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Research paper



Probable Maximum Precipitation Comparison using Hershfield's Statistical Method and Hydro-Meteorological Method for Sungai Perak Hydroelectric Scheme

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Abstract

One of the potential risks attributed to the occurrence of dam overtopping and dam wall failure due to the inadequacy of the spillway capacities is the loss of life and property damages in the downstream area. The current practices in most countries in minimizing these risks are by analyzing the extreme precipitation that leads to extreme flood. Extreme precipitation is best known as Probable Maximum Precipitation (PMP) and this estimation is useful in determining Probable Maximum Flood (PMF) in reviewing the spillway adequacy of dam structures. This paper presented PMP estimations using two approaches; physical method (Hydro-meteorological Method) and statistical approach (Hershfield's Method) at the Sungai Perak Hydroelectric Scheme that consists of four cascading dams namely Temengor dam, Bersia dam, Kenering dam and Chenderoh dam. The highest PMP estimates from these two methods will be chosen as the rainfall input to establish PMF hydrographs. Estimations using Hydro-meteorological generalized map produces 40-50% higher estimates compared to Hersfield's method with the PMP values of 550mm (1hours), 600mm (3hours), 800mm (6hours), 820mm (12hours), 1300mm (24hour) and 1600mm (72 hours). Accepting the Hydro-meteorological Method to determine PMF values for this hydroelectric scheme may be the best course since the estimations of the extreme precipitations using this method are the highest.

Keywords: *Herhfield's Statistical; Hydro-meteorological; Probable Maximum Precipitation;overtopping*

1. Introduction

Pollutants carried by urban storm water runoff are considered as significant contributor to the degradation of receiving waters [1]. Therefore, various researches have been conducted to improve the water quality of the river [2-5]. Moreover, in the last few decades river management and restoration play an important role in the environment especially in the field of natural disasters such as flooding [6-8]. PMP as defined by the WMO (World Meteorological Organization), as "the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year" [9]. PMP have been found to be useful in the operational application and to overcome any possible chance of overtopping failure as well as for public safety and hazards downstream of any of these structures [10]. PMP values often used in deriving PMF for large dam spillways as it is helpful in determining the dam's spillway capacities [11].

Some of the methods available for estimating the PMP as stated earlier are local method (using several years of maximum storm), transposition method (transposing the recorded storm characteristics to another area), combination method (combining two or more storms to form long durations of artificial storms sequence), inferential method (theoretical model or ratiocination model), generalized method (generalized estimation), statistical method (statistical estimation). However in Malaysia, there is no unified procedure to estimate PMP values. The PMPs are estimated based on the suitability of the methods and the type of data available for the study. This is also agreed by WMO "Procedures for estimating PMP cannot be standardized as they vary with the amount and quality of data available, basin size, and location, basin and regional topography, storm type and climate…[12]"

In this study, PMP estimates are calculated for the Sungai Perak Hydroelectric Scheme that is consisted of four dams namely Temengor dam, Bersia dam, Kenering dam, and Chenderoh dam along the Perak River. This series of the dam situated after one another in a cascade system such that the runoff discharge of one hydropower plant used as the intake discharge of the second hydropower plant [13]. PMP assessment is crucial from time to time as a safety measure for the hydrological structures and to estimate the flood risk that may happen in the future. Inaccurate estimations of PMP will produce low PMF values and can increase the risk of dam overtopping and failure to the dam wall structure. This occurrence can cause loss of life, property damages to the populations at Sungai Perak downstream that are densely populated at the downstream of the scheme.

In this study, estimations of PMP are calculated using two approaches; physical approach (Hydro-meteorological method) and statistical approach (Hershfield's method). The concept of Hydro-meteorological method is by maximizing the major historical storm events and transposing the major storm in the region that having the similar meteorologically properties [14]. Different topographic and meteorological characteristics of areas give different procedures in estimating PMP by using this method. Meanwhile, statistical approach (Hershfield's method) is the method developed by Hershfield that requires long historical rain-

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fall data in that particular area [15-16]. The analysis conducted in this study will be discussed in the next section.

