Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

REPORT TO
CURRAGH RESOURCES INC.

REVIEW OF FLOOD ESTIMATION METHODOLOGIES
FARO MINE, YUKON TERRITORY

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TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The purpose of this report is to select the most appropriate methodology to use in peak flood estimation for the design of structures for Rose and Vangorda Creeks, Yukon Territory. The selection consists of previous hydrologic investigations conducted on streams in the region.

The best method of determining the relationship between peak discharge and the probability of being exceeded (and its reciprocal the return period or recurrence interval) for a particular stream is to statistically analyze the stream's gaging station data, and apply a theoretical probability distribution to the data. For streams that do not have a gaging station, or do not have a sufficient length of record, one can either apply a deterministic watershed model, or conduct a regional analysis.

Deterministic models are increasing in popularity, but they require estimations of many watershed parameters. The regional analysis, on the other hand, applies a theoretical distribution to the gaging data for stations within a hydrologic region, and determines the relationship of peak discharge and its recurrence interval to one or more of a watershed's characteristics. Often the watershed's drainage area is the only characteristic employed in the regression, since it dominates the hydrologic response of a watershed and its streams.

The two streams of interest, Rose and Vangorda Creeks, do not have gaging stations with sufficient length of record to have their own, independent, flood frequency analysis completed. Therefore, one must employ either a deterministic model or a regional analysis to estimate the flooding potential of these streams. All of the previous work reviewed in this report applied a regional analysis in one form or an other. A deterministic model was applied by only one consultant, but not used to complete their analysis because the model did not handle the hydrologic process of significance (rainfall and snowmelt combined).

2. DESCRIPTION OF PREVIOUS WORK

A brief discussion of the previous hydrologic investigations is presented below in chronological order. The description and critique of some of the previous work is based on their presentation in Curragh Resources Ltd. (1988).

1976 Montreal Engineering - A regional analysis was conducted to estimate floods for Vangorda Creek for the Kerr-AEX Grum Joint Venture. The analysis used the flood records of three gaging stations on the Pelly River. A regression was performed to define a relationship of the stream's drainage area at the gaging station to the mean annual flood (MAF) for stream at the station. Then the ratio of the peak flow to the MAF for each station was plotted assuming an extreme-value distribution. A line of best fit was drawn through the data for the three stations. This line is used to estimate the peak flood with a particular recurrence interval given the MAF for a location, as calculated from their regression of MAF to drainage area.

1979 Northwest Hydraulic Consultants Ltd. - A regional analysis was conducted to estimate the 100-year discharge for seven sites traversed by Foothills Pipe Lines Dempster Lateral. Their analysis was based on a Water Survey of Canada (WSC) statistical analysis of the records of 23 gaging stations in Yukon Territory which assumed a log Pearson Type III distribution. The MAFs for the gaging stations were plotted against the station's drainage area on log-log paper and a linear regression completed to arrive at a relationship of MAF to drainage area. Likewise the 100-year flood was plotted against the station's drainage area and a linear regression completed. Mean annual flood coefficients for the 23 gaging stations were derived by dividing the MAF by the station's area raised to the power found in the first linear regression (0.85). The 100-year flood coefficients were derived by dividing the station's 100-year flood by its drainage area raised to the power found in the second linear regression (0.7). A map of these flood coefficients at each station was prepared. The MAF and 100-year flood discharges for any ungaged stream is found by selecting from the map the coefficients of the geographically closest station and multiplying the selected flood coefficient by the drainage area raised to the appropriate power (0.85 for the MAF and 0.7 for the 100-year flood).

1979 Hydrocon Engineering Ltd. - The regional analysis by Northwest Hydraulic Consultants was employed by Hydrocon Engineering in a preliminary design for a diversion of Vangorda Creek. The flood coefficients from the station along Pelly River at Pelly Crossing were used to estimate the MAF and 100-year floods from the drainage area above the diversion. A 25 percent safety factor was added to the calculated flows. The adjusted flows were plotted on log-probability paper and connected with a straight line so that peak discharges at different recurrence intervals could be estimated.

1980 Hydrocon Engineering Ltd. - The same methodology as employed in the Vangorda Creek study was applied to a study of Rose Creek for the design of a tailings disposal project.

1983 Underwood McLellan Ltd. - A regional analysis was conducted to determine the flood risk of streams in the Yukon River Basin. A computer program developed by Environment Canada was used to analyze data from gaging stations with nine or more years of record. The statistical analysis assumed the three parameter log-normal distribution. The basin was divided into four regions based on climate and physiography. For each region, the MAF was plotted on log-log paper against the station's drainage area. And for each region, the ratio of the floods of various recurrence intervals to the MAF at each station was calculated and then the ratios for a particular recurrence interval in the region were averaged for the region. For an ungaged stream, its drainage area can be used to find its MAF, and the ratios applied to the MAF to estimate the peak discharges for various recurrence intervals.

