PROBABLE MAXIMUM FLOOD ESTIMATOR FOR BRITISH COLUMBIA

Prepared For: Agriculture and Agri-Foods Canada
Agri-Environment Services Branch

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EXECUTIVE SUMMARY

Water Resource Consultants Ltd. (WRC) was engaged by Agriculture and Agri-Food Canada (AAFC) to develop a protocol to estimate probable maximum flood (PMF) peak flows and runoff volumes based on past studies of PMFs. The results will be useful for preliminary estimates of PMF's or as rough checks on detailed PMF analyses to compare the magnitude and volume of the estimated flood with other PMFs.

British Columbia has a long history of PMF development by the public and private sector primarily for the design and protection of dams for water supplies and hydro-electric development. Information on PMF studies was gathered from government agencies and hydro-electric authorities in British Columbia and from adjacent watersheds in Montana, Idaho and Washington. This study assembled the results from the detailed PMF studies for these projects and correlated the flood peaks and volumes to the drainage area to develop equations that can be used to estimate the PMF potential at other sites.

Because of the diverse topography and hydrological characteristics within the province the PMFs were divided into regional groupings. These were Vancouver Island, British Columbia Coastal, Columbia Basin, British Columbia Interior, and one region comprising the Okanagan and Bridge River Basins. This last falls within Zones 12B and 15 in the British Columbia Streamflow Inventory. The equation for the British Columbia Interior was developed from data that included the Columbia River Basin. Zone 12B and 15 peaks for areas less than 8,320 km^2 are estimated using the equation developed for data within the two zones. It is recommended that the overall provincial equation be used for areas greater than 8,320 km^2.

RECOMMENDED REGIONAL EQUATIONS FOR ESTIMATING PMF PEAKS FROM DRAINAGE AREA		
	Peak Flows m^3/s	Figure No.
Vancouver Island	$Q=17.795A^{0.8156}$	Figure 4.12
British Columbia Coastal Region	$Q=23.753A^{0.7808}$	Figure 4.11
Columbia Basin	$Q=19.704A^{0.6281}$	Figure 4.9
British Columbia Interior	$Q=19.933A^{0.6351}$	Figure 4.8
Zone 12B and Zone 15	$Q=37.805A^{0.6042}$ for $A \geq 8320$ km^2 $Q=2.1086A^{0.9240}$ for $A<8320$ km^2	Figure 4.14

Envelope curves were also developed for volumes, however, the scarcity of data will limit their usefulness.

ACKNOWLEDGMENTS

This project could not have been completed without the contributions of information on probable maximum floods from water resources agencies and hydroelectric corporations in British Columbia, Washington, Idaho and Montana namely BC Environment, BC Hydro, Avista Corporation, Idaho Department of Water Resources, Washington State Dam Safety, the US Army Corps of Engineers (USACE), and the US Bureau of Reclamation. Special thanks go to Will Jolly and colleagues for coordinating input from British Columbia, for making available paper and electronic copies of numerous PMF studies in British Columbia, and for making contacts with state agencies in Washington, Idaho and Montana; to Terry Oswell, Graham Lang and staff at BC Hydro for extracting PMF data from BC Hydro Projects and providing the data to us; and to Steve Fry from Avista Corporation, Martin Walther, Washington State Dam Safety, Bob Berger, Rob Romocki and Richard Hynes and colleagues with the US Army Corps of Engineers (USACE), and Larry Wolf, US Bureau of Reclamation for path finding and providing access to reports. We would also like to thank Ron Woodvine and Kirby Rietze, Agri Environmental Services Branch, Agriculture and AgriFood Canada for initiating this project.

TABLE OF CONTENTS:

LIST OF FIGURES:

LIST OF TABLES:

1.0 INTRODUCTION

1.1 STUDY PURPOSE

Water Resource Consultants Ltd. (WRC) has been engaged by Agriculture and Agri-Food Canada (AAFC) to develop a protocol to estimate Probable Maximum Food (PMF) peak flows and runoff volumes for streams in British Columbia. Appendix A is the study Terms of Reference.

1.2 BACKGROUND

Envelope curves of PMF peak flows and runoff volumes have proven useful over the years for preliminary estimates of PMFs or as rough checks on detailed PMF analyses to compare the magnitude and volume of the estimated flood with other PMFs.

British Columbia has a long history of PMF development. A record of PMFs provided by BC Hydro for this project contains data from 1964 to 2005. The literature gathered for the study included data from reports that were prepared as recently as 2009.

The procedure for the development of the PMF has changed considerably over that time. Current practice utilizes sophisticated analyses of atmospheric physics to determine the largest storm or probable maximum precipitation (PMP) that could occur in a particular basin. This storm is applied to a dynamic rainfall-runoff model which simulates a runoff and stream flow. Earlier methods were less deterministic.

Despite the more sophisticated and standardized procedures, considerable variability can still exist between estimated PMFs. For example the hydrologist completing the PMF study must make judgements regarding the criteria for antecedent conditions such as initial soil moisture, storage in existing reservoirs, and the relative contribution from rainfall and snow melt, and in the calibration of the runoff model.

An examination of PMFs in Alberta conducted by Alberta Environment in 2008 concluded that there was no standard for the development of the PMF other than the generally accepted process of using PMP and a runoff model which can simulate flow in the various regions of the catchment and route it through the stream network to the required location of the PMF estimate.

2.0 STUDY METHOD

2.1 GENERAL

The basic procedure was to:

1) gather together information on the PMF studies that have been done in British Columbia as well as those in the northwestern region of the United States, namely Idaho, Montana and Washington;

2) extract data on PMFs including peak, volume, drainage areas and other pertinent data for each study;

3) assemble the information into a data base for use in subsequent analysis;

4) calculate the unit PMF peak and unit volume for each location;

5) arrange the data by regions with similar geographic and hydrologic characteristics for analysis at the regional level;

6) for each region and the province as a whole, plot the unit values against drainage area and determine the best fit line through the data using regression analysis;

7) develop the standard error for each regression relationship;

8) compare plots of peak flow to relationships developed for the Canadian prairies in a previous study, and to empirical relationships using the Creager and Francou-Rodier formulae; and

9) select the most suitable relationships for use in estimating PMFs in British Columbia.

Agencies responsible for dams in British Columbia and in the northwest Pacific region of the United States (Washington, Idaho and Montana) were contacted to gather information about PMFs in their jurisdiction. These were generally government agencies (provincial, state and federal) and hydroelectric authorities. A sample of the initial letter of request to each of these agencies is given in Appendix B. Additional information was gathered through an Internet search. A list of reports referenced is given in Appendix C.

2.2 DATA AND ANALYSIS

The basic data extracted from these reports were the probable maximum flood peak and volume, gross drainage area and date of study. The data of study is of some importance as the method of calculating the PMF has evolved over time. As a general rule the current methods of calculating the PMF tend to produce higher values of flow than those from earlier dates. This can be important in understanding the variance in the plots of PMF data against drainage area. The data used in this study are summarized in Appendix D.

The data locations are shown on Figure 2.1. The map shows a heavy concentration of data on Vancouver Island and the lower mainland of British Columbia and in the Columbia River basin in both Canada and the United States.

The data were analysed to determine the relationship between PMF peak and gross drainage area, the PMF volume and gross drainage area. As is common practice the data was best represented by a log-log scale. The best fit line and standard error were determined by regression analysis using the statistical routine in Microsoft Excel. The standard error was plotted to show the variability about the best-fit line. Plots of the residuals and the line fit plots comparing the predicted y to the original values (from MicroSoft Excel) were used as a visual check of the results. These are shown in Appendix F.

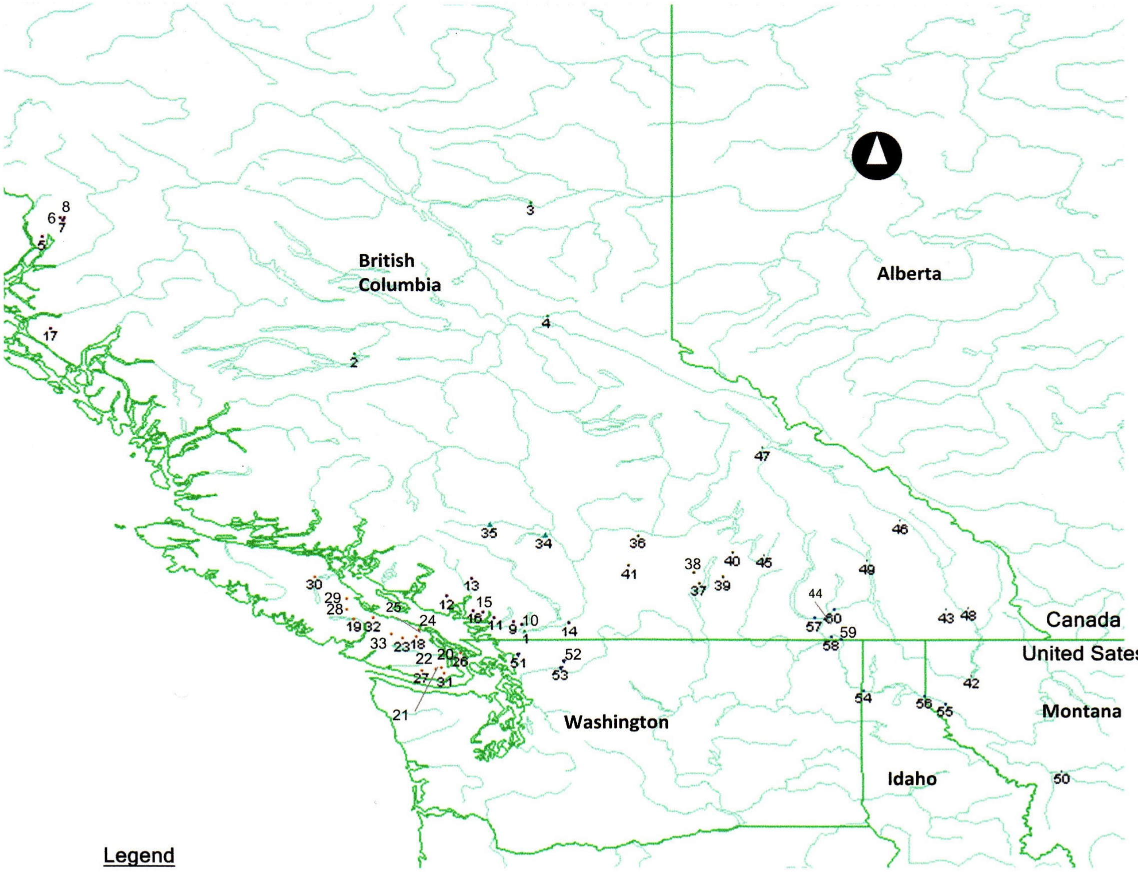
Each relationship was examined using the Nash-Sutcliffe Efficiency Coefficient (E) to determine the effectiveness of the relationship in predicting the PMF. The objective was to obtain an E greater than zero and as close to 1 as possible. A perfect model would yield an E=1. An E=0 indicated that the relationship was no better than the mean as a predictor of the PMF.

Nash-Sutcliffe Efficiency Coefficient

$$E = 1 - \frac{\Sigma(Q_p - Q)^2}{\Sigma(Q_p - Q_m)^2}$$

where Q_p = predicted PMF
Q = known PMF and
Q_m = mean of known PMFs

The data were also tested to see how they fit with theoretical (empirical) envelope curves of extreme floods as developed by Creager and Francou-Rodier. The equations are shown below.



Legend

1	Fraser River at Mission	21	Sooke Reservoir	41	Nicola River
2	Kenney Dam	22	Deception Creek Reservoir	42	Libby Dam
3	GMS (WAC Bennett)	23	Jump Creek Dam	43	Phillips Dam
4	Proposed McGregor Diversion	24	Lower Chase River Dam	44	Brilliant Dam
5	Anyox	25	Middle Chase River Dam	45	Sugar Lake
6	Homestake Creek	26	Buck Lake Dam	46	Spillimacheen
7	Trout Lake	27	Bear Creek	47	Mica (spring PMF)
8	Upper Kitsault River	28	Elsie Dam - Ash River Project	48	Aberfeldie
9	Alouette	29	Comox	49	Duncan
10	Stave	30	Strathcona	50	Milltown Project
11	Coquitlam	31	Humpback Dam	51	Lake Whatcom
12	Clowhom	32	Horne Lake Dam	52	Upper Baker Dam
13	Cheakamus	33	Fourth Lake Dam	53	Lower Baker Dam
14	Wahleach	34	Seton	54	Albeni Falls Dam
15	Seymour Falls Dam	35	La Joie	55	Noxon Rapids Dam
16	Cleveland Dam	36	Afton Tailings Facility East /West Dams	56	Cabinet Gorge
17	Falls River Dam	37	Rose Valley Reservoir	57	Keenleyside
18	Westwood Lake	38	Big Horn Dam	58	Seven Mile
19	Stamp River Dam	39	Postill Lake Dam	59	Boundary Dam
20	Butchart Reservoir	40	North Silverstar Lake	60	Kootenay Canal

Figure 2.1: Location of Probable Maximum Floods

Creager Equation

$$Q = 46CA^{0.894A^{-0.048}}$$

where Q = Peak flow in ft^3/sec
A = Drainage area in mi^2
C = Creager's coefficient

Francou-Rodier Equation

$$\frac{Q}{10^6} = [\frac{A}{10^8}]^{1-0.1k}$$

where Q = Peak flow in m^3/sec
A = Drainage area in km^2
K = coefficient based on the slope of the line

3.0 PROBABLE MAXIMUM FLOODS

3.1 PEAK FLOWS

3.1.1 Organizing the PMF Data

The data gathered for this project included instantaneous, one hour, six hour and 24 hour (mean daily) flood peaks. The data set also includes peaks from sites with substantial upstream controls such as the Columbian River Basin in Canada and the United States, and some of the water supply and hydro-electric dams on Vancouver Island and the lower mainland of British Columbia.

To facilitate the subsequent analysis it was necessary to take all of these PMFs and develop them into a database with reasonably similar characteristics, preferably one with instantaneous peak flows with minimum influence from upstream controls.

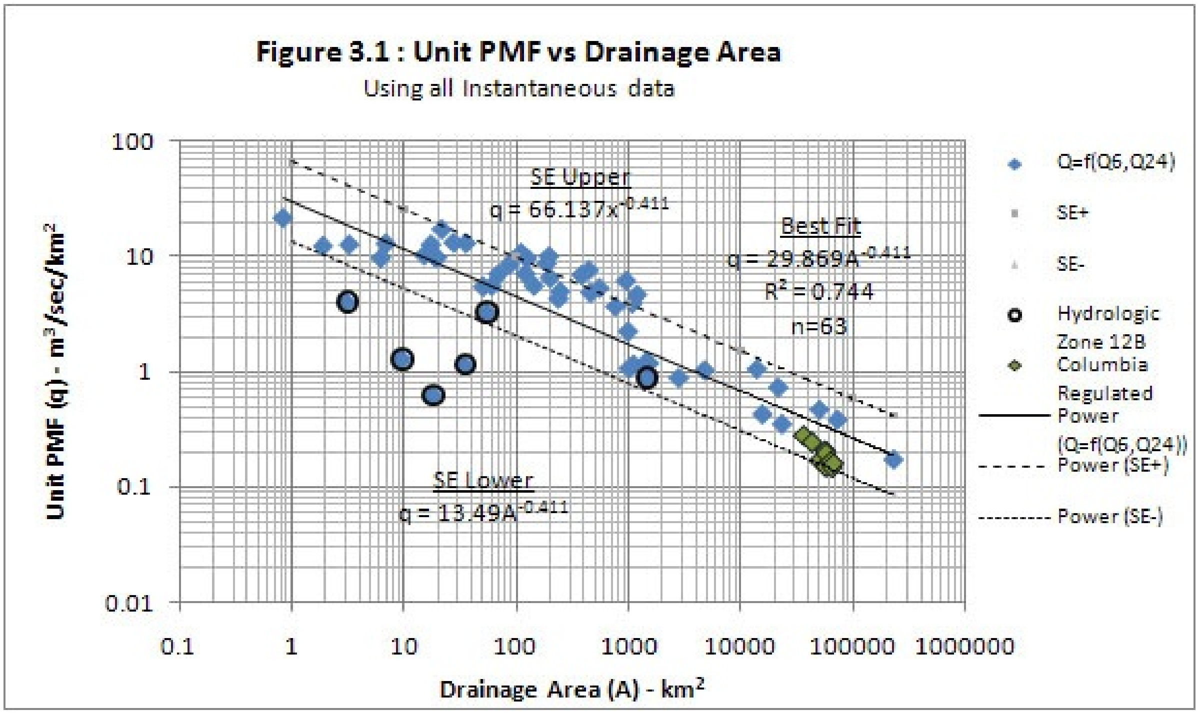
Organizing the database was conducted in three steps: 1) develop a basic data set with a common time unit for the PMF analysis i.e. instantaneous or mean daily, 2) separate the data into regulated and unregulated PMFs; and 3) sort the data into regional subsets. This last step also involved examining the data set for anomalies (outliers) which could be explained by regional differences.

