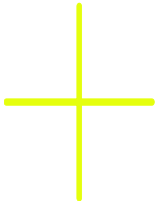




A Statistical Method Similar to the Hershfield Procedure for Estimating Probable Maximum Flood in Ontario



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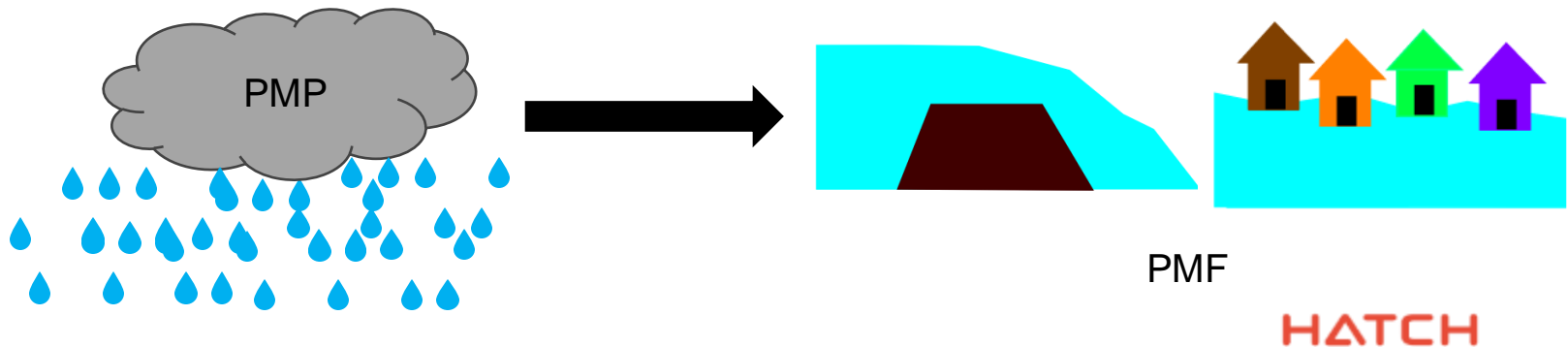
HATCH

Introduction

- PMP and PMF Definitions
- The need for simplified PMF estimation
- The methodology
- Database
- Results
- Discussions
- Conclusions

PMP and PMF

- PMP – Probable Maximum Precipitation: Theoretically, the greatest depth of precipitation for a given duration that is physically possible
- PMF – Probable Maximum Flood: the flood that is expected from the most reasonably severe combination of critical meteorological and hydrological conditions
- The PMF is used in the Consequence Classification of Dams, Flood Studies, Infrastructure Design and More



PMF Derivation Procedure

- Estimation of PMP: PMP could be Regional, Statistical, or site specific. The derivation of PMP requires many experts from different field and can be very expensive
- After the PMP is determined, a rainfall-runoff study is required to derive the PMF. This involves model set-up, calibration and validation. Model simulation with conservative assumptions of variable combinations
- The processes of PMP and PMF requires extensive resources and significant cost
- For high potential hazard category dams, the statistically derived and the regional PMP may not be sufficient

Simplified Solutions

- Sometimes, all that is needed is an estimate of the approximate magnitude of PMF for some preliminary decisions
- More detailed study will be needed later
- Simplified with certain degree of accuracy PMF estimation would be desired in this case
- Some approaches exist: such as, empirical equations, (e.g. BC equations and Zhou' 2023 equation for Ontario)

Statistical Method - PMP

- A statistical method to derive PMF, based on the procedure developed by Hershfield in 1961 and 1965 for PMP
- Hershfield analyzed about 95,000 extreme storms of 2654 stations (about 90% stations are in USA)
- He derived the relationship:
$$h_m = \bar{h}_n + k_m s_n$$
- $K_m = 15$ was the maximum observed value for storm depth which he used as an approximation of PMP

$$P_{PMP} = P_N + K_{PMP} S_N$$

Hershfield Method for PMP

- Later in 1965 Hershfield revised the statistical method and varied the K_m with the average storm depth.
- The method was accepted by the world meteorological organization (WMO) as one of the standard approaches for PMP estimation
- It was found that a constant $K_m = 25$ could be used as a reasonable estimation in Ontario