1985 Acres Consulting Services Ltd. - A regional flood frequency analysis was developed in the study of the Rose Creek Reservoir. Stream gage data from five local stations were independently analyzed assuming a three parameter log-normal distribution to estimate the peak discharges for floods at various recurrence intervals. Every station's peak discharges for 10 recurrence intervals (2-, 5-, 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 10000-year recurrence intervals) were plotted against the drainage area of the station on log-log paper. The line of best fit for each recurrence interval was drawn through the data to define the relationship of peak discharges at specific recurrence intervals to drainage area.

1986 Janowicz - A regional analysis was employed to estimate peak discharges for the design of hydraulic structures in Yukon Territory. The data from 90 gaging stations with six or more years of record were analyzed by a computer program developed by Environment Canada assuming two parameter log-normal distribution. The stations were divided into two hydrologic regions. Relationships between the peak discharges at selected recurrence intervals and drainage area were developed for the two regions. The relationships resulted from simple linear regression of the data in log-log space.

1988 Curragh Resources Ltd. - The review of peak flow estimates for Rose and Vangorda Creeks by Curragh Resources did not contain a separate and original regional analysis. The report did contain summaries of previous work, graphical comparisons of the different flood estimates, and excerpts from the referenced work.

3. CRITIQUE OF PREVIOUS WORK

It is common for a regional analysis to first collect the data from each gaging station, rank annual peak floods, plot the data according to some plotting rule, calculate statistics of the data, apply the statistics to one of the theoretical probability distributions, and draw the flood frequency distribution through the station's data. The choice of theoretical distributions is subjective, with the suitability of the choice being the visual appearance of how well the distribution fits the data. Often the data from stations with similar hydrologic responses (climate and physiography) are grouped together, and a homogeneity test is conducted to authenticate the groupings. The peak discharges for various recurrence intervals from the theoretical flood frequency distributions for all the stations in a region (by groups) are tabulated. The peak discharges for each station is divided by the station's mean annual flood (recurrence interval of 2.33-years) to get a ratio of peak discharges at specific recurrence intervals to MAF. These ratios for the stations in the region are plotted on log-probability paper and the median of the ratios is taken as the ratios of peak discharges to MAF to use for ungaged streams in the region. To arrive at the MAF for the ungaged stream, the MAF is plotted against the drainage area for each station in the region on log-log paper and a linear regression completed. It is preferred to calculate statistics of the relationship of ratio of peak discharges to recurrence interval and of the relationship of MAF to drainage area so that confidence intervals may be placed about both relationships.

The analyses by Montreal Engineering and Acres Consulting Services selected data from a limited number of stations, and this selection may bias their results because the size of the stations' drainage areas were much larger than the Rose and Vangorda Creeks drainage areas.

The analysis by Northwest Hydraulic Consultants did not remove the influence of drainage area on the estimation of peak discharges. Selecting the flood coefficients from one hydrologically similar station will be significantly influenced by its drainage area. The work by Hydrocon Engineering is the most conservative estimation of extreme floods. It may not be an accurate method of estimating peak discharges, because it employed the Northwest Hydraulic Consultants methodology which may be affected be the influence of drainage area.

The analysis completed by Underwood McLellan Ltd. is the best application of regional analysis for the area that was reviewed, but their analysis excluded their most recent two years of data from the single station flood frequency analysis. These two years had annual peak discharges which were lower than the median annual peak discharges of record. By excluding these two years of record, the statistical analysis attributed a lower recurrence interval (more frequent occurrence) to the extreme flows of record. The stations used in the Underwood McLellan regional analysis had drainage areas significantly larger than the drainage areas than Rose and Vangorda Creeks, but by relating peak discharges to MAF, the effects of drainage size is reduced.

The regional analysis conducted by Janowicz included records from gages on small drainage basins. The Janowicz analysis did consider the effects of drainage area by plotting peak discharges for the stations against their drainage area and doing the linear regression for selected recurrence intervals separately. Some of the stations used in the analysis were operated seasonally (Curragh, 1988) and may have missed the annual peak floods in some years.

4. RECOMMENDATION

From the descriptions of the regional analyses, the methods used by Janowicz and by Underwood McLellan are preferred over the other methods reviewed. To compare these two methods, local stream gaging data was used to evaluate how well each method predicted the recurrence interval of discharge recorded by the local gaging station. Unfortunately, there is limited record of peak discharges for the Rose and Vangorda Creeks.

For the scant four years of record for the gage on Rose Creek below Faro, one year, 1967, documented a stream discharge of significance. Comparing this year's discharge to the annual peaks for the period of record at other gages in the region (region as defined by Underwood McLellan), the weather in 1967 produced stream flows in the area that would be plotted with recurrence intervals between two- and eight-years. The regional analysis by Janowicz predicts that a discharge of the magnitude recorded at Rose Creek below Faro (drainage area assumed to be 210 km^2) would occur between a five- and a ten-year recurrence interval. The Underwood McLellan analysis predicts that a discharge of this magnitude would occur between a 10- and a 50-year recurrence interval.

The regional analysis conducted by Janowicz for the Department of Indian and Northern Development best represents the flooding that has occurred and is likely to occur along Rose Creek in the vicinity of Faro. The Janowicz analysis was better than the Underwood McLellan method at assigning the correct recurrence interval to the peak discharge recorded by the gaging station on Rose Creek below Faro. The Underwood McLellan method may have fit the historical data better if the analysis included the two most recent years of stream gaging data which were available.