3.1.2 Selection of PMFs (Best Fit and Standard Error for Unit PMF and PMF Peaks)

The instantaneous peaks were selected as the basic data set for analysis. For the purposes of this study instantaneous and one hour were assumed to be the same. Where reports did not specify the duration of the PMF, it was assumed that the peaks were instantaneous. Where possible this was verified by examination of the plotted hydrographs.

Figure 3.1 shows the unsorted probable maximum flood (PMF) data for all locations expressed in $m^3/s/km^2$ plotted against drainage area in km^2. A regression analysis was performed on the data to determine the best fit relationship between the unit PMF and the total area, and to determine the Standard Error. The R^2 value was 0.744 for the unadjusted data set. This provided the base against which subsequent improvements to the data set could be measured.

Examination of Outliers - Figure 3.1 shows several outliers that are fairly extreme. There are several possible reasons for this such as the selection of method used to determine the PMF



or the influence of natural factors such as topography and or regional climate variation. An examination of the reports did not uncover any specific problems with the methodology.

Four of the most extreme outliers are in the Okanagan in the area corresponding to Hydrologic Zone 12B in British Columbia's Streamflow Inventory (See Figure 3.2). The Okanagan Valley is in a zone of lower precipitation, having the lowest rainfall in the province for durations of 24 hours or less as shown in the Rainfall Frequency Atlas of Canada. While it is beyond the scope of this study to do a detailed analysis of the outliers, it seemed reasonable to remove these outliers on the assumption that the relationship was influenced by regional climatic factors.

Two of the Zone 12B PMFs fit within the lower boundary of the standard error of the best fit line for the overall data set. Perhaps this is because they are in the more northern portion of Hydrologic Zone 12B. However, as there was no clear-cut way of differentiating these PMFs from the other four, it was decided to remove all six Zone 12B PMFs from the data set. Removing these data increased the coefficient of determination to $R^2 = 0.886$.

Removing the impacts of regulation on the PMF - The study required a data set that was relatively free from influences of upstream control structures. Information from a study conducted for Brilliant Creek Dam on the Kootenay River estimated that upstream regulation reduced the PMF at that location by 68 percent of what would have occurred without

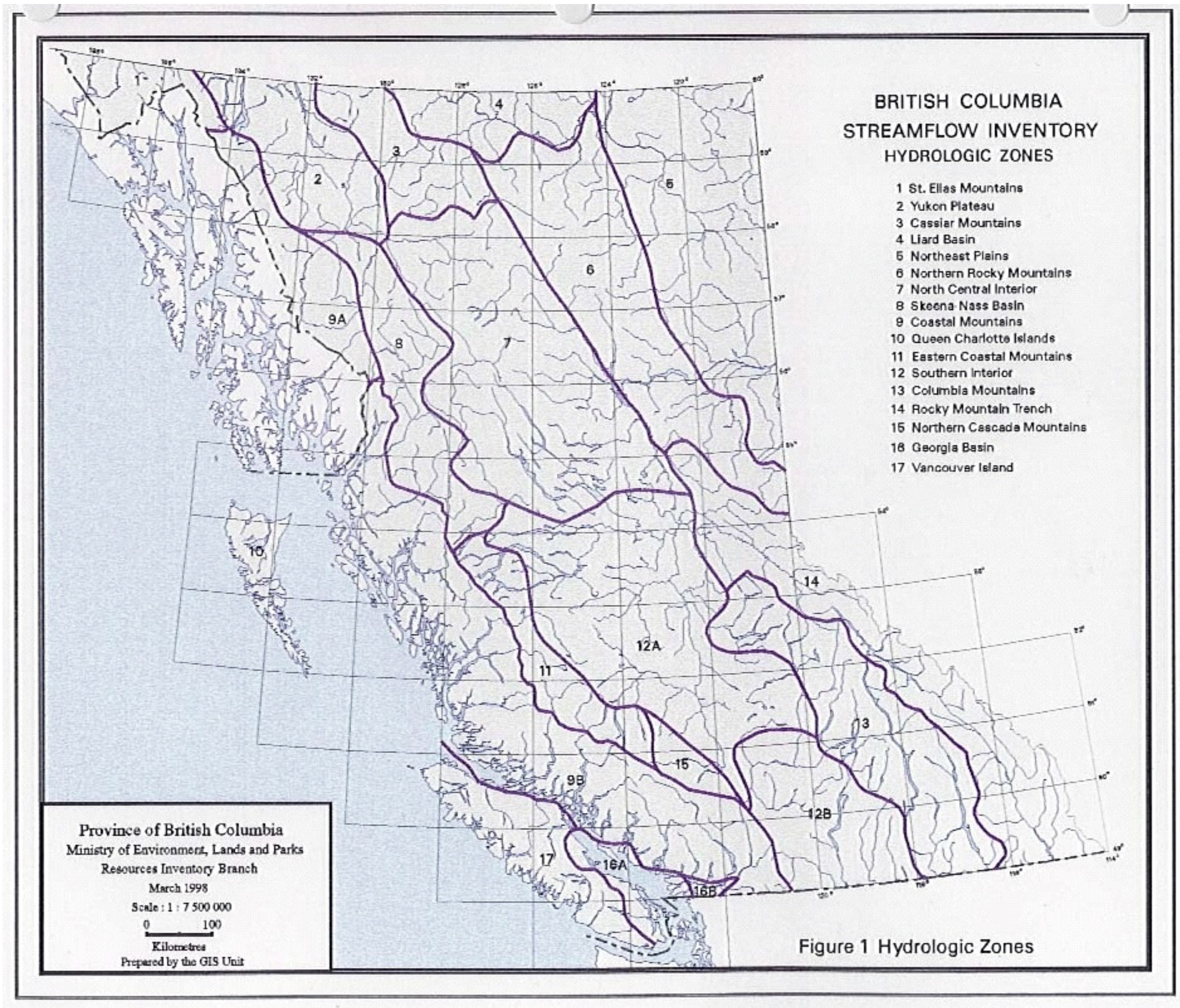
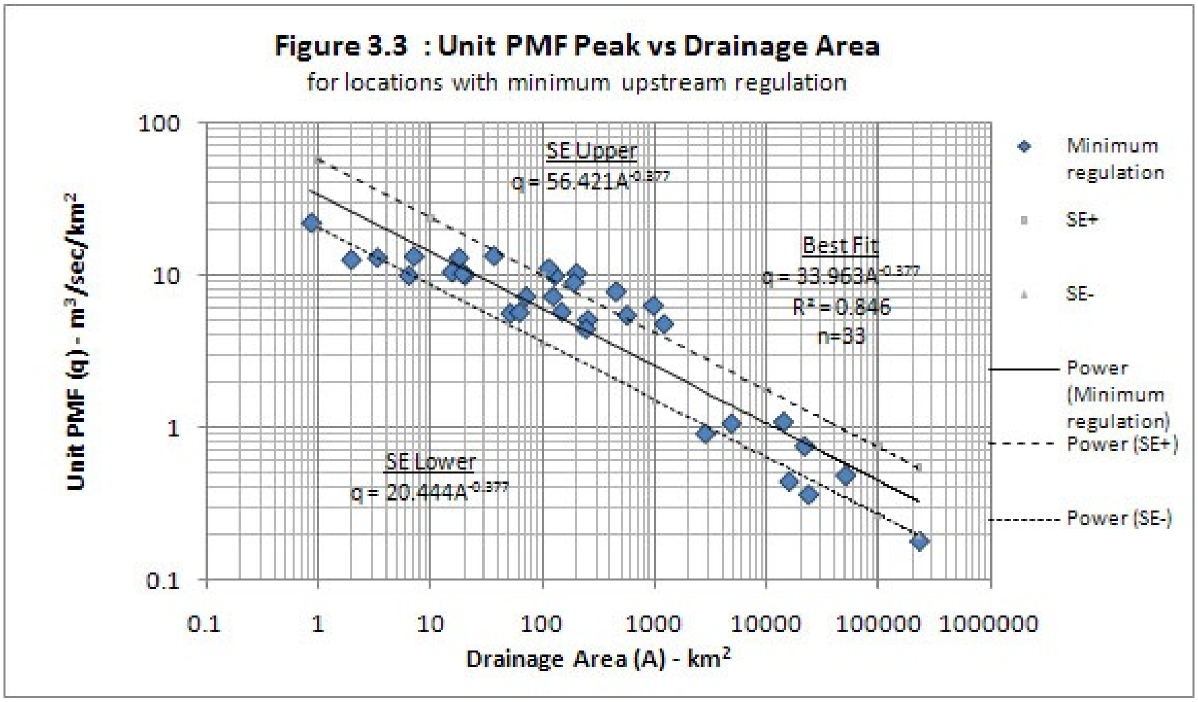


FIGURE 3.2 HYDROLOGICAL ZONES



regulation. The amount of reduction would differ for each location depending upon the portion of the basin controlled and the type and volume of the control. The next step then was to separate the PMFs from watersheds with substantial regulation from those that were felt to be minimally influenced by upstream regulation.

The study reports were examined to determine if upstream controls existed and to what extent they might influence the PMF. As well each PMF site was located on Google Earth and the area upstream examined for control structures. Only those with major upstream works were deemed to be "regulated". Dams on the Columbia River system, except for those in the headwaters, would fall into this category. PMF sites on watersheds with run-of-the river dams, dams controlling a small portion of the area, and other small storage projects were designated as having "minimum regulation".

Following these criteria the data were sorted into two groups; one for basins with only minor influence from upstream controls, and the second for those known to be substantially influenced by upstream storage. Data from the regulated basins were discarded leaving instantaneous PMFs for basins with no or minor regulation as the principal data set.

Several (10) data points for the Columbia River basin in Canada and the United States were removed from the data set. These are shown in green in Figure 3.1. It should be noted that removal of these PMFs reduced the R^2 to 0.86 reflecting the influence of removing a large clustering of data with similar characteristics on the regression analysis.

Fraser River - The data set contained a PMF for the Fraser River at Mission, British Columbia which has the largest drainage area in the data set (228,000 km²). The Fraser River does have some upstream controls, the largest being the Kenny Dam on the Nechako River. The Kenny Dam controls about 6 percent of the drainage area. As well the hydroelectric projects on the Bridge and Stave River systems, located on the lower portion of the basin, control another 2 to 3 percent of the area. Given the overall size of the basin it was felt that these structures would not have a major influence on the PMF.

Regression analyses were undertaken on the unregulated data set with and without the Fraser River PMF to determine the effect of the Fraser River on the relationship between PMF and drainage area. The coefficient of determination was slightly higher when the Fraser River PMF was included. It was therefore concluded that for the purpose of this study the Fraser River PMF would be included in the data set with minimum upstream regulation.

A basic data set comprising 33 PMFs was then assembled from the instantaneous and one hour peak data for those stations having minimum effects from upstream regulation. The data sets used subsequently in this report are sites with minimum regulation. These data and the best-fit regression line are shown on Figure 3.3. There is a reasonably good fit between the unit runoff (q) and the watershed area. The R^2 value is 0.846. More data points would be preferred if the data is to support the development of regional relationships as that would divide the data set into smaller sets which would have less statistical validity.

3.1.3 Extension of Data Set

The data set was increased to 46 stations using the six hour and 24 hour data. The primary source of this information was the data provided by BC Hydro. Relationships were developed between the one hour PMF and the six hour and 24 hours PMFs for those projects with overlapping data. These are shown in Figures 3.4 and 3.5. Although there were very few points there was a very good relationship between the one hour PMFs and the six and 24 hour PMFs with R^2 values of close to 1.0 (0.999). This provided a means of estimating the instantaneous or one hour peak based on the reported six or 24 hour values. The process was to first fill the missing data points using the six hour data. One hour peaks were estimated by applying the power relationship in Figure 3.4 to the six hour peaks. (The linear relationship would have produced similar results.) The 24 hour data were then used to fill the remaining points as shown on Figure 3.5. The extended data set is listed in Appendix E.

The resulting data sets were compared to the original unregulated data set by comparing R^2 values for each set. The R^2 was reduced slightly to 0.836 but essentially unchanged. However, a longer data set would provide additional points for use in regionalisation. A plot of unit PMF versus area using the extended data set is shown in Figure 3.6. Similarly PMF peaks for the extended data set were plotted against drainage area in Figure 3.7.

Figure 3.4 : Relationship between 6-hour and 1-hour PMFs

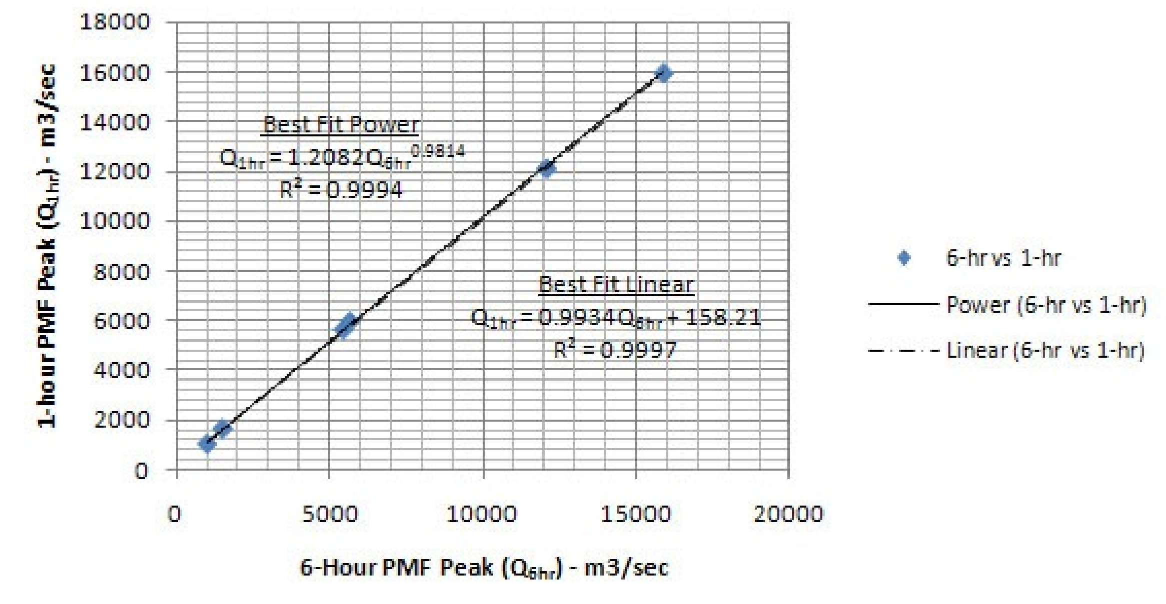
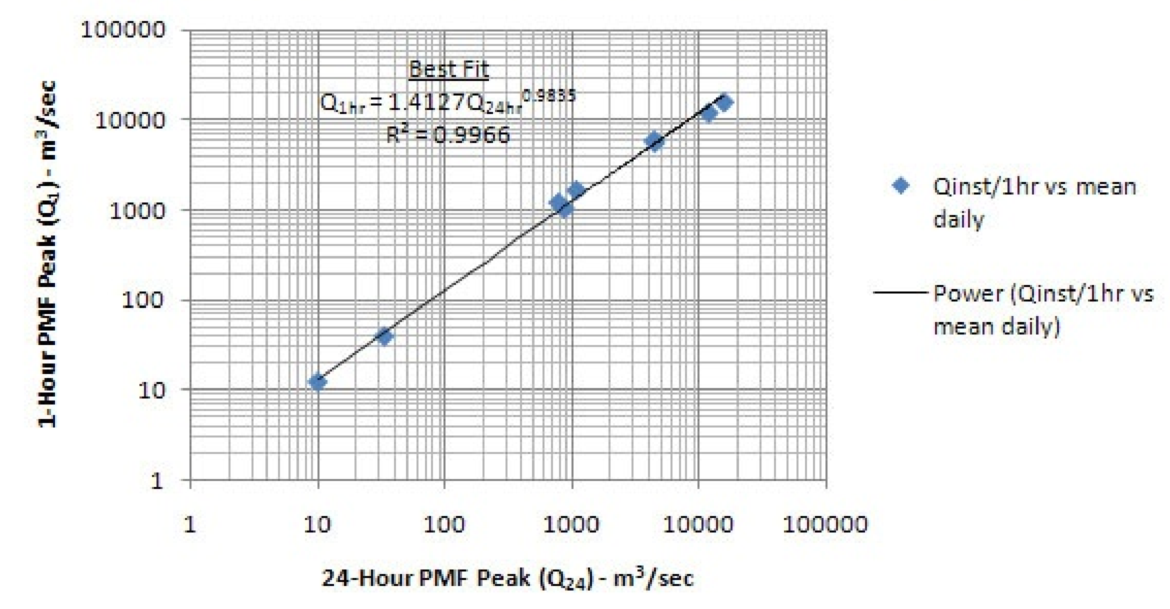