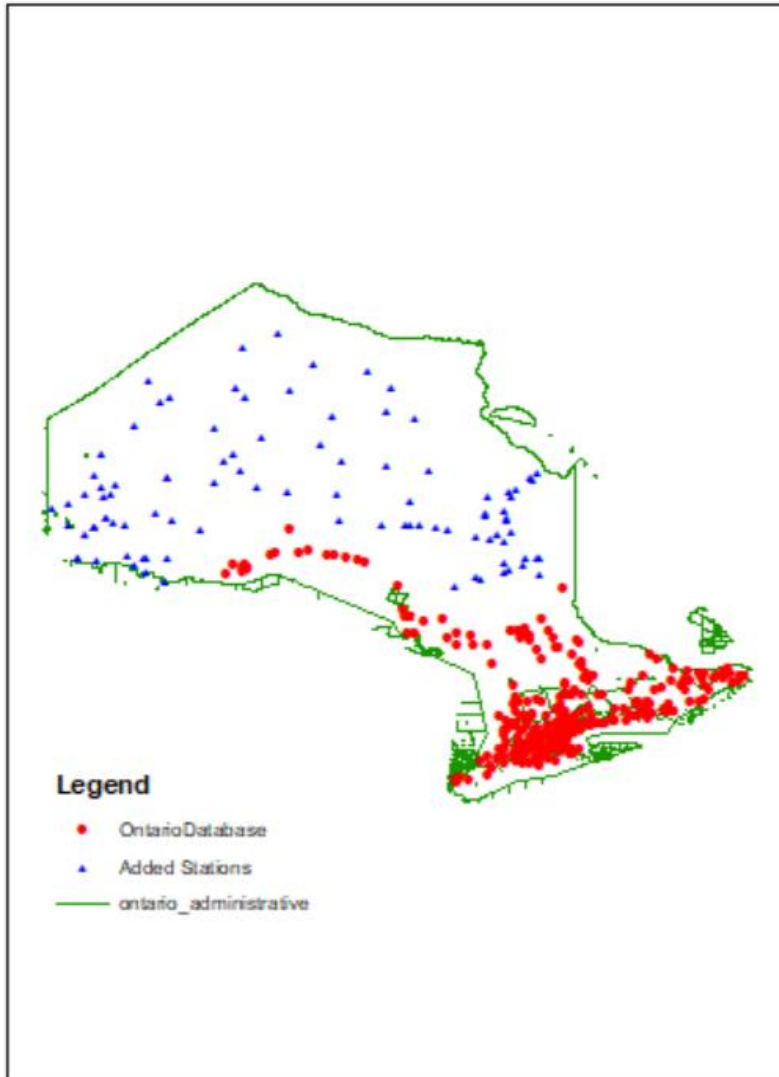
Can the Hershfield Method be Applied to Estimate the Probable Maximum Flood (PMF)?

- This assessment is trying to use the same procedure to see if the Hershfield approach can be applied to estimate PMF
- If yes, what is the K_m range?
- Is there any relationship between K_m and the mean of the annual peak flows for a stream flow time series?

The Database for Ontario

- Ontario MNR released a peak flow database in 2014
- The database has 297 station's flood records and the statistics, for great lake watersheds
- To cover the entire Ontario Province, additional 99 stations in the Northern Ontario were analyzed by the authors, using the HYDAT data
- The updated database has a total 396 stations
- The stations have at least 10 year of data

Spatial Distribution of the Ontario Database



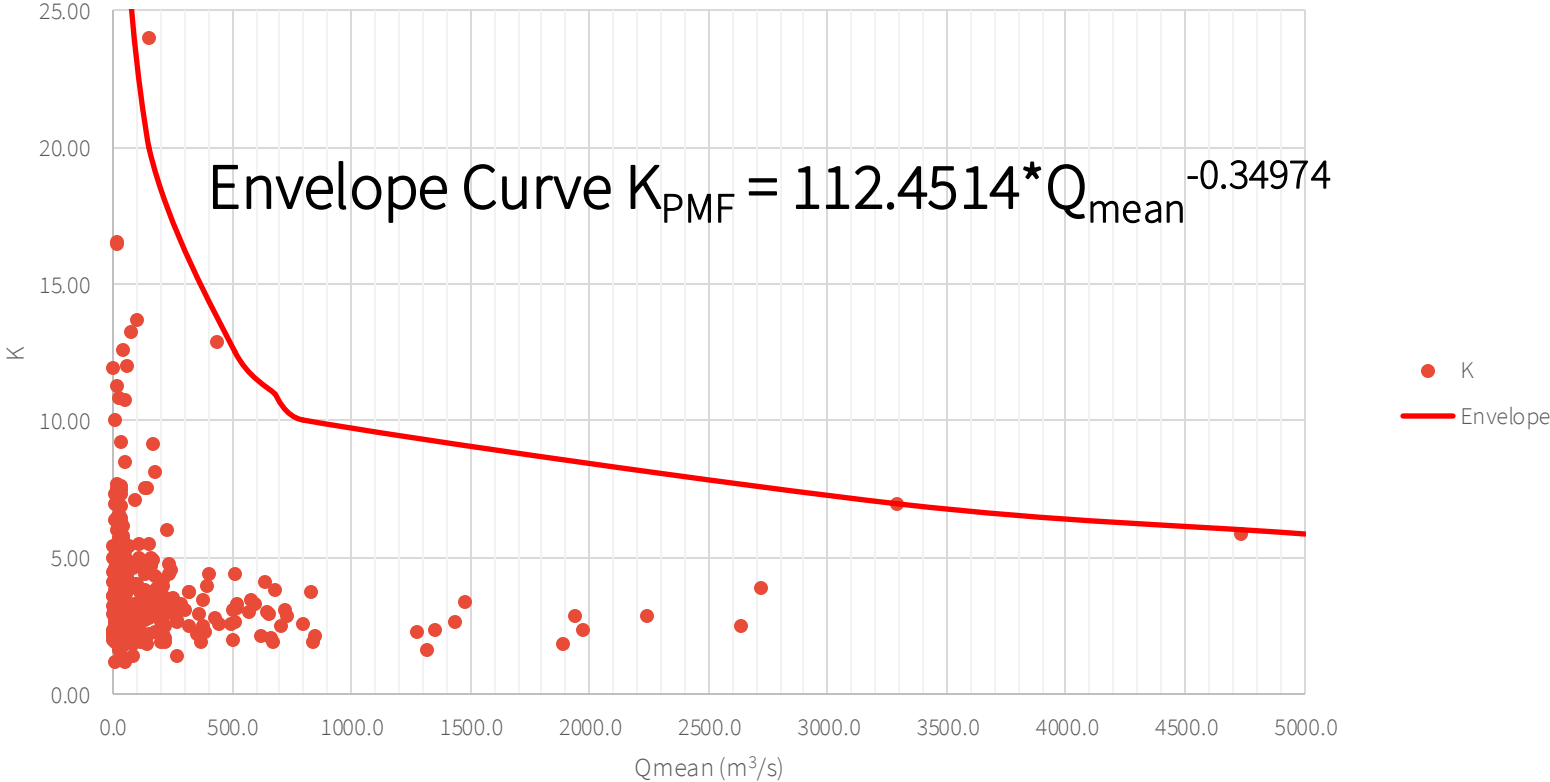
| | DA | Flow | Flow's CV |
|-------|-----------------|-------------------|-----------|
| | km ² | m ³ /s | |
| Min | 0.1 | 0.2 | 0.1 |
| Max | 118000.0 | 5304.8 | 1.2 |
| Mean | 4081.9 | 213.3 | 0.4 |
| StDev | 12244.4 | 564.7 | 0.1 |