2. Study Area Location

Sungai Perak Hydroelectric Scheme is located along the Perak River that consists of 4 cascading dams namely Temengor dam, Bersia dam, Kenering dam and Chenderoh dam. The oldest dam in this scheme is Chenderoh dam, which is also the oldest hydroelectric dam in Malaysia. The constructions of the upper three dams are done between 1974-1983 with different sizes and designs. The river valley is dominated by agricultural activities. The current land-use built-up area and cleared land to constitute less than 10% and agricultural use at about 38.5% and forest land with more than 50%, with other uses constitute the rest. The forests are habitats to rich terrestrial and aquatic flora and fauna. The current land use data were obtained from the Department of Town and Country Planning. The study area is covered with tropical rainforests which are totally dependent on a continuing warm and wet climate throughout the years [17] Rainfall is abundant and important parameter behind all calculations of the PMP.

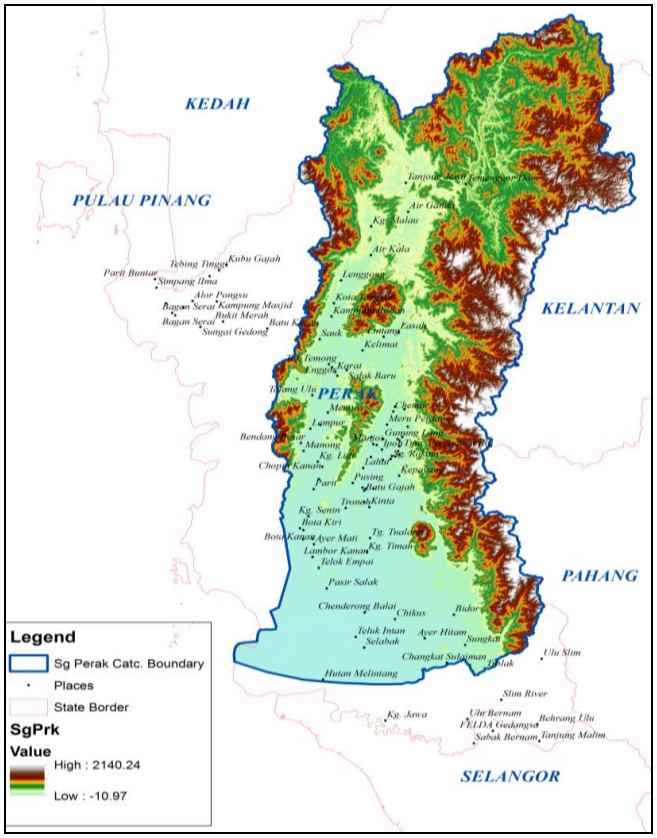


Fig. 1: Location of Sg. Perak Hydroelectric Scheme Basin

3. Methodology

Two approaches are adopted in this study to determine the PMP estimates, namely as the physical approach (hydro-meteorological method) and statistical approach (Hershfield's Method). These methods are used to calculate the PMP estimates for the durations of 1hour, 3hour, 6hour, 12hr, 24hour and 72hour. Figure 2 shows the flowchart of PMP studies in this paper.

3.1. Hydro-Meteorological Method

The hydro-meteorological method is based on an assumption where PMP values can be obtained from a storm in which there is the optimum combination of available moisture in the atmosphere and 'efficiency' of the storm mechanism [9]. PMP estimations using hydro-meteorological method would require rainfall data and other climatological data during the historic storms. Such storms normally give the greatest rainfall depths of record for a particular location or the surrounding area. These values are required to be estimated for the design of the risk structures such as dam spillways.