Figure 3.5 : Relationship between 24-hour and 1-hour PMF Peaks



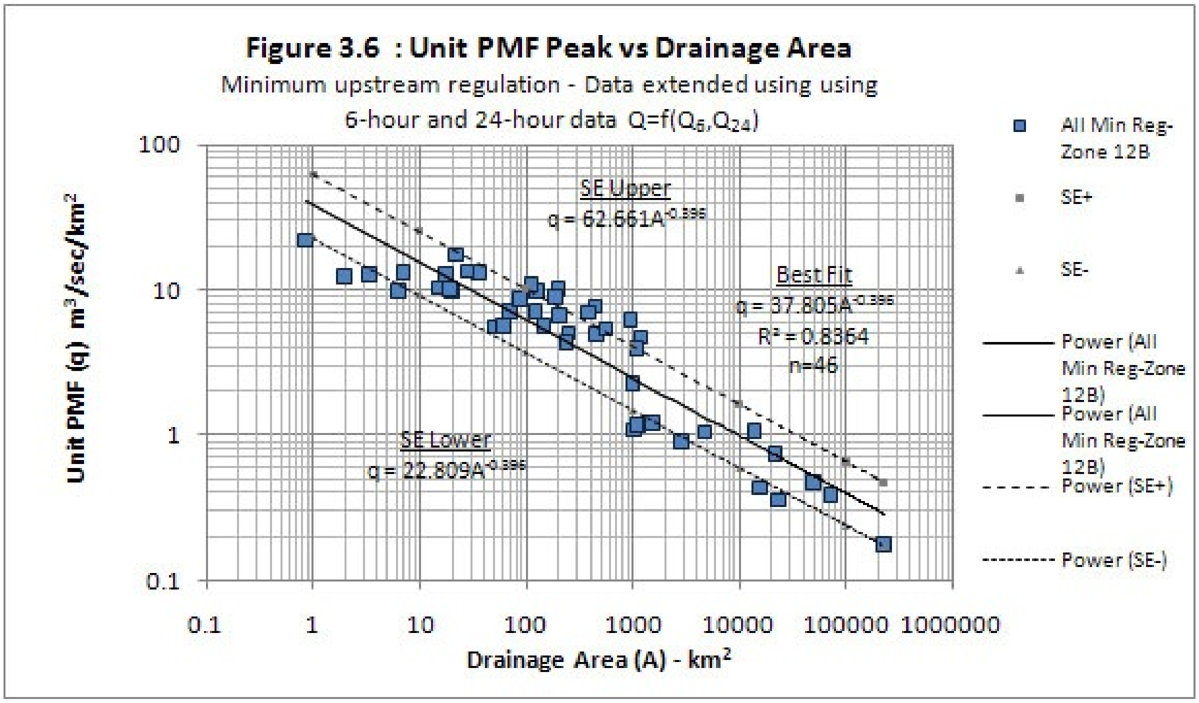


Figure 3.6 : Unit PMF Peak vs Drainage Area
Minimum upstream regulation - Data extended using using
6-hour and 24-hour data Q=f(Q6,Q24)
Unit PMF (q) m3/sec/km2
Drainage Area (A) - km2
SE Upper
q = 62.661A-0.396
Best Fit
q = 37.805A-0.396
R² = 0.8364
n=46
SE Lower
q = 22.809A-0.396
All Min Reg-Zone 12B
SE+
SE-
Power (All Min Reg-Zone 12B)
Power (All Min Reg-Zone 12B)
Power (SE+)
Power (SE-)

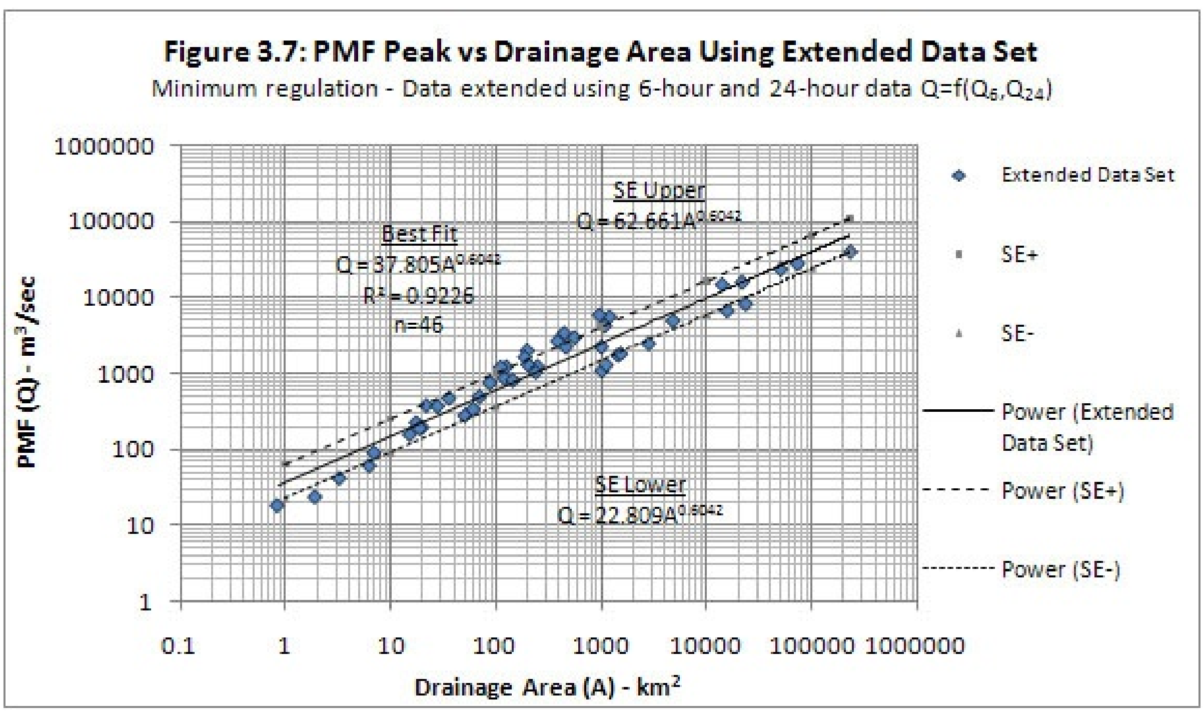


Figure 3.7: PMF Peak vs Drainage Area Using Extended Data Set
Minimum regulation - Data extended using 6-hour and 24-hour data Q=f(Q6,Q24)
PMF (Q) - m3/sec
Drainage Area (A) - km2
SE Upper
Q = 62.661A0.6042
Best Fit
Q = 37.805A0.6042
R² = 0.9226
n=46
SE Lower
Q = 22.809A0.6042
Extended Data Set
SE+
SE-
Power (Extended Data Set)
Power (SE+)
Power (SE-)

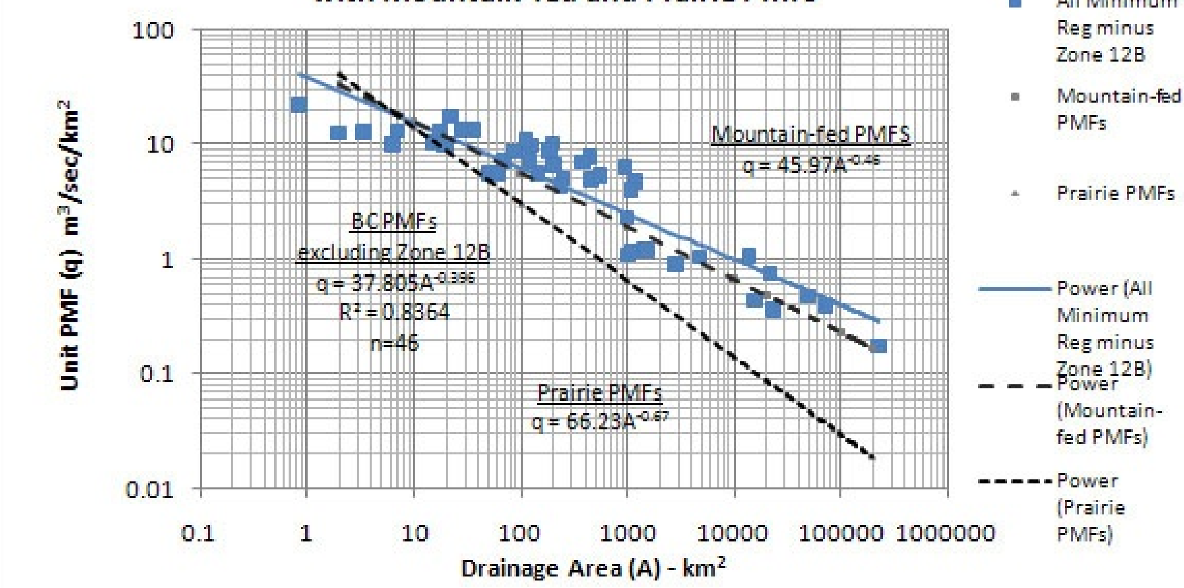
3.2 COMPARISON TO OTHER STUDIES

3.2.1 Probable Maximum Flood Estimator for the Canadian Prairies (2009)

A study of probable maximum flood peaks for the Canadian prairies, completed in 2009, developed curves showing the relationships between the unit PMF and drainage area for Mountain fed and Prairie streams. These curves have been superimposed on a plot of the British Columbia data as shown on Figure 3.8. The Prairie curves have a much steeper slope than the British Columbia curve. The Mountain fed curve is closer to the British Columbia curve although still with a slightly steeper slope.

The Prairie region curves are higher for the small drainage areas reflecting the influence of convective storms. The flatter slope for the Mountain-fed curve is partially attributable to the attenuation of flood peaks in the larger basins of the Saskatchewan River system which is due to floods originating in the mountains and flowing across a large area with very little inflow. This results in a low unit yield over a very large drainage area. It is interesting to note that the point for the Fraser River at Mission falls close to the Mountain fed line suggesting a similar attenuation due to the distance between the source and the study location, and the relative timing of peaks in the lower and upper parts of the basin. Since the British Columbia data and the Mountain fed data originate from the same mountain range the similarity is not surprising.

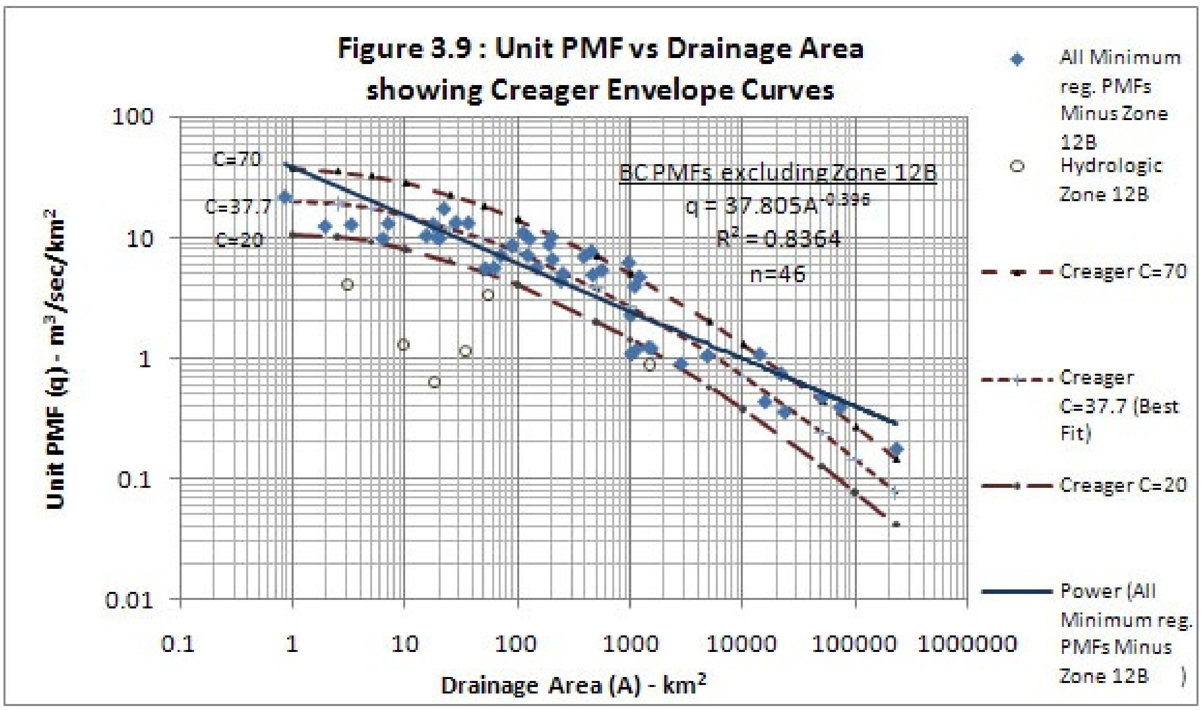
Figure 3.8 : Comparison of British Columbia PMFs with Mountain-fed and Prairie PMFs



3.2.2 Comparison to Empirical Extreme Flood Curves

Two empirical relationships were considered: Creager and Francou-Rodier. The Creager envelope curve is commonly used as a check on PMFs in Canada. The Francou-Roudier method is not commonly used in Canada, however, it was noted by one of the contributors to this study. For that reason it was included for a brief look at how it might apply to PMFs in British Columbia. The envelope curves for both methods where superimposed upon the data and compared to the best fit regression line developed in this study. Comparisons using both methods are discussed in the following paragraphs.

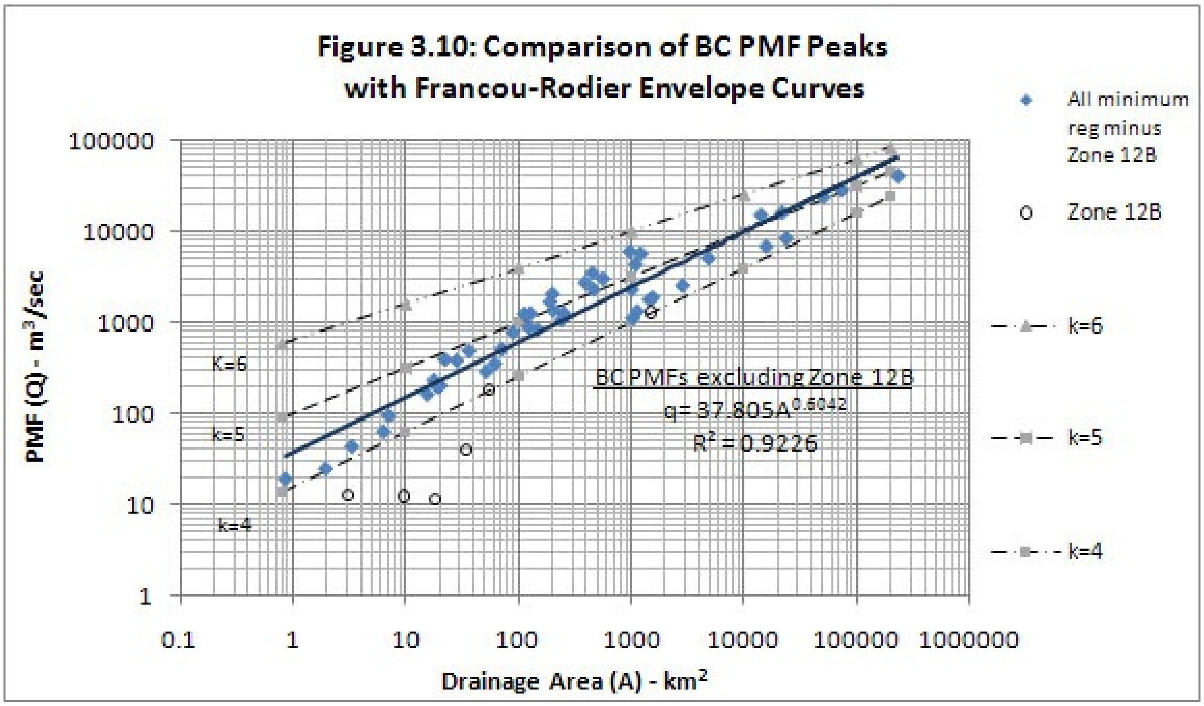
Creager - The shape of the Creager curve showed a good relationship with the British Columbia data. As shown in Figure 3.9, the Creager equation with C = 70 provides a reasonable approximation of the upper boundary while C = 20 approximates the lower boundary.