The Procedure

Extract the statistics for each station including:

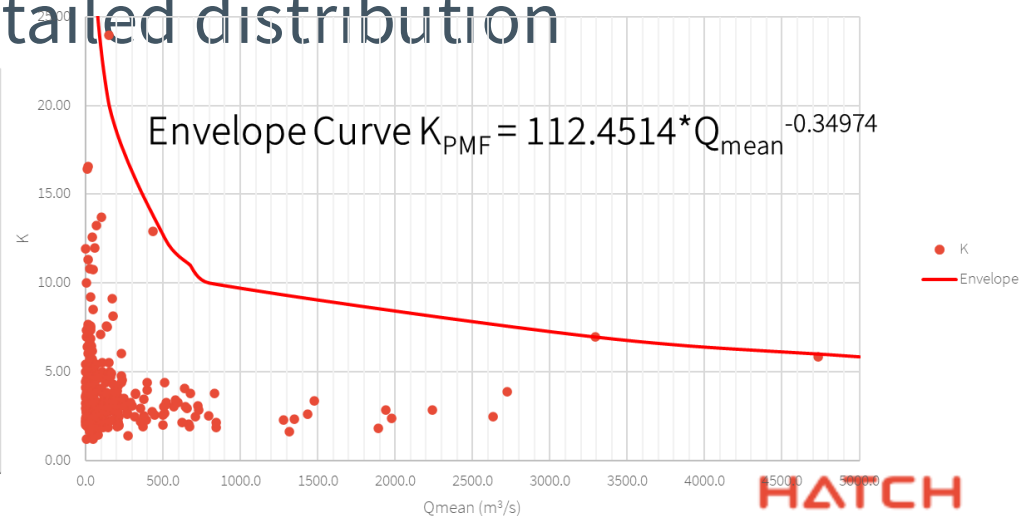
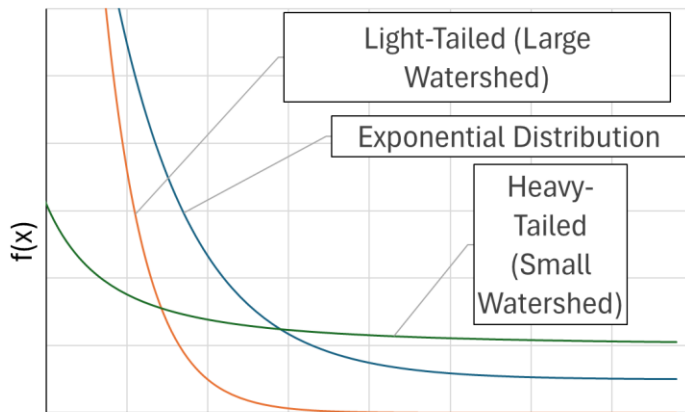
1. The mean peak flow of the time series of each station
2. The standard deviation of each station
3. The historical maximum flood of each station
4. Use these variable to calculate the K_{\max} for each station
5. Plot the K_{\max} against Q_{mean}
6. Fit an envelope curve based on the results
7. Calculate the empirical relationship between Q_{mean} and K_{\max}

The Plot



K_{PMF} variation with Q_{Mean}

- Steep slope for low Q_{Mean} , becoming milder when Q_{Mean} exceeds 900 m^3/s
- Larger watersheds have higher mean peak flows
- Smaller watersheds have higher K_{PMFs}
- Higher K_{PMFs} means more deviation from the mean and a heavier tailed distribution



