designed to simulate the precipitation-runoff processes of watershed systems including converting precipitation to discharges and determining the effects of lake routing.

The model was set up with three subcatchments as described in Section 2. The hydrographs from each subcatchment were calculated in the model and added together to produce the total downstream flow at two key points, just upstream of the diversion channel and at the lower end of the diversion channel. As routing effects in the diversion channel would be negligible this was not included in the model. Flows were also tabulated for the North Fork as it is understood that the Haul Road crossing is under consideration for use in flood attenuation. The area reduction factor for the PMP used to derive the PMF for the North Fork was 0.78, the same as the basin-wide PMP. The resulting flow from the North Fork would be the flow that would be expected to contribute to the PMF for the entire basin.

It was assumed at mine closure that the Haul Road crossing would be removed so the potential attenuation effect of this feature was not included in the model. It was also assumed that the Faro Creek diversion would not fail in the PMF and the flow would continue to be diverted around the pit. This is a conservative assumption as there would be some attenuation effect if Faro Creek flowed through the pit.

To model peak flows from a basin it is necessary to define the catchment areas and the processes the model will use to convert precipitation to discharge. There are three processes that need to be defined: loss, transform and baseflow.

The loss process determines the amount of precipitation that is lost to infiltration and the US Soil Conservation Service (SCS) curve number method was used to characterize losses. The SCS curve number method combines infiltration losses with initial abstractions to derive rainfall excess, which is the portion of the rainfall available for runoff. As part of the SCS method it is necessary to define the initial loss, percent impervious and the CN number, which is parameter characterizing soil moisture conditions. The CN number is a composite parameter that integrates the soil and land use conditions in a watershed. For the subcatchments in the model these values were assigned based on the extreme conditions consistent with the PMP methodology. The CN number was set between 85 and 95 representing wet antecedent conditions.

The second process that needs to be defined is the transform process. Precipitation that does not infiltrate becomes direct runoff that travels across the ground to streams and rivers. The transform process determines and surface routing of the runoff. For the Rose Creek model the SCS unit hydrograph method was used. The SCS unit hydrograph is a dimensionless unit hydrograph that was developed by the SCS from recorded data on small watersheds. The dimensionless unit hydrograph is built-in to the HMS model and is selected by the user. The SCS unit hydrograph is a single parameter hydrograph defined by the lag time. This means that the shape of the hydrograph is a function of the basin lag time. The longer the lag time, the wider the hydrograph and the lower the peak.

The June 2004 event on Vangorda Creek was examined and the time to peak at the gauge at Faro estimated to be about 6.5 hours based on the recording rain gauges at Faro and VanGrum. This is longer than would be expected from standard response time equations which is likely due to the fact that the VanGrum gauge is not located in the headwaters where the highest storm intensities would have occurred. The percent runoff from the June 2004 event was estimated to be 58% indicative of the high runoff potential in the area.

A number of response time empirical equations have been developed over the years. The expression proposed by Watt and Chow (1985) consolidated the lag time data from across North America. The Watt and Chow general equation for basin lag time applies to natural basins with minimal effective lake and swamp storage. was used for the hydrologic modelling. As noted by Watt and Chow, because of non linearities in basin response, the equation may overestimate lag time for very large precipitation events.

Estimates of lag time for the Rose Creek subcatchments are provided in Table 3. These values are similar to the values adopted for the North Fork and South Fork subcatchments in Northwest Hydraulics (2004).

The third process, baseflow, determines the contribution to channel flow from groundwater. A constant monthly baseflow method was used to define the contribution from groundwater and recession flows from storms prior to the occurrence of the PMP storm. This was based on mean monthly flow records from Vangorda Creek. For the period of record the largest mean monthly flow in June was in 1992 with a mean monthly flow of 4.04 m^3/s. Prorating to the other catchments the baseflows used in the modelling were as shown in Table 3

Table 3: Base flows and response times for Rose Creek subcatchments

Subcatchment	Area in km^2	Baseflow in m^3/s	Lag time in hours
North Fork	122.5	5.4	3.5
South Fork	83.5	3.7	2.7
South Slope	11.3	0.5	0.6

4.2. Snowmelt

The most critical conditions for a rain-on snow flood event are when there is a relatively shallow snowpack on the basin. A deep snow pack has the tendency to absorb precipitation and retard runoff. A shallow snowpack will contribute to excess runoff and would likely be removed during the PMP event. A shallow snowpack could occur at the later stages of the spring snowmelt in early June which is the month when the PMP is most likely to occur.