A best fit Creager curve with C = 37.7 was determined using least squares analysis. The Creager formula with C = 37.7 was then used to estimate the PMF peaks for each of the areas. The efficiency in predicting the peak flow was quite high with a Nash-Sutcliffe efficiency coefficient of 0.75. While this is very good it is less than that using the log-log regional relationships discussed later in this report.

Francou-Rodier - The literature gives the Francou-Rodier equation as $Q/10^6=[A/10^8]^{1-0.1k}$ where Q is the PMF and A is the corresponding watershed area. K=tan(1-a) where a represents the slope of the line when plotted on log-log scale. K varies from 0 to 6 with 6 being the "world maximum" for extreme events. Figure 3.10 shows plots of the Francou-Rodier superimposed on a plot of the British Columbia data for PMF peaks. For the British Columbia data the k is between 4 and 5. The Francou-Rodier curves do not fit the data as well as the Creager curves and are steeper than the best fit lines developed for this study.

It should be noted that both empirical methods were developed using recorded extremes. The Creager curves, however, are commonly used as a check of PMF data. PMF data generally fits well within the range covered by the Creager equation.



3.3 PMF VOLUMES

There were very few data points available for PMF volumes which precludes doing a regional analysis. Some data were available in the information provided by BC Hydro and in the reports provided by the BC Ministry of the Environment. With so few data points the analysis was limited to examining the relationship between PMF volume and drainage area on a provincial basis.

Figure 3.11 shows the unit runoff volume versus drainage area. The slope is much flatter than for peaks showing a slight reduction in unit volume as the area increases. The very small R^2 value shows a weak statistical relationship.

In a regression analysis on a small number of points one outlier can exert considerable influence on the results. Such is the case with the PMF volume for Jump River (Vancouver Island) shown on Figure 3.11. Removal of this point would increase the R^2 value to 0.54, however, there is no obvious physical justification for doing so.

Figure 3.12 shows the total volume versus area, providing a simple basis for estimating volume from drainage area. The apparent high R^2 value is somewhat misleading because, in effect, this relationship correlates drainage area against drainage area multiplied by a unit runoff. Since the unit runoff is almost constant, the equation is almost area versus area.

It was also observed that the conditions producing each PMF were quite different which would likely influence the relationship with drainage area, particularly for the small sample available for this study. For example the Fulton Dam PMF volume (1,563,000 dam^3) was derived from the 1:100 year 24-hour spring rain storm combined with the Probable Maximum Snow Accumulation (PMSA). The PMSA was assumed to produce the 1:10,000 year snowmelt which accounted for almost 95% of the total runoff. On the other extreme, the PMF for Stamp River was calculated using the 96-hour fall PMP event with no snowmelt. The 96-hour PMP was 907 mm compared to the 24-hour PMP of 366 mm. Other sites had varying combinations of rainfall and snowmelt.

Additional data would be required to provide useable volume relationships. As can be seen later in this report in the examination of PMF peaks the regional relationships all outperformed the province wide relationship in predicting peaks. It would be reasonable to assume that the same would hold for PMF volumes if more data was available.

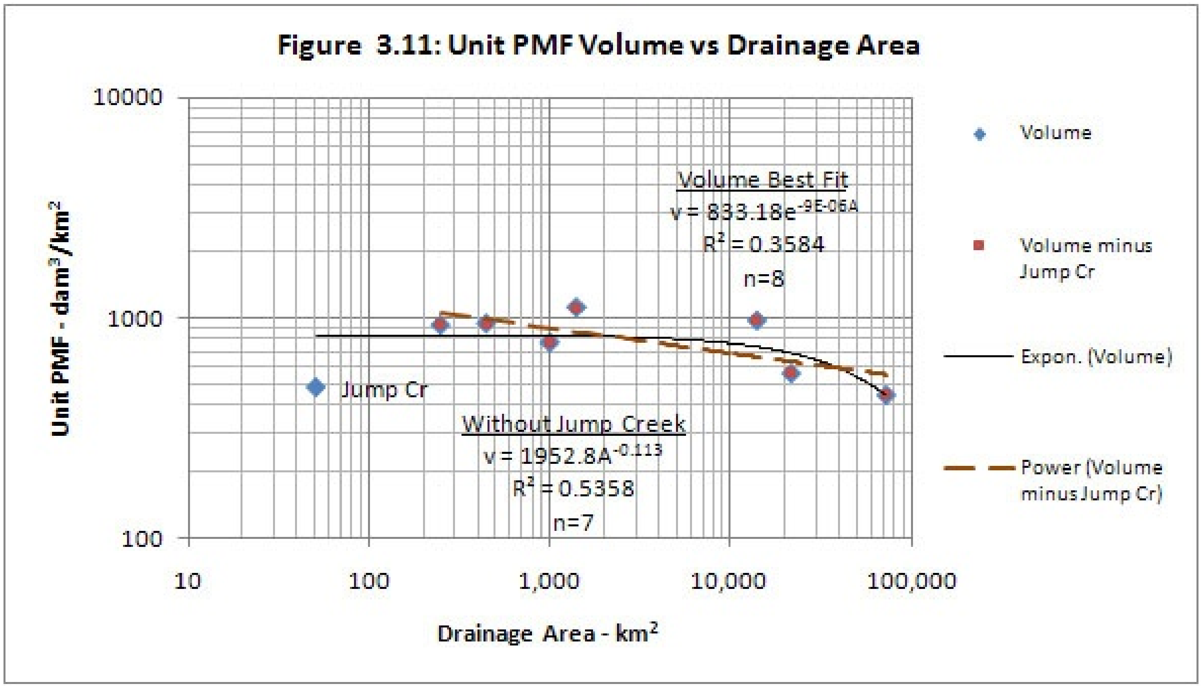


Figure 3.11: Unit PMF Volume vs Drainage Area
Unit PMF - dam3/km2
Drainage Area - km2
10000
1000
100
10
100
1,000
10,000
100,000
Volume Best Fit
v = 833.18e-9E-06A
R2 = 0.3584
n=8
Jump Cr
Without Jump Creek
v = 1952.8A-0.113
R2 = 0.5358
n=7
Volume
Volume minus Jump Cr
Expon. (Volume)
Power (Volume minus Jump Cr)

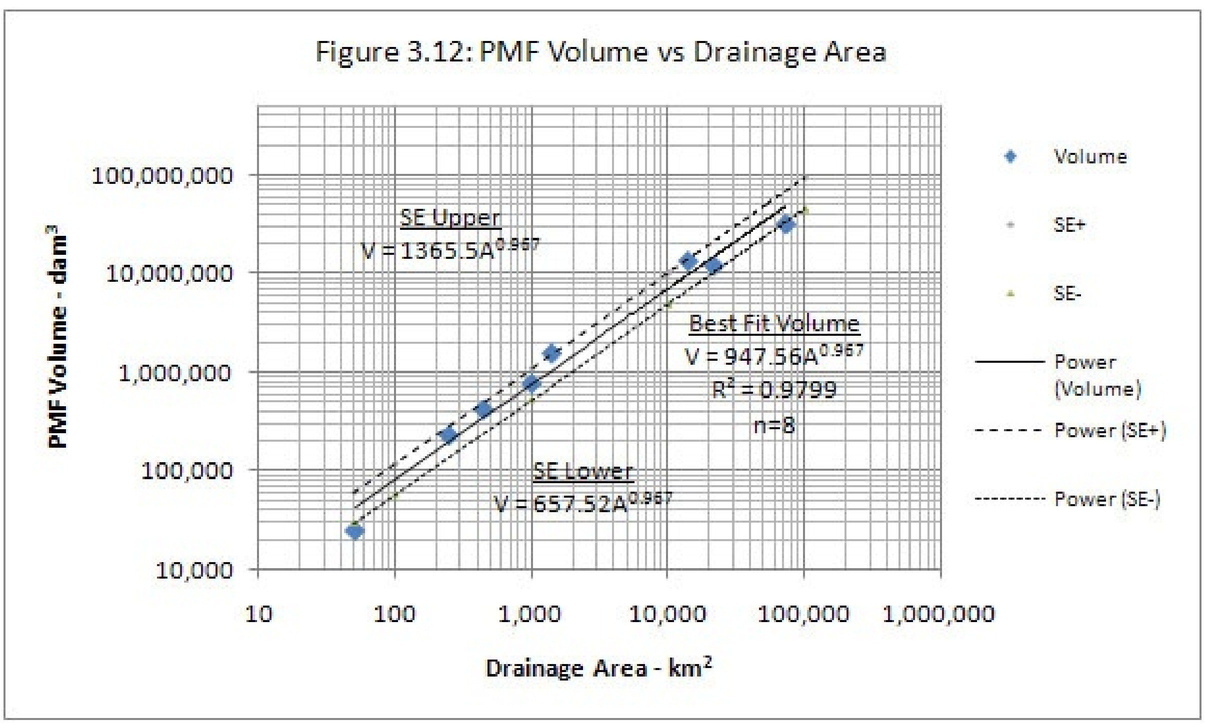


Figure 3.12: PMF Volume vs Drainage Area
PMF Volume - dam3
Drainage Area - km2
100,000,000
10,000,000
1,000,000
100,000
10,000
10
100
1,000
10,000
100,000
1,000,000
SE Upper
V = 1365.5A0.967
Best Fit Volume
V = 947.56A0.967
R2 = 0.9799
n=8
SE Lower
V = 657.52A0.967
Volume
SE+
SE-
Power (Volume)
Power (SE+)
Power (SE-)

4.0 REGIONALISATION

4.1 REGIONAL SCAN

BC Environment's Streamflow Inventory uses 17 Hydrological Zones, each having its own hydrologic characteristics which theoretically would suggest that a different PMF relationship might be developed for each zone. As well the PMF data provided by BC Hydro was divided into seven regions: Vancouver Island, Costal, Bridge River, Okanagan, Kootenay, Columbia and Peace River.

The small size of the data set precludes dividing it to that many portions. However, both the BC Hydro regions and BC Environment's hydrological zones provided a rough guideline for the initial attempts at regionalisation. As discussed earlier, the hydrological zones provided the rationale for separating out the outliers from the Okanagan data in Zone 12B.

Comparing the location of the PMF data in Figure 2.1 with the hydrological zones in Figure 3.2 suggests that possible subgroups for the study would include Vancouver Island (Island), the costal region (Coastal), the Columbia River basin including the Kootenay and U.S. tributaries of Pend d'Oreille and Clark Fork (Columbia) and the BC Interior (BCI). These are illustrated in the plot of PMF versus drainage area in Figure 4.1. Note that there were two points in north west Washington State (NW WA), one on the upper Skagit River basin and the other a PMF developed from local drainage to Lake Whatcom. After some testing both were included with the coastal data in the next section.

A best fit regression line was developed for PMF peaks and drainage area for the Island, Coastal and Columbia groups. The R^2 values were Island (0.97), Coastal (0.96) as shown in Figure 4.2. All of these are higher than the $R^2 = 0.92$ calculated for the larger data set comprising all of the PMFs, supporting the case for regionalisation. The remaining groups did not have sufficient data to do a statistical analysis. They would be considered in the consolidation of groups in the next section.

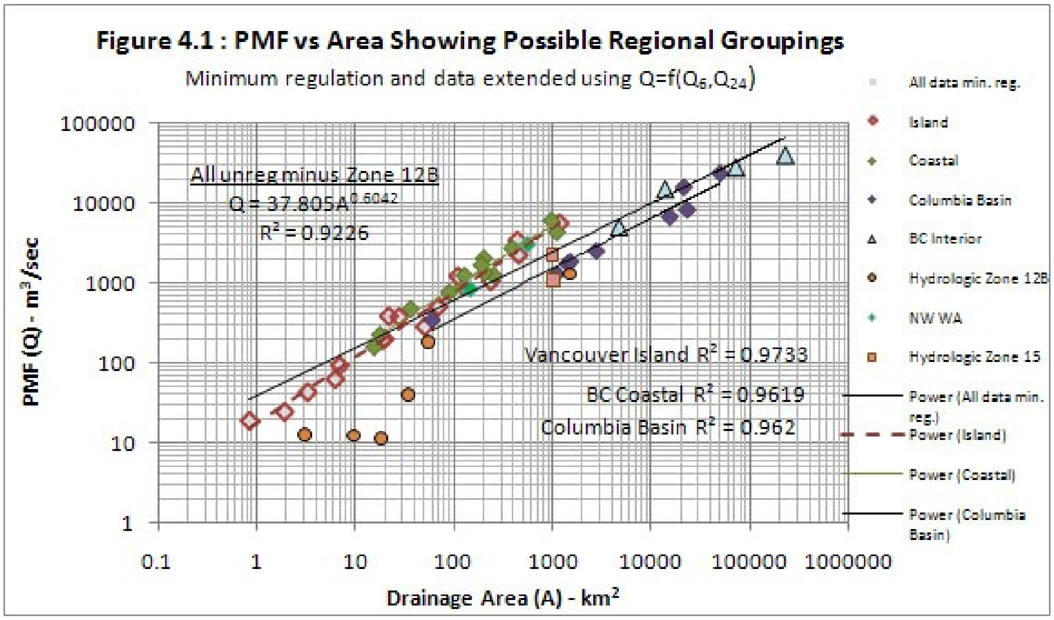


Figure 4.1 : PMF vs Area Showing Possible Regional Groupings
Minimum regulation and data extended using Q=f(Q6,Q24)
All unreg minus Zone 12B
Q = 37.805A^0.6042
R² = 0.9226
Vancouver Island R² = 0.9733
BC Coastal R² = 0.9619
Columbia Basin R² = 0.962
PMF (Q) - m³/sec
Drainage Area (A) - km²
All data min. reg.
Island
Coastal
Columbia Basin
BC Interior
Hydrologic Zone 12B
NW WA
Hydrologic Zone 15
Power (All data min. reg.)
Power (Island)
Power (Coastal)
Power (Columbia Basin)

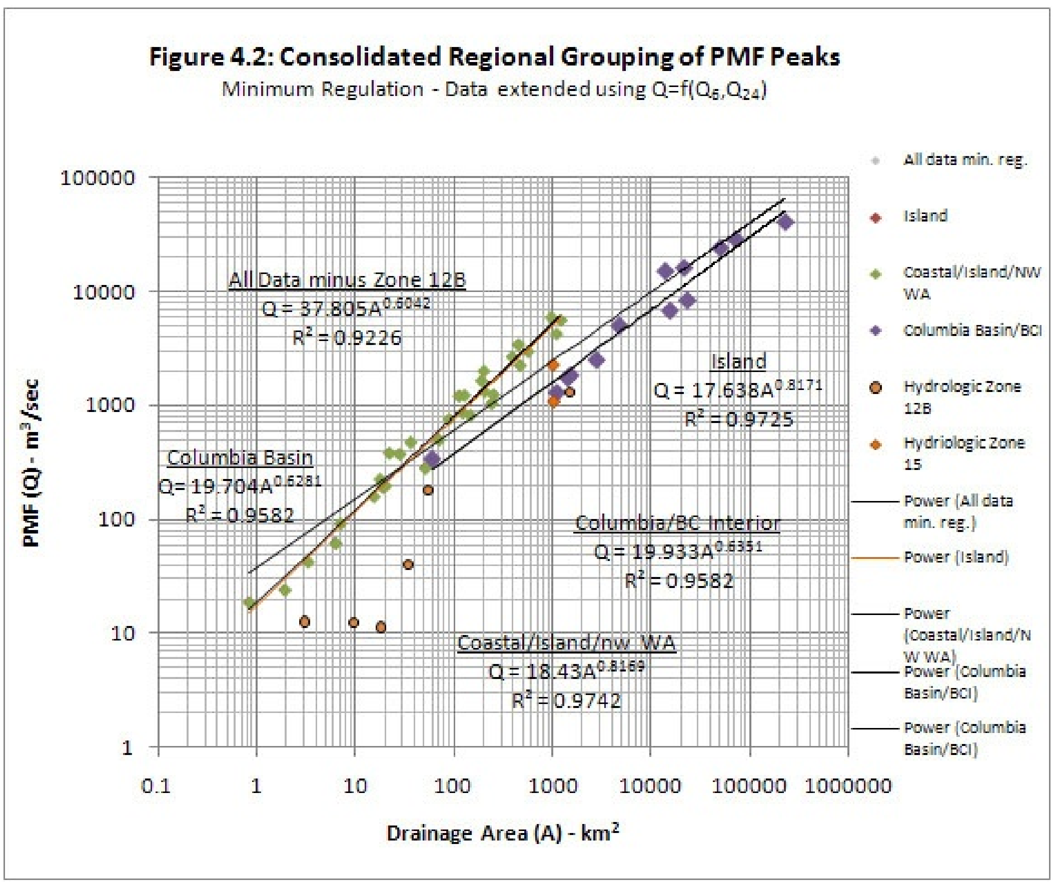


Figure 4.2: Consolidated Regional Grouping of PMF Peaks
Minimum Regulation - Data extended using Q=f(Q6,Q24)
All Data minus Zone 12B
Q = 37.805A^0.6042
R² = 0.9226
Island
Q = 17.638A^0.8171
R² = 0.9725
Columbia Basin
Q= 19.704A^0.6281
R² = 0.9582
Columbia/BC Interior
Q = 19.933A^0.6351
R² = 0.9582
Coastal/Island/nw WA
Q = 18.43A^0.8169
R² = 0.9742
PMF (Q) - m³/sec
Drainage Area (A) - km²
All data min. reg.
Island
Coastal/Island/NW WA
Columbia Basin/BCI
Hydrologic Zone 12B
Hydriologic Zone 15
Power (All data min. reg.)
Power (Island)
Power (Coastal/Island/NW WA)
Power (Columbia Basin/BCI)
Power (Columbia Basin/BCI)

4.2 CONSOLIDATED REGIONS

Attempts were made to improve the statistical relationships between PMF peaks and drainage area, and include the smaller data sets for the BC Interior, Bridge River, the Okanagan (Zone 12B) and north west Washington by consolidating the data into larger groups. The improvement was measured by the change in the coefficient of determinations (R^2). Several combinations were tried leading to the formation of two groups - Columbia/BC Interior, and Coastal/Island/NW WA (two stations in northwest Washington) as shown in Figure 4.2. The coefficients of determination for both groups were better than that for the overall data set.