Tail behavior

- Macdonald et al. (2024) analyzed the tail behavior of flood series and found that threshold processes in runoff generation lead to heavier tails
- The threshold in storage greatly impacts the amount of runoff generated:
 - Small watersheds: During storms, the small amount of storage will fill up quickly and then have an extreme flood
 - Large watersheds: To exceed the storage threshold requires a much more extreme precipitation event
- Overall, the variation in K_{PMF} /tail behavior of floods is due to these threshold processes

The Empirical Equation

- $K_{PMF} = 112.4514Q_{Mean}^{-0.34974}$

- The envelope curve is assumed to be the K_{PMF} for Ontario Streams
- The PMF can then be estimated by the K_{PMF}

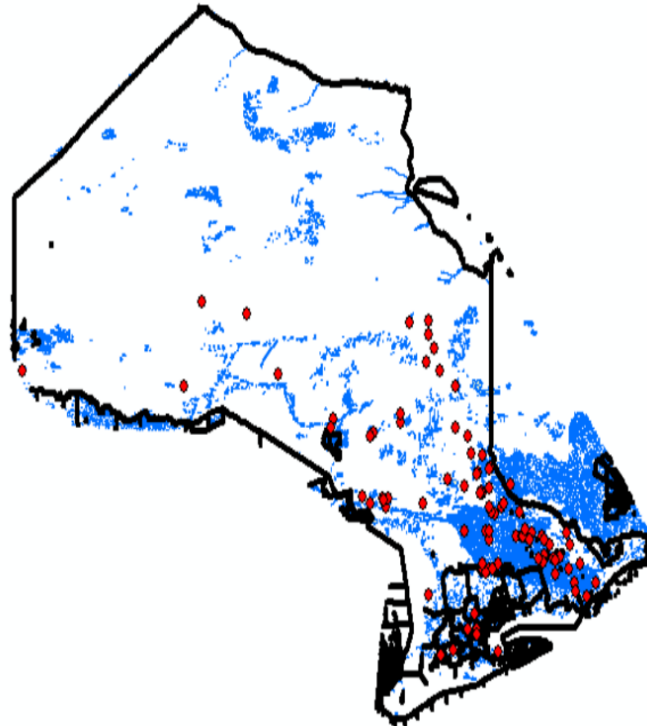
The Procedure to Derive PMF for Ontario Stream

- Obtain the mean of the peak flows (Q_{mean}) and the standard deviation (S_N) of the floods
- Estimation of the K_{PMF} based on the following equation: $K_{\text{PMF}} = 112.4514 Q_{\text{Mean}}^{-0.34974}$
- The PMF peak flow: $Q_{\text{PMF}} = Q_{\text{mean}} + K_{\text{PMF}} S_N$
- Original Hershfield Equation:

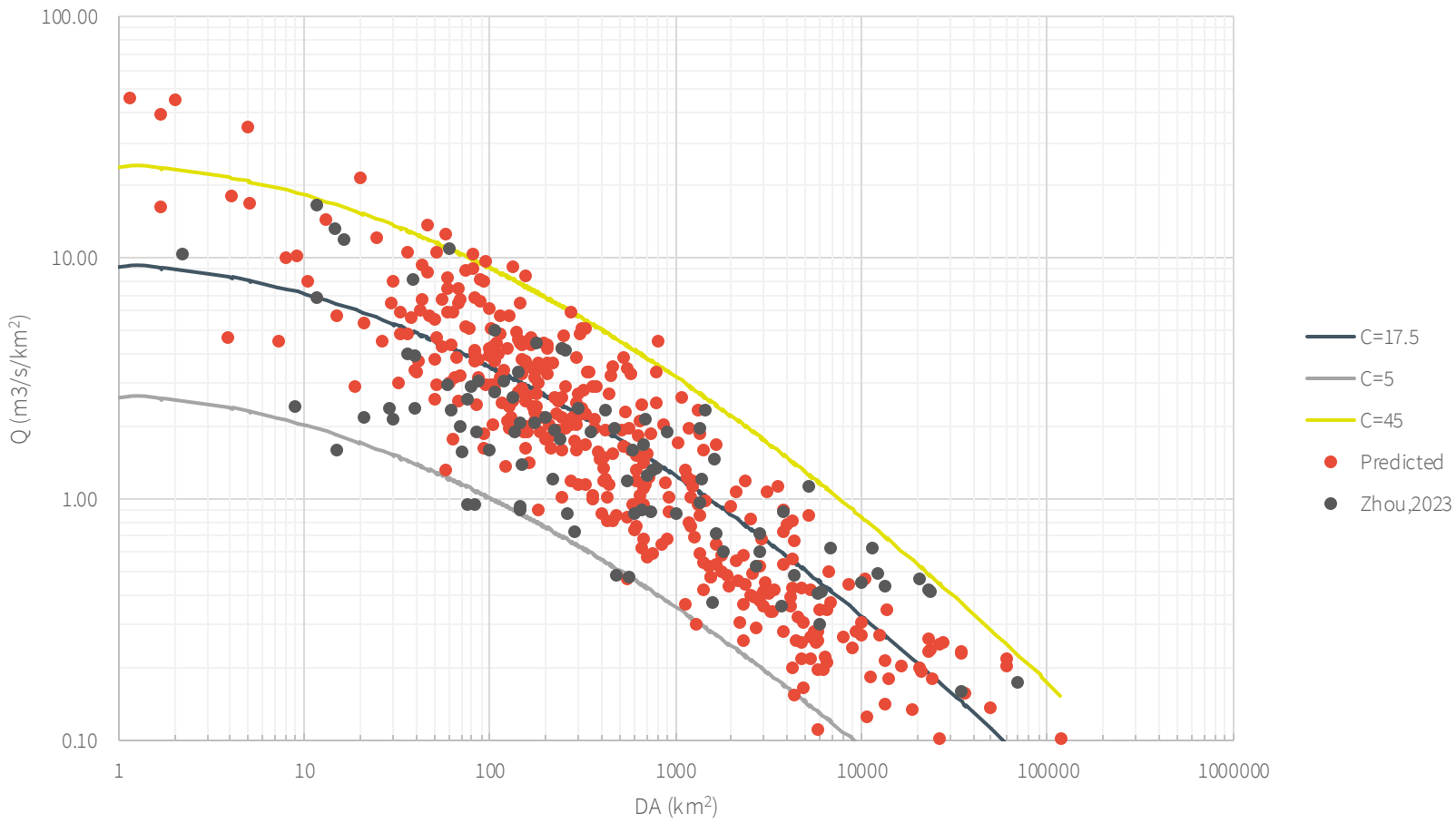
$$h_m = \bar{h}_n + k_m s_n$$

How good are the estimations?

- The PMF estimations are compared to a database of 92 PMF estimates in Ontario (Zhou, 2023)
- The 92 PMF are derived by normal approaches (PMP-PMF)