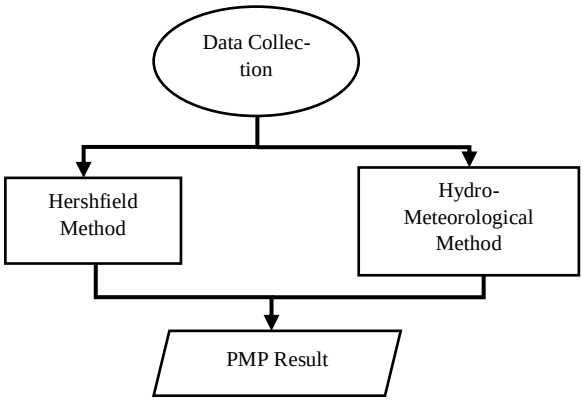


Fig. 2: Flowchart of PMP Studies

3.2. Hershfield's Method

In estimating PMP values in this study, another method used is Hershfield's statistical method. This method is suitable to be used whenever long rainfall data are available. Rainfall data from selected stations will be used to execute the rainfall frequency analysis using this method.

3.3. Rainfall Data Collection

For data collections, there are 37 rainfall stations that available within the catchment boundaries. Out of 37 stations, 9 stations are owned by the Department of Irrigation & Drainage (DID) meanwhile the remaining 28 stations are owned by Tenaga Nasional Berhad (TNB) along the Perak river. The most extended rainfall data availability should be at least up to 10 years. Therefore, only 16 rainfall stations are to be used in this study based on good historical records available (data records more than 10 years) and the status of the rainfall stations whether it is still operating or has been shut down. Figure 3 shows the location of rainfall stations in the Sg. Perak Hydro-electric scheme watershed meanwhile Table 1 shows the lists of rainfall stations used in this study that consists of 11 TNB stations and 5 DID stations.

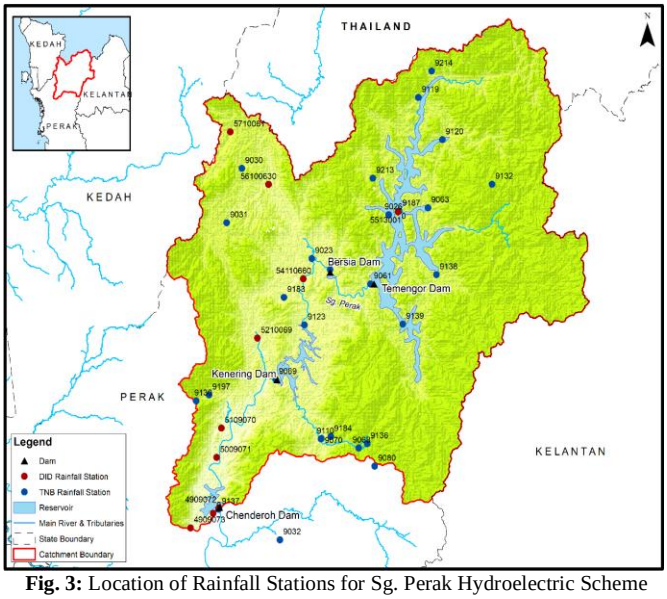


Fig. 3: Location of Rainfall Stations for Sg. Perak Hydroelectric Scheme

Table 1: List of stations in Sungai Perak Basin

No.	Station No.	1-hr (mm)	3-hr (mm)	6-hr (mm)	1-day (mm)	3-day (mm)	5-day (mm)
1.	9030	86.0	97.5	109.5	131.3	234.2	252.7
2.	9061	80.5	112.0	138.0	201.6	255.0	364.7
3.	9069	96.0	139.5	150.1	150.4	186.5	241.7
4.	9071	86.0	137.5	154.0	160.0	221.5	257.1
5.	9119	67.5	107.2	155.2	196.5	263.0	355.0
6.	9120	78.0	101.5	127.0	166.5	219.0	276.0
7.	9132	76.0	110.8	136.6	250.5	312.0	450.0
8.	9136	78.0	133.6	143.6	148.0	237.5	324.0
9.	9137	80.0	102.0	102.5	149.3	203.0	298.5
10.	9138	65.5	104.0	122.0	198.0	200.5	208.5
11.	9139	56.8	105.0	113.0	154.5	162.0	182.5
12.	5109070	60. 7	75.5	116.0	160.5	290.5	330.0
13.	5210069	69.5	90.6	127.6	154.0	238.5	250.0
14.	5411066	157.1	214.5	220.3	258.0	285.0	306.0
15.	5610063	105.7	168.0	185.0	186.0	220.0	265.0
16.	5710061	115.6	126.5	126.5	186.2	269.0	344.0