The R^2 for the Columbia/BC interior group did not change significantly from that for the Columbia basin by itself suggesting that the consolidated grouping could be used to represent PMFs for both regions.

The Coastal/Island/NW WA group performed about the same as the Island by itself. There was however a small improvement in the R^2 for the coastal region. The inclusion of the two data points from Washington State further strengthened this relationship.

The unit PMF for the two consolidated groupings, Columbia/BC interior and Coastal/Island/NW Washington, and the Island, Coastal and Columbian Basin groups by themselves were plotted against drainage area. These are shown in figures 4.3 to 4.7. Figures 4.8 to 4.12 show the peak flow (Q) versus drainage area.

The Columbia/BC interior and the Columbia groups showed an excellent correlation between the PMF and drainage area with $R^2 = 0.883$ and 0.898 respectively. These are both higher than that for the overall minimum regulated data set ($R^2 = 0.846$). The values for the other three groupings were much lower with R^2 ranging between 0.65 and 0.67. However, given that the relationship between PMF peak and drainage area was very good, these relationships still might provide useful information as they represent more local areas.

4.3 FURTHER ANALYSIS OF PMFs IN ZONE 12B

An attempt was made to develop a relationship that would include the PMFs in Zone 12B. An examination of data in adjacent areas showed that two stations that were originally included in the Coastal region, Seton and Lajoie in BC Hydro's Bridge River system, might be combined with the data in Zone 12B. The Bridge River data fell within Zone 15 which was adjacent to Zone 12B. As well both zones were located within the boundaries of the British Columbian Interior low flow zone defined by BC Environment.

The data for the two zones were plotted against the drainage area on Figures 4.13 and 4.14. While the unit PMF showed virtual no dependence on drainage area the PMF peak had a reasonably good relationship with $R^2 = 0.92$.

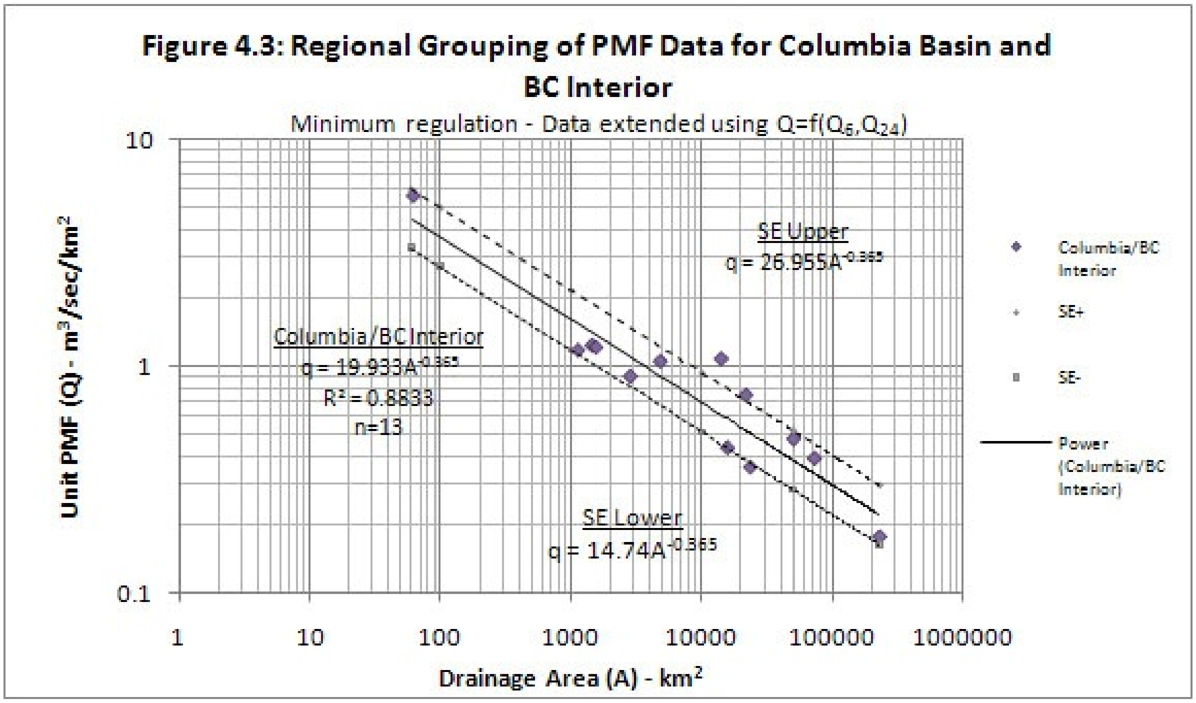


Figure 4.3: Regional Grouping of PMF Data for Columbia Basin and BC Interior

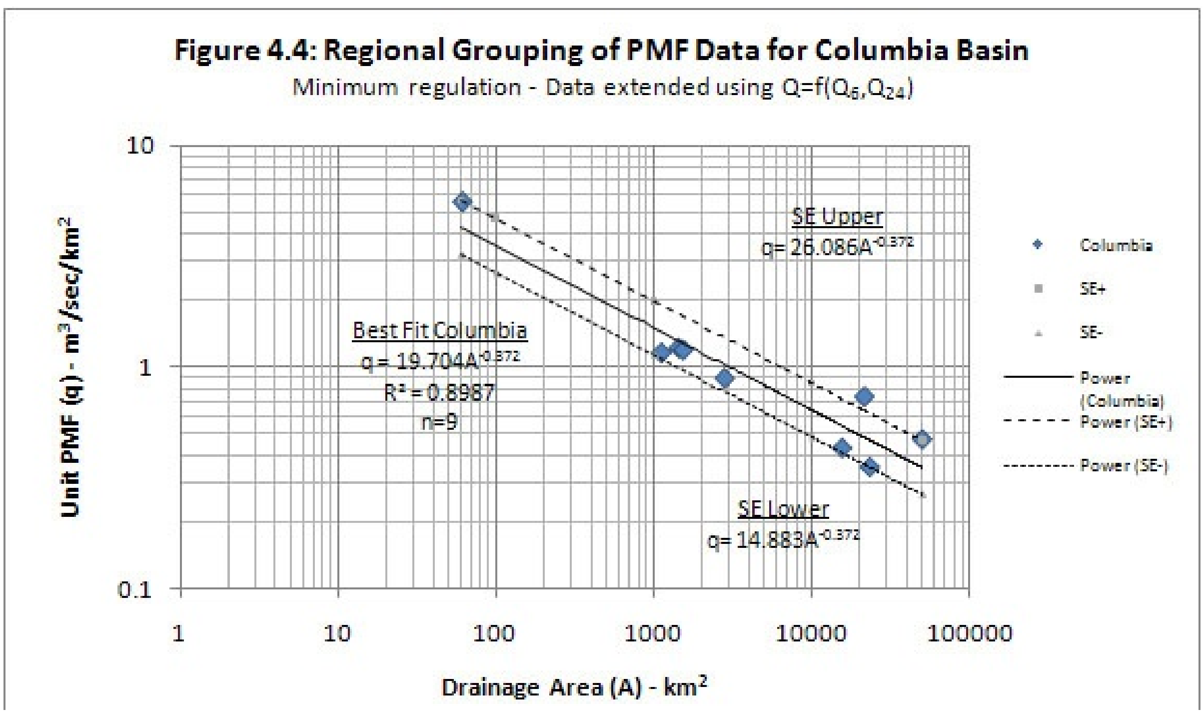


Figure 4.4: Regional Grouping of PMF Data for Columbia Basin

Figure 4.5 : Regional Grouping of Unit PMF Data for BC Coastal Region including Vancouver Island/NW Washington

Minimum regulation - Data extended using $Q=f(Q_6,Q_{24})$

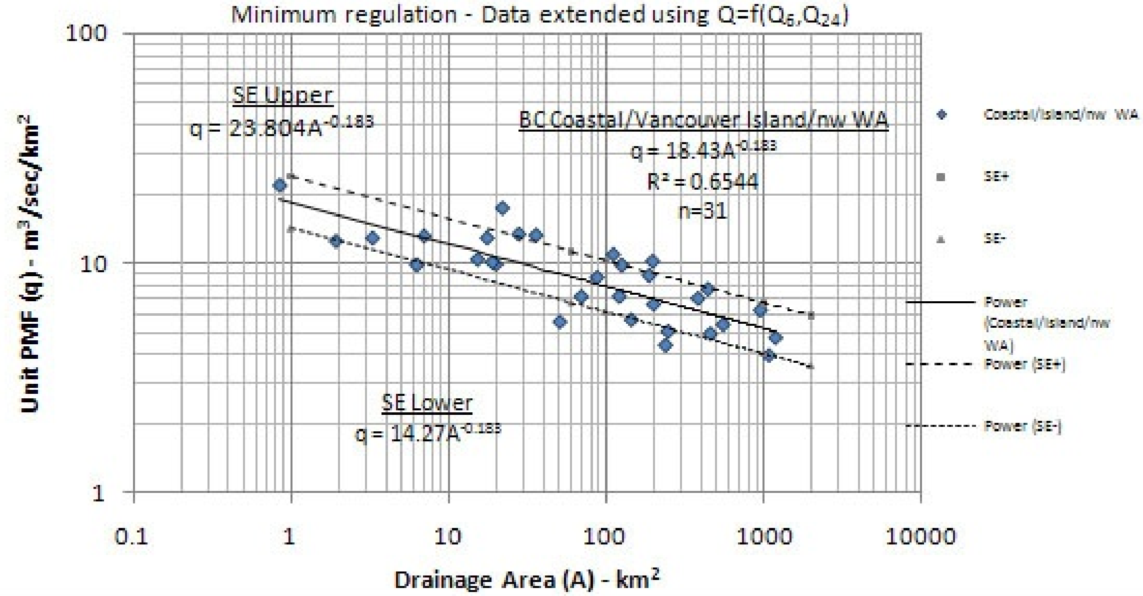
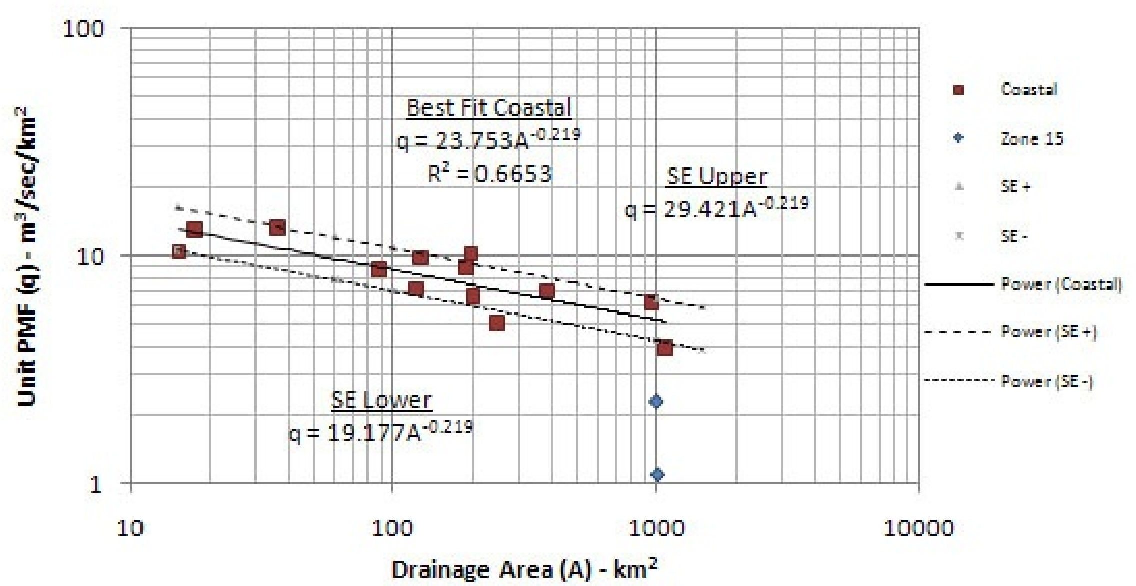


Figure 4.6: Regional Grouping of Unit PMF for BC Coastal Region

Minimum regulation - Data extended using $Q=f(Q_6,Q_{24})$



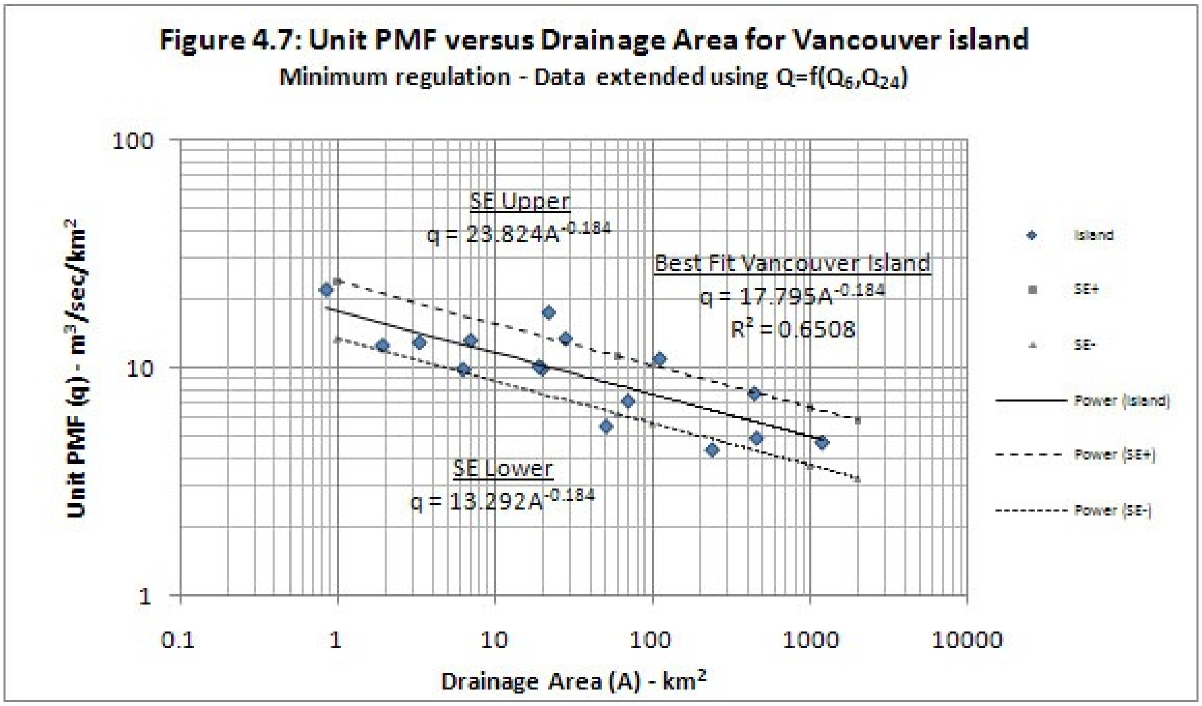


Figure 4.7: Unit PMF versus Drainage Area for Vancouver island
Minimum regulation - Data extended using Q=f(Q6,Q24)
Unit PMF (q) - m3/sec/km2
Drainage Area (A) - km2
100
10
1
0.1
1
10
100
1000
10000
SE Upper
q = 23.824A-0.184
Best Fit Vancouver Island
q = 17.795A-0.184
R2 = 0.6508
SE Lower
q = 13.292A-0.184
Island
SE+
SE-
Power (Island)
Power (SE+)
Power (SE-)