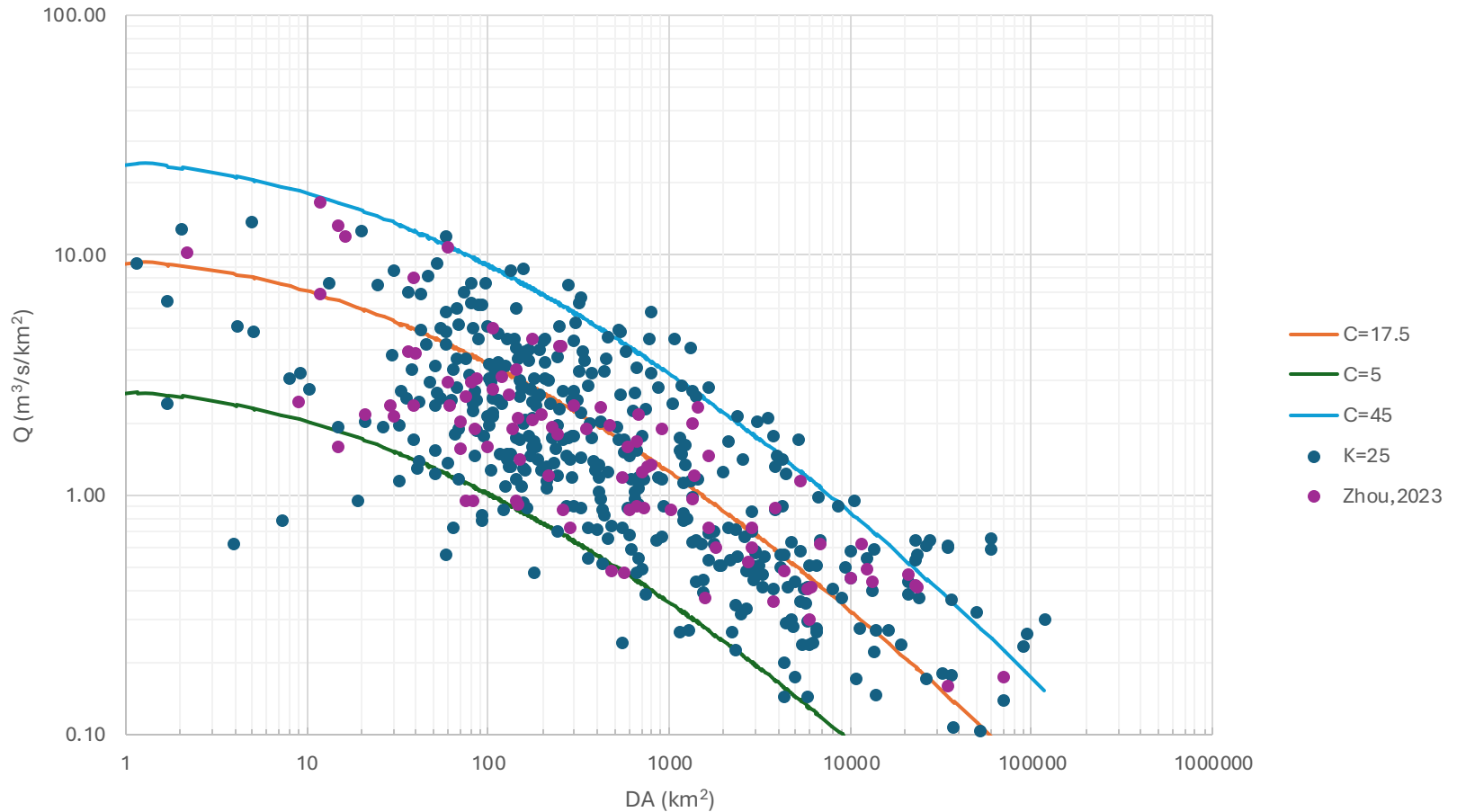
Comparison



What the Comparison Means

- The estimated PMFs by this method for the 396 stations fall into the same range of Zhou's 2023 PMF estimates on the Creager Curves
- C value is between 5 to 45 with an average of about 17.5
- A few small watershed ($DA \leq 20 \text{ km}^2$) gives higher estimates above the C=45 curve
- The method worked well for PMF estimation

Can a Constant K_{PMF} work? For $K_{PMF}=25$



When K_{PMF} is assumed to be 25

- Some stations falls below the C=5 on the Creager Curve
- Some stations are above C=45 on the Creager Curve
- For majority of stations, $K_{PMF} = 25$ provides reasonable estimates

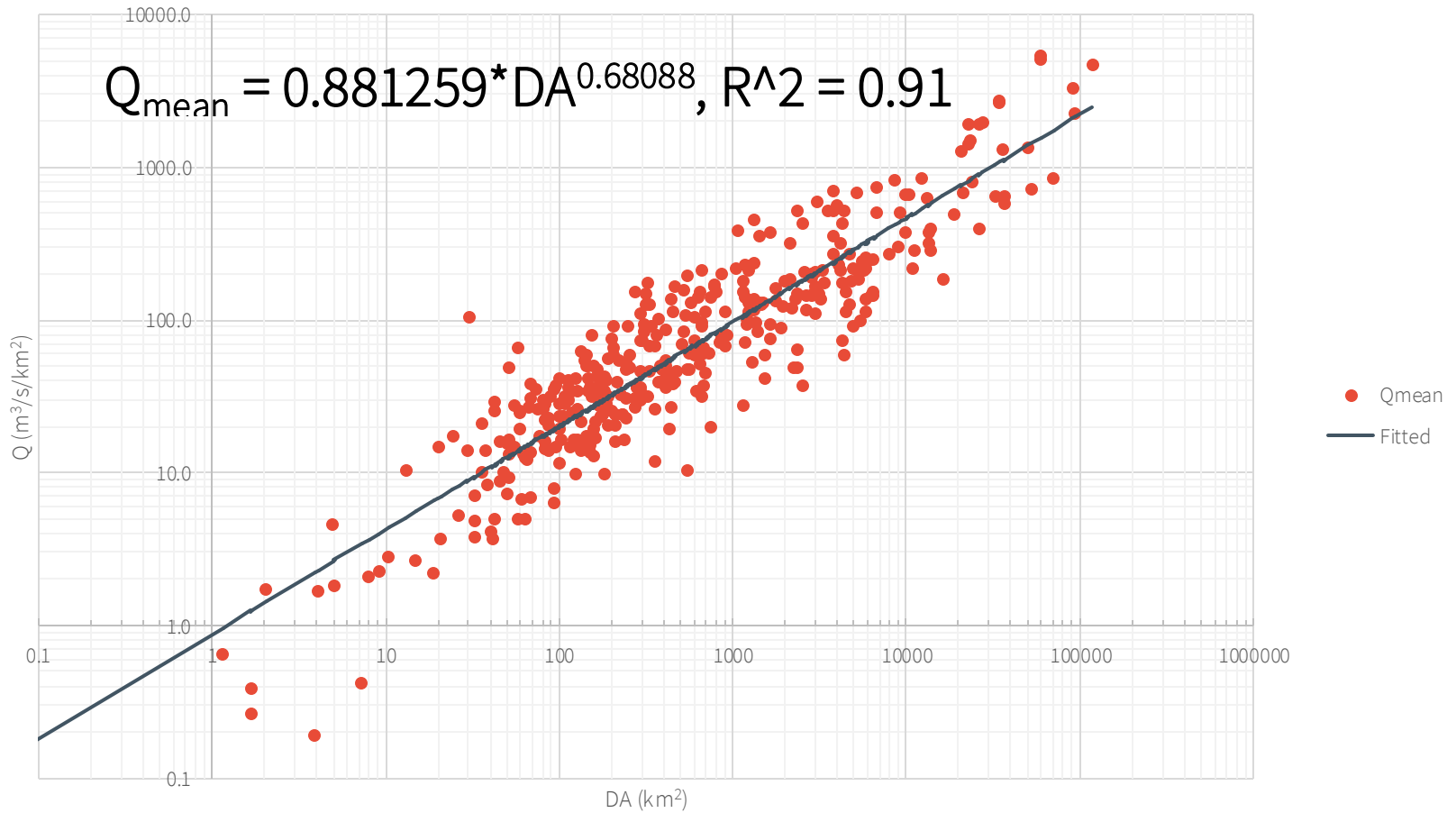
Flow Proration

- Not all site has flow records but a site may be located nearby a flow station where may has hydrological similarities
- Flow proration method can be applied to transfer the estimate at nearby station to the site
- It shall be remembered that the K_{PMF} is a function of Q_{mean} but Q_{mean} varies with drainage size. Therefore, a proper adjustment of K_{PMF} is needed when doing proration (see detailed discussion in the paper)