For designing hydraulic structures in the vicinity of Faro, the peak discharge for the drainage area of interest con be calculated using the Janowicz regression coefficients. The peak discharges against recurrence interval, using the Janowicz analysis, is plotted for two locations (Figure 1). The recurrence interval should be selected based on the expected life of the structure and the consequence of the structure failing if a larger discharge occurred. It should be noted that the further one extrapolates the data, the greater the uncertainty in the extrapolated value being the true value. The Underwood McLellan analysis has illustrated this nicely.

Sincerely,

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Enclosures

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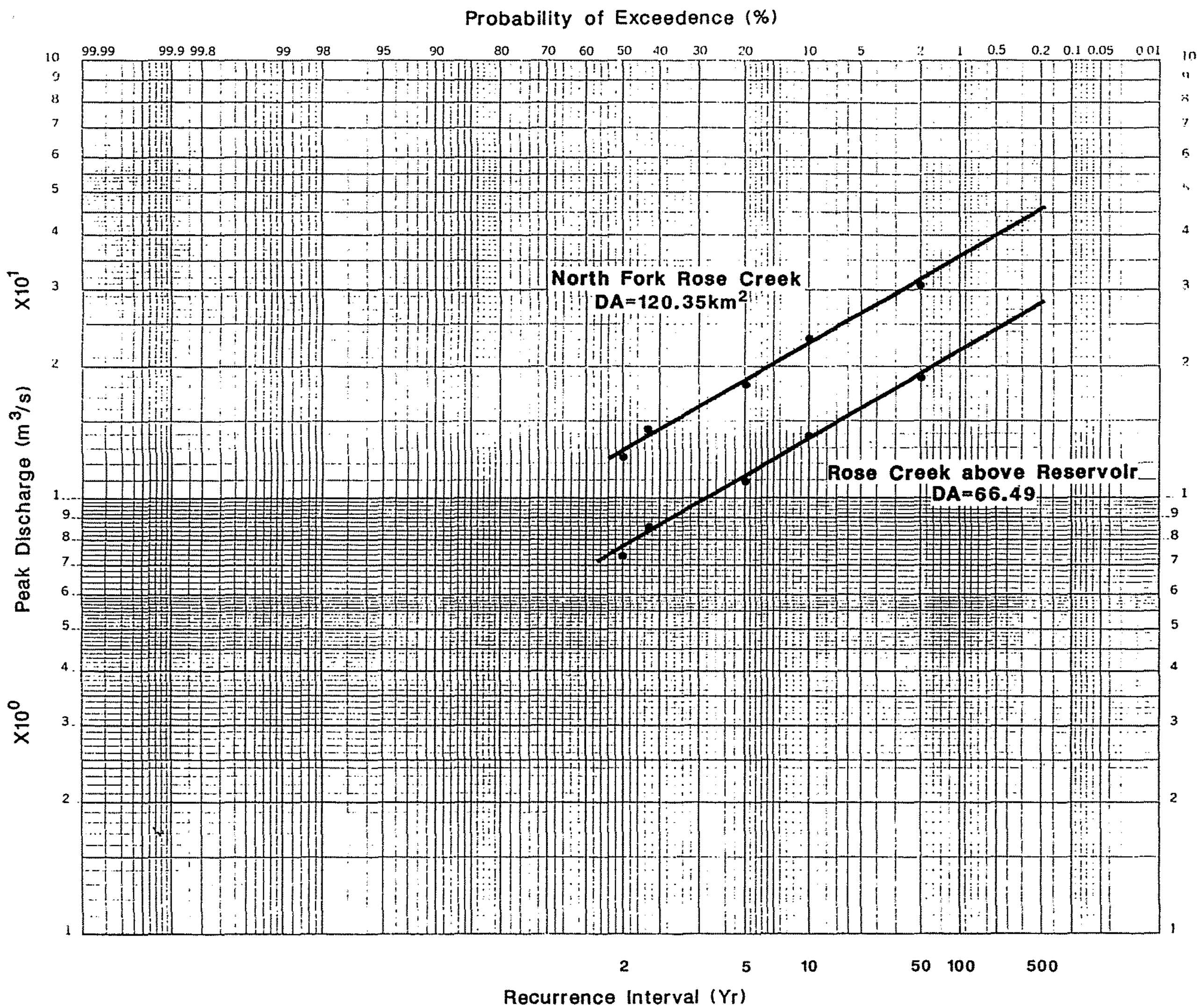
FIGURES



Flood Frequency Using Janowicz (1986) Analysis

$$Y = a(D.A.)^b$$

Recurrence Interval (Yr)	a	b
2	0.186	0.876
MAF(2.33)	0.226	0.865
5	0.301	0.856
10	0.385	0.850
50	0.629	0.811

Y=Peak Discharge (m^3/s)
D.A.=Drainage Area (km^2)
MAF=Mean Annual Flood

FIGURE 1
FARO MINE FLOOD FREQUENCY
CURRAGH RESOURCES, INC.

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