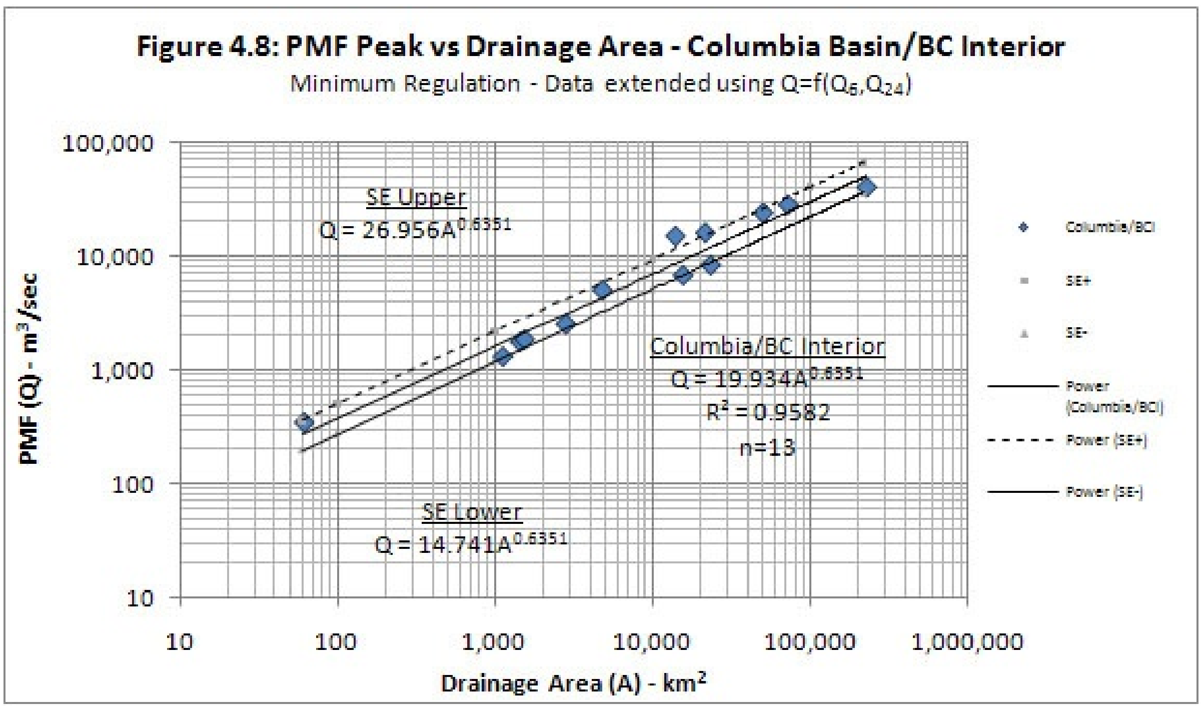


Figure 4.8: PMF Peak vs Drainage Area - Columbia Basin/BC Interior
Minimum Regulation - Data extended using Q=f(Q6,Q24)
PMF (Q) - m3/sec
Drainage Area (A) - km2
100,000
10,000
1,000
100
10
10
100
1,000
10,000
100,000
1,000,000
SE Upper
Q = 26.956A0.6351
Columbia/BC Interior
Q = 19.934A0.6351
R2 = 0.9582
n=13
SE Lower
Q = 14.741A0.6351
Columbia/BCI
SE+
SE-
Power (Columbia/BCI)
Power (SE+)
Power (SE-)

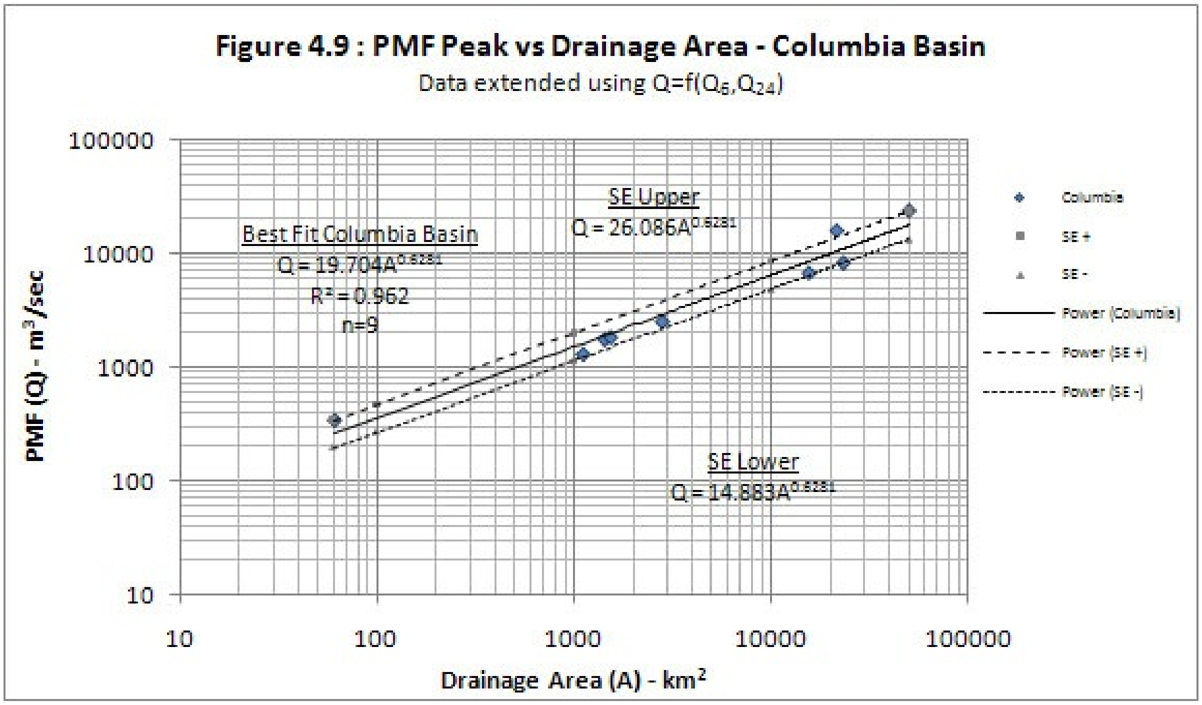


Figure 4.9 : PMF Peak vs Drainage Area - Columbia Basin
Data extended using Q=f(Q6,Q24)
Best Fit Columbia Basin
Q = 19.704A^0.6281
R² = 0.962
n=9
SE Upper
Q = 26.086A^0.6281
SE Lower
Q = 14.883A^0.6281
PMF (Q) - m³/sec
Drainage Area (A) - km²
Columbia
SE +
SE -
Power (Columbia)
Power (SE +)
Power (SE -)
100000
10000
1000
100
10
10
100
1000
10000
100000

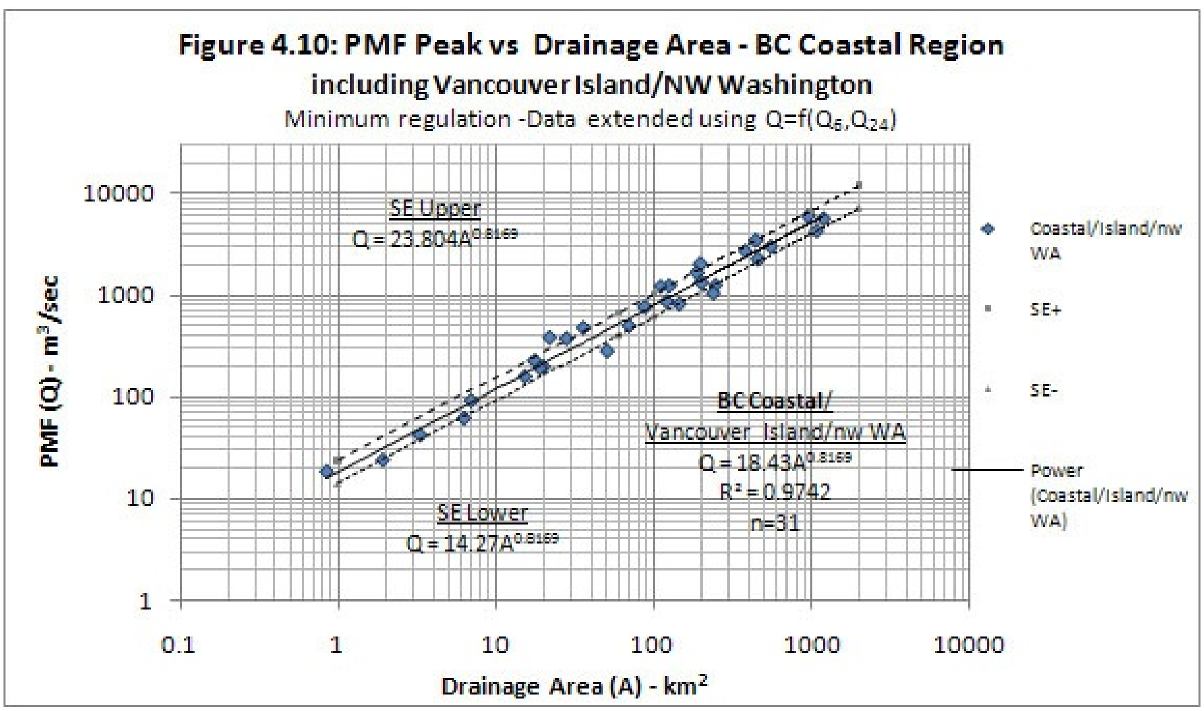


Figure 4.10: PMF Peak vs Drainage Area - BC Coastal Region including Vancouver Island/NW Washington
Minimum regulation -Data extended using Q=f(Q6,Q24)
SE Upper
Q = 23.804A^0.8169
SE Lower
Q = 14.27A^0.8169
BC Coastal/ Vancouver Island/nw WA
Q = 18.43A^0.8169
R² = 0.9742
n=31
PMF (Q) - m³/sec
Drainage Area (A) - km²
Coastal/Island/nw WA
SE+
SE-
Power (Coastal/Island/nw WA)
10000
1000
100
10
1
0.1
1
10
100
1000
10000

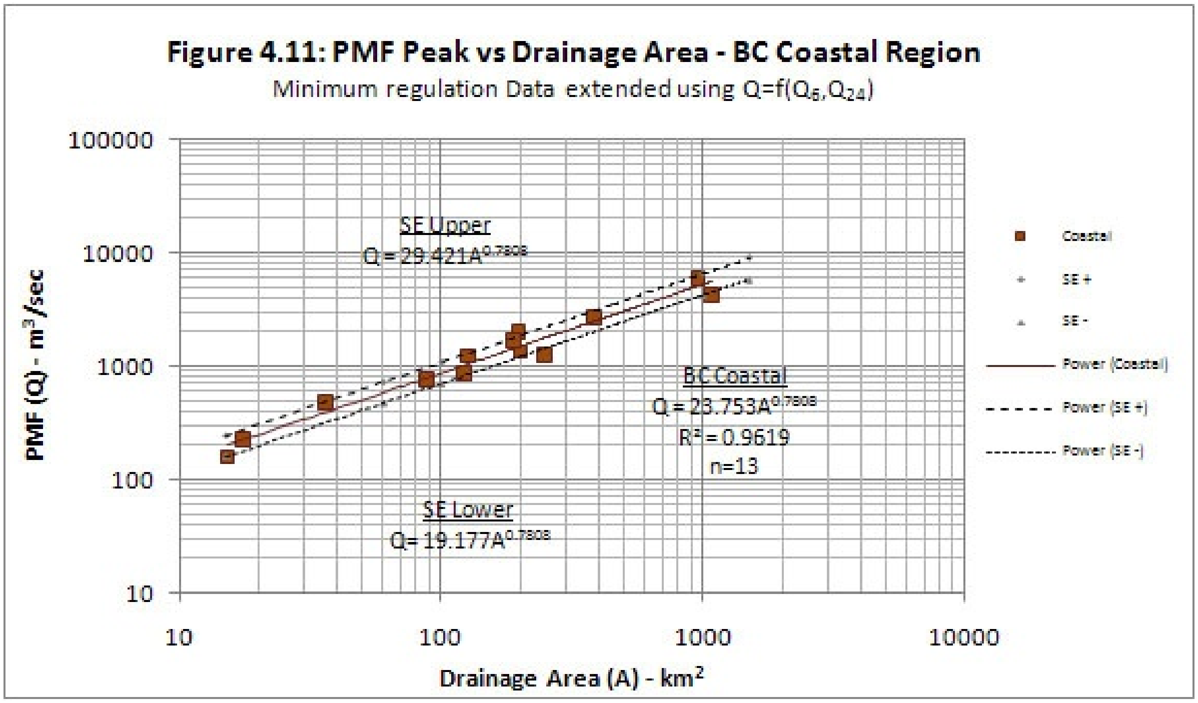


Figure 4.11: PMF Peak vs Drainage Area - BC Coastal Region
Minimum regulation Data extended using Q=f(Q6,Q24)
SE Upper
Q = 29.421A^0.7808
BC Coastal
Q = 23.753A^0.7808
R² = 0.9619
n=13
SE Lower
Q= 19.177A^0.7808
PMF (Q) - m³/sec
Drainage Area (A) - km²
100000
10000
1000
100
10
10
100
1000
10000
Coastal
SE +
SE -
Power (Coastal)
Power (SE +)
Power (SE -)

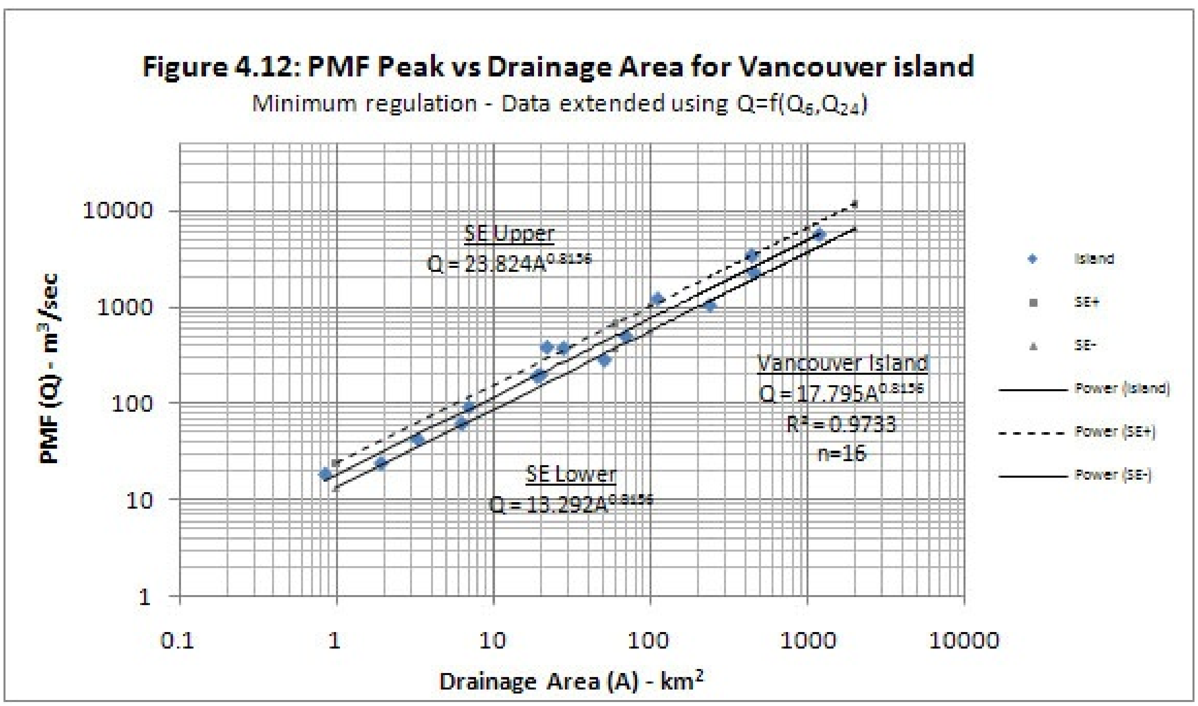


Figure 4.12: PMF Peak vs Drainage Area for Vancouver island
Minimum regulation - Data extended using Q=f(Q6,Q24)
SE Upper
Q = 23.824A^0.8156
Vancouver Island
Q = 17.795A^0.8156
R² = 0.9733
n=16
SE Lower
Q = 13.292A^0.8156
PMF (Q) - m³/sec
Drainage Area (A) - km²
10000
1000
100
10
1
0.1
1
10
100
1000
10000
Island
SE+
SE-
Power (Island)
Power (SE+)
Power (SE-)