3.4. PMP Estimations using Hershfield's Method

The statistical method in this study was by NAHRIM Technical Research Publications No.1 and based on the Hershfield's method, that is used widely throughout the world. For this technique, there needs requirement extended historical data. Analysis rainfall data for the past ten years for 16 rainfall stations. The PMP values are obtained using conventional statistical analysis that is by adding the mean of the annual rainfall with frequency factor, K_m that has been multiplied by the standard deviations of the series. Figure 4 shows the flowchart of Hershfield's method used in this study.

$$\text{MMF} = W_m / W_s \quad (1)$$

$$X_{PMP} = \overline{X} + K_m \sigma_n \quad (2)$$

Where $\bar{x}$ is the mean of the annual maximum precipitations, K_m is the frequency factor and σ_n is the standard deviations of the series. The determination of K_m involves getting the values for mean and standard deviations of the series without including the highest precipitation for the 10 years for each station. Where,

$$K_m = (\overline{X}_n - \overline{X}_{n-1}) / \sigma_{n-1} \quad (3)$$

K_m values can also be obtained using the K_m curve developed by NAHRIM. Figure 5 shows the K_m envelope curve and its equations. The nomogram envelope curves are developed based on the relationship between the frequency factor, K_m and the mean annual maximum rainfall for various durations. In this study, the envelope curve equations involved are:

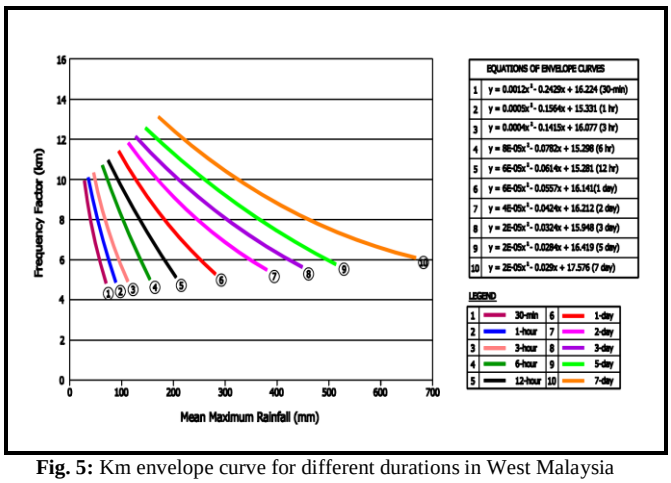


Fig. 5: Km envelope curve for different durations in West Malaysia

$$K_m = (0.0005\ x^2) - (0.1564\ x) + 15.331 \quad \text{(1 hour duration)} \quad (4)$$

$$K_m = (0.0004x^2) - (0.1415\ x) + 16.077 \quad \text{(3 hour duration)} \quad (5)$$

$$K_m = (8E\text{-}05\ x^2) - (0.0782x) + 15.298 \quad \text{(6 hour duration)} \quad (6)$$

$$K_m = (6E\text{-}05\ x^2) - (0.0614x) + 15.281 \quad \text{(12 hour duration)} \quad (7)$$

$$K_m = (6E\text{-}05\ x^2) - (0.0557x) + 16.141 \quad \text{(24 hour duration)} \quad (8)$$

$$K_m = (2E\text{-}05\ x^2) - (0.0324x) + 15.948 \quad \text{(72 hour duration)} \quad (9)$$