Snow pillow data for Withers Lake 190 km north of Faro were reviewed. The data were provided by Ric Janowicz of Yukon Department of Environment. The elevation of the snow pillow is 975 m which is similar to the lowest elevations of the Rose Creek watershed. In 2003 there was about 50 mm of snow water equivalent persisting into the first week of June at Withers Lake which represents shallow snowpack conditions. Snow persisted on the ground at Withers Lake into the first week of June for about 3 years out of the 9 years of record. It was concluded that it is possible that an amount of snow, similar to that recorded in the first week of June in 2003 at Withers Lake, could cover the entire Rose Creek watershed prior to the PMP event. Therefore a rain-on-snow event was modelled.

The rate of snowmelt during a rain event was based on equations developed by Gray (1970). The methodology requires estimates of daily temperature during the storm event, wind speed and rainfall intensity. The estimate of daily temperature during the PMP event was based on the conditions recorded during the Quiet Lake storm which was the controlling storm for development of the PMP. The mean temperature during the PMP event was estimated to be 10 degrees Celsius and the mean wind speed 10 km/h. The Gray equations indicate a melt rate for the rain-on-snow conditions of 2.06 mm/h. This melt rate was added to the input precipitation to simulate rain-on-snow conditions.

The total daily melt corresponds to 49.5 mm. Based on records at Withers Lake, this quantity of snow water equivalent is reasonable to assume on the Rose Creek watershed prior to a PMP in early June.

4.3. Results

The results of the analysis for the lower end of the Rose Creek Diversion Channel are shown in Table 4.

Table 4: PMF for the Rose Creek Diversion Channel for various scenarios

CN	Rainfall only m^3/s	Runoff %	Rain-on-snow m^3/s	Runoff %
85	392	53	570	65
90	470	66	637	75
95	548	81	692	86

As discussed in Section 4.2 it is quite possible that the PMP could occur with a snowpack covering the entire basin. Under these conditions the antecedent conditions would be very wet and/or the ground could be frozen. Therefore it is recommended that the scenario with a CN value of 95 combined with snowmelt should be selected for deriving the PMF.

The recommended PMF values for Rose Creek are as follows:

North Fork	384 m^3/s
Upper end of Rose Creek Diversion	674 m^3/s
Lower end of Rose Creek Diversion	692 m^3/s

Figure 4 shows the PMF hydrographs for the lower end of the Rose Creek Diversion and for the North Fork of Rose Creek.

4.4. Comparison with other high flows

The Guidelines on Extreme Flood Analysis prepared in 2004 for the Province of Alberta are the most recent guidelines on derivation of PMF in Canada. The Guidelines recommend that PMF estimates should be subjected to empirical checks and comparisons designed to set them in context and to verify that they appear reasonable and compatible with estimates for other projects.

The Creager diagram that plots peak unit discharge against drainage area has been used extensively to provide a context for PMF estimates and other large floods. Maximum known discharges for Canadian rivers were presented using the Creager Diagram in Watt et. al. (1989). The concave curves of the Creager coefficient C are based on a double exponential equation. The curves, shown in Figure 5 illustrate C values of 20, 30, 60 and 100.

There are few data available on extreme peak flows from rainfall events in northern Canada. An extreme summer storm in the Mackenzie Mountains in NWT that occurred in July 1970 was documented by MacKay et.al. (1973). The storm was thought to cover an area of about 80,000 km^2 and caused devastating floods in east side tributaries of the Mackenzie River. The peak flow in the Arctic Red River was calculated by the slope-area method to be 7,640 m^3/s for a drainage area of 15,130 km^2. This represents a Creager C value of 35. During the same event the Mountain River recorded a flow with a C value of 30. These points are plotted on Figure 5.

In June 1971 a rain-on-snow event occurred in the Fort Nelson area in northern BC and was documented by Smith (1975). The Fort Nelson and Muskwa Rivers experienced flows with Creager C values of 32 and 34 respectively as shown on Figure 5.