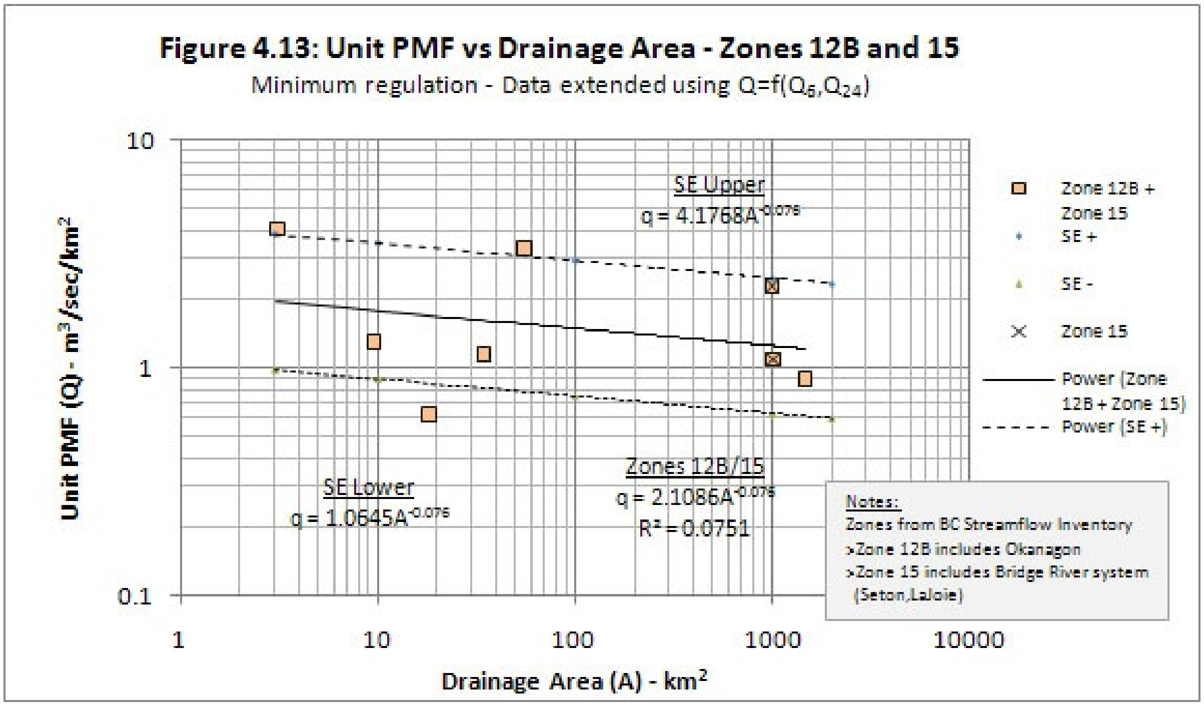


Figure 4.13: Unit PMF vs Drainage Area - Zones 12B and 15
Minimum regulation - Data extended using Q=f(Q6,Q24)
SE Upper
q = 4.1768A-0.076
SE Lower
q = 1.0645A-0.076
Zones 12B/15
q = 2.1086A-0.076
R² = 0.0751
Unit PMF (Q) - m3/sec/km2
Drainage Area (A) - km2
Zone 12B + Zone 15
SE +
SE -
Zone 15
Power (Zone 12B + Zone 15)
Power (SE +)
Notes:
Zones from BC Streamflow Inventory
>Zone 12B includes Okanagon
>Zone 15 includes Bridge River system (Seton,Laloie)

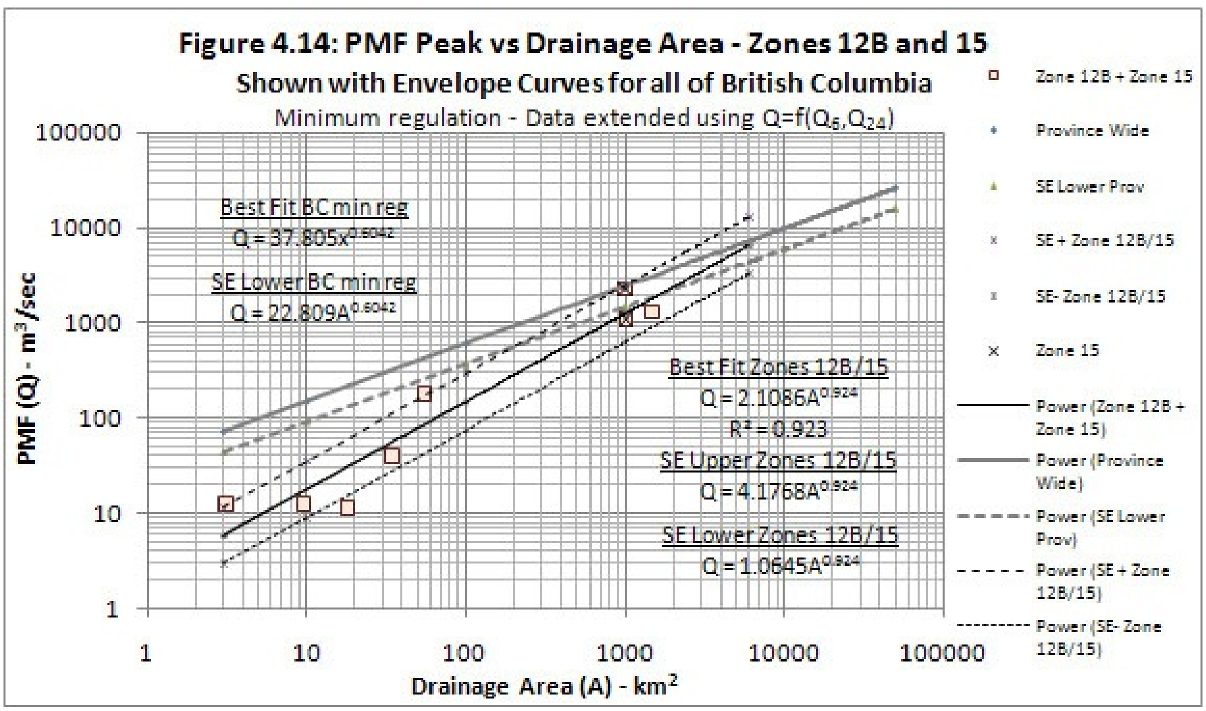


Figure 4.14: PMF Peak vs Drainage Area - Zones 12B and 15
Shown with Envelope Curves for all of British Columbia
Minimum regulation - Data extended using Q=f(Q6,Q24)
Best Fit BC min reg
Q = 37.805x0.6042
SE Lower BC min reg
Q = 22.809A0.6042
Best Fit Zones 12B/15
Q = 2.1086A0.924
R² = 0.923
SE Upper Zones 12B/15
Q = 4.1768A0.924
SE Lower Zones 12B/15
Q = 1.0645A0.924
PMF (Q) - m3/sec
Drainage Area (A) - km2
Zone 12B + Zone 15
Province Wide
SE Lower Prov
SE + Zone 12B/15
SE- Zone 12B/15
Zone 15
Power (Zone 12B + Zone 15)
Power (Province Wide)
Power (SE Lower Prov)
Power (SE + Zone 12B/15)
Power (SE- Zone 12B/15)

The provincial relationship between PMF and drainage area was plotted on Figure 4.14 and compared to the PMF versus drainage area relationships for the Zone 12B and Bridge River data. The Zone 12B/15 curves were much steeper intercepting the provincial curves at the Area and PMF coordinates of 8,320 km^2 and 8,830 m^3/s respectively. Considering the three largest PMFs from Zone 12B/15, one falls close to the provincial curve while the other two fall just below the lower bounds of the Standard Error of the provincial relationship.

A similar test was done using the Columbia/BC Interior relationships between PMF peak and drainage area. The intersection point was much lower (2,400 km^2 and 2,800 m^3/s) as shown on Figure 4.15. Both Zone 15 values (Bridge River) plotted within the bounds of standard error with the LaJoie data plotting on the upper boundary. One of the Zone 12B data points (Nicola Lake) also plotted within the bounds of the Standard Error.

It might be possible to combine the Zone 12B/15 curve with either the provincial or Columbia/BC Interior curves to form an envelope curve for Zone 12B/15 . While the provincial curve would provide the more conservative estimate of the PMF the Columbia/BC Interior curve should also be given consideration.

4.4 IMPACT OF VARIABILITY IN PROBABLE MAXIMUM PRECIPITATION (PMP)

Figure 4.16 shows the Coastal/Island unit PMF and selected PMP data plotted against drainage area. The values for Seton and La Joie (Bridge River system) plotted well outside the expected standard error. The resulting analysis led to the removal of the Bridge River stations from the Coastal group and inclusion with the Zone 12B data as discussed in the previous section. Their inclusion in the Coastal group did lead to an examination of the impact of variability of PMPs on the PMF.

PMP data from the Analysis of Probable Maximum Precipitation for Southwest British Columbia[1] shows a wide variation in average point 24 hour PMP values for 16 BC Hydro watersheds in southwestern British Columbia. Eleven of these correspond to watersheds used for the Coastal/Island[2] region in this study. The PMFs for these watersheds have been plotted as labels on their respective data points in Figure 4.16.

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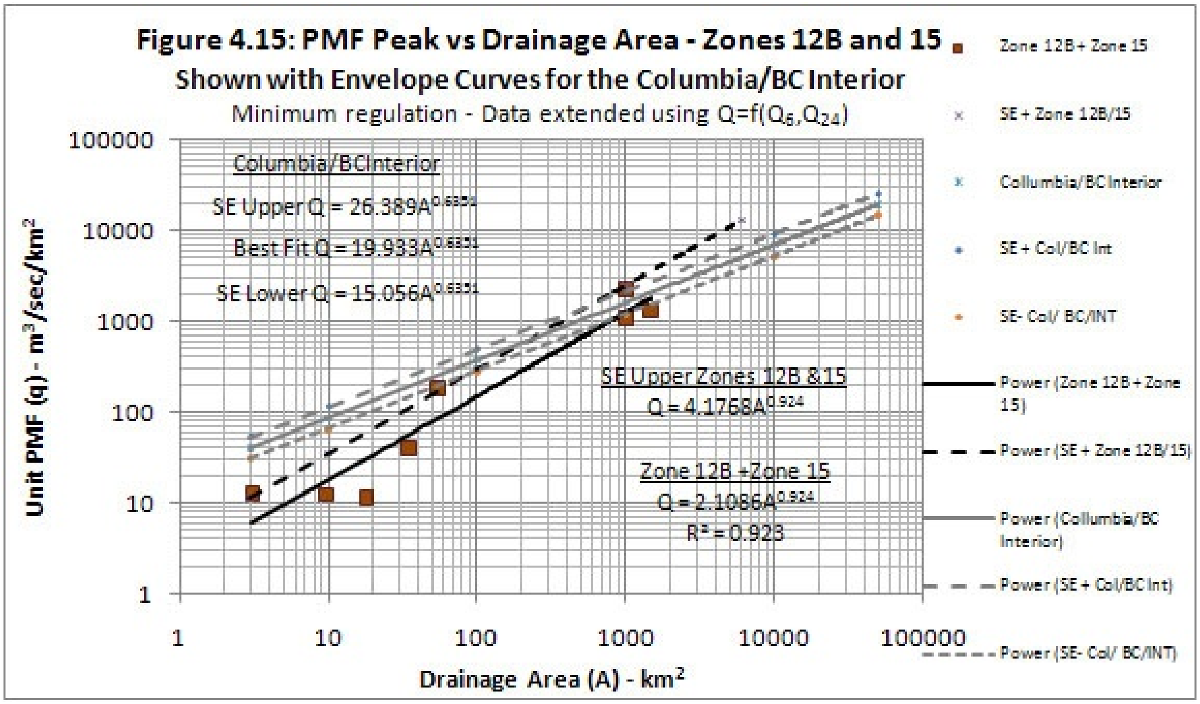
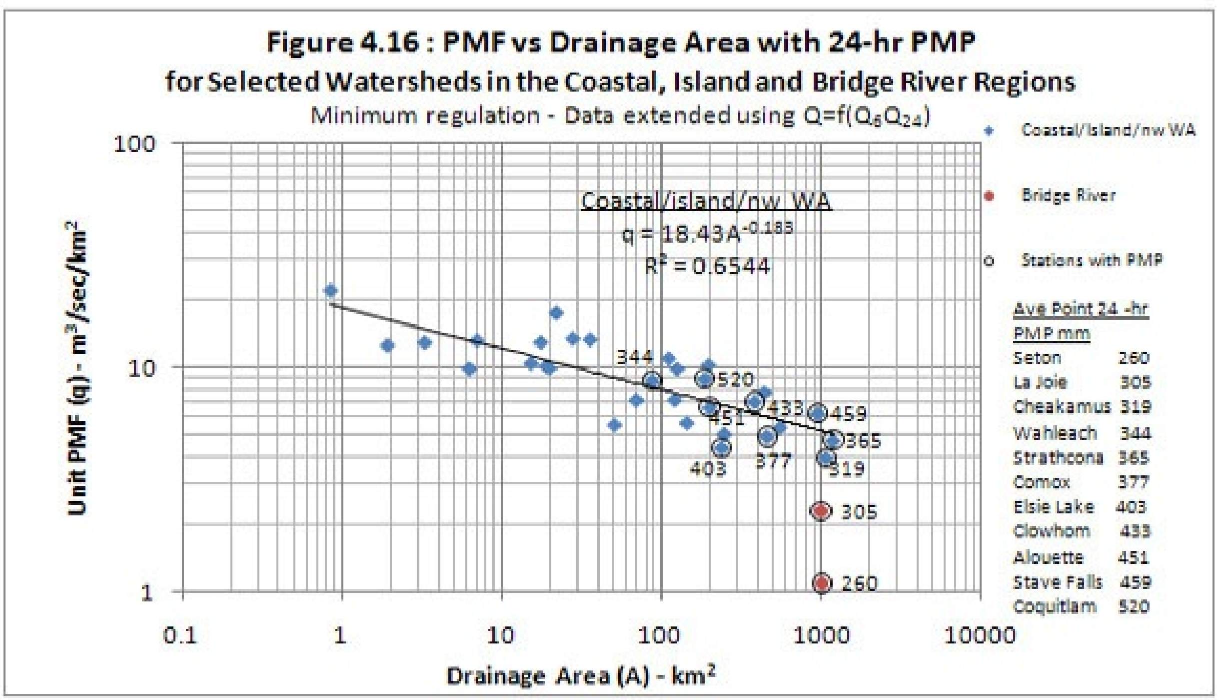
[1] Analysis of Probable Maximum Precipitation in Southwest British Columbia - Prepared for British Columbia Hydro and Power Authority by Water Management Consultants, February, 2003.

[2] The original analysis in this study included the Bridge River locations with the Coastal data. These were subsequently moved to the Zone 12B/15 group.

The average point 24 hour PMP for the 11 stations plotted ranged from 260 mm for Seton Dam to 520 mm for Coquitlam Dam. When these PMPs were used as labels for the data





points it indicated a pattern in which the PMFs for an area with a higher PMP would plot above the trend line while PMFs for lower PMPs would plot below the line. This could prove useful in using the relationship as predictors of preliminary PMF values.

A multiple regression analysis was conducted (PMF = f (Area , PMP)) using data from the 11 watersheds having PMP data. The R^2 was 0.76. A second multiple regression analysis was carried out with more data points. The resulting R^2 was 0.67.

A more detailed analysis of the additional PMPs similar to that done by BC Hydro in southwest British Columbia would be required to take this analysis further. Nevertheless the brief analysis indicates that local variations in PMP should be one of the considerations that would influence the estimation of PMFs from the graphical relationships presented in this study.

4.5 REGULATED PMFs IN THE COLUMBIA RIVER BASIN

PMF data were available for 10 locations in the heavily regulated watersheds along the Pend d'Oreille, Clark-Fork, Kootenay and upper Columbia Rivers. Because the PMFs for these locations appeared in a definable group in Figure 3.1, it was investigated further as shown in Figures 4.17 and 4.18. Even though these basins were highly regulated the unit PMF shows a slight inverse relationship to drainage area (R^2 = 0.72) possibly due to the cumulative effects of regulation as you move from upstream to downstream.

The peak PMF on the other hand was completely independent of the drainage area. A plot of the PMF peak against drainage area shows that most peaks lie between 8,500 and 11,000 m^3/s with a mean PMF of 10,100 m^3/s. This reflects the influence of the operation of upstream reservoirs to meet the operational requirements for flows in the Columbia river Basin. The effect of operational assumptions is illustrated by the high and low ranges of PMF peak for Noxon Rapids and Cabinet Gorge on the Clark Fork River which range between 8,500 and 11,800 m^3/s.

This might have some utility for comparing the PMFs within this highly regulated regime.