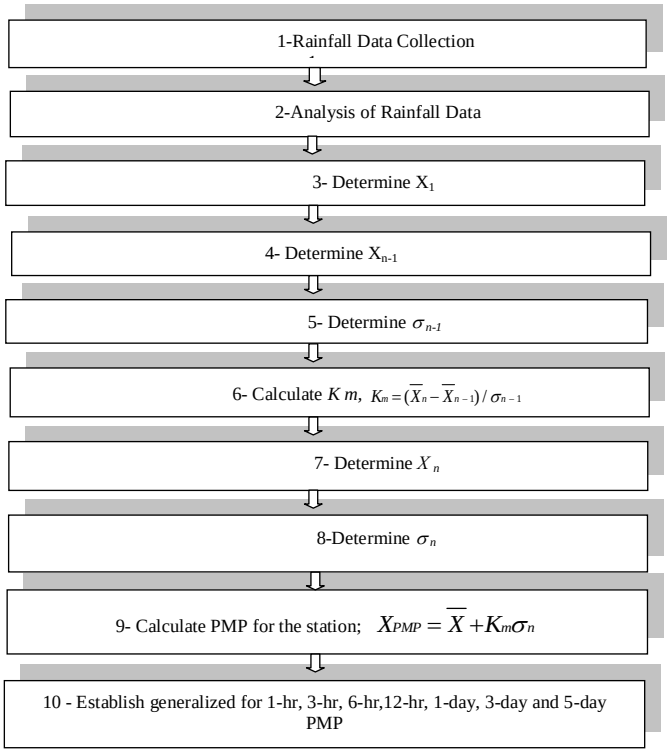


Fig. 4: Hershfield's Method Flowchart

Both PMP obtained using Km statistical and then compared Km from the envelope curve, and for further analysis highest PMP are chosen. Other than analytical method, Hershfield generalized map also available for PMP computations. Mapping the statistical PMP values for each durations on the broad base maps of East and West Malaysia were developed by NAHRIM. These maps are useful for PMP estimations without undertaking detailed mathematical calculations.

3.5. PMP Estimations using Hydro-Meteorological Method

The hydro-meteorological method in this study was accorded to NAHRIM Technical Research Publications No.1. The project location needs to be identified on the transposed map developed by NAHRIM to determine the zones for the project location for both short durations (less than 12 hours) and longer duration (more than 12 hours). The most severe storm event within the region is then determined and R_0 (highest observed rainfall) is obtained for the duration of 1 hour, 3 hours, 6 hours, 12 hours, 24 hours and 72 hours. Moisture maximization factor (MMF) then obtained for each durations based on the zones located. In the NAHRIM guideline, MMF is the 'ratio of the highest amount of moisture recorded in the study area during the period of the storm to that recorded in the storm'.

Where W_m is the precipitable water corresponding to maximum dew point at the location of the storm, meanwhile, W_s is the precipitable water corresponding to storm dew point. Using moisture maximization obtained, the maximized rain depth, then calculated by multiplying it with the highest rainfall observed (R_0) obtained earlier. The storm then transposed to the study area by transferring major storm where the rainfall occurred in other areas where it could occur. The rainfall is transposed using three adjustment factors; Topography Transposition Factor, Distance Topography Factor and Barrier Transposition Factor. These three factors were then determined for all six durations based on the zones located. All three factors are then averaged and multiplied by the storm maximization factor to obtain the PMP for each duration. The hydro-meteorological generalized map is also used in the PMP estimations by intersecting the rainfall stations on the isohyets maps for all six durations. Figure 6 shows the flowchart of a Hydro-meteorological method used in this study..