The Rose Creek PMF values are plotted on Figure 5 for the North Fork, South Fork and Rose Creek Diversion. The PMF estimates for Rose Creek represent C values of around 20. These are lower than the recorded C values in northern BC and nearby NWT as described above. This is likely due to the potential storm rainfall on the east side of the divide being considerably less than on the west side. In Taylor (2005a) it was concluded that the orographic barriers separating the Faro Mine area from other regions would have caused significant modification of the storms. For that reason, a decision was made to use only Yukon storms in the PMP analysis. Furthermore there are no precipitation data available for the July 1970 event in the Mackenzie Mountains.

Creager C values for three PMF analyses in Alberta are also plotted in Figure 5. These PMF values represent a C value of about 60. The highest recorded C value in Alberta was 45 for the 1987 Simonette River flood.

It would normally be expected that PMF estimates would exceed the Creager values from recorded events. The Rose Creek PMF does not exceed the Creager values from floods in the eastern Mackenzie Mountains and northern BC because the PMP values derived by Taylor (2005a) indicate a relatively dry climate in the Faro area with limited potential for producing extreme rainfall.

To provide confirmation of the Creager values derived in the modelling we reviewed data for stream gauges located only in southeast Yukon for drainage areas less than 7,500 km^2. Maximum recorded floods on basins larger than 7,500 km^2 would most likely be a result of snowmelt-only events. Table 5 summarizes the maximum recorded flows at selected gauging stations in southeast Yukon and the corresponding Creager C values. Many of these floods would have had a snowmelt component.

The C values in Table 5 are all less than 10 with the largest value of C= 7 for the 1992 flood on the Hess River above Emerald Creek. This assessment supports the conclusion that the Faro area has a relatively dry climate with limited potential for producing extreme rainfall. When compared with other recorded floods in southeast Yukon, the estimated Rose Creek PMF Creager values of 20 are consistent with the expectation that Creager values for PMF estimates should be greater than Creager values for maximum recorded floods in the region. The values for Hess River and Hyland River are plotted on Figure 5 and fall well below the C=20 line.

Table 5: Maximum recorded floods in southeast Yukon for basin areas less than 7500 km^2

Station ID	Station name	Area km^2	Peak flow m^3/s	Date	C value
10AA005	Big Creek at km 1084 Alaska Highway	607	105	06/06/1997	2
10AA004	Rancheria River near the mouth	5100	652	14/07/1988	5
09BA001	Ross River at Ross River	7250	762	02/06/1972	5
10AD002	Hyland River at km 108.5 Nahanni Range Road	2150	463	16/06/1992	5
09BB001	South Macmillan River at km 407 Canol Road	997	208	16/06/1992	3
09BA002	Pelly River below Fortin Creek	5020	621	20/05/1993	5
09DA001	Hess River above Emerald Creek	4840	963	15/06/1992	7
09AD002	Sidney River at km 46 South Canol Road	372	65.8	01/06/1983	2
20BC003	Vangorda Creek near Faro	91.2	18.6	18/05/1993	1
29BC004	Blind Creek near Faro	618	44.4	18/05/1993	1
29BB001	Boulder Creek at km 387 North Canol Highway	84.1	29.2	01/06/1985	2
29AD003	Rose River #1 at km 104.9 South Canol Highway	942	102	14/06/1999	2

5. CONCLUSIONS

The point 24-hour PMP estimates for Rose Creek were provided by Taylor (2005b). The estimates range from 86 mm at the lower end of the watershed to 175 mm at the highest elevations. The watershed was divided into subcatchments and area-reduction factors applied to the PMP values. The area-wide 24-hour PMP estimates were as follows:

North Fork	92 mm
South Fork	94 mm
South Slope	75 mm

These PMP values are relatively low compared with PMP values derived in other parts of Canada. The PMP values indicate that the Faro area has a relatively dry climate with limited potential for producing extreme rainfall. Furthermore the PMP analysis concluded that there would be a considerable range of point PMP values with elevation. In other word the orographic influences on PMP are significant in the Rose Creek watershed.