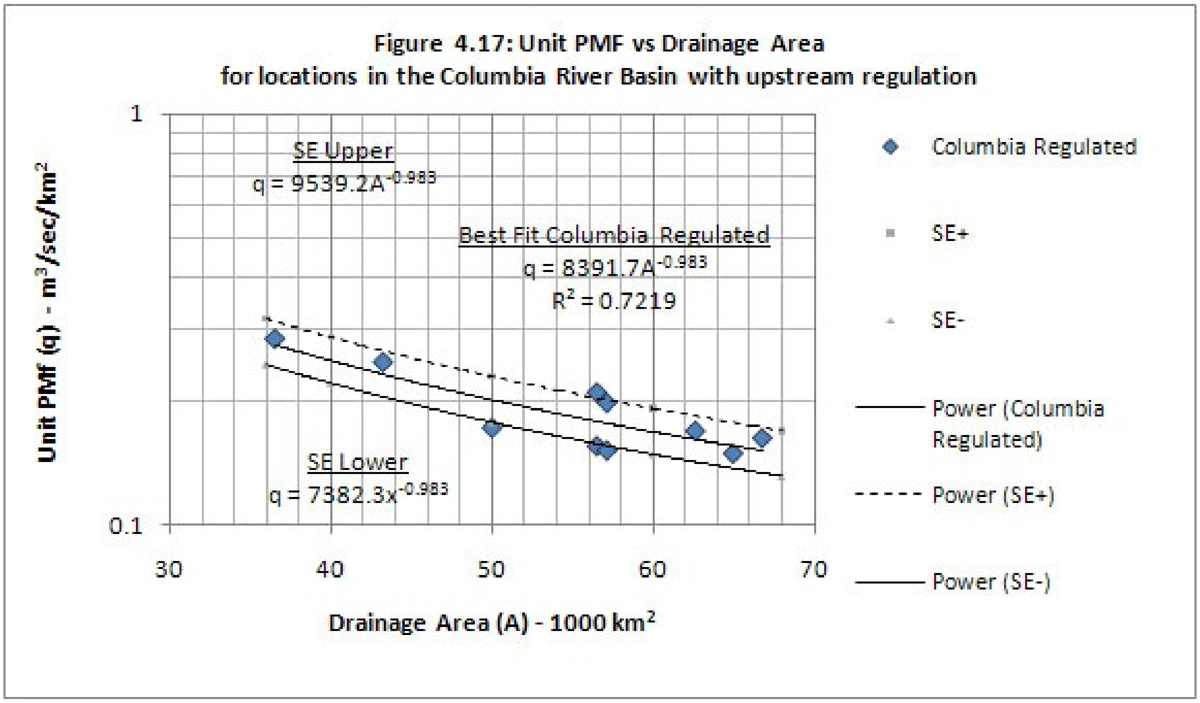


Figure 4.17: Unit PMF vs Drainage Area
for locations in the Columbia River Basin with upstream regulation
SE Upper
q = 9539.2A^-0.983
Best Fit Columbia Regulated
q = 8391.7A^-0.983
R² = 0.7219
SE Lower
q = 7382.3x^-0.983
Unit PMf (q) - m³/sec/km²
Drainage Area (A) - 1000 km²
1
0.1
30
40
50
60
70
Columbia Regulated
SE+
SE-
Power (Columbia Regulated)
Power (SE+)
Power (SE-)

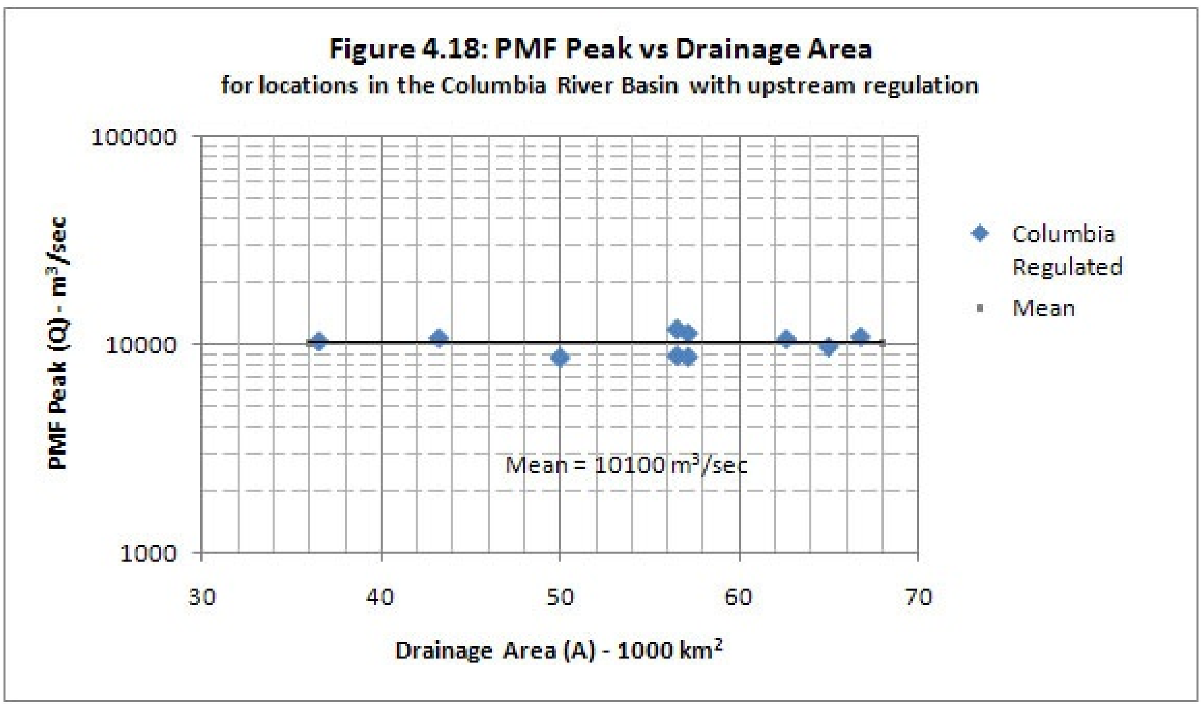


Figure 4.18: PMF Peak vs Drainage Area
for locations in the Columbia River Basin with upstream regulation
PMF Peak (Q) - m³/sec
100000
10000
1000
Mean = 10100 m³/sec
30
40
50
60
70
Drainage Area (A) - 1000 km²
Columbia Regulated
Mean

5.0 DISCUSSION AND CONCLUSIONS

5.1 GEOGRAPHIC LIMITS

PMF data gathered for this study tended to be clustered in areas around Vancouver Island, the coastal region, and the Columbia Basin reflecting the concentrations of hydroelectric development in those areas as well as the heavily developed water supply systems for the City of Vancouver, and the Cities of Victoria and Nanaimo on Vancouver Island. This leads to the conclusion that the curves would be more reliable for those regions. The extension of the Columbia River curves to include the more northern locations such as the Peace River shows promise, however, this needs to be used with caution considering the scarcity of data that went into developing the relationships.

The extended data sets in Figures 3.6 and 3.7 show a very good relationship between unit PMF and drainage area ($R^2 = 0.84$) and PMF peak and drainage area ($R^2 = 0.92$). From a visual inspection, unit PMF values appear to be clustered above the trend line for areas between 20 and 1000 km². This would lead to low estimates if Figure 3.6 was used as a predictor. An examination of the residuals (predicted q and actual q shown in Appendix F) supports this. For areas less than 20 km² and greater than 1000 km² the values tend to plot below the line resulting in higher predictions. Figure 3.7, peak flow versus drainage area, exhibit similar characteristics.

5.2 REGIONALIZATION

The regional analyses illustrated in the Figures 4.3 to 4.12 show a visually better fit with no obvious groupings above and below the trend line. This is supported by examination of the residuals. The best fit line for the Columbia region has a high R^2 for both the unit PMF versus area and the peak PMF versus area (R^2 equal 0.90 and 0.96 respectively), showing a high dependency of the PMF on area.

The best fit line for the regional data for Vancouver Island and the coastal region has a flatter slope and a much lower R^2 for the unit runoff, $R^2 = 0.65$ for the coastal/Island region compared to $R^2 = 0.84$ for the province overall.

The PMF peak versus area relationship for the coastal/island data shown on Figures 4.10 to 4.12, however, shows a reasonably good relationship with R^2 between 0.96 and 0.97. This suggests that despite the low R^2 for the regional unit PMF data for the island and coastal regions, the resulting peak PMF may be more appropriate than that developed using the provincial relationship. This conclusion is further supported by the analysis of prediction efficiency in the follow section.

5.3 PREDICTION EFFICIENCIES

The regional relationships and the overall provincial relationships were tested to determine their ability to reproduce the original peak flow data using the relationships $y = ax^b$ established by the regression analysis. The ability to reproduce unit PMF and peak PMF values was measured using the Nash-Sutcliffe efficiency coefficient (E). The results, shown in Table 5.1 indicate that the regional groupings should be used to estimate the PMF.

TABLE 5.1
EFFICIENCY IN PREDICTING PROBABLE MAXIMUM FLOWS FROM DRAINAGE AREA USING REGRESSION EQUATIONS

PMF Region (number of PMFs predicted)	Prediction Equation				Prediction Efficiency - Using Nash-Sutcliffe Efficiency Coefficient (E)	
	Data Used to Develop Equation	**Equation**	**n**	**R^2**	**Unit PMF (q)**	**PMF Peak (Q)**
Island (16)	All data extended (Q=q*A)	$q=37.805A^{-0.396}$	46	0.836	0.458	-0.140
	All data extended	$Q=37.805A^{0.6042}$	46	0.923	--	-0.136
	Coastal+Island+NW WA (Q=q*A)	$q=18.43A^{-0.183}$	31	0.655	0.456	0.962
	Coastal+Island+NW WA	$Q=18.43A^{0.8169}$	31	0.974	--	0.962
	Island Data	$q=17.795A^{-0.184}$	16	0.651	0.440	0.962
	Island Data	$Q=17.795A^{0.8156}$	16	0.973	--	0.962
Coastal minus Seton, LaJoie (13)	All data extended (Q=q*A)	$q=37.805A^{-0.396}$	46	0.836	0.389	-0.367
	All data extended	$Q=37.805A^{0.6042}$	46	0.923	--	-0.364
	Coastal+Island+NW WA (Q=q*A)	$q=18.43A^{-0.183}$	31	0.655	0.176	0.904
	Coastal+Island+NW WA	$Q=18.43A^{0.8169}$	31	0.974	--	0.904
	Coastal Data (Q=q*A)	$q=23.7531A^{-0.219}$	14	0.665	0.551	0.907
	Coastal Data	$Q=23.753A^{0.7808}$	14	0.973	--	0.907
Columbia (9)	All data extended (Q=q*A)	$q=37.805A^{-0.396}$	46	0.836	0.828	0.821
	All data extended	$Q=37.805A^{0.6042}$	46	0.923	--	0.820
	Columbia+BC Interior (Q=q*A)	$q=19.933A^{-0.365}$	13	0.883	0.863	0.815
	Columbia+BC Interior	$Q=19.933A^{0.6351}$	13	0.958	--	0.816
	Columbia (Q=q*A)	$q=19.704A^{-0.372}$	9	0.899	0.827	0.722
	Columbia	$Q=19.704A^{0.6281}$	9	0.962	--	0.723
Interior (4)	All data extended (Q=q*A)	$q=37.805A^{-0.396}$	46	0.836	0.795	0.715
	All data extended	$Q=37.805A^{0.6042}$	46	0.923	--	0.713
	Columbia+BC Interior (Q=q*A)	$q=19.933A^{-0.365}$	13	0.883	0.476	0.875
	Columbia+BC Interior	$Q=19.933A^{0.6351}$	13	0.958	--	0.875
All min reg data (46)	All data extended (Q=q*A)	$q=37.805A^{-0.396}$	46	0.836	0.620	0.860
	All data extended	$Q=37.805A^{0.6042}$	46	0.923	--	0.860

Equations for the Columbia/BC Interior produced better results than those for the Columbia Basin by itself. The efficiency for the combined Columbia/BC Interior was 0.82 compared to 0.72 for the Columbia Basin by itself. Predictions using all of the British Columbia data were equally as good achieving an efficiency of 0.82.

Columbia/BC Interior equation predicted the PMF peaks for the BC Interior with an efficiency of E = 0.875. It should be noted that there were only four points predicted. Nevertheless this relationship is better than that using the province wide equation.

Similarly the Vancouver Island and Coastal equations performed slightly better than the combination of Island/Coastal/NW WA.

The overall result of the efficiency analysis is that either the more localized regional relationship or the broader regional relationships could be used to predict PMFs for the coastal, Island and Columbia regions with relatively equal confidence. Intuitively the smaller regions would be more sensitive to local variability in hydrology and geography.

5.4 VARIABILITY IN PROBABLE MAXIMUM PRECIPITATION (PMP)

Consideration of the PMP can explain some of the variability of the PMF about the trend line. Using data from the Analysis of Probable Maximum Precipitation for Southwest British Columbia[3] shows a wide variation in average point 24 hour PMP values for 16 BC Hydro watersheds in southwestern British Columbia. Eleven of these correspond to watersheds used in this study. PMPs varied from 260 mm to over 500 mm.

A multiple regression analysis yielded and R^2 of 0.76 using the PMP data provided in the BC Hydro and corresponding PMF and drainage area data gathered for this study. Attempts to expand this with additional PMP data extracted from various reports used in this study resulted in a lower R^2.

It was concluded that a more detailed evaluation of the PMP data was required. The brief analysis did, however, show that local variations in PMP should be considered when interpreting the results of the PMF envelope curves developed for this study.

5.5 COMPARISON TO PREVIOUS STUDIES

Envelope curves for probable maximum flood peaks for the Canadian prairies were superimposed on a plot of the British Columbia data as shown on Figure 3.8. The Prairie

[3] Analysis of Probable Maximum Precipitation in Southwest British Columbia - Prepared for British Columbia Hydro and Power Authority by Water Management Consultants, February, 2003

curves have a much steeper slope than the British Columbia curve reflecting the influence of convective storms on the prairies. The Mountain fed curve is closer to the British Columbia curve although still with a slightly steeper slope. The shape of the Mountain fed curve is influenced by the attenuation of flood peaks in the larger basins of the Saskatchewan River system which is due to floods originating in the mountians and flowing across a large area with very little inflow. The point for the Fraser River at Mission falls close to the Mountain fed line suggesting a similar attenuation due to the distance between the source and the study location and the relative timing of peaks in the lower and upper parts of the basin.

5.6 EMPIRICAL RELATIONSHIPS

As discussed earlier in Chapter 3 this study briefly examined the use of two empirical relationships for estimating extreme floods; the first developed by Creager and the second by Francou-Rodier.

An examination of Figure 3.9 shows that the shape of the Creager curves fairly closely approximates the visual trend in the plot of unit PMF versus drainage area for the province. The curve with Creager C = 70 shows a good approximation of the extreme boundary for areas between 20 km² and 200,000 km² and one with C = 20 would provide a reasonable approximation of the lower boundary. This leads to the conclusion that further consideration should be given to the Creager curves.

No conclusions have been arrived at regarding the Francou-Rodier curves shown on Figure 3.10.

5.7 CONCLUSIONS

Figures 4.3 to 4.12 provide a basis for estimating the peak PMF based on drainage area and location. The best fit curve provides an average condition and the standard error range provides guidance for users to apply in evaluating the special features of the specific drainage basin under consideration and the degree of safety factor to be considered to the project under investigation.

The results of the study include the digital data spreadsheets for each of the resulting graphs which will permit the addition of new data when it becomes available and will allow hydrologist to easily plot the results of the PMP studies as simple check against other results. It also provides a good basis for further analysis.

6.0 RECOMMENDATIONS

It is recommended that the best fit equation in Table 6.1 be used to estimate probable maximum flood peaks for British Columbia.

TABLE 6.1
RECOMMENDED REGIONAL EQUATIONS FOR ESTIMATING PMP PEAKS FROM DRAINAGE AREA

	Peak Flows m^3/s	Figure No.
Vancouver Island	$Q = 17.795A^{0.8156}$	Figure 4.12
BC Costal Region	$Q = 23.753A^{0.7808}$	Figure 4.11
Columbia Basin	$Q = 19.704A^{0.6281}$	Figure 4.9
BC Interior	$Q = 19.933A^{0.6351}$	Figure 4.8
Zone 12B and Zone 15	$Q = 37.805A^{0.6042}$ for $A \geq$ 8320 km^2 $Q = 2.1086A^{0.9240}$ for $A <$ 8320 km^2	Figure 4.14

Adjustments can be made based on the Standard Error limits identified on each figure to adjust for special drainage basin characteristics or to generate more or less conservative estimates.

Consideration should also be given to the variation in probable maximum precipitation (PMP) that occurs particularly in the Island and Coastal Mountain Regions.