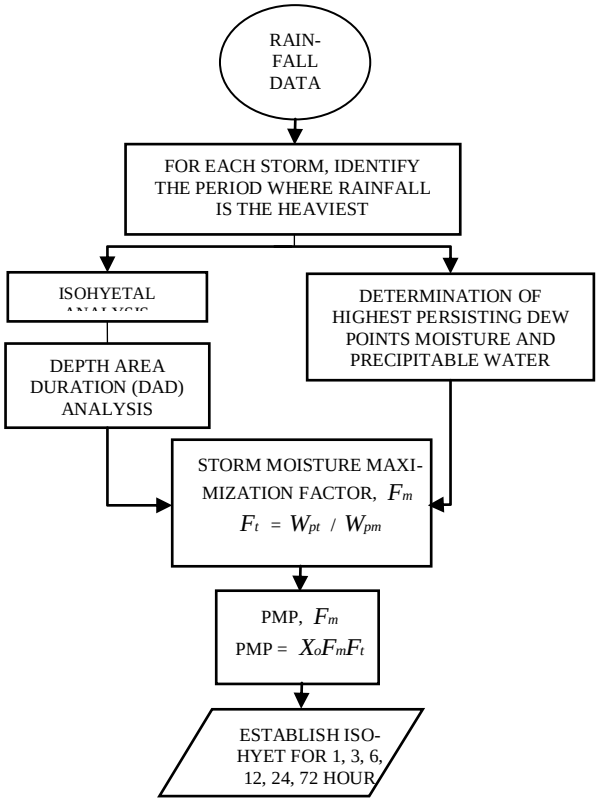


Fig. 6: Hydro-meteorological Method flowchart

4. Results and Discussion

4.2. Comparisons of Hershfield's PMP

The statistical method used in this study based on Hershfield's method and statistical analysis of the previous rainfall data has applied for the rainfall stations involved. The data were analyzed in an attempt to estimate PMP for 1 hour, 3 hours, 6 hours, 12 hours, 1 day, and 3 days based on an appropriate frequency factor. The frequency factor (Km) is determined using two methods which are by using Herfield's Km formula and Km envelope curve as in the NAHRIM Technical Guideline in estimating PMP. Table 2 shows the PMP estimations via Hershfield's Method using different Km values.

The results indicate that PMP acquired using NAHRIM envelope curved gives higher estimations than the derived PMP that using statistical Km values. This finding recorded was same by [18]. Putuhena also found that the statistical method using NAHRIM's K_M values is found to be the most reliable since the PMP estimations by SESCO displays almost similar PMP estimations. PMP values are also determined using Hershfield's generalized map developed by NAHRIM.

Table 2: PMP estimations using derived Km values

Duration (hr)	PMP (mm)							
	Temenggor		Bersia		Kenering		Chenderoh	
	Derived Km	Km Envelope Curve	Derived Km	Km Envelope Curve	Derived Km	Km Envelope Curve	Derived Km	Km Envelope Curve
1	85.9	202.4	208.7	202.4	276.4	300.4	276.4	300.4
3	126.1	252.2	202.9	262.0	268.4	354.7	268.4	354.7
6	191.3	336.8	210.0	336.8	301.4	465.9	301.4	465.9
12	365.9	477.2	365.9	477.2	372.9	495.7	372.9	495.7
24	453.4	634.6	453.4	634.6	453.4	634.6	453.4	634.6
72	404.2	891.7	404.2	891.7	481.4	891.7	608.5	891.7

Table 3: PMP estimations using Nahrim Hershfield's Generalized Map

Duration (hr)	Generalized Map PMP (mm)			
	Temenggor	Bersia	Kenering	Chenderoh
1	160	160	175	180
3	280	280	280	280
6	310	310	310	310
12	500	500	500	500
24	770	770	770	770
72	1400	1400	1400	1400