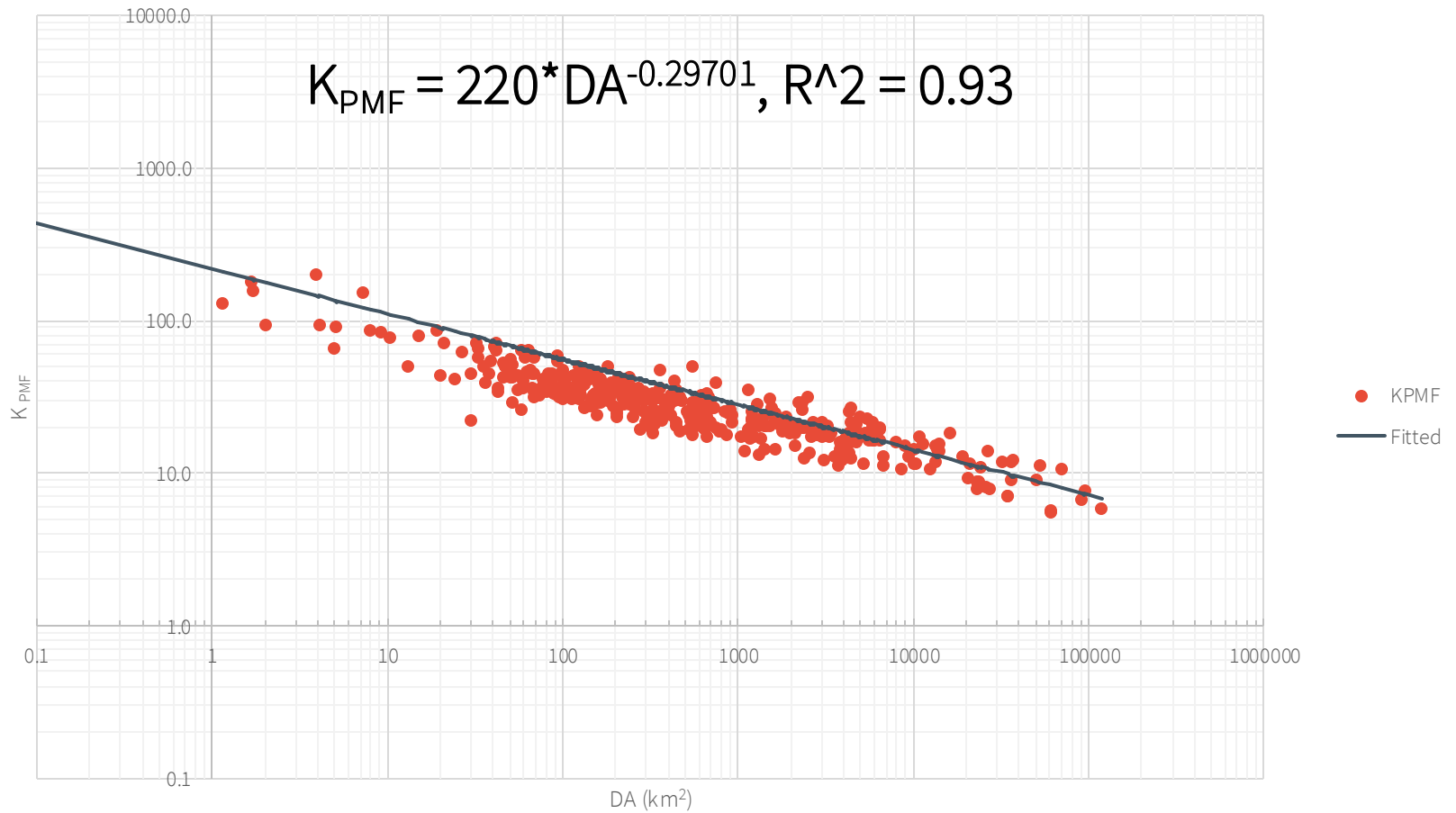
Ungauged Sites

- For many ungauged sites, there is no Q_{mean} and Standard deviation S_N , and there is no nearby station as a reference site
- In this case, a Q_{mean} – DA relationship was derived based on the 396 data points
- And a K_{PMF} – DA relationship was also derived
- It was found that the average $CV = S_N/Q_{\text{mean}} = 0.4$
- This average can be used for ungauged site
- Note to be conservative, $CV = 0.5$ to 0.6 may be applied