The hydrologic analysis determined the PMF resulting from the PMP. It was concluded that a rain-on-snow event would be an appropriate PMF scenario. The recommended PMF values for Rose Creek are as follows:

North Fork	384 m^3/s
Upper end of Rose Creek Diversion	674 m^3/s
Lower end of Rose Creek Diversion	692 m^3/s

These values were compared with recorded flood events in the general area using the Creager Diagram. The Rose Creek PMF values represent Creager coefficients of around 20. An event in the Mackenzie Mountains to the east of the site in 1970 had a Creager value of 30 to 35. A flood event in the Fort Nelson area to the south of the site had Creager values between 32 and 34.

It would normally be expected that PMF estimates would exceed the Creager values from recorded events. The Rose Creek PMF does not exceed the Creager values from the eastern Mackenzie Mountains and northern BC because the PMP values derived by Taylor (2005a) indicate a relatively dry climate in the Faro area with limited potential for producing extreme rainfall particularly at lower elevations in the watershed. This was supported by an analysis of peak flows from gauges only in southeast Yukon which showed Creager values much lower then the estimated PMF for Rose Creek.

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FIGURES

Figure 1 Rose Creek Watershed Area

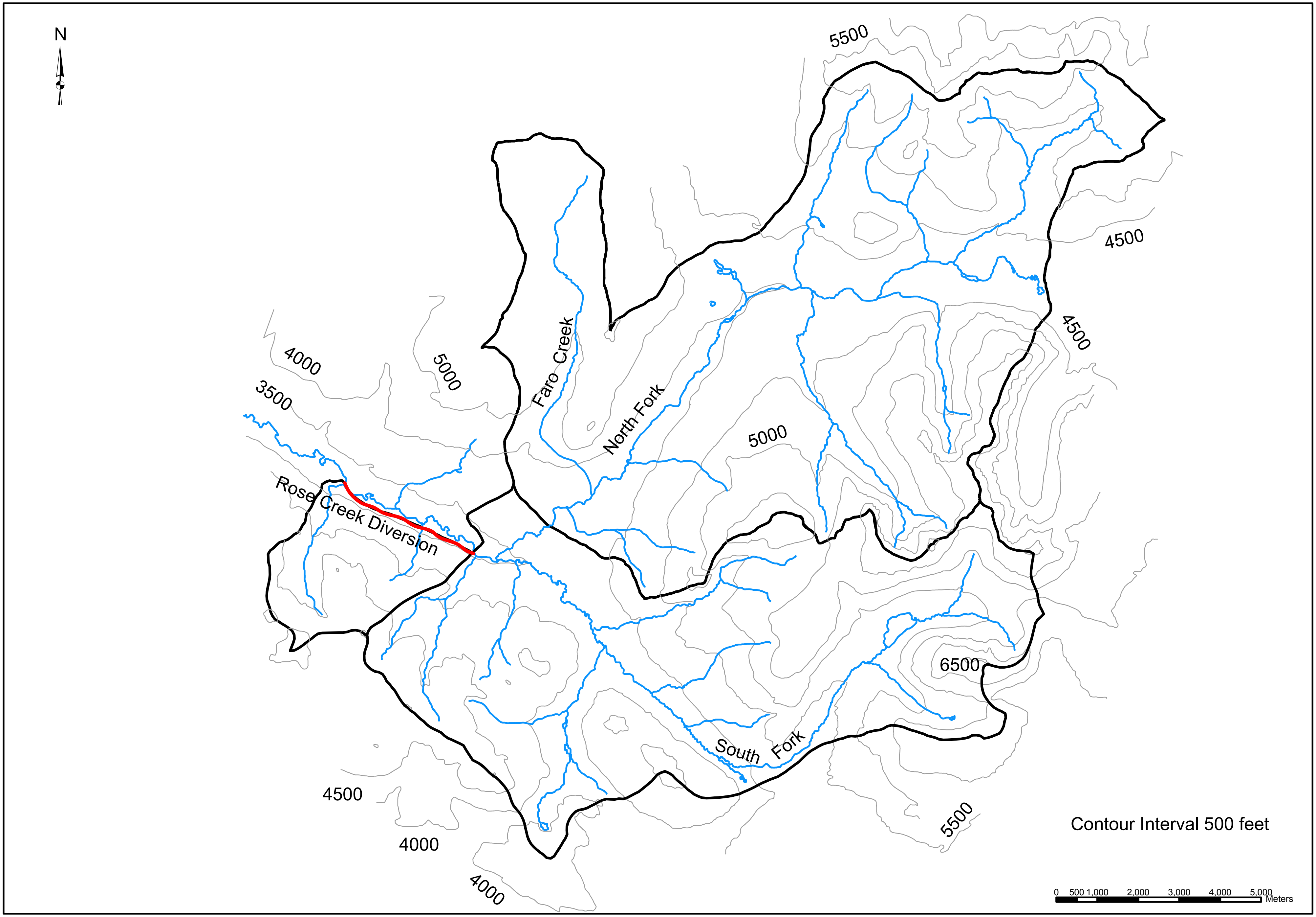
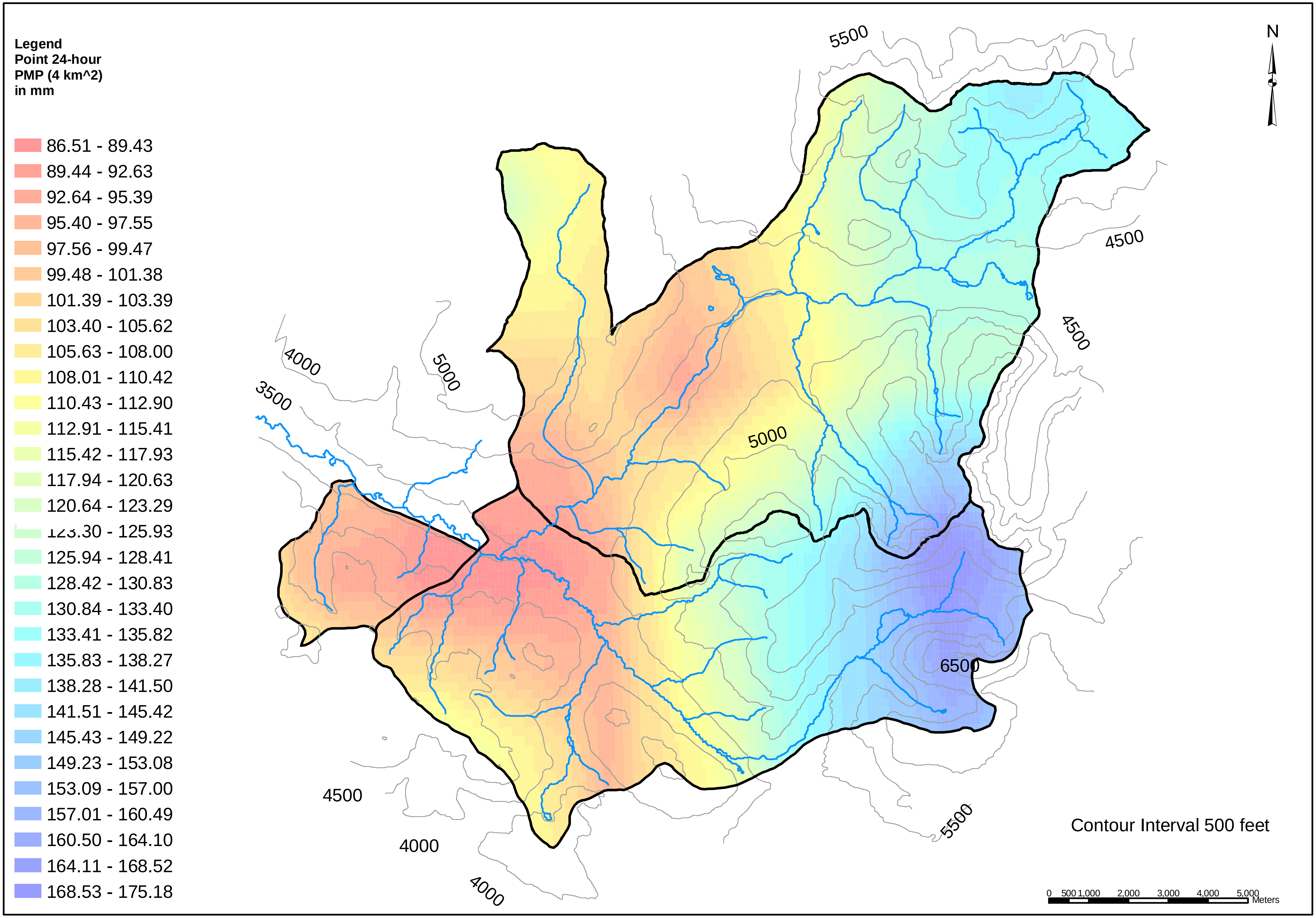