4.1. Comparisons of Hydro-Meteorological Method

In this study, the Hydro-meteorological method is used for PMP estimations by NAHRIM Technical Research Publications No.1. Two PMP values for each duration of 1 hour, 3 hours, 6 hours, 12 hours, 24 hours and 72 hours are obtained using both calculated and Hydromet generalized map. The calculated Hydro-met's PMP obtained by multiplying the maximized rain depth and the average of the adjustment factors meanwhile PMP using generalized map obtained by determining the location of the rainfall stations on the isohyets of PMP for West Malaysia. Both calculated and generalized map's PMP shows the slight difference and this shows that both estimations are acceptable. Results show the PMP obtained by using generalized map are slightly higher than the calculated Hydro-meteorological method with the PMP of 550mm (1 hour), 600mm (3 hours), 800mm (6 hours), 820mm (12 hours), 1300mm (24 hours) and 1600mm (72 hours). The most preferable PMP estimations would be the highest PMP on that particular duration, therefore PMP using generalized map is chosen for further analysis. This is because in designing a dam structure, we have to design it using the values that is resulting from the worst-case scenario that could possibly happen. This is to avoid structural failure to the dam structure. Table 4 shows the results of PMP estimates using calculated and Hydro-met's generalized map.

Table 4: PMP comparisons for calculated and generalized map Hydro-meteorological method

Duration (hr)	PMP (mm)	
	Calculated Hydro-Met	Hydro-Met Generalized Map
1	586.38	590
3	773.96	700
6	795.66	800
12	818.17	820
24	1285.0	1300
72	1600.1	1600

4.3. Comparisons between the Statistical and Physical Approach

Between the two methods discussed, the one that produces the highest PMP estimations is chosen as the most preferable method to be used as rainfall inputs for PMF studies. In order to develop PMF hydrographs, it is important to select only the highest values of precipitations that will result in the maximum flood. This is important to check the adequacy of the dam spillway for the worst case of precipitations. These PMPs that have been analyzed in previous sections are compared to the most critical values and can be used in hydrology modeling of PMF studies.

Based on PMP estimations of both physical and statistical approaches, results show that the estimations by using physical approach (hydro-meteorological method) are the most significant for all six durations. According to NAHRIM Technical Research Publication No.1, "Generally the PMP derived by the physical method is more than the PMP derived by statistical method even though some exceptions are evident due to the data records and several climatic and geographical factors". This statement proves that the estimations of PMP in this study are acceptable. Meanwhile, for Hershfield's method, the PMP analysis can be done for a longer duration. As recommended in [19] 6 days PMP values are used to evaluate PMF in designing the spillway of Bakun Dam

Table 5: PMP values comparison between the statistical and physical approach

Duration (hr)	PMP (mm)				
	Statistical Hershfield Method				Hydro-meteorological
	Temenggor	Bersia	Kenering	Chenderoh	
1	202.4	202.4	300.4	300.4	586.38
3	252.2	262.0	354.7	354.7	773.96
6	336.8	336.8	465.9	465.9	795.66
12	477.2	477.2	495.7	495.7	818.17
24	634.6	634.6	634.6	634.6	1285.0
72	891.7	891.7	891.7	891.7	1600.1

5. Conclusions

The findings in this study display higher PMP values using physical approach (Hydro-meteorological method) than PMP obtained using statistical approach (Hershfield's method). Estimations using the physical approach produces 40-50% higher estimates compared to the statistical approach with the PMP values of 550mm (1 hour), 600mm (3 hours), 800mm (6 hours), 820mm (12 hours), 1300mm (24 hours) and 1600mm (72 hours). Since the hydro-meteorological method concept is by maximizing rainfall depth and transposed it to the study area, we can say that the PMP values were somehow a bit too high for specific areas because precipitation distributions are always different from one area to another. Therefore, further studies need to be done on the hydro-meteorological method to improve the adjustment factor by using its developed adjustment factor that represents the current rainfall data for the exact location. The longer length of rainfall data also needs to be used with a minimum of 20 years historical data to obtain more reliable results in determining PMP using the statistical method. Besides that, longer durations of estimations can also be carried out since the catchment areas for Sungai Perak Hydroelectric Scheme are enormous with the territory of 6,686 km2. Review of the PMP estimations up to 5 days is required to compare and determine the peak flow for the PMF establishments. To establish PMF hydrographs, it is best to use the PMP using Hydrometeorological method as input rainfall since the method achieved the highest estimations compared to Hershfield's statistical method.

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