$Q_{\text{mean}} - \text{DA}$



K_{PMF} - DA

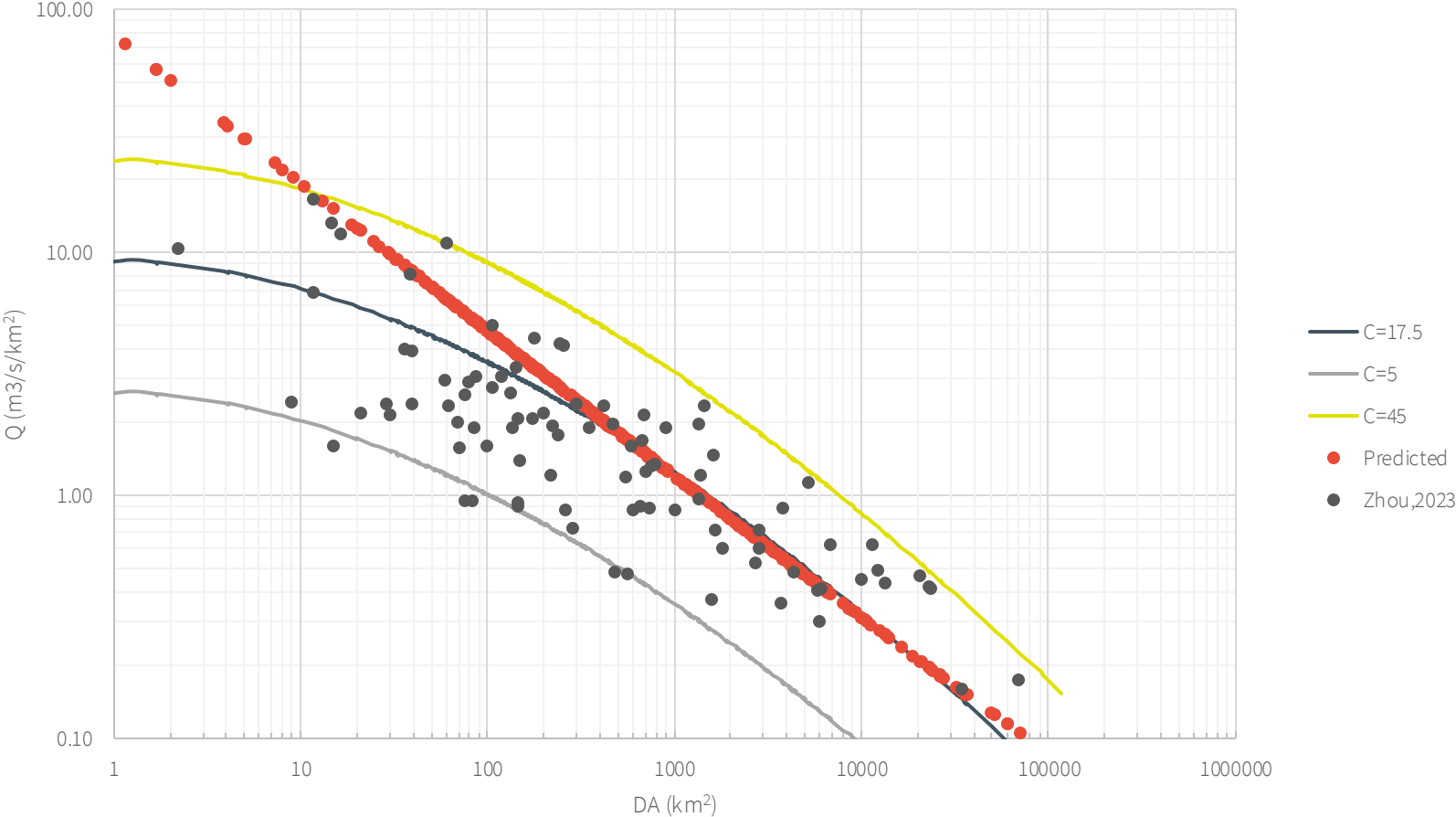


The procedure for Ungauged Site in Ontario

- Estimate Q_{mean} from the $Q_{\text{mean}} - \text{DA}$ curve
- Estimate K_{PMF} from the $K_{\text{PMF}} - \text{DA}$ curve
- Assuming $\text{CV} = 0.4$ to 0.6 , to estimate StDev ($S_N = \text{CV} * Q_{\text{mean}}$)
- Enter these estimates into the equation:

$$Q_{\text{PMF}} = Q_{\text{mean}} + K_{\text{PMF}} S_N$$

Testing of This Method for Ungauged Site



Comments of this method

- Most of time this estimation works reasonably well
- For sites with $DA \leq 10 \text{ km}^2$, this method may over estimate the PMF
- For other sites with $DA > 10 \text{ km}^2$, the estimates are within the acceptable range
- (note: this method leads to a straight curve on the Creager plot since all variables are estimated based on empirical equations)

Conclusions

- The method described a reasonable PMF estimation approach that can be used for Ontario when streamflow data are available
- When streamflow data are not available, the PMF could also be estimated simply using the drainage area
- The Hershfield approach for PMP can be extended to estimate PMF. The K value for floods is higher than the K value for storms
- It shall be noted that the peak flow is only one of the variable defining PMF. The total runoff volume and the duration are also important. These variables shall also be determined to fully define the PMF hydrograph.
- **For important sites where more accurate PMF is required, site specific PMF study is recommended**

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Discussion/Question

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