Figure 2 Rose Creek Watershed 24-hour Point PMP



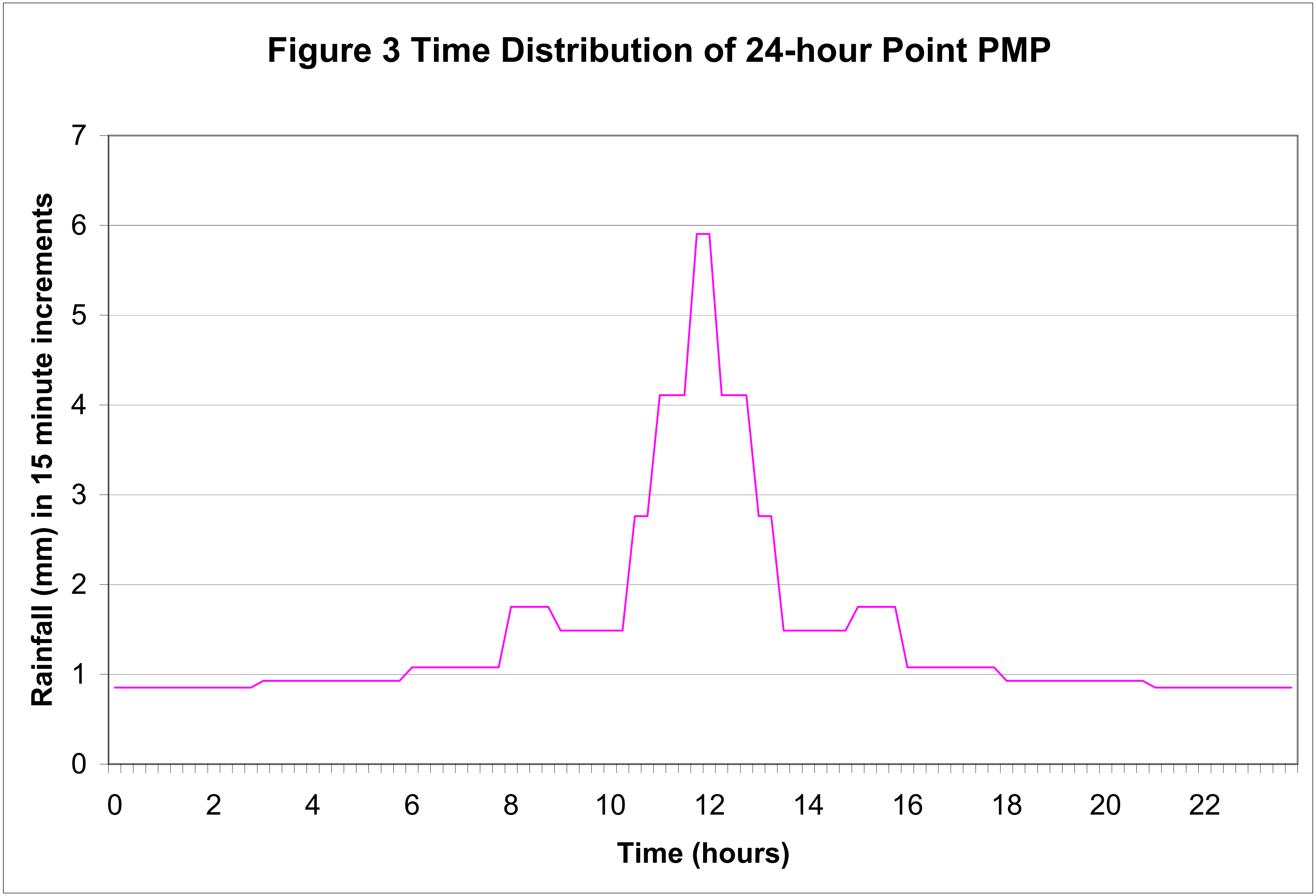


Figure 3 Time Distribution of 24-hour Point PMP
Rainfall (mm) in 15 minute increments
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20
22
Time (hours)

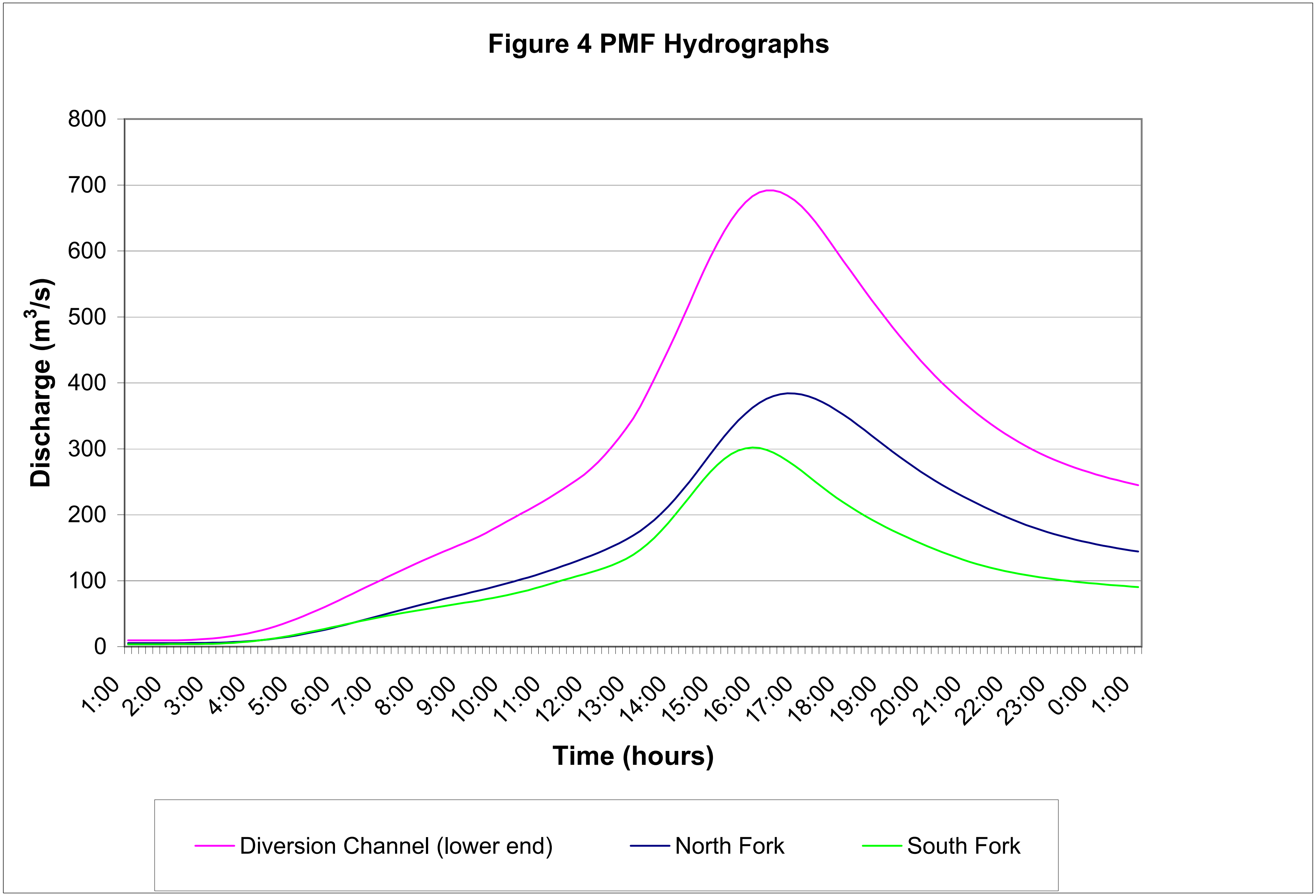


Figure 4 PMF Hydrographs
Discharge (m3/s)
800
700
600
500
400
300
200
100
0
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
Time (hours)
Diversion Channel (lower end)
North Fork
South Fork

Figure 5: Creager